University of Southern Queensland

Faculty of Engineering and Surveying

Design, Development and Implementation of Innovative & Pervasive Applications using Emerging Communication Technologies for Highly Mobile Organisations

A Dissertation submitted by

Keyurkumar Jayantibhai Patel, BE, MEng

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Principal Supervisor
Dr Wei Xiang

Associate Supervisor
Associate Professor Nigel Hancock

Abstract

Information and Communications Technology (ICT) industry is rapidly expanding, constantly changing and oriented around emerging technologies. In recent times, research data from industry skills demand and job advertisements shows that there is clearly vast skills shortages to develop applications leading to computer and telecommunications networks for financial, banking, energy, health, engineering, aviation, tourism, hospitality and education sectors.

Applications based on the wireless technologies both short range (Bluetooth® and IEEE 802.11x family) and long range (next generation cellular technologies) reliant on telecommunication networks are growing at an alarming rate with an increased demand for security, quality of service, scalability, mobile multimedia, bandwidth usage, infrastructure and innovation. This demand brings major technological challenges for the management, developers and end-users in the ICT sector. This dissertation presents an investigation into these challenges in form of a decade of individual professional projects requiring fundamental design from the principles of wireless communications. Innovative and pervasive solutions are developed for the highly mobile organisations using amalgamation of compatible and cost effective emerging communication technologies.

Highly mobile organisations span the aviation, power generation and distribution, hospitality, tourism, education, and telecommunication sectors. These industries execute numerous and distinctively different real-time business transactions. From the preliminary research and investigations in each, suitable technological solution for each organisation's problem is designed, developed then implemented. This dissertation is assembled from my research input to nine commercial projects executed between 2001 and 2010. Each was 'cutting edge' and technically challenging at the time of execution. These comprise:

- a secure wireless technology implementation at the Sydney Airport Corporation Limited (SACL) between 2001 and 2003;
- implementation of a secure on-site and off-site electricity meter reading solutions for the Hong Kong Electricity Company (HEC) between 2004 and 2005;
- design and development of wireless food ordering system, iPod as a visitor's personal guide and voice over internet protocol (VoIP) for student attendance

recording and retrieval application (SARRA) for the Box Hill Institute (BHI) between 2005 and 2007;

- a new three layered packet switching media access control (MAC) framework was developed with the quality of service mechanism for the Aricent® Group between 2007 and 2009;
- a new modular data link layer (M-DALL) was developed for a multiple radio access technologies (RATs) for the Aricent® Group between 2008 and 2009;
- digital living network alliance (DLNA) enabled mobile terminals integrated with home gateway (HG) and an adaptive quality framework was developed for the Aricent® Group between 2009 and 2010; and
- a heuristic buffer management scheme on Android® to enhance video quality for smart phones was developed for the Aricent® Group between 2009 and 2010.

One of the major key performance indicators for these projects was to develop and implement solutions in their respective organisations. This dissertation is based on these projects. To date a total of 15 manuscripts (international refereed conferences and journals) and one book in the form of international refereed conference proceedings are published.

Certification of Dissertation

I certify that the ideas, experimental work, results, analyses and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other tertiary award, except where otherwise acknowledged.

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Signature of Candidate Date

(Keyurkumar Jayantibhai Patel)

Endorsement

_____ _____

Signature of Principal Supervisor Date

(Dr Wei Xiang)

_____ _____

Signature of Associate Supervisor Date

(Associate Professor Nigel Hancock)

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Dissertation Overview

Telecommunication is the fastest growing part of the Information Communication Technology (ICT) industry with the emergence of real-time and multimedia rich applications, distributed systems and mobile technologies needs to be compatible with the existing skills sets, applications and infrastructures.

Chapter 1 presents a fundamental understanding on emerging communication technologies, their classification and implications on the third and fourth generation wireless and mobile services. Discussions on standards and technologies are done only as needed and relevant to projects to get the readers up to speed on the technologies. This chapter undertakes qualitative comparison of emerging technologies and demonstrates with examples, the features, effort and investments in these technologies. Chapter 1 concludes with the implications of current downturn in global economy and consumer reaction towards new technologies.

Chapters 2, 3, 4, 5 and 6 are based on five major projects carried out between 2001 and 2007. These projects are based on short range communication technologies and were commercially financed and business driven which warranted return on investment, ease of use, simple design, and scalable. They mainly focus on data communication. In summary, the topics of these chapters are as follows.

Chapter 2 presents wireless technology implemented at the Sydney Airport Corporation Limited (SACL). Wireless Technology, an integral part of the telecommunication industry, is growing at an alarming rate with increased security being the main challenge for developers and end users. It discusses tackling initial challenges and issues faced during the implementation of wireless technology and how security issues and wireless application were implemented at the Sydney Airport – a highly mobile organisation. The decision to deploy and manage the wireless spectrum throughout the Airport campus meant the Wireless Local Area Network (WLAN) will be a shared medium with public users, tenants and aircraft communications, sharing the same available bandwidth. Therefore to protect unintended users from breach of existing security policies adopted by their corporate network a comprehensive security solution needed to be established. This chapter focuses on how WLAN architecture and security challenges of implementing a

common use wireless infrastructure were addressed. Authentication and data privacy challenges are also presented. The complete WLAN connectivity for tenants, public and corporate usage is presented. My role in this project was as a research engineer. Tasks included but not limited to, infrastructure research, feasibility analysis, technical proposal development and design review.

Chapter 3 presents a comprehensive technical overview on how a wireless application is developed and implemented using short range wireless technology – Bluetooth®, to securely collect electricity meter readings using on-site and off-site techniques. A huge manpower is coordinated by electricity distributor – Hong Kong Electricity Company (HEC), to collect electricity usage data from the electricity meters. It is an expensive task and prone to obtain wrong readings. An innovative solution is presented which automates and simplifies the meter reading task using Bluetooth. This solution is referred as On-site Meter Reading. Mobile communication has been used in technologically motivated countries like Singapore and Hong Kong. In early 2003, meter reading was accomplished by using an electricity meter equipped with a modem to connect to a GSM network through a serial interface with firmware control. Few problems existed due to physical constraints of buildings. One of the major problems was connectivity due to the GSM coverage. Since any Bluetooth enabled digital power meter can form a wireless network (piconet) and with Bluetooth enabled smartphone, staff of electricity companies can collect numerous meter readings from a distance of up to 100 m away from electricity meters. Within seconds, the data collected by smartphone are sent to the energy provider's central office via mobile network. This solution is referred as Off-site Meter Reading System. As a result of these solutions, electricity distributor has considerably reduced the operating cost, elimination of human error and avoided unnecessary estimation. My role in this project was as a lead technical consultant in a team consisting two members. My specific responsibilities included research, develop, test, implement and document the project. Overall management including finance, coordination and client liaison was the responsibility of the other team member.

Chapter 4 presents the design and development undertaken to create an innovative application of wireless food ordering system in a training restaurant run by students at the Box Hill Institute (BHI). This chapter presents an in-depth technical operation of Fountains Integrated Wireless Ordering System which includes systems architecture,

workings, software development and implementation. It is demonstrated that by using wireless enabled PDA, food ordering system can increase coordination efficiency for restaurants and caterers. It saves time, reduces human errors and provides superior quality customer service. I strongly believe that with the increase use of wireless enabled PDA in restaurants, this application will become an important teaching and learning tool for the hospitality educators and students. Combining simple design, lower development and readily available emerging communications technologies, this chapter concludes that this system is an attractive learning and teaching solution for hospitality industry and educators. I was the key stake holder as a project manager and a mentor.

Chapter 5 showcases the design and development of an iPod as a visitor's personal guide at BHI. Since late 2004, the iPod has been successfully and effectively used for various purposes in entertainment and education industry which includes media player, external data storage device, a PDA replacement and for pod-casting. An emerging application is developed as an interface designed around a central scroll wheel of an iPod for the navigation, recording and playback facility which provides latest information to visitors visiting "innovation walk" within the Institute. With the increasing use of digital media together with the handheld devices, this iPod application will eliminate need of a human guide and will provide an entertaining experience to visitors. This solution can be implemented at various landmark tourist destinations such as mines, aquariums, museums etc, and in near future will replace existing expensive technologies. I was the key stake holder as a project manager and a mentor.

Chapter 6 aims to provide an in-depth technical in-sight into development of an innovative student attendance recording application using emerging communication technologies. Development of Voice over IP (VoIP) Student Attendance Recording Application (VoIP SARRA) for BHI is presented. This project demonstrates application programming, test bed setup, design considerations, design decisions, future plans as well as creative usage of emerging communications technologies. Developed application combines Cisco VoIP telephony and network systems and integrates it with existing database systems with the aim to provide BHI with an efficient and secure way to record and store student attendance data. This project is a success and when fully integrated within existing system, it will provide BHI with a cost effective and efficient student attendance recording and reporting system. This chapter concludes that the developed

application has a potential for use to record student attendance at other Australian education providers. I was a project manager and a mentor in this project.

Chapters 7, 8, 9 and 10 are presented as a breakdown of four major projects executed between 2007 and 2011 for Aricent® Group (www.aricent.com). These chapters set out research development for the future – Next Generation Mobile Communication. These projects were commercially financed and business driven which warranted superior multimedia experience, quality of service, innovative design, scalable architecture and interoperability with other compatible technologies. They mainly focused on voice, video and data communication in 3G and 4G. In summary, the topics of these chapters are as follows.

Chapter 7 presents a new Packet Switching Media Access Control (PSMAC) Framework architecture with a three-layer approach for the NEXT GEN Mobile Terminal suitable for all IP based wireless networks. The design goal of a new NEXT GEN PSMAC Protocol was to provide support for enhanced mobility management; handover strategy with IPv6 protocol, high throughput with efficient quality of service (QoS) oriented packet transmission mechanism, scheduling techniques, and traffic and flow control mechanism. PSMAC Protocol stipulates the QoS requirements for an application depending upon traffic type and mapping various parameters for different kinds of flows, which would ultimately make sure that an application receives the QoS it requested. Simulations results are presented. This chapter concludes that proposed new PSMAC Framework for mobile terminals provides high-speed data transfer and ensures high throughput for different code rate and modulation techniques. I was a collaborating systems engineer in this project.

Chapter 8 presents a new Modular Data Link Layer (M-DALL) for NEXT GEN Mobile Terminal to abstract common metrics and introduces a single interface for retrieving radio link layer information. Present 3G Mobile Devices often support multiple communication technologies. If software developers want to control the configuration or monitor the characteristics of active Radio Access Technologies (RATs), their mobile applications will have to use different programming interfaces for each technology on the various supported platforms. M-DALL offers a flexible query interface and a powerful notification mechanism to the application layer that enables applications to become link-aware. The M-DALL also compromises common data functionality that is extended

through specific parts of dedicated RATs like GPRS, UMTS, CDMA2K and WLAN, that could serve as a basis for existing and future Protocol stack development through reusable software components. The M-DALL also provides enhanced Services like handover, data storage and a method of power consumption. The evaluation of these enhanced services by means of analysis, simulations and prototyping is a topic of ongoing and future work. Additionally, special attention was paid to keep the M-DALL extendible for emerging networking technologies. I was a collaborating systems engineer in this project.

Chapter 9 presents advanced QoS Framework for the Digital Living Network Alliance-enabled Home Gateway (DLNA-HG) to provide enhanced services for accessing and sharing various multimedia contents which are distributed over DLNA capable devices in a digital home environment. Many measurement studies have characterized the media access patterns and user behaviours. In order to gain insights into the current system, we have analysed these patterns for most commonly used applications among consumers. An analysis was carried out and it shows that the QoS is delivered on a best-effort basis in a connected home environment. Motivated by these observations we propose a QoS framework for DLNA-HG. DLNA home networked device interoperability guidelines were adopted with the proposed QoS-enabled media distribution architecture for interoperability of multimedia networking and QoS management among respective networked devices. By combining the DLNA guidelines with the proposed QoS architecture and integrating them into a standard home gateway and multimedia devices, interoperability of media distribution among different networked devices and an easy-to-use management of QoS for multimedia services in a digital home environment were offered. The architecture presents an innovative perspective of identifying, classifying, prioritizing and assigning the primary QoS parameters to devices. In other words, deterministic quality-of-service is ensured by a process of sequential delegation, i.e. at each stage the best fit for the given request is determined and the information is passed to the next stage. It is the responsibility of the element in the subsequent stage to analyse and act on this information to move closer to the optimal solution. A prototype is built based on this architecture demonstrating the QoS feature that is implemented in a DLNA-HG. The performance characteristics for a trial problem are also presented. I was a collaborating systems engineer in this project.

Chapter 10 is the final chapter of the dissertation. Android® is a mobile operating system running on the Linux kernel initially developed by Google, and later the Open Handset Alliance. This chapter presents a new architecture for efficient end-to-end performance delivery on Android. This allows developers to write managed code in the Java language, controlling the device using Google® developed Java libraries. Most research efforts have concentrated on advancement in video compression techniques resulting in DivX/Xvid codecs for better performance on handheld devices. Initial investigations reveal that these techniques are actually taking less time compared to entire execution time in a typical media playback system. However, it enlists that the buffer management methods employed in multimedia framework can significantly impact the overall end-to-end performance on these resource constrained devices. Motivated by these observations, a heuristic buffer management scheme to improve end-to-end performance for Android based devices is presented. An existing buffer management methods used within Packet Video Multimedia Framework (PVMF) of Android is discussed. How buffering schemes used between processors in hardware platform can further contribute to the performance bottleneck is also described. Consequently, a heuristic buffer management scheme is proposed to ensure a uniform buffer allocation among PVMF components and between processor-coprocessor of the hardware platform. To validate the approach, an experiment was performed using the heuristic buffer management technique to playback Xvid content on Zoom2 hardware platform based on Android®. The performance characteristics of the trial experiments are conducted. Experimental results lead to conclusion that the technique is effective at improving overall system performance significantly. The benchmark performance is achieved to further characterize this method. Finally, evaluation trade-off between memory and performance using the method with combinations of measurements using the experimental setup are also presented. I was a collaborating systems engineer in this project.

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1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
A/V	Audio Video
AAA	Accounting, Authentication and Authorisation
ACK	Acknowledgement
ADSL	Asymmetric Digital Subscriber Line
ADT	Average Decoding Time
AES	Advanced Encryption Standard
AMPS	Advanced Mobile Phone Systems
AP	Access Point
API	Application Programming Interface
ARM	Acorn RISC Machine
ARQ	Automatic Repeat Request
ASP	Active Server Pages
ATD	Automatic Call Distribution
ATM	Asynchronous Transfer Mode
BCP	Basic Call Processing
BCSM	Basic Call State Model
BER	Bit Error Rate
BHI	Box Hill Institute
BRS	Baggage Reconciliation System
CDF	Common Data Functions
CDFF	Common Data Function Framework
CDMA	Code Division Multiple Access
CIP	Channel Interface Processor
CLP	China Light and Power Limited
CMMS	Computerised Maintenance Management System
CPU	Central Processing Unit
CRD	Centralised Relational Database
CRE	Composite Radio Environment

CRM	Customer Relationship Management
CSD	Circuit Switching Data
CSV	Comma Separated Value
CTI	Computer Telephony Integration
DB	Dynamic Bandwidth
DHCP	Dynamic Host Configuration Protocol
DLLF	Data Link Function Framework
DLNA	Digital Living Network Alliance
DMA	Direct Memory Access
DMP	Digital Media Player
DMS	Digital Media Server
DMZ	De-Militarised Zone
DPF	Digital Picture Frame
DSP	Digital Signal Processor
DS-UWB	Direct Sequence Ultrawide Band
DTG	Decoding Time Gaps
DVB	Digital Video Broadcasting
DWDM	Dense Wavelength Division Multiplexing
EAP	Extensible Authentication Protocol
EAP-TLS	EAP Transport Layer Security
Ec/Io	Energy per Chip to Total Receive Power
EDGE	Enhanced Digital GSM Evolution
EMI	Electromagnetic Interference
ESP	Encapsulation Protocol
EU	European Union
FER	Frame Error Rate
FHS	Frequency Hopping Sequence
FHSS	Frequency-Hopping Spread-Spectrum
FTP	File Transfer Protocol
GPP	General Purpose Processor
GPRS	General Packet Radio Service
GSM	Global System for Mobile
GUI	Graphical User Interface
HC	Handover Control

HDTV	High Density Television
HG	Home Gateway
HTML	Hyper Text Mark-up Language
HTTP	Hyper Text Transfer Protocol
HTTPS	Hyper Text Transfer Protocol over Secure Socket Layer
I/O	Input/Output
ICT	Information Communications Technology
IEEE	Institute of Electrical and Electronics Engineers
IIS	Internet Information Services
IM	Instant Messaging
IN	Intelligent Networks
INAP	Intelligent Networks Application Part
IP	Internet Protocol
IPTV	Internet Protocol Television
ISM	Industrial, Scientific and Medical
ISP	Internet Service Provider
IVR	Interactive Voice Response
J2EE	Java 2 Platform Enterprise Edition
J2ME	Java 2 Platform Micro Edition
JAIN	Java APIs for Integrated Networks
L2TP	Layer Two Tunnelling Protocol
LAN	Local Area Network
LEAP	Light-weight Extensible Authentication Protocol
LLC	Logical Link Control
LNA	Low Noise Amplifier
LTE	Long Term Evolution
MAC	Medium Access Control
MAP	Mobile Application Part
MCU	Microcontroller Unit
MIC	Message Integrity Check
MIH	Mobile Independent Handover
MMS	Multimedia Messaging Service
MPEG	Moving Pictures Experts Group
NAK	Non-Acknowledgement

NEXT GEN	Next Generation
ODBC	Open Database Connection
OFDM	Orthogonal Frequency Division Multiplexing
OMAP	Open Multimedia Application Platform
OMR	Off-site Meter Reading
PA	Power Amplifier
PAN	Personal Area Network
PBX	Private Branch Exchange
PC	Personal Computer
PCS	Personal Communication System
PDA	Personal Digital Assistant
PDCP	Packet Data Convergence Protocol
PDU	Packet Data Unit
PHP	Personal Home Page or Hypertext Pre-processor
PMP	Portable Media Player
PoS	Point of Sale
PSTN	Public Switched Telephony Network
QoE	Quality of Experience
QoS	Quality of Service
QM	QoS Manager
R&D	Research and Development
RADIUS	Remote Authentication Dial-In User Service
RAT	Radio Access Technology
RB	Radio Bearer
RF	Radio Frequency
RLC	Radio Link Control
RSCP	Received Signal Code Power
RSSI	Received Signal Strength Indicator
RTP	Real-time Transport Protocol
RTT	Round Trip Time
RX	Receiver Module
SACL	Sydney International Airport Corporation Limited
SAR	Specific Absorption Rate
SCP	Service Control Point

SD	Secure Digital
SDK	Software Development Kit
SDU	Service Data Unit
SIB	Service Independent Building Block
SIG	Special Interest Group
SLEE	Service Logic Execution Environment
SLP	Service Logic Program
SMS	Short Messaging Service
SNDCP	Sub-Network Convergence Data Protocol
SNR	Signal to Noise Ratio
SQL	Server Query Language
SSI	Signal Strength Indicator
SSID	Service Set Identifier
SSL	Secure Socket Layer
SSP	Service Switch Point
TAFE	Technical and Further Education
TDM	Time Division Multiplexing
TDMA	Time Division Multiple-Access
TFTP	Trivial File Transfer Protocol
TKIP	Temporal Key Integrity Protocol
TTI	Transmission Time Interval
TX	Transmission Module
UMA	Unlicensed Mobile Access
UMTS	Universal Mobile Telecommunications Systems
UPnP	Universal Plug and Play
USB	Universal Serial Bus
UTP	Unshielded Twisted Pair
UTRAN	UMTS Terrestrial Radio Access Network
UWB	Ultra Wide Band
VB	Visual Basic
VLD	Variable Length Decoding
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network
VWLAN	Virtual Wireless Local Area Network

WAMP	Windows Apache MySQL PHP
WAN	Wide Area Network
WAR	Wireless Access Router
WCDMA	Wideband Code Division Multiple Access

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Chapter 1
Introduction to Emerging Communication Technologies

1.1 Introduction

Telecommunications service providers form an integral part of communications infrastructure. This infrastructure forms the backbone of modern-day services, such as connection to the internet service provider (ISP) via T1, virtual private network (VPN), switching, routing etc. Equipment manufacturers, swings from prosperity to downturns have been reflected in their respective stock performances [1]. However, the more recent and sudden slowdown, particularly in capital spending on networking equipment, has resulted in massive corporate restructuring and workforce realignment in the information communications technology (ICT) industry. Through merger and acquisition strategies, major telecom equipment suppliers such as Cisco, Alcatel-Lucent, Juniper, Qualcomm and Nortel, expanded their product portfolios globally.

First generation (1G) mobile was analogue voice and offered no roaming or security. In the 1990s, mobile services based on digital mobile technologies ushered in the 2G of wireless that we have today. In the US, these were referred to as personal communication systems (PCS) and used technologies such as time division multiple-access (TDMA), code division multiple access (CDMA) and global system for mobile (GSM). The main focus of wireless mobile services has been voice telephony. However, in recent years there has been growing interest in data services as well. While data services are available over advanced mobile phone systems (AMPS), these are limited to quite low data rates (<10 Kbps). Higher speed data and other advanced telephone services are more readily supported over the digital second generation (2G).

2G cellular networks were introduced in early 2000 and included mobile systems such as GSM communication and their evolutions, often called 2.5G systems such as enhanced digital GSM evolution (EDGE), general packet radio service (GPRS) and IS136 [1]. These systems are based on TDMA technology. 2G systems essentially offered the same service, voice with the advantages of digital transmission and global standardisation, including roaming and tighter security. Taking 9.6 Kbps as the data rate available for 2G, 2.5G offers higher rates anything from 14.4 Kbps at launch to a maximum of 160 Kbps.

More importantly, 2.5G also offers ‘always-on’ and per packet charging (as is the case with i-mode).

Anticipation that average revenue per user would continue to decline, 2G wireless service operators looked to third generation (3G) broadband services as the next promising opportunity to maximise business growth. 3G mobile networks known as universal mobile telecommunications systems (UMTS and CDMA2000) based on code division multiple access (CDMA) technology that provides speed up to 2 Mbps. Wireless equipment manufacturers invested heavily in the research and development (R&D) of 3G system equipment and handsets [2]. Spending on 3G product and system development by most of the major wireless equipment manufacturers has curved upward steeply [2].

As 3G equipment manufacturers continued to promote and encourage 3G capabilities and full-colour video wireless handsets, wireless service providers, investors and consumers became excited and anxiously awaited the arrival of 3G.

The major expectation from the fourth generation (4G) of wireless communication networks is to be able to handle much higher data rates, which will be up to 1 GB in the wireless local area network (WLAN) environment and 100 MB in cellular networks. A user, with a large range of mobility, will access the network and will be able to seamlessly reconnect to different networks, even within the same session. The spectrum allocation is expected to be more flexible and spectrum sharing among the different sub-networks is anticipated [3]. In such a composite radio environment (CRE), it is anticipated that there will be a need for more adaptive and reconfigurable solutions on all layers in the network [4].

The sudden economic slowdown at the end of 2001 and again in 2008 caught almost everyone off-guard. The telecom industry suffered severe downturns in sales and revenue. The following factors were responsible [1-5]:

- 2G/3G/4G license auctions;
- uncertain 2G/3G/4G profitability;
- network over-build and competition;
- heavy debt among telecom start-ups and dot coms;

- B2C and B2B investment spending cuts; and
- write-offs on acquisitions and many more.

1.2 Emerging Communication Technologies

1.2.1 Wireless Fidelity

Wi-Fi is the popular name for the wireless Ethernet 802.11x standard for WLAN. It allows collections of personal computers, dumb terminals and other distributed computing devices such as personal digital assistant (PDA) etc, to share common resources and peripherals. One of the most popular LAN technologies was Ethernet. Over the years, the IEEE has approved a succession of Ethernet standards to support higher capacity LANs over a diverse array of media [5].

The two most fundamental 802.11x family are 802.11a which operates at 11 Mbps in the 2.4 GHz band and 802.11b which operates up to 54 Mbps in the 5 GHz unlicensed spectrum band. Other 802.11x standards include 802.11g which offers up to 100 Mbps in the 2.4 GHz band; 802.11e which adds quality-of-service support to manage latency which is important for supporting voice telephone; 802.11h solves problems like interference with satellites and radar using 5 GHz; and 802.11i which adds security features of Wi-Fi protected access (WPA) by replacing wired equivalent privacy (WEP). 802.11i uses advanced encryption standard (AES). WLAN operate using unlicensed spectrum in the 2.4 GHz band. The current generation of WLAN support up to 512 Mbps data rates within 100 meters of the base station. Most typically, WLAN are deployed in a distributed way to offer last-hundred-meter connectivity to a wired backbone corporate or campus network. Typically in a corporate environment, WLAN are implemented as part of a private network. The base station equipment is owned and operated by the end-user community as part of the corporate enterprise, campus, or government network. In general, use of the network is free to the end-users that is, it is subsidised by the community as a cost of doing business, like corporate employee telephones.

Although each base station can support connections only over a range of a hundred meters, it is possible to provide contiguous coverage over a wider area by using multiple base stations. A number of corporate business and university campuses have deployed such contiguous WLAN [5]. Still, the WLAN technology was not designed to support

high-speed handover associated with mobile users moving between base station coverage areas.

In the last couple of years numerous service providers are offering Wi-Fi services for a fee at hotels, airport lounges, and coffee shops. In addition, there is a growing movement of so-called "Free Nets" where individuals or organizations are providing open access to subsidized Wi-Fi networks [6].

1.2.2 Bluetooth®

Bluetooth® is a short-range wireless technology designed to enable short range communication without the need for computers, entertainment systems and other smart electronic devices to correctly set up a complete two way communication system on the first try [7]. Bluetooth tech low-power uses frequency-hopping spread-spectrum (FHSS) communication in the 2.4 GHz industrial, scientific, and medical (ISM) band, in which unlicensed devices are permitted to communicate in most countries of the world.

Bluetooth (Ericsson trademark) takes its name from Harald Blatland, a Danish king born in AD908. An Ericsson-led consortium including IBM, Intel, Nokia, and Toshiba, have developed the technology. A second group, the Bluetooth special interest group (SIG) was then formed to promote the technology and comprised 1371 member companies in early January 2000 [7].

Bluetooth technology permits devices to communicate with each other, synchronise data, and connect to the Internet at high speeds without wires or cables. A Bluetooth radio and baseband controller can be installed on a device that links to a universal serial bus (USB) port, a PC Card, or integrated on a system board to add Bluetooth functionality to a computer or other host device. Bluetooth air interface is based on a nominal antenna power of 0 dBm (1 mW) with the extensions for operating at up to 20 dBm (100 mW) worldwide [8]. This interface complies with ISM band rules up to 20 dBm in America, Japan and most European counties. The Bluetooth radio uses frequency hopping method to spread the energy across the ISM spectrum in 79 hops displaced by 1 MHz, starting from 2.402 GHz and stopping at 2.408 GHz [9]. SIG completed the work to harmonize this 79 channel radio to work globally and has instigated changes within Japan, Spain, and other countries [8].

There are also worries that the part of the radio spectrum used by Bluetooth is becoming too crowded. A report by Aegis Systems® said that Bluetooth, other wireless networking systems, microwave ovens, outdoor broadcast units, and radio-based CCTV unit may all interfere with each other [10]. Another potential drawback for Bluetooth is speed. Bluetooth sends information at about 725 Kbps. By comparison, cell phones in the next few years are expected to go faster than 2 Mbps.

1.2.3 Intelligent Networks

Intelligent Networks (IN) service model was the first step to releasing service control from the hands of switch manufacturers and as such presented telecom operators with a new vehicle for realising services that enhanced the basic call control capabilities of stored program control switches [11]. IN rely on the decoupling of a number of telephone switch functions from the stored program controller, renamed a service switch point (SSP). The functions left behind in the SSP are called the basic call state model (BCSM). The functions separated out are incorporated into a centralised service execution environment as a service independent building block (SIB) called the basic call processing (BCP) function. The services, constructed from SIBs to form a service logic program (SLP), run inside this environment called the service logic execution environment (SLEE), inside a physical platform called the service control point (SCP). All of this distributed processing is facilitated by a protocol called Signalling System Number 7 (SS7) [11]. The remote method invocation protocol that runs on top of SS7 is known as the intelligent network application part (INAP). Mobile telephone networks implement a protocol on top of SS7, called the mobile application part (MAP). This protocol is the glue that allows mobile networks to support roaming subscribers. The combination of IN and mobile networks come together to deliver the wireless intelligent network (WIN).

The core software of an SCP, the service logic is generally bespoke to a specific manufacturer's SLEEs services written for one manufacturer's SCP are not readily transportable to another manufacturer's product [11]. This arrangement has been changed to soft switches and application servers are utilising common application frameworks such as Java APIs for Integrated Networks (JAIN) and Java 2 Enterprise Edition (J2EE) which allow developers to create services based on a common (manufacturer independent) set of libraries and application programming interfaces (APIs).

1.2.4 Voice-Based Services

Call centres, the workhorse of telephone sales and customer care where agents answer calls from customers, make extensive use of voice server based services to provide customer filtering, in-queue announcements and self-serve services for customers. Call centre services are performed on specialist interactive voice response (IVR) platforms [11] either on the customer's premise or on in-net platforms provided by a telecommunication operator. The in-net platforms incorporate features on intelligent peripherals.

The cost of implementing the circuit switched based services meant that smaller customers have been excluded from this marketplace and only the larger call centres or companies who are able to afford it, can implemented automated services.

1.2.5 Computer Telephony Integration

Computer Telephony Integration (CTI) signalled the move from automatic call distribution (ACD) or private branch exchange (PBX) only services, where call routing decisions are made by proprietary routing engines configured through text-based terminals, to a new era in call routing and configuration [11]. The ability to utilise corporate databases such as those held by marketing to segment the inbound calls based on the market segmentation of the customer. CTI has also created the ability to integrate multiple call centres in different physical locations into a single entity. The combination of CTS and intelligent network services has created the ability for call centres to route calls across national and international boundaries transparent to the caller [11].

There are essentially two types of CTI, first-party call control and third-party call control. First-party call control is where a computer takes over the role of a telephone handset's functions and links the basic call functions of a handset (make call, release call, transfer, hold, caller number presentation) to a software package that provides database integration.

Third-party call control is a much more powerful capability, allowing a computer to control and monitor a large collection of telephone sets via a special interface connected directly to the PBX or ACD. This link instead of carrying telephony signalling messages

carries status and control messages about all the events occurring in the PBX or ACD, from on – and off-hook messages from handsets through to call arrivals on trunks and call queue events. This control messages allow the computer system to establish new calls, terminate exiting calls and even control the destination of newly arriving calls.

The first generation of CTI products brought about the control of circuit switch based PBX and ACD allowed for increasing complexity over the control of call routing through the use of information from customer databases. Second generation CTI allows for the integration of systems that provided a view of the customer and their relationship with the customer relationship management (CRM) tools, web collaboration and email routing with conventional time division multiplexing (TDM) platforms. Future generation CTI is combining Voice over Internet Protocol (VoIP), electronic CRM (eCRM) and IP voice servers to bring a level of integration beyond that which was previously possible to create packet telephony call centres [11].

The future generation CTI servers will combine the ACD routing capabilities and will go beyond this to provide a truly integrated solution for 'contact' routing [11]. Presently, this is a new service that has gained significant interest in the telecommunications and Internet industries as a means of combining location-based information with the instant communications of Instant Messaging (IM).

1.2.6 Ultra Wide Band

Ultra Wide Band (UWB) was praised excessively as a replacement for Bluetooth, as it offers much higher data speeds (currently 40 to 60 Mbps). The IEEE 802.15.3 committee is tasked with developing one ultra-wideband PAN standard, but it not been able to converge on DS-UWB (direct-sequence) or MB-OFDM (multiband orthogonal frequency division multiplexing) since neither side has been able to gather the necessary 75% support [3].

1.2.7 Zigbee

This radio technology gained acceptance for a very little time by the sensor networks community [11]. Zigbee operates under unlicensed band of 2.4 GHz worldwide. It has a capacity of achieving raw data transmission of 250 Kbps for 10 channels to 20 Kbps for 1 channel. Transmission distance is in the range of 30 to 245 feet with constraints like

power and environmental characteristics. The most recent application of this technology is electricity meter readings in Seoul, South Korea with the help of Ember's smart chip and NURI Telecom.

Whilst writing of this thesis, Zigbee and WiMax have emerged with suites of commercial products, in particular for the energy sector. Some of the world's leading utilities, energy service providers, product manufacturers and technology companies are supporting the development of Zigbee Smart Energy[1].

WiMax is seen as a "last mile" broadband wireless access alternative to cable modem service, digital subscriber line (DSL) or T1/E1 services. There is no global license spectrum from WiMax but the WiMax Forum has published three licensed profiles at 2.3 GHz, 2.5 GHz and 3.5 GHz to drive an effort towards standardisation and lower the cost of implementation. Intel® has been the driver of the WiMax adoption. Mainly, due to number of chipset are developed by Intel®. Like all wireless technologies, WiMax can operate at either higher bitrate or longer distance but not both. Smart Grid is an aggregate of multiple networks and multiple power generation companies with multiple operators and distributors. Smart Grids increases the connectivity, automation and coordination between suppliers, consumers and networks that perform long distance and local distribution functions. In US, WiMax has been promoted heavily by GE Energy® used for Gridnet™ and SmartStreet™. In Australia, energy market is regulated by the Australian Energy Regulator (AER). AusGrid (previously Energy Australia) is contracted to develop SmartGrid SmartCity project. AusGrid uses WiMax but not will not roll out WiMax for Smart Metering, instead will use long term evolution (LTE) technology. However, SP AusNet® is the only corporation known in the world to date to plan and implement WiMax for Smart Metering using Channel 7 subsidiary Vivid Wireless®[2].

1.2.8 Wireless LAN

While 3G promises broadband wireless Internet access data services in the future, IEEE 802.11 Wireless LAN (WLAN) technology is becoming increasingly available in

[1] Zigbee alliance, Zigbee Smart Energy Overview, assessed on 09 February 2012 from http://www.zigbee.org/standards/zigbeesmartenergy/overview.aspx
[2] Impaq Consulting, "Review for WiMax for Smart Metering and other applications Rev 1.0", 12 April 2011.

enterprises and public locations such as airports, restaurants, hotels, and other public places. The popularity and proliferation of WLAN can be attributed to the following factors [3]:

- need for Internet access outside the office or home
- growing popularity of notebook PCs and PDAs
- availability of enterprise virtual private network applications
- high rate of data transfer (e.g., 11 Mbps or 54 Mbps)
- affordably priced equipment
- compatibility with existing LAN protocols (IP compatible)
- no operating license or frequency usage fee required (ISM band)

The emergence of WLAN has changed the view of existing wireless services competition, and it has negatively impacted the deployment of 3G networks [3]. However, since the strength of 3G is in its wide-area coverage and high speed mobility, WLAN could complement 3G networks by providing subscribers with a variety of service capabilities in the future.

The 2.4 GHz ISM band is fairly congested. With IEEE 802.11n, there is the option to double the bandwidth per channel to 40 MHz which results in slightly more than double the data rate. However, when in 2.4 GHz, enabling this option takes up to 82% of the unlicensed band, which in many areas may prove to be unfeasible.

IEEE 802.11n-2007 wireless networking standard was amended and published in October 2009 to IEEE 802.11n-2009. IEEE 802.11n improves network throughput over the two previous standards, namely 802.11a and 802.11g with a significant increase in the maximum net data rate from 54 Mbps to 600 Mbps (slightly higher gross bit rate and slightly lower maximum throughput) with the use of four spatial streams at a channel width of 40 MHz. IEEE 802.11n standardised support for multiple-input multiple-output (MIMO) and frame aggregation, and security improvements, among other features.

1.2.9 3G

The first commercial offerings of 3G services began in Japan in October 2001. 3G extends these data rates up to 3.6 Mbps and support several simultaneous Quality of

Service (QoS) classes for multimedia delivery [3, 6 and 11]. 3G has been dominated by the air interface technology and the spectrum available to deploy it around the world.

3G is a technology for mobile service providers which combine wireless communications and the Internet. Mobile services are provided by service providers that own and operate their own wireless networks and sell mobile services to end-users, usually on a monthly subscription basis. Mobile service providers use licensed spectrum to provide wireless telephone coverage over some relatively large contiguous geographic serving area. Historically, this might have included a metropolitan area. Today, it may include the entire country. From a user perspective, the key feature of mobile service is that it offers (near) ubiquitous and continuous coverage. That is, consumers can carry-on telephone conversation while driving along a highway at 100 km/h. To support this service, mobile operators maintain a network of interconnected and overlapping mobile base stations that handover calls as those customers move among adjacent cells. Each mobile base station may support users up to several kilometres away. The cell towers are connected to each other by a backhaul network that also provides interconnection to the wireline public switched telecommunication network (PSTN) and other services. The mobile system operator owns the end-to-end network from the base stations to the backhaul network to the point of interconnection to the PSTN (and, perhaps, parts thereof).

Ongoing controversy about the likely migration to 3G for developing countries, two main standards have been proposed, UMTS also known as Wideband CDMA (WCDMA) and CDMA 2000. CMDA2000 is a relatively simple upgrade of existing CDMA technology. If CDMA2000 succeeds and WCDMA does not, or if CDMA2000 succeeds much more quickly than WCDMA, any European Union (EU) policy that may have assumed WCMDA or locked operators into WCMDA may prove to be a very costly public policy decision [6]. So, not only there is a historical question about the relative advantages of the European and North American approaches to standardisation policy for 2G but also a current policy questions about the 3G bands. There are a number of differences between CDMA 2000 and WCDMA. However, CDMA2000 is a natural migration from CDMA-One, which WCDMA is essentially incompatible with any existing technology [7].

1.2.10 4G

Mobile device technology and advanced software, together with the influence of the Internet, are creating a vast array of Web-based services to which people want easy, 24-hour access from any location. Microprocessors are rapidly becoming smaller, faster, more power-efficient, and less expensive, which means they will be used more often and in more places to create a host of intelligent devices that will increase access to those services. Wired and wireless bandwidth is expanding at a rapid rate, providing the final component necessary to create "universal connectivity" among all of these new devices and instant availability of the information and services they help to deliver. Carrier technologies such as 3G, CDMA and GPRS are now readily available in many countries.

The key differentiator for 4G is speed offering from 2 Mbps to 1 Gbps using orthogonal frequency division multiplexing (OFDM) and space-time coding [4]. Since this view of 4G is about defining a whole new system, it also means that, a new radio access network needs to be developed [16], and perhaps a new core network as well, to support the new air interface. This should be based on IP and a new spectrum must be identified and assigned in which the 4G systems can operate. Without doubt, however, 4G networks will be based on IP transport just as 3G was based on asynchronous transfer mode (ATM) in the 1990s and GSM on 64 Kbps TDM technology in the 1980s. The only real question is whether IP itself will have evolved out of recognition or will have been replaced by a newer networking technology [11].

In my opinion, moving beyond 2011, technology road map and time frame should justify the final definition for 4G i.e. 4G = 3G + IPv6 + Seamless Mobility + Interoperability + Rich Multimedia Experience. This poses a new concept of providing management of wireless systems. Multiple Radio Access Technology (RAT) standards are used in wireless communication. Figure 1-1 shows a generic composite radio environment in 4G networks which can be roughly categorised in four sets, cellular networks, and broadband radio access (BRAN), digital video broadcasting (DVB) and satellite communications, and adhoc and sensor networks with emerging applications.

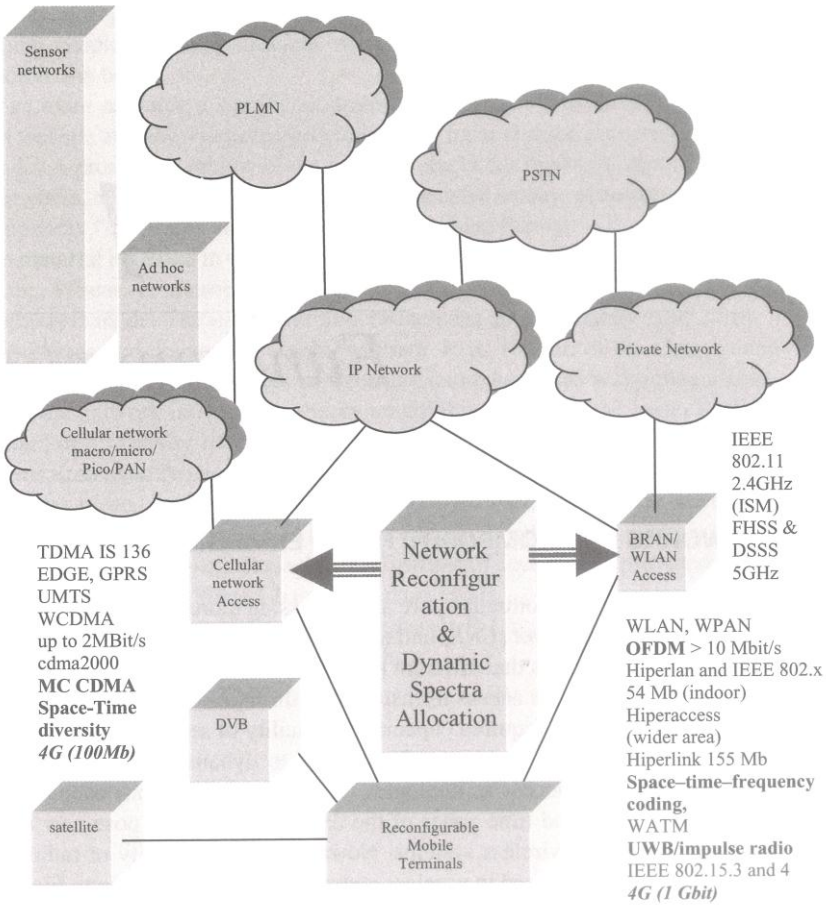

Figure 1-1 – CRE in 4G networks [4]

Figures 1-2 and 1-3 show the architecture of a terminal capable of operating under CRE and architecture of a terminal operating under reconfigurable context respectively. The terminals include software and hardware components (layer 1 and 2 functionalities) for operating within different systems. The word ‘terminal’ can mean anything from fixed telephone to set-top boxes or an integrated handheld cellular phone. The higher protocol layers, in accordance with their peer entities in the network, support continue to access IP-based applications. Different protocol stacks can further enhance the efficiency of the protocol stack. There is a need to provide the best possible IP performance over wireless links, including legacy systems [4].

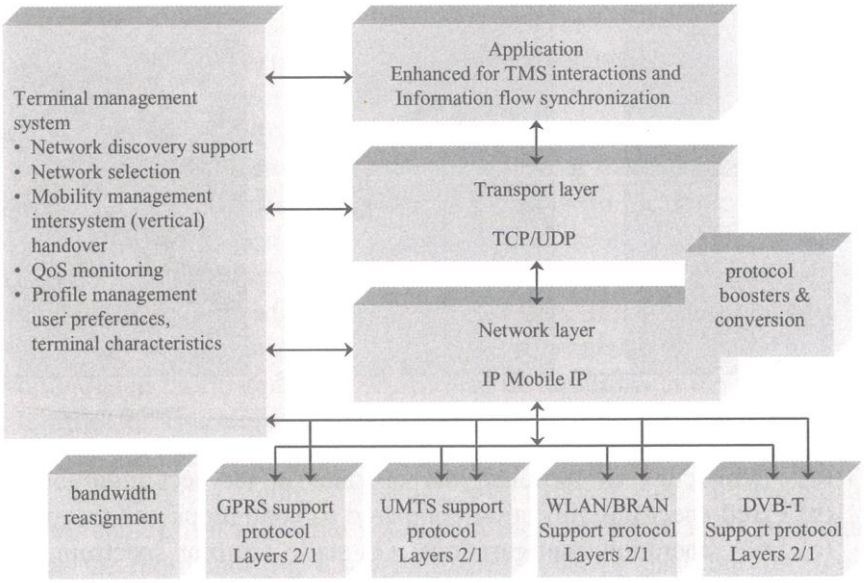

Figure 1-2 – Architecture of 4G Terminal operating under CRE [4]

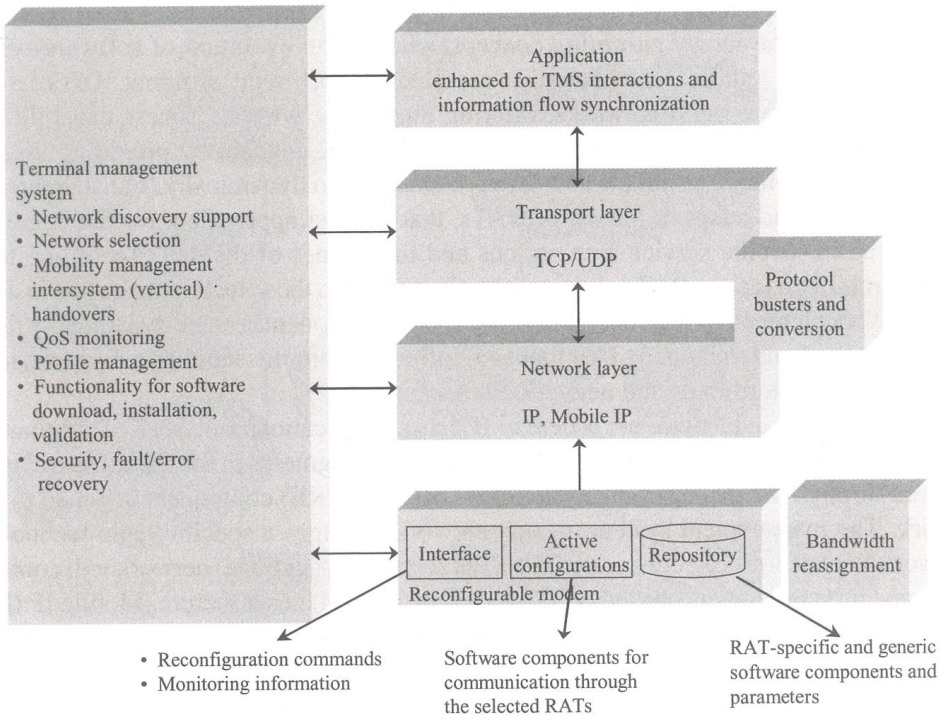

Figure 1-3 – Architecture of 4G terminal operating under reconfigurable context [4]

The fourth generation of cellular is expected to achieve high levels of user experience and capabilities that previous technologies such as 2G and 3G lacked. To quantitatively state these requirements, ITU-R benchmarked challenging figures for uplink and downlink

traffic that would be supported by 4G networks. These include peak data rates of up to 100 Mbps for high mobility and 1 Gbps for non-mobile devices, an all-IP packet network, use of scalable channel bandwidths from 5 to 40 MHz, spectral efficiencies of at least 3 bit/s/Hz and support for smooth heterogeneous network handover and high quality multimedia transmission. To meet these challenges, two parallel technologies are under development and testing namely long term evolution (LTE) Advanced, standardized by 3GPP [12] and Mobile WiMax (802.16m), standardised by IEEE [13]. These technologies feature functionalities like carrier aggregation [14], Orthogonal Frequency Division Multiple Access (OFDMA), enhanced Multiple-Input Multiple-Output (MIMO) capabilities, link adaptation, frequency selective scheduling, multipoint transmission and relaying [15]. With all these capabilities put to work, user experience with multiple services will increase and operators would be able to attract more customers. But all this comes with complexities in handling a large number of users running a multitude of services [16].

Operators would specifically be interested in selling their network capabilities by offering granular services targeted to different consumer markets. This would then be supported by policy and charging functionalities to handle user traffic consistent with their service level agreements [17]. User-service prioritization hence becomes of prime importance for properly distributing the available network resources. Service prioritisation is not a single step function but instead is strongly coupled with other major Quality of Service (QoS) enabling entities in the network. Determining these relationships and the methods that could be adopted for prioritisation is an emerging challenge [18-20]. The goal of moving into the 4G solution is also motivated by the fact that operators need to provide multiservice offerings to users in contrast to the previously used single service so that the users can have more options to choose the service which suits them best [16-20]. Examples of such multiservice offerings include multimedia telephony, social networking, e-gaming and mobile TV [18].

The competition is to provide the highest level of QoS to the users and leverage the system to perform near to or better than the IMT-Advanced standard. Both LTE-Advanced and Mobile WiMax should be true broadband networks that provide data rates equal or greater than even the most reliable wired technologies like Fiber-to-the-Home

with optimised QoS provisioning [19]. All this should come with reduced network operating cost and compatibility with other systems [16].

Prioritisation itself defines a way of giving more importance to users that have paid more and are expecting higher service level availabilities from the operators [21]. The customers may have different types of subscriptions with the operator and at times it becomes difficult to properly classify the users with priority and much more difficult if the subscriptions are on a traffic type basis [22, 23]. Prioritisation, while depending on the traffic mix being dealt with; always puts the operator on the safe side since it tends to avoid any congestion events in case of user over-loads [23, 24].

1.3 Implications for In-Service Provision

1.3.1 Standards

It has long been accepted in the telecommunications industry that standards are required to govern the physical, electrical, and procedural characteristics of communication equipment. Whereas communication equipment vendors recognize that their equipment will generally interface to and communicate with other vendors' equipment. Computer vendors have traditionally attempted to monopolize their customers. The proliferation of computers and distributed processing has made that an untenable position. Computers from different vendors must communicate with each other and with the ongoing evolution of protocol standards; customers will no longer accept special-purpose protocol conversion software development [7]. For 3G, there is a relatively small family of globally sanctioned standards [25], referred to as IMT-2000. At the time, there was still an uncertainty as to which of these will be selected by service providers.

Example 1: In the US, it was originally hoped that the PCS spectrum licenses would be used to provide many new types of wireless communication and data services, not just the type of highly mobile service for which it has been used principally to date. In Europe, GSM was adopted as the 2G standard for mobile networks and began to be deployed in the early 1990s, before the PCS spectrum was auctioned in the US where different service providers adopted multiple and incompatible standards for their 2G service offerings [7, 25].

Example 2: The European Telecommunications Standard Institute published the SGM standard 1990 and by 1995 it had become the de facto standard in Europe. This is in contrast to the US where multiple incompatible standards were adopted [7, 25].

1.3.2 Deployment and Business Model

With respect to deployment, 3G and 4G will require substantial investment in new infrastructure to upgrade existing 2G networks. Towers and backhaul network will still remain useable. For Wi-Fi, it is hoped that deployment can piggyback on the large existing base of WLAN equipment already in the field. In contrast to 3G, Wi-Fi access can emerge decentralised, bottom-up fashion. While the prevailing business model for 3G services and infrastructure is vertically integrated. This opens up more possibility for heterogeneous and complex industry chain model [6]. In contrast to mobile, WLANs were principally focused on supporting data communications.

However, with the growing interest in supporting real-time services such as voice and video over IP networks, it is possible to support voice telephony services over WLANs [30]. This has implications for the magnitude of initial investment required to bring up WLAN or 3G wireless service and for the network management and operation support services required to operate the networks. However, it is unclear at this time which type of network might be lower cost for equivalent scale deployments, either in terms of upfront capital costs (ignoring spectrum costs) or on-going network management costs.

With Bluetooth, it seems that almost every company that is capable of designing a semiconductor chip has published a roadmap of its Bluetooth silicon extending several years into the future [26]. The chip roadmaps even include dates, capabilities, and silicon technologies. Scores of companies have announced products. If 10% of those products are successful, the Bluetooth market would be enormous. Currently there are more than 40 Bluetooth products that are approved by the Bluetooth SIG. The first of these products was approved in June 2000 and the majority of these products have been approved to date. At this point, there are few products that can be widely used, but as stated earlier, the explosive growth of the market will potentially fuel quick adaptability and adoption by numerous users [27].

The cost to produce the chipsets was estimated to decrease significantly over the same 6-year period from $42.20 in 2000 to $13.15 in 2005 [27]. This cost reduction, along with the growing mobile workforce, encouraged new and innovative uses of Bluetooth technology.

1.3.3 Occupational Health and Safety

There are a number of national and international regulations, standards, and recommendations dealing with electromagnetic exposure in the radio frequency range. The limits are generally very similar and are usually based on recommendations from the World Health Organization (WHO) and the International Radiation Protection Association (IRPA). The limits have been set with a wide margin in order to protect people from any known negative health effects of both short-and long-term exposure to electromagnetic fields.

The safety margin is sometimes as high as 50, i.e. the limits are set at 50 times lower than the level at which one knows that heating related effects can begin to occur [7, 25]. When a radio transmitter is close to a person as may happen in the case of Bluetooth, the highest power absorption per unit mass in a small part of the body is established and compared with the basic limits given in the standards. This parameter is known as the specific absorption rate (SAR) [7].

The worry about Bluetooth multiplies from the fact that the frequency used by Bluetooth to establish radio links happens to be the same frequency as any household microwave ovens' use. The key difference is that the Bluetooth radio is extremely low power. Investigation as to the potential health risks is an ongoing concern with Bluetooth as well as cell phones and many other radio emitting devices.

The maximum exposure levels from Bluetooth products are well below the prescribed safety limits. The risk of Bluetooth devices causing electromagnetic interference in sensitive electronic equipment, e.g. medical devices, is minimal because of the very low output power. In late 2001, Bluetooth was cleared against human health risk [8].

1.3.4 Short Term Solutions

Many companies failed completely after the telecom bubble burst in late 2000, the overall industry was severely damaged. Further, questionable accounting practices and subsequent bankruptcies have led to an erosion of investor confidence in the entire telecommunications industry [5]. Few factors which may put Telcos back in business are provided below.

1.3.5 Adopting Supply Chain Management

Focusing on core competency and sub-contracting non-core functions has become a global trend. Dell Computer's success strategy in the PC industry is a role model for the telecommunications industry [27].

1.3.6 New Revenue with SMS and MMS

In light of uncertain prospects for 4G rollout and the difficult financial situations of many wireless carriers, it might take several years before 3G wireless platforms are completely established that can deliver promised multimedia services. Currently, SMS has become popular among cell phone users. Enhancement to SMS is MMS, which allows subscribers to transmit pictures, music, or video clips, as well as transfer files among mobile phone subscribers.

1.3.7 Future Directions

In the next few years, I envisage major investments (by those that can) and divestments by business that are refocusing their strategies and preparation by telecoms operators to move their networks from the current TDM based infrastructures to packet based systems. In the UK, Vodaphone® has publicly committed resources in 3G/4G mobile networks and an enhanced packet based backbone networks, respectively [29]. This trend will continue over the next many years and it will not take too long to transform the networks from the PSTN to the multimedia future with more players both existing and new entrants such as ISPs and ITSPs deriving revenue from voice and data services and competing with conventional telecoms operators.

The largest force of change in the industry now is the declining margin from basic voice services, as they reach commodity status. That is not to say there is no revenue left in

voice, just not as much profit. Telcos have embraced the future generation network infrastructures as a means of transforming their businesses to seek new higher margin products with quality of IN service.

Bandwidth has also reached a state of excess. Technologies such as dense wavelength division multiplexing (DWDM) have created a surfeit capacity in anticipation of the broadband future [30]. The future has not transformed as fast as the original market hyperbole forecast. The upshot is an industry waiting for something to happen. The something is broadband access to eat up all this backbone capacity with revenue generating services. The broadband local loop has been slow to start in all but Singapore, caused by weak regulators and strong incumbents [10]. USA and UK has seen a number of competitive local access providers suffer because of the combination of the slow process of unbundling and a major decline in expected demand [30]. Transmission bandwidth may increase more in the future, particularly considering the potential of fiber optic technology. If the above empirical rule were to hold, the data rate of the next few decades will be:

Year 2010	⟶	Year 2030
10^{11} b/s		10^{12} b/s

Considering that the bible, when coded with an 8-bit character set code, results in approximately 40,000,000 bits, we would transmit the content of 250 bibles per second in 1990; 2500 bibles per second in the year 2010; and 25,000 bibles per second in the year 2030 [31].

1.4 Conclusions

Communications technologies have increased the speed with which we can communicate at a rate that far exceeds the increase in travel speeds over the last century. When a new ICT technology is announced, it usually takes only few months before products starting to appear in the market. In order to achieve the full operational efficiency of IP networks, the vision of an “all IP” network has been promoted by the industry.

“Energy Efficient Technologies” and “Enhanced Mobility Management” are hot R&D topics in Next Generation (NEXT GEN) IP deployment. Significant R&D funding is

already invested among telecom manufacturers desiring to develop new IP technologies and equipment ranging from IP customer premise equipment gateway to IP core network and IP network management system. Over the years, huge amount of capital will be invested in the telecom industry, resulting in too many companies producing too many products.

While the economic slowdown continues, more bankruptcies and mergers can be expected. Smaller, weaker carriers cannot survive, and the assets of bankrupt companies will be sold to the remaining stronger players. Vodaphone, Sprint and Verizon are looking to become a major force in the 4G mobile telecommunications by building a new 4G infrastructure, unencumbered by having to write off investment in existing 2G, 2.5G and 3G equipment. This enforced slowdown is good news. At least, this change of pace "in comparison" will sustain for a while.

Chapter 2
Scalable and Secure Wireless Communication Technology Implementation for the Sydney Airport Corporation Limited (2001-2003)

2.1 Introduction

Sydney Airport's aviation history began in 1919 [32]. Sydney Airport is 93 year old site and 8 kms far from Sydney CBD. It serves 8.7 million international and 15.5 million domestic passengers per year. The site consists of 886 hectares of area consisting three runways (3962 m, 2438 m and 2530 m). It has five terminals with 34 international, 31 domestic and five airfreight gates.

At the Airport Council International (ACI) World Assembly in Santiago in November 2000 the airport community expressed the importance of a Wireless Infrastructure at Airports managed by the Airport Authority [33]. The following resolution was agreed upon:

"Airport Operators should assert control over the use of Wireless Infrastructure at Airports, both inside and outside terminal buildings. Tenants, concessionaires and others should use a common infrastructure for wireless managed by the Airport Operator. In return for this exclusivity, Airport operators should constantly evaluate competing technologies, so as to maintain low costs, increased capacity and security in line with demand for the benefits of all tenants, concessionaires and others"

With this endorsement from the ACI and the fundamental limitations of three wireless channels for the IEEE 802.11 spectrum, the Sydney Airport Corporation Limited (SACL) embarked on the challenge of becoming the sole provider of Wireless Infrastructure at the International Terminal and Airfield. Past experience indicated that business customers preferred to install their own networks, and wireless still an evolving technology with no ratified security standards and ease of deployment gave SACL a unique challenge. In early 2001, 120-access points within the International Terminal (Terminal 1) and at various sites on the airfield within its existing wired network as shown in figure 2-1 were deployed [33].

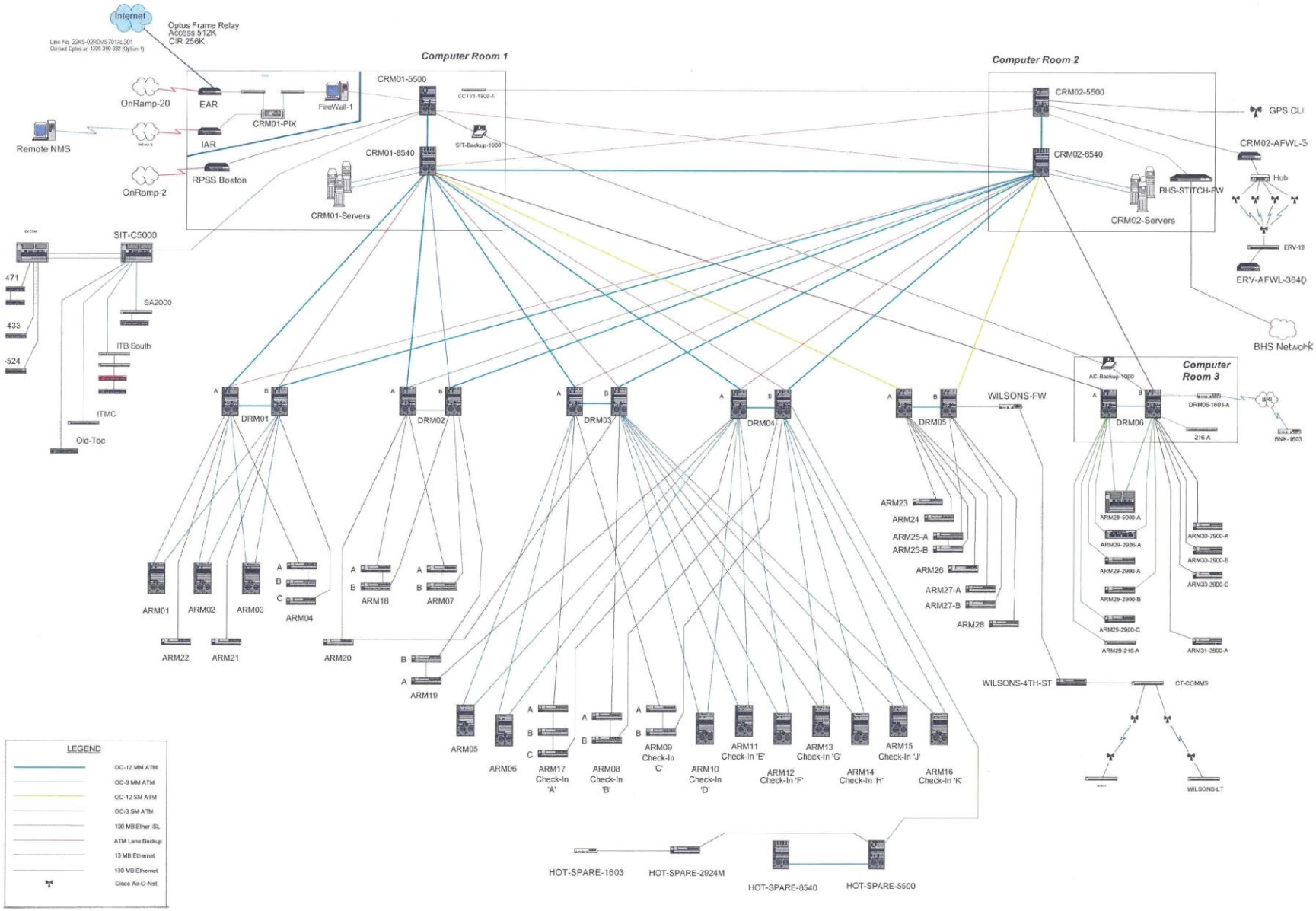

Figure 2-1 – Existing SACL Wired Communication Network

2.2 WLAN Architecture and Security Challenges

With a typical Wireless LAN, transmitted data is broadcast over the air using radio waves because of this, the boundary for SACL's network has moved and is now located in many airfield remote sites. Without stringent security measures in place, the wireless infrastructure is equivalent of putting Ethernet ports everywhere. Sydney Airport WLAN implementation in early 2001 deployed Cisco Aironet 350 Series Access Points. The IEEE 802.11b standard adopted uses the unlicensed 2.4x gigahertz frequency band providing only three non-overlapping channels (1, 6 and 11) with data-rates of 1, 2, 5.5 and 11 Mbps [34].

WLAN deployment challenge was to ensure that the implementation of the wireless network did not breach its existing security policies for the corporate network. The wireless network infrastructure was regarded in much the same fashion as the Internet, an un-trusted zone.

Even with this view, it was ensured that wireless network security protects wireless virtual local area network (WVLAN). Figure 2-2 outlines the type of wireless and network security implemented.

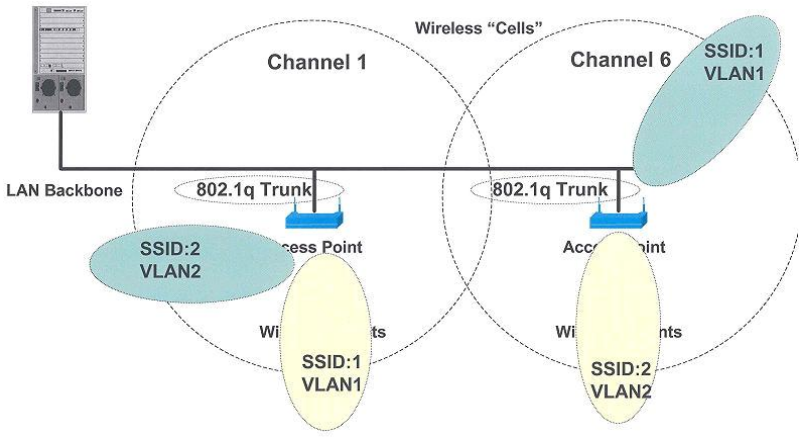

Figure 2-2 – Wireless and Wired Network Security

2.3 Network Architecture and Security Policy

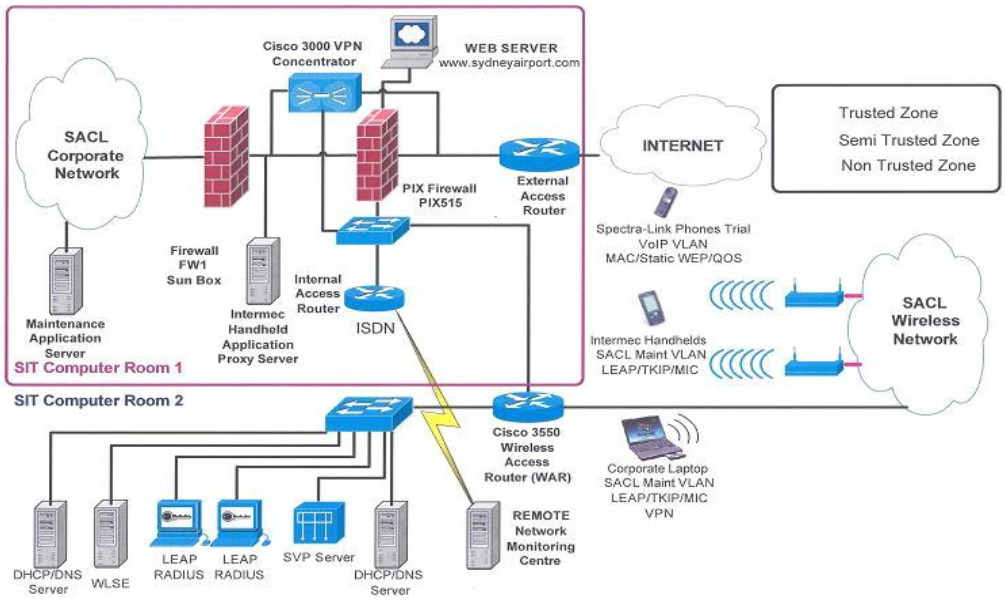

Figure 2-3 – Network Architecture and Security Policy

An important decision when deploying a WLAN is how it will interface back into the corporate infrastructure. WLAN was designed so that the WLAN infrastructure access is located outside the corporate firewalls as shown in figure 2-3. This approach creates more administration, with the configuration of the external access network consisting of router access lists and firewall rules, though still remains manageable, as it was not required to maintain multiple wide area network (WAN) remote sites. Other considerations in this decision are that the WLAN network is not deployed in order to replace the wired LAN in the office and is a network not solely accessed by SACL users. All external access from the wireless network is via the wireless access router (WAR). The WAR is a Cisco 3550 Router configured to perform access-list filtering on all traffic based on source and destination IP address, protocol and port numbers.

As stated previously, the wireless infrastructure at the airport was regarded as an un-trusted zone. There are only two ways that a SACL wireless client can gain access to data from the corporate network. The first option is to install an application proxy server. The proxy server allows data to move from the wireless un-trusted zone to a semi-trusted zone located in the de-militarised zone (DMZ) outside corporate network firewall 1. This application proxy server located in the semi-trusted zone accesses the corporate network or trusted zone via firewall 1 on the clients' behalf. The second option and only way

resources can be accessed directly from an un-trusted to a trusted zone is via the use of a VPN. A VPN is established between SACL's wireless client and the Cisco VPN concentrator connected in parallel to the PIX firewall located in the DMZ. Both of these methods are described in detail in section 2.7.

2.4 SACL Wireless Authentication

Originally SACL only offered a Cisco proprietary wireless security solution of light-weight extensible authentication protocol (LEAP) for all tenants and concessionaires utilising SACL's Infrastructure. The LEAP utilises a 128 bit dynamic WEP key along with remote authentication dial-in user service (RADIUS) username and password authentication.

The WEP key is dynamically assigned from one of two RADIUS servers (Cisco Secure ACS 2.6 or greater) when an authenticated user associates with an access point (AP). This WEP key is again negotiated between the client and the RADIUS server after a pre-configured period set on the RADIUS server. At present, this period is set at less than 10 minutes.

The new firmware software introduced by Cisco for their AP support the termination of 802.1q trunk. This allows a trunk to be provisioned between the AP and an Ethernet switch; the end-result allowing users in a WVLAN cell to belong to different VLAN. With the use of different VLANs, user traffic is segmented per group (i.e. per VLAN) with the use of differentiated security policy per VLAN.

The service set identifier (SSID) is used to map the client to the WVLAN. RADIUS attributes passed in between the Access Point can also override this mapping if the users is not authorised for that SSID. Up to 16 WVLANs can be supported on each AP.

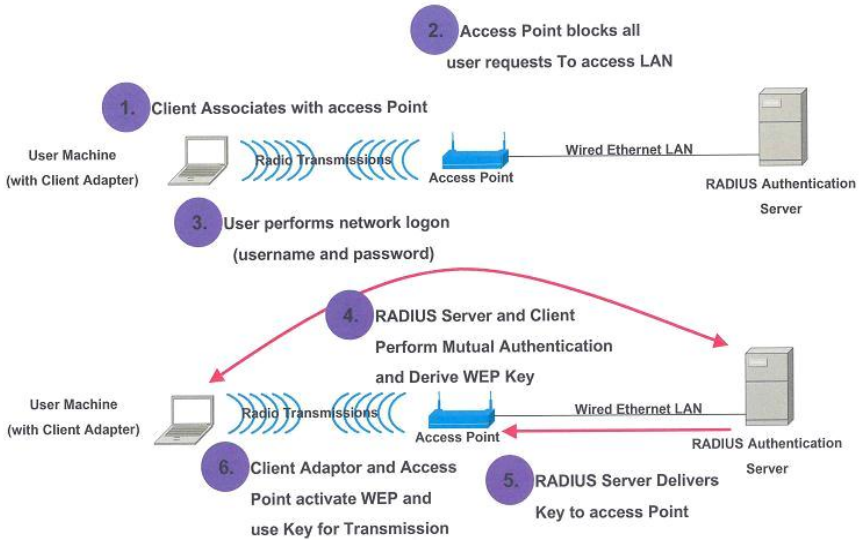

Figure 2-4 – SACL Wireless Authentication – LEAP

The introduction of WVLAN allows the use of non-priority Client Cards, along with different security models. Although it was believed that the Cisco LEAP solution is still the most secure and manageable solution presently available, when used in conjunction with temporal key integrity protocol (TKIP) and message integrity check (MIC), (TKIP and MIC security are explained in section 2.5 below) it is possible for a static WEP, media access control (MAC) and or EAP security options to be used on a separate WVLAN.

This enables the use of all vendors 802.11b wireless clients adaptor and give greater flexibility for products not yet supporting LEAP such as most Voice over IP Wireless Phones. At present, LEAP solution is used as shown in figure 2-4 with TKIP and MIC enabled as all their devices make use of Cisco Client Adapters.

2.5 Wireless Data Privacy Enhancements

While WLAN security that relies on SSIDs, open or shared-keys, static WEP keys or MAC authentication is better than no security at all, it is not sufficient and/or truly manageable for the size of the airport wireless network.

At Sydney Airport, like all wireless network administrators were eagerly waiting the wireless IEEE 802.11i security standard that will allow vendor interoperability and solve all known vulnerabilities of WEP, the basic mechanism to date for interoperable security

of Wireless 802.11b products. The IEEE 802.11i standards were published at the end of 2003. The Wi-Fi Alliance represented by many of the wireless vendors and in conjunction with the IEEE, has driven an effort to bring strongly enhanced, interoperable Wi-Fi security to market in the first quarter of last year. The result of this effort is Wi-Fi protected access (WPA). WPA is a specification of standards based on interoperable security enhancements that strongly increase the level of data protection and access control for existing and future wireless LAN systems.

WPA was designed to run on existing hardware as a software upgrade and is derived from and will be forward compatible with the IEEE 802.11i. One of the 802.11i components not required in WPA is AES support. AES replaced 802.11's WEP initialisation vector RC4-based encryption under 802.11i specifications. Migrating to AES encryption required hardware changes, so this was deferred by the Wi-Fi Alliance until the formal standard is in place to give vendors and customers some breathing room. However, 802.11i will require hardware changes regardless of whether WPA gets deployed in the near future or not.

Cisco was awarded WPA certification on the new internetworking operating system (IOS) software available for both the 1100 and 1200 series AP range, with firmware for the 350 Series APs, installed at the airport. Until the release, it was planned to use Cisco's proprietary solution that features a subset of the 802.11i draft. Cisco has developed an 802.1x authentication type called extensible authentication protocol (EAP) Cisco Wireless, or Cisco LEAP. APs can be configured to support Cisco LEAP and all 802.1x authentication types, including EAP Transport Layer Security (EAP-TLS provides for certificate based mutual authentication that relies on client-side and server side digital certificates).

With 802.1x authentication types such as LEAP and EAP-TLS, mutual authentication is implemented between the client and a RADIUS server. The credentials used for authentication, such as a log-on password, are never transmitted in the clear, or without encryption, over the wireless medium. Another benefit of 802.1X authentication is centralised management of WEP keys. Once mutual authentication is successfully completed, the client and RADIUS server each derive the same WEP key, which will be used to encrypt all data exchanged. The result is per-user, per-session WEP keys. AP

software running at the airport provides several enhancements to WEP keys that have formed part of the WPA. These WEP enhancements include Cisco's pre-standard TKIP and support for MIC.

When TKIP, also known as key-hashing support, is implemented on both the AP and all associated client devices, the transmitter of data hashes the base key with the IV (Initialization Vector of RC4 Key Scheduling Algorithm) to create a new key for each packet. By ensuring that every packet is encrypted with a different key, key hashing removes the predictability that an eavesdropper relies on to determine the WEP key by exploiting IVs.

When MIC support is implemented on both the AP and all associated client devices, the transmitter of a packet adds a few bytes (the MIC) to the packet before encrypting and transmitting it. Upon receiving the packet, the recipient decrypts it and checks the MIC. If the MIC in the frame matches the calculated value (derived from the MIC function), the recipient accepts the packet; otherwise, the recipient discards the packet. Using MIC, packets that have been (maliciously) modified in transit are dropped. Attackers cannot use bit-flipping or active replay attacks to fool the network into authenticating them, because the MIC-enabled client and APs identify and reject altered packets.

In early to mid-2000, hackers used three main types of attacks against wireless networks. They are denial of service (DoS), address resolution protocol (ARP) poisoning or spoofing and WEP key-cracking. Upon realisation of these types of attacks, SACL had few options. They were installation latest hardware firewalls from Cisco along with third party safety softwares and manual defence mechanisms. An administrator can guard against the attack using any number of radio frequency spectrum management tools, which sample the airwaves and determine the channel which is being jammed by ARP spoofing or DoS. Administrators could then dynamically reassign the channel used by their access equipment and restore service to the wireless network. However, as new protocols came into effect, SACL network was continuously upgraded by employing tri-mode wireless routers that operates with the 802.11g, 802.11i and later 802.11n protocols. Hence, SACL was adequately equipped and prepared to resist hacking attacks.

2.6 Computerised Mobile Maintenance

The initial deployment of the wireless network within Terminal 1 and the airfield coincided with the Mobile Maintenance Project. The Project utilised the wireless network to track and complete maintenance work in the field. Maintenance staff at Sydney Airport uses the computerised maintenance management system (CMMS) also known as MAXIMO. Figure 2-5 shows schematic of the CMMS. The one limitation about MAXIMO was its inability to follow staff to the job. Previously "Work orders" or job sheets were printed directly off the system and then taken into the field by the relevant trade staff or technician. Once the work was completed, the sheet was completed manually and the written data then entered in MAXIMO, either on return to the workshop or at the end of shift.

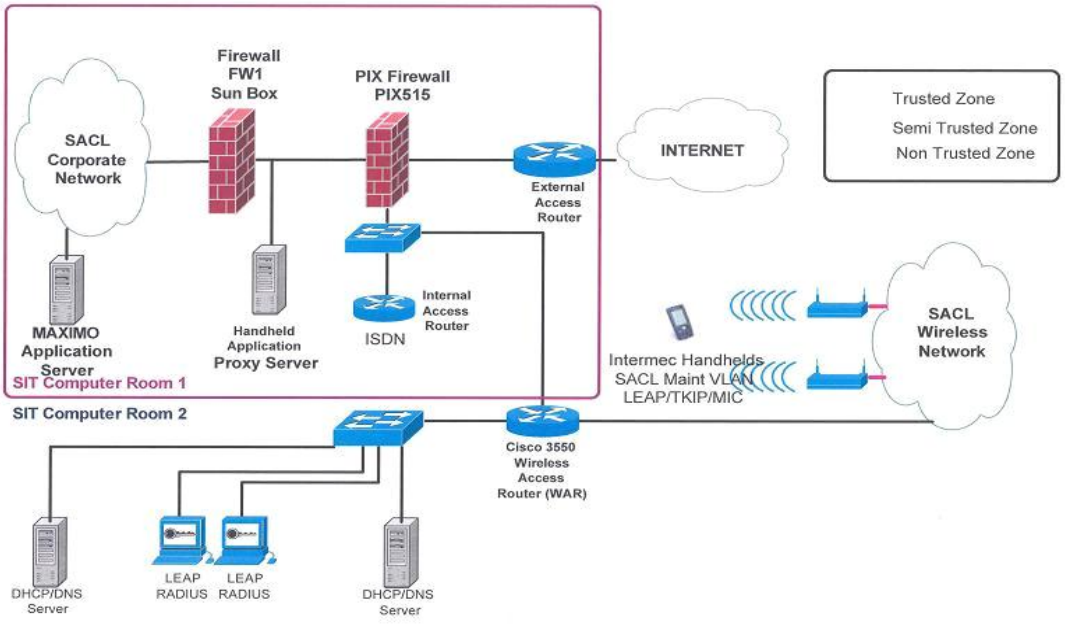

Figure 2-5 – Computerised Maintenance Management System

The mobile solution utilising an industrialised handheld PDA eliminates re-entry of data and has a positive follow-on effect in allowing more accurate reporting and a paperless system. With the limitation of VPN clients for PDA's at the time of delivery for the project an application proxy server was installed within SACL's semi-trusted DMZ area to proxy wireless client requests to the MAXIMO Application Server. The PDA used was fitted with a Cisco Client Adaptor card and set up to use LEAP. The only changes from the initial installation is the upgrade of wireless client driver to utilise Cisco's TKIP and MIC security enhancements configured on the Access Points.

2.7 Wireless VPN Remote Access Solution

In December 2002, SACL embarked on a corporate remote access solution. The solution enables corporate users to access the corporate network with all desktop applications from broadband internet access, corporate dialup and wireless access. By placing the wireless infrastructure access outside the corporate firewalls, allows best usage of remote access VPN solution. The implemented solution integrates a Cisco VPN 3000 Concentrator, Microsoft 2000 Certificate Server, Microsoft VPN Client, USB Port Token, and centralised remote PC firewall (ZoneLabs Integrity®) to provide strong security, ease of use and centralised management. The original goal was to utilise the Cisco VPN Client which allowed cooperative reinforcement with the remote PC firewall.

The ZoneLabs VPN enforcement feature ensured that the VPN users can only connect to, and remain connected to the network as long as the client is running a verified version of ZoneLabs firewall agent and the client is enforcing the most up to date security policy.

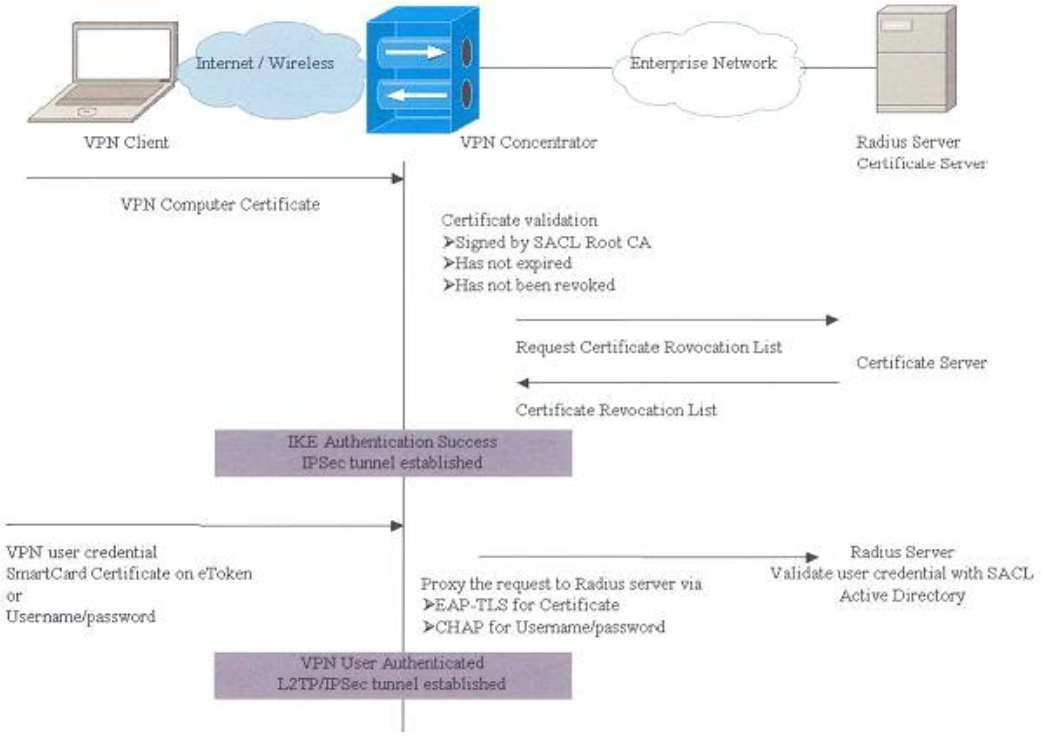

Figure 2-6 – VPN Authentication Process

The Cisco VPN client used was incompatible with a few of the corporate applications which required the Client to have a virtual adaptor IP address in order to ftp data from a server back to the remote PC. Cisco released a VPN client that has a virtual adaptor which

is still being piloted. In the interim period, SACL chose to utilise a Microsoft VPN client that does not provide cooperative reinforcement of the remote PC's Firewall. It is shown in figure 2-6. Remote PC's have utilised the Microsoft XP operating system to lock down the ZoneLabs application to ensure the user cannot shutdown the Firewall. As all the wireless users within SACL are utilising Cisco's wireless adaptors the same WVLAN utilising LEAP is used. This will change in the near future as the new laptops have inbuilt wireless adapters.

As the VPN solution does not require the additional wireless security as it is geared for broadband and hotspot users, another wireless VLAN will be created with a different security model. Figure 2-6 shows the present VPN establishment and logon process to the corporate network. Strong authentication is required to secure the VPN connections. VPN users must have a computer with a valid SACL digital certificate, valid Windows account or USB eToken with SmartUser certification to successfully establish a VPN connection. After the use of valid Digital Certificate for Internet Key Exchange (IKE) authentication, Microsoft VPN uses internet protocol security (IPSec) encryption, ESP (encapsulation Protocol), layer two tunnelling protocol (L2TP) and Transport IPSec.

2.8 Wireless Voice over IP Pilot Program

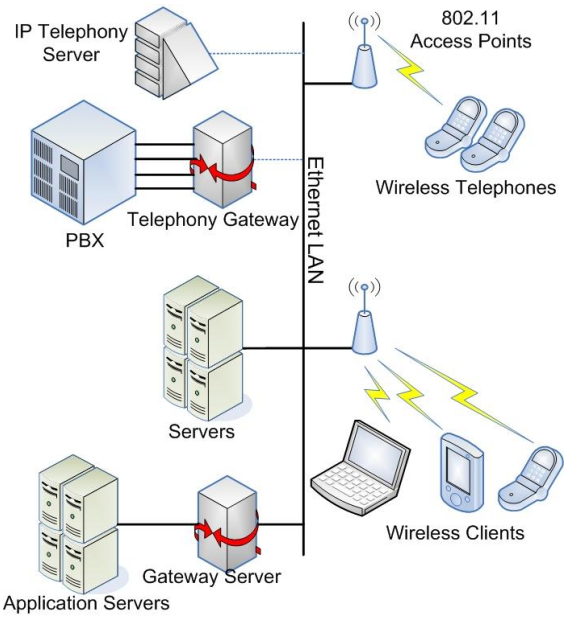

Figure 2-7 – Wireless VoIP Pilot Program

The third device that was trialled across its wireless LAN was a piloting of wireless IP phones and undertook a Voice over IP (VoIP) trial. The schematic for the same is depicted in figure 2-7 above. This pilot program included the deployment of wireless handsets that ran over the Terminals live wireless network. The wireless IP handsets used were spectra-link phones. These phones did not support LEAP so a dedicated WLAN with static 128-bit WEP was set up across the International Terminal. This WVLAN was also given the highest QoS on each access point to ensure phone calls would not drop out if a wireless access point is supporting multiple clients.

Knowing the security vulnerabilities of static WEP SACL combined MAC level security on the Wireless VLAN. MAC level security on the Cisco Access Points can be centrally managed by the Cisco Secure ACS RADIUS Servers. This is performed by entering the MAC address of the phone as a user and password in the RADIUS server. The security solution is not ideal though the only means available at the time of the pilot. Cisco latest release of software for the 1100 and 1200 Access Points has a feature known as fast secure roaming. This feature allows EAP authentication to be used for Wireless Voice over IP.

2.9 Tenant Wireless Connectivity

The wireless infrastructure is a shared medium for both the airport and its tenants, it was necessary to establish connections back into the tenant's own corporate network. Figure 2-8 shows how the connection is implemented indicating demarcation points. A range of IP addresses is assigned to each tenant who will either hard code or utilise DHCP servers. Every tenant utilising wireless Infrastructure will be given a dedicated 100 MB unshielded twisted pair (UTP) routed connection to the WAR. Within the WAR access-lists filtering on IP address, protocol and port numbers are configured.

It was advised that the 100 MB Ethernet port be connected to the tenant's network via their own firewall. The tenant is responsible for any additional security measures such as VPN using their own wireless clients. The tenant is set up with their own WVLAN that can be given a security policy that best meets their needs or device capabilities.

Until, the introduction of WVLAN there was only one option that was to use Cisco Client Adaptors utilising LEAP. This interoperability proved to be challenging with one of the International Airline Lounges already entered into a commercial agreement with an ISP to provide wireless internet access to their frequent flyer members.

As the airport could not control the public users' client adaptor card, an interim solution was put in place. Other tenants wanting to utilise Symbol® barcode scanning devices were informed the warranty on the device would be void if they replaced the wireless adaptor with a Cisco Card. With the release of WVLAN, two organisations utilising SACL's wireless network were able to use Symbol® devices with Symbol® wireless client adaptors. Both are using static WEP with Symbol's own VPN solution AirBEAM Safe®.

2.10 Public Wireless Internet Connectivity

A public wireless network was deployed to allow high speed internet connectivity to any public users as shown in figure 2-8. The airport is strategically well placed to target this market of mobile professionals. SACL have partnered with ISPs to offer their existing customers and new subscribers all the internet services including email, Web browsing and connection back into their corporate networks via secure VPN. Like most hot spots, the wireless public LANs are set to open authentication with no WEP key encryption configured.

The portal page login for the subscriber is made by opening a secure socket layer (SSL) encrypted session hypertext transfer protocol over secure socket layer (HTTPS). The difference between most hotspots is that the airport hosts three unencrypted WLANs on each of its access points. As the airport had the wireless infrastructure installed, it made commercial sense to cater for multiple service providers instead of the usual approach for ISPs grabbing of real estate.

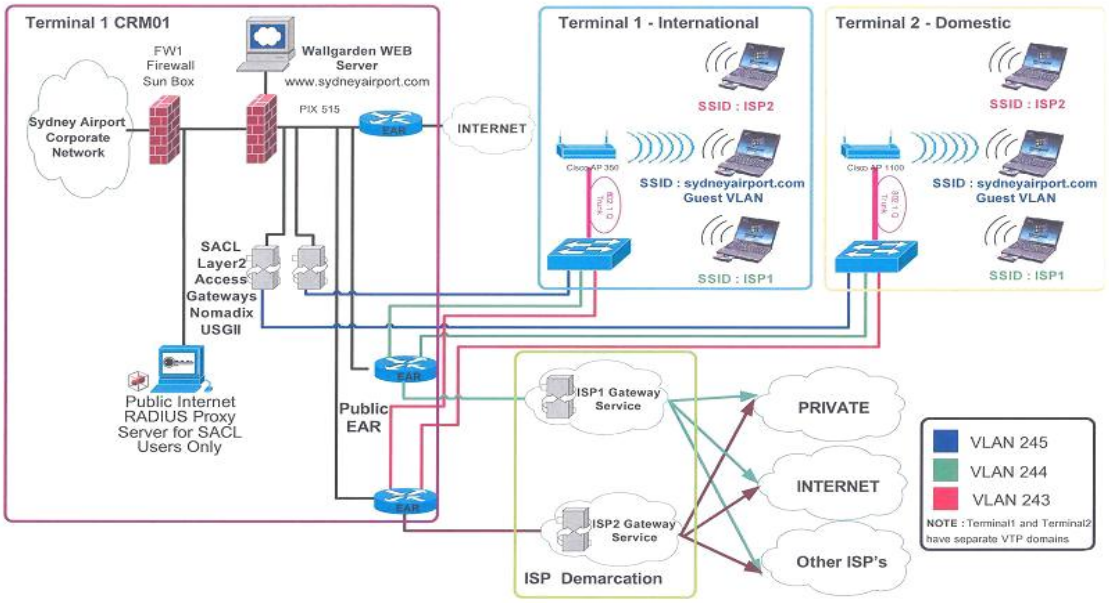

Figure 2-8 – Public Wireless Internet Connectivity

The commercial model with each of the ISP is based on revenue share of subscriber usage. The subscriber can be classified as retail and wholesale. A whole sale customer refers to a subscriber who is signed with a roaming partner of the ISP. To cater for multiple ISPs proved quite challenging.

The technical challenges of routing users down different internet service connections, government regulations on IP interception rules in Australia, and the airport not wanting to lawfully become an ISP led to the decision of running multiple WVLANs. The latest 350 IOS firmware for Cisco APs allows for multiple unencrypted VLANs. Therefore, the control of the access point infrastructure and WLAN services on the airport site was maintained while being responsible for ensuring the WLAN technical capability of the network. Each ISP is provided with a non-broadcast unencrypted WLAN with their nominated SSID as set up in their other hotspot sites. This WLAN will be connected to the ISP's gateway service infrastructure. The ISP will ensure compliance with the relevant government regulations.

This compliance will mean that they will solely be responsible for interception of all IP traffic pertaining to their WLAN on the airport site. The ISP shall provide a non-repudiable system for reporting and auditing of the airport hotspot Site. The system shall be accessible in real or close to real-time. The airport require on-line data such as billing

or RADIUS accounting records that detail each users IP session time along with data byte usage.

2.11 Customer Satisfaction

SACL have a number of different customers utilising the wireless infrastructure. Internal use of the wireless network has been limited to laptop uses and trials of SIP VoIP telephones. The laptop users range from Security officers working on the airfield to staff moving between terminals. The laptop users can access all desktop applications with the use of VPN. Remote access solution for broadband users is identical to the wireless implementation. The SIP VoIP phone trial has been limited due to time constraints of other projects running.

From the experience, I would say it worked just as good if not better than the GSM coverage within the Terminal building. Unlike GSM, a poor signal did not drop-out a phone call. External users come in the form of public Wireless internet subscribers. SACL has partnered directly with two ISPs – Telstra and Optus. In order to facilitate this model and provide competition on pricing between the providers, the end user has had to suffer due to the technology short comings. This has been caused by the inability to broadcast multiple SSIDs.

New users are required to manually configure their SSID settings in order to connect to unrestricted internet service of Telstra and Optus. The latest Cisco codes are released at regular interval to allow multiple broadcast SSIDs. Figure 2-9 depicts wireless coverage as of early 2004 and total wireless connectivity diagram is shown in figure 2-10.

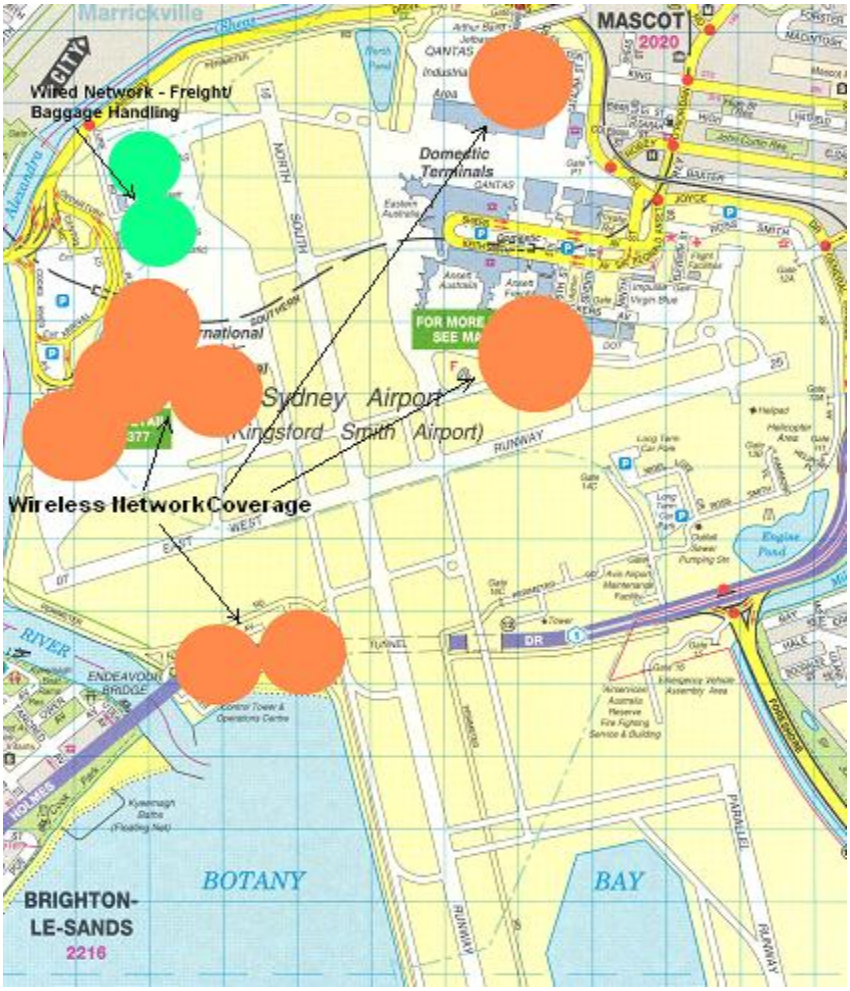

Figure 2-9 – SACL Wireless Deployment [Courtesy of Ausway Maps]

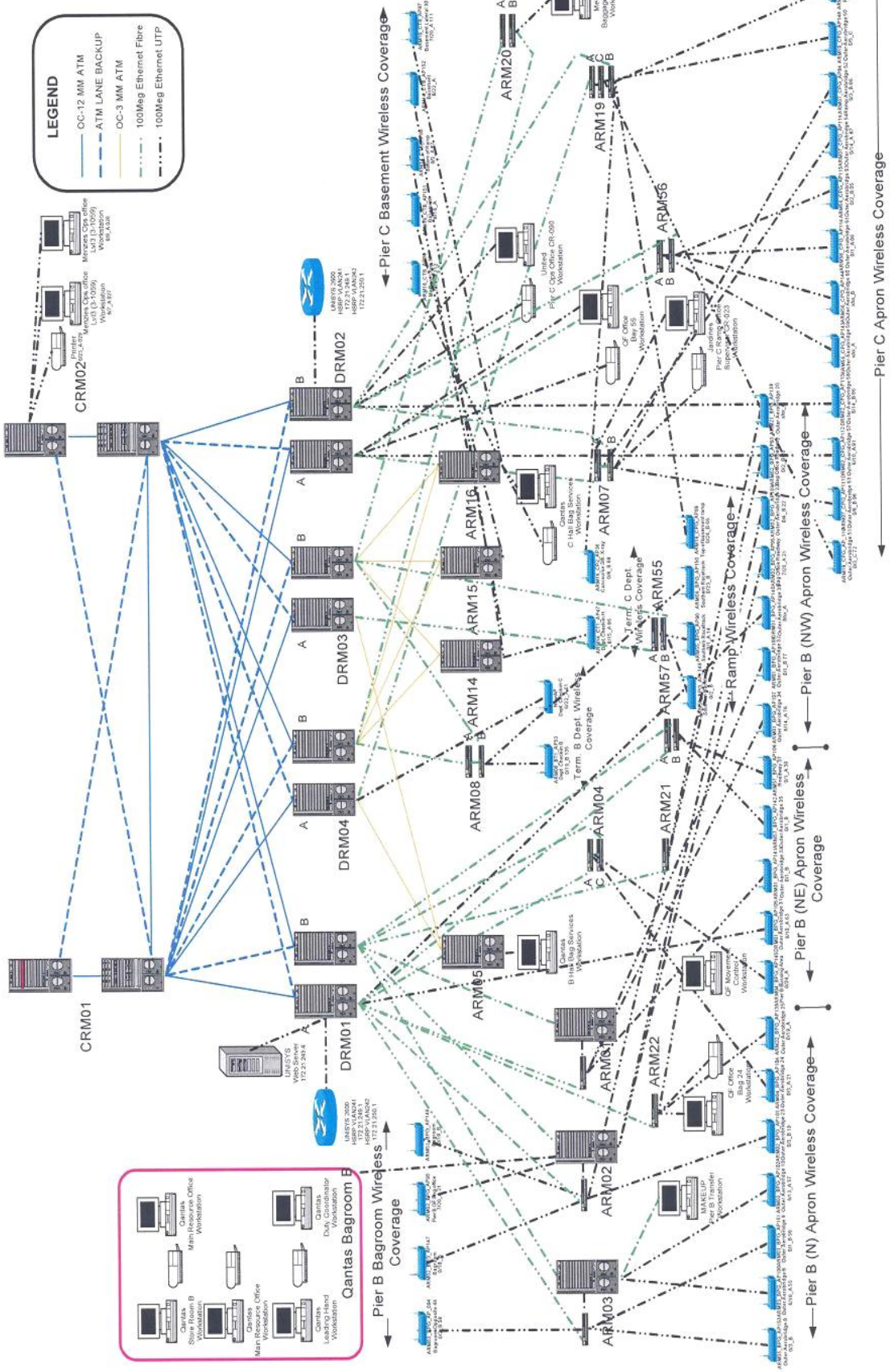

Figure 2-10 - Total Wireless Connectivity Diagram

2.12 Conclusions and Future Projects

The security interoperability challenges are being addressed by Wi-Fi Protected Access range of Wi-Fi products based on the upcoming IEEE802.11i standard. With the WPA and ultimately 802.11i standard implementation in place, the need for add-on solutions such as VPN may be deemed unnecessary in some Enterprise WLAN environments.

Other future enhancements not referenced here include the release of 802.11g Wireless Access Points. 802.11g can ideally deliver 54 Mbps maximum data rate and offer an additional and compelling advantage – backward compatibility with 802.11b equipment. This means that 802.11b client cards will work with 802.11g access points and 802.11g client cards will work with 802.11b access points. Because 802.11g and 802.11b operate in the same 2.4 GHz unlicensed band, migrating to 802.11g will be an affordable choice for Sydney Airport with existing 802.11b wireless infrastructures [Figure 2-10].

One drawback is that 802.11b products cannot be "software upgraded" to 802.11g because 802.11g radios will use a different chipset than 802.11b in order to deliver the higher data rate. However, like Ethernet and Fast Ethernet, 802.11g products can be co-mingled with 802.11b products in the same network. Sydney Airport will continue to provide solutions to business needs by utilising innovative and leading edge technology.

Future applications include Mobile Self Service, Check-In Kiosks, Radio Frequency (RF) Bag Tags, Wireless Point of Sale (PoS), Wireless Stock Take, WVoIP, and Government requirements for baggage reconciliation by end of 2007.

SACL's main revenue source from wireless comes from the Baggage Reconciliation System (BRS) [33]. This system is used by the baggage handlers to scan bags with the use of symbol handheld devices to ensure a match between bags and passengers on the aircraft. As with most evolving technologies vendor interoperability and adoption of lose standards has created a few minor issues that are been resolved with input from both Symbol and Cisco. The system has been operable since the beginning of last year. SACL also have a number of tenant utilising similar technology as the BRS for stocktaking and are talking with Airlines who see wireless as a cheap alternative to upload maintenance reports and catering records when docking the aircraft. Previous methods have been low speed connections offered by GSM modems.

The advances in the 802.11i standard have only been recent and SACL have not had an ample opportunity for testing and hence continue to utilise a VPN solution. Due to this inability to carry out testing the move to a new office area has not been timely and meant that SACL have data outlets wired to the workstation desks. Other factors affecting this are due to some of SACL's applications are not geared for wireless even at 54 Mbps as they require application downloads from the Server. Once testing and these application issues are resolved, the adoption of AES encryption is believed to be seen as the addition of VPN security as being a thing of the past.

It will also provide the opportunity to move some of the wireless infrastructure inside the corporate firewall. SACL's first use for 802.11i is a bridging solution for a Contract Office located out in the airfield. The ability to provide AES encryption across a link will negate the need for complicated encryption solutions for either end user or network administrator. So far, it is safe to say that the wireless technology will play an important part in the future of Sydney Airport's Total Journey Experience.

2.13 Projects Status

In 2006, complete e-Tag automation of the ground transport access system was developed, with commissioning targeted by the end of calendar 2006. This initiative will enhance transport efficiency through the terminal roads and pick-up zones, and further reduce ground transport management operating costs.

Check Bag Screening Project was $90 million upgrades of the baggage systems in T1 and T2 is in the final stages of completion. The system has been operational in T1 since 1 January 2006 as required by the Federal Government. The work to provide additional redundancy and backup systems is in the final stages of testing. The T2 work was trialled and tested in September 2006 and made available in early 2007. To improve asset and financial management, SACL upgraded its maintenance management systems with the latest version of the Maximo Asset Management System (MXES), introduced a new Oracle-based project management system and started work on a new energy metering and billing system. SACL also upgraded the T2 data network.

In 2007, new technologies such as LED taxiway lighting, radio frequency identification bag tag scanners and wireless VoIP equipment were trialled which have the potential to lower costs, improve productivity and improve service to customers. To improve data management, communications and system efficiency, Sydney Airport upgraded its data network capacity from one gigabit per second to ten gigabits per second and upgraded the storage capacity from 20 Tb to 80 Tb to accommodate the additional closed circuit television cameras and higher resolution digital footage. As a part of a continuous improvement process, help desk and fault management process to the Maximo Asset Management System were migrated. Additionally, a new energy and water metering and billing system were completed.

In 2009, new maintenance workshops and project offices to replace facilities that had to be demolished to make way for new aircraft parking bays were completed. The new workshops include state-of-the-art equipment for testing airport lighting products, including a photometric laboratory and an electronic mobile airfield lighting monitoring system.

Australian Government mandated security screening procedures to restrict the carriage of liquids, aerosols and gels onto international flights commenced on 31 March 2007. This new security measure required Sydney Airport to provide additional passenger screening infrastructure as well as contracting and training 100 new passenger screening staff at T1. A further security initiative was the commencement of 100 percent checked bag screening for all flights from T2. This involved the design and construction of a $37 million system capable of screening 3,600 bags per hour and involved training of additional 45 staff. Sydney Airport was able to commence 100 percent screening ahead of the Government mandated target date of 1 August 2007. T1 has operated with 100 percent checked bag screening since 31 December 2004.

Sydney Airport continues to work cooperatively with the Australian Federal Police on the implementation of a unified airport policing model for the airport. This was a key recommendation of Sir John Wheeler's 2006 review of airport security and policing arrangements. This initiative involves an Airport Police Commander, intelligence and investigative units, and a counterterrorism first response service along with specialist airport community policing. A major airport security service contract was tendered and

awarded in December 2006 for the provision of various aviation security functions including passenger and checked baggage screening at T1 and T2, perimeter vehicle patrols, access control, guarding and security surveillance monitoring. The contract was designed to provide enhancements to airport security outcomes through improvements in the management and supervisory structure, staff training and competencies along with a strong performance management regime. An improvement to the background checking arrangements for Aviation Security Identification Card was made with the introduction of a centralised Government background checking unit. Sydney Airport has been working closely with the Attorney General's Department and the Office of Transport Security to design significant changes to the current airport identification application process. The next phase of this project will see the development of a new database with on-line applications and seamless integration with the new background checking unit.

Chapter 3

Development and Implementation of Wireless Application for Securely Recording Electricity Consumption for the Hong Kong Electricity Company (2004-2005)

3.1 Introduction

Hong Kong Electricity Company Ltd (HEC) and China Light and Power Ltd (CLP) employ several personnel to collect and record the electricity meter readings in and around greater Hong Kong. Human errors are easily created due to manually recording a large number of meter readings. It is time and resource consuming. There are the cases that some meters are installed inside a private house, a private front yard or back yard. The power company staffs will not be able to record the meter readings if the owner or occupancies are not in their houses. In some cases, it is not so easy to make arrangement with the owner or occupiers for meter reading. Estimation of electricity usage is commonly used. It may be a large deviation from the actual reading and hence, customers make complaints which trigger administrative overheads which results in financial loss to the company. In some cases, some electricity meters are installed near the ceiling in many old buildings and that makes it necessary to have a ladder to record usage reading. This is not a convenient procedure and creates an occupational, health and safety issue. There are cases in Hong Kong that the dwelling owners or occupiers refuse to allow entry to the power company staff members on property. In this instance, it is very difficult to get an actual record of electricity usage. Hence, energy generation and distribution contractors pay high cost for inefficient operation for electricity meter reading. Figure 3-1 represents a general schematic of electricity distribution and transmission in Hong Kong.

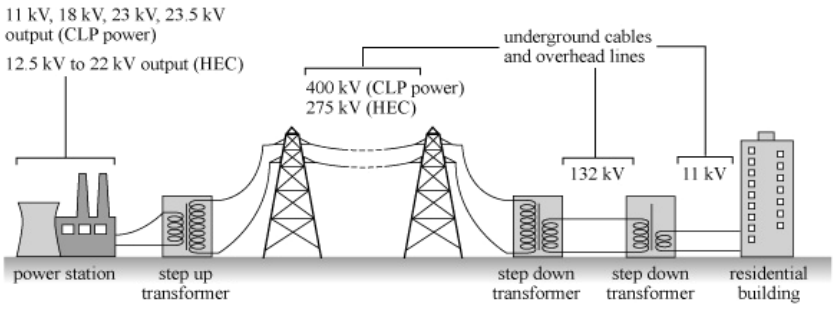

Figure 3-1 – A schematic of electricity distribution and transmission in Hong Kong [courtesy of HEC]

This necessitates periodic automatic reading of electricity through a mobile communication network. The communication channel can be a fixed line telephone, a trunk radio or a mobile channel. Fixed telephone line is not convenient due to the need to install a telephone cable in the meter room. In many cases, customers do not allow the installation of any telephone cables on their properties. Wireless technology can be an ideal solution for this issue. Mobile communications system is used in many countries for the same purpose as it eliminates the requirement to install a private wireless network. It is not expensive and there is no need to build another network when there is a working mobile network. In this investigation Global System for Mobile Communication (GSM) network is used. However, the solution presented is applicable to other mobile networks. At present, modern electricity meters are manufactured with serial port for GSM modem. The locations of meter rooms are usually poorly covered by a GSM network and this prevents an easy implementation of an automatic electricity meter reading system. A solution using Bluetooth® and GSM technologies to make a wireless connection between a meter room and a mobile network access interface is proposed and investigated for the feasibility in the following sections.

3.2 GSM Solution for Electricity Meter Reading

The GSM solution for electricity meter reading is shown in figure 3-2 below.

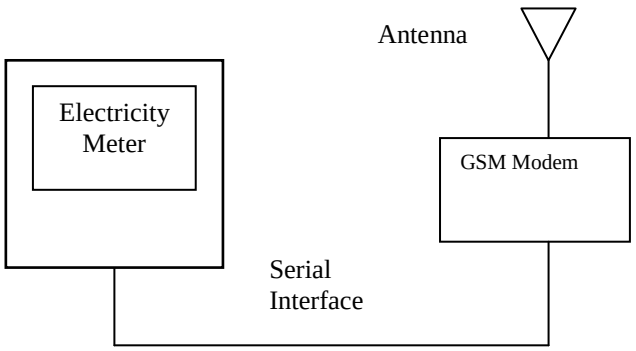

Figure 3-2 – Connection of GSM modem

The GSM modem is connected to a server in the control centre by a GSM network. The server in the control centre handles the power meter reporting operation. It sends a command to request a set of readings from the meter. The data received can be real time or pre-recorded. The server is programmed to obtain data periodically. This is quite flexible and the readings can be programmed in any time interval.

3.3 Problems with the GSM Network Solution

It is very common in large and densely populated cities that the electricity meter room is located in the ground floor or the basement and mainly in the center of the building. The mobile coverage is usually poor in meter rooms. Figures 3-3, 3-4 and 3-5 show typical layout of the most common building in an urban area. These buildings are usually poor for mobile coverage for an automatic electricity meter reading solution using GSM.

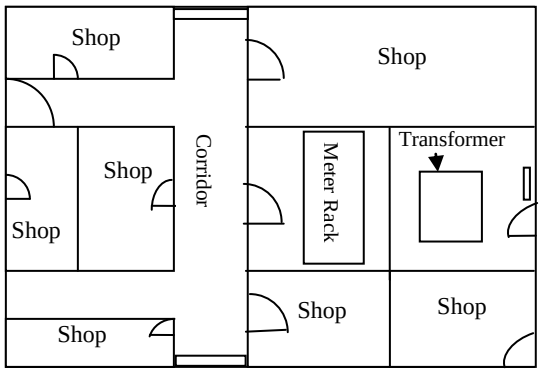

Figure 3-3 – Typical layout of a shopping mall

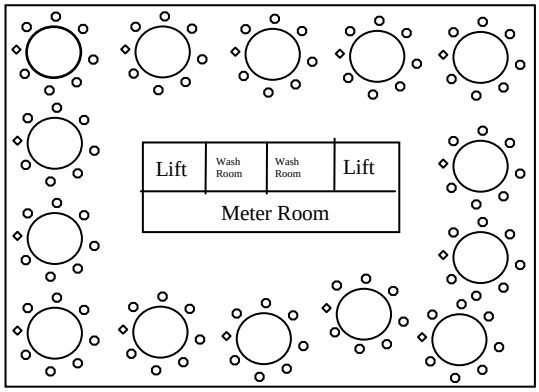

Figure 3-4 – Typical layout of a large restaurant

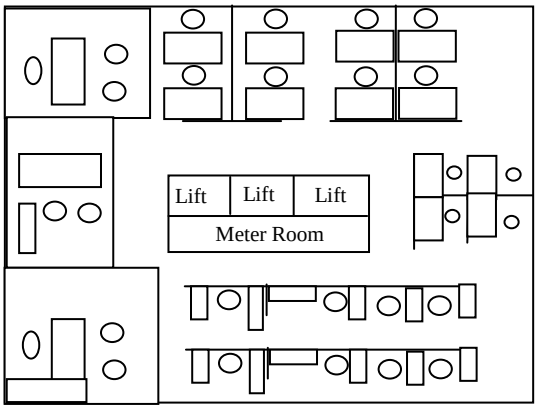

Figure 3-5 – Typical layout of a multi-storey office block

The problem is further complicated by the fact that a power meter is usually placed inside a metal rack as shown in figure 3-6 below. The metal rack tends to further reduce the signal strength of the mobile network. In general, a site is not suitable for installation of GSM modem if the measured signal strength is lower than -88 dBm at the meter location. Unfortunately, an investigation of the signal strength shows that it is invariably below -88 dBm in meter rooms.

Figure 3-6 – Electricity meters in a secure rack

One solution to this problem is to use a cable to make the physical connection between a GSM modem and a meter. This is definitely not convenient. Besides this, some customers do not allow the installation of any additional cable on premise. Wireless solution seems to be the solution in this case. But there are many factors that affect the choice of wireless system. They are propagation distance, interference, building structure, indoor layout, power supply, and cost and licensing requirements. Most customers prefer to use a wireless link in unlicensed frequency band, the industrial, scientific and medical (ISM) band because this band is accepted globally.

Bluetooth technology is the good contender because it operates in the ISM unlicensed radio frequency (RF) band and it has a complete protocol stack [35] with reliable RF link [36] and efficient security algorithm [37, 38]. The cost of Bluetooth solutions is also competitive [37]. A Bluetooth link has to make a connection through concrete walls. In some cases, the line of sight path is blocked by metal rack in the meter room. Multiple reflection paths are the standard mode of propagation. The high voltage transformer will

also be a factor because the GSM signal is interfered by the high voltage impulse from the transformer. It increases the bit error rate and hence affects the reliability of the wireless link. The design of this kind of Bluetooth devices have to be robust to maintain a reliable communication in such a poor radio environment. The design work itself involved desktop analysis and field trials to meet Bluetooth hardware and software specifications for this application. Bluetooth Class 1 RF design is necessary together with error correction and packet retransmission technique in software.

3.4 Solution for On-Site Power Meter Reading

Using a Bluetooth wireless link, the meter and GSM modem can be placed in different locations to solve the GSM coverage problem. Figure 3-7 shows the system configuration of an automatic power meter reading system using GSM and Bluetooth Technology.

The central control office in the above diagram is the control office of HEC/CLP. The server in a central office will send the command to meters through PSTN, GSM and Bluetooth Link to request the power usage reading. Digital meters will respond to the server with the required data upon receiving the command. The control centre handles a large number of meter readings. Each digital electricity meter has a unique identity code so that the server can correctly verify and validate.

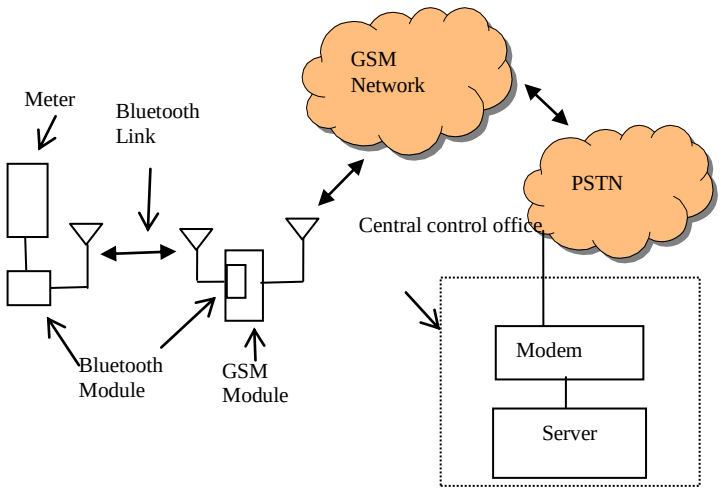

Figure 3-7 – Automatic meter reading and reporting system using GSM and Bluetooth

This system is simple and reliable. The major concern in the design is the Bluetooth propagation link and security. The communication between the meter and the GSM modem is working a complicated propagation environment. During trials, in most cases,

Bluetooth wireless link passes through a thick concrete wall as shown in figures 3-8 (a to d). To ensure a reliable wireless link for such an environment, Bluetooth Class 1 module has to be employed to increase the transmission power from 0 dBm to 20 dBm and the receiver sensitivity from -75 dBm to -85 dBm. It increases the penetration depth and propagation distance.

Consideration was given to the placement of antenna which was carefully selected and directivity of antenna was designed realistically. A directional antenna is preferred since it improves the propagation quality for this application due to two Bluetooth modules are installed in fixed locations [39]. An accurate computation of the major signal paths also significantly improves the propagation distance and signal quality [39].

Figure 3-8 (a)

Figure 3-8 (b)

Figure 3-8 (c)

Figure 3-8 (d)

Figure 3-8 – (a) GSM and Bluetooth modules mounted on the wall; (b) power supply main switch; (c) power distribution panel in a metal rack; and (d) rear view of power distribution panel

Figure 3-9 depicts line diagram from figures 3-8(a), 3-8(b), 3-8(c), and 3-8(d). Since Bluetooth module is required to be very near or inside the power meter casing, the physical antenna cannot be large and hence, a patch antenna is selected and considered appropriate for the application due to its directional characteristics. Figure 3-10 shows the antenna placement and directivity from the scenario in figure 3-9.

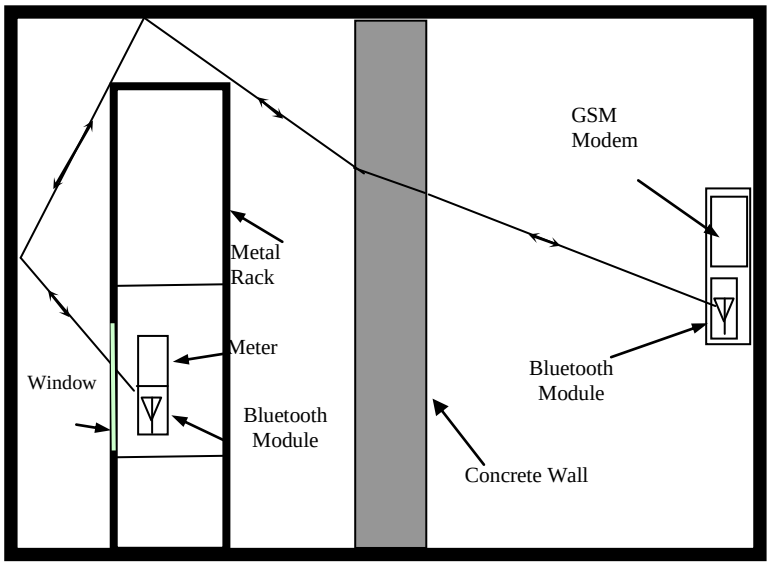

Figure 3-9 – Line diagram of reflected signal path of Bluetooth wireless link

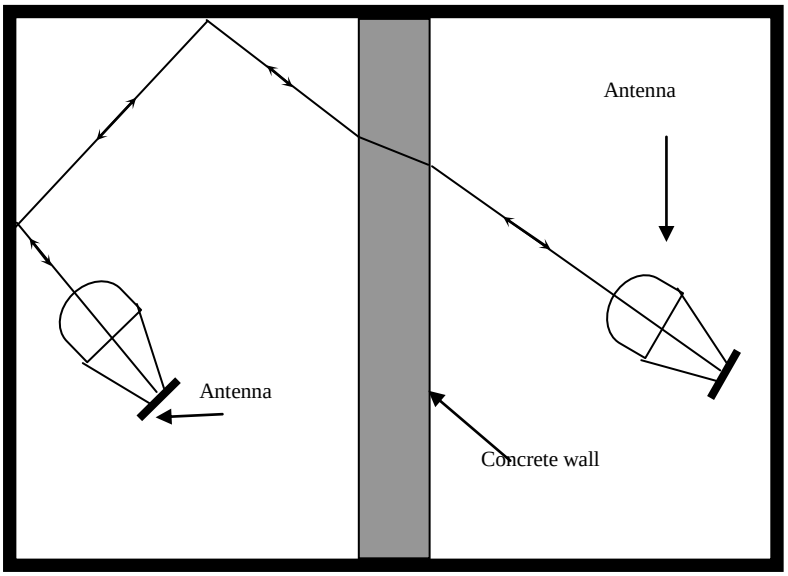

Figure 3-10 – Antenna directivity and propagation path

The propagation path loss (Lp) of two Bluetooth Class 1 module can be calculated as follows:

Consider the line of sight case. The path loss in an indoor open area is,

$$Lp = 36 \log(4\pi d/\lambda) - 46.7 \text{ dB} \quad (3.1)$$

where,
Transmission power = 20 dBm
Antenna gain = -3 dBi
Receiver Sensitivity = -90 dBm
Propagation loss = -78 dBm
Propagation range = 100 to 105 m

The attenuation of a thick concrete wall with thickness of 25 cm ranges from 20 dB to 30 dB. A signal path will be attenuated 30 dB in the worst case if it passes through a concrete wall. The propagation range will become 20 m in this case. If antenna has a gain of 2 dBi instead of -3 dBi, the propagation distance will be approximately 30 m. As shown in figure 3-10, the signal is reflected twice from the wall and ceiling and then pass through a thick concrete wall, the calculation of signal strength is complicated.

Multi-ray propagation model tool must be used to calculate the signal strength and hence the propagation distances [39]. In addition to hardware design, the link distance can also be improved by software. The following two techniques help improve the signal propagation range,

- use of a single time slot DM1 and implement retransmission can reduce the chance of being interfered and hence effectively lengthening the propagation distance; and
- implementation of retransmission of failed data block in the application layer in addition to the default retransmission of packet in the baseband of Bluetooth.

The next problem of concern is the security of the link. It is not desirable for anyone holding a Bluetooth device to collect data from the meters. The Bluetooth modules installed between the electricity meter and the GSM modem must form a trusted device pair with data encrypted and hence, the encryption is based on the SAFER+ algorithm which is proven to satisfy most secure applications. Physically, both Bluetooth devices were set for not to be discovered by other Bluetooth devices.

3.5 Solution for an Off-site Meter Recording and Reporting System

The present system can be further developed to be used in general customer scenarios. An estimation of electricity usage is made until there is an access to the physical meter. With the Bluetooth module installed in the digital power meter and with the Bluetooth enabled smartphone as shown in figure 3-11 can be used to collect the power meter readings wirelessly and the data is sent back to central office through any available mobile network. This eliminates requirement for accessing the premise and known as Off-site Meter Reading (OMR). With this framework, power company staff can obtain meter reading within 100 m from the electricity meter. Fewer people are required to record large number of dwellings in an urban environment. This dramatically saves time and resources, increases operational efficiency and reduces operational cost [40].

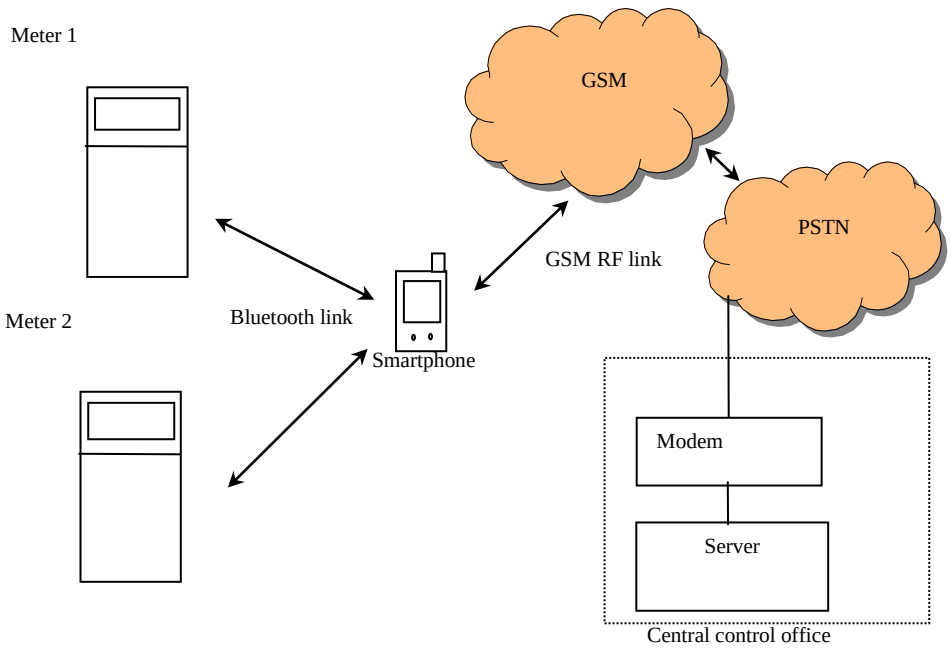

Figure 3-11 – Off-site meter recording and reporting system

3.6 System Configuration

As shown in figure 3-11, the OMR system consists of mainly five components. They are:

- Bluetooth enabled digital electricity meter;
- Bluetooth enabled Smartphone;
- GSM mobile network;
- PSTN; and
- a server modem unit.

GSM network is used here to describe the concept due to the fact of its huge coverage worldwide. Other networks such as IS-95, PDC or DAMP etc, can also be accessed for this purpose. The system uses a modem connected to PSTN. It is a circuit switching data (CSD) application. It can be a packet data network connected to the internet with GPRS and mainly dependent on the system operating cost.

There are two wireless links in the system. Bluetooth wireless link is a short range piconet for meter readings collection and a GSM link is used to send the data to central office. As shown in figure 3-11, the smartphone can initiate sessions with many meters at a time. Every meter can be identified by their Bluetooth address. The Bluetooth addresses are stored in the memory of the smartphone. The power company staff will need to first select a region of the meter locations in the smartphone and a list of meter addresses will be displayed. The staff can click the meter addresses to build a Bluetooth piconet. Meter readings can then be collected through the piconet. Due to the limitation of the Bluetooth protocol [35, 36], a piconet can only include seven meters. Therefore, there will be many piconets of seven meters. A user of the smartphone can select a piconet every time. Once the meter readings are stored in the smartphone, they can be sent to the central control office by the GSM network. The meter reading collection can be completed in a short time at the user's finger tips.

3.7 Design Considerations

The Bluetooth specification allows for three different types of radio powers. They are Class 1, Class 2 and Class 3. These power classes allow Bluetooth devices to connect at different ranges. Class 3 is a low power class of 1 mW radio. The radio links of Class 3 devices can communicate up to 10 m.

However, human bodies, furniture, concrete walls etc, absorb microwaves, reception may not be reliable at the limit of this range. So, when using 1 mw radios, a more realistic distance for reliable operation in a normal room will probably be 5 m. This only provides a low cost, low power communications solution which has a sufficient range to replace a cable. For Class 2 devices, communication distance is a maximum of 20 m but a more realistic distance was found to be 10 m. The maximum realistic range for a Class 1 at 100 mW radio is found to be about 100 m.

The electricity meters are installed in a wide range of environments. Some meters are installed inside a private house, a private front yard and back yard. The meters may be placed a long distance away from the power company staff holding the smartphone taking meter reading. Some meters are put in a concrete room located at the center of building. The wireless links need to have the capability to penetrate concrete wall. In considering the standardisation and worldwide availability, Bluetooth technology is chosen for this application and feasible to design a Class 1 Bluetooth module for the electricity meters.

Due to the added power amplifier (PA) and low noise amplifier (LNA), Class 1 Bluetooth solution has better penetration capability and longer propagation distance than other classes of Bluetooth solutions. The maximum guaranteed distance of Class 1 Bluetooth wireless link is 100 m. Anyway, class 1 Bluetooth devices are higher cost and power consumption than Class 2 and Class 3 because of the added microwave PA and LNA.

It was a judgement call to use appropriate smartphone for this application. Almost all the Bluetooth smartphones are designed in Class 2 for battery power saving. An external Bluetooth module is needed to upgrade the smartphones to Bluetooth Class 1 and this increases the cost.

Considering cost and the nature of application, three system configurations as shown in figures 3-12, 3-13 and 3-14 were considered. It was the most realistic approach to find the correct configuration of Bluetooth Class.

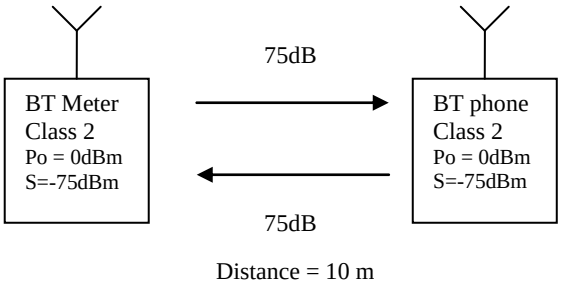

Figure 3-12 – Class 2 Configuration

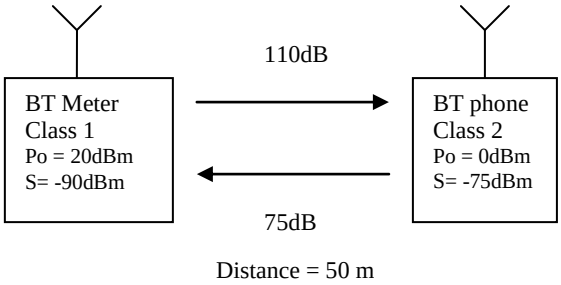

Figure 3-13 – Class 1 and Class 2 combination

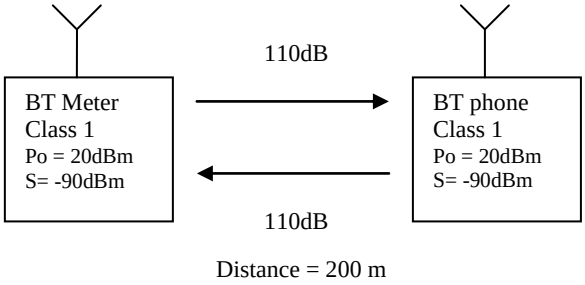

Figure 3-14 – Class 1 configuration

Figure 3-12 shows a low cost system configuration. A Class 2 Bluetooth module is installed in electricity meter. It is also not necessary to employ external Class 1 Bluetooth module for smartphone. This configuration has propagation distance of 10 m. It is only suitable for very short range data communication such as taking electricity meter readings installed near the ceiling or stairs of old buildings.

Figure 3-13 shows a Bluetooth Class 2 and Class 1 combined configuration. The electricity meter is equipped with Class 1 Bluetooth module while the smartphone is just the standard class 2 Bluetooth phone. The distance between the phone and meter can be 50 m maximum.

If the measurement must be taken 100 m away, it is necessary to employ full Class 1 solution as shown in figure 3-14. The distance for Line-of-sight can be up to 200 m but in most cases it will affect by objects of environment for such long distance. The system is specified to 100 m coverage distance although it can be longer. An external Class 1 Bluetooth module is necessary for smartphone. The external module is usually a modified secure digital (SD) card using standard SD input/output (I/O) interface. Electricity meter should have a Class 1 Bluetooth module installed.

An antenna is a critical component to affect the coverage distance of the Bluetooth system. As it is not much space for the antenna in both electricity meter and smartphone, small antennas are usually employed. The gain of such small antennas is -3 dBi to -4 dBi. This is the reason for the specified propagation distance is shorter than the calculated value.

3.8 System Hardware

The major hardware devices of the system are the digital electricity meter, Bluetooth module for meter, smartphone, Bluetooth SD card for smartphone, modem and server. The server can be a PC running Windows 2000 server or Windows server 2003. The modem can be an ADSL modem, cable modem or even dial up modem. The smartphone can be a common smartphone product in the market with Bluetooth inside. The digital electricity meter is supplied by manufacturer such as Elster Metering Limited. The two Bluetooth modules were design to install in meters and smartphones.

Figure 3-15 shows Class 1 Bluetooth module hardware design installed inside a digital electricity meter. A 16-bit microcontroller unit (MCU) is used to handle the Bluetooth communication link for meter readings collection. Class 2 Bluetooth module can be a commercial module solution in the market or designed by using Bluetooth chipsets. PA and LNA are used to increase the transmission power to 20 dBm and improve the sensitivity to -90 dBm.

The Bluetooth module in the smartphone side is similar except the interface is SD I/O rather than RS232. For Class 2 Bluetooth solution, power amplifier and LNA are not necessary for a module. No external Bluetooth module is needed for Bluetooth enabled smartphone.

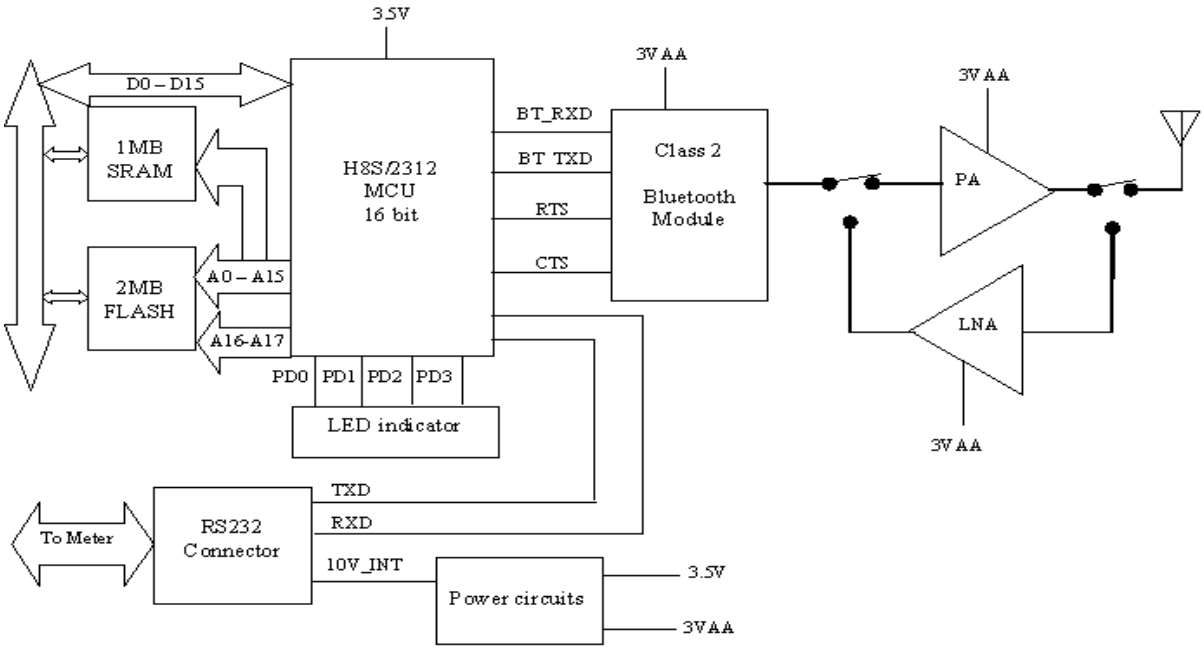

Figure 3-15 – Class 1 Bluetooth module design for power meter

3.9 System Software

The system software for off-site meter recording solution is formed by two parts both running simultaneously – one in a smartphone and the other in the electricity meter. Both smartphone and power meter uses Bluetooth serial profile for communication [36]. Figure 3-16 shows Bluetooth profile hierarchy. Serial Profile is a basic profile for many other advanced profiles. Only the RS-232 characteristic is applied for the system proposed here.

The serial profile provides RS-232 serial cable emulation for Bluetooth device. In this way, legacy applications do not have to be modified to use Bluetooth, they can simply treat a Bluetooth link as a serial cable link. It is suitable for the developed application in the meter reading system.

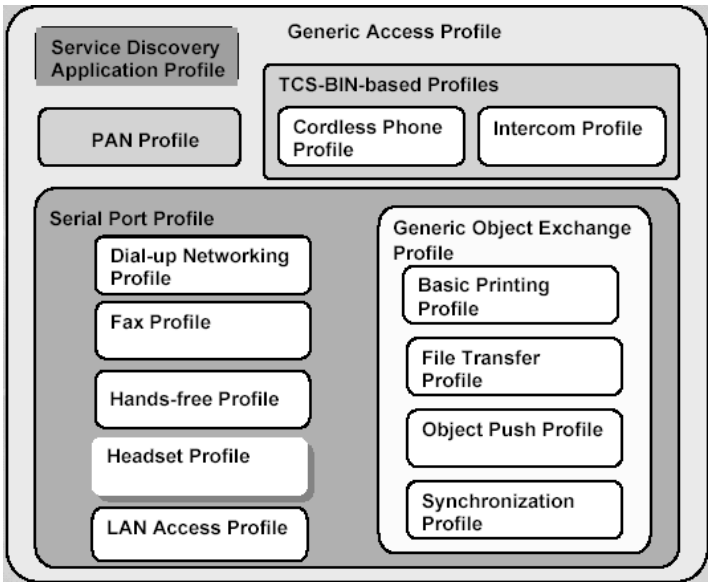

Figure 3-16 – Bluetooth Profile Hierarchy

In a smartphone, there is mainly the meter reading software to handle the meter reading job. This includes three major sub-programs. They are server, power meter and multi-mode interface (MMI). Server is responsible for the server connection through GSM network. Meter governs the meter communication via Bluetooth link. MMI is for user interface.

There is a simple scheduler program to handle the meter reading job in the meter side. The scheduler is responsible to scan the Bluetooth device, handle authentication, send meter data on receiving the commands from smartphone and store the meter reading history as preset by a user.

The security of the system is handled by Bluetooth Security Mode 2 [37, 38]. Figure 3-17 shows the security architecture of Bluetooth Security Mode 2 [37]. Smartphone and meters are set as bonded devices which are marked in a database as trusted and can be given unrestricted access to all services.

The operation of the OMR software is illustrated in figure 3-18. The Bluetooth transceiver in meter is programmed to be the slave of Bluetooth piconet and periodically enter inquiry scan state to make it available to inquiring devices. The smartphone is programmed as master of Bluetooth piconet. Inquiry process is started when user turns on the Bluetooth application in the smartphone. To establish a connection, the smartphone is instructed by the meter readings collection application to carry out the paging procedure.

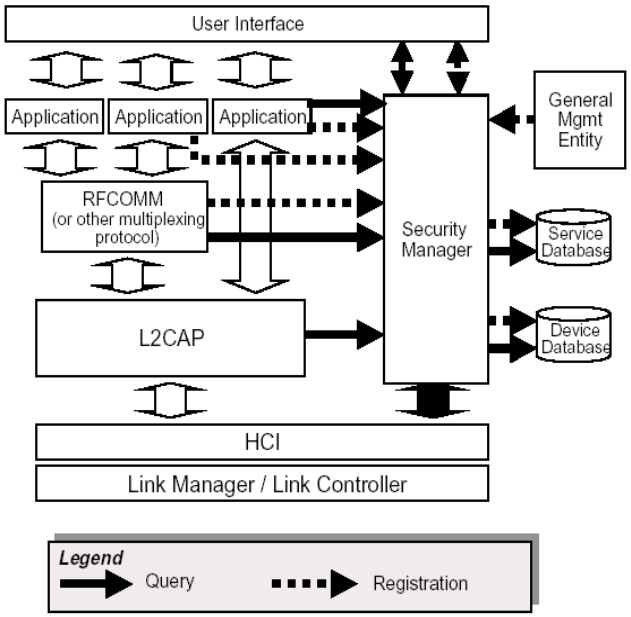

Figure 3-17 – Security Architecture

The smartphone as a master of the piconet first enters the page state, where it will transmit paging message directed at the intended "slave" device (the intended meter). The Slave meter acknowledges the paging message and the master smartphone enters the master response sub state and responds with its frequency hopping sequence (FHS) packet.

Once the slave meter receives the FHS, it updates its own clock timing and synchronisation word or an access code reference before entering the connection state. After authentication and ciphering, the meter readings collection application starts to collect the meter readings. The meter readings will be sent back to server once received from the meter by the smartphone.

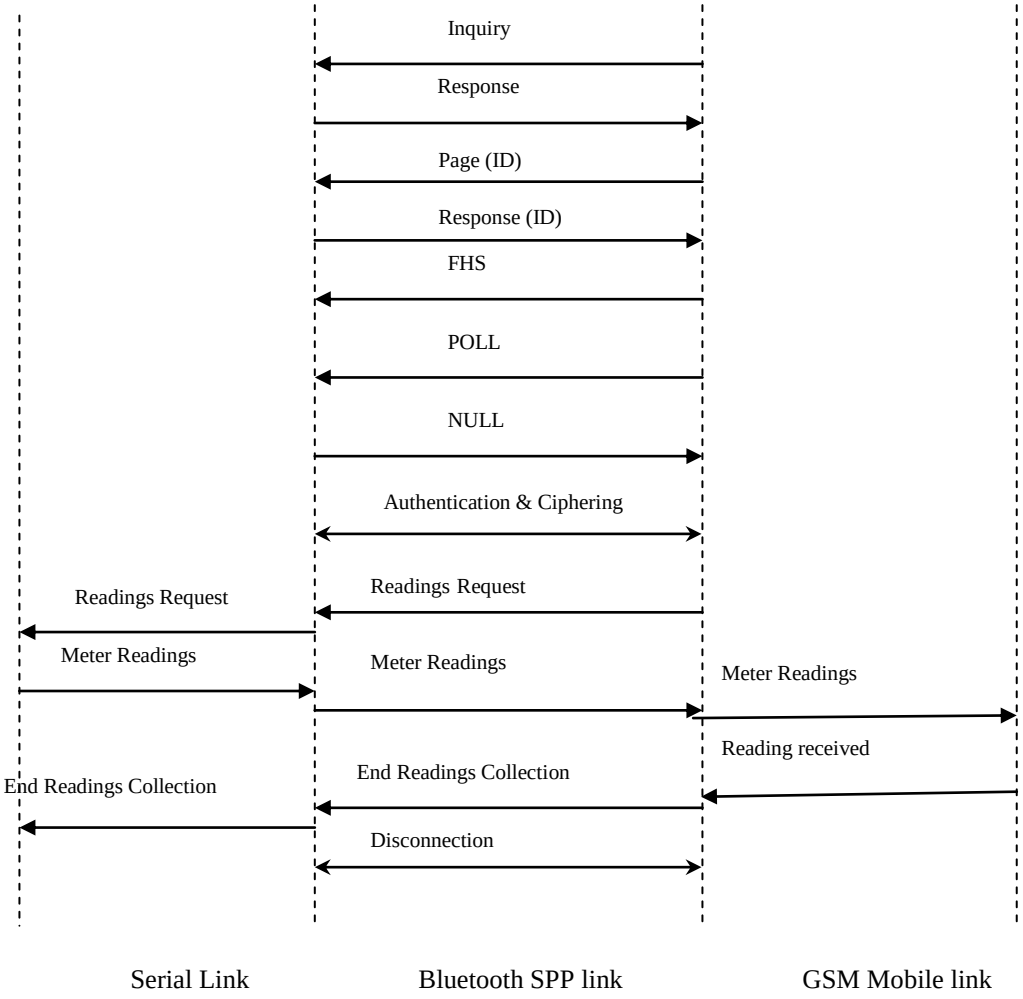

Figure 3-18 – Operation of OMR software

3.10 Conclusions

Traditionally, fairly large size manpower is coordinated by electricity companies to record the electricity meter reading. It is a costly job and easy to get errors in some readings. In some cases, companies are unable to access the private dwellings due to either animals or security devices and so are required to estimate the power usage. In this chapter an innovative solution developed simplifies required task by using Bluetooth. Electricity meter recording can be performed at ease and efficiently from Bluetooth enabled smartphone connected via GSM/PSTN network with Bluetooth enabled electricity meters.

By using either on-site or off-site solutions, human error is eliminated for a faulty meter reading and not required to estimate the electricity usage. As a result, HEC/CLP has reduced the operation cost dramatically. Good signal strength was a challenge as meter rooms are usually poorly covered by the mobile network coverage especially, when they

are located in the basement. The on-site power meter reading solution proved to be a good solution where cable connection is possible but not convenient due to its intrusiveness. Mobile network modems in a location having a good coverage signal can use on-site power meter reading solution.

The OMR solution provided in this chapter integrates the Bluetooth and mobile networks for electricity meter readings. The smartphone is the key device to bridge the Bluetooth network and Mobile network for recording of electricity meter readings. The cost of the system is low. It involves only two hardware designs which are the Class 1 Bluetooth modules for meters and smartphone. The development and system cost are low. This new idea improves the efficiency of meter reading work and also dramatically reduce the resource and operation cost. With this system, power company staff can finish the meter reading collection in a very short time at his or her finger tip. The idea has been accepted by a power company in Hong Kong. Bluetooth wireless technology seems to be the best option available for this application due to its fully standardised protocol and reliable performance. Commercial systems based on this prototype have been built and tested. To date, overall performance of this solution was found to be satisfactory.

Difficulties still exist due to the propagation environment, which are caused by the complicated indoor propagation patterns, signal shielding, signal attenuation and multipath interference. It found that a directional antenna is preferred to increase the propagation distance and a propagation model is needed to compute the signal propagation patterns so that the antenna can be set pointing to the direction with the maximum signal strength. Automatic retransmission for negative acknowledgement must be enabled in both in the baseband and the application layer so that a reliable data link can be established. The solutions developed are not only limited to electricity usage application. It can also be applied to automatic gas and water usage readings. The Bluetooth is mainly applied in mobile headset currently. The integration of Bluetooth and mobile technologies such as 3G and 4G can generate many valuable applications.

Today, mobile applications for energy sector have grown immensely. There are several applications available for the domestic utility segment. The most famous is the iPhone App. The eQ-3 (a German company) has designed a program that controls windows, radiators, light switches and dozens of other household appliances at the touch of a button.

Control4 (a US company) offers a home management system that automatically dims the light when you're watching a movie. It is also capable of blocking a PC and/or TV when kids are doing their homework. It can be operated by iPhone and iPod Touch. Ecobee, Lutron and Tendril offer similar smart phone applications. Just as the use of smart phone technology with multiple consumer applications has transformed the telecommunications industry and the way people communicate, so too will the smart grid revolutionise the energy industry and the way people use energy.

Chapter 4

Design and Development of a PDA based Wireless Food Ordering System for the Box Hill Institute (2005-2006)

4.1 Introduction

As mobile devices become smaller, cheaper, better and more connected, they are changing the way people access and work with information [41]. The convenience and powerful functionality offered by mobile devices, such as PDA, has encouraged many industries to find benefits in using them. Wireless and handheld devices abounded, as vendors pitch their common themes of one-to-one computing, instant communication and, anytime, anywhere information access [41]. Originally, the PDA was intended to be an electronic version of a "personal organizer", however, with the introduction of more powerful CPUs, operating systems and memory, today's PDA are being customised for various applications. Unlike desktop PCs and laptops, mobile devices have many constraints such as screen display size, interaction techniques and bandwidth over mobile networks [42]. Despite these constraints, PDAs are the preferred mobile device for business applications because they are highly portable, have ability to communicate with PC and can access information from remote location.

Recent studies [43, 45], have documented the potential of PDAs to affect the quality of patient care within the healthcare industry. It has been shown that the potential for a robust handheld computing to positively affect the outpatient ambulatory clinical setting is enormous [43]. The ability to link data on a PDA (client) to a central database (server) allows unlimited potential in developing point-of-care applications and systems for patient data management [44]. It is demonstrated that several potential uses of PDAs as learning tools including reading course materials, as a communication tool, for supporting activities including real-time conferencing [45].

Web-based applications provide access to data and services from a remote server, which may in-turn access databases distributed across the enterprise network or the Internet [46]. Web-based applications are the preferred method of accessing data remotely because they provide solutions that are easy to administer and are user-friendly. The use of Internet protocols and subsets of World Wide Web formatting and coding standards for

wireless applications shortens the development cycle drastically and frees up developers to concentrate on more important issues [47].

The food ordering process in a restaurant requires the coordination of simple tasks. Instructions flow mainly from customers to waiters then to kitchen staff, then to bar and finally to cashier [48]. In a medium to large and busy restaurant it is always difficult to coordinate the entire process without having an efficient ordering system. Errors in ordering processes lead to incorrect meal preparation and prepared in a sequence are non-consumable and added cost to the business [49]. Web-based wireless applications on PDA are instantly available and subsequently extremely mobile. Data on PDAs is continuously saved; this supports incremental order creation which user finds convenient [50]. Advantages associated with the adoption of wireless technologies in restaurant environments include increased efficiency, greater speed of service, enhanced usability, improved accuracy, increased productivity and raising business image [48 – 51].

4.2 Related Work

A number of PDA based mobile applications have been designed, implemented and developed for commercial use in a restaurant environment. Easy-Order® was one of the first e-commerce applications of pervasive technology developed to interact with the mainframe computers [51]. Wireless web-based ordering system named iMenu® [52], is one of the first approaches that use wireless multi-tiered Internet architecture to build commercial pervasive computing systems in the restaurant industry. Developers have selected .NET platform as programming environment, C# as the programming language and active server pages in .NET (ASP.NET) for the user interface [52]. Using PocketMate® [53], orders can be sent directly from the table to the bar or kitchen, which ensures that customers receive their orders faster and are happier. PocketMate has provision for an extra drink to be ordered to increase the dollar per head [53]. It is developed as a platform independent application using Java Macro Edition (J2ME) and MySQL.

4.3 Approach in selecting PHP / Mobile Technology

Good decisions about selecting a technology from variety of choices needs to be based on a realistic understanding of current performance and how limitations can be

addressed [54]. There are other mature technologies adopted by mobile content providers for interactive and complex applications development. PHP was decided to use as one of main programming technology and decision was based on the facts like,

- PHP is useful to develop a user-friendly, cross platform language and compatible interface with the range of operating systems;
- unlike other scripting languages PHP is more like programming languages, which has functions, variables etc;
- PHP works on the majority of the web servers with performance similar to ASP. Windows Apache MySQL and PHP (WAMP) server was used which made the task simpler as it is embedded with PHP configuration. Application was designed to work in a web server-database environment and the language was developed purely to serve the web pages [55], and
- In-house expertise.

Unlike iMenu [49], my approach in-line with the BHI was to build a simple, stand-alone and web-based wireless application. Connectivity between client and server is continuous in two-tiered web-based client-server architecture. A "session" is a connection established by PDA via access point to the server and then server transmits processed information via access point to an appropriate printer. Within the restaurant, sessions are independent and no interactive sessions are required. Web client requests and web server responses consist of multiple series of discrete requests and responses that allow the transfer of data between a mobile web client and web server (Figure 4-1). This data transfer mechanism is best suited for devices with browser and valid network connectivity.

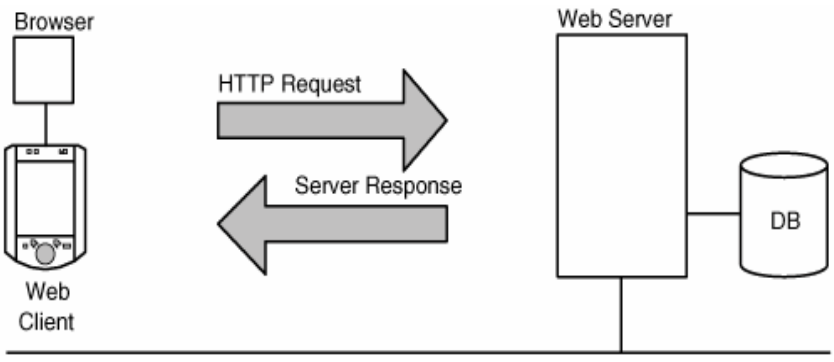

Figure 4-1 – Mobile Applications: Architecture, Design and Development

Other mobile application development platforms like JSP, ASP, Java Servlets, CGI-bin, J2ME and PHP can be used to develop web-based applications interacting with mobile devices. Recently, most popular are J2ME and C# for .Net platform because they provide a complete application-programming framework on PDAs. However, the decision of not to choose these programming languages was based on the fact that J2ME uses mobile information device profile functionality (MIDP). MIDP lets developer create small applications called Midlets. Midlets provide richer, interactive sessions which are portable, downloadable and robust [56]. But Midlets consume considerable storage and memory space which has long initial download times and the programming methodology is complex. J2ME applications are portable and available on anything that runs Java Virtual Machine [57]. As discussed earlier application development in J2ME is slightly more complicated than developing a page length code compared with web-based technologies such as XHTML, cHTML, PHP, JavaScript etc. Furthermore, consideration was given to learning environment for students as a part of project base learning for application development and later, it can be implemented in training restaurant with ease.

4.4 Methodology

At Box Hill Institute, the teaching and learning strategy is to support classroom teaching with skill based activities. In line with this strategy, hands-on experience and methodology used for this project should be based on laboratory experiments. Applied research was of considerable importance. Its strength as a research strategy is that they allow the investigator to make strong claim about findings [52].

Layout of the Fountains Restaurant at the Box Hill Institute is shown in figure 4-2. The layout is an important design consideration for understanding the technical operation of the Fountains Innovative Wireless Food Ordering System (FIWOS). The restaurant consists of bar area, serving area, demonstration theatre and a kitchen. All operational areas of the restaurant directly interconnect the main waiting floor, making it an efficient layout.

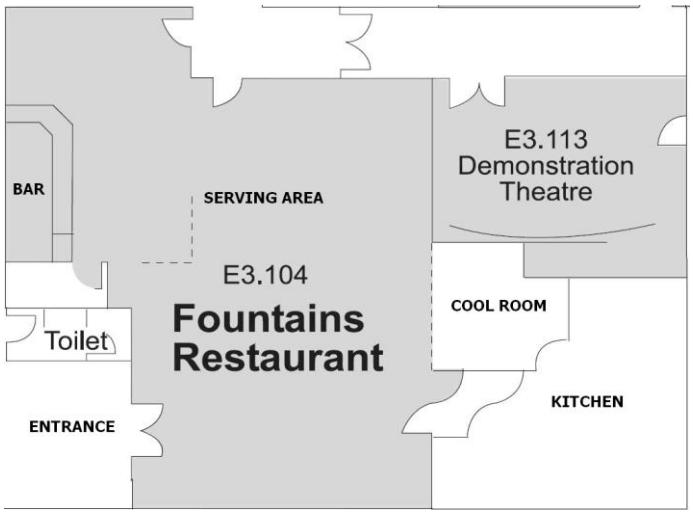

Figure 4-2 – Layout of Fountains Restaurant

FIWOS network has been designed around a single access point situated in the middle of the restaurant (Figure 4-3).

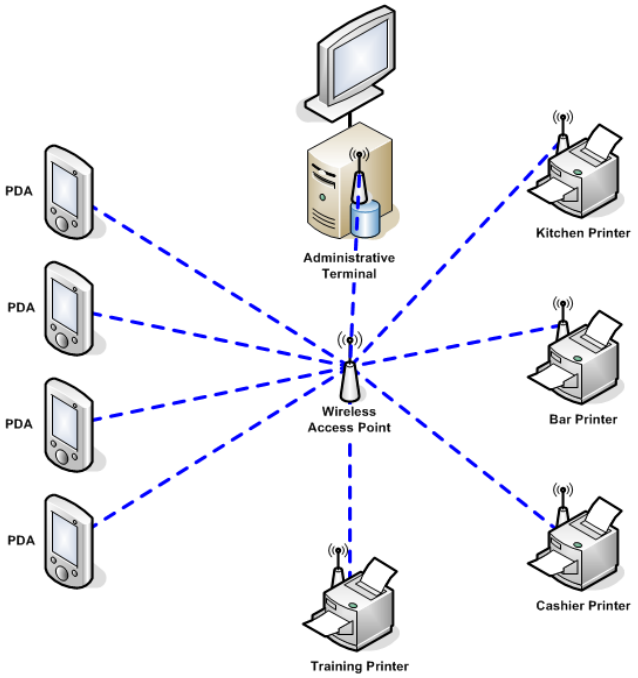

Figure 4-3 – Logical Wireless Network Diagram

All food orders that are entered into the handheld devices by waiting staff are then transmitted wirelessly to the printers in the kitchen and bar, where the appropriate orders are printed, and the administrative terminal, where the orders are logged. This communication is provided through the WAP, which will act as the bridging point between the wireless and wired networks. One of the advantages of this network design is that any of the devices that are connected to the access point are mobile and can be moved around

without affecting connectivity. This is crucial, as any lack of connectivity will impact the operation of the system.

4.5 System Architecture

Scripting languages require browser software on the client device. A browser interface is easy to access static content or displaying the list of application and services. A web browser on a PDA sends a GET request for information to the web server. The client browser also submits information to the web server using POST request. Part code written in PHP for a PDA client is shown in figure 4-8, to clearly describe how web client request and web server responses coordinate the wireless communication. Considering learning environment for students both within the area of application development and then use of application in training sector, I selected technologies which were easily available, reliable and popular even to the novice users. FIWOS has been developed using 802.11g, PHP, JavaScript, Microsoft Access and Visual Basic (VB). PHP is a cross platform language, compatible with the range of operating systems. It was designed to work in a web server-database environment and the language was developed purely to serve the web pages [54]. System architecture (see figure 4-4) includes following components:

- Application software written using PHP and JavaScript for PDA user interface and it's communication with centralised database located on a server or PDA client.
- Centralised relational database (CRD) developed using Microsoft Access.
- Back-end application software (BAS) was written using VB to administer database from the administrative terminal.
- Wireless connectivity using 802.11g,
    - between a PDA client and a web server, and
    - between a PDA client and wireless printers.

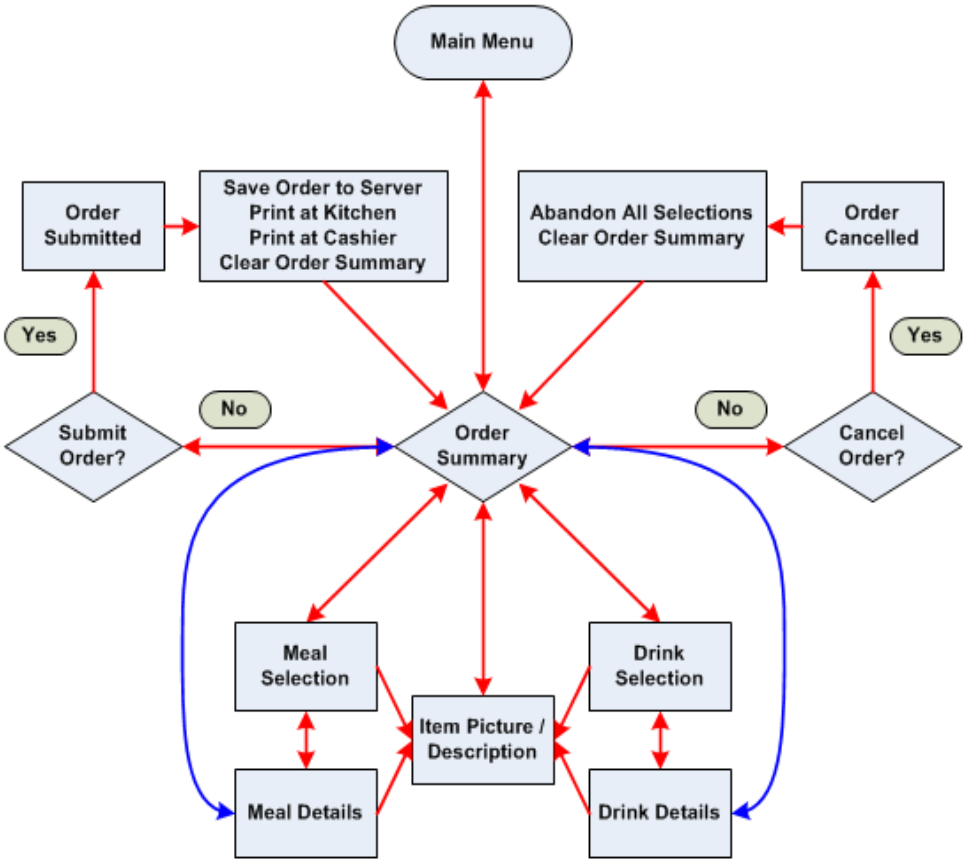

Figure 4-4 – System Information Flow Diagram

4.6 PDA Client

PDA client is a web-based application located in web server together with the database. This will be accessed wirelessly by PDA to create, print and close the order. Database of food, drink, orders and tables will be handled from the administrative terminal using admin-client. Waiting staff can access PDA client onto their PDA via wireless access point. Based on database they can select items for orders for a particular table and then submit the order for printing and later for storing the order. It is developed using PHP. It is made up of several files, each of which performing a particular function within the application.

Figure 4-5 – Table Summary

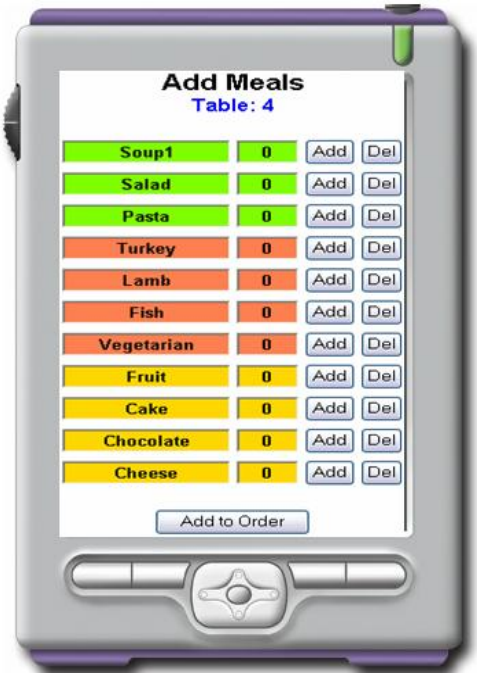

Figure 4-6 – Add Meals Sub-menu

Table Summary (Figure 4-5) is the first page user will see when they logon to the ordering system. This will display table status. To start a new order, select a vacant table from the list and press “Create Order” button and Add Meals (Figure 4-6) page will appear. “Finish order” button will close the order and print it to appropriate locations such as kitchen, Bar, Cashier. To get the latest table status press “Refresh List” button. Meals can be selected or removed from the list and then can be added into the order using “Add Meals” page shown in figure 4-6.

4.7 Centralised Relational Database

Microsoft Access database was used to develop a simple CRD. Database is the core of the whole FIWOS ordering system. PDA client will communicate with the database to get the information for the system. It contains the database to store data and the graphical user interface to access the database. Important feature of this database is a table of tables which keeps track of status on each table in the restaurant. On each order submitted by the PDA, the table changes its vacant status to occupied status with the ability to reopen the same order for modification. Reports can be generated efficiently on number of orders taken. Table 4-1 lists various tables created for CRD.

Table 4-1 - Centralised Relational Database

Tables	**Description**
Entrees	Maintains no of entrees available
Mains	Maintains no of mains available
Desserts	Maintains no of desserts available
Drinks	Manages drinks available
Tables	Maintains table status and numbers associated
Orders	List total no of orders, it's value and date
OrderDetails	Maintains order status, content and its number
Users	List no of users with username and passwords

4.8 Back-end Application Software

Graphical user interface (GUI) as shown in figure 4-7 is created for administration purpose of the system. Administrative person can have permission to login to this system can make changes to the database. It has an ability to change passwords and also add new users and passwords to the systems.

It contains several interfaces to view, add, edit, delete items of the database and can store photos for appropriate items. Also this system has a report generating facility to get printable reports of items and summaries. Back end application was design to keep it simple so that using this feature even a cook or chef or a manager can amend menu, prices and total number of dishes reflecting seasonal flavours and market demand.

Figure 4-7 – Back-end GUI

4.9 Wireless Connectivity

Secure wireless connectivity between a PDA client and a web server and between a PDA client and wireless printers is an important aspect of this project. Functions PrintOrder and PrintTest in the "Scripts.php" file of the PDA client defines the printing functions that determine how each of the receipts are formatted and printed to a particular printer. These functions are presented in figure 4-8. A wireless LAN is created using 802.11g enabled wireless access point. Based on radio frequency, wireless capability of PDA transmits the data in real time to a web server. For restaurant environment, mobility is required only within the floor area of the restaurant and so wireless LAN is a good choice. Java Script functions are added to help PHP to implement printing functionality. Functions PrintOrder and PrintTest in the "Scripts.php" file of the PDA client defines the printing functions that determine how each of the receipts are formatted and printed to a particular printer.

```
function PrintOrder($printername, $tableno,
$printitems, $printqty) {
$handle = printer_open($printername);
printer_start_doc($handle, 'Order');
printer_start_page($handle);
$tablefont = printer_create_font("Arial", 72, 48,
500, false, false, false, 0);
$headingfont = printer_create_font("Arial", 72, 48,
500, false, true, false, 0);
$bodyfont = printer_create_font("Arial", 72, 48,
200, false, false, false, 0);
printer_select_font($handle, $tablefont);
printer_draw_text($handle, "Table: $tableno", 350,
50);
$y = 100;
printer_select_font($handle, $headingfont);
printer_draw_text($handle, 'Item', 0, $y);
printer_draw_text($handle, 'Qty', 1000, $y);
$y = 200;
$fontsize = 72;
printer_select_font($handle, $bodyfont);
for($x = 1; $x <= count($printitems); $x++) {
$y+=$fontsize;
printer_draw_text($handle, $printitems[$x], 0, $y);
printer_draw_text($handle, $printqty[$x], 1000,
$y);
}
printer_delete_font($tablefont);
printer_delete_font($headingfont);
printer_delete_font($bodyfont);
printer_end_page($handle);
printer_end_doc($handle);
printer_close($handle);
}
function PrintTest() {
$p = printer_open('HP 6200 Network');
printer_set_option($p,
```

```
PRINTER_PAPER_FORMAT,
PRINTER_FORMAT_A4);
printer_start_doc($p, “Testpage”);
printer_start_page($p);
$pen =
printer_create_pen(PRINTER_PEN_SOLID, 1,
“000000”);
$font = printer_create_font(“Courier”, 37, 19,
PRINTER_FW_NORMAL, false, false, false, 0);
printer_select_pen($p, $pen);
printer_select_font($p, $font);
for ($i = 0; $i < 4600; $i+=100) {
printer_draw_line($p, $i,0,$i,6700);
printer_draw_text($p,$i,$i,0);
}
for ($i = 0; $i < 6700; $i+=100) {
printer_draw_line($p, 0,$i,4600,$i);
printer_draw_text($p,$i,0,$i); }
printer_delete_font($font);
printer_delete_pen($pen);
printer_end_page($p);
printer_end_doc($p);
printer_close($p);}
```

Figure 4-8 – Wireless Connectivity for a PDA Client

Figure 4-9 depicts a snap shot of “PrintTest.php” file is an included file in the application that provides some alternative printing ability in the case of printer to accept RAW data from “Scripts.php”. The main difference between this file and the print functions defined in the “Scripts.php” file is that this is written in a JavaScript.

```
<script language=“JavaScript”>
var gAutoPrint = true; // Flag for whether or not to
automatically call the print function
function printSpecial()
{
if (document.getElementById != null)
{
var html = '<HTML>\n<HEAD>\n';
if (document.getElementsByTagName != null)
{
var headTags =
document.getElementsByTagName(“head”);
if (headTags.length > 0)
html += headTags[0].innerHTML;}
html += '\n</HE' + 'AD>\n<BODY>\n';
var printReadyElem =
document.getElementById(“printReady”);
if (printReadyElem != null)
{
html += printReadyElem.innerHTML;}else
{alert(“Could not find the printReady section in the
HTML”);
return; }
html += '\n</BO' + 'DY>\n</HT' + 'ML>';
```

```
var printWin = window.open(“”,”printSpecial”);
printWin.document.open();
        printWin.document.write(html);
        printWin.document.close();
        if (gAutoPrint)
        printWin.print(); } else
{ alert(“Sorry, the print ready feature is only
available in modern browsers.”);
}}</script>
//// To be added to controls
<div id=“printReady”>
<p>Hello World! Your Printable Page Content Goes
Here</p>
</div>
<form id=“printMe” name=“printMe”>
<input type=“button” name=“printMe”
onClick=“printSpecial()” value=“Print this Page”>
</form>
//// To be added to controls
```

Figure 4-9 – Alternate printing option

Complete FIWOS system installation procedures, source codes and user manual are provided at Appendix A.

4.10 Security

Web-based wireless ordering system can be provided efficiently with high level security and implemented effectively for the same, [48] proposed that web-server should reside in a special subnet or “demilitarised zone” which then can be attached to the firewall. The firewall performs protocol level filtering to allow connection from authorised users only. The developed system has been tested within existing wireless LAN environment which uses 802.11b/g enabled wireless access points.

Today, very few access points incorporate WEP encryption and most wireless routers are sold with WEP turned off. Security analysts have criticised WEP’s inadequacies, and the US Federal Beaureu of Investigation (FBI) has demonstrated the ability to break WEP protection in only three minutes using tools available to the general public. To overcome these issues, WPA and WPA2 were created which protects data and privacy [58]. It is based on IEEE 802.11i standard. For this application, it was observed that no real threat with the food ordering system which has an in-built WPA2 encryption-decryption protocol within the access point or wireless router. This mechanism allows hardware addresses (MAC addresses) to be configured for wireless access to retrieve and store on the server.

4.11 Limitations

After configuring the equipment the testing was done successfully using two PDAs. Testing using more than two PDA is not done yet however, considering simple operation I do not see any technical hurdles. At present, this system does not provide opportunity to monitor stock and inventory control for the restaurant. If implemented in a day long busy restaurant then recharging PDA battery(s) would be a challenge. Finally, connectivity is done using static IP addresses and MAC addresses of PDA are stored in access point. Due to present vulnerabilities in wireless technology, it may not make this system entirely secure enough to defend itself against attacks. However, considering nature of application, I strongly believe WPA is secure enough for food ordering transactions.

4.12 Lessons Learned

This project met all scope and cost goals. The project cost was approximately $25,000 or approximately 50% of the approved budget. The project team often got bogged down on several occasions with on-going modifications to the system. Throughout this project, there seems to be no shortage of enthusiastic suggestions emanating from the members of the team. There was lots of consideration and respect for opinion within the group that allowed each team member's idea to be explored in detail. One of the things that went right is the communication between team members. In addition to the problem of being unable to source test equipment, the project came across a situation where none of the team had sufficient knowledge or ability in wireless application programming. There were several attempts to hire an industry professional to come and demonstrate client/server applications however, there were several scheduling issues.

It was difficult to come to an arrangement with a time that stakeholders could meet on a regular basis for the training. The team has learned from the beginning that there are going to be a lot of aspects of the project that will not be able to be completed immediately with the existing skills set. With this in mind, the team has very effectively learned how to retrieve information through their own research through books, magazines, the Internet and above all using self-initiative. From a project manager's perspective, I endeavour to ensure that some of the more fundamental documentation is agreed upon and delegated as tasks from day one. There were some difficulties with this during the project as most of the

project management and documentation areas were fairly new or had not been previously put into practice. Also, during the first two weeks of the project, I focused more on establishing the team and its roles and responsibilities for the deliverables so that there would be a much more solidified platform moving forward in the project.

4.13 Future Work

In addition to PDA and wireless technology, the location identification feature provided by GPS can be integrated to FIWOS to deliver latest information from to waiters on the floor. Research has been done to integrate these technologies for the development of the PDA/GPS guide system for tourism industry has been done [58]. Alternate development for client-side print control needs to be explored further. Implementation into hospitality environment will make wireless ordering system more efficient. The restaurant business is not consistent every day of the week. Coordination of orders submitted by multiple PDAs would be efficient with the implementation on queuing principle especially during peak time. Location Based Tourism System (LBTS) and GPS have been explored separately for use in tourism industry [59].

Further research can be done to see the possible implementation of LBTS together with GPS in existing system and apply new system in highly mobile food industry, for e.g. pizza delivery. Once hospitality students learn this new way of taking food orders and processing financial bills then the challenge would be to optimise the system by using their feedback.

Currently this system has no interface with standalone financial system. Interesting thing would be to develop a total solution customising according to clients requirements at the Box Hill Institute interfacing with their financial and business activity reporting. Furthermore, mobile applications can use message queue applications with the store-and-forward mechanism. This will allow user update to be placed in the message queue if no connection has been established prior to the communication. The application software written for this keep sending messages until it is successful.

4.14 Conclusions

This chapter presented applied research based on laboratory experiments to demonstrate how mobile devices such as PDA can be effectively used in hospitality environment and educators should consider how they use the technology for routine teaching, innovation and creativity. It was proved that a simple, an effective and readily available technologies can be appropriately amalgamated to create user-friendly application at very low cost.

Low cost applications are useful in learning environment especially, considering publicly funded institutes. FIWOS has been tested for its functionality into special purpose built wireless communication laboratory. Two Dell® Axim™ PDAs were used, one Linksys® WAP11 Wireless Access Point, one Dell® Desktop PC with Windows XP® running on 512 MB RAM and Pentium® 4.4 GHz processor and a Brother® Wireless Multi-function colour printer. Stakeholders were involved to test each stages of this project. Results of various tests were documented as a part of effective learning process. Pervasive computing and in particular, mobile wireless application development is now part of the Box Hill Institute's higher education programs.

Chapter 5

Design and Development of a Visitor's Personal Guide using iPod for the Box Hill Institute (2006)

5.1 Introduction

Over the past few years use of mobile devices has been increased for various purposes. Apple released its first iPod on October 23, 2001, a breakthrough MP3 player. Apple's latest iPod is available today which is considered as Portable Media Player with many functions providing rich multimedia experience. It focuses on the playback of digital video as well as storing and displaying pictures and video [60]. Since then, iPod has been successfully and effectively used for various purposes including media player, bootable drive, external data storage device, a PDA replacement and for Podcasting.

Academic and tourism are two areas where the use of mobile device is encouraged to gain benefits from the technology. For academic use of iPod, its recording and storage capabilities has been explored by some educational institutes across the US. According to [61], iPod supports individual learning preferences and needs, easy-to-use tool for recording interviews, field notes and small group discussions etc. Tourism industry is also identified as a potential area to use mobile technologies. Dublin Tourism discovered use of iPod as a Portable Tourist Guide which then followed by their neighbour Scotland in 2003 [62].

Sales of interactive portable MP3 player have increased explosively since last few years. In 2005, Information Media Group predicted that sales will continue to increase at the rate of 45% for next six years [63]. The iPod is currently the world's best-selling digital audio player and increased its popularity in Australia seven fold [60]. Greg Joswiak, the worldwide vice president of iPod marketing said, "As of August 2005, market share in Australia is 68% of digital player market".

With the increasing use of digital media together with the handheld devices, this iPod application will eliminate need of a human guide and will provide entertaining experience to visitor. It will be very useful for landmark tourist destinations such as aquarium, museum etc. There will be a huge demand as increasing flow of tourists in Australia.

Tourism Australia 2010 report says increase of total tourists from 9.982 million in 2009 to 18 million in 2010 [64].

5.2 Background

Tourism is an important activity for human life as a source of pleasure and reserved for holiday period. Several new places are visited by numerous people every year. Prominent tourist spots are usually places such as an art gallery, a palace, a commercial destination such as stock market, a parliament house etc.

Every new visitor suffers from preconceptions and anxiety on their lack of knowledge about the visiting site. This acts as a barrier and must be overcome before effective and enjoyable experience can take place. Thus far, the tourism industry in Australia has promoted via various communication mediums such as location maps, information centres, interactive touch screens, video screens etc. Tourism has been a popular area for mobile information systems and other PDA based systems [65].

Audio and video has been neglected or underused as a leaning medium in recent years [66]. A general view is that video is a better tool for leaning than audio. Animation and interactive media like simulations can attract attention but they proved to be expensive. Hearing is an astoundingly efficient skill according to [67].

Portable media players such as PDA and iPod can provide information anytime and anywhere. These devices come with their own hard-drive and eliminate transportation of storage devices, which is a requirement for video communication. iPod with in-built speakers and microphone make it easier to record and playback information stored into its hard-drive. Besides its popularity and ease of use, listening to an iPod and similar devices at public places is socially accepted.

At Box Hill Institute (BHI) it was realised the use of iPod as a part of “Innovation Walk”. The “Innovation Walk” is developed with the aim of showcasing the institute’s prized innovations. Career teachers, overseas visitors, students, industry and government dignitaries and community can undertake the walk independently or as a guided tour.

Figure 5-1 and 5-2 shows concept of the Innovation Walk and its snap shot from the BHI website.

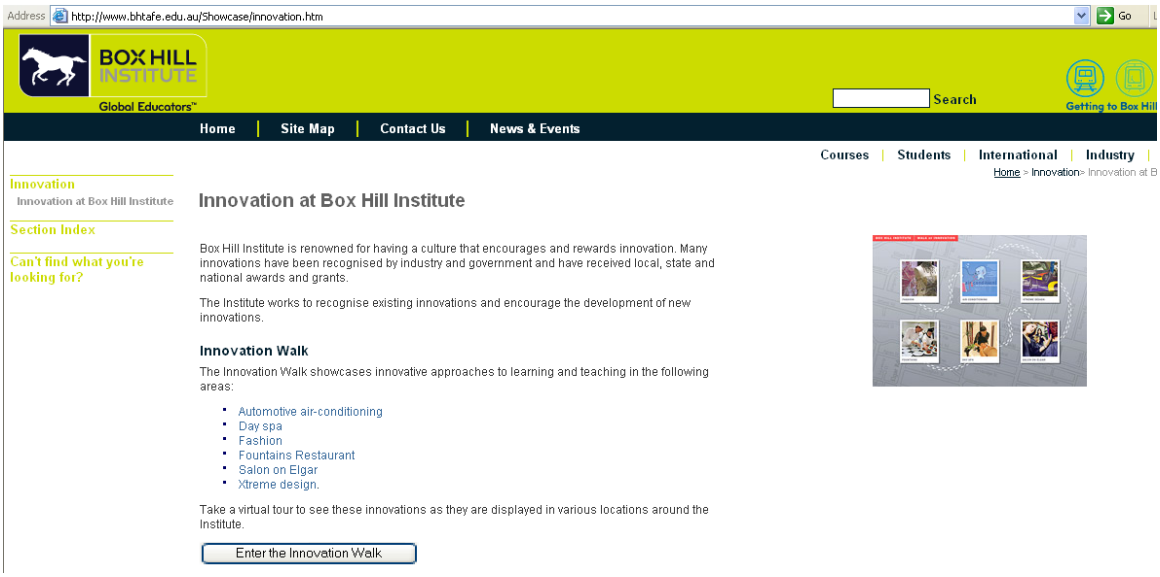

Figure 5-1 – Innovation Walk Website

Figure 5-2 – Sections of the Walk of Innovation

5.3 Personal Guide Design

The visitor's personal guide itself will be in the form of an iPod that can be programmed to give details of a defined list of locations, as well as playing an audible narration of each featured location. This will allow visitors to navigate the visitor's site on their own with the use of the iPod. Following technologies can been considered initially to program the iPod as per the requirements:

- create an application in J2ME on java platform porting it to the iPod.
- install a variant of Linux (more on this later) and modifying its operation to create the system from this platform; and
- create a text-based guide on the iPod.

Text-based option is the easiest way with some limitations and given preference on the basis of the estimated time and skills available. To get multiple text pages to run is a fairly simple concept. It requires a specifically named file located under the "Notes" folder that acts as an index page, from which the menu would be created and all other note will be created. As discussed earlier iPod as storage devices can easily be connected to a computer via the USB port and the drive that is mounted for the iPod can be navigated easily from the "My Computer".

5.4 Content Page

Open up the "Notes" folder and create a new file called "Main.linx". File name as "Main.linx" is required for two reasons. The first reason is that by naming the file "Main", the iPod will automatically display the page as an index, rather than providing a list of available files to open. Secondly, the extension ".linx" of the filename defines the method used to display on the iPod screen a link to another text file.

The iPod has two methods of displaying a link. The default is to have a link created within a text file appear as a hyperlink, similar to that of an html webpage with the word or sentence underlined. The second method is to display the links as an actual menu item on the iPod. This method would be ideal for the contents of the visitor's guide.

Once the “Main.linx” file has been created and located correctly, the next step will be the contents of the main page. This will create the major links to each of the locations that will contain information. This is achieved by opening up the “Main.linx” file in Notepad and entering the following:

<title>

5.5 Alternative Operating Systems for Apple’s iPod

Currently there are two main alternatives to Apples’ iPod Operating System iPodLinux (open source venture into porting Linux onto the iPod) and Rockbox (an open source replacement firmware for mp3 players).

iPodlinux [68] and Rockbox Operating System [69] are able to replace the Apples’ Operating System and still maintain the same functionality. The alternative operating systems are capable of playing MP3’s and other audio formats, videos and reading notes. The main difference between Apples’ Operating System is that iPodlinux and Rockbox can:

- play video games;
- run applications;
- develop your own applications without requiring commercial development tools; and
- programmers can develop their own applications or modify/customise existing iPodlinux GPL applications.

Certain Linux applications are recompiled to run on the iPod without modification. Both alternatives to Apples iPod Operating System have a following of enthusiastic programmers and developers who have figured the workings of the five generations of the iPod. Developers and programmers of the iPodlinux have contributed a lot to an Open Source operating system by setting up internet relay chat rooms, news groups, forums, wikis and websites. Sourceforge [70] hosts the source code and development comma separated value (CSV) tree, which is maintained by the iPodlinux core developers. Documentation of the iPod hardware components such as microcontroller, display, memory, battery and so on is now accessibly to everyone. Rockbox Operating System developers thank the hard work of iPodlinux project because if it wasn’t for iPodlinux

documentation and developers the Rockbox Operating System may have never been ported to the iPod.

5.6 An alternative iPod operating system

iPod as a visitor's personal guide project initially was looking at the bleeding edge mobile Java J2ME application technology to fulfil its requirements. After research it was discovered that, there are other ways to implement a tour guide on an iPod. The research found iPod Notes, iPodlinux and Rockbox.

- iPod Apple Operating System is proprietary and therefore close source.
- iPodLinux and Rockbox are open source Operating System that has been written under the GNU General Public License.
- iPod Apple OS only supports a crippled html language in "Notes" which allows the development of interactive Notes that can contain pictures, video and text.
- How iPod can be programmed for iPodLinux?

Programming for iPodLinux is done in C programming language and as a prerequisite the standard functions and libraries must be used. Here is an example of the "Hello World" code using the printf function from stdio.h library. Using notepad or a C application, the following can be entered to get desired code:

- Start off by including the pre-compiler derivative includes statement:

  #include <stdio.h>

- Next, to create the main function from which the code to print "Hello World" will be inserted (Figure 5-3).

```
int main (int argc, char **argv)
{
printf ("Hello World!\n" );
return 0;
}
```

Figure 5-3 – Sample Main Function created using "C" Programming Language

- Save the code you have entered into notepad using the filename of hworld.c. The step is to compile hworld.c using the arm complier tools,

arm-elf-gcc hworld.c -o hworld -elf2flt

- Execute “hworld” on the iPod running iPodlinux. It will display “Hello World” to the iPod screen. Once you are happy with your application it can be packaged as a module and inserted into the Podzilla menu structure.

Developed prototype application using an Apple iPod is shown in figure 5-4.

Figure 5-4 – Design of a Main Menu

5.7 Advantages

This application on iPod will:

- eliminate need for a human guide;
- provide a self-guided tour with entertainment to visitors;
- lead to interactive customer service;
- provide flexibility to tourists to tour the area as per their own need, time and interest; and

- achieves a great tourists turnaround time as no need to wait for some predefined number of tourists.

5.8 Future Trends

This concept can be further developed to provide visitors with the information in languages other than English, in a multicultural community environment. Also enhancement to the application can be made to discover the possibilities of porting iPodLinux platform on current version of iPod, which is not done thus far. Further to that possibilities of using iPod on commercial environment like PDA will be investigated. Cost effective solution can be implemented at various landmark tourist destinations such as mines, aquariums, museums etc, and in near future will replace existing expensive technologies.

5.9 Conclusions

It is demonstrated that iPod can be used as an innovative and cost effective tool. To realise the use of iPod as a visitor's personal guide, iPod's simple user interface was designed around a central scroll wheel can be explored for the navigation and recording/ playback facility. It provides latest information to visitors. Furthermore, iTunes can add entertaining experience with preferable music while using it as a personal guide.

I realised that I had found a solution that was not only easier, but innovative which helped me progress my research in ways I didn't even knew that I can with an iPod. Results of this research are being used to further fine-tune the end-product that is to use as a visitor's guide. Further investigations and other ideas spinning-off from the core idea are on-going research topics within BHI.

Chapter 6

Design and Implementation of an Innovative Student Attendance Recording and Retrieval Application (SARRA) for the Box Hill Institute (2006-2007)

6.1 Introduction

The persistence of high rates of absenteeism is a major concern for all levels of education providers. Educators strongly believe that a consistent school attendance is essential for educational success, with low standards of academic achievement, including low levels of English language and literacy skills, almost universally attributed by teaching staff to high levels of absenteeism among the student body.

Several notable factors that influence student attendance and grades are motivation, prior grade point average (GPA), self-financing by students, hours worked on jobs, quality of teaching, and nature of class lectures. These factors lead to student behaviour, teacher attributes, and course characteristics on class attendance and performance [71].

At the Box Hill Institute (BHI), attendance for international students needs to be reported using the approved method to BHI's International Student Office. It is mandatory that international students shall meet the 80% attendance. One of the significant priorities for BHI was the application development to reduce time, error and administration overheads on reporting of attendance to government agencies in order to comply with regulations, especially with Educational Services for Overseas Students (ESOS) Act 2000.

While the World is moving towards an entirely unified voice and data network, Voice over Internet Protocol (VoIP) is becoming increasingly popular. Converging voice, data and video networks are providing many positives for business and individuals alike. At present, nine Victorian State's Technical and Further Education (TAFE) colleges are looking to deploy VoIP or have already completed rollouts. Eventually there will be an estimated 9,000 VoIP handsets in action in State of Victoria. This deployment allows convergence of a number of technologies including; unified messaging services, virtual classrooms utilising videoconferencing, Internet Protocol Television (IPTV) and other customised services [72].

BHI faces the common technology issues that constrain other institutes, limited funding and staff resources. Added challenges were that some students' families need their child's attendance and results to be communicated spontaneously, some students lack a home computer and/or Internet services.

In late 2005, BHI fully implemented Cisco's voice system designed for the educational environments that handles large call volumes without frequent busy signal; enables deployment of phones in every classroom; provide rich voicemail capabilities and effectively support its customer – staff and students. In 2007, Institute had over 22,000 equivalent full time students, over 800 equivalent full time staff, eleven major departments and four campuses which mainly relied on funding from the Victorian State Government from Schedule Contact Hours (SCH). BHI offers more than 500 full time and part time courses which range from one week short courses up to two years diplomas and a maximum of three years degrees in several specialties. Budget and staffing constraints required that the new applications created and implemented on existing funded infrastructure to maximise return on investment and reduce administration overhead. Implementation of new applications should be incremental and appreciable. Also its management and maintenance be both centralised and efficient thus, eliminating the need for the frequent and costly service visits by contractors.

Due to the complex-hybrid and manual procedures involved in the present system, it was a challenging task to come up with an innovative solution designed around available Information Communications Technology (ICT) infrastructure. There are many VoIP solutions available commercially. At first, Avaya®, 3Com® and Cisco® products were investigated. Cisco infrastructure was present at BHI and this made the decision easier as a preferred development platform. With respect to the voice quality, high performance and reliability, systems integration, simplicity and speed of management Cisco's telephony products were preferred comparatively.

Cisco acquired VoIP company Selsuis Systems® in the late 1990s and released their own version (or second generation) of phones in 2000 with HTTP and XML capabilities. Using XML®, it allowed Cisco to deliver a user friendly interface with additional functions which provided the user with an interactive experience with their phone. The biggest advantage of

Cisco VoIP phones is that they are completely open for any third party software development and customisation [73].

This chapter aims to provide an in-depth technical in-sight into development of innovative student attendance recording application using emerging communication technologies. Development of Voice over Internet Protocol Student Attendance Recording and Retrieval Application (VoIP SARRA) for the BHI is presented. This chapter demonstrates application programming, test bed setup, design considerations, design decisions, future plans as well as creative usage of emerging communications technologies. Developed application combines Cisco VoIP telephony and network systems, integrates it with existing database systems with the aim to provide BHI's management with a cost effective, efficient and secure way to record and retrieve student attendance data. This project is a success and when fully integrated within existing system, it will provide BHI with a cost effective and efficient student attendance recording and reporting system. It is concluded that this application has a potential for use in recording and retrieving student attendance at other Australian education providers.

6.2 Related Work

There are several other competitive products in the market for student attendance recording and management applications for use in education sector. These products are primarily US based and are not user friendly to customise for the Australian education system. Some of the examples of attendance recording software found in the market are,

- Phone Top K-12 (Attendance Manager®)
- Sirius – School (RollMarker®)

Phone Top K-12, Attendance Manager®, is a US designed application which combines student attendance recording with other functions such as visitor tracking and student information [74]. This has been developed for the Cisco IP Phone and integrates comprehensively with their other education based products, although does not integrate with Australian based database systems.

Another example is the Australian based Sirius' School – RollMarker® application, which is part of their Schools in Sync portfolio. This program has integration into some of the current database systems, although it does not integrate with the Student Management and Recording Tool (SMART®) database system. It also provides access to data entry from a number of devices including networked PC, pocket PC and laptop [75]. The Department of Education & Training (DET) was trialling Sirius solution in 2007 [76]. 16 high schools in Australia were using this system in 2007 and they are all based on non-Cisco IP Phone.

6.3 Project Justification

An executive decision was made to develop "an innovative solution" and "maximise return on investment" using newly installed Cisco VoIP phones. If computers were used as human machine interface (HMI) using HTML or even XML application, I believed that this would not have contributed to an innovation solution as several off-the-shelf application are available to achieve the end state. Furthermore, due to complexity and sensitivity of the SMART system, it was decided to give only minimum access or one-way submission access to teachers to SMART. This was accomplished by Cisco VoIP phones, where individual IP addresses were given data retrieval rights in addition to successful teachers logging process. Only submit right was awarded to teachers after secure authentication. This mechanism was programmed in a Cisco Call Manager® and a web server. Section six and following sections explains this mechanism.

BHI is Cisco Systems®, Apple® and Microsoft® academy training centre and hence, all class rooms have different computer systems with distinctively different hardware profiles. To add a newer application to work on both MAC and PC architectures will further complicate existing network systems. Furthermore, quite a few class rooms are isolated from production network due to delivery of advanced network systems courses. Therefore recording attendance using Cisco VoIP phones installed in all classrooms makes obvious decision.

The VoIP SARRA application was proposed with a view to replace the current process of student attendance recording system at BHI. The application shall provide functionality for teachers and administrators to view scheduled classes for the day on Cisco VoIP phone (installed in every classroom) and to update the class attendance via a user friendly

interface. The final implementation of the application into the BHI environment aims to adequately meet its needs to,

- more efficient service for teachers and students to record attendance;
- reduce cost – they will be redeemed through a more efficient solution;
- enable more up-to-date data obtained from the system; and
- real time reporting of class roll information.

These criteria will be met by replacing the current, lengthy and manual system that is in place throughout BHI's campuses with the VoIP SARRA application and data entry system. VoIP SARRA interfaces with an existing and in-house developed – SMART database system.

6.4 Student Attendance Recording Process

6.4.1 Current Process

There are over three different processes in place for student' attendance recording at BHI. Each education department has its own requirements and procedures. These procedures require significant manual work from teachers and administrators causing lengthy delays to enter the data and sometimes it compromises data security and integrity. Two of these procedures are detailed in figure 6-1 in form of a flow chart. It shows how administrators perform large amounts of data entry manually and generate teaching rolls on a fortnightly basis every semester.

TAFE education courses enrolment process is similar to the higher education enrolment (degree courses) process at Universities. For example, TAFE teachers create their own rolls and as such variations on the standard roll. They are required to hand-in attendance sheets every semester, whereas on the other hand, degree teachers do not create their own roll books and hand in their completed attendance sheets at the end of each teaching periods or semesters.

Issues were identified of possible human error, data loss, security and integrity in manual processes. Having a paper based system for storing of data either temporarily prior to entry

into electronic database or permanently in file storage poses risks of data being lost or compromised by unauthorised third parties.

An extended time period between two weeks and four weeks before data is required to be submitted to office staff for manual entry provides teaching staff with the ability to alter data after the date of the class and compromises data integrity. It also means that there is a significant delay for teachers and staff to access this data from the SMART database for routine administration purpose.

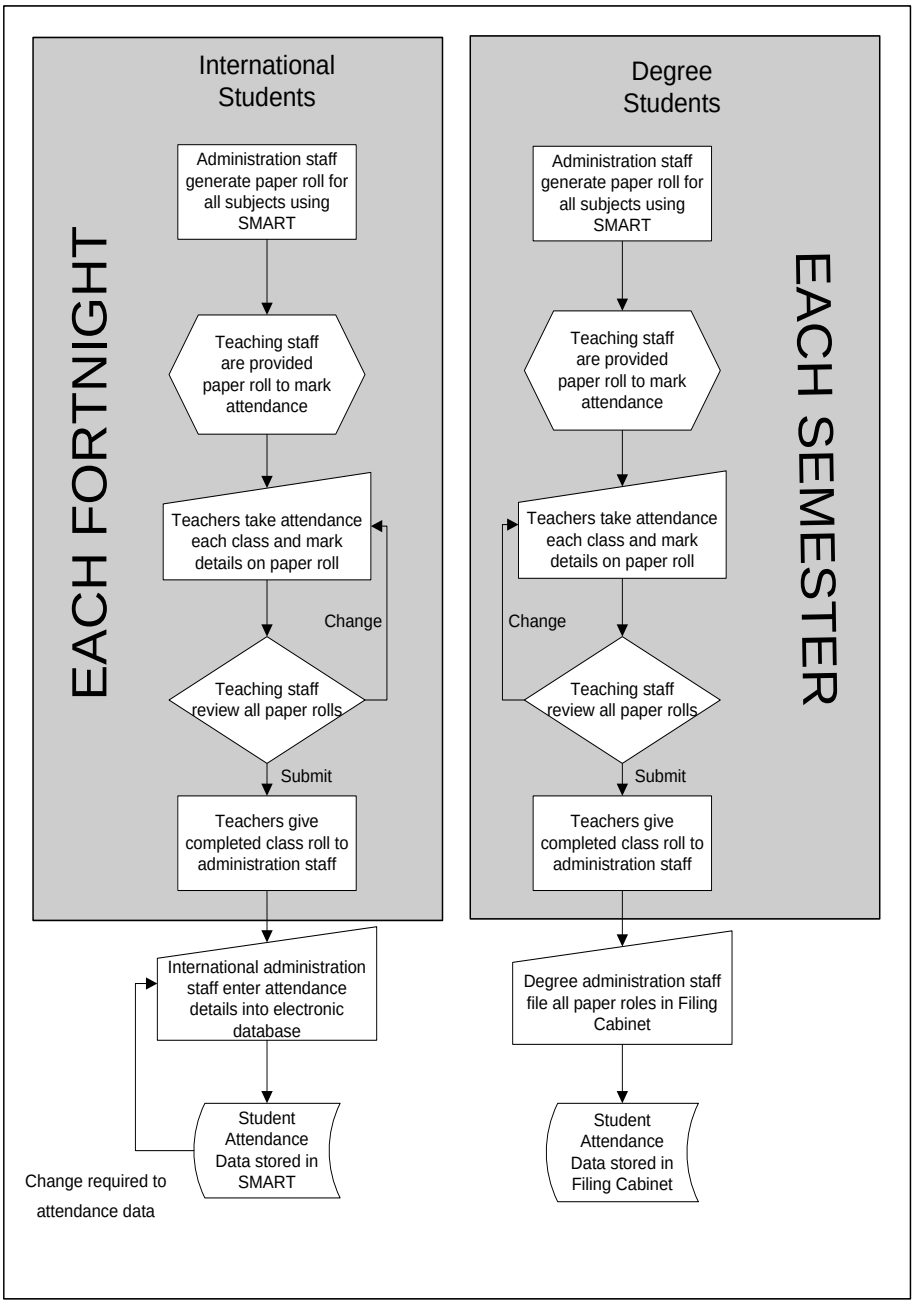

Figure 6-1 – Current Process

6.4.2 Proposed Process

The VoIP SARRA application provides significant advantages over the existing student attendance recording process at the BHI. The new process with VoIP SARRA is shown in figure 6-2. VoIP SARRA acts as an immediate interface between the teacher and the SMART database which stores all student attendance data. Because the application can be run from any Cisco VoIP Phone within the institute the teaching staff can enter students attendance for the class electronically and immediately during the class time. Teachers can then choose to save their data and submit later that day. The setup of VoIP SARRA was configured in a way that it only allows teachers to access the classes for the current day to be edited to avoid teaching staff revising and further manipulating the data.

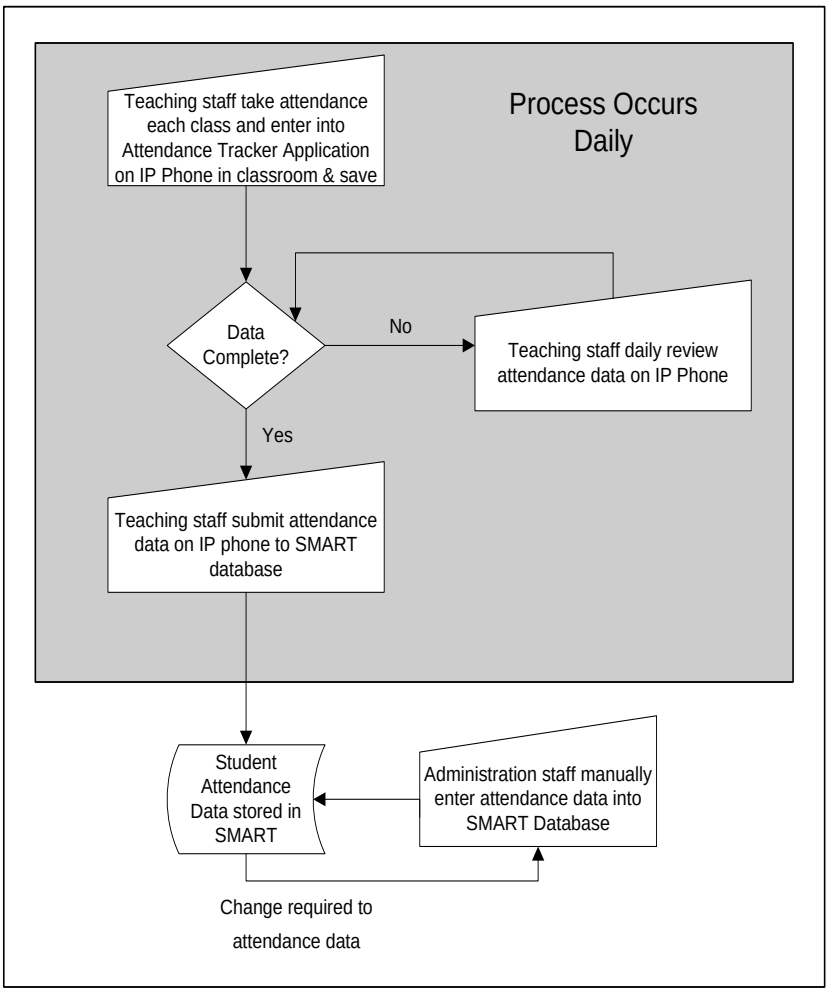

Figure 6-2 – Proposed Process

Any further changes to the submitted data can only be changed by the administrator or a system administrator. Electronic storing of all data means it is more space efficient storage

of data and less chance that the data can be compromised or lost provided backup of electronic data should take place on a regular basis.

6.5 Application Prototype

Significant amount of work was completed during 2007 in order to have the VoIP SARRA application ready for the demonstration. The tasks that were carried out for the prototype stage were,

- a completed prototype application VoIP SARRA for Cisco VoIP Phones;
- an in-depth research and documentation pertaining to selection of an appropriate development software and programming language;
- the development and testing of the application;
- develop the application's main functions in association with a mirror SMART database, thus avoiding any interruption to production SMART database; and
- provide a regular project progress, project and management reports in the form of presentations, meeting minutes and documentation.

Using mirrored SMART database the prototype application provided the following functions,

- teacher login;
- class selection from classes scheduled for that day for the logged in teacher;
- display class lists with student ID;
- attendance recording for students in selected class;
- saving of class attendance data to dummy database (updateable within the same day of attendance taken);
- submission of final class attendance data to replica SMART database;
- integration with Cisco Call Manager Emulator; and
- tested and verified compatibility with Cisco phones; 7940, 7960, 7970 & Cisco Communicator Softphone and basic help files.

The functionality not provided in the initial prototype, but to be provided in the final release were,

- the ability to select between different types of department within BHI, i.e. Vocational Education and Training (VET) and Higher Education Programs (HEP);
- complete testing integration with production SMART database;
- integration with production Cisco Call Manager server;
- VoIP SARRA production server consisting application and web server environments;
- complete installation instructions and administrator/user training;
- ability for administrators to manually adjust data through PC web interface; and
- reporting tools via web interface.

6.6 System Architecture

6.6.1 Design Overview

The application prototype of VoIP SARRA utilises many different technologies including Voice over IP hardware and applications. The basic physical components used to build the application are,

- Web Server,
- Cisco Call Manager Server,
- Cisco IP Phones, and
- Database Server

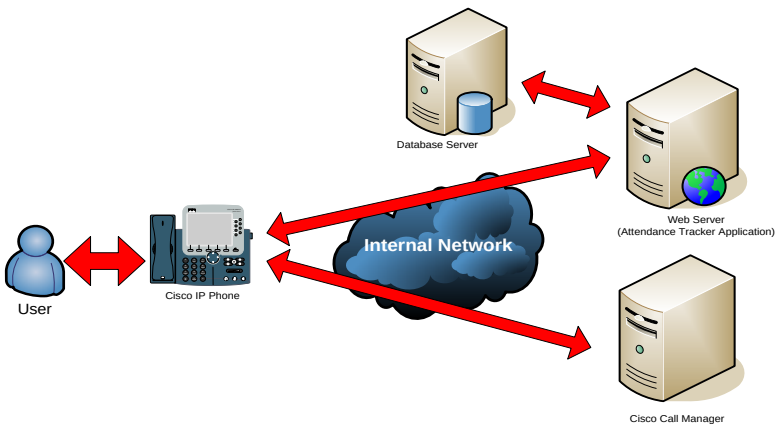

Figure 6-3 – Application design overview

The VoIP SARRA coding is stored on a web server. When initiated it sends and receives HTTP to and from the phone. The phone receives its services menu and points to the web server via a Trivial File Transfer Protocol (TFTP) configuration file retrieved from the Cisco Call Manager which handles all of the phones call functionality. The web server retrieves information and writes information to the mirror SMART database server. Figure 6-3 shows how this system interacts at the basic physical level.

6.6.2 Cisco VoIP Phones and there Comparison

As previously mentioned, the VoIP SARRA application uses the Cisco IP Phone digital display as its output to the user. The Application runs on 79XX series Cisco models i.e. 7940/7960/7970. Table 6-1 depicts their comparison.

Model 7906 is a basic phone and have four buttons and a single line black and white display. This model was not selected due to limited display and was not programmable. Cisco Communicator is programmable, touch screen, mouse clickable, Internet ready, six line displays with buttons. This model is a top of the range and expensive product and used mainly by executives, thus not chosen. Model 7970 are less expensive and have almost all functionality like Cisco Communicator but BHI did not install this model in classrooms. Model 7970 were mainly used by executive management and managers, thus not selected for testing and prototyping. However, codes developed for the VoIP SARRA with minor changes in existing codes can be executed on this model. Finally, models 7940 and 7960 were selected for the trials due to installed separately in majority of classrooms, both are we bit expensive than the basic model 7906. However, 7940 and 7960 are programmable and have two and six lines of black and white displaying capacity respectively. The only difference between 7940 and 7960 is the number of vertical side buttons. All models of phone utilises the following protocols as shown in figure 6-4, of which HTTP was only focused,

- HTTP – Communication between phone and web server
- RTP (Real-Time Transport Protocol) – Sends voice packets to and from the phone
- Skinny Client Control Protocol (SCCP) – Communication with Call Manager

Table 6-1 – Comparison of selected Cisco VoIP Phones for Application Development

Phone Model No	Brief Description	Picture	Compatibility Status
7940	• Standard • Black and White • 2 lines display with button		Yes – Tested
7960	• Standard • Black and White • 6 line display with button		Yes – Tested
7970	• Colour • Touch screen • 6 line display with button		Yes – Tested
Cisco Communicator	• Software Phone • Colour • Mouse Clickable screen • 6 line display with buttons		Yes – Tested
7906	• Black and White • 1 line display		No

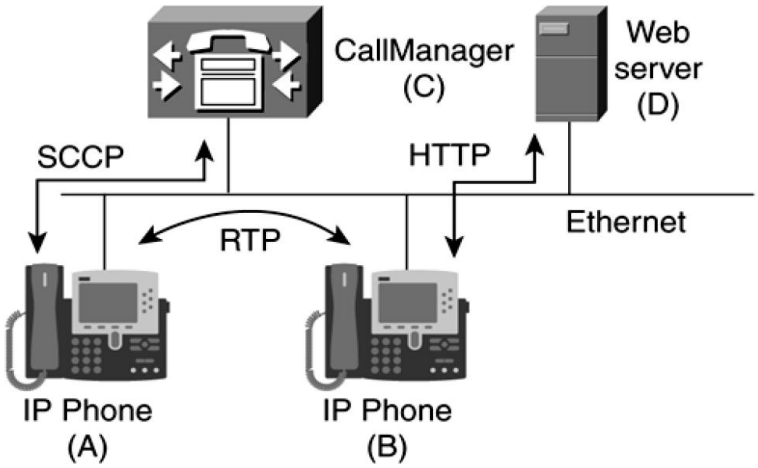

Figure 6-4 – Phone Protocols [72]

The 7940/7960 phones can display images on the screen, but they must first be converted to binary pairs and then hexadecimal digits. A program is supplied with the Software Development Kit (SDK) from Cisco Inc., which converts any image in the correct format to its hexadecimal equivalent which is called Channel Interface Processor (CIP) image. A CIP image is essentially a plain ASCII text similar to hexadecimal characters. The image must be black and white and a specified depth and width are depicted in figure 6-5.

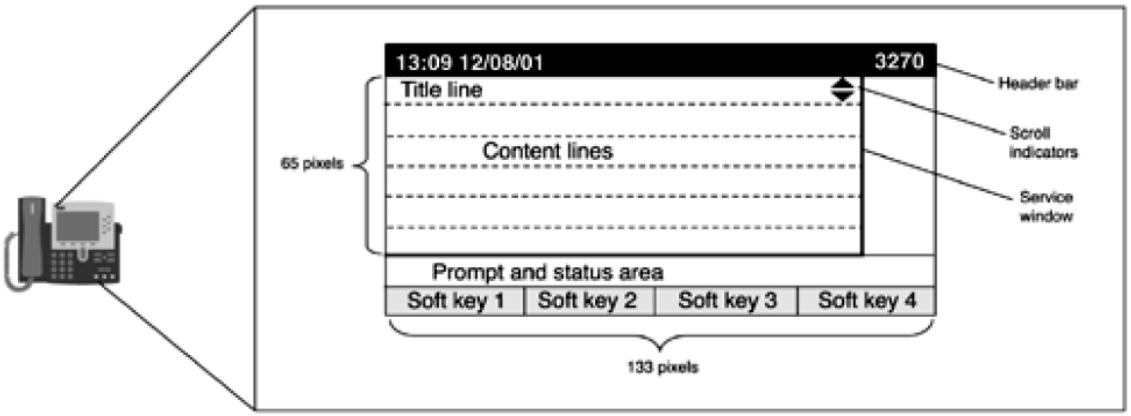

Figure 6-5 – Cisco VoIP Phone Interface [72]

6.6.3 Cisco Call Manager

Cisco Call Manager® is a purpose built server on Windows® which controls the IP Telephony system and its users. It is generally a Windows 2000 or UNIX based server running the Call Manager application. Cisco Call Manager hardware was not used for the prototype, instead an emulator software which performs the basic functions was used as required by the Cisco IP phone. Emulators enable services usage such as TFTP file

download and services menu locations. Cisco Call Manager screen is shown in figure 6-6 below.

Staff login to the Cisco IP Phone in each classroom with a roaming profile which provides them with their own customised services menu and other features. They can then enter the student attendance from this interface. The VoIP SARRA application does not reside on the Call Manager and if any services web applications were installed on the Call Manager it could cause performance degradation on the server [73].

The Call Manager software allows us to configure a user or group of users with access to particular services. A service relates to a menu item on the services menu which points to an URL. Therefore services menu item can be assigned to point to the VoIP SARRA application and have this viewable only by selected teaching staff (mainly coordinators).

Figure 6-6 – Cisco Call Manager configuration screen

To enable a phone to use the correct Call Manager or Cisco Emulator, the phone was required to be configured to accept a Dynamic Host Configuration Protocol (DHCP) IP

Address and then enable alternate TFTP server and configure the TFTP server address with the IP Address of your Cisco Call Manager (CCM) or Call Manager Simulator (CMSim). The CCM or CMSim then sends the phone a TFTP configuration file which tells it where to point to for the services menu and ultimately the VoIP SARRA application on the web server.

6.6.4 Application and Web Server

The application is required to be installed onto a web server with specific parameters configured relating to the application. This may or may not be shared with other web applications, although preferably VoIP SARRA should be the only application on the web server.

The web application must be installed in its own virtual web page to prevent it from conflicting with any other web applications that may be running on the same server [60]. The web application can be reached through a normal web browser or the phone, for example by navigating to,

http://<servername>/<directory>/splash.ASPX

Although, high traffic load testing was not performed, it is safe to say that the application is not particularly resource hungry. The application will run on any server or PC compatible with Windows Server or Windows XP Operating systems. The application has been tested to run on both Windows 2003 server and Windows XP. The required components are listed in table 6-2.

Table 6-2 – Server Software Requirements

Required Applications	**Version**
ASP.NET	2.0
VB.NET	2.0
.NET Framework	2.0
Cisco SDK	NA
IIS (Internet Information Services)	4.0 or above

6.7 The Application – VoIP SARRA

The VoIP SARRA has been programmed using a combination of Visual Basic, ASPX and XML utilising the .NET framework. An ASP page is essentially a HTML webpage which contains server side scripts. The web server processes the scripts prior to sending data to the client (Cisco IP Phone) [77].

XML is transported over HTTP to provide the Cisco IP Phone with the information required to display the web application pages on the screen. This allows Cisco IP Phone items such as menus, pictures and input boxes to be displayed for the user. Figure 6-7 shows how the whole system interacts with sub-systems and applications.

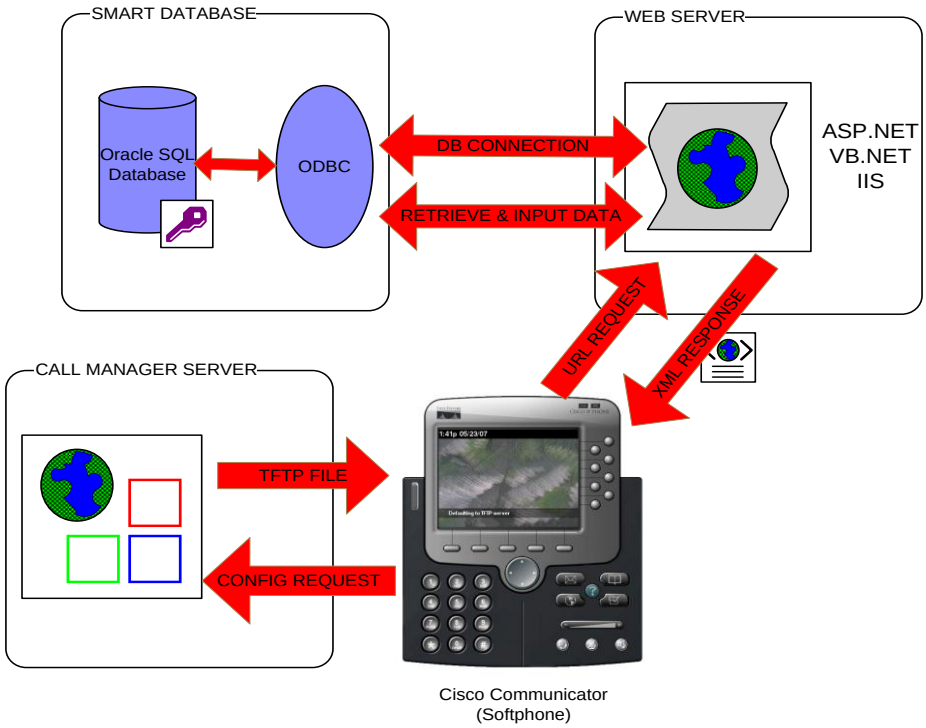

Figure 6-7 – Application Data/Msg flow

6.7.1 XML

Extensible Mark-up Language (XML) builds on the basic structure of HTML, but is a language in its own right. It was created by the W3C (World Wide Web consortium) to improve and enhance HTML past its current capabilities [78]. There are quite a few software applications and networking protocols utilised to deliver information from the database to the phone via the web application. The web server runs the VB code within the

ASPX webpage. XML is generated from the ASPX/VB code and is essentially what is sent to the phone as a dynamically generated XML file. Figure 6-8 illustrates an example of XML code as received by a web browser.

XML and HTML are both tag based although HTML tags are predefined (~100 tags) and XML tags are completely customisable and has none predefined. XML provides access to web pages and similar content without the high intensive overhead that html has [78].

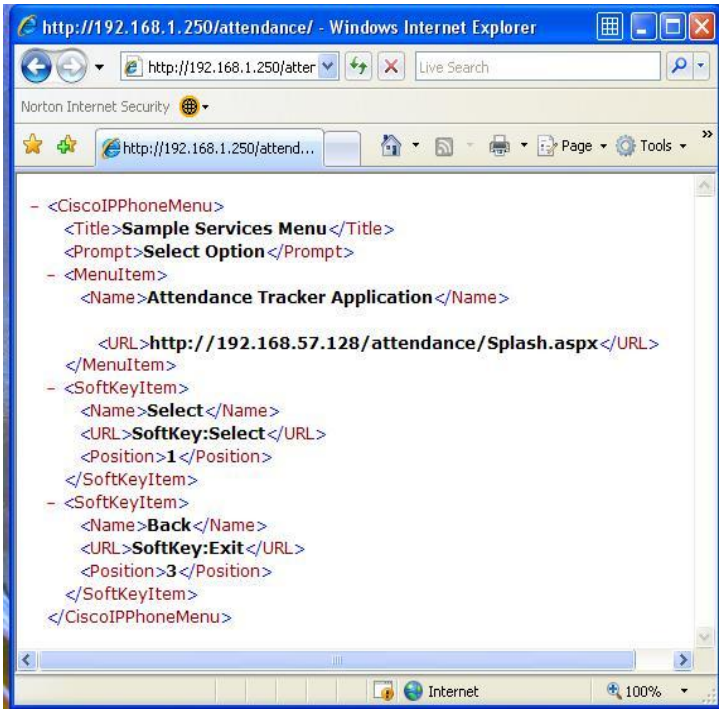

Figure 6-8 – XML Coding

The Cisco IP Phones only understand predefined XML objects which are developed by Cisco and will return an error if the data it receives is not in the correct format. It is important that the following code is included in each ASPX.vb file so that the phone knows what kind of content to expect and is sent in the HTTP header.

Response.ContentType = "text/XML" [72]

6.7.2 VB.NET

Visual Basic .NET (VB.NET) is an object-oriented computer language and is the recent version of Microsoft's Visual Basic® [79]. It is commonly known as Rapid Application

Development (RAD) programming language [80]. This language was selected due to its strengths when combined with ASP.NET/Open Database Connection (ODBC) [80], compatibility with the chosen hardware, software and database systems and product availability. VB.NET's was also considered with regards to ease of programming for beginners.

Considering the code for VoIP SARRA is written in VB.NET and XML; outputs is dynamically created and send to the client i.e. Cisco IP phone. The in-depth application logic is handled from VB.NET and connections to the database are managed via ODBC framework.

6.7.3 HTTP

Hyper Text Transfer Protocol (HTTP) is the protocol used to send messages between the phone and the web server.

The phone requests the next URL and the server responds with the URL data. Figure 6-9 shows the interaction between the web server and the phone via HTTP request and response.

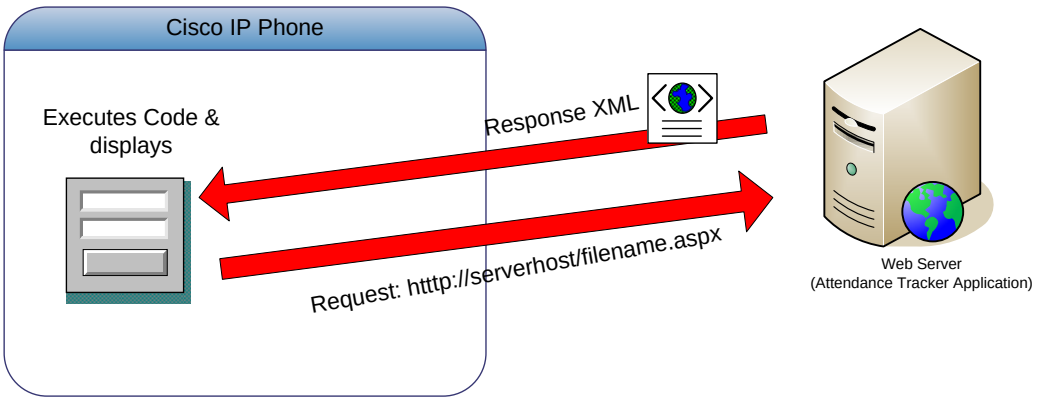

Figure 6-9 – HTTP Response & Request

The HTTP request consists of: either a GET or POST method and also describes the client and its HTTP abilities, i.e. version of HTTP supported. The HTTP response consists of information about the web server and the content type that is it submitting to the client. The header also includes the length of the response.

6.7.4 Database

The database that was used for the development was a replica version of the SMART database. The SMART database runs is deployed on Oracle database version 9.0i. Application uses ODBC protocol to connect with the SMART database. The VoIP SARRA application connects to the database by passing the username and password as input by the user on the phone interface. Teachers are given read only access to the database and as such are not able to modify data after they have submitted it to the system.

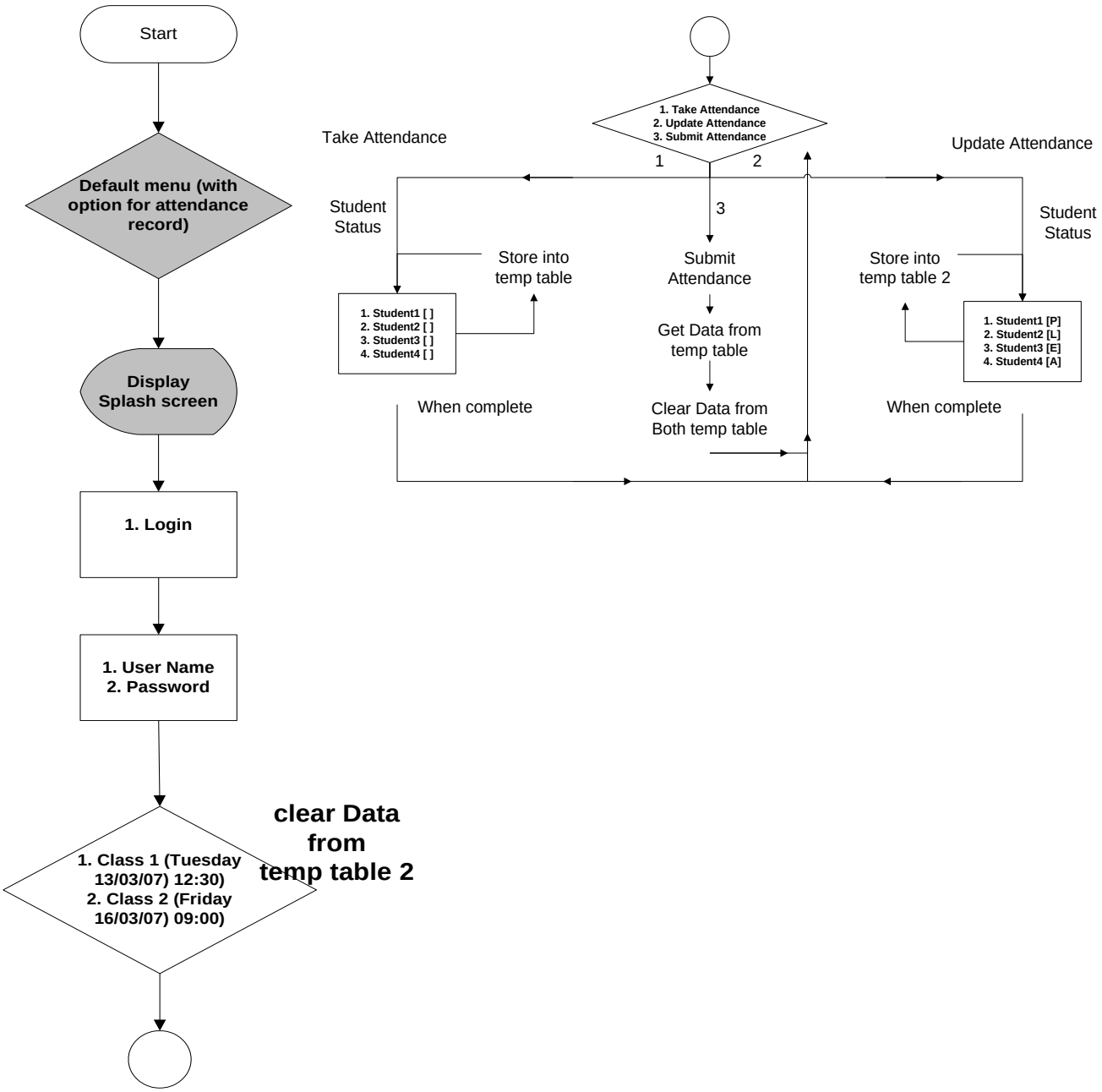

Figure 6-10 – Database Logic

Teachers are able to save attendance data prior to final submission but must submit same day. Database logic and SQL Database are shown at figure 6-10 and 6-11 respectively.

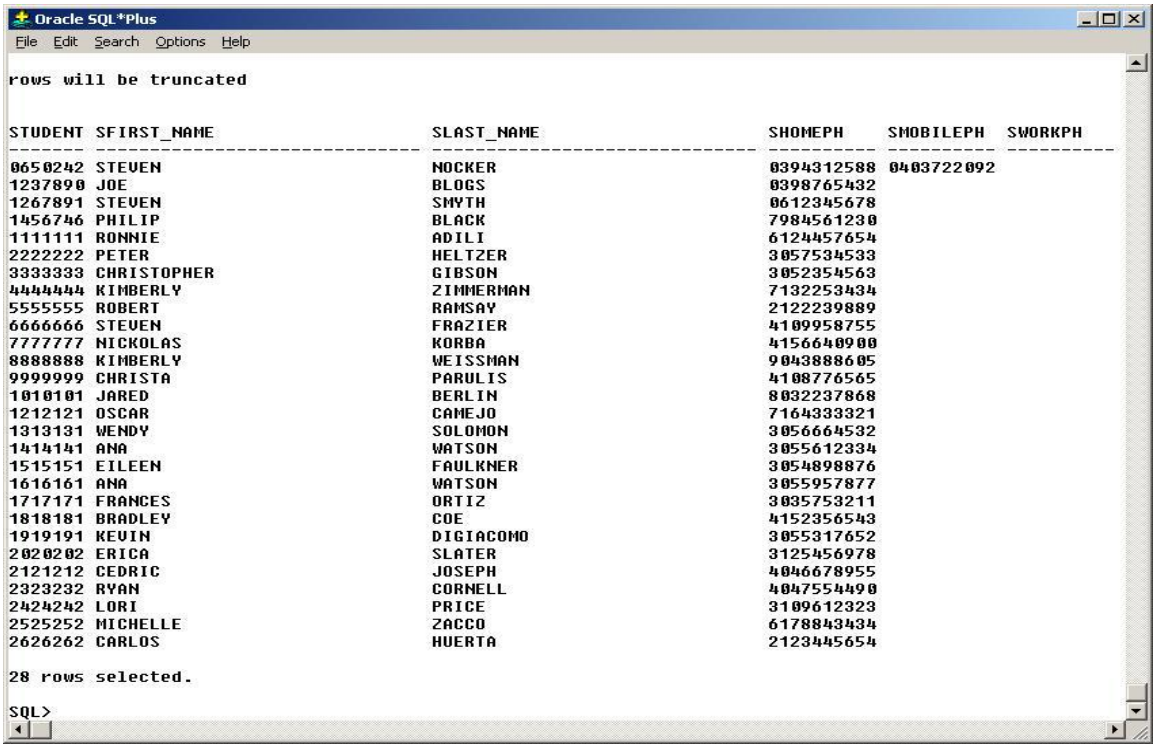

Figure 6-11 – SQL Database

6.8 Development Environment

Development environment was created with the view to being a portable environment that all programmers involved in the project could use at home or at BHI or at work to maximise the flexibility for ease of development. As all stakeholders had laptops, the development task was carried out independent of location.

Cisco Softphone Communicator was used such that testing of developed application without the need of the actual hardware phone itself can be done. This proved a very good idea and incorporation of physical phone was not required until the final phase of the demonstration of the solution. A couple of trials on Softphone were all that was needed in order to run the application on the physical phone. By using two laptops (namely A and B) different types of environments were created on each, this means that all stakeholders in turn tested the compatibility of the application and related components on two different systems. Cisco Communicator Softphone shared the host PC's IP address and a separate Dynamic Host Configuration Protocol (DHCP) for physical phones (7940, 7960 & 7970).

This required that a DHCP server be setup in order for phones to obtain a dynamic IP address. In the development and testing phases, VMware® running Windows2000 Server® with DHCP server enabled was used.

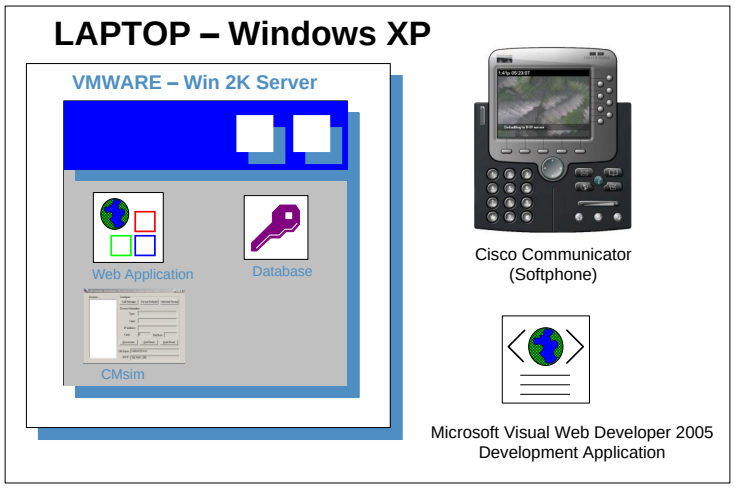

Figure 6-12 – Laptop – A configurations

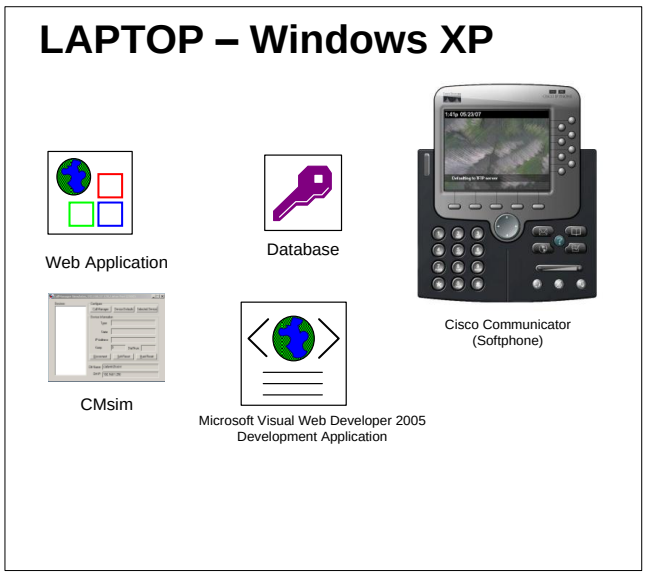

Figure 6-13 – Laptop – B configurations

Laptop A setup contained a VMware image with Windows 2000 Server installed running the web application, the Oracle database and CMSim. VMware is very useful because you can easily make backups of the image and transport from one VMware client to another. A hub was required with Laptop A setup when connecting a physical phone due to the VMware program running on the laptop requiring an Ethernet port. Visual representation is depicted in figure 6-12. Laptop B setup contain web application, database, CMSim®, Cisco Softphone® and Microsoft Visual Web Developer 2005® components on the one operating

system, Windows XP® with web server functions enabled. Laptop B configuration is illustrated in figure 6-13.

Generally, an emulator is a piece of hardware used for tests; it is self-contained, and is able to be hooked to some kind of development environment whereas a simulator is a piece of software that duplicates as precisely as possible the processor so anybody can "run" codes to see if it is correct. Usually simulators are developed for new architectures to test them out before it is committed to silicon. Occasionally, a vendor will let customer have access to the simulator to help speed development for that architecture. Due to the mobile and compact development environment, it was decided to use Cisco Call Manager Emulator® and CMSim, to provide the call manager functions to the phones rather than a real call manager server or call manager express running on a router. This meant that a small application can be run from any of the computers or VMware sessions which could send the TFTP file to the phone with the service menu instructions included. The application is included in the Cisco SDK which is downloadable from the Cisco Inc. website.

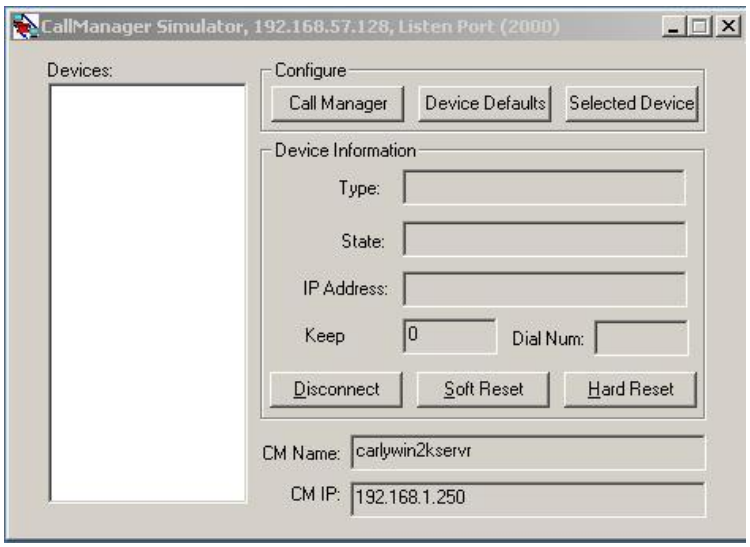

Figure 6-14 – Call Manager Emulator configuration screen

The application main interface is show in figure 6-14. The phone devices which are connected to the CMSim are usually listed in the left pane and any device information retrieved from the device is listed on the right (Type, State, IP Address etc) pane. The name of the CM Name where the CMSim is running, in this case is the name of Laptop A. When configuring the phone for the emulator you insert the CM IP, Laptop A's IP

address in as the TFTP Server address. You can disconnect devices, soft reset and hard reset them from this interface.

6.9 Project Constraints and Limitations

Due to number of constraints, there were few limitations during development of VoIP SARRA. The implementation environment at the BHI, both technical and procedural has significantly influenced the progressive decisions made with regards to the application development and technologies used. Some limitations were purely due to Cisco VoIP phone hardware and some limitation rose mainly due to software coding limitations.

6.9.1 Constraints

Constraints for the project were,

- BHI's current student attendance procedure;
- BHI's proposed future Attendance Policy and Procedure;
- application requirements from BHI Staff;
- state of BHI's hardware and software systems including database integration;
- time restrictions;
- procurement cost;
- Cisco VoIP Phone software and hardware limitations; and
- level of technical knowledge of project stake holders.

6.9.2 Limitations

Cisco IP Phones are engineered so that they understand a number of predefined XML items. This type of static configuration makes most coding tasks much simpler as the objects are predefined and it's just a matter of programming the VB.NET code around the dynamic data would be preferred to display on the phone. On the other hand this can be a setback for customised applications as it restricts the usage of only predefined XML objects and set parameters.

When developing the code for the student list and to enter attendance screens, it was found that only up to maximum of five menu items per screen were available. This meant that the

teachers would need to scroll the interface as well as it would need to have something like a “next page” function and split the total enrolled students in the subject across multiple screens. Two options of the screens were created to evaluate the ease of use using focus group consisted of three teachers and two administrators.

6.9.3 Development of Options Due to Limitations

Option 1 (Figures 6-15 and 6-16) is the preferred option, uses an XML object as an input and provide with an easy way to interface the phone and a one-step data submission approach. The user would enter the attendance value for each student using the phone number pad and then press the submit button to move to the next screen.

When the submit button is pressed the data is sent in HTTP:Request to the web server with the entered variables and the request for the next page. The web server then sends the requested next page back to the phone as HTTP:Response. It was found from the focus group consisting of few teachers that this method was simple and easy to navigate for the user.

Figure 6-15 – Preferred Class List Screen

```
' CALL A FUNCTION TO GET THE DATA OUT OF THE DB
Response.Write(RS2XML(dReader, "InputItem"))
' CONTINUE THE OUTPUT TO THE PHONE
Response.Write("<SoftKeyItem>" + Environment.NewLine())
Response.Write("<Name>Submit</Name>" + Environment.NewLine())
```

```
Response.Write("<URL>SoftKey:Submit</URL>" +
Environment.NewLine())
Response.Write("<Position>1</Position>" +
Response.Write("</SoftKeyItem>" + Environment.NewLine())
Response.Write("<SoftKeyItem>" + Environment.NewLine())
Response.Write("<Name>Clear</Name>" + Environment.NewLine())
Response.Write("<URL>SoftKey:&lt;&lt;</URL>" +
Environment.NewLine())
Response.Write("<Position>2</Position>" + Environment.NewLine())
Response.Write("</SoftKeyItem>" + Environment.NewLine())
 Response.Write("<SoftKeyItem>" + Environment.NewLine())
Response.Write("<Name>Back</Name>" + Environment.NewLine())
Response.Write("<URL>http://192.168.57.10/SelectDBInput.aspx</URL
>" + Environment.NewLine())
Response.Write("<Position>3</Position>" + Environment.NewLine())
```

Figure 6-16 – Preferred Class List Code

Option 2 (Figures 6-17 and 6-18) uses an icon menu XML object, which an user can update via a two steps process involving selection of a student and then selection of an attendance value by updating the page with new icons. This method involves the phone and web server sending requests and responses for each student rather than each page of students and therefore could increase traffic load on the web server and the network.

Figure 6-17 – Alternative Class List Screen

```
dim i as integer
Response.Write("<CiscoIPPhoneIconMenu>" +
Environment.NewLine())
Response.Write("<Title>Class: " & classname & "</Title>" +
Environment.NewLine())
```

```
Response.Write("<Prompt>Select Student and Attendance</Prompt>" +
Environment.NewLine())
 For i = 0 To studentcount Step 1
Response.Write("<MenuItem>" + Environment.NewLine())
Response.Write("<IconIndex>" & iconindexnum(i) & "</IconIndex>" +
Environment.NewLine())Response.Write("<Name>" & studentname(i) &
"</Name>" + Environment.NewLine())
Response.Write("<URL></URL>" + Environment.NewLine())
Response.Write("</MenuItem>" + Environment.NewLine())
 Next i
            'Icons
            ' 0 = Absent
            ' 1 = Present
            ' 2 = Late
Response.Write("<IconItem>" + Environment.NewLine())
Response.Write("<Index>0</Index>" + Environment.NewLine())
Response.Write("<Height>8</Height>" + Environment.NewLine())
Response.Write("<Width>4</Width>" + Environment.NewLine())
Response.Write("<Depth>2</Depth>" + Environment.NewLine())
Response.Write("<Data>FFFFFFFFFFFFFFFF</Data>" +
Environment.NewLine())
Response.Write("</IconItem>" + Environment.NewLine())
Response.Write("<IconItem>" + Environment.NewLine())
Response.Write("<Index>1</Index>" + Environment.NewLine())
Response.Write("<Height>8</Height>" + Environment.NewLine())
Response.Write("<Width>4</Width>" + Environment.NewLine())
Response.Write("<Depth>2</Depth>" + Environment.NewLine())
Response.Write("<Data>FFFFFFFF00000000</Data>" +
Environment.NewLine())
Response.Write("</IconItem>" + Environment.NewLine())
Response.Write("<IconItem>" + Environment.NewLine())
Response.Write("<Index>2</Index>" + Environment.NewLine())
Response.Write("<Height>8</Height>" + Environment.NewLine())
Response.Write("<Width>4</Width>" + Environment.NewLine())
Response.Write("<Depth>2</Depth>" + Environment.NewLine())
Response.Write("<Data>0000FFFFFFFF0000</Data>" +
Environment.NewLine())
Response.Write("</IconItem>" + Environment.NewLine())
```

Figure 6-18 – Alternative Class List Code

6.9.4 Preferred Option

Option 1 was preferred because the feedback received from the focus group preferred this option was favoured by teachers compared with Option 2. Option 1 was realistic, simple and easy to navigate. It only requires using horizontal buttons for navigation, selection and data entry whereas, Option 2 requires use of both horizontal and vertical buttons. Based on this decision, VoIP SARRA application functional diagram is shown in figure 6-19 below.

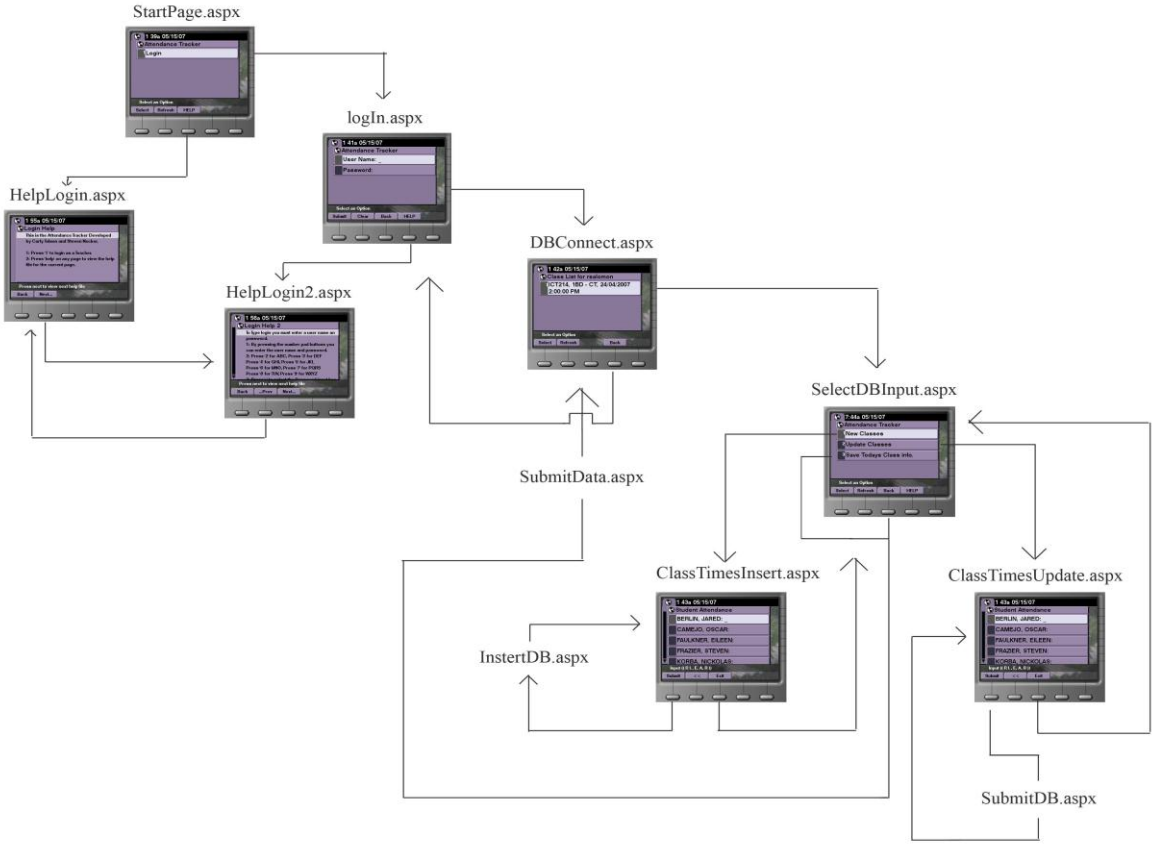

Figure 6-19 – VoIP SARRA Application Functional Diagram

6.10 Evaluation

From BHI management's perspective this application is an efficient solution due to the observations recorded during an informal evaluation carried out over a semester (12 weeks) in a class of third semester computer systems degree.

Considerable administrative overhead was reduced due to administrative staff avoiding time spent entering or retrieving data from paper based attendance to SMART. During paper based/hard copy attendance records retrieved from frequent visits to the record room, resulting in delay. In some cases, attendance sheets were missing from the records and later were found with the teaching staff. In this case, enquiry handling staff had to call back to parents with the response. With the VoIP SARRA, SMART provided the queried data on demand while parents enquiring in a real time (on phone or in person). Thus provide an expedient customer service. An average reduction of almost two hours per week per administrative staff for work processes related to attendance recording was noted. In total, two hours were reduced per week (considering one EFT administrative staff dedicated for

degree student service). For BHI this is considerable amount of time saving per administrative staff. Attendance record is sent electronically to parents' email ID on consent provided by a student however; this feature was not trialled due to legal issues.

Teaching and management staffs can query SMART during an audit without relying on administrative staff to reproduce paper based attendance records. Mandatory reporting of attendance records to external agencies was made simple and easy due using one of the features of the VoIP SARRA which sends queried period of attendance by the BHI's Registrar to requesting agency via web interface.

Comparison was made between same students of the third semester who were in second semester previously. Total class size was 18 students in both semesters of 24 contact hours each. During comparison between paper based records (i.e. second semester) and electronic records (i.e. third semester), it was found that an average weekly attendance increased between minimum of 5.6% to a maximum of 33.4%. During the third semester, there were few varied and exceptional circumstances which involved couple of students faced welfare issues. These resulted in their absence in lectures, labs and tutorials for few consecutive weeks. Those weeks were not compared in this evaluation. Consideration of public holidays was given. This comparison was for teaching period only, assessment period of two weeks at the end of the semester was not considered. Some of the students were curious to know the new system and after understanding the VoIP SARRA, they took keen interest in proposing their own creative ideas to further develop the VoIP SARRA. Complete sources codes for the VoIP SARRA system is provided at Appendix B.

6.11 Lessons Learned

This project was completed covering all statement of work, on time and well under budget. The project cost was approximately $10,000. Throughout this project, there seems to be no shortage of enthusiastic suggestions emanating from the members of the team and students of BHI. There was lot of consideration and respect for opinion within the group that allowed each team member's idea to be explored in detail. One of the things that have gone right was communication between team members whenever there were meetings among stakeholders. The team learned from the beginning that there are going to be a lot of aspects of the project that will not be completed immediately with the existing skills set.

With this in mind, the team had very effectively learned how to retrieve information through their own research through books, magazines, the Internet and above all using self-initiative. From a project manager's perspective, I ensured that some of the more fundamental documentation was agreed upon and delegated as tasks from the beginning. Initially, I focused more on establishing the team and its roles and responsibilities for the deliverables so that there would be a much more harmonious environment to move forward.

6.12 Future Work

VoIP SARRA was developed using BHI degree students and staff, in kind contribution of subject matter experts (SMEs) from Cisco Inc. and Microsoft Inc., so the development cost was not a major constraint or consideration for VoIP SARRA. BHI is only one of the four Super Cisco Academy Training Centres (Super CATC) in the World. BHI is also a Microsoft Academy® and the first Apple Academy® in Australia. All hardware and software used for the application development were donated by the Cisco Systems®. and the Microsoft®. If similar solution was to be developed commercially then the development cost is estimated to be between AUD 100K and AUD 150K. Due to these reasons, VoIP SARRA makes a cost effective solution for the institute.

A basic interface for models 7940 and 7960 were trialled in this project. In future, it is planned to add full support for the 7970 VoIP phone by utilising all of the extra features such as graphical interface and touch screen inputs. It is also envisaged to develop this product for commercial purpose so that an inbuilt phone model recogniser with alternate code depending on which ever Cisco phone model being used will identify connected phone model and use determined sets of codes accordingly for successful interface. This will give flexibility to use any Cisco VoIP phone models and hence will be advantageous. Full load testing is also planned. Furthermore, there is a potential for creating additional reporting tools using VoIP SARRA and back-end database systems. User manuals for teachers and maintenance manuals for administrators are planned.

6.13 Conclusions

The implementation result after evaluation period of VoIP SARRA has been successful and demonstrated that innovative applications can be developed and implemented in an education environment to make student attendance data readily available which saves time and resources. From the evaluation, I conclude that the BHI is a better place for improved and modern record keeping facility.

The VoIP SARRA project was successfully built and demonstrated to satisfy BHI's management with its requirements and to provide a novel solution by amalgamation of low cost and readily available emerging technologies. It was planned that in late 2008, BHI's Information System Advisory Committee will roll out a project to integrate VoIP SARRA at Institute wide in live production environment with other systems currently in use.

Many issues and restrictions were encountered and surfaced during the execution of the project and the team learnt several lessons. The team can use new information discovered in future commercial development of the VoIP SARRA. Although the project was challenging and frustrating at times, the team enjoyed challenges and became more determined to complete this project creatively and effectively. The VoIP SARRA is dependent on Cisco VoIP Call Manager® and Cisco VoIP Phones® as it was developed considering the hardware as a primary constraint and the software as a secondary constraint.

Chapter 7

Design and Development of a New Three Layered MAC Architecture for the NEXT GEN Mobile Terminals for the Aricent Group (2007-2009)

7.1 Introduction

Gradual shift towards all IP based communication architecture will require end-to-end packet communication and supporting Quality of Service (QoS) in 4G Mobile Networks will be a major challenge due to varying bit rates, channel characteristics, bandwidth allocation and handover support among heterogeneous wireless networks. Although there are no robust specifications for 4G systems yet, it is clear that 4G will support higher data rates than 3G and data rates are expected to reach up to 100 Mbps on a downlink and 20 Mbps on an uplink. Several 4G/3G Network architectures have been proposed in various research papers [81 – 91]. Review of this architecture has identified scope for improvement in the key areas of new protocol with more focus on mobility, resource QoS management.

In this chapter, the approach is towards identifying a new software protocol for the Mobile Terminal. One of the new protocols identified in the 4G mobile terminal, the Packet Switching Medium Access Control (MAC) protocol is to achieve efficient multiplexing such that 4G mobile could satisfy different QoS requirements for different services. The following functionalities are addressed:

- provide simultaneous & multiple service activation for real-time and non-real-time applications;
- end-to-end QoS management under varying network conditions; and
- to ensure efficient radio resource management when various types of services coexist.

7.2 Proposed New NEXT GEN MAC Layer

A new MAC layer for the NEXT GEN Mobile Terminal is proposed to overcome some of the challenges being faced currently in the wireless networks as shown in figure 7-1.

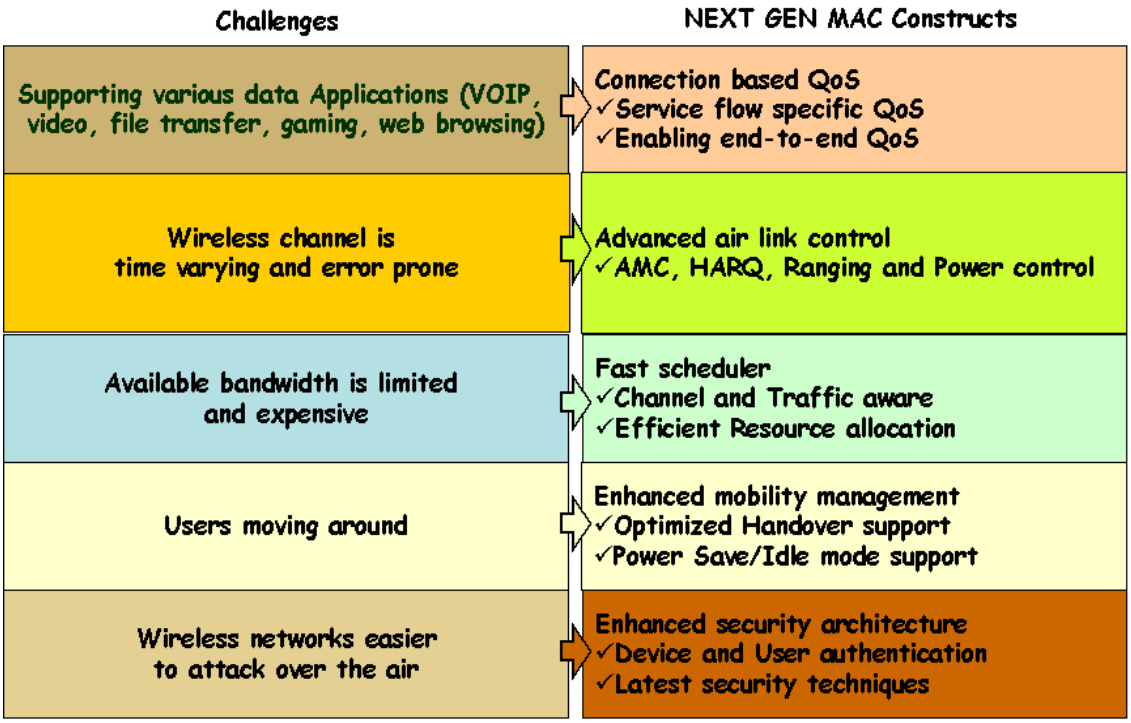

Figure 7-1 – Challenges and related solutions in the proposed MAC architecture

The main objectives of the proposed 4G MAC layer are listed below:

- to support high-speed data transmission of up to 20 Mbps on UPLINK and 100Mbps on Downlink;
- to ensure high reliability and high efficient data transmission to provide high data throughput;
- to provide efficient transport of heterogeneous traffic supporting QoS for various applications;
- to provide efficient packet transmission methodology and effective radio resource strategy for ensuring better QoS for multimedia traffic flow;
- to provide delay and bandwidth guarantees for various kinds of applications;
- to maintain fairness among various traffic flows based on priority;
- enhanced mobility management;
- on-demand bandwidth management; and
- enhanced security.

Based on the objectives shown above, the proposed NEXT GEN MAC Layer has been divided in to three major sub-layers as shown in figure 7-2. They are, Mobility

Management Sub-layer, Resource Management Sub-layer and QoS Management Sub-layer.

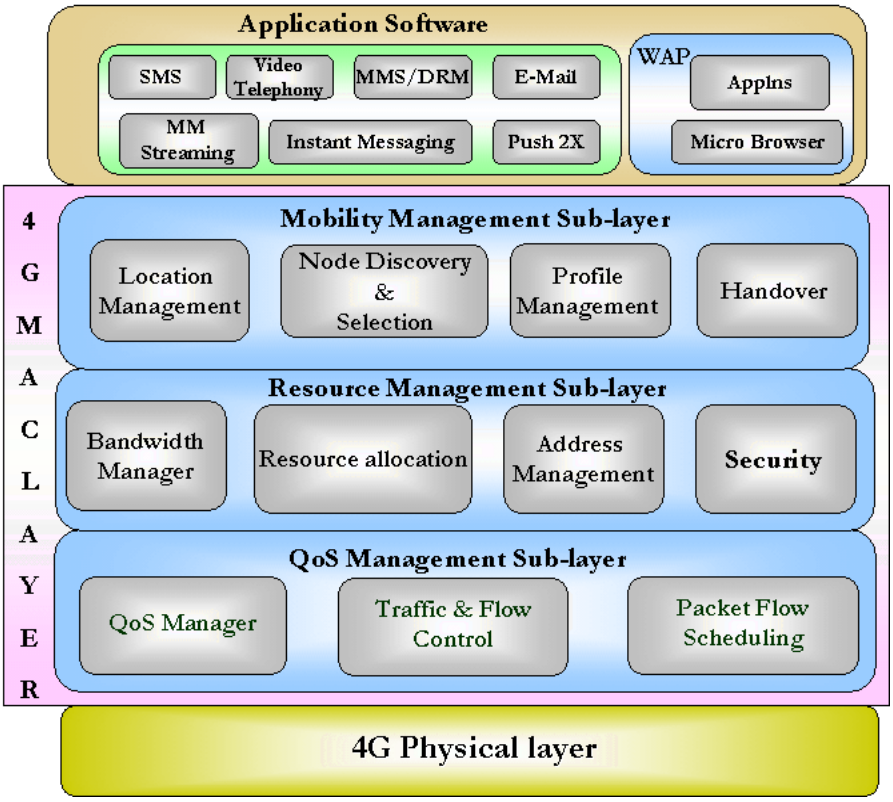

Figure 7-2 – Proposed new NEXT GEN MAC Layer

Proposed MAC layer maintains interaction internally with mobility management, resource management and QoS management sub layers as shown in figure 7-2. The functionalities carried out by these sub-layers include, location management; handover management; paging support; profile management; authentication; resource negotiation; cell discovery & selection and end-to-end QoS provisioning of real-time and non-real-time data. The functionalities provided by each sub-layers are briefly described below:

7.3 Mobility Management Sub-layer

Mobility Management is one of the essential functions that support roaming users with mobile terminals to enjoy their services through wireless networks when they are roaming into a new service area. Mobility management contains two major related components, location management and handoff management. The former concerns how to locate a mobile node, track its movement and update the location information while the latter

focuses mostly on the control of the change of the mobile node's access point during active data transmission. The functionalities of Mobility Management Sub-layer are,

- *Location Management*, supports services like location registration, location paging and location update procedure. Location management includes locating roaming terminals in order to deliver data packets despite the fact that their locations may change from time to time. The essence of location management is constituted by the mechanism for mapping the name of the mobile node to its IP address. Operations of location management include,

    - *Location Registration*, also known as location update or tracking i.e. the procedure that the network informs the mobile node through special messages by including the location information entries stored in some databases in the networks.

    - *Location Paging*, also known as location searching. In most cases, location information is stored in databases and is only the approximate position of a mobile device. Location paging is then the procedure that when calls/packets need to be delivered to the target mobile device, the network tries to find the mobile devices exact locality.

- *Node Discovery & Selection*, synchronises with the network, MAC initiates the selection process with the desired base station. The process has been divided into channel synchronisation, authentication message exchange, registration, and smooth connectivity. Upon completion of the network selection process, the MAC layer creates one or more service flows to send data to the Base Station based on the trigger from the application layer.

- *Profile Management*, stores mobile terminal profiles and application profiles. Static profile holds information that does not change very often and includes mobile terminal profiles, applications and its QoS requirements. Dynamic profile holds information such as current QoS network parameters like bandwidth, delay, jitter, packet loss and throughput.

- *Handover Management*, controls the change of mobile terminals attachment to a foreign network in order to maintain connection with the moving terminal during active data transmission. Operations of Handover Management include,

    - *Handover Triggering, initiates handover process according to conditions which includes signal strength deterioration, bandwidth decrease or insufficiency, new better connection available, cost and quality trade-off, flow stream characteristic, network topology change, etc., Triggering may even happen according to a user's explicit control.*

    - *Fast Handover, should be quick enough in order to ensure that the mobile node can receive data packets at its new location within a reasonable time interval and to reduce the packet delay as much as possible. This is extremely important for real-time services.*

    - *Seamless Handover, should minimise the packet loss rate to zero or near zero. Fast handoff and seamless handoff together sometimes referred to as smooth handover. While the former concerns mainly packet delay, the later focus more on packet loss.*

    - *Movement Detection and Prediction, i.e. mobile node's movement between different access points can be detected and predicted so that the next network that will soon be visited is able to prepare well in advance and packets can even be delivered before and/or during handoff simultaneously to the old attachment point.*

    - *Handover Control, adopts different mechanisms for the handover control. Typical example include, mobile controlled or network controlled, Layer 2 or Layer 3-triggered handover.*

    - *Packet Routing, changes the delivering route of the succeeding data to the new connection path in the mobile terminal after the new connection has been successfully established.*

7.4 Resource Management Sub-layer

The MAC entity manages the Radio Resource by logically splitting it into two parts,

- First portion of bandwidth, named, Radio Bearer (RB) is negotiated with the network and, once allocated by the network, the MAC layer maps the QoS class with respective RB.
- Second portion of bandwidth, named Dynamic Bandwidth (DB) can dynamically vary depending directly on the QoS for specific applications; this MAC Traffic class is used to map the best effort class of the IP layer.

Resource management requires allocation/de-allocation of resources to sustain a communication session. The allocation/de-allocation is carried out within the serving domain and along the communication path between peer end terminals, before and during a session. The functionalities provided by resource management in general and its sub-layers are briefly described below:

- *Bandwidth Manager/Traffic Classification* – Applications with very different characteristics and network requirements compete for bounded network resources. Often, the result is that critical transactional applications suffer unacceptable levels of performance degradation during network congestion. However, bandwidth manager enables users to allocate required bandwidth, thereby providing dramatic improvement in throughput for critical data. Before bandwidth allocation can be performed, MAC layer must identify the traffic that is travelling through it. This process is called traffic classification and it has been categorised as Multimedia traffic, File transfer Traffic, Web traffic, Interactive traffic and Best effort traffic. The details are explained in section 7.2.3.1.3.

- *Resource Allocation*, responsible for the Radio Resource, thus, generates bandwidth requests to allocate RB for a specific traffic flows by reserving them. It performs resource handling which is adaptive to amount of traffic. It controls and receives some measurement parameters from the physical layer and performs control of the radio resource by differentiating the service classes. Finally, it reports the measurement results to the network.
- *Power Control*, is based on the principle that a mobile has a concatenated uplink and downlink phase, and that the transceiver will enter a low power-operating mode for the

remaining time. Although this strategy has a negative effect on the capacity of the channel, it allows the mobile to turn the power off from the wireless interface for a longer period. This choice was made since in a mobile multimedia environment, it is more important that connections have a certain QoS than highest possible bandwidth.

- *Connection Re-establishment*, is the process to generate connection between the mobile terminal and the new cellular network. The main task of the operation relates to the discovery and assignment of new network connection based on the handover strategy.

- *Security*, Protocol should support performing accounting, authentication and authorisation (AAA) services

7.5 QoS Management Sub-layer

The QoS management sub-layer establishes, maintains and releases wireless connections between the base-station and the mobile and also provides support for handover and mobility services. Multimedia networking requires at least a certain minimum QoS and bandwidth allocation for satisfactory application performance. This minimum QoS requirement has a wide dynamic range depending on the user's quality expectations and application usage modes.

A QoS management sub-layer receives transmission requests from the mobiles. The key to providing QoS for these connections will be the scheduling algorithm that assigns the bandwidth. The functionalities of QoS management sub-layer software module are traffic & flow control, real-time traffic management, packet flow scheduling, radio link control functionalities and QoS manager. The detailed explanation on all software modules is provided in the following sub-sections.

7.5.1 QoS Manager

Applications contact the QoS manager when setting up a connection. The QoS manager will inform the applications when they should adapt their data streams when the QoS of a connection has changed significantly. Figure 7-3 conceptually illustrates the role of adaptive applications in the QoS Management Sub-layer.

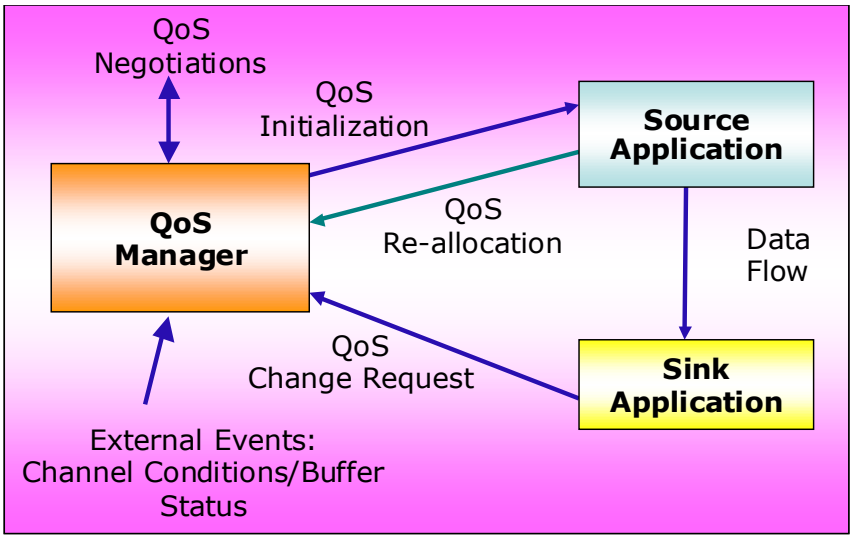

Figure 7-3 – QoS Management Sub-layer

The application requests a new connection for a certain service class that defines the media type (e.g. video, audio, data), interactivity model (e.g. multimedia browsing, videoconference), and various QoS traffic parameters (e.g. required bandwidth). The service classes allow multimedia sessions to transparently adapt the quality of the connection when the available resources change marginally without the need to further specify details and without explicit renegotiations.

Network resource allocation is done in two phases. First, the QoS manager checks the availability of resources on the base-stations coverage area at connection setup. The necessary resources are estimated based on the required service. The new connection is accepted if sufficient resources are estimated to be available for the connection to operate within the service contract without affecting the service of other ongoing connections. Otherwise, the connection is refused. Second, while the connection is in progress, dynamic bandwidth allocation is performed to match the requirements of interactive traffic and the available resources. When the available bandwidth changes (because congestion occurs, or the error conditions change drastically), the QoS manager reallocates bandwidth among connections to maintain the service of all ongoing connections within their service contracts. The QoS manager located in QoS Management Sub-layer is configured according to applications & network specific QoS requirements and resource availability. The QoS manager module functionalities are briefly described below:

- *QoS Mapping*: performs the function of automatic translation of QoS at different levels of application requirements.

- *QoS Monitoring*: allows tracking the ongoing QoS levels. QoS Monitoring function compares the actual measured traffic against the agreed QoS profile so that the traffic is handled appropriately. The measured traffic measures the actual burst rate and amount of packets in the buffer against the CIR (Committed Information Rate) and PIR (Peak Information Rate).

- *Flow Scheduling:* manages the forwarding of flows in an integrated manner.

- *Flow Policing:* observes or monitors whether the QoS required by a user is being maintained or not.

- *Flow Synchronisation:* requires controlling the precise timing of multimedia interactions.

- *QoS Maintenance:* compares the monitored QoS against the expected performance and then performs tuning operations on resource modules to sustain the delivered QoS.

- *QoS Degradation:* issues a QoS indication to the user by the QoS maintenance mechanisms.

The mandatory parameters are monitored for ensuring better QoS for various applications in the QoS Management sub-layer. They are as follows:

- *Throughput:* is the amount of data transferred from one place to another, specifically the bit rate that the connection can achieve.

- *Latency or Delay:* is the amount of time it takes for a packet to travel from its source to its destination

- *Jitter:* is the delay variation experienced by data frames, with respect to the average delay.

- *Frame Error Ratio (FER):* is defined as the percentage of frames, with non-recovered errors, with respect to the total frames received correctly. A frame is a service data unit received by a high layer.

- *Bit Error Rate (BER):* is the percentage of bits, with non-recovered errors, divided by the total number of bits that have been transmitted, received or processed over a given time period.

QoS Management consists of three tasks, Queue Management, MAC Management and Scheduler.

7.5.1.1 Queue Management (QM)

QM deals with the length of packet queues, while scheduling algorithms determines which packets to send next.

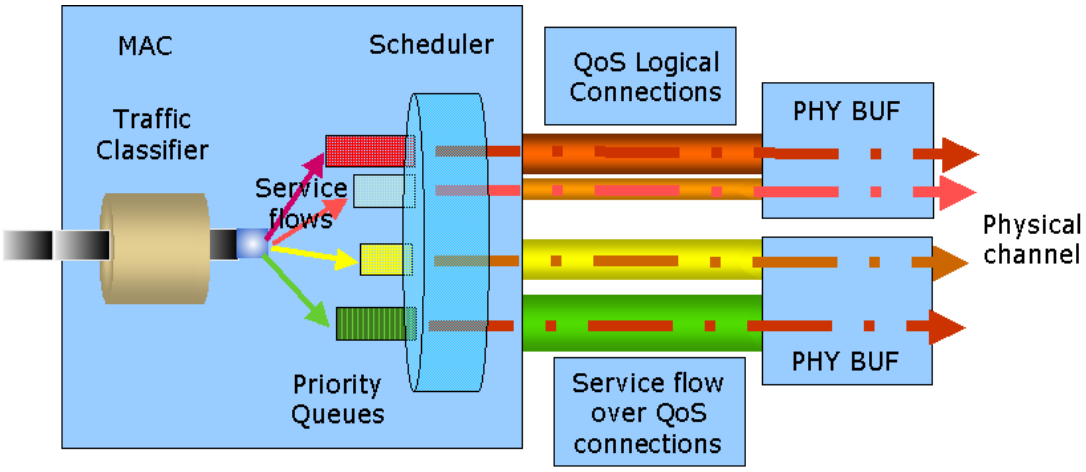

Figure 7-4 – Queue Management

The QoS Management solution is shown in figure 7-4 which employs different scheduling algorithms in order to support the following service requirements:

- Associate packets into service flow
- Define QoS parameter for each service flow
- Dynamically establish QoS-enabled service flows
- Associate QoS service flow with logical connections

- Define transmission ordering and scheduling on the air interface.

7.5.1.2 MAC Management

Software block as shown in figure 7-5 has the task of buffering the signalling packets and forwarding them to the Physical layer depending on the signalling channel to be used (i.e. common or dedicated).

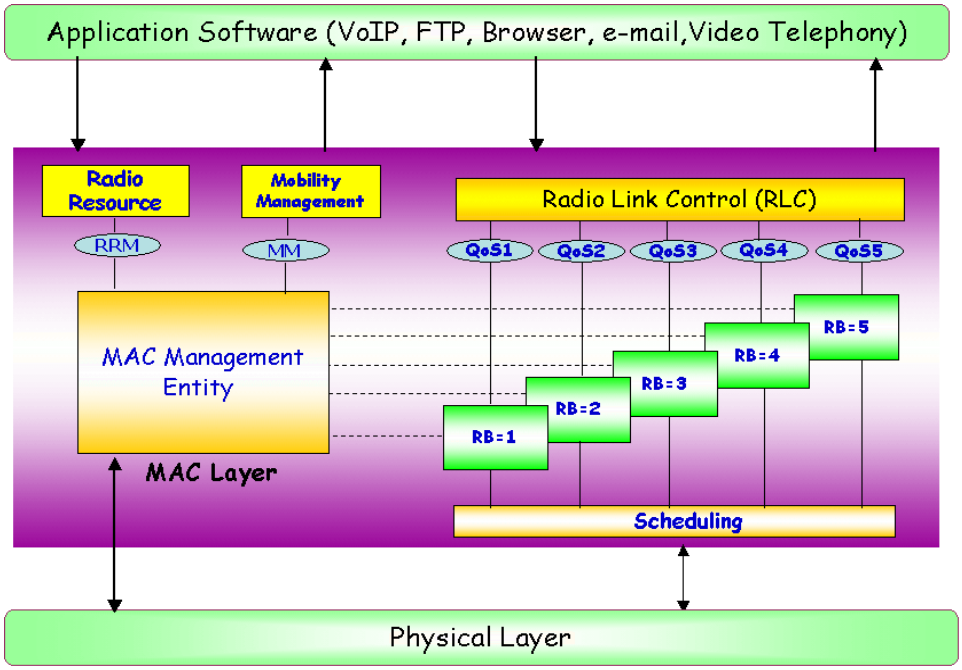

Figure 7-5 – MAC Management Interface

The functionalities of MAC management are listed below,

- maximum QoS for each type of application
- subscriber preferences for certain services
- preferred end-user QoS for each application
- transmission capabilities (e.g. delay, bandwidth, jitter)
- Information components transmitted on the uplink during connection request are,
- terminal / source id and destination id
- connection type and QoS information
- payload length / data segment size
- payload status

The MAC Manager handles establishment or release of connections requested by the upper layer. In case of establishment, a new RB is created; state variables and timer values are initialised according to the configuration setup. In case of release requested, all the relevant protocol parameters, state variables and timers are released. The MAC manager also takes care of communicating to network to get the IP address and other parameters to establish IP connectivity during initialisation of the MAC Protocol.

7.5.1.2.1 Radio Link Control (RLC)

The RLC Protocol used is a Windows® based selective repeat Automatic Repeat Request (ARQ) technique. The ARQ algorithm uses a selective retransmission technique using a fixed window size. The RLC layer receives an acknowledgment after transmitting the whole block of data. The ACK packet contains a flag bits to indicate whether a particular packet transmission was successful or unsuccessful. Unsuccessful packets are re-transmitted by appending those packets in the next data block. A retransmission timer is used to compensate a lost ACK packet. Retransmission timer value is selected based on the expected ACK packet arrival time. The RLC data flow diagram is shown in figure 7-6.

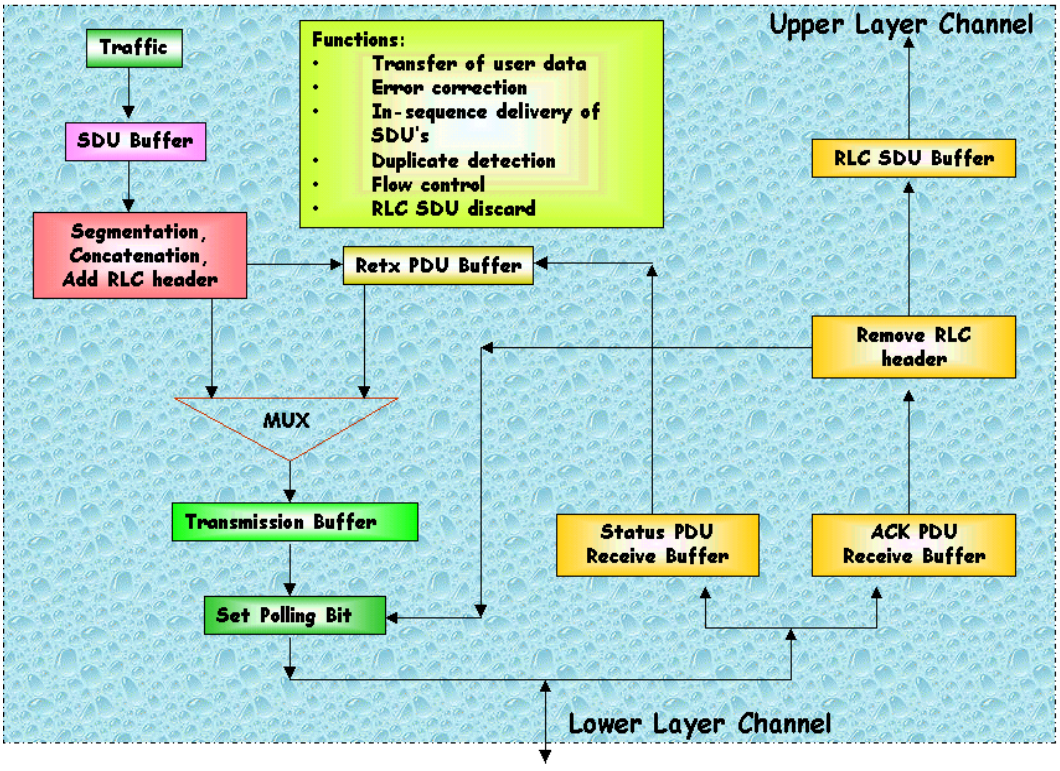

Figure 7-6 – Radio Link Control Data Flow Diagram

Figure 7-7 depicts the software architecture of the RLC Module considered for the 4G MAC layer. Detail descriptions of each sub-component are explained below:

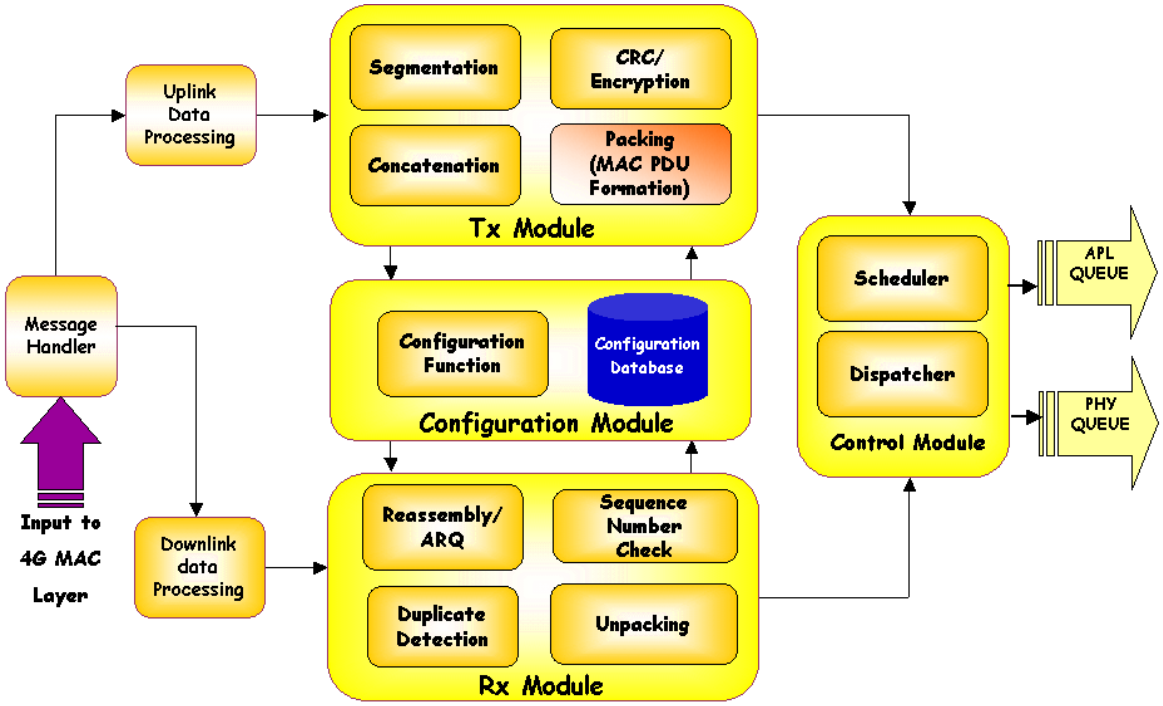

Figure 7-7 – Radio Link Control Software Architecture

7.5.1.2.1.1 Transmission Module (TX)

The TX Module performs the segmentation function where a single Service Data Unit (SDU) is segmented into different Packet Data Unit (PDU). This module forms the Layer 2 PDU from the SDU received from the upper layers and takes care of the data transmission in uplink. The TX Module takes care of the functionalities like segmentation, concatenation, padding, ciphering and multiplexing of PDU. They are briefly described below:

- *Segmentation* – Performs segmentation of variable-length higher layer SDU into smaller RLC PDUs. This process is undertaken to allow efficient use of available bandwidth relative to the QoS requirements of a connection service flow.

- *Concatenation* – If the content of an RLC SDU does not fill an integer number of RLC PDU, the first segment of the next RLC SDU may be put into the RLC PDU in concatenation with the last segment of the previous RLC SDU.

- *Padding* – When concatenation is not applicable and the remaining data to be transmitted does not fill an entire RLC PDU of a given size, the remaining portion of the data field shall be filled with padding bits.

- *Ciphering* – When transmitting a MAC PDU on a connection that is mapped, the sender shall perform encryption and authentication of the MAC PDU payload. When receiving a MAC PDU on a mapped connection, the receiver shall perform decryption and data authentication of the MAC PDU payload.

- *Multiplexing of PDUs* – Preserves the order of higher layer PDUs that were submitted for transfer by RLC using the acknowledged data transfer service. If this function is not used, out-of-sequence delivery is provided.

- *Transfer of user data* – Used for conveyance of data between users of RLC services. RLC supports acknowledged, unacknowledged and transparent data transfer. Setting of QoS controls transfer of user data.

- *Packing* – The process of combining multiple MAC SDUs into a single MAC PDU. On connections with variable length MAC SDU, Packed PDU contains a sub-header for each packed SDU. On connections with fixed length MAC SDU, can save up to 10% of system bandwidth.

- *Cyclic Redundancy Check (CRC)* – The CRC covers the generic MAC header and the Payload of the MAC PDU. The CRC shall be calculated after encryption; i.e. the CRC protects the Generic Header and the ciphered Payload. A service flow may require that a CRC be appended to each MAC PDU carrying data for that service flow.

- *Ciphering* – Prevents unauthorized acquisition of data.

- *MAC Protocol Data Unit Formats* – The MAC PDU is the data unit exchanged between the MAC layers of the BS and the Mobile Terminals. A MAC PDU consists of a fixed-length MAC header, a variable-length payload and CRC.

- *Transmission & Reception of MAC PDUs* – Incoming MAC SDUs are formatted with segmentation and/or packing, before being conveyed over one or more connections. After traversing the air link, MAC PDUs are reconstructed back into the original MAC SDUs so that the format modifications performed by the MAC layer protocol are transparent to the receiving entity.

7.5.1.2.1.2 Configuration Module

The configuration request from Layer 3 is handled depending on the request from the upper layer i.e. whether establishment, re-establishment, modification or release. The configuration handler does the required configuration in the configuration table. In case of establishment requested by Layer 3, State variables and Timer values are initialized according to the specified parameters. In case of modification, all the protocol parameters indicated are modified and rest of the state variables and timer values are kept intact. In case of release requested by Layer 3, all the protocol parameters, state variables and timers are released. Various parameters used in configuration module are,

- *Configuration Parameters Updation*: Whenever upper layer posts a primitive for initialization or termination of the entity, the Configuration database is updated.

- *Synchronisation/Initialization Procedure*: Process of exchanging SYNC and ACK control frames for synchronisation and initialisation.

- *Frame Formation*: Formation of RLC frame according to the formats defined and adding appropriate fields.

- *Frame Validation*: Frames received are validated before further processing.

- *Control Unit Processing*: Received control frames are handled in control unit.

4G Wireless terminals are envisioned to provide QoS guarantees and thus, the MAC layer must efficiently evaluate the available resources and perform access in such a way that the QoS requirements of applications and user are satisfied.

7.5.1.2.1.3 Receiver Module (RX)

The receiver module at the receiving side receives the PDU and forms the SDU. RX performs the reassembly of PDU received in one Transmission Time Interval (TTI), SDU formation, Duplication Detection and Error Detection by sequence number checks. They are briefly described below:

- *Reassembly* – If the segmented frames are received, the reassembly procedure is performed before storing it in the re-sequencing buffer or delivering it to upper layer.

- *Error correction* – Provides error correction by retransmission (for example, Selective Repeat, Go Back N, or Stop-and-Wait ARQ) in acknowledged data transfer mode.

- *Duplicate detection* – Detects duplicated received RLC PDU and ensures that the resultant higher Layer PDU is delivered only once to the upper layer.

- *Flow control* – Allows an RLC receiver to control the rate at which the peer RLC transmitting entity may send information.

- *Sequence Number check (Unacknowledged data transfer mode)* – Guarantees the integrity of reassembled PDU and provides a mechanism for the detection of corrupted RLC SDU through Sequence number checking in RLC PDU when they are reassembled into a RLC SDU. A corrupted RLC SDU is discarded.

- *Decryption* – When receiving a MAC PDU on a mapped connection, the receiver shall perform decryption and data authentication of the MAC PDU payload.

- *ARQ Schemes* – ARQ processing is the process of retransmitting MAC SDU blocks ("ARQ blocks") that have been lost or garbled. The 4G MAC uses a sliding window based approach, where the transmitter can transmit up to a negotiated number of blocks without receiving an acknowledgement. The receiver sends acknowledgement or negative ACK messages to indicate to the transmitter, which SDU blocks have successfully been received and lost. The transmitter retransmits blocks that were lost

and moves the sliding window forward when SDU blocks are acknowledged. The Automatic Repeat Request (ARQ) protocol is used, consisting,

- *Positive acknowledgement* – The destination returns a positive acknowledgement to successfully received, error free PDU.

- *Retransmission after time-out* – The source retransmits a PDU hat has not been acknowledged after a predetermined amount of time.

- *Error detection* – The receiver detects error (this function is actually performed by the MAC layer) and discards damaged PDU, sending a negative acknowledgment to ask the source to transmit again the PDU as shown in figure 7-8. Two kinds of ARQ are used in the MAC Layer: stop-and-wait and Go-back-N.

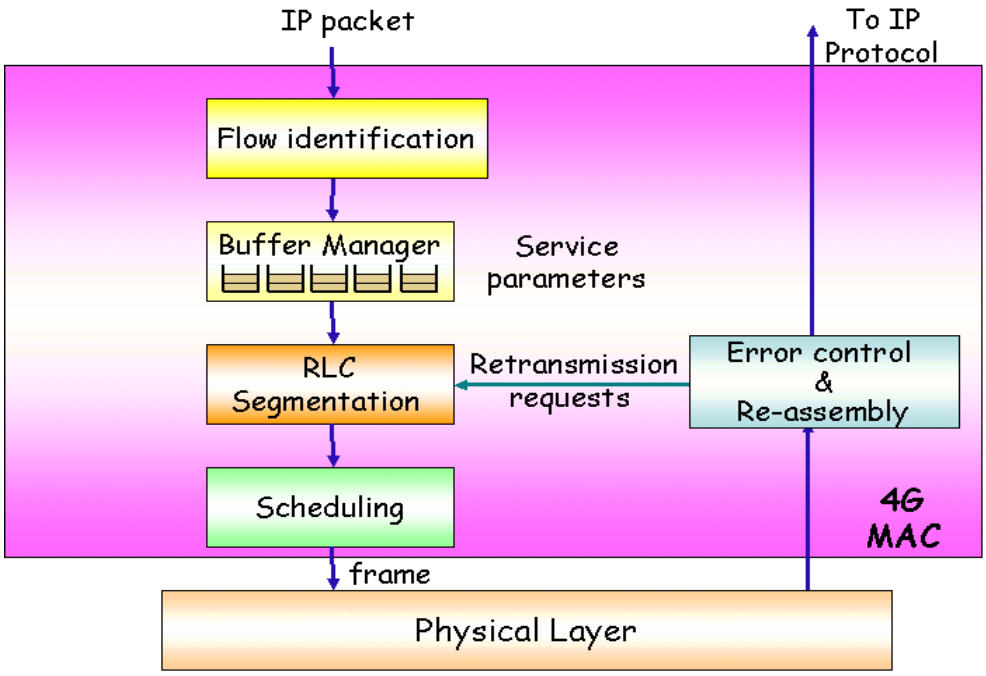

Figure 7-8 – Actual Data Flow through IP

7.5.1.2.2 Buffer Management Module

The operation of RLC involves forming PDU from SDU at the transmitting side and reassembly of the PDU into SDU at the receiving side. The rate at which data is transmitted may be less than the rate at which data is received. All these necessitate the use of buffering. Various buffers used in the RLC entity operation are briefly explained below:

- *Control Buffer*: All control related frames e.g. SYNC, NAK (Non-Acknowledgement) are queued for transmission.

- *Re-Transmission Buffer*: A copy of the transmitted frame is stored in the re-transmission buffer to be used for retransmission.

- *SDU Buffer*: This buffer holds the Data received from upper layer intended to be processed by MAC sub-layer.

- *Re-sequencing Buffer*: Frames received in the forward direction are stored in this buffer to be re-sequenced and delivered to Upper layer.

- *NAK List*: Non-Acknowledgement list consists of the frame sequence numbers for which the retransmission has been requested. The NAK/Abort timer values are also maintained in the list corresponding to each NAK control frame.

- *MAC/PHY Interface Buffer*: Frames that are to be transmitted from MAC are put in the MAC/PHY interface buffer.

7.5.2 Traffic and Flow Control Module

The main functionalities of traffic & flow control software modules are to support real-time traffic management in maintaining larger bandwidth and higher speed of operation. This module identifies efficient packet transmission mechanism to provide flexible wireless access schemes for multimedia services with reliable QoS assurance and provides enough radio resources for a new multimedia request to ensure the QoS requirement without degrading the service quality for current service.

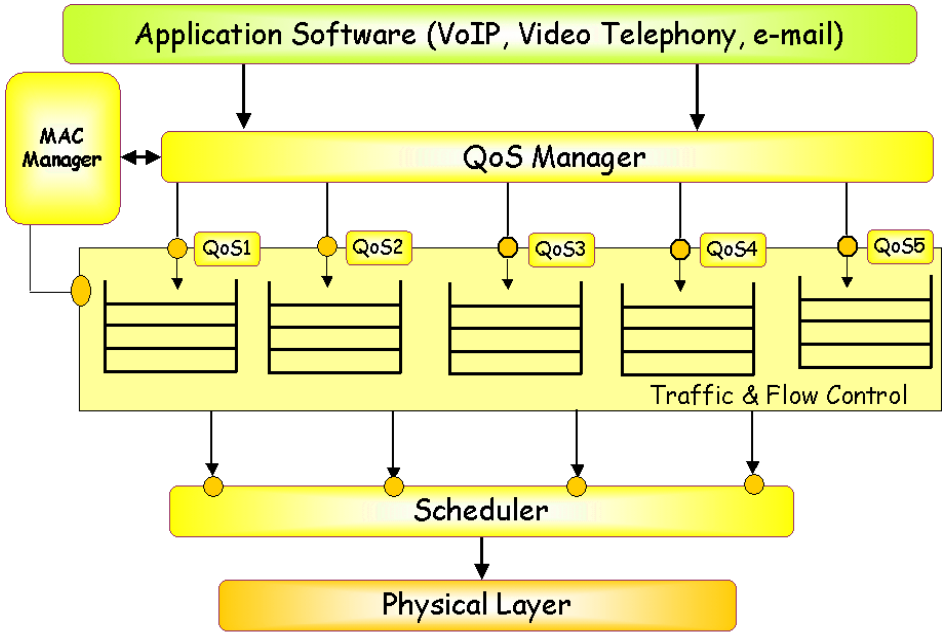

Figure 7-9 – Traffic and Flow Control Module

The traffic and flow control module is shown in figure 7-9, classifies the traffic into five separate classes. They are,

- *Multimedia traffic (QoS 1)* – This traffic of application includes Multimedia streaming, VoIP (Voice over Internet Protocol), teleconferencing and other multimedia traffic. This class requires large bandwidth, small delay and jitter. High priority should be given to this class and the bandwidth should be reserved when the application is running.

- *File transfer traffic (QoS 2)* – FTP application is a typical traffic flow example and this requires large throughput. It is not sensitive to delay and delay jitter. This class should be suppressed if it coexists with higher priority traffic.

- *Web traffic (QoS 3)* – This class includes normal web browsing. It should not be over-starved by other traffic because active user interaction is involved. Hence a fair portion of bandwidth should be reserved but the priority is assigned as not important.

- *Interactive traffic (QoS 4)* – This class includes delay-sensitive traffic of applications like e-mail access, games. It should be transmitted with minimal delay because of their sensitive characteristic to round trip time (RTT).

- *Best-effort traffic (QoS 5)* – This class is transmitted with best effort only. This service is typically provided by the Internet today for Web surfing. The key parameters are required are minimum reserved traffic rate and traffic priority.

7.5.3 Packet Flow Scheduling

In the NEXT GEN wireless terminals, multiple information flows with various QoS requirements can be forwarded to the MAC layer at the same time. Due to various QoS requirements, these flows can be served using different application types of traffic flows that are most suitable for each flow. During the decision process, the decision block may end up selecting a specific traffic class for multiple services. Since these services cannot be interleaved into a single MAC frame, a QoS-based scheduler is used in order to guarantee the QoS requirements of each flow. Scheduler schedules all traffic according to the QoS requirements and tries to minimise the number of transitions the mobile has to make. It schedules the traffic of a mobile such that all downlink and uplink connections are grouped into packets taking into account the limitations imposed by the QoS of the connections. In general there are three phases: uplink, downlink, and reservation.

The scheduler maintains two tables, a request and a schedule table. The request table maintains several aspects of the current connections handled (like the connection type, the connection queue size and status, the error state of the channel, the assigned bandwidth, the requested reliability). The Scheduler is designed to maintain the admitted connections as much as possible within the negotiated connection QoS parameters. The following requirements are considered,

- *QoS Guarantee*: The QoS requirements for each flow should guarantee throughout the connection.

- *Channel Dependent Scheduling*: If wireless channel conditions change throughout the connection, scheduler should be able to adapt to these changes in order to provide fairness to each traffic flow.

- *Dynamic Behaviour*: If the number of traffic flows assigned may vary during the course of scheduling, the scheduler has to be easily configurable to adapt to these dynamic changes.

- *Delay*: End-to-end delay of all packets received by the MAC and forwarded to the higher layer.

- *Load*: Total number of bits received from the higher layer. Packets arriving from the higher layer are stored inside the MAC Layer buffer.

- *Throughput*: Total number of bits sent to the higher layer from the MAC layer. The data packets received at the physical layer are sent to the higher layer if they are destined for this station.

- *Scheduling algorithm*: Determines the transmission time for the packet in each queue to provide QoS assurance, which will influence the delay of services. In order to address the requirements of the scheduler in NG wireless terminals, Bin Sort Fair Queuing (BSFQ) scheduler is proposed in order to accommodate the unique characteristics of the wireless medium based on one of the ideas presented in [85].

7.6 Implementation Methodology

Generally, the MAC layer will be implemented as a single task in the operating system used in the mobile terminal device and this section briefly explains about the additional software handlers been required in terms of handling the messages from higher and lower layers. The handlers required are Primitive Handler, Message Handler, Error Handler, State Handler and Timer Expiry Handler as shown in figure 7-10. The functionalities of all the handlers are briefly explained below:

- *Primitive Handler* – For every signal received, there is a Primitive Handler. The Primitive handler takes the MAC signals from the MAC queue. The Primitive Handlers depending on the state invoke the respective state handlers. If say, MAC_CONNECTION_REQ Primitive Handler is invoked then it will first decode the

message received. Depending on the message type the message handlers are invoked. Also Timer Expiry Handler is invoked to maintain the timers present in each state.

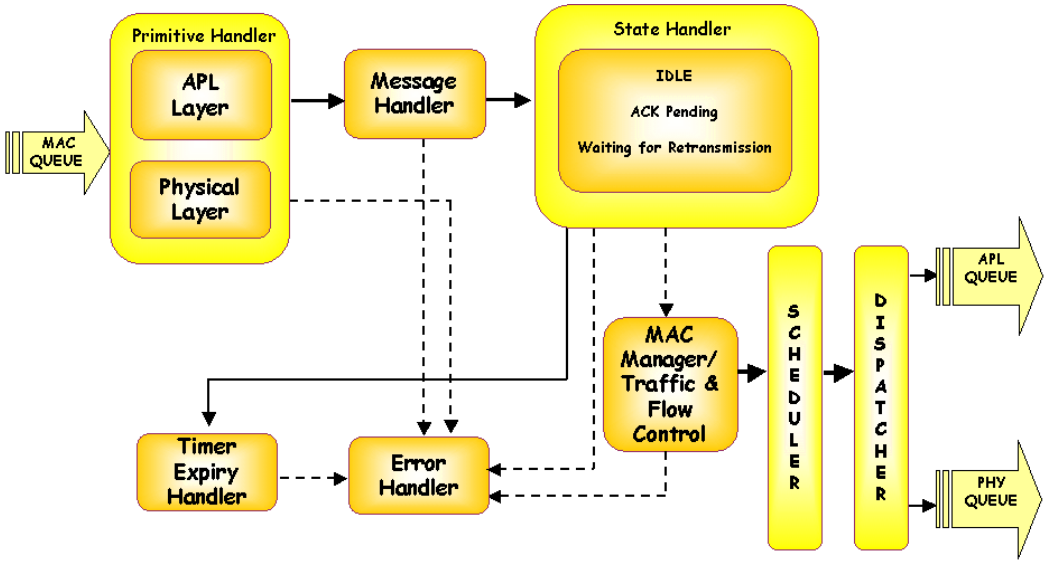

Figure 7-10 – MAC Implementation Methodology

- *Message Handler* – The Message Handler receives the decoded message from the Primitive Handler. Depending upon message type, the respective procedures are followed. The message handler first selects the entity for which message is received after that depending upon the state, corresponding state handlers are invoked.

- *State Handlers* – The primitive handlers, Timer Expiry Handlers and Message Handlers invoke the state handlers. Each state handler calls a function corresponding to that state and processes the signals. The outgoing messages are encoded in the message encoder and state of the entity is updated.

- *Error Handler* – runs procedures to handle abnormal cases. It also consist Error Handling and recovering mechanisms for signals and messages received. Message handlers, State handlers or Primitive Handlers can invoke Error Handling procedures.

- *Message Encoder and Decoder* – will interpret the message received as byte array, and put the various message elements into the proper structures as required by the particular message, and vice versa.

- *Scheduler* – is responsible for scheduling packets from traffic queues at mobile terminal for transmission on channel. Bandwidth allocated to each mobile terminal for uplink transmission must be properly allocated to various uplink flows so as to satisfy the QoS requirement.

- *Dispatcher* – will route the signal to respective queue depending upon the message.

7.7 Simulation and Results

Simulated MAC layer functionalities with Orthogonal Frequency Division Multiplexing (OFDM) system and the block diagram used in simulations block diagram is shown in figure 7-11. Conceptually the physical layer can be described in terms of upper and lower physical layers. The upper physical layer includes scrambling, channel coding, interleaving, and modulation to form data symbols while the lower physical layer maps the data symbols to frequency bins and forms OFDM symbols.

Figures 7-11 and 7-12 provides simulation results of the data throughput. It is shown that the achieved data rate of up to 15.26 Mbps on the Uplink and 71.28 Mbps on the Downlink for specific modulation technique with frame duration of 1ms can be achieved.

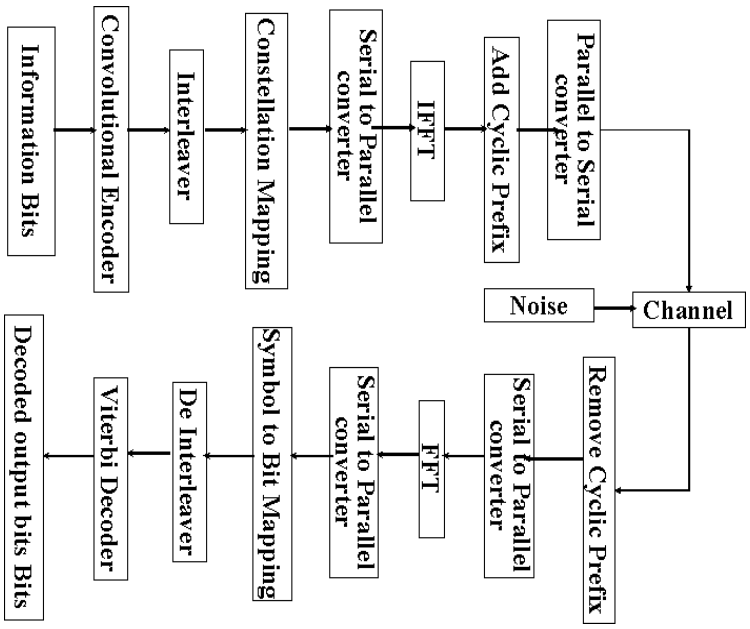

Figure 7-11 – OFDM Physical Layer Model

To achieve the maximum data rate of 20 Mbps on the Uplink and 100 Mbps on the Downlink, various analysis & simulations were performed with the help of MATLAB® Simulation Tool using OFDM System.

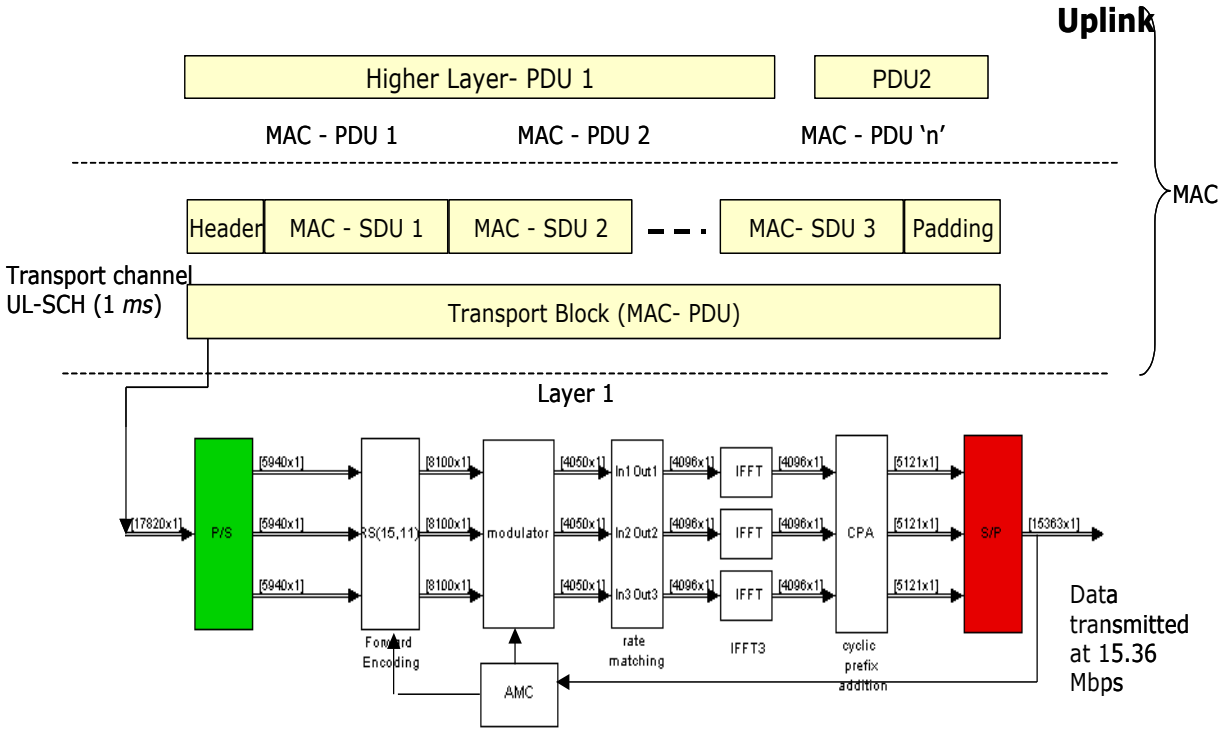

Figure 7-12 – Simulation Result for Uplink

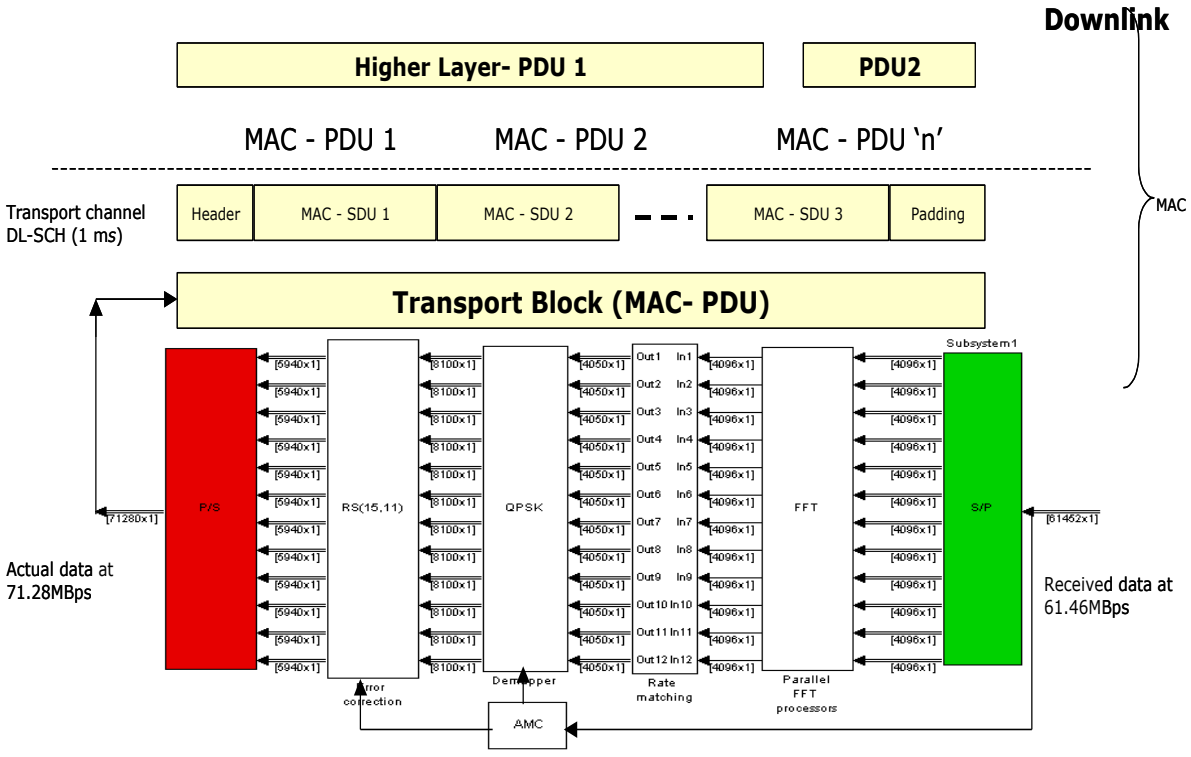

Figure 7-13 – Simulation Result for Downlink

Table 7-1 provides the simulation throughputs with respect to different modulation techniques, bits per sub carrier, code rate and guard interval to achieve to minimum and maximum date rate of NEXT GEN system.

Table 7-1 – Mode related OFDM Parameters for different Data Throughputs

Mode	Modulation	Bits per Sub-carrier	Code Rate	Data rate (Mbps) for Different GI			
				1/4	1/8	1/16	1/32
1	BPSK	1	1/2	6.75	7.50	7.94	8.18
2		1	2/3	9.0	10.0	10.58	10.90
3		1	3/4	10.12	11.25	11.91	12.27
4	QPSK	2	1/2	13.5	15.0	15.88	16.36
5		2	2/3	18.0	20.0	21.17	21.81
6		2	3/4	20.25	22.5	23.82	24.54
7	16 QAM	4	1/2	27.0	30.0	31.76	32.72
8		4	2/3	36.0	40.0	42.35	43.63
9		4	3/4	40.5	45.0	47.64	49.08
10	64 QAM	6	1/2	40.5	45.0	47.64	49.09
11		6	2/3	54.0	60.0	63.52	65.45
12		6	3/4	60.75	67.5	71.46	73.63
13	128 QAM	7	1/2	47.25	52.5	55.58	57.27
14		7	2/3	63.0	70.0	74.11	76.36
15		7	3/4	70.87	78.75	83.37	85.90

Table 7-2 provides the value of parameters that were selected for OFDM system in order to achieve desired throughputs.

Table 7-2 – OFDM Related Input Parameters

Parameters	Values
Operating Frequency	3 GHz
Bandwidth (BW)	20 MHz
Total number of sub carriers (N)	256
IFFT Size	256
Number of Data sub carriers	216
Number of Pilot sub carriers	40
OFDM symbol duration (T_s)	12.8 *usec*
Guard interval duration (T_g)	0.8 *usec* (T_s /16)
Total symbol duration (T)	13.6 *usec* ($T_s + T_g$)
Sub carrier spacing (Δf) = BW/N = $1/T_s$	78.125 KHz

7.8 Conclusions

This chapter discussed the design aspects and implementation methodology in detail for the proposed new MAC protocol for 4G networks. Discussion on simulation results for various data rates with different modulation techniques to satisfy the 4G network QoS requirements. This chapter introduced a new scheduling technique which can alter priority to different types of traffic based on QoS requirements. This technique can easily be configured to support for number of different priority traffic rather than few priorities such that decision is made efficiently.

The proposed MAC protocol takes care of scheduling techniques, traffic & flow control, mobility management, and packet access control and handover strategy. However, the proposed protocol necessitates new base stations for 4G communications. Further study and investigation supports vertical handover to other cellular networks in mobility management sub-layer and new scheduling algorithms as a part of QoS Management sub-layer for the NEXT GEN MAC layer implementation.

Chapter 8

Modular Data Link Layer (M-DALL) for NEXT GEN Mobile Terminals Enabling Wireless Aware Applications: A Platform Independent Software Design for the Aricent Group (2008-2009)

8.1 Introduction

Today, large number of wireless networks based on different Radio Access Technologies (RATs) and standards are found. New RATs will be developed to complement those that exist already today. Each RAT will have its strengths and weaknesses with respect to capacity, cost, achievable data rates and support for end user mobility. Hence, no single RAT will be able to fully support all services and user requirements. It can be anticipated that within a few years' time, a mobile terminal will have a choice of access technologies via which it can connect to the mobile communication infrastructure. It will be a challenge to allow for a mobile user to seamlessly communicate throughout multiple networks [92]. Therefore, a major requirement for the future is to achieve the cooperation of those heterogeneous networks. Innovative mobile applications gain from these new possibilities but the involved design complexity gets higher due to several reasons.

Firstly, the interfaces used to retrieve link-layer information drastically differ from various technologies [92, 93]. Application programmers who want to run their implementation over multiple RATs, e.g. WLAN as well as Bluetooth have to implement the network related part for each technology from the beginning.

Secondly, the flexibility and functionality of these interfaces is severely limited [92, 93]. For example, link-aware mobile applications have to monitor characteristics of the wireless connection themselves.

Thirdly, mobile operating system entities offering a flexible interface to track the frequently changing conditions in the wireless communication are not available today [94].

Finally, measurement results available from present device drivers are rarely comparable [94]. Often only very specific and detailed data can be read out but no performance QoS metrics are offered.

8.2 Related Work and Proposed Concept

Research studies [95 – 102] have focused on providing generic link layer APIs and other studies [103 – 105] focused on generic protocol stack approach. Various approaches are presented separately in different methodology. But my approach is towards providing an integrated solution in the form of an M-DALL for the 3G/B3G mobile terminals. It envisage to cover various aspects like measuring the signal strength and providing handover facility to application layer; taking care of all Common Data Functions (CDF) in a framework and support interface with other layer to measure and ensure the required QoS. Based on user profile settings in a more practical and integrated way, it will provide solution to Original Equipment Manufacturer (OEM) for easy implementation. Parameters from Layer 2 (and above) to ensure a modular approach relevant to emerging technologies were considered.

In this chapter, a new concept of a Modular Data Link Layer (M-DALL) is presented and depicted at figure 8-1, where M-DALL enables a cooperation of different access networks at the link layer.

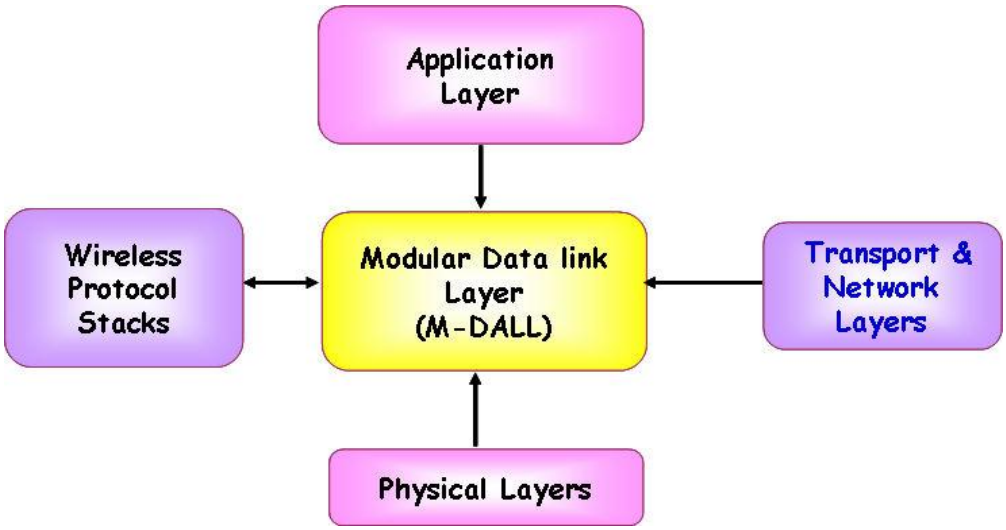

Figure 8-1 - M-DALL Concept

So the issue is that not is single acceptable and useful reference API is provided in the public domain [95, 96]. An M-DALL which provides an extendibility to permit different underlying wireless interfaces and networking technologies that exist now and will emerge in the future is proposed. One of the important emerging technologies is composite multi-mode radio [96]. Flexibility of mobile devices to operate in different modes of operation & dynamically reconfigure will be made available through M-DALL.

8.3 High Level Requirements

The various requirements of the M-DALL are explained below as per figure 8-2.

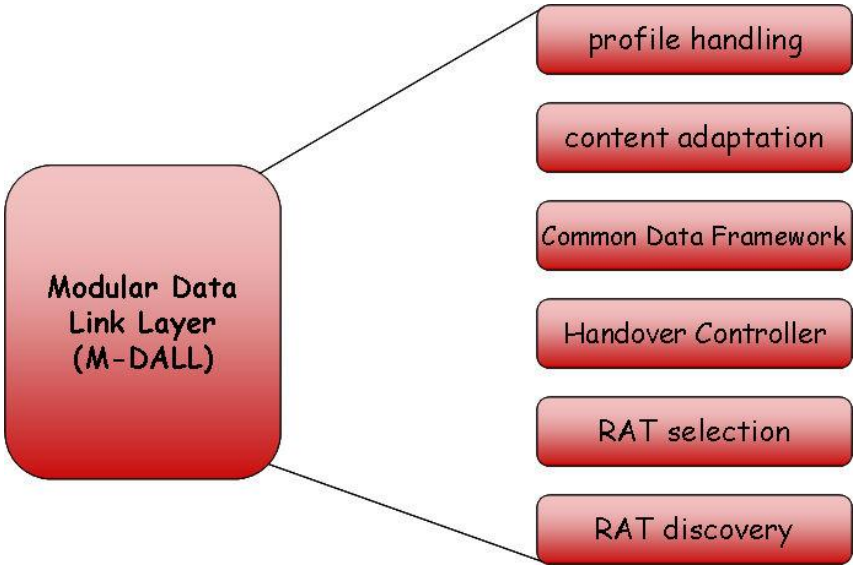

Figure 8-2 – M-DALL High level Requirements

- Hide the heterogeneity associated with the use of multiple RATs as well as the properties and deficiencies of the radio link from the higher layer with respect to both users and services.
- Provide an API simplifying access to link layer information of the application layer.
- Enable the integration of different RATs in a common Framework that would seamlessly provide all functionalities inherent in conventional radio access networks including handover, context transfer and QoS support.
- Provide a set of generalised data layer control and processing functions, responsible for efficient cooperation between RATs.

- Provide a Unified interface to the upper layers and physical layers acting as a Multi-RAT convergence layer.
- Facilitate the LLC/SNDCP/PDCP/RLC/MAC/RLP functionalities of multiple RATs supported, in order to maximise the Layer 2 performance.
- Provide a modular architecture that readily caters for the integration and co-operation of different types of existing and future RATs.
- Support the service requirements of the higher layer traffic.
- Provide enhanced services like Data Storage, Resource Optimisation, Content Adaptation and power consumption method.

In addition to provide a uniform API, the architecture of the M-DALL has been designed to fulfil the following requirements:

- *Extensibility*: Proposed architecture should be able to easily integrate new Radio link layer technologies, possibly providing new features.
- *Platform independent*: Proposed Software architecture should be able to be integrated on multiple software and hardware platforms.
- *Scalability*: Proposed architecture should be light enough to be used on Mobile devices.
- *Battery life*: Proposed architecture should not be a major source for battery power drain.

8.4 M-DALL Interface Architecture

The proposed M-DALL is to provide software API that will hide network standards heterogeneity behind a common set of functionality applicable to all types of networks. I believe that such an API is a step forward in the direction toward intelligent radio aware software that will be able to accommodate multiple radio standards in a seamless way. Figure 8-3 shows the various interfaces of M-DALL with other layers like Application, Transport, Network and Physical layers.

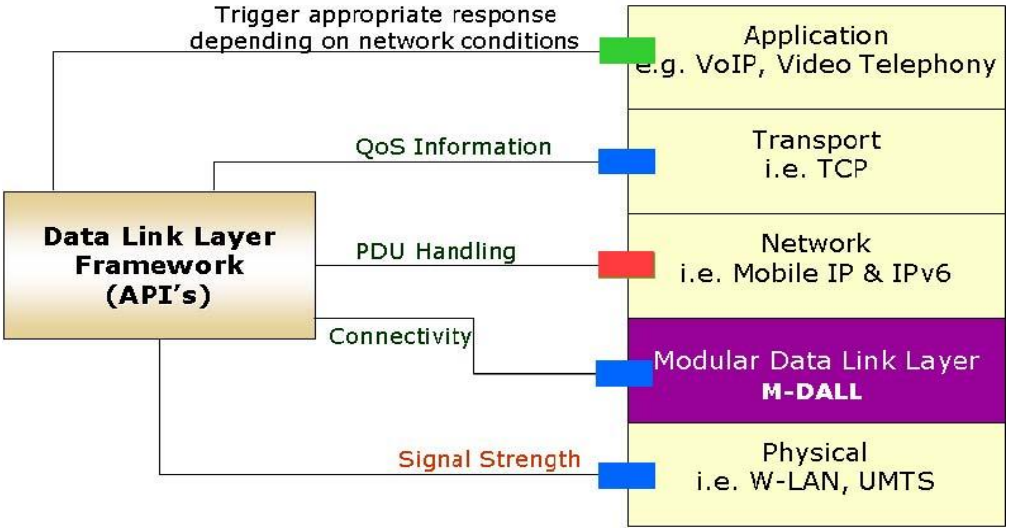

Figure 8-3 – M-DALL Interface Architecture

The M-DALL will help to resolve the complexity and interoperability problem related to the large number of different APIs and methods used for accessing communication interfaces, especially in the wireless domain. The M-DALL provides APIs from specific link technologies to the applications or can include any higher layer protocols, middleware or application software. It achieves this by regarding a link to be a generic means of providing a communication service. Links are made available and configured through application software to permit abstraction from specific platforms and technologies. The M-DALL support functionality for transmission over an access link. It embeds access specific transmission methods and protocols. The M-DALL provides the following interfaces with various layers as depicted in figure 8-3.

8.4.1 The Application Layer Interface

Through the application layer interface, the M-DALL is configured and reconfigured. Based on that, the M-DALL monitors the performance of the access link and the QoS that is perceived by an access flow. It also observes the availability (including load) of the access links and based on certain rules and thresholds (event filtering and classifications) configured, it reports link events (triggers) to application layer, e.g. when the performance of the access link changes by a certain amount, when a new access link is detected or lost, when a QoS requirement of a flow cannot be met anymore and when the resource costs for access link pass a threshold or resources become scarce. It also receives measurement queries to report on access link and resource status frequently to the application layer.

8.4.2 The Network Layer Interface

The Protocol stack design and development of wireless terminals is a complex and therefore it is a challenging issue. The M-DALL shortens the developing process of wireless communications protocols. The Common Data Function Framework (CDFF) as shown in figure 8-4 which is part of M-DALL receives Layer 3 PDUs from specific RATs (like GPRS, UMTS, WLAN) provided by the upper layer. The CDFF performs the specific task according to the configuration done by upper layers. For the transmission of Layer 3 PDUs, usually segmentation in smaller transmission units is performed.

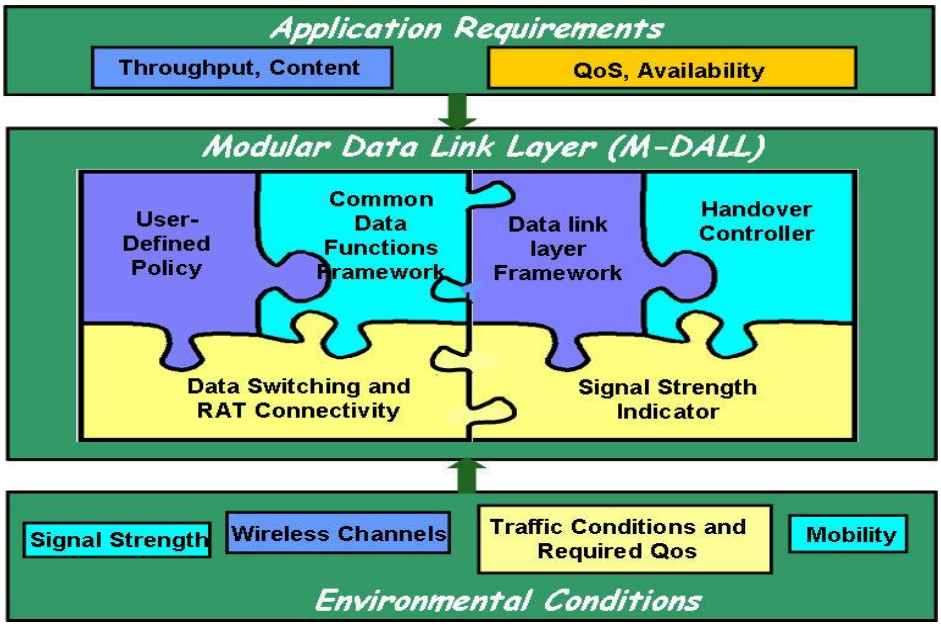

Figure 8-4 – M-DALL Software Modules

The CDFF is the realization of the various protocol stacks as illustrated in figure 8-4, and software architecture is designed in such a way, that the common functions of all wireless protocol stacks are combined in CDFF. These common functions can be repeatedly used with a different set of parameters corresponding to the specific Wireless communication technology. The CDFF has interfaces with major sub layers like Radio Link control (RLC) of UMTS, Packet data convergence protocol (PDCP) of UMTS, Sub-network dependent convergence protocol (SNDCP) of GPRS, RLP of CDMA2K and Logical Link Control (LLC) of WLAN. The CDFF specific functional part corresponds to various sub layers of Layer 2 protocol functionality of specific RATs and the CDFF controls the underlying configurations of different RATs.

8.4.3 The Transport Layer Interface

The M-DALL measures QoS parameters for various multimedia applications via the Transport Layer Interface. This approach is to identify the traffic flows and configure the QoS requirements for certain traffic flows via a separate control interface. This interface allows having the QoS negotiation mechanism and applying common policies and methods to provide the required service quality.

8.4.4 The Physical Layer Interface

The M-DALL provides a new API that enables technology-independent configuration and flexible monitoring of lower layer settings and characteristics. M-DALL offers a powerful query mechanism that enables applications to gather link layer information in a flexible and usable manner. Additionally, mobile applications can register with M-DALL for notifications and define specific conditions depending on the actual use case. Some of the Multimedia applications could benefit from Physical layer interfaces which are sensitive to varying QoS such as video conferencing, video streaming, video-on-demand and VoIP-clients.

8.5 M-DALL Software Architecture

The most important requirement of M-DALL is the ability to acquire link-layer information, provide common data functions and facilitate handover decisions. This section introduces the software architecture of the M-DALL as an initial step in the implementation for multi-mode capable mobile devices.

As shown in figure 8-5, the following are the additional software modules identified as a part of the M-DALL:

- Data Link Layer Framework (DLLF)
- Common Data Functions Framework (CDFF)
- Handover Controller (HC)
- DLLF & its Interface Architecture

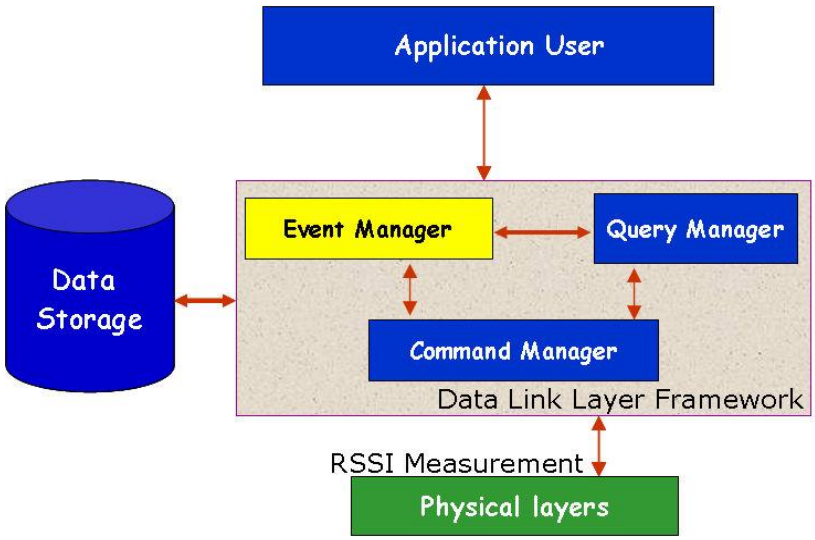

Figure 8-5 – Link Layer Architecture

Figure 8-6 presents a graphical overview of the different components involved in the implementation of the DLLF which is part of M-DALL. It contains three main components.

- Queries,
- Notifications, and
- Commands.

DLLF query specifies a request made by an application to retrieve information about RAT. A notification request is used to specify a condition that should trigger an asynchronous notification. Finally a command is a request specifying an action that should be executed to modify a link layer state. The following is an overview of the basic elements composing the M-DALL architecture.

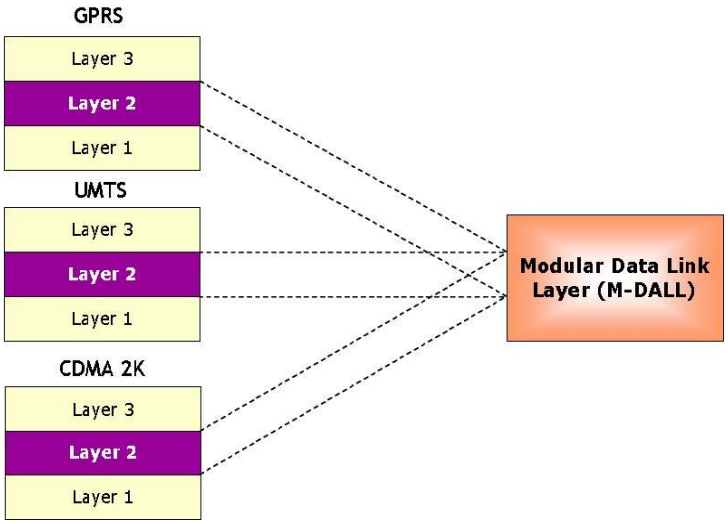

Figure 8-6 – Layer 2 Interface Architecture

The query manager module is in charge of analysing the queries and notification requests coming from link users. The command manager module handles commands and forwards it to corresponding link provider. The event manager module takes care of handling events arriving from the link providers (new link arrivals, new value for a link characteristic) and in particular of the evaluation of registered notification requests. Finally the storage module, represented outside of the DLLF, is an optional component used to cache link characteristics collected from various modules in order to prevent access to the drivers or hardware for each query. The DLLF achieve a set of core functions that map the different RAT link layer functions both vertically and horizontally.

8.5.1 Common Data Function Framework (CDFF) Software Architecture

The M-DALL deepens the concept of Layer 2 protocol stack software in the context of wireless terminals. The CDFF which is part of M-DALL compromises common functionality that is extended through specific parts of dedicated RATs like GPRS, UMTS, CDMA2K and WLAN as shown in figure 8-7 and will serve as a basis for future protocol stack development through reusable software components. Thus, the CDFF provides a flexible design approach for realisation of existing and future wireless protocol stacks.

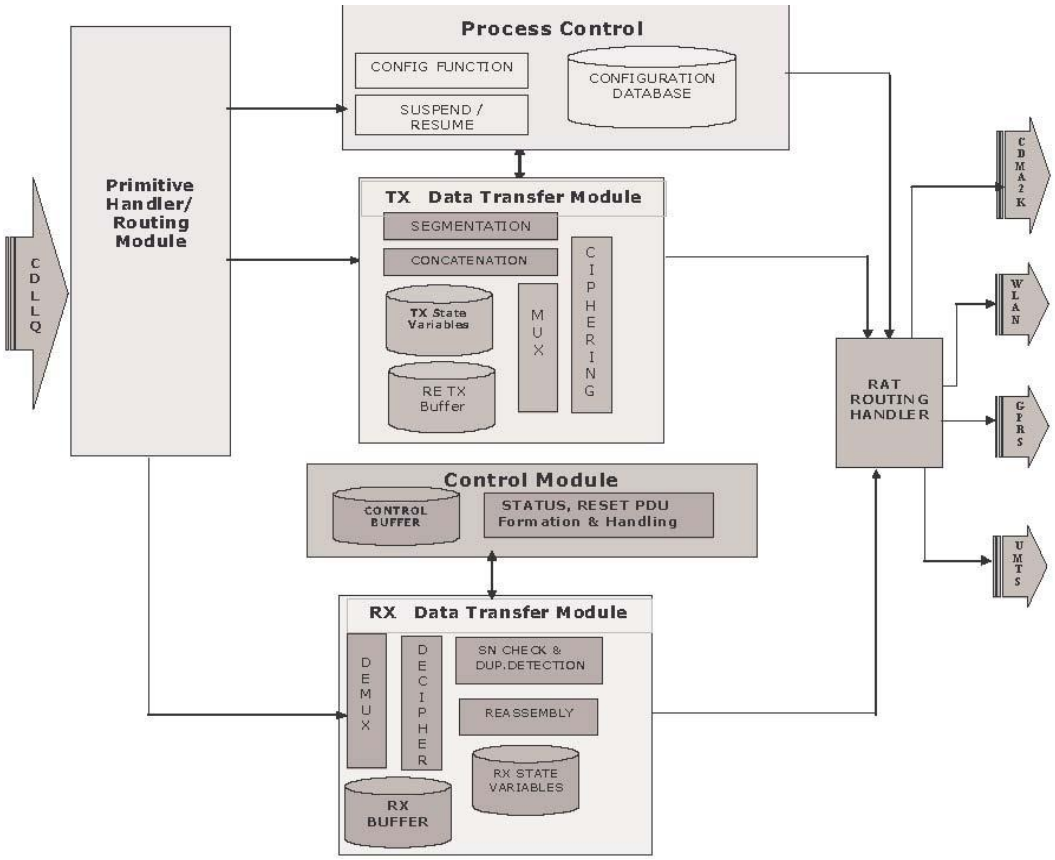

Figure 8-7 – CDFF Software Architecture

The requirements on the radio link layer can differ for various radio access technologies. For example, header compression of higher layer protocol fields is deployed in cellular wide area networks, whereas it may not be required for wireless local area networks. Therefore, the CDFF offers a library of functions, which can be separately enabled and configured according to the requirements. To give an example, a function performed for non-conversational data by each radio link layer is ARQ to recover from transmission errors by retransmitting erroneous data blocks. However, different ARQ are used in various radio link layers, which differ only in details although the same functionality is performed. The RLC protocol of UTRAN has generalised the ARQ functionality by specifying an ARQ library, which can be configured in various ways. This allows configuring the UTRAN RLC ARQ function very similarly to ARQ functions used in other link layer protocols. The same kind of generalisation has to be expanded to other link layer functions. This shall result in generic data function for priority handling and scheduling, data segmentation and also link security handling.

Further, the main aim of CDFF is to gather these common parts in a single data link layer and the targeted advantages of this CDFF are maintainability, code sharing and protocol development through reusability. The following are the common functionalities considered for the CDFF:

- Queuing of incoming data;
- Queue management with packet discard functionality;
- Header compression of higher layer protocol fields;
- Segmentation of higher layer datagram into transport blocks with sizes that are suited for efficient radio transmission;
- Dynamic scheduling of data for transmission;
- Priority handling of data transmission;
- Error handling with the help of FEC;
- ARQ protocols Send and Wait ARQ, Go Back N ARQ or Selective Reject ARQ;
- Correction of transmission errors;
- Reassembly;
- Concatenation;
- Padding;
- Transfer of user data;
- In-sequence delivery of higher level PDUs;
- Duplicate detection;
- Flow control;
- Sequence number check;
- Protocol Error Detection and recovery;
- Multiplexing of PDUs;
- Ciphering;
- Suspend/Resume function;
- Header Compression; and
- Buffer Management (N-PDU Buffering).

The functionality of the CDFF is explained with the architectural diagram as shown in figure 8-7 and 8-8. The communication inside the CDFF is performed by employing generic service primitives and PDUs.

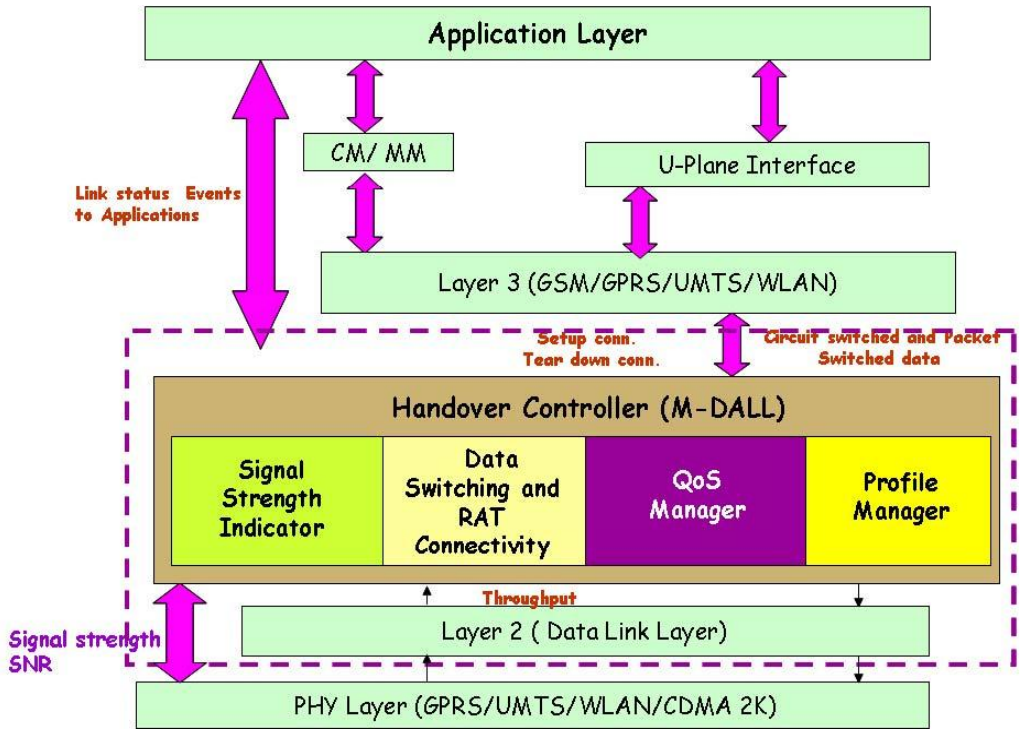

Figure 8-8 – Handover Controller in M-DALL

The following functional blocks constitute the CDFF architecture:

- *Primitive Handler Module* – This software module handles primitives received from the Layer 3 protocols of different RATs validates and passes the information to RAT Routing Handler.

- *RAT Routing Handler* – The Routing handler gets the signals from the CDFF message queue and stores in the SDU buffer. It also ensures that the Layer 3 PDU's are handled respectively based on RAT specific and communicates to TX Data Transfer module or to RX Data Transfer Module for further processing.

- *TX Data Transfer Module* – This module takes care of the data transmission in uplink. It forms the Layer 2 PDUs from the SDUs received from the upper layers for the respective RAT (e.g. UMTS, GPRS) and performs the segmentation function where a single SDU is segmented into different PDUs. In addition, it performs the concatenation, ciphering and multiplexing functionalities for specific RATs configured by the upper layers.

- *Control Module* – During data transfer, the Control Module performs the transmission and flow control. It takes care of the Status PDU formation and Status report handling. In the case of errors, the Control Module also performs the recovery through a reset procedure for specific RATs.

- *RX Data Transfer Module* – This module at the receiving side receives the PDU and forms the SDU. It performs the reassembly of PDU received in one TTI. SDU formation, duplication detection and error detection by sequence number check are performed by this module and the data units are passed to respective Layer 3 RATs. More specifically, the CDFF. It performs the following:

    - provides a unified interface to the upper layers and physical layers acting as a Multi-RAT convergence layer.
    - controls the RLC/MAC functionalities of multiple RATs supported in order to maximise the Layer 2 performance, while efficiently utilising the radio resources allocated by the L3 – Radio Resource Protocol (RRP) of various RATs.
    - provides a modular architecture that readily caters for the integration and co-operation of different types of existing and future RATs.

The proposed modular concept of a generic data link layer enables link layer functions for future multi-mode capable handhelds and provides a flexible design approach for realisation of existing and future wireless protocol Stacks.

8.5.2 Handover Controller

Offering of seamless handovers is one of the most important requirements for a complete mobile system because of communication range is limited [106, 107].
Following are couple of examples for the RAT selection algorithm:

- Select the radio access flow with the highest radio link quality (e.g. highest SNR). The motivation here is to select a radio path with the best radio link conditions leading to high quality communications.
- Pre-defined priority list (e.g. preferred RATs and/or operators) that is used in selecting the radio access flow.

Based on the above criteria, a complete and detailed functional analysis of the specific detection is described below. The traditional handover algorithms use the received signal strength as the main trigger for handover decisions. Examples for such attributes are listed below. The following abstract detection basic parameters are identified:

- link_quality (RAT, thr1): establishes if the radio link (downlink) with the RAT specified has acceptable quality (better than threshold thr1);
- QoS(type): evaluates a parameter (specified in the field type) representative of the QoS provided by the serving RAT;
- Neighbour (thr1): locates candidate RATs which offer a radio link of acceptable quality;
- RAT_selection (RAT): selects the best RAT with respect to link quality by making a comparison between abstract performance metrics offered by the serving RAT and by the vector of neighbour RATs;
- HO_trig (type, thr2): gives an alarm if the QoS parameter (type) provided by the serving VAP degrades behind the warning threshold (thr2).
- Error rates (Bits, Frames or Packets): measured based on different units such as bits, frames or packets.

Each of the above procedures is finally mapped through the adaptation modules into one or more system-specific function calls. The selection of a RAT is the core of the whole algorithm. Although several decision mechanisms can be implemented, choice was to use a simple comparison between abstract performance metrics. Then, the algorithm is represented by the possibility to dynamically set all the parameters involved in the procedure. On one side, the user can specify the weights to be assigned to each interest performance numbers, such as signal strength, cost, transmission rate, power consumption, etc for the decision metric composition. On the other side, to avoid unnecessary oscillations between two interfaces, the user can declare warning and optimal thresholds for each performance indicator.

The critical aspects of HC is a collection of signal strength information from local physical layers (from GSM, UMTS and WLAN), selection of specific RAT based on the measurement parameters (like RSCP, RSSI, Ec/Io) and generate triggers for making

handover decisions. It provides facilities for continuous measurement of QoS parameters to monitor the required QoS during the actual data flow and does the comparison of defined QoS parameters with the actual QoS based on the type of services (e. g. video telephony, video streaming). It continuously monitors and compares the QoS parameters with the defined and actual parameters for the specific service. It also provides user selection by providing an option for selecting the best network for downloading large data or media files capable of supporting a higher data rate. It also makes smart decision to perform vertical handover and invokes appropriate RAT in the Mobile Terminal for signalling and actual data flow. As shown in figure 8-8, the following software modules are part of the Handover Controller for providing seamless handover across different cellular networks:

- Signal Strength Indicator (SSI)
- Profile Manager (PM)
- QoS Manager (QM)

The functionalities of each software module are explained below:

- *SSI* – The SSI software module identifies and monitors the existing and alternative RATs like GPRS and WLAN. The monitoring of the existing RAT should be done continuously so as to check if the signal strength of the existing home network (GPRS) and foreign network (WLAN) is above the threshold value, where it fails, it gives a trigger to the Handover Connection Manager to perform smooth vertical handover.

- *PM* – The PM is used to store user profiles, terminal profiles and network profiles. The PM provides information about all types of cellular network profiles, User preferences and QoS profiles as well as information on QoS actually delivered for active application services. The Static profile holds information that does not change very often and includes Wireless Networks, Applications and its QoS requirements. The Dynamic profile holds the current information such as current QoS network parameters like bandwidth, delay, jitter, packet loss and throughput.

- *QM* – The QoS manager is responsible for measurement and monitoring of QoS parameters like jitter, delay, packet loss, throughput and FER. Its main task is to store the predefined QoS attributes in the information database, monitor and compare the

negotiated QoS parameters with the actual values such that if a change in the negotiated value occurs, then initiate the triggers smart decision maker to perform a vertical handover.

The M-DALL trigger for handover is an abstraction of a notification from the link layer to the application layer that a certain event has occurred or is about to occur. The components of an M-DALL trigger are the event that causes a trigger to fire, the entity that receives the trigger and the parameter that is delivered with the trigger.

8.6 M-DALL Enhanced Services

In this section, some new ideas for possible new and enhanced services based on the usage of the M-DALL are presented.

8.6.1 M-DALL for Unlicensed Mobile Access

M-DALL appears to be an appropriate solution to integrate approaches to unlicensed mobile access (UMA) and IP wireless networks. As UMA enables the connection to unlicensed spectrum networks via IEEE 802.11 or Bluetooth (PAN profile is required), UMA could take advantage of M-DALL capabilities as shown in figure 8-9, to manage the available links and to select the most adequate technology. Therefore M-DALL could be integrated within the UMA mobile terminal architecture to manage the access to the unlicensed spectrum links, facilitating the handovers between technologies. Despite the fact that many of the previous features are already supported by M-DALL, the access to the wireless networks within UMA managed by M-DALL would probably require a new link in order to support the special needs of the wireless link for the UMA architecture.

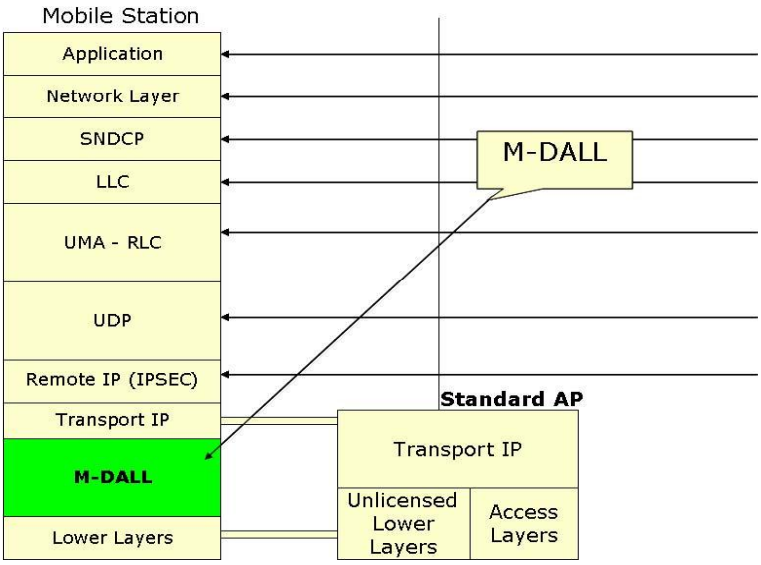

Figure 8-9 – M-DALL for UMA

8.6.2 M-DALL for IEEE 802.21-based Media Independent Handover

The IEEE working group 802.21 (WG 802.21) is currently standardising approaches to realise mobile independent handover (MIH). The information necessary to make effective handover decisions is lacking in part because the 802.XX network provides insufficient information to the upper layers. Thus, there is a need to develop a standard that permits information exchange between mobile terminals and/or networks to enable mobile terminals to make more effective handover decisions.

M-DALL is very appropriate for implementing 802.21-based MIH, as shown in figure 8-10. All required features are supported by the latest M-DALL or could easily be added when the final 802.21-standard is available. Additionally, M-DALL is able to further abstract the link layer access and enable technology-independent handover-management. The latest standard draft still relies on technology-specific interfaces that are to be defined by the respective technology-standardisation [93]. M-DALL would solve this problem and offer the same interface for all deployed technologies. Moreover the implementations of the 802.21 events are very flexible and new developments can be included without any need to change higher layer entities.

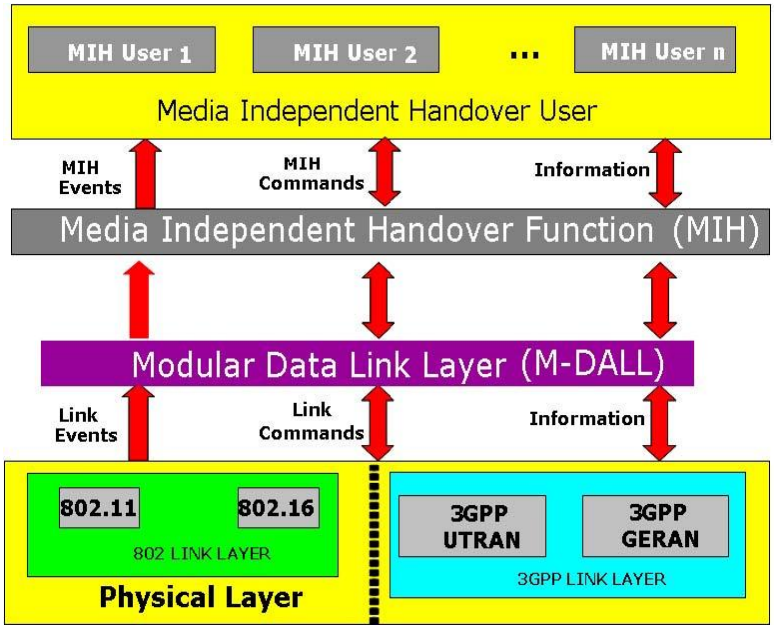

Figure 8-10 – M-DALL for IEEE 802.21-based MIH

Mobile devices running M-DALL for all deployed technologies allow the gathering of link layer information in a well standardised and technology-independent way. The interfaces used between the MIH function and different link layers are not clearly specified yet. Additionally, those interfaces might partially be technology-dependent introducing further complexity. Using M-DALL instead would solve these problems and allow media independent analysis. The final set of standardised events was not yet decided at the time of execution of this project. Some examples for events that are described in the draft standard [80] are listed below:

- Link Up
- Link Down
- Link Going Down
- Link Parameters Change
- Link Handoff Complete

8.6.3 M-DALL for Voice

M-DALL can improve the quality of voice calls as it differs by independently selecting different RATs. The M-DALL role can be classified as follows:

Roaming Prediction: M-DALL can notify the voice application upon changes in detected infrastructure (entering or leaving an access point) so that handover is anticipated.
Voice Quality Improvement: as the conditions of a RAT can vary over time (either due to congestion or the wireless link becoming noisy), M-DALL can help monitoring the dynamic network state and help the voice application take countermeasures. For example,

- a different voice codec can be selected; or
- in case of excessive packet losses, M-DALL can notify the voice application to apply error concealment techniques (like Audio Adaptive Playout);
- cross-layer optimisation techniques can also be used to fine tune MAC and PHY parameters according to network condition estimates.

8.6.4 M-DALL for Battery Life

As presented in the description, the M-DALL storage maintains the attributes provided by known link layers (bandwidth, signal strength, etc). The main issue is updating these values while still limiting battery consumption due to polling or code execution. To reach this goal, the following strategy is used. All attributes maintained in the M-DALL storage have an associated timestamp indicating the last time they were updated. When a query request is performed, the validity of the requested attribute(s) is specified in the query and passed to the storage database (SDB). For each requested attribute, the SDB checks with the associated attribute timestamp and the validity of the attribute. If the attribute is too old, a query is forwarded to the corresponding application to retrieve the current version of the attribute. This "lazy update" strategy enables the M-DALL to keep the number of queries to the bare minimum required by applications.

8.6.5 M-DALL for Power Saving

The power saving mechanism describes how M-DALL can collaborate with other layers to reduce power consumption. The power saving mechanism describes an interface to mobile applications and other higher layers and translates to the appropriate low-power states of the wireless bearer used and it is depicted in figure 8-11.

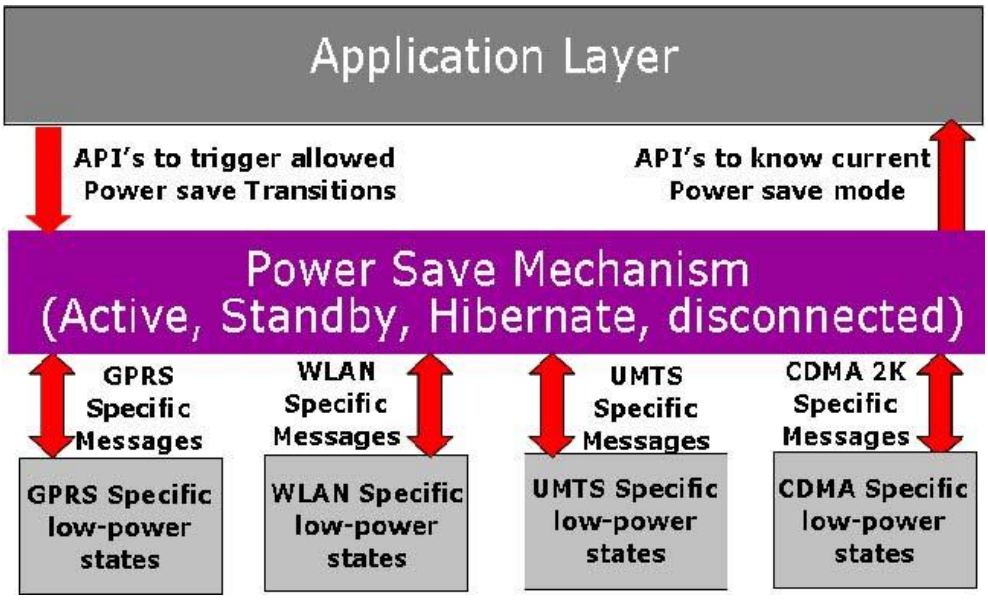

Figure 8-11 – M-DALL for Power Saving

However, one of the design goals was to avoid introducing any new protocols between M-DALL, Application and Physical Layer for power saving. Therefore, the proposed power saving mechanism relies on existing interface API's used by the DLLF link-layer protocols to decide the desired power saving mode transition. The PS mechanism defines four abstract modes of the connection between M-DALL, Application and Physical layers:

- *Active*: the radio is in the active mode. The M-DALL has full IP connectivity and can communicate in full speed.
- *Standby*: the radio is in a power-saving state maintaining synchronisation. The M-DALL must re-establish its connectivity upon becoming active again because timeouts may occur depending on the selected parameters of the underlying bearer power-saving state.
- *Hibernate*: the RAT is in a deep-sleep state and other higher-layer network state may be lost. So the Mobile Device Software must re-establish this state upon becoming active again. Thus, the wake-up process is in general faster than establishing a brand new connection.
- *Disconnected*: The radio is off. No state is kept to restore the connection. A new connection establishment process must be repeated.

8.6.6 M-DALL Storage Library

The M-DALL Storage library provides support for the caching of Radio link information collected from the underlying RATs. To limit the memory footprint on memory constrained devices, the M-DALL storage has been implemented from scratch and to be flexible, the storage library has been implemented as a generic storage.

8.7 Conclusions and Future Work

In this chapter, the systems architecture and enhanced services of M-DALL was presented. The M-DALL in terms of a collection of functionalities which enable and facilitate efficient data link-layer inter-working among multiple radio accesses technologies was also presented. The DLLF offering a common interface to monitor the characteristics of various RATs was introduced. The M-DALL performs the generic functions by offering a common set of functions in a CDFF, which is enabled by the specific RAT. The M-DALL is a contribution towards the paradigm of future generation wireless networking to achieve cooperation between different radio access networks and technologies. In future, it is envisaged that the M-DALL will be the link layer which will be generally deployed in all 3G/4G mobile devices. This will enable seamless communication in a future of heterogeneous networks.

In the near future, the immediate task would be refinement of the M-DALL software architecture and fully working prototype implementation of M-DALL on different platforms. The evaluation of enhanced services by means of analysis, simulations and prototyping is a topic of ongoing and future work. Although, the intuitive M-DALL seems practical, further work is required to test its effectiveness in the real-world environment. I conclude that the proposed M-DALL is a stepping stone towards a unified solution targeted for 4G systems. M-DALL manifests itself as a valuable framework by enabling a cooperation of different access networks at the link layer, therefore adding to customer satisfaction and opens multiple dimensions for revenue generation opportunities.

Chapter 9

Development and Implementation of DLNA-enabled Mobile Terminal and Home Gateway offering an Adaptive QoS framework for the Digital Home Environment to Cater for Multimedia Services for the Aricent Group (2009-2010)

9.1 Introduction

Various access technologies like Wi-Fi and Bluetooth are used in the home network. In designing and implementing a media distribution system in a converged home network there are two design considerations. The first is the interoperability of media management and control between different types of multimedia devices [108, 109]; and the second is the Quality of Service (QoS) management for multimedia to satisfy user's quality expectation because multimedia applications such as Audio/Video (A/V) streams, voice and games are bandwidth and delay sensitive [110 – 113].

The Home Gateway (HG) accommodates various international standards including Open Services Gateway initiative framework (OSGi) [114], Digital Living Network Alliance (DLNA) and the networking function of the conventional home gateway [108, 109]. HG is used as a fundamental technique to support inter-networking, QoS, and safe use between applications as well as a network for providing various intelligent services. HG not only pursues the integration of middleware technology that automatically controls home appliances and provides various services, but also convergence between data communication and broadcasting. In addition, the DLNA-supported home media devices are generally configured with private IP addresses based on Dynamic Host Configuration Protocol (DHCP) or automatic IP addressing mechanism. Therefore, this arrangement compromises the fact that multimedia transmission is not allowed when a DLNA device with a private IP address receives and transmits media contents from/to the Internet. The current generation of HGs provides insufficient QoS for meeting the demands of existing and emerging multimedia applications and likewise provides insufficient bandwidth management for optimum utilisation. Therefore, a home network service needs to support different data service traffic apart from the control traffic ensuring required QoS.

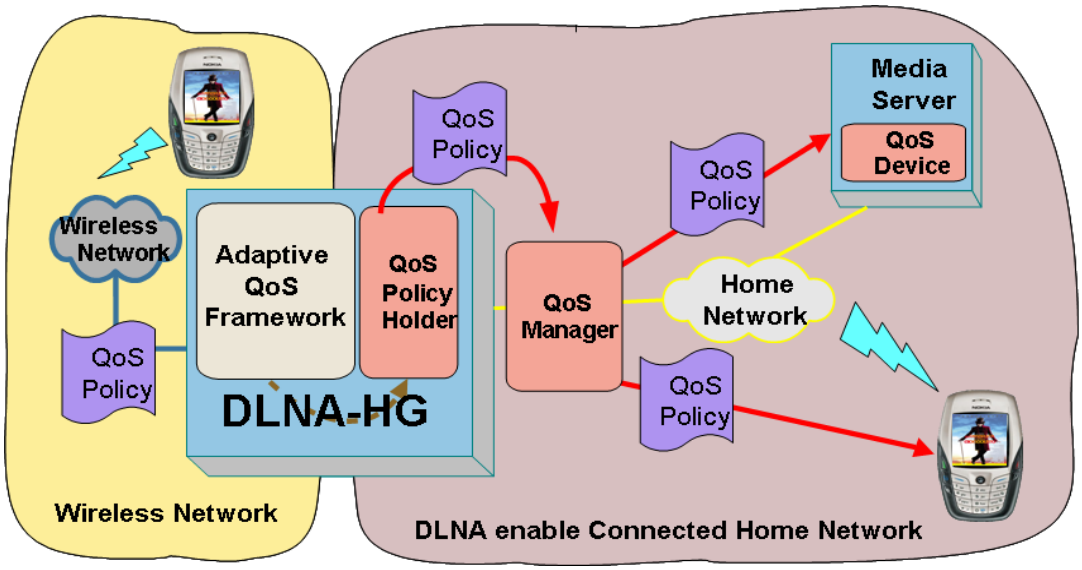

Figure 9-1 – DLNA Enabled Home Gateway with QoS Support

Hence, to help solve these problems, this chapter presents in detail, a new adaptive QoS framework for a DLNA enabled HG with the key features as illustrated in figure 9-1. They are as follows:

- bandwidth allocation policy,
- QoS parameter mapping scheme,
- different traffic classification,
- a set of QoS Key parameters for measurement and controlling the multimedia traffic, and
- feedback technique for ensuring the better QoS in the digital home network.

9.2 Design Approach

This section gives an overview of the design for the new QoS Framework. As a general requirement, the QoS Framework in a home gateway should allocate and manage bandwidth for active home devices automatically and efficiently. Before explaining the proposed QoS Framework for the DLNA enabled home gateway, the typical life cycle of a smart home with four steps is introduced.

9.2.1 Device Discovery

The home gateway is able to discover new home devices in two ways using Universal Plug and Play (UPnP) protocol either by sending an active search signal or by listening to passive announcements generated by devices [115, 116]. Bandwidth requirements and other characteristics of devices are also sent to the QoS framework at this step [117].

9.2.2 Device Removal

Upon removal of any devices from the home network, the QoS framework releases the bandwidth occupied by that device [118].

9.2.3 Bandwidth Allocation

Firstly, configuration models are used to determine how much bandwidth and what priority should be assigned to the device. If the bandwidth required is available, it is assigned to the device. Otherwise, the QoS framework calls the bandwidth arbitrator to see if it is possible to release some bandwidth from devices with lower priority [119]. If this is possible, bandwidth is assigned, otherwise the device is deregistered.

9.2.4 Bandwidth Re-allocation

The modules within QoS framework responds to the bandwidth reallocation request. However, it only reallocates bandwidth if it is available. Otherwise nothing is done [120].

9.3 Proposed Adaptive QoS Framework

This section gives an overview of the design of the proposed QoS framework. As a general requirement, QoS framework in a DLNA-HG should allocate and manage bandwidth for active home devices automatically and efficiently. Figure 9-2 depicts proposed software modules in adaptive QoS framework.

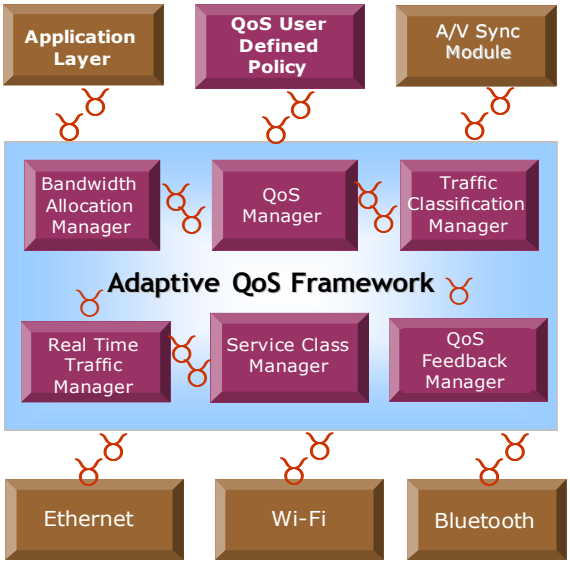

Figure 9-2 – Proposed Software Modules in Adaptive QoS Framework

The proposed QoS Framework contains the set of identified software modules,

- Bandwidth Allocation Policy
- QoS Manager and its Key Mapping Parameters
- Traffic Classifier
- Service Class Manager
- Real Time Traffic Manager
- QoS with Feedback Mechanism
- Audio/Video Sync Manager

The QoS Framework discovers and controls QoS for the devices connected in the home network and is responsible for requesting and releasing the QoS assigned to various traffic streams. In addition, the DLNA enabled Home Gateway provides interfaces for the Control Point to initiate QoS setup, releasing and updating.

9.4 Bandwidth Allocation Policy

In this section, the bandwidth allocation policies are described that are part of the proposed QoS framework and then the set of QoS parameters and its mapping to various application are discussed and finally, the media distribution considering few multimedia use cases are presented.

Bandwidth allocation policies are used for arbitration when the physical bandwidth is not sufficient for all the traffic requested by DLNA devices. A set of common bandwidth allocation policies should be followed in all models. These policies are:

- Policy 1: Traffic with higher priority always gets the bandwidth.
- Policy 2: Among the traffics with same priority, those non-isolated and non-bounded traffics are always reduced or suspended to release bandwidth.
- Policy 3: Among the traffics with same priority, if all traffics are either isolated or bounded, the latest one that gets it allocation is suspended to release bandwidth.
- Policy 4: In exception of all above policies, security traffics, if exist, should never be suspended to release bandwidth.

Bandwidth allocation is a complex issue in home networking environment, especially when multiple devices are competing for bandwidth. The four major parameters need to be considered while allocating bandwidth for various devices:

- *Characteristics of Traffic*: Differentiation has to be made between delay sensitive, delay jitter sensitive and throughput sensitive traffics.
- *Presence of Home User*: If home users are not at home, traffics involving user interaction should be given a lower bandwidth, and vice versa.
- *Presence of other Device Traffic*: If bandwidth is insufficient, it should be allocated to the devices with higher priority, unless manually configured by users.

9.5 QoS Manager

The QoS manager located in QoS Management Sub-layer is configured according to applications, network specific QoS requirements and resource availability. The QoS manager modules functionalities include the following:

- *QoS Monitoring* allows tracking the ongoing QoS levels achieved by the lower layers.
- *Flow Scheduling* manages the forwarding of flows in an integrated manner.
- *Flow Policing* observes or monitors whether the QoS required by a user is being maintained or not.

- *Flow Synchronisation is required to control the precise timing of multimedia interactions.*
- *QoS Maintenance compares the monitored QoS against the expected performance and then performs tuning operations on resource modules to sustain the delivered QoS.*
- *QoS Degradation issues a QoS indication to the user by the QoS maintenance mechanisms.*

In the proposed QoS Framework, a set of QoS parameters are considered and the brief definitions of the key parameters are explained as follows:

- *End-to-End Delay*: The time duration from the event when a data packet is transmitted by a source to the event when it is received at the destination.
- *Delay Jitter*: The delay between two successive data packets received at the destination.
- *Bandwidth*: The bandwidth reserved for a packet or a flow.
- *Throughput*: Total number of bits sent to the higher layer from the MAC layer. The data packets received at the physical layer are sent to the higher layer if they are destined for this station.
- *Packet Delivery Ratio*: The ratio between the data packets sent by a source and data packets successfully delivered to the destination.
- *Load*: Total number of bits received at the app level. Packets arriving from the higher layer are stored inside the buffer.
- *Scheduling Algorithm*: Determine the transmission time for the packet in each queue to provide QoS assurance, which will influence the delay of services.

9.6 Traffic Classification

Before bandwidth allocation can be performed, DLNA-HG must identify the traffic that is travelling through it and this process is called Traffic Classification. The proposed DLNA-HG classifies the traffic into seven classes. They are,

- *Multimedia Traffic* – This traffic includes IPTV streaming, VoIP applications, video conferencing and other multimedia traffic. This class requires large bandwidth, small

delay and delay jitter. High priority should be given to this class and the bandwidth should be reserved when the application is running.

- *Security Traffic* – This traffic includes securities which normally work when the user is outside the home. This class occurs periodically and frequently. Hence a relatively small bandwidth but high priority should be reserved for this class.

- *Device Control Traffic* – This traffic belongs to control signals for home appliance. These are normally small and short messages. These signals appear at user request. This class is assigned with high priority but with no bandwidth reservation requirement.

- *File Transfer Traffic* – Typical file transfer traffic is File Transfer Protocol (FTP) traffic. Large throughput is required by this class. It is not sensitive to delay and delay jitter. This class should be suppressed if it coexists with higher priority traffic.

- *Web Traffic* – This traffic includes normal web browsing. It should not be over-starved by other traffic because active user interaction is involved. Hence a fair portion of bandwidth should be reserved but the priority is assigned as not important.

- *Interactive Traffic* – This traffic includes delay-sensitive traffic of applications like telnet. It should be transmitted with minimal delay because of their sensitive characteristic to RTT.

- *Best-effort Traffic* – This traffic is transmitted with best effort only. According to the needs of the system and user, DLNA Gateway can classify traffic into other classes such as DNS, mail, etc.

Other factors that can influence the allocation of bandwidth may also exist. This is greatly depending on the future development of home technology. The proposed QoS framework can cope with new technologies by expanding its bandwidth allocation models. In the QoS framework, two models are proposed to handle users at home and users out of home.

9.7 Service Class Manager

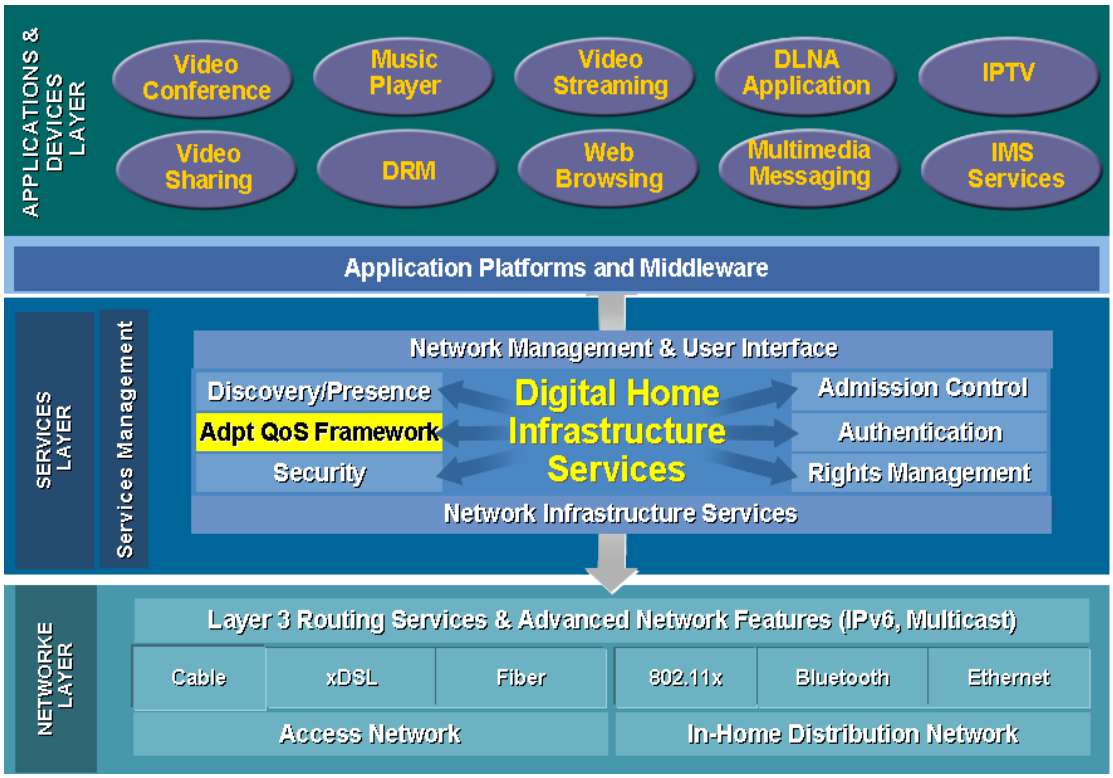

Figure 9-3 – Interface of Adaptive QoS Framework within Services Layer

Based on the above traffic classification and as per the guidelines provided by DLNA on network connectivity, four service classes are defined as shown in figure 9-3 by mapping all the defined traffic class according to the characteristic of the service traffic and been summarized as follows:

- *Service Class 1*: this traffic class has the characteristic which is sensitive for the delay and the jitter, such as voice traffic, A/V streaming service. Therefore, it must be allocated to the fixed bandwidth.
- *Service Class 2*: this traffic class has the characteristics that are generated uncertainly such as the control packet for the home automation and sensitive for the delay. It also has the small size packet. It is inefficient to reserve the bandwidth due to its characteristic. Therefore, this type of traffic is transmitted using the prioritised QoS mechanism.

- *Service Class 3*: this traffic class requires the small delay and the large amount of the bandwidth. For example, if a user wants web surfing or home networked game, the user satisfaction is decreased as the delay is increased.
- *Service Class 4*: in this traffic class, FTP, E-mail, periodic reports uses the huge amount of the bandwidth because its generation is burst. This traffic is served based on the best-effort.

9.8 Real-Time Traffic Manager

The Real-time traffic manager supports real-time traffic management in maintaining larger bandwidth and higher speed of operation. The RTM identifies efficient packet transmission mechanism to provide flexible wireless access schemes for multimedia services with reliable QoS assurance. This module also provides enough Radio Resources for a new multimedia request to ensure the QoS requirement without degrading the service quality for current service.

9.9 QoS with Feedback Mechanism

Figure 9-4 shows a framework for adapting QoS using user feedback. The steps in the framework are as follows:

- The source (or) the user specifies the values of different QoS parameters with their minimum/maximum values and tolerance limits.
- The QoS parameters along with their respective values are given to the QoS Manager.
- If QoS Manager receives QoS parameters for a packet of the flow for the first time, it sorts the parameters according to their relative importance or weights. After that, the QoS Manager calls a method to take care of the parameter that is relatively the most important. After that, it takes measures to take care of the next relatively important parameter (if possible), and so on.
- The packet is then delivered to the destination according to its QoS specifications and the source is informed accordingly.
- If the source or the user is satisfied with the QoS of the packet delivered, the next packet is sent to the destination.

- If the source is not satisfied with the QoS of the packet delivered, it informs the QoS Manager about the change it wishes to have in the QoS. The QoS Manager tries to adjust the QoS parameters accordingly.

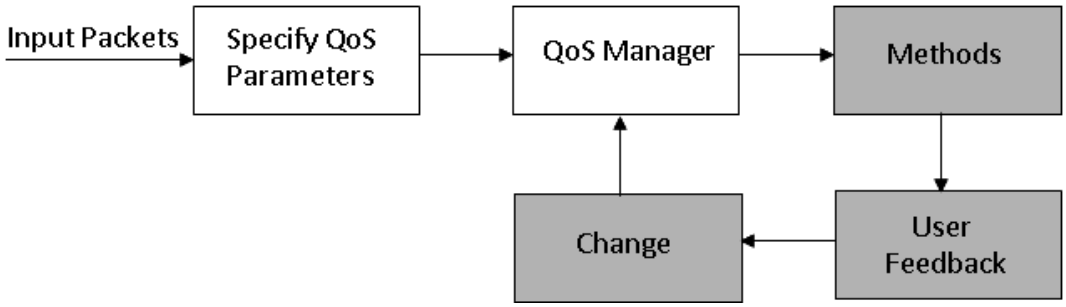

Figure 9-4 – Execution Process for QoS Framework

Note that the source specifies the values of QoS parameters, their minimum and/or maximum values, relative importance, and tolerance limit for each parameter. As mentioned above, QoS Manager sorts the parameters according to their relative importance. The QoS Manager calls appropriate methods for providing the QoS. The fact that which method has to be called first depends upon the relative importance of the parameters. Depending upon the relative importance of QoS parameters, different methods are invoked.

The first and the foremost task that the QoS Manager needs to perform is sorting of the QoS parameters according to their relative importance. Another set of input is the user feedback, in case when some form of QoS has been provided to the flow but the user is not satisfied with the QoS. Once the QoS parameters have been sorted, appropriate methods are required to be called to provide the given level of QoS.

9.9.1 A/V Synchronisation Module

A/V Sync is one of the key aspects of the media flow between client and server. In the proposed QoS Module, logic has been derived which would help in achieving the sync at both the ends.

9.9.2 Receive Side Video Rendering

This section explains the logic used for rendering the video frames using the rendering time stamps available for every frame with the real-time transport protocol (RTP) header information.

The first frame is rendered as soon as it is decoded. The system time at this point is taken as the reference time. Let this time be Tr. Let Td be the system time when a subsequent decoded frame is available. Let Tp be the presentation time of the frame decoded at instance Td. This time is relative to the first frame's timestamp in media time units.

- If (Td – Tr) == Tp, render the frame immediately.
- If (Td – Tr) < Tp, set a timer for (Tr – Td) == Te where, Te is the approximate overhead for firing of the timer. In the timeout function, render the frame without any checks.
- If (Td – Tr) > Tp, frame is delayed for display. This condition should not occur if all performance parameters are met.

9.9.3 Send Side Video Frame Timestamp Generation

This section describes the logic used for generating the video time stamps to be used in the RTP headers. Based on the frame capture rate configuration, calculate the frame time stamp whenever a frame is available. For the first frame, the time stamp shall be 0. For subsequent frames, let 'F' be the capture rate in frame/second and let (Tr) be the frame time stamp which will be calculated as (1/F) * 1000 milliseconds.

Current frame time Tf = Tr + Ta – where, Ta is initially 0, and Ta = Tf after every calculation for a frame i.e. it contains the accumulated time. The advantage would be the uniform timestamps for all frames.

9.9.4 Example: Streaming on Mobile over DLNA-HG

If a user wants to watch a movie on his mobile (from internet through streaming), the following the actions are triggered in the system.

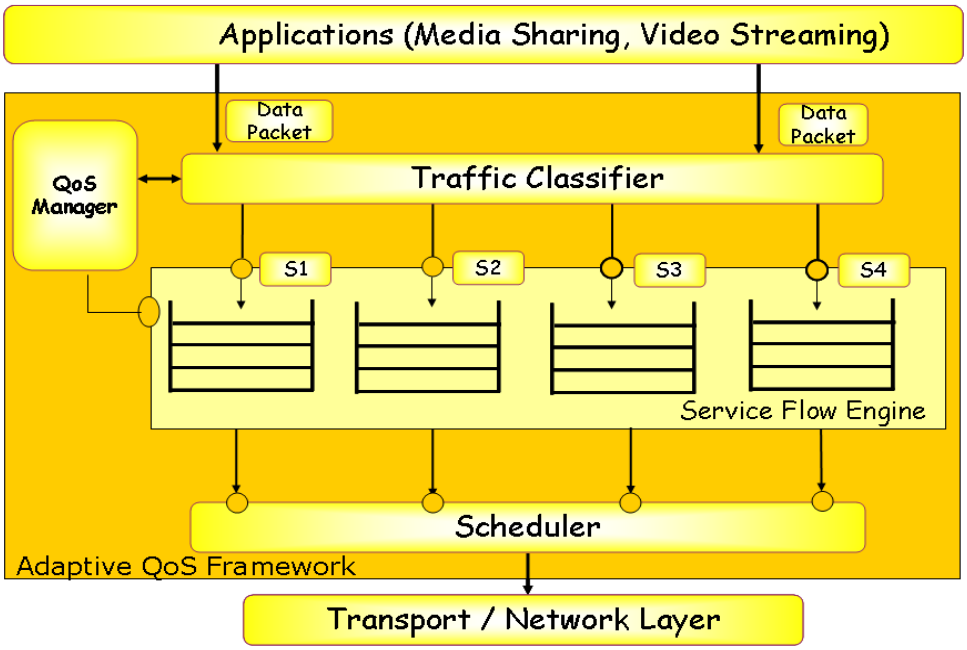

Figure 9-5 – Execution Process of QoS Framework

The diagram shown in figure 9-5 depicts the typical working model of the proposed QoS Framework. It primarily emphasises on guaranteed QoS by solving dynamic programming problems of bandwidth allocation by the proposed progressive optimality algorithm on DLNA HG. Based on the classification presented in section 9.3, at every stage recalculation and incorporation of information which propagates till the resource is allocated to the control point is carried out. This information is used in the decision making at successive stages. This can reduce communication overhead by reducing the available choices at each stage. This intelligent traversal method between stages also incorporates deterministic system state behaviour making it efficient.

The control point (mobile device) discovery is performed and the results are updated to the QoS Framework.

Within the framework, firstly, the bandwidth allocation policy is applied to determine the optimal bandwidth required for such application. For the above example, policy 2 or policy 3 may be applicable depending on the location of the user.

Secondly, subset of the key QoS parameters are selected which are applicable to the above selected bandwidth policy. Ex: Route lifetime may not be a critical requirement of

streaming kind of applications. Hence, may take a backseat during execution. The QM acting as a device for the control point acts as a control point to the QoS framework in responding with the information necessary for the actual control point. Subsequently, the traffic classification is performed which determines the kind of traffic class to invoke at the control point to access the service of the device. In this example, it falls under multimedia traffic. Once the control point is aware of the traffic class, the QM maps the parameters identified in the stage 2, with the priority (if any) and assigns the service class to the requested control point.

The process demonstrated in the above usage scenario shows a progressive approach to obtain optimal and deterministic QoS.

9.10 Media Distribution System with QoS

In this section, the design of the media distribution system is described. Consideration was given to a home network in which all network devices are interconnected by a DLNA enabled home gateway. As depicted in figure 9-6, the system composes three types of devices: a media server device, a media renderer device and a DLNA-HG gateway. Each element is implemented as explained below.

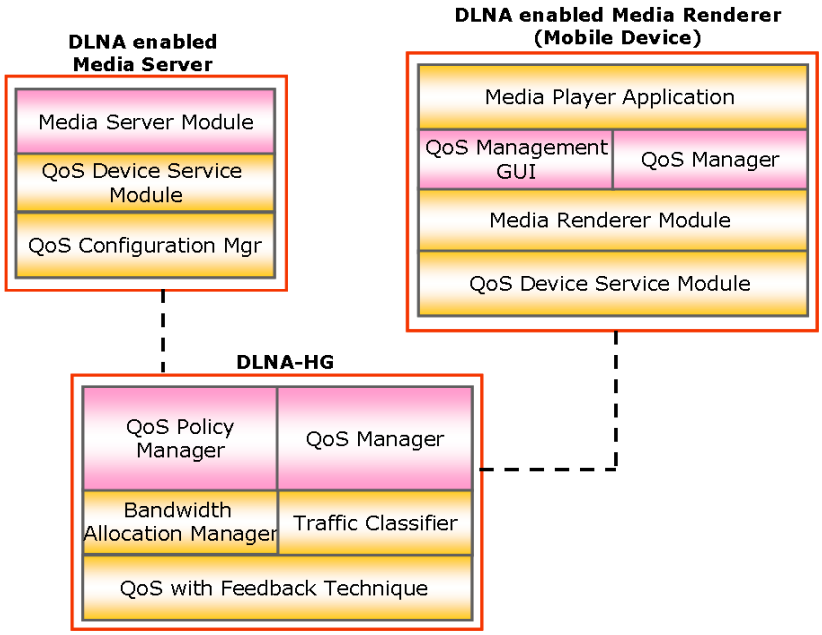

Figure 9-6 – Media Distribution between Gateway, Server and Renderer

9.10.1 Media Server Device

The media server device contains a media server module and a QoS Framework containing QoS device service module and a QM. The media server module stores multimedia contents and provides the control point of media renderer device with content directory service, connection manager, A/V transport and HTTP service. The QoS device service module provides interfaces to query the static QoS capabilities and run time state of the device. It requests the QM to assign Traffic class priority to a traffic stream identified by {source port, destination port, source IP, destination IP} according to the Traffic Importance number assigned by user. Then the QoS priority module assigns QoS user-priority to traffic streams according to Traffic Importance number to QoS user-priority mapping table. Because both Traffic Importance number and QoS user-priority have values from 0 through 7, the values of Traffic Importance number are mapped to the same values of user-priority.

9.10.2 DLNA -HG Device

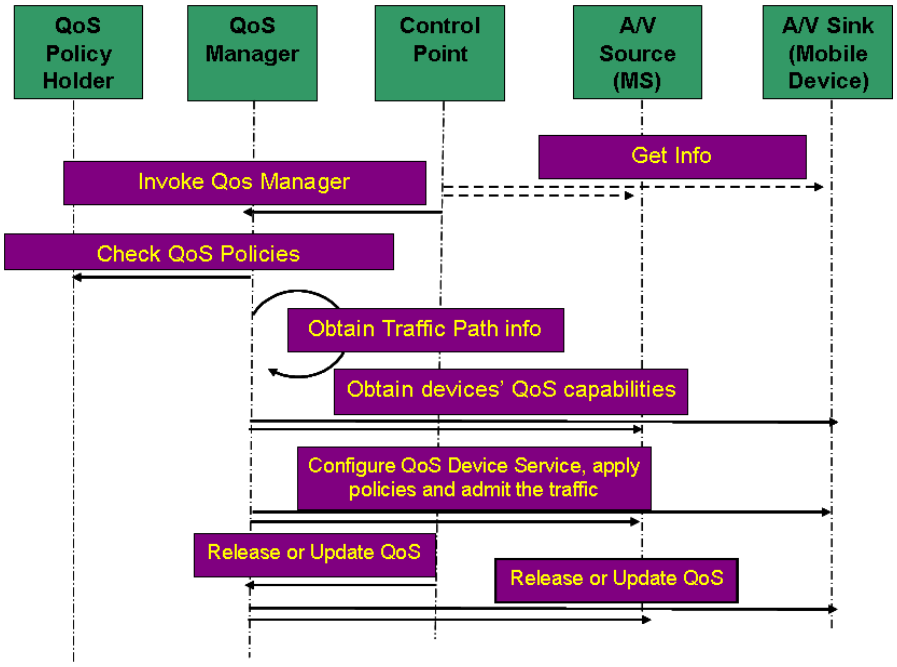

Figure 9-7 – QoS negotiation between DLNA-HG, Media Server and Mobile Devices

The above message sequence chart shown in figure 9-7 demonstrates QoS negotiations between DLNA-HG, Media Server and Mobile devices. A typical use case shown above is

a new control point trying to access a service offered by mobile device. The control point uses device discovery mechanism and requests the information about the services offered by the mobile device. The mobile device intimates the QM about the status of the services. The QM in-turn verifies the policy holder, priority list and the information obtained in the response and updates the control point about the status. This way, QM has control information about bandwidth usage, service usage on device and so on at all points of time.

The QM will then invoke the traffic classifier (Figure 9-5), for further processing. The traffic classifier class in turn will determine which type of traffic class best suits the request and allocates it. This information percolates down which is used for priority classification and determining the service class that needs to be assigned to the control point. The control point, on receiving this information also notifies the A/V source about the type of service it will be using. This component interacts with the QM and ensures A/V sync is achieved for that particular control point. The QM is updated on successful completion of any operations like end of playback. The corresponding device is also notified about the detachment of the control point.

9.10.3 Media Renderer Device

The media renderer device contains a media player, which a control point and a QoS Management GUI are integrated in to a media renderer module, a QoS device service module and QM. The media player is a multimedia player for various audio and video formats such as MPEG-1, MPEG-2, MPEG-4, mp3, etc. By integrating the control point and the QoS Management GUI into the media player, users can control media distribution and edit QoS policies conveniently. The control point discovers media server devices and displays media contents stored in them.

When a user selects media content in the browsed list and clicks the PLAY button, the Control Point requests the QM to setup a QoS traffic stream providing the information of source, sink and content to be streamed which contains a description of content QoS requirements. After completion of QoS setup, the mobile device request the media server device to stream the specified media content using HTTP protocol. User can add, delete and modify QoS policy for a traffic stream through the QoS Management GUI. By saving edited policies in the QoS policy holder of the DLNA-HG gateway, it provides a

centralised mechanism for enabling or disabling QoS policy for the entire network and for classifying traffic according to information provided in the request for QoS for a particular traffic stream.

QoS setup information for traffic streams and static QoS capabilities of multimedia devices in the home network can also be browsed using the QoS Management GUI. The media renderer module provides the control point with media rendering control service, connection manager service and A/V transport service.

9.10.4 Example: Media Distribution

While a mother watching a stored movie in the digital media server using the media player from the desktop in the living room, the movie transfer from the Digital Media Server to the desktop is suddenly interrupted due to best-effort traffic generated by her kids. So she stops playing the media and opens the QoS Management GUI from Desktop through the media player. After finding that A/V traffic has the same priority as best-effort traffic, she assigns higher priority to A/V traffic and resumes playing. She is satisfied with the provided quality of service.

Figure 9-8 shows the test bed for the scenario described above. Network connectivity among devices is Fast Ethernet (100 Mbps). The bandwidths of A/V stream and best-effort traffic are 20 Mbps (one HD level MPEG2-TS stream) and 100 Mbps, respectively. An Ethernet switch is used to allow the A/V stream and the best-effort traffic to share the bandwidth of an Ethernet port of the DLNA-HG gateway. To illustrate the implemented system in action, a media distribution usage scenario and describe the associated theory of operation is presented.

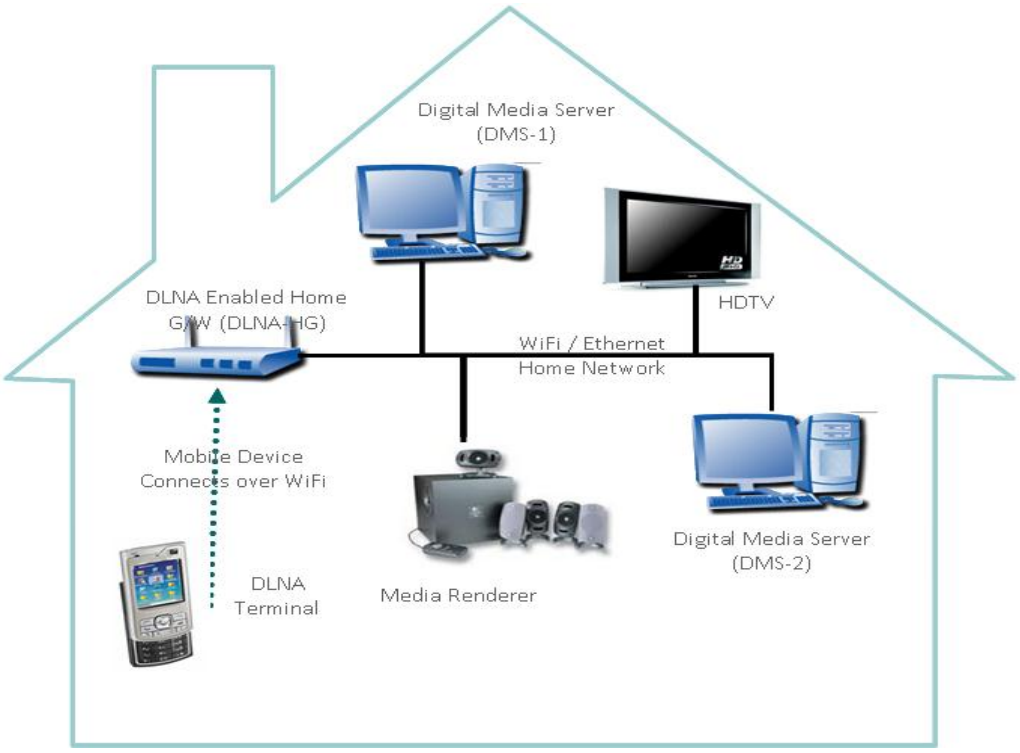

Figure 9-8 – Test Bed Setup

When a user turns on the HDTV and DLNA-HG and then executes the media player program, the control point of the home server discovers the digital media server and displays media contents stored in it through the media player GUI.

After he or she selects a movie and clicks the PLAY button, the DLNA-HG control point requests the QM to setup a QoS traffic stream by passing information such as Traffic Class and Traffic ID to DLNA-HG Gateway. Then the QM requests the QoS policy holder within the DLNA-HG Gateway to provide appropriate QoS policy for the requested traffic stream.

Based on this QoS policy, the QM request the Digital Media Server to assign network resources for the new traffic passing the traffic importance number of the QoS policy after it queries the static QoS capabilities and run time state of the digital media server.

The QM module then requests to assign priority to a traffic stream identified Traffic ID (source port, destination port, source IP, destination IP). After completion of QoS setup, the control point requests the Media Sever module to stream the specified content.

When the DLNA-HG receives A/V frames generated by the digital media server after he or she have assigned traffic importance number 5 to AV stream using the QoS Management GUI, the Home Gateway puts them into the respective input port and output port.

When the DLNA-HG receives A/V frames, it treats the frames as Best effort and the forwarding module puts them into the respective input port and output port.

9.11 Prototype Implementation and Results

In this section, experimental setup of the architecture shown in figure 9-9 is briefly described. Experiments were conducted to verify its feasibility and evaluate the multimedia streaming performance in a connected home environment with the proposed adaptive QoS Framework on DLNA- HG as well as on a mobile terminal with digital media player. The test bed was setup to measure the performance of multimedia streaming application. DLNA Client is streaming at 400 Kbps multicast video from the DMS-1. DMS-2 is running several FTP sessions at the same time. Two tests are done, one with an Adaptive QoS framework, and the other without the framework. Performance of the DLNA-HG without and with QoS framework is show in figure 9-10 and 9-11 respectively.

WMG160 was used as a gateway device (wireless multimedia gateway). UN55B8000XF was used as a HDTV. Omnia SCH-i910 was used as a DLNA terminal. SENS X20 NT X20 was used as a digital media server which included Intel Pentium® Mobile 740 (1.73GHz) processor, 4 GB RAM, 1 Tb HDD with Windows XP Professional as an OS. All products used were sponsored by Samsung.

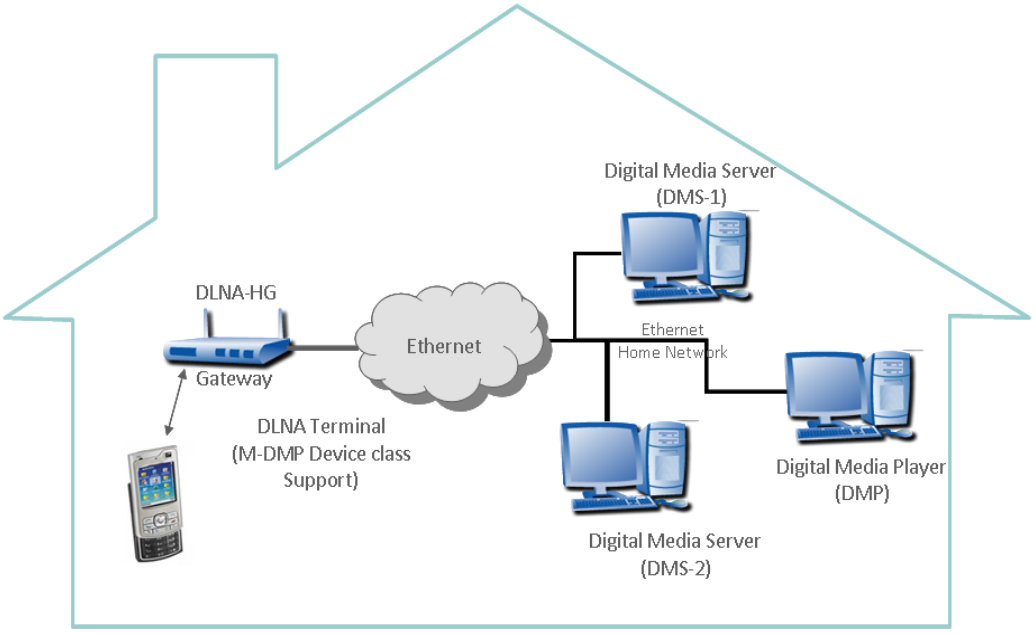

Figure 9-9 – Experimental Test Environment

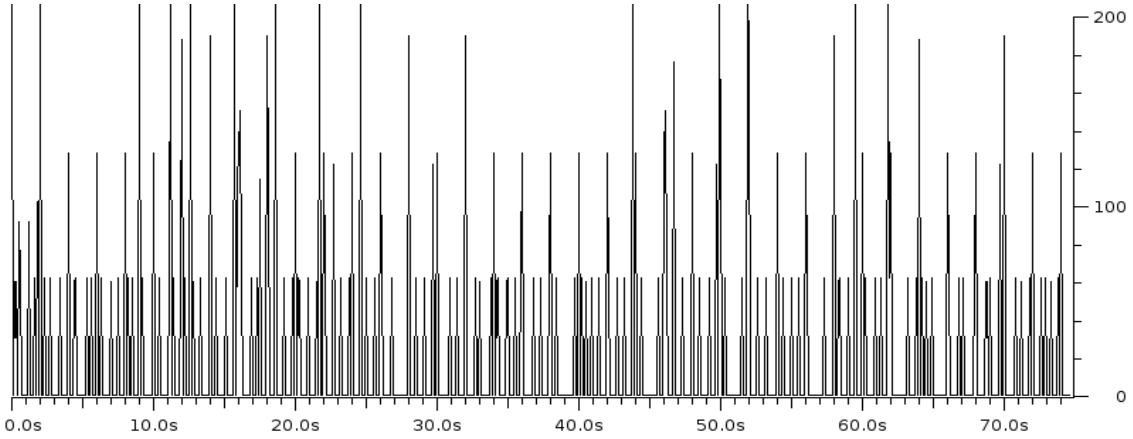

Figure 9-10 – Throughput of Video Streaming without QoS Framework

It can be clearly noted from the figure 9-10 and figure 9-11 that without the QoS framework, throughput of video stream decreases dramatically with the increasing number of FTP sessions. With the proposed QoS framework, the bandwidth is maintained at a constant level that guarantees the performance.

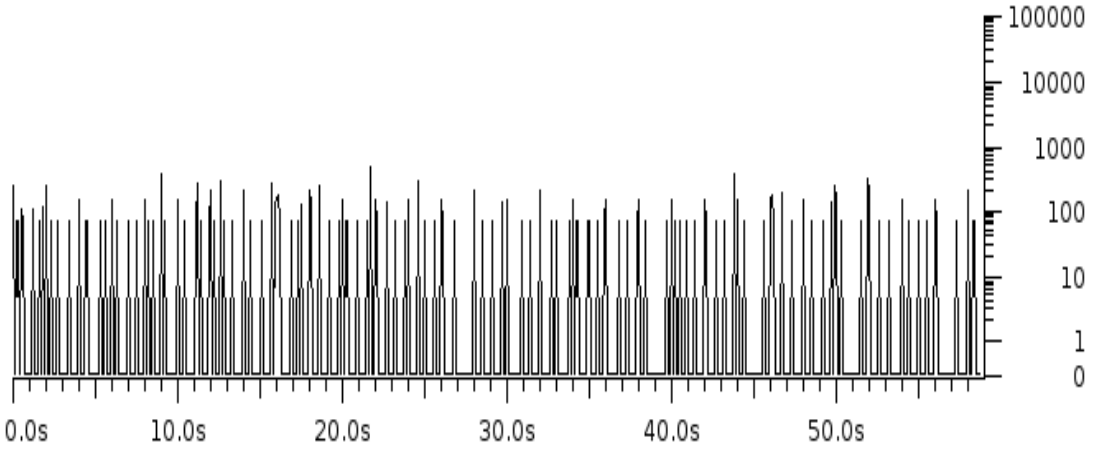

Figure 9-11 – Throughput of Video Streaming with QoS Framework

The performance characteristic for a trial problem of video streaming is summarised. The same results are extrapolated and tested for various real-time scenarios providing perceivable enhancement in QoS.

In the proposed architecture, the DLNA-HG acts as the server component for inter-networking between the home network and the Internet. The home server has both a public IP address for an external network interface and a private IP address on its local network interface. The DLNA devices including DMS1, DMS2, and M-DMP are connected to the private IP configured home network. The DMS devices within the home are connected to the home server.

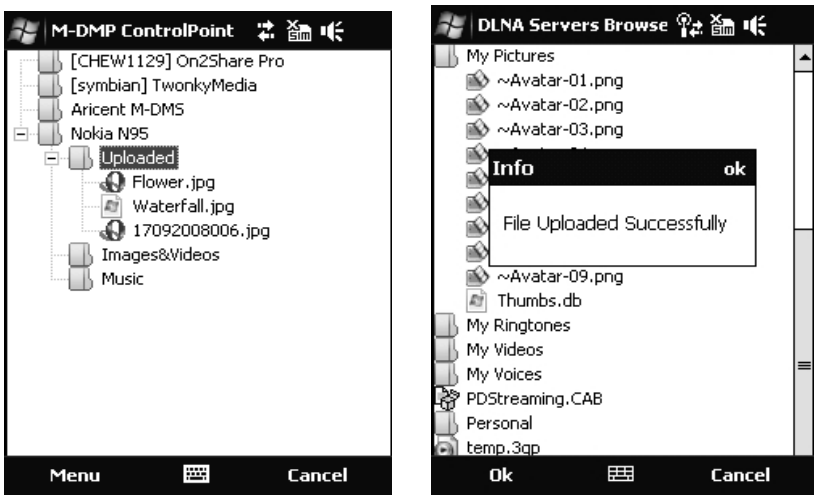

Figure 9-12 – GUI for Media Content Sharing running over DLNA enabled M-DMP and M-DMS

The HTTP is used as a protocol to communicate between the DLNA-HG Server and DLNA Agent via the Internet. The UPnP [110, 111] is used to gather and share media information and content among DLNA supported A/V media devices connected in the home network.

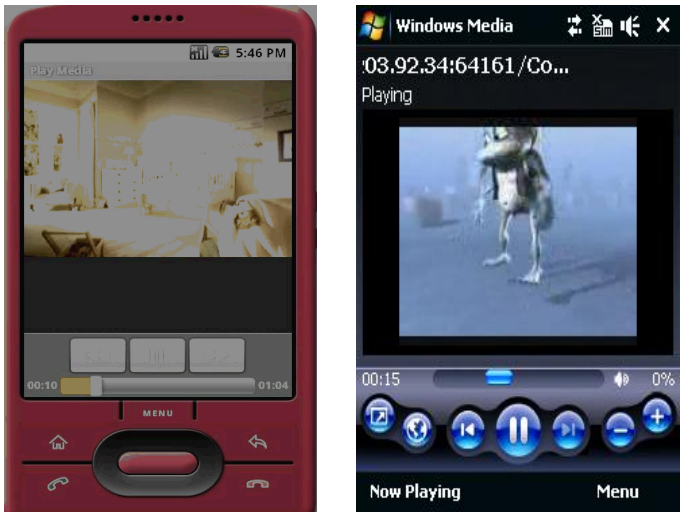

Figure 9-13 – DLNA based Video Player streaming the media running over DLNA enabled Android and Windows mobile devices

9.12 Conclusions

DLNA-based media streaming application including the DLNA agent function that a user inside of his home used for communicating with the DLNA-HG to dynamically obtain device profiles is presented. Furthermore, service information pertaining to the DLNA devices in-house for real-time access and to stream the media contents distributed over the home is also presented.

The GUI of the application shown in figure 9-12 and figure 9-13 is implemented on Android and Windows Mobile. Applications can be executed over M-DMP & M-DMS enabled DLNA devices connected in the home network and then, implementation of the GUI of the DLNA-based media sharing application on several DLNA capable devices was performed. For example Digital Picture Frame (DPF) and Portable Media Player (PMP) connected to the home network based on a Private IP including a DLNA Agent function. The screened list items (Figure 9-13) provides a list of the DLNA devices and multimedia contents distributed at the home.

A QoS-aware DLNA gateway enables quality-guaranteed internet services to be delivered to every single device in a digital home, subject to overall bandwidth limitations [117 – 120]. In this chapter, design and development of a QoS framework for a DLNA Gateway was carried out. The approach is considered innovative and experimental. It is shown that a QoS-enabled DLNA gateway can support a group of applications by allocating bandwidth based on application class or user-specified policy. The proposed QoS Framework architecture for the DLNA-based Home Gateway gathers media information and shares media contents among distributed DLNA-supported A/V media devices in the home and hence improved QoS for the real time multimedia streaming. Future work includes verification of the transmission and delay times for the real time multimedia streaming which in my opinion is an important aspect for the streaming quality.

Chapter 10

Development and Implementation of a Heuristic Buffer Management Scheme on Android to Enhance Video Quality on Digital Handheld Devices for the Aricent Group (2009-2010)

10.1 Introduction and Rationale

Over the past few years, consumers have embraced digital technologies and are acquiring and managing high definition media content on various consumer electronic devices like Set-top Box (STB), HDTV and so on. All of these "Digital Entertainment" has led them to demand high definition content on resource constrained hand held devices [121]. In response, the leading manufacturers in the consumer electronics, mobile device, and personal computer marketplaces have banded together to stimulate technological advancements in codecs, especially video codecs to create a working model solution for their diverse products. Xvid is one such result which is widely adopted in the industry. Xvid even though uses lossy compression techniques, is admired for its ability to provide very high compression ratios while ensuring better quality than current MPEG-4 video codecs [122].

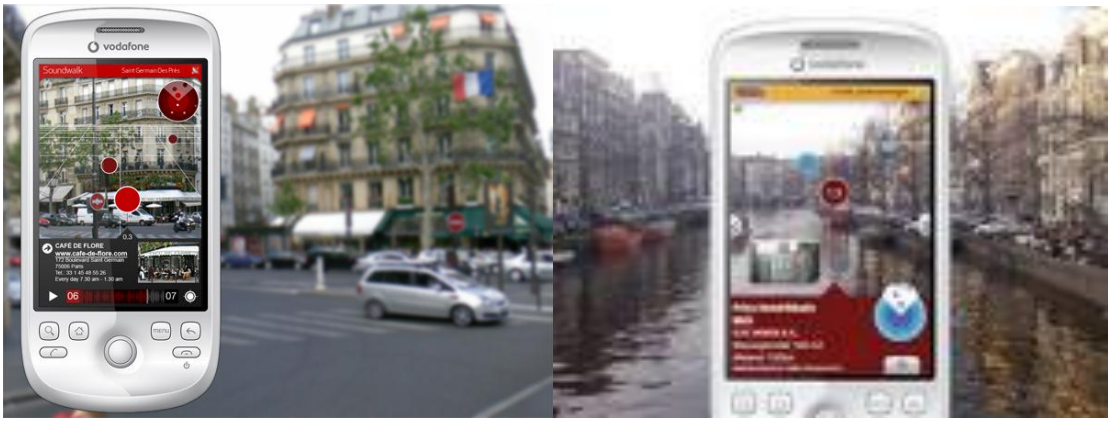

Figure 10-1 – Real Time Scenario

On the other hand, Android making an impressive impact amongst the early adopter consumers is ensuring mass market success precisely due to "the cost factor with appealing entertainment experience" [123]. Consumers are now looking forward to enjoy the same rich HD multimedia content like DivX/Xvid on Android based handheld devices as shown

in figure 10-1. This intensive surge has created a dramatic shift in the technology space precisely due to stringent performance requirements. Design consideration of media management framework for devices like HDTV is very different from resource constrained handheld devices. The media buffer management used within framework can significantly contribute to overall system overhead. In particular, the Packet Video of Multimedia Framework (PVMF) makes use of nodes which caters to basic functionality of media management is ineffective to achieve high end-to-end system performance for HD content. Android having a modular architecture supports codecs as OpenMax compliant components which might further contribute to the system delay [124]. This has turned out to be a constraint for not utilising the underlying hardware like Zoom2 optimally. Hardware platform like Zoom2 which have dedicated DSP processor to perform high intensive operations like video decoding can offer high end-to-end system performance, if coordinated well with multimedia framework components of the software platform [125, 126].

In this chapter, a heuristic buffer management scheme on Android is presented to address and overcome above mentioned constraints. The said buffer management scheme ensures uniform buffer allocation across source-decode nodes and between General Purpose Processor (GPP) – Digital Signal Processor (DSP). The need for such a mechanism to leverage the support offered by underlying hardware efficiently while optimally utilising the multimedia framework for efficient resolution in a constant time factor is demonstrated. A proof-of-concept architecture is also developed to verify the feasibility of the approach.

10.2 Design Approach

Technological advancement in video quality, especially for resource constrained handheld devices has led to experimentation of lossy compression techniques as well. However, algorithms used to implement the codecs are often complex and require higher CPU utilisation which may lead to frame drops or frames to be delivered late to rendering component. This further degrades the overall system performance. In general, multimedia frameworks like Packet Video in Android have intermediate shared buffers between sources and decode nodes as well as between decode and sink to avoid such situations. This buffer scheme suffices to cater to basic functionality like video playback. However,

with high definition content like Xvid codecs, this mechanism proves to be inefficient in handling the complexities involved within the system [127, 128]. Initial investigations reveal that, with these techniques the current systems tend to over utilise CPU to provide better services to the end user, which may not be a desirable and effective way of to improve the video quality. Hence, this problem is approached in a profoundly different way which avoids over-utilisation of CPU at the same time optimal utilisation of multimedia frameworks to achieve better video quality. It was ensured that a uniform buffer allocation is done by having a One-to-One mapping of the number of shared buffers between the GPP and DSP and between source-decode nodes based on processor speed of underlying hardware and the limitations of the packet video framework. Android primarily based upon an opaque delivery model. Applications and services can expose their functionalities to the system, and at runtime, other applications can request these functionalities. This model is particularly used to provide a co-ordination mechanism that effectively takes advantage of the underlying platform like Zoom2 and effectively utilises the design aspects of Android for easier portability and deployment of the solution.

10.3 System Model

In this section, insight on the codecs sub-system architecture of Zoom2 board running on Android platform is provided. Then discussion on the existing buffer management strategies within the PVMF multimedia framework of Android is presented. A detailed analysis of factors alleviating performance bottleneck are examined.

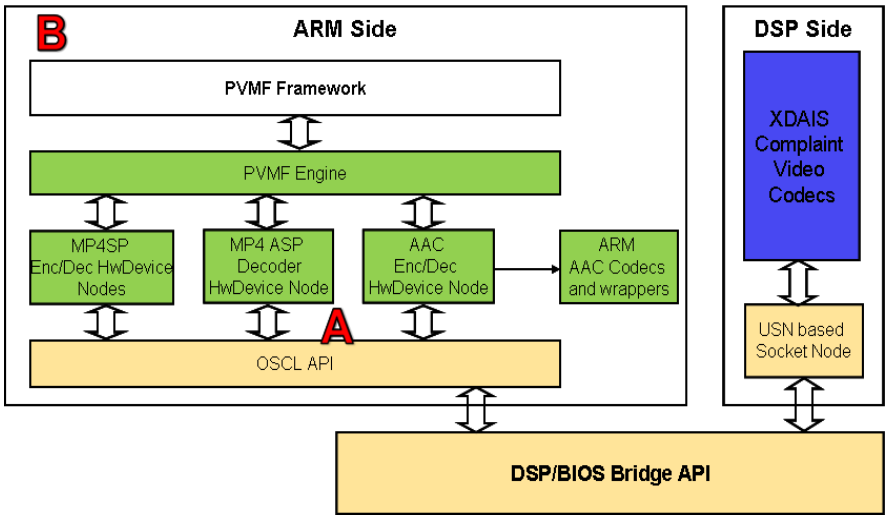

Figure 10-2 – System Architecture

Consequently, an efficient heuristic buffer management scheme bridges the codec-sub system and buffer management within framework uniformly to achieve high end-to-end performance.

System architecture shown in figure 10-2 describes the codec-sub system architecture of Zoom2 on Android. It has two building blocks, the ARM side core and the DSP side core of OMAP chipset. Generally, video decoding being highly processor intensive operation, a dedicated co-processor to perform this task is supported in the hardware. This co-processor is capable of performing highly complex algorithms in minimum time factor very efficiently and effectively. Two main design issues surface immediately. Firstly, the scheduling of the source node within PVMF framework which is responsible for providing data to decoder node may not necessarily coincide with the scheduling of the DSP processor to get the decoded video output instantly. This results in degraded performance for high definition content.

10.4 Existing System

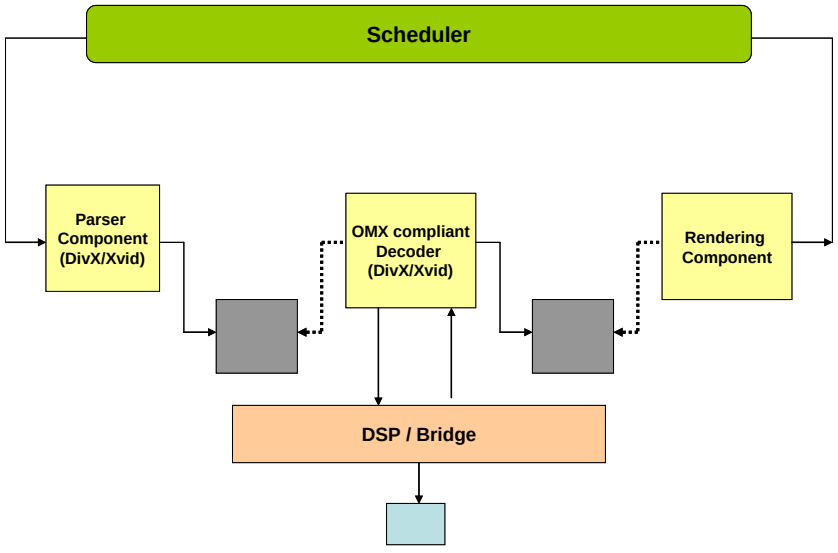

Figure 10-3 – Existing Middleware System Model

Figure 10-3 depicts the working model of the existing system within Android. Secondly, the DSP co-processor sees a continuous data burst at regular intervals often getting overloaded for data processing while remaining idle for data at other times. This situation occurs due to the non-availability of buffers incessantly. Hence, the proposed buffer

management scheme resolves these two issues by allocating uniform number of buffers between source-decode nodes as well as between GPP-DSP blocks so as to avoid the problems that might arise due to scheduling at different time instants.

System model shown in figure10- 3 outlines the middleware architecture of the existing system within Android. The scheduler within the multimedia framework triggers the source component for playback of multimedia content. The source component usually a parser/network element will parse the file for local playback, extracts the encoded video data and places in an intermediate buffer shared between the source and the decode element in the pipeline. The number of buffers shared is controlled by the source component. As a next step, the OMX compliant decoder component will retrieve the data, performs video decoding using the DSP processor and then places it in the shared buffer between the decoder and the renderer element. The main problem encountered with this approach is the synchronisation between the decoding speed and the rate at which the data is being placed in the shared buffer between source and decoder.

If the shared buffer is full, then the source component has two options. It can block itself and wait for further notification from scheduler when the buffer is available. However, blocking not being a good design approach especially for applications like streaming involving network operations, the other option is to drop the data within the framework. Either case leads to performance degradation of the system. The other issue is the interaction among the components.

Once the pipeline is built as shown in figure 10-3, the media flow happens in a serial fashion with minimum interference from the scheduler. This is particularly important to handle synchronisation issues. In the proposed system shown below, it shows on how the buffer management scheme will avoid such issues and improves the overall system performance.

10.5 Proposed System: Heuristic Buffer Management Technique

Figure 10-4 shows the working model of the proposed system. Linux Controlled Media Library (LCML) layer of Android acts as abstraction for communication between the processors. The video data after decoding will be encapsulated in an OpenMax IL

compliant component so as to be able to use by the PVMF of Android. This multimedia framework uses this OpenMax component for pipeline construction and for data flow in the playback.

In the proposed system shown in figure 10-4, a heuristic buffer management scheme which overcomes the problem detailed in the previous section is presented. In this method, four buffers between the source component (parser in this example) and the OMX compliant decoder node of Android framework are allocated. Initially all the four buffers are empty. These buffers are populated when the data is available to the source component. To certain extent, this solves the synchronisation problem between source and decoder components.

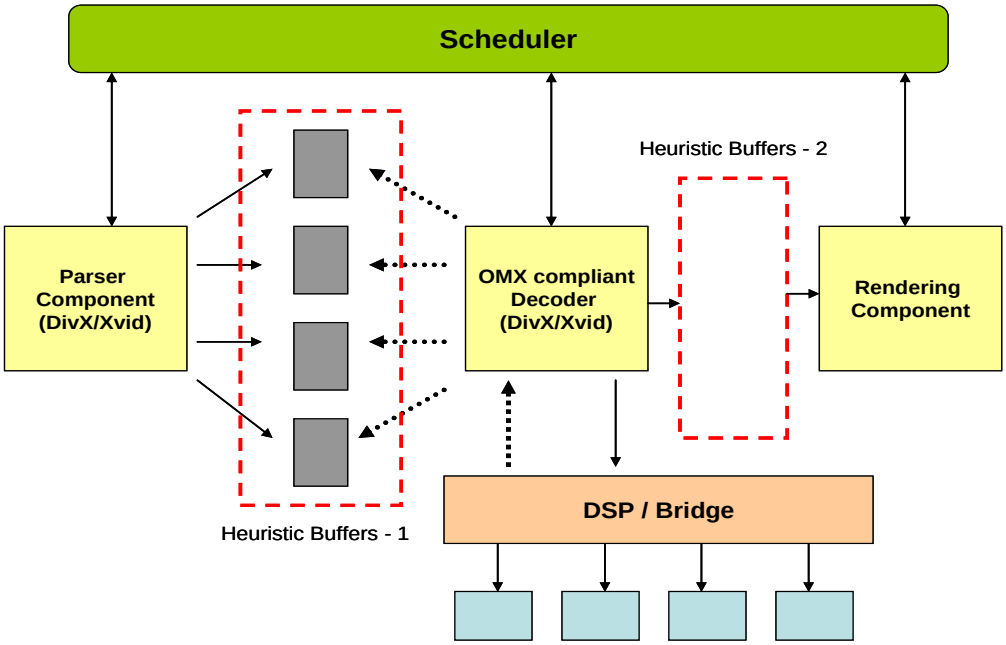

Figure 10-4 – Proposed Middleware System Model

Considering the worst case, if the data buffer tends to get full, a notification is sent to the scheduler to intimate decoder about the condition. The decoding component then uses the support provided by underlying hardware Zoom2 to have more than one (four in this case) buffers shared between GPP and the DSP. This optimal number for buffer allocation yields maximum throughput as it will be easier for the scheduler to manage and as a matter of fact avoid frequent over/underflows. Such a setting ensures optimal usage of underlying hardware resources (processor) at the same time also avoid overhead that occur due to frequent re-scheduling. It must be noted that there is a one-to-one mapping of the number of buffers between the source-decoder components and the ARM-DSP side buffers.

This approach guarantees a direct interaction of all the components within the pipeline and the scheduler. The framework just facilitates the execution process by constructing the graph and identifying correct components to be built in the graph. Hence, the same technique is also followed between the decoder-render to achieve playback synchronisation as well.

The multimedia framework architecture in Android is modular, meaning that it consists of units that can be interchanged with each other to provide only the functionality you need. In addition, it supports OMX specification to define its standard interfaces, you can write new components (such as codecs), and easily incorporate new components. A node is the basic building block of the Android multimedia framework. To process a multimedia file, any application uses only the nodes it needs to get the multimedia data, process it, and send it to a target device. A node is basically a generic object. Its functionality is determined by the way it processes data, and the interfaces it implements.

An engine interface defines the set of methods that the framework expects nodes of a specific type to have. For example, all nodes must implement the ThreadLogOn and ThreadLogOff methods defined in the PVMFNodeInferface interface so that the library can create and destroy them.

The implementation of an interface is declared as a structure of pointers to implemented functions in a defined order. Each node can have multiple input and output channels, so if you have a file format that's interleaved with more than one data stream, you can have as many output data channels as the input data stream contains. This is how the MPEG System parser works, for example – it parses MPEG System data into two streams, video and audio. An MPEG System encoder filter works the opposite way; it has separate input channels for sound and video, and one output channel.

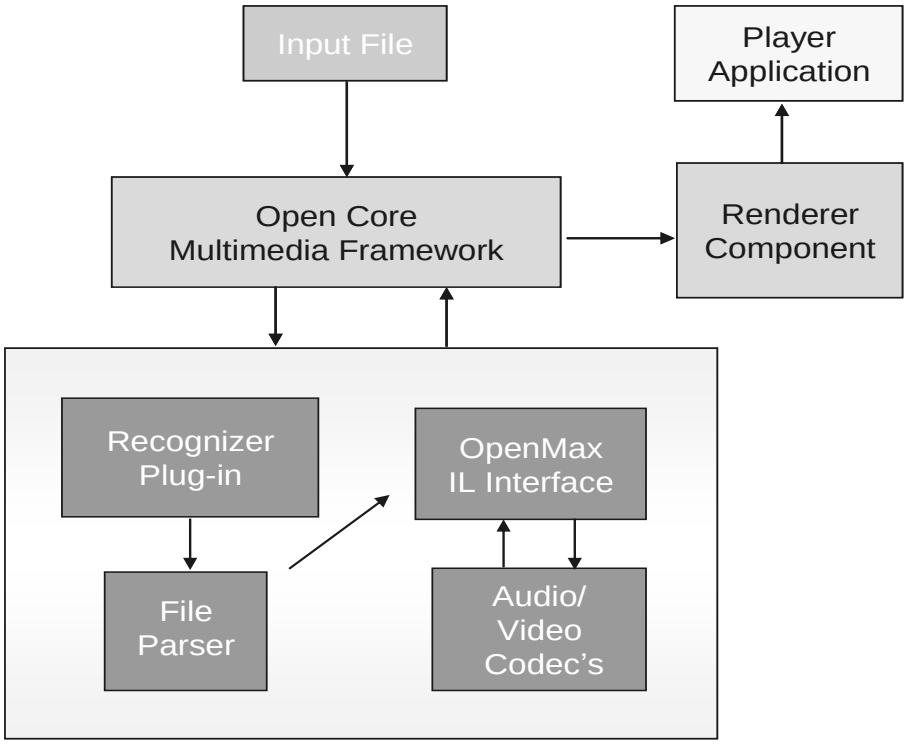

Figure 10-5 – Component Architecture on PVMF on Zoom2 Platform

Because the multimedia architecture uses a "plug-in" framework concept, each node component can easily be integrated (plugged in) with existing nodes in the system. As shown in figure 10-5, Recogniser Plug-in performs the functionality of adding the newly formed nodes to packet video framework. This component also addresses the issue of delay that might be contributed at runtime in finding out the component. The architecture considers and provides a way to handle interpolation of intermediate frames in an efficient manner.

It extensively leverages the support provided by underlying platform by having a split solution leveraging IVA2.2 and Cortex-A8 core. It emphasises effective utilisation of the support provided by platform making a viable choice for handling blocking artefacts, motion outliners.

105.1 Variable Length Decoding (VLD) Engine Method

Various measurement techniques have revealed that maximum CPU cycles and processor time is taken while decoding a variable length encoded buffer. This process is called variable length decoding. Hence, an optimisation or efficient mechanism to ensure VLD

contributes significantly to the overall performance improvement. Since these are CPU intensive operations, a piece of hardware called VLD engine is provided by the underlying chipset. For example, Zoom2 has this facility. The timing of configuring this VLD engine is also important so as to ensure optimum power consumption as well. This parameter is another method to assure improved performance for high quality codecs like DivX and Xvid.

10.5.2 Shared Cache Method

The internals of the DSP architecture also provides an insight of the available of the shared cache within DSP for better fine tuning. The cache size is the key parameter which needs to be configured. On one hand, an excessive cache size will lead to more memory access than needed and will degrade performance. On the other hand, if the cache size is less than the needed memory then the cache misses will be high leading to memory issues. Hence, there is a cache fine tuning method must be in place which varies for different type of decoding technique, i.e. having cache size as a parameter will the GPP initialises the co-processor is a good practice.

10.5.3 Direct Memory Access Method

The hardware/underlying platform generally specific to a category of devices have a feature for Direct Memory Access (DMA). This feature is particularly useful as it avoid the most expensive CPU operation of memory copy of the buffer from GPP to DSP side. This means the DSP/GPP will use the DMA technique for exchange of data between them. This saves considerable memory CPU time by avoiding memory related operations. Though it is a common technique, this also comes with the overhead to the programmer as the memory address spaces on the GPP and the DSP side is different i.e. an address 0x00024401 may not exactly correspond to the same memory location on the DSP side memory. Hence, a careful balance between the use of feature and the overhead incurred should be worked out depending on the cost of CPU cycles saved between memory operation (in the first case without DMA) and the Address Translation (second case with DMA).

10.6 Test Bed

To prove the feasibility of the architecture outlined above, a fully working prototype on Zoom2 board is developed. The prototype has been tested on both the Android emulator, based on ARM processor, was customised to model the typical functionalities and user interface of an lVI, and also on the actual target Zoom2 hardware powered by Zoom2 platform. The memory requirement with such an implementation is also presented. It was also noted that such a high end-to-end performance is achieved with a minimum increase in footprint making it viable candidate for commercial deployment. Experiment was executed in two phases.

- encoder/decoder component level; and
- at system level with Android as the software platform.

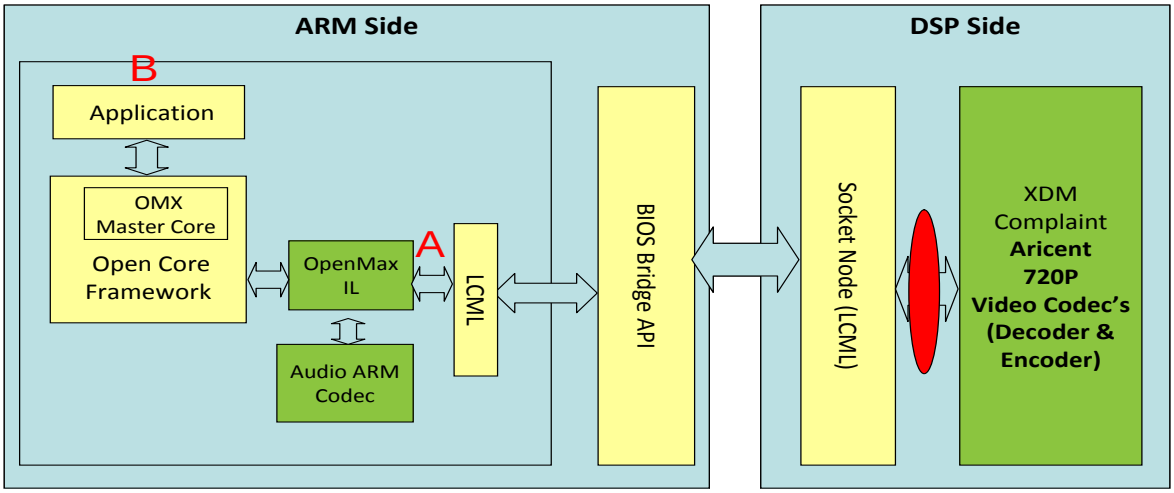

Figure 10-6 – Component Architecture of Zoom2

Time gaps are measured at point A and B in figure 10-6 shows the time between before and after each frame decode call. As shown in figure 10-7, a snapshot of the result on Zoom2 board is depicted. The said buffer management scheme was implemented and tested on the actual hardware platform. The points "A" and "B" marked in red as shown in Figure 6, gives us the integrated system level performance. The architecture considers and provides a way to handle interpolation of intermediate frames in an efficient manner. It also has an extendible design to handle very complex decoding algorithms like correlation based BME for motion estimation.

Figure 10-7 – Results shown on Zoom2 board using Heuristic Buffer Management Scheme

It extensively leverages the support provided by underlying platform by having a split solution leveraging IVA2.2 and Cortex-A8 core. It emphasises effective utilisation of the support provided by platform making a viable choice for handling blocking artefacts and motion outliners. The technique is also effective at managing the nodes of the PVMF framework and the player/author engine scheduling mechanisms [129]. The technique can be viewed as a solution to the optimization problem for any multimedia framework like gstreamer, dshow as most multimedia frameworks work on pipelining concept.

10.7 Performance Evaluation and Memory Requirements

In this section, results from the experiments to characterise the adaptation performance approach is presented.

OpenMax compliant encoder/decoder components were used in this project. Figures 10-8 and 10-9, shows the memory requirements on DSP and Cortex RAMS. The tables within figures 10-8 and 10-9 are the result from the experiment. The adaptation performance is measured with respect to both codec sub-system level and at system level.

DSP RAM requirements for DivX/xVid (resolution = 640*480):

Heap Memory requirements:

Memory		Size (KB)
L1DRAM	Persistent	0
	Scratch	47.4
EXTERNAL	Persistent	2229
	Scratch	0

Data Memory requirements:

Memory	Size (KB)
L1DRAM	0
EXTERNAL	3.5

Stack Memory requirements:

Memory	Size (KB)
L1DRAM	2

Program Memory requirements:

Memory	Size (KB)
EXTERNAL	116

Figure 10-8 – DSP RAM requirements on OMAP

Cortex RAM requirements for DivX/xVid (resolution = 640*480) :

Heap Memory requirements:

Memory		Size (KB)
L1DRAM	Persistent	0
	Scratch	0
EXTERNAL	Persistent	2760
	Scratch	0

Stack Memory requirements:

Memory	Size (KB)
L1DRAM	4

Program Memory requirements:

Memory	Size (KB)
EXTERNAL	100

Figure 10-9 – Cortex RAM requirements on OMAP

Figure 10-10 illustrates the performance analysis and number of resolution types obtained from the experiment. It shows that the proposed approach supports flexible adaptation for multiple multimedia framework dimensions. The memory footprint results demonstrate that the adaptation can cover a wide range of products and is fine grained. The performance statistics and numbers for different resolution types are shown in figure 10-10. The numbers show that the approach yields better output than benchmarked by industry standards. The performance quoted is for the Xvid and DivX Video codecs in Linux environment which also includes the system overheads for rendering and A/V sync wherever applicable [124]. The performance shown is for medium motion, medium complex sequences. The decoder bit rate factor and all decoder input bit streams are generated at 30 fps - 4~5 Mbps to handle Xvid.

Benchmark Measurement Test (BMT) Report												
Platform				OMAP 3430 SDP ES 2.0				**Codec components**			DivX Decoder (Mobile Profile) XviD Decoder (Portable Profile)	
Demo	**Resolution**	**Bit rate (mbps)**	**Audio Codec + OpenMAX**	**Frame Count**	**Decoding performance measured at SN (A)**				**Decoding performance measured at System (B) IVA 2.2 @ 430 Mhz**			**Remarks**
					Average (m. Secs)	**Total (Secs)**	**Peak (m. Secs)**	**Performance (FPS)**	**Average (m. Secs)**	**Total (Secs)**	**Performance (FPS)**	
DivX (Mobile Theatre Profile)	640*480	1.4	AAC	1801	16	28	23	**69**	33	60	**30**	Demo with A/V Sync
	720*480	3.1	AAC	1502	16	24	23	**62**	33	50	**30**	Demo with A/V Sync
	1280*720	2.2	-	1500	33	50	47	**30**	33	50	**30**	Only Video Playback 720p for HD Profile
	1280*720	2.3	-	1377	34	47	51	**30**	33	46	**30**	Only Video Playback Covering B-Frames
XviD (Portable Profile)	640*480	1.4	AAC	1801	16	28	23	**69**	33	60	**30**	Demo with A/V Sync
	720*480	3.1	AAC	1489	16	24	41	**62**	34	50	**30**	Demo with A/V Sync
	720*480 (B-frames)	3.1	AAC	1376	21	29	33	**47**	33	45	**30**	Demo with A/V Sync
		2.8	AAC	3574	20	73	39	**49**	34	120	**30**	Demo with A/V Sync
	1280*720	4.3	-	1485	34	51	61	**30**	34	50	**30**	Only Video Playback 720p for HD

Figure 10-10 – Performance Analysis

10.8 Time Measurement

The Time gaps are measured at point A and B in Figure 6 shows the time between: before and after each frame decode call. The Gettimeofday function provided by the underlying platform is used for measuring time to ensure the accuracy of the measurement. The decoding time gaps (DTG) in mili-seconds are summed across the multiple decode calls which considers the minute delay possible in the system.

The decode time frame is calculated as,

Decode time frame (T) = Σ DTG / no. of frames displayed (10.1)

The above mentioned performance figures have two important points worth noting:

- the overhead for rendering both audio and video in synchronisation is also considered; and

- the performance statistics also considers the boundary cases with minimum I-frames and considerable B-frames. This case is particularly important because b-frame prediction involves more CPU time for decoding compared to p-frames.

The frames per second (fps) and average decoding time (ADT) are calculated using the formulae below:

FPS = Frame Count / Total Decoding time (seconds) (10.2)

Average Decoding Time (in ms) = (Total decoding Time in seconds * 1000) / Frame Count (10.3)

Since the rate at which encoded data is received and given out at decoder is only available dynamically, and then only a portion of the media content is known. Approximation of the optimal time by considering a finite context, i.e. number of packets/frames, from the packet sequence number and time stamps is calculated.

A related concern is the finite number of bits allocated in each of the buffers to store the decoded data. Stated another way, to truly realise an optimal timing would require a buffer size big enough to hold all of the decoded frames of a presentation, and enough bits in each buffer to hold exactly one frame uniquely. From the experiment, the buffer management implementation suggests the optimal number of buffers to be four (4) for the most real-time applications like video streaming.

10.9 Conclusions

In this chapter, the issue of enhancing video quality on Android through heuristic buffer management scheme is presented. The existing buffer management schemes are ineffective to achieve high end-to-end performance, especially for high definition content. That said, a heuristic buffer management scheme was proposed and tested to ensure efficient synchronisation through uniform buffer allocation in multimedia framework and the processors of underlying platform. Subsequently, this chapter validates the method by demonstrating performance improvement of media delivery of HD codecs like Xvid/Divx on Zoom2 platform based on Android. In-line with these endeavours, a proof-of-concept

architecture extending the Android platform to accommodate a new buffer management scheme is demonstrated. An experiment to playback HD 720 p content on Zoom2 was performed to verify the approach.

Thus, it can be concluded from the experiment results that the system is effective at improving the video quality significantly. A related aim of this chapter is to inform the scientific community about the design in new environments by benchmarking the performance achieved using the buffer management method. Observations from experiments also confirmed that the memory and CPU utilisation is low enough to be deployed over a wide spectrum of handheld devices. Future work includes verification for real-time applications like video conferencing where delay plays a major role. It is planned to extend this novel architecture on different processors like Intel Atom processor to cater for 4G and mobile internet devices.

Whilst finalising this dissertation, it was confirmed that the Intel® and Google® will work together to optimise future versions of Google's Android® mobile software for Intel's "Atom" processors, hoping to speed the development and time-to-market of future Intel-powered smartphones [130].

It should be noted that heuristic buffer management scheme is only a minor technological enhancement for giants like Google and Intel to be used in their products. However, the decision to invest into mobile sector for both giants means a diversification from a traditional PC/Web market to smart phone band-wagon. This means that the development for the modern mobile communication system will be boosted by research and commercialisation. Thus, safe to say that the commercial potential is end-less.

Chapter 11
Conclusion

This dissertation is my technological journey of past ten years. Communication technologies have evolved from wired to wireless with many emerging applications. During this time, I have tried to cope with the selected few technologies and created a series of solutions. These solutions are based on amalgamation of multiple wireless technologies and software development tools. The result is a range of innovative, pervasive and cost effective solutions.

Investigations presented in this thesis via several chapters were applied research in nature. Each project was 'cutting edge' and technically challenging at the time of execution. Following is the summary of the contributions made in the thesis:

The thesis is a collation of experimental projects involving design, development and implementation of innovative and pervasive applications using emerging communication technologies for highly mobile organisations. A secure wireless technology was implemented at the Sydney Airport Corporation Limited (SACL); a secure on-site and off-site electricity meter reading solutions were implemented for the Hong Kong Electricity Company (HEC); design and development of wireless food ordering system, use of an iPod as a visitor's personal guide and voice over internet protocol (VoIP) for student attendance recording and retrieval application (SARRA) were implemented for the Box Hill Institute (BHI); a new three layered packet switching media access control (PCMAC) framework was developed with the quality of service mechanism, a new modular data link layer (M-DALL) was developed for a multiple radio access technologies (RATs), digital living network alliance (DLNA) enabled mobile terminals integrated with home gateway was developed, an adaptive quality framework using heuristic buffer management scheme on Android was developed to enhance video quality for smart phones for the Aricent Group.

Data Communications as its practised today is fairly sophisticated and requires practical knowledge of subjects ranging from common-carrier offerings, to communications processors, to regulatory matters. This field is really growing rapidly but considered in its infancy with the kinds of networks and applications for data communication that are predicted for the future. Thus, a new breed of professional with multiple skills sets is

becoming more important in the telecommunication and ICT industries, commerce and Government, so called “Enterprise Communications Specialist”. Before a data communications system can be properly designed, managers must specify such operational demands as traffic routes, message volume, urgency, accuracy, and language (medium or type of codes).

Network wide QoS is needed to deliver priority service to higher-paying customers. Service providers want to use QoS as a basis for offering various classes of services to different segments of mobile professional end-users and residential end-users with fixed budget.

While capital spending continues to decline, many telecom manufacturers will restructure their corporations, trim workforces, better manage their suppliers and inventories, identify core competitive advantages and focus on operating efficiencies that will improve profitability. Operating with voice and data channels on the same private line can lead to significant economies.

In order to create any applications based on the new emerging technologies, it must be innovative, cost effective, user-friendly and interactive. The ability for end users to design their own applications will be the arrival of true multimedia applications that combine voice, video and data features into a single customised application.

New business models needs to be developed that enable full use and return on investment. Broadband 3G/4G wireless manufacturers and service operators are already restructuring and repositioning themselves to prepare for the next wave of opportunities and crisis. As people head toward increase in bandwidth, processing power, storage capacity, distributed computing, untethered oral, visual and haptic interfaces and independent of location – use of ICT will continue to evolve. The only constant will remain is the ability to cope with the emerging communication technologies.

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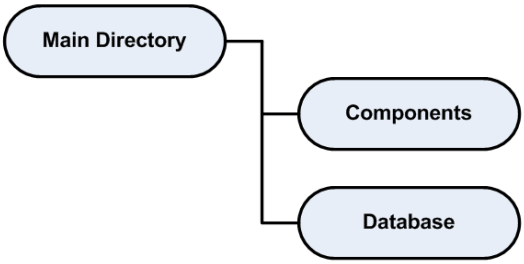
Appendix A – FIWOS System Installation Procedure, User Manual and Source Codes

Appendix A is provided on the compact disc attached with this dissertation. Appendix A contains the following:

1. Back-End Application Installation
2. Web Server Installation in Windows XP Pro
3. Configuration of Wireless Access Point 1200 to Default Settings
4. PDA Configuration for the Front-end
5. Setting a wireless Brother® printer
6. PDA Ordering System
7. User Manual for the Back-end Application
8. Program structure for the FIWOS source codes is provided below:

The FIWOS software is made up of several files, each of which performing a particular function within the application. These files are grouped into three categories; the main directory, and the sub-directories "Components" and "Database". The program files are grouped into these categories using the following directory structure:



The following is a list of source code files and their relative directory for the FIWOS software:

Filename	Type	Directory
TableSummary.php	PHP Script	Main Directory
OrderSummary.php	PHP Script	Main Directory
AddMeals.php	PHP Script	Main Directory
AddDrinks.php	PHP Script	Main Directory
EditItem.php	PHP Script	Main Directory

Database.php	PHP Script	Components
EditOrder.php	PHP Script	Components
Scripts.php	PHP Script	Components
PrintTest.php	PHP Script	Components
VarHandlerPost.php	PHP Script	Components
VarHandlerGet.php	PHP Script	Components
Fiwos.js	JavaScript	Components
Fiwos.css	Cascade Style Sheet	Components
Fiwos.mdb	Access Database	Database

Appendix B - VoIP SARRA Source Codes and Cisco XML Objects

Appendix B is provided on the compact disc attached with this dissertation. Appendix B source codes are arranged as shown below:

1. Background Code (Non-Interface)
2. Splash Screen
3. Login Menu
4. Login Screen
5. Class Selection Menu
6. Class Submit/Update Menu
7. Student Insert Input
8. Student Update Input
9. Login Help
10. Login Help 2
11. Insert DB (Non-Interface)
12. Update DB (Non-Interface)
13. Replica Database Configuration
14. Cisco XML Objects
15. Alternative Menu