Realistic Simulation of a Wireless Signal Propagation in an Urban Environment

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***Abstract*–This paper presents results obtained from a 3D ray tracing electromagnetic model designed to map the signals in a high rise environment (urban) within the same floor and at the floors above and below that floor. Apart from using ray tracing, the dielectric properties of the materials from each floor are included to achieve realistic signal profiles. The simulation is done for scenarios based on a single base-station and multiple base-stations on the same floor and multi-floors. We have refined existing indoor propagating model to obtain realistic signal distribution in a high rise building. New model include the dielectric properties of materials exists in real environment. The simulation program is written in Visual C++.**

Keywords*–*wireless signal propagation; wireless simulation; measurement of dielectric; ray tracing method

I. INTRODUCTION

Due to the highly competitive nature of the wireless communication industry where more than one service provider is involved, it is important to have a quality grade of service from different service providers to address the need of their subscribers. It is recognised that the environment factors have the most significant contribution to the Grade of Service (GoS) of a wireless system [1]. The GoS equation is calculated as:

$$GoS = \frac{number\_of\_blocked\_calls + 10 * number\_of\_interrupted\_calls}{total\_number\_of\_calls} \quad (1)$$

There are several simulators developed using different approaches: statistical path loss model, statistical model, ray tracing model and exact electromagnetic solution In competing for service, a provider must be able to guarantee a certain grade of service and to do this the provider must be able to assess the propagation characteristics of the environment. Direct measurement is one method of assessing the signal distribution and hence the GoS. But this is not always possible because of its intrusive nature and its time consuming requirement. Ray tracing modelling with the dielectric properties of the materials in an environment appears to be the most realistic way of assessing the signal distribution for the correct location of a base station and estimating the GoS. Simulation is more realistic since a compact ray tracing algorithm was developed by for indoor propagation [2] and actual dielectric properties of the environment materials measured and calibrated for a close match.

The introduction of the Dynamic Channel allocation (DCA) technique has opened up a new dimension in call routing. This in a sense has made the business of multi-service providers more competitive because a free channel is available for every provider to access on the first in best served principle. We have refined our indoor propagating model to obtain signal distribution in a high rise building. The signal distribution is used in two simulation scenarios representing a multi-service multi-provider wireless environment [2]:

1) Multiple networks with multiple service providers within a single cell area.
2) Multiple networks with multiple service providers in a multi-floor building scenario.

The main aim of the model is to enable a service provider to determine the location of base stations and also to quickly assess the GoS before embarking on the process of tendering for the service. Our indoor propagation model together with our network simulator MobileSim© developed in C++ can be used to establish the performance under different loads with multiple service providers on the same floor and on multiple floors in a high rise environment.

II. MEASUREMENT OF THE DIELECTRIC PROPERTIES OF MATERIALS

In order to get accurate simulation results, the dielectric properties of the materials of a specific environment must be used. For this purpose we compose a data base of dielectric properties of materials which are measured by us or available in the literature. Dielectric characterization is an essential step in the simulation of the propagation of electromagnetic waves in a wireless environment. The dielectric constant and loss factor have a profound influence on the performance of wireless systems. Numerous methods of measuring dielectric constant and loss factor have been developed to date. Some require expensive equipment, such as an Automatic Network Analyzer (ANA) and some rely on basic equipment, such as an impedance bridge or a slotted line. The open ended coaxial probe [3], a recent development, has become popular because it is easy to use with an ANA. Its major advantages are in the speed and the broadband nature of measurement, enabling the investigation of temperature and time variation effects as well as any frequency resonance effects. However, there are several drawbacks with this method. The sample must be homogeneous and optically flat to obtain good results. The sampling size is very small. It is not usually accurate for low loss dielectric materials. There is also the problem with lift-off where minute air gaps between the probe and the dielectric material can influence the accuracy of the measurement.

We investigate a waveguide technique of dielectric measurement. It consists of an open waveguide terminated by a short circuit plunger. When the material is very lossy, the short circuit becomes ineffective because signal never gets to it. In this case we have an infinite line measurement.

As shown in Fig. 1, a short circuit at the open end of the loaded waveguide will determine the adequacy of the infinite line assumption. According to Altschuler [4], the dielectric properties are then given by:

$$\varepsilon_r = \left[\frac{1}{\left[1+\left(\frac{\lambda_c}{\lambda_g}\right)^2\right]}\right] + \left[\frac{1}{\left[1+\left(\frac{\lambda_g}{\lambda_c}\right)^2\right]}\right] \cdot \left[\frac{\left[r - i\left[\tan\left[\kappa\cdot(D-D_R)\right]\right]\right]}{\left[1 - i\cdot r\cdot\left[\tan\left[\kappa\cdot(D-D_R)\right]\right]\right]}\right]^2 \quad (2)$$

Where $\kappa = 2\pi/\lambda g$, λg = guide wavelength, λc = cut-off wavelength, r = VSWR measured by any impedance meter, $\kappa\cdot(D-D_R)$ represents the phase shift in the minimum position relative to the reference short circuit and εr represent the dielectric properties.

For medium and low loss materials, it is not practical to use the infinite line technique because the sample size could become unacceptably long; we use another method of measurement by using the short circuit to provide a correct length for an open circuit. With an ANA, the dielectric characterization can be simplified to the point of placing the short circuit over the sample in the waveguide and then shifting it to a distance equal to one quarter of the guide wavelength to create an open circuit as shown in Table 1.

TABLE I. OPEN CIRCUIT FROM A SHORT CIRCUIT

Waveguide	Equivalent o/c length (mm)
WR284	57.1
WR340	43.0
WR430	36.8

Our method uses only one port of the network analyser and after calibration; a short circuit then an open circuit are placed behind the sample to measure the corresponding admittances Y_{sc} and Y_{oc}. The advantage of this method is to use only one port, thus reducing calibration time and most importantly, not involving solutions of a transcendental equation.

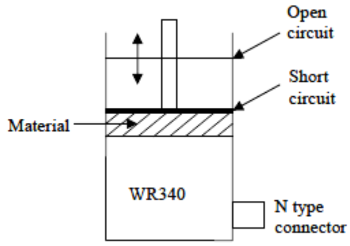

Figure 1. Waveguide sample holder

It is accurate for both low loss and high loss materials as discussed by Altschuler [4]. The dielectric properties of a material are given by the products of Y_{sc} and Y_{oc}.

$$Y_g = Y_{SC}.Y_{OC} = \frac{1}{Z_{SC}.Z_{OC}} \quad (3)$$

$$Y_g = Y_{SC}.Y_{OC} = \frac{\sqrt{\left(\varepsilon_r - \left(\frac{\lambda}{\lambda_c}\right)^2\right)}}{\sqrt{\left(1-\left(\frac{\lambda}{\lambda_c}\right)^2\right)}} \quad (4)$$

Where,

Y_{sc} = admittance of the sample when it is terminated by a short circuit.

Y_{oc} = admittance of the sample when it is terminated by an open circuit.

λ_c = cut off wavelength and λ is the free space wavelength.

We then measure the short circuit (Y_{sc}) and open circuit (Y_{oc}) admittances. Where, a = width of the rectangular waveguide and $Y_\varepsilon = G_\varepsilon + i\, B_\varepsilon$. Let $Y_\varepsilon = g + jb$, ε'r and ε''r can then be calculated from equation 3 as:

$$(\varepsilon_r)^{\mathrm{I}} = \left[\frac{\left[G_\varepsilon + \left(\frac{\lambda_g}{2\cdot a}\right)^2\right]}{\left[1+\left(\frac{\lambda_g}{2\cdot a}\right)^2\right]}\right] \quad (5)$$

$$(\varepsilon_r)^{\mathrm{II}} = \frac{-B_\varepsilon}{\left[1+\left(\frac{\lambda_g}{2\cdot a}\right)^2\right]} \quad (6)$$

TABLE II. TYPICAL RESULTS FOR MATERIALS

Materials	**Dielectric Properties**
Concrete	2.96 – i0.0626
Wood	1.82 – i0.04914
Nylon	3.03 – 0.038784
Glass	5.95 – i0.03332

Metal	infinity
Wet Brick	3.3 - i0.3
Plaster Board	2.1 - i0.12
Polypropylene	2.3 - i0.002

The present method is not broadband but it has several advantages over the open ended and open shielded coaxial probe in characterising the dielectric properties of building materials:

1) The sample size is much bigger, which can account for any inhomogeneity and provide a better average characterization.
2) The sample surface need not be very flat as in the case of the open-ended probe.
3) Method is simple to calibrate and measure.
4) It is not expensive.

III. ELECTROMAGNETIC PROPAGATION SIMULATION USING RAY TRACING METHODS

The environment used in our simulation is a typical office (in a centre of the building there is a provision of lift, stairs and toilets and they surrounded by compartments in each floors) in Hong Kong. The frequency is 1.8GHz, and the materials in the environment consist of concrete floor, nylon carpet, wood panel, glass windows and doors. Layout description is given in Fig. 2.

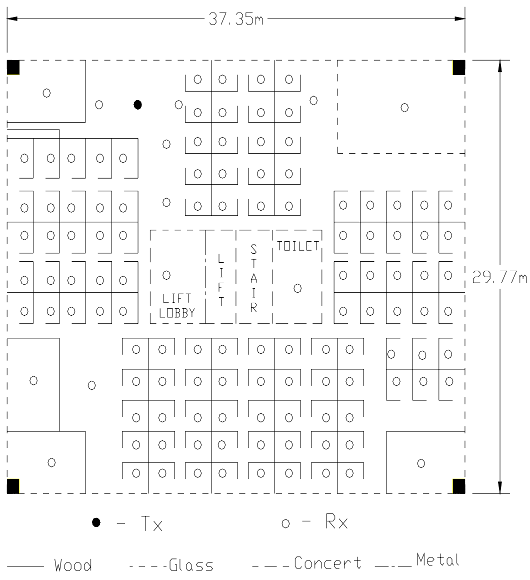

Figure 2. Floor layout of a typical office in Hong Kong

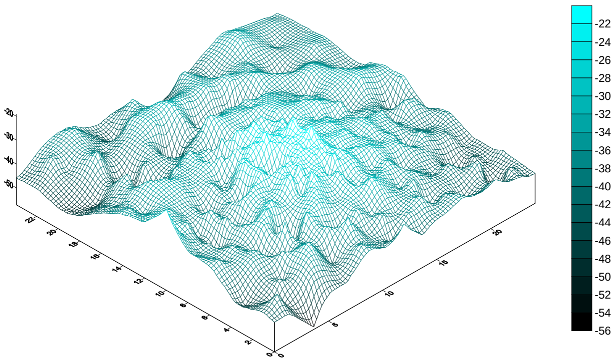

Figure 3. Simulated 3D Signal distribution of a typical office

The path loss profile can be seen in Fig 3. It shows high signal loss in areas where there is a higher density of building objects density. The meeting rooms and corridor reflect lower signal loss. Fig. 4 depicts output result of signal strength verses distance in the typical office environment at 1.8 GHz. As distance increases signal strength reduces. Fig. 5 shows that our simulated power distribution (continuous line) is in agreement with ideal Rayleigh (dotted line) from -15 dBr up to 35 dBr and beyond.

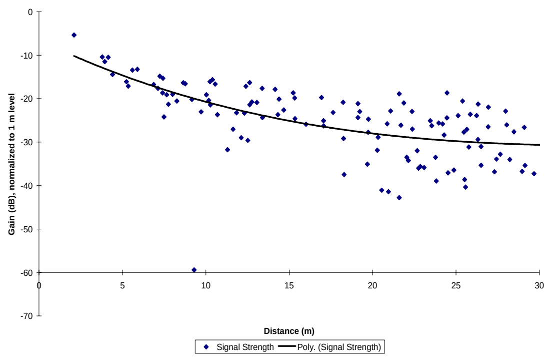

Figure 4. Signal Strength vs. distance in the typical office (1.8 GHz)

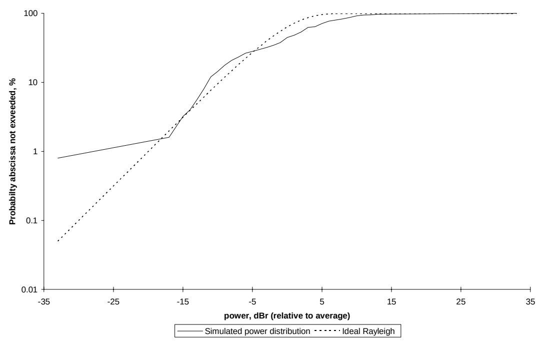

Figure 5. Simulated cumulative distribution function of power in the typical office

Fig. 6 shows simulation result output between log distance and power dB reference up to 1 m. It is observed that as power increases log distance increases.

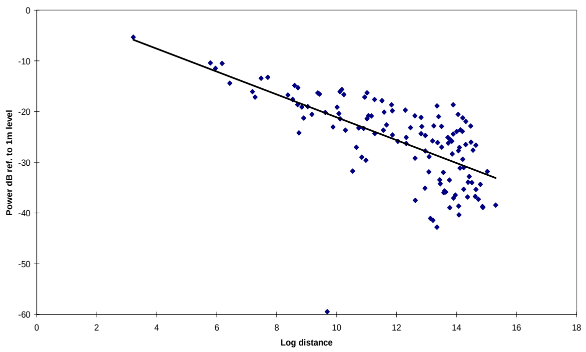

Figure 6. Distance power law

Fig. 7 shows simulation result output between T-R separation (m) and RMS time delay spread (ns). It can be seen from Fig 7 that as distance increases RMS time delay increases. Over 35 meters, RMS time delay increases by 18 ns.

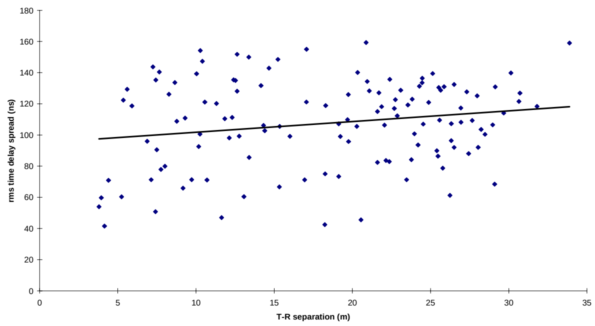

Figure 7. RMS time delay with distance

IV. SIMULATION PARAMETERS AND PROPAGATION MODEL

A. Multiple Service Provider Simulation in the Same Area

The simulator MobileSim© for multiple service providers on multiple floors are used to investigate the performance of the tele-traffic system when multiple service providers share the frequency spectrum in the same area. Spectrum planning is not compulsory in a DCA network. For a maximum of 12 carrier frequencies in operation, input traffic parameters of 6 Erlang and 7 Erlang are used to simulate the GoS of the teletraffic system. The number of service providers are varied between 1 and 7 and ten carrier frequencies are available in the simulation. The simulation studies the effect of GoS with the change in traffic loads and the number of floors used. The results are plotted in Fig. 8, depicts the GoS of the system degrading logarithmically as the number of service providers increases. Under a constant traffic load of 6 Erlang, the wireless system can only support 1.2% GoS with a single service provider. Increasing the number of service providers will exceed 1.2% GoS; call congestion and call dropouts increase. With two service providers allocated the same spectrum, the GoS increases to 21% and 26% for a traffic load of 6 and 7 Erlang respectively.

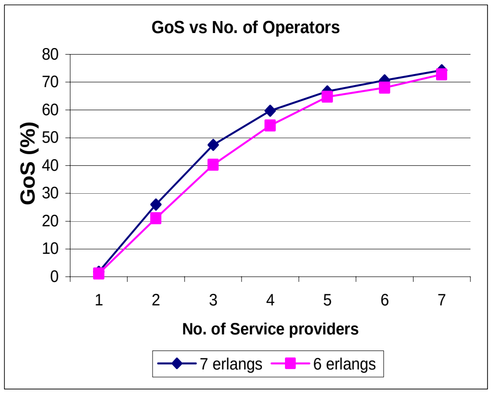

Figure 8. Performance in a multi-service provider environment

Using seven service providers simultaneously, the GoS degrades to 72.8% and 74.3%. This study concludes that multiple deployments of service providers within the same area will place a tremendous strain on the wireless system resources. Further spectrum planning and frequency allocation is needed to resolve this problem.

B. Performance of Multiple Service Providers Over Multiple Floors

Under this simulation scenario, we investigate the performance of the DCA algorithm in a multi-floor application. The ETSI [1] has limited the study to three floors, but we extend it up to seven floors, as seen in Fig. 8 and 9, which is more realistic scenario in an urban environment. Two carrier frequency carriers are used with the traffic at 6 Erlang. The GoS is presented in a scenario with increasing numbers of floors, with an independent service provider on each floor. A maximum of seven service providers are used in the simulation.

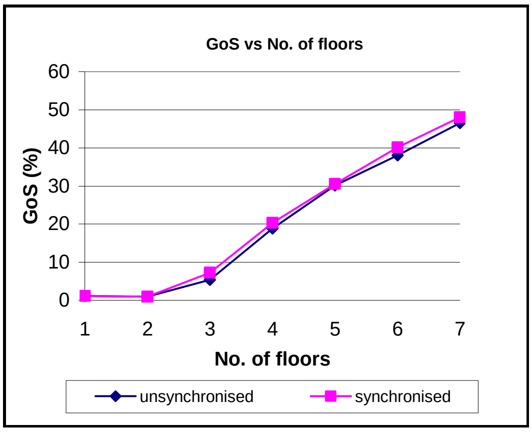

Figure 9. The performance of DCA (GoS) with up to seven service providers, one on each floor

V. CONCLUSION

We have used our propagation model with realistic dielectric properties of the materials in a specific environment to obtain the propagation characteristics of the environment as shown in Fig. 2 to Fig. 7. We then use the data to input into our simulator MobileSim© to obtain the performance of a DCA in a scenario for multiple providers and multiple floors. In a multiple floor multiple service provider scenarios; DCA requires a minimum of 4 carriers in order to maintain a GoS of 0.95 at 5.6 Erlang of traffic. For the GoS to be maintained regardless of the number of floors added, the number of carriers has to be increased by the number of floors occupied by a service provider. If the service is synchronised among the multiple service providers, it performs 5% to 15% better. Including dielectric characteristics of the environment in the simulations improves the GoS of the system by a margin of 0.15% to 6.4%.

The simulation is executed for scenarios based on a single base-station and multiple base-stations on same floor and multi-floors. In a single base-station, no handover is required. In multiple base-stations, when users move from cell to cell, handover occurs and are taken into account. Our simulations include the dielectric properties of materials for materials in the environment. In many cases they are measured directly. The simulation tool for DCA deployment can be further extended to include other wireless standards such as 3G as sharing of the spectrum becomes unavoidable.

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