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Procedia Computer Science 225 (2023) 2153–2162

Procedia Computer Science

www.elsevier.com/locate/procedia

27th International Conference on Knowledge-Based and Intelligent Information & Engineering Systems (KES 2023)

Routing Protocol for Healthcare Applications Data Over the 6LoWPAN-based Wireless Sensor Networks

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Abstract

Wireless Sensor Networks (WSNs) have increasingly been adopted as a viable solution in the healthcare industry for many years. One novel application of WSNs in healthcare is real-time health data collection and tele-healthcare service delivery via the Internet. With the increasing number of applications of Wireless Sensor Networks (WSNs) in healthcare has emerged during the past decades, especially during the COVID-19 pandemic which has affected millions of people, particularly the elderly, the advantages and benefits of applying WSNs to monitor patients and improve the quality of healthcare have become clearer. Today's sensing and communications technologies have reached a point where these WSNs can be readily implemented and deployed, albeit with some limitations and security concerns.

Collecting patients' health data or vital signs from WSNs deployed in hospitals or elderly nursing homes has been one of the most challenging tasks in the healthcare industry. In this paper, our main focus is on the routing protocol for human psychological data generated by healthcare application over the 6LoWPAN-based Wireless Sensor Networks (WSNs) as well as the development of affordable healthcare applications by leveraging novel WSN technology. Firstly, we present our latest achievements in implementing healthcare systems using the framework proposed in [**?**]. Additionally, We employ this framework to simulate 6LoWPAN-based Wireless Sensor Networks (WSNs) in two different healthcare settings using the network simulator NS-3. Finally, we provide preliminary results from the application of the developed application in on-site hospitals and nursing homes.

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Keywords: Healthcare Services; Healthcare Industry Applications; Patient Monitoring; Wireless Sensor Networks (WSNs); 6LoWPAN; Network Simulator(NS-3); IEEE 802.15.4 (ZigBee); RPL Routing Protocol.

1. Introduction

The interest in developing technical solutions to address problems with healthcare delivery has never been stronger than today, particularly over the last three years, the COVID-19 pandemic that has rapidly spread around the world.

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10.1016/j.procs.2023.10.206

The global aging population presents numerous challenges for the healthcare industry to deliver services to those who need it. As a result, there is an unprecedented shortage of healthcare workers healthcare industry is experiencing an unprecedented shortage of healthcare workers, and healthcare practitioners and providers are under immense pressure to deliver much-needed services to the millions of people who require healthcare.

Wireless sensor networks (WSNs) are one of many applicable solutions that have been proven to be highly valuable in various areas, including industrial and home automation, healthcare, agriculture and environments, and military operations. Currently, there are many ongoing researches efforts to explore how WSN technology can be applied to alleviate the pressures faced by healthcare service providers. Moreover, the utilization of WSN technology can not only complement human healthcare service providers, but also improve the quality of healthcare at a reduced cost. With advancements in sensing technology and communication technology, healthcare services can become more affordable for the public.

In this paper, we will review the framework for developing applications using the 6LoWPAN based Wireless Sensor Networks [**?**], followed by simulating two healthcare applications in on-site hospitals and nursing homes using the NS-3.

We have made several contributions as follows:

- Investigate a general approach to developing low-cost applications for healthcare;
- Thoroughly review the framework to build reliable sensor networks that communicate the patient's or elderly's physiological data to the healthcare providers including doctors, nurses, and researchers.
- Analyze the performance of the developed applications under different scenarios with simulated environments.

The paper is structured into four sections. In section 2, we review the challenges of applying WSNs in healthcare. In the following section 3, the protocol stack for the sensor nodes is proposed, similar to the traditional computer network nodes such as hosts and/or routers. The framework proposed in the previous study [**?**] has been further refined and described in section 3. The implementation of the WSNs for healthcare will be given in section 4, it is based on a list of communications standards which has currently been used in the Low-Power and Lossy Networks using IPv6, in particular on the WSNs. In section 5, three configurations of the WSNs for three different healthcare setting are described. In the final section 6, we briefly summarize the progress of the current work and also the direction of future work has been presented.

2. Healthcare Applications and the Challenges of WSN for Healthcare

Healthcare systems have evolved from the medical database to web-based networks, to social networks, to ubiquitous computing, and even to cloud computing.

2.1. Healthcare data and services

The healthcare services scope have been expanding from traditional hospital care to at-home healthcare to telemedicine, and to the healthcare analytic studies.

1. Health monitoring: it is to monitor a patient in the clinical setting or at home regardless of the patient's or caregiver's location. The monitoring system is often necessary to constantly monitor a patient's vital signs such as blood pressure, heart rate, body temperature, and Epigallocatechin gallate(EGCG).
2. Body health monitoring: It continuously monitors physiological data during the patient's stay at the hospital or home. It can be useful for emergency cases. It can also help people by providing healthcare services such as memory enhancement, medical data access, cancer detection, asthma detection, and monitoring blood glucose.
3. At-home healthcare: This care is related to the aging population. At-home healthcare provides affordable care to the elderly while they live independently.
4. Tele-medicine: It enables clinical work to be performed remotely, providing healthcare services and education over a distance. Although tele-medcine dates back to 1960's, its adoption has been lukewarm due to limitations in patient's data collection technology. However, it is anticipated that the novel Wireless Sensor Networks(WSNs) technology will play a crucial role in the remote patients' data collection.
5. Healthcare analytics: Healthcare analytics can help in streamlining various aspects of healthcare delivery [**?**].

2.2. Wireless and Sensor Network Technology for Healthcare Data Management

It is not new that mobile ad-hoc networks (MANETs) have been widely used by doctors for healthcare and medical services. There are many structural resemblances between Wireless Sensor Networks and traditional ad-hoc networks. But the traditional ad-hoc networks have less constraints on resources than WSNs. These innate constraints of the WSNs, have rendered many technologies and protocols which worked well on the ad-hoc networks, no longer feasible for WSNs. For instance, particularly in routing protocol in the network layer, where the AODV protocol have been proven to be efficient for the ad-hoc networks; but the ADOV is not good for the WSNs. In [**?**], a performance study shows that the AODV require much higher memory in each node to maintain the routing state for each active used path, which is a serious limitation for the WSNs.

Hence some novel and more efficient algorithms have to be developed specifically for the packets routing on the WSNs [**?**]. Research and development of routing algorithms in the WSNs were initially driven by defense applications; the primary design goal of a routing algorithm operating in the context of the WSNs is to minimize power consumption and thereby extend the network lifetime.

Apart from that, there are more vulnerabilities in the WSNs than in the ad-hoc networks. For instance, in most cases, the WSNs are vulnerable to various sensor data faults and this vulnerability hinders efficient and timely responses in healthcare applications. Security is particularly important in healthcare WSNs, where the sensor data are sensitive medical data of patients. Privacy is another major concern of patients and the greatest barrier to the WSNs healthcare deployment. Healthcare applications normally impose constraints on the end-to-end reliability, which measures how well the healthcare system performs in the presence of disturbances.

A healthcare system normally consists of a number of WSNs and the gateway routers; in which each of the WSNs is primarily used to gather the data in the specific environment such as a nursing home and/or clinic ward; while the gateway routers are interfacing the WSNs with the Internet, as shown in Figure 1.

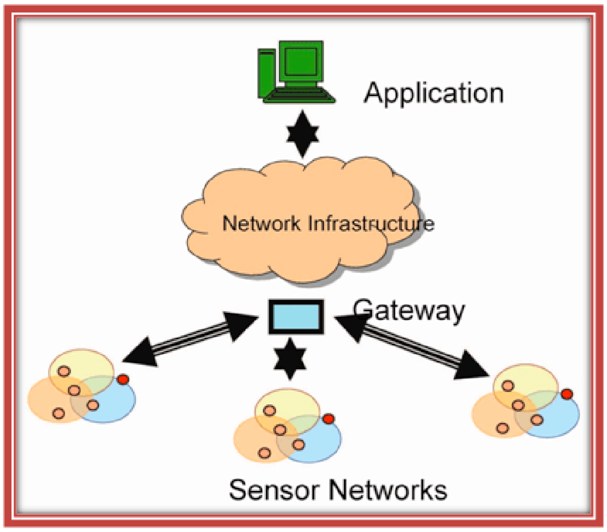

Fig. 1. The Architecture of WSNs

The primary applications of WSNs in healthcare include monitoring patients and checking temperature, aiming to gather patients' chronicle data and home automation. As mentioned above, the core components of the WSNs are the sensing devices and wireless communication nodes. More and more sensing devices and wireless devices are being used in the healthcare systems such as smart phones and low-power devices. This trend results in the Internet of Things(IoT), where the IPv6 address schema for the IoT devices becomes a compulsory alternative.

3. Framework for Developing the WSN-Based Applications

In this section, we will propose the protocol stack of the WSNs for healthcare in this section. The protocol stack of the WSN-based healthcare system is shown in Figure 2. Unlike the Internet protocol stack with four layers, the proposed stack has five layers with an additional layer. They are the application layer, routing layer, and adaptation layer, IEEE 802.15.4 MAC and IEEE 802.15.4 PHY.

Essentially there are two considerations when exploiting the routing protocol for the WSNs, as mentioned in the preceding section, we have to always keep in mind that with the energy constraint and simple and cheap wireless sensor nodes, the routing protocols used in the traditional ad-hoc networks are no longer applicable in the WSNs. The second consideration is the networking address schema. Since the WSNs networking nodes can be any lower power communication devices, the IPv6 with 128-bit address spaces must be adopted.

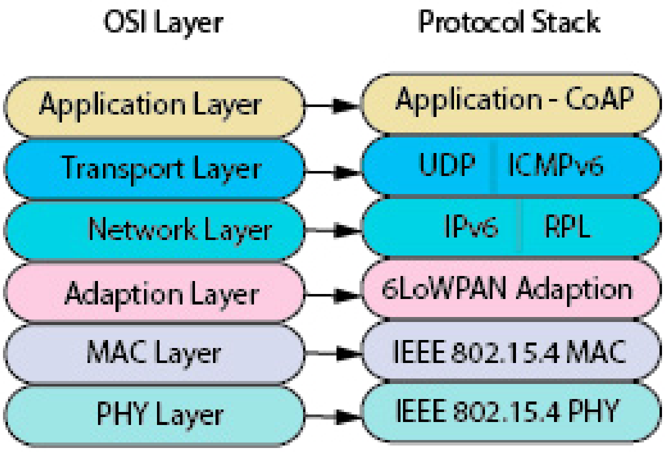

Fig. 2. A simplified 6LoWPAN network

In the following sections, we will discuss more details about each protocol layer and its protocols.

3.1. Application protocols

For a general WSN, the sensing nodes are used to sense their surroundings and/or to trigger a signal. Nevertheless, the applications are highly distinct in nature. The applications operate under different constraints, which are designed by application parameters. The applications generate sensor data with different patterns. For instance, the application of the WSNs in healthcare normally generates traffic with the Poisson distribution.

The interface between the devices in the applications is handled by the routing protocols that establishing communication routes in the network through message exchanges. The application and the routing protocol parameters have to be tuned to one another to obtain the optimal behavior of a large network.

There are many security issues related to the application protocols. In regard to the WSNs for healthcare, one eminent concern is the intrusiveness of privacy. These sensing devices are susceptible to electronic interference and channel noise. Potentially, there might be some ethical issues as well.

3.2. Multi-hop Routing protocols

The are a number of routing protocols that are based on the IPv6 address schema. Hence they can be adopted by the WSNs for healthcare. In this section, we will briefly overview a few of them that have been widely studied in the last decade.

First of all, the RPL is a proactive routing protocol[**?**]. As its name implies, RPL is a distance-vector routing algorithm originally designed for low-power and lossy networks using IPv6. The RPL supports ubiquitous sensing applications such as the WSNs based healthcare applications.

The RPL components include the WSN nodes, [**?**] and local border routers(LBR). The WSNs nodes act as hosts or intermediate routers for transmitting packets in WSN; while the router translates packets through WSN to user hosts from the Internet. The WSNs node and the LBRs apply a new concept of Directed Acyclic Graph (DAG), this DAG is separated into multiple Destination Oriented DAG(DODAG), where the roots of these DODAG are normally LBRs.

The DPDAG is a logical configuration on the WSN nodes, so a WSN node can join multiple DODAGs to support routing optimization.

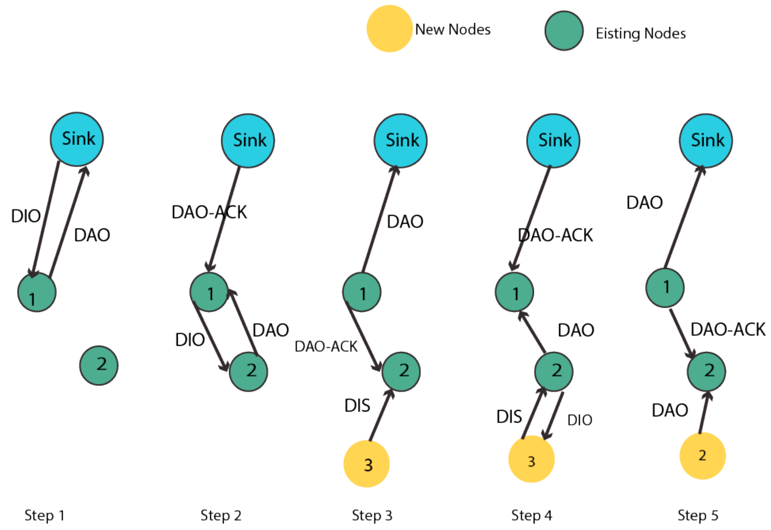

Fig. 3. RPL protocol

Secondly, there are also many ongoing research that attempts to develop the AODV-like protocols, but the protocol are relied on the IPv6 addressing schema. Unlike RPL, LOAD and its successor, LOADng is a reactive routing protocol for the low power and lossy networks [**? ?**]. LOAD is a derivative of AODV and with some simplifications over AODV, eg. removal of intermediate Route Replies and of sequence numbers. As a reactive protocol, it does not maintain a routing table for all destinations in the network, but initiates a route discovery to a destination only when there is data to be sent to that destination to reduce routing overhead and memory consumption. Both LOAD and LOADng are based on the principles of Route Request/Route Reply exchanges for Route Discovery.

Lastly, we would not indent to give an exhaustive list of the multi-hop routing protocols on the IPv6 addressing. We just pointout that all these routing protocols are vulnerable to the `warmhole attacks` [**?**].

3.3. 6LoWPAN - IPv6 Routing Protocol for Low Power and Lossy Networks

In this section, we introduce an additional layer in the proposed protocol stack, called 6LoWPAN. The 6LoWPAN is an adaption layer in the network protocol stack for integrating low-power network such as IEEE 802.14.4 into IPv6 Protocol.

The 6LoWPAN network consists of one or more host nodes local to LoWPANs, which are all connected by the IPv6 address to the Internet through a gateway (or border router), as shown in Figure 4. The network deals with small packet size, low bandwidth and requires resource saving for maintaining the life of network nodes.

The LoWPAN supports both star and peer-to-peer topology; the topology can be changed frequently because of uncertain radio frequency, mobility and battery drain.

The 6LoWPAN is responsible for connecting the border router node in the WSNs to the Internet. It fragments the packets at the IPv6 layer, and then reassembles them in the data link and physical layer. There are two distinct approaches for forwarding packets in this layer: mesh-under or route-over. By taking advantage of network simulation, it has shown that the route-over forwarding approach is more scalable and robust over than that of the mesh-under forwarding 6LoWPAN network [**?**].

3.4. IEEE 802.15.4 – ZigBee

The most relevant communication standard for WSNs is IEEE 802.15.4, which operates in Low-Rate Wireless Personal Area Networks (LR-WPANs). The IEEE 802.15.4 MAC specifications and IEEE 802.15.4 PHY specifications are standardized by the ZigBee consortium.

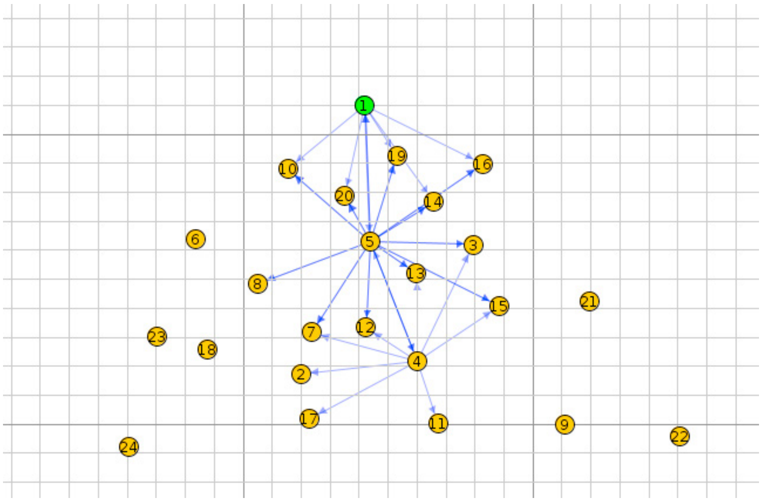

Fig. 4. A simplified 6LoWPAN network

The ZigBee standard is a low-cost, low-power wireless communication standard that is mainly used to create Wireless Personal Area Network (WPAN). It has provided the mesh capabilities for the IEEE 802.15.4 standard by network and security layers and an application framework. ZigBee includes many different areas of practical applications such as home automation, healthcare, lighting management and telecommunication services.

The ZigBee Alliance consists of a group of companies. These companies manufacture inter-operable products to their customers. However, all the ZigBee nodes require an IEEE 802.15.4/IP gateway to establish communication with IP networks. Three categories of ZigBee nodes are: ZigBee coordinator, ZigBee router, and ZigBee devices. That indicates the ZigBee nodes will interface with the IP network via the ZigBee coordinator.

4. Simulations the WSN application in Healthcare

In the previous section, we have outlined a framework of building the WSNs for low rate and noisy networks. We can clearly observe the WSNs for healthcare just well fit in the category of application. In this section, we look at how the WSNs for healthcare in different settings are implemented by adopting the general approach of network simulation.

4.1. The WSNs Simulator

There are plenty of network simulators for WSNs. The NS-3 simulator is one such designed for communication networks. The NS-3 is an open source software, virtually a model library for various communication networks. The majority of models are for the IPv4 based networks; while an increasing number of research are emerging for the IPv6 addressing based network and wireless networks. Apart from the NS-3, other network simulators such as Cooja, TOSSIM and OMNET++ Castalia have been explored to simulate the WSNs.

In this study, we will focus on how to apply the NS-3 network simulator to design networking nodes including the NetDevices, Interface containers and Node containers. Figure 5 show the model design of the NetDevice, Interface and Node in the NS-3. The justification for choosing the NS-3 network simulator is that the RPL model, the 6LoW-PAN adaptation model the LR-WPAN model(based on IEEE 802.15.4 MAC and PHY) have been developed and are available for use.

4.2. Simulation of the 6LoWPAN-based WSNs using NS-3

Although there are many multihop routing protocols have been implemented such as AODV, DSR, OLSR on the NS-2 and NS-3 network simulators; however, they are all developed for the Mobile Ad-hoc networks(a.k.a MANETs)

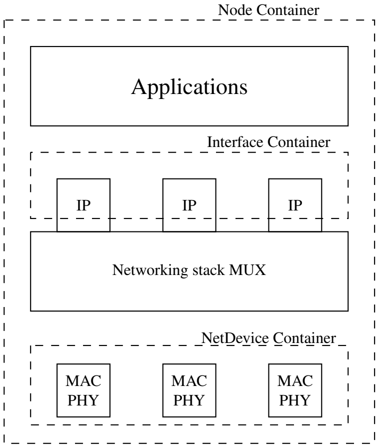

Fig. 5. The NetDevice and Nodes Container in NS3

and based on the IPv4 addressing schema. In this section, we will adopt the RPL although both RPL and ADOVv6 are in the development stages and have some bugs and wired behaviours that have to be fixed.

Other network simulators such as COOJA, OMNET++, have been popularly used to study the features and performance of the WSN-based applications, however, they are proven to be better in the simulation of the WSNs with the RPL protocol, instead of the mixed 6LoWPAN-based applications with traditional Wireless Ad-hoc networks [**?**].

In the case of multiple RPL instances, how RPL nodes select and optimize routes is crucial. The Objective Function(OF) defines the approach to determine DODAG selection, rank computation, and parent selection of an RPL node. Among the two existing objective functions: The Objective Function Zero (OF0), and the Minimum Rank with Hysteresis Objective Function (MRHOF), which have been defined by the ROLL working group, we have chosen the Objective Function Zero (OF0) in our experiments.

The Objective Function Zero (OF0) is defined as the following equations:

$$\begin{aligned} rankIncrease &= ((RANK\_FACTOR * STEP\_OF\_RANK) + RANK\_STRETCH) * MIN\_HOP\_RANK\_INCREASE \\ rank &= parentRank + rankIncrease \end{aligned} \tag{1}$$

where $RANK\_FACTOR$, $STEP\_OF\_RANK$, and $RANK\_STRETCH$, $MIN\_HOP\_RANK\_INCREASE$ are prior defined constants by the ROLL working group.

5. Three Scenarios of WSNs for Healthcare Application

Normally the latency of message delivery is used as a metric to analyse the performance. The latency is measured at the application level, ie. the difference between the time the application message was created at the source node and the time at which the application layer at the receiver nodes senses the message.

Figure 6 is a sketch of a nursing home with four WSNs in each patient's room.

The primary difference between the WSNs based healthcare application is lie in the deployment environment. In the context of hospitals, the sensor nodes position or location of the WSNs based healthcare is varying within a hospital wards or theater, but the gateway node or the border routers are fixed; On contrary, in the context of nursing homes at where elders are living, sensor nodes can be always mounted or deployed at the fixed at location of the living room, kitchen, the bath room etc. This will impact the routing protocol either using RPL or static routing.

The second difference the WSNs healthcare application is dependent on whether they are used within a certain time of the day or for all day every day. Normally in the hospitals, the WSNs application is used for a certain period of hours of day; but in nursing homes, they are used or need to be continuously operational for 24 hours and 7 days a week.

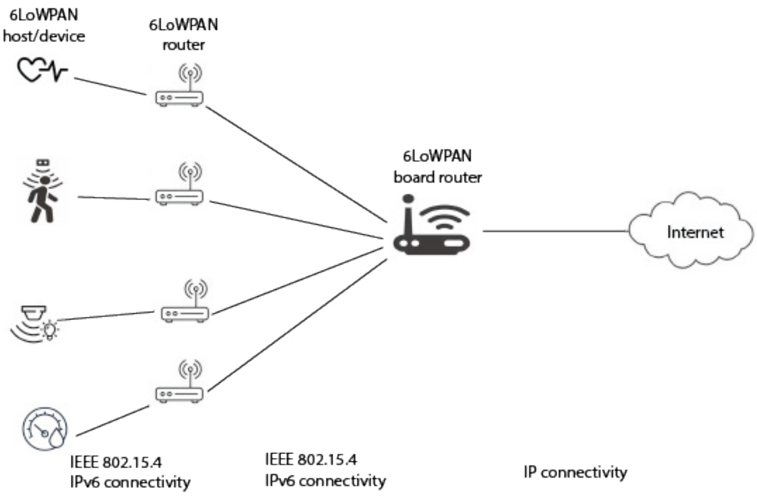

Fig. 6. A sketch of the healthcare system with four WSNs

5.1. The application of WSNs in Hospitals

The WSN based healthcare system has 4 WSNs and each WSNs in the settings consists of a mesh network of ZigBee sensors and one ZigBee router. All four ZigBee routers route the patient's data to a remote base station within the hospital.

A hospital caregiver can access the patient's data at any point in time and doesn't have to be present in the patient's room to examine the readings.

Each WSN is comprised of 4 or more sensor nodes and one router is responsible for monitoring the movement of the patient and collecting their physiological data such as blood pressure and temperature, and then transmitting to the base station in the hospital corridor.

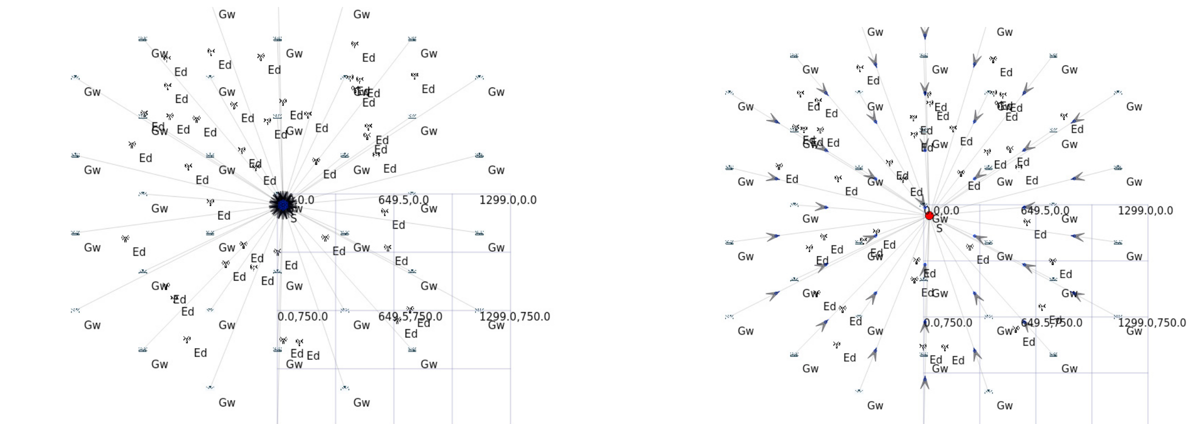

Fig. 7. The simulated WSNs based system in the hospital

Figure 7 show data transmitting through the sensors and the gateway within the simulated WSN-based healthcare system in hospital.

5.2. The application of WSNs in Care Center

When it comes to the implementation, the overall application of WSNs in care centers is a network of 6LoWPAN networks; Each 6LoWPAN network consists of one or more local LoWPANs. Local LoWPANs are connected by the

IPv6 addressing to the through a gateway (or border router). The LoWPANs devices might be ZigBee nodes or other types of low-power sensors.

The data gathered from the gateway (or border router) would be routed to the data center through the dedicated wireless ad-hoc network.

Figure 8 show data transmitting through the ensors and the gateway within the simulated WSN-based healthcare system in the nursing home or care center.

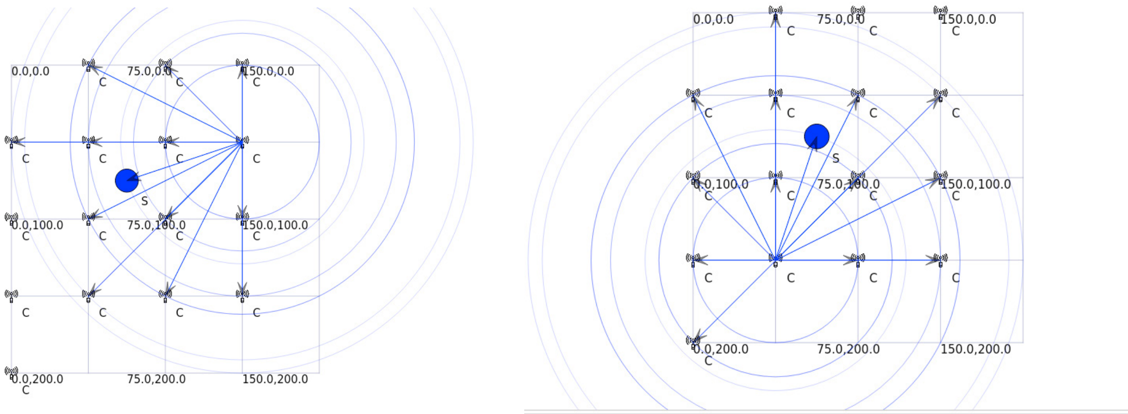

Fig. 8. The simulated WSNs based system in the nursing home or care center

5.3. *Collection of Long-Term Databases of Clinical Data*

Sensors link the physical with digital world by capturing and revealing real-world phenomena and converting these into a form that can be processed, stored, and acted upon. The data that is gathered by the sensors in a WSN can be used in two ways:

1. Healthcare applications that leverage wireless sensor networks analyze the data gathered by sensors to infer and make decisions about the state of a patient's health and well-being. By improving monitoring consistency, continuous monitoring enhances data quality and precision for decision support, leading to better titration of therapeutic interventions.
2. The continuous for gathered data can be analyzed utilizing artificial intelligence and data analytic techniques to find solutions to the unsolved problems in the healthcare systems.

While there have been many research conducted on this scenario, we will not be presenting our efforts in this work. However, we plan to discuss more details about the scenario in our future work.

6. Conclusion

In this paper, we have presented our latest progress of study that continues on the previously proposed framework for designing and developing efficient and low-cost healthcare application systems based on Wireless sensor networks.

The study has gone through from further scrutinizing the requirements and characteristics of healthcare application systems deployed in the three primary environments. It has reviewed the framework of the layered protocol stack that can be applied while building the 6LoWPAN-based WSN application systems to meet the requirements of healthcare services.

The routing protocol of healthcare application data such as psychological and vital signs data over the 6LoWPAN based Wireless sensor network has been discussed. By using routing protocol RPL, and in accordance with the proposed framework to meet the stringent needs of low-cost, efficiency and reliability of underlying communication networks, we have developed a wireless patient monitoring and data collecting(WPMDC) system in the hospital environment. The developed healthcare applications have been simulated as the 6LoWPAN based WSNs in network simulator NS-3 and some preliminary results show that the framework be applicable to other healthcare related environments such as nursing homes for aged care services.

From the performance analysis of the developed WPMDC system, we have gained many insights into the requirements of healthcare services and a deeper understanding of the routing protocol RPL over the reliable communications on the wireless sensor networks(WSNs) with the nature of low cost and noisy. In the future, we would continue the study on both the performance analysis and security.

References

[1] John Patrick C. Agustin, Joshua H. Jacinto, Wilbert Jethro R. Limjoco, and Jhoanna Rhodette I. Pedrasa. IPv6 routing protocol for low-power and lossy networks implementation in network simulator - 3. In *IEEE Region 10 Conference (TENCON)*, Malaysia, November 5-8 2017.

[2] S. Bangalore Lakshmana. A study on the impact of transmission power on the message delivery latency in large ZigBee networks. Master thesis, Eindhoven University of Technology, UK, 2015.

[3] Salem Belhaj and Sofian Hamad. Routing protocols from wireless sensor networks to the internet of things: An overview. *International Journal of Advanced and Applied Sciences*, 5(9):47–63, 2018.

[4] Yi bo Chen, Kun-Mean Hou, and Jean-Pierr Chanet. A RPL based adaptive and scalable data-collection protocol module for NS-3 simulation platform. In *PROTOCOLNICST'2103 New Information Communication Science and Technology for Sustainable Development: France-China International Workshop*, Clermont-Ferrand, France, 18-20 September 2013.

[5] Thomas Clausen, Jiazi Yi, and Ulrich Herberg. Lightweight on-demand ad hoc distance-vector routing - next generation (loadng): Protocol, extension, and applicability. *Computer Networks*, 120:125–140, 2017.

[6] Khalid A. Darabkh, Muna Ai-khras, Jumana N. Zomot, and Mohammed Atiquzzaman. RPL routing protocol over iot: A comprehensive survey, recent advances, insights, bibliometric analysis, recommendations, and future directions. *Elsevier*, 207, 2022.

[7] Kevein Mc Gee and Martin Collier. 6LoWPAN Forwarding Techniques for IoT. *2019 IEEE 5th World Forum on Internet of Things (WF-IoT)*, pages 897–902, April 15-18 2019.

[8] Yih-Chun Hu, Adrian Perrig, and David B. Johnson. Wormhole attacks in wireless networks. *IEEE Journal on Selected Areas in Communications*, 24(2):370–380, Feburary 2006.

[9] Vikas Kumar. *Kealthcare Analytics Made Simple*. Packt Publishing Ltd., 2018.

[10] Zhongwei Zhang, Jianxiong Wang, and Xiaohua Hu. A framework of developing the healthcare applications using the 6LoWPAN wireless sensor networks. In *1st EAI International Conference on Forthcoming Networks and Sustainability in the IoT Era*, Turkey, 1-2 Oct 2020.