A Framework of Developing Health Care Application Systems Using 6LoWPAN Based Wireless Sensor Networks

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Abstract. There were an increasing number of innovative applications of Wireless Sensor Networks (WSNs) in health care domain. It has never been such clearer to appreciate the advantages and benefits of applying the WSNs to improve the quality of health care in a wide variety of areas. Thanks to the sensing and communications technology of today, it has also reached a point where these WSNs applications can be readily implemented and deployed to function although there are some limits and hinderance from the viewpoint of security concerns.

In this paper, we provide a protocol stack applicable to the WSNs for health care systems, and to outline a framework to implement the WSNs in two different health care settings. Following the proposed framework, we have simulated a WSNs based health care application for the settings of hospitals and/or nursing homes for the performance study.

Keywords: Health care · Wireless Sensor Networks (WSNs) · 6LoWPAN · Network Simulator (NS-3) · IEEE 802.15.4 (ZigBee)

1 Introduction

With the COVID-19 pandemic infecting millions of people around the world at the moment, the health care industry is experiencing an unprecedented shortage of health care workers; the health care practitioners and providers are under enormous pressure to hold up the much-needed services for the millions of virus infected victims.

In the last couple of decades, the wireless sensor networks (WSNs) have been used in many areas including industrial and home automation, health care [10], agriculture [9] and environment [5], and military. There are many research into

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how to apply the WSNs technology to mitigate these pressures from health care service providers. In addition to that, the exploitation of WSNs technology can not only complement the human health care service providers, but also improve the quality of health care at a reduced cost. With the advances in sensing technology and communication technology, the application of WSNs makes possible for the health care service to be more affordable for public.

In general, wireless sensor networks (WSNs) comprise a number of autonomous, low-power, spatially distributed, wireless sensor nodes. A WSNs based health care system is just one type of WSNs application, primarily devised for the health care environment such as hospitals and nursing homes, etc. The potential benefits of WSNs based health care systems are enormous, yet to be fully exploited and unleashed, there are many challenges facing us while applying the WSNs applications in reality. The tangible benefits include: location flexibility, all time availability, quick adaptability and low-cost in communications. Here the flexibility refer to the WSN system collects and communicates data wirelessly with minimal input from the patient. The availability allows the physiological data to be monitored continuously. The adaptability makes possible to change the mission of the application of the WSNs as the medical needs changes. The last benefit is that using the WSNs in health care provides a low-cost communication infrastructure.

Among these many challenges, the major one is the data acquisition and communications within sensor nodes. Since the sensor nodes have a limited energy supply, the protocol responsible for data transmitting among the sensing and routing devices must be very stingy and efficient. Apart from the data communication protocol, the security protocol and security mechanism in the WSNs applications is even more complex and challenging. On the top of these security concerns that are general to all type of WSNs applications, there are more issues that are specific to the WSNs for health care, where the sensitive medical data of the individual are dealt with. Privacy is another major concern of patients and the greatest barrier to the deployment of WSNs applications. Deployment of the WSNs application for health care impose constraints on end-to-end reliability, which measures how well the system performs in the presence of disturbances. The integration of multiple sensing devices could cause a problem when operating at different frequencies.

This paper is structured as follows. In Sect. 2, an introduction to the WSNs technology is used in the development of health care system is given. Also in Sect. 2, a review of challenges of applying the WSNs in health care is delineated. In the following Sect. 3, the protocol stack for the sensor nodes is proposed, which is similar to the traditional computer network nodes such as hosts and/or routers. The implementation of the WSNs for heath care will be given in Sect. 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 Sect. 5, three configurations of the WSNs applications for two different health care setting are described. In the final Sect. 6, we briefly summarize the progress of the current work and also the direction of future work has been presented.

2 Challenges of the WSNs for Health Care

Health care systems have evolved from the medical database to the web-based networks, to the social networks, to the ubiquitous computing, and even to the cloud computing. The scope of Health care services have been expending from the traditional hospital care to the at-home health care, to the tele-medicine, etc.

2.1 Health Care Services

We delineate these services as follows:

1. Health monitoring: This service is to monitor a patient in the clinical setting or at home regardless of the patient's or care-giver's location. Monitoring system is often necessary to constantly monitor a patient's vital signs such as blood pressure, heart rate, body temperature, and EGCG.
2. Body health monitoring: This service is to continuously monitor physiological data during the patient's stay at the hospitals or home. It can be useful for emergency cases. It can also help people by providing health care services such as memory enhancement, medical data access, cancer detection, asthma detection, and monitoring blood glucose.
3. At-home health care: This care is related to aging population. At-home health care provides affordable care to the elderly while they live independently.
4. Tele-medicine: This foresight service allows clinical work to be performed remotely. It refers to the provision of health care services and education over a distance.

2.2 Wireless Technology in Health Care and Medical Services

It is not new that the mobile ad-hoc networks (MANETs) have been widely used by doctors for health care and medical services. There are many structural resemblances between the Wireless Sensor Networks and the traditional ad-hoc networks. But the traditional ad-hoc networks have less or virtually no constrains on resources than the WSNs put on. 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 networking or routing protocol in the network layer of the TCP/IP stack, where the Ad Hoc On-Demand Distance Vector (AODV) protocol have been proven to be efficient for the ad-hoc networks; but the ADOV is not of any good for the WSNs. In [6], a performance study show that the AODV require much higher memory in each node of the WSNs to maintain the routing state for each active used paths, which is a serious limitation for the WSNs.

Hence to ameliorate this problem, some novel and more efficient algorithms have to be developed specifically for the packets routing on the WSNs [3]. 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 lifetime of the WSNs nodes and/or devices.

Apart from that, there are more vulnerability in the WSNs than 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 response in the health care applications. Security is particularly important in the WSNs health care applications, where the sensor data are sensitive medical data of patients. Privacy is another major concern of patients and the greatest barrier to the WSNs health care deployment.

The health care applications normally impose constraints on the end-to-end reliability, which measures how well the health care system perform in the presence of disturbances.

A WSNs based health care system is normally consists of a number of the WSNs networks and the gateway routers; in which each of the WSNs networks 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 Fig. 1.

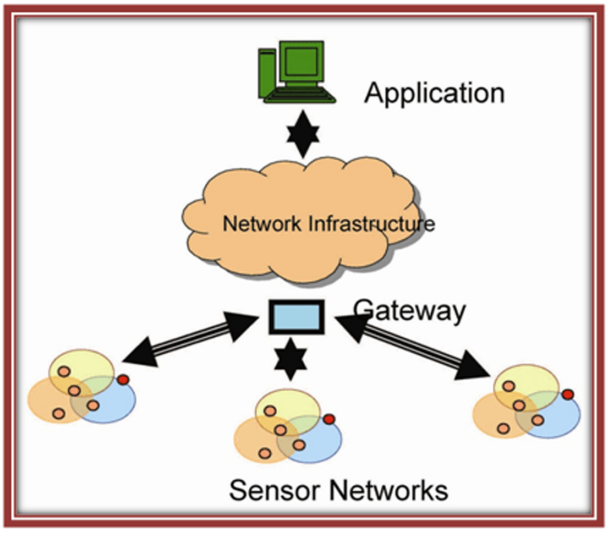

Fig. 1. The Architecture of WSNs Application

2.3 Wireless and Sensing Devices in Health Care

The primary applications of WSNs in health care include monitoring patients and checking temperature, aiming to gather patients' chronicle data and home automation. As mentioned above, the core components of the WSNs network are

the sensing devices and wireless communication nodes. More and more sensing devices and wireless devices are being used in the health care systems such as the smart phones and low power devices. This trend results in the Internet of Things (IoT), where the IPv6 address schema for the IoT devices become a compulsory alternative.

3 Standards for Protocols of the WSNs Networks

In this section, we propose the protocol stack for the WSNs in health care. The proposed stack of the WSNs based health care system is shown in Fig. 2. Unlike the Internet protocol stack which has four layers, the proposed stack has five layers with an additional layer. These five layers are 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 in health care, 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 networks and their applications. The second consideration is the networking address schema. Since the WSNs networking nodes can be any lower power communication devices, the IPv4 schema becomes invalid but the IPv6 schema with 128-bit address spaces must be adopted.

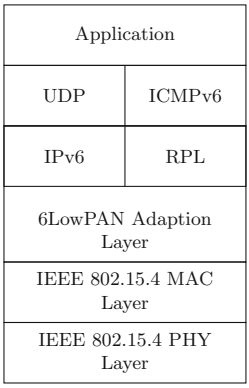

Fig. 2. Protocol Stack

In the following sections, we discus more details about each of these layers and its protocols.

3.1 Application Protocols

For a general WSNs, the sensing nodes are used to sense their surrounding 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 WSNs in health care normally generate the traffic with the Poisson distribution.

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

There are many security issues related with the application protocols. In regard to the WSNs for health care, one eminent concerns is the intrusiveness to the privacy, due to 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

There are a number of routing protocols which are based on the IPv6 addressing schema. Hence they can be adopted during the development of the WSNs applications for health care. In this section, we briefly overview a few of them that have been widely studied in the last decade.

First of all, Routing Protocol for Low-Power and Lossy Networks (RPL) is a proactive routing protocol [4]. As its name implies, the RPL is a distance-vector routing algorithm originally designed for low power and lossy networks using the IPv6 addressing schema. The RPL supports ubiquitous sensing applications such as the WSNs based health care applications.

RPL components include the WSN nodes [1], and local border router (LBR). The WSNs nodes act as hosts or intermediate routers for transmitting packets in the WSN nodes; while the router translate packets through the WSN nodes to user hosts from the Internet. The WSN node and the LBR routers apply a new concept of Directed Acyclic Graph (DAG), this DAG is separated into multiple Destination Oriented DAG (DODAG), where the root 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.

Secondly, there are also many ongoing researches that attempt to develop the AODV-like protocols, but the protocols are relied on the IPv6 addressing schema. Unlike the RPL, the Lightweight On-Demand Ad hoc Distance (LOAD) and its successor, LOAD - Next Generation (LOADng) is a reactive routing protocol for the low power and lossy networks [2,6]. The LOAD is a derivative of the AODV and with some simplifications over the AODV, eg. removal of intermediate Route Replies and of sequence numbers. As a reactive protocol, LOAD 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 point out that all these routing protocols are vulnerable to the `warmhole attacks` [8].

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, which is called 6LoWPAN – an acronym of IPv6 over Low-Power Wireless Personal Networks. The 6LoWPAN is an adaption layer in the network protocol stack for integrating low-power network such as IEEE 802.15.4 into IPv6.

The 6LoWPAN network consists of one or more sensing nodes or host nodes local to the LoWPANs, which are all connected by the IPv6 addresses to the Internet through a gateway (or border router), as shown in Fig. 3. The network deals with small packet size, low bandwidth and requires resource saving for maintaining the life of network nodes.

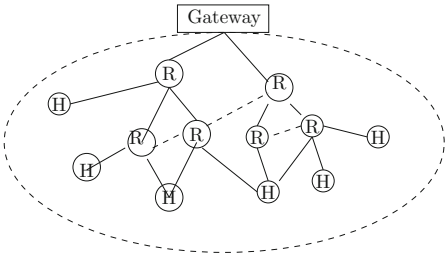

Fig. 3. A simplified 6LoWPAN network

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 networks to the Internet. It fragments the packets at the IPv6 layer, 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 route-over forwarding approach is more scalable and robust over than that of the mesh-under forwarding 6LoWPAN network [7].

3.4 IEEE 802.15.4 – ZigBee

The most relevant communication standard for the 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.

The ZigBee standard is a low-cost, low power wireless communication standard which is mainly used to create the Wireless Personal Area Network (WPAN). The ZigBee standard has provided the mesh capabilities for the IEEE 802.15.4 standard by network and security layers and an application framework. The ZigBee networks include many different areas of practical applications such as home automation, health care, 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 networks via ZigBee coordinator.

4 Implementation of the WSN in Health Care

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

4.1 The WSNs Network Simulator

There are plenty of network simulators for the WSNs. The NS-3 simulator is one such designed for many 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 addressing based networks; while an increasing number of researches 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 applications.

In this study, we would focus on how to apply the NS-3 network simulator to design the networking nodes including NetDevices, Interface containers and Node containers. Figure 4 show the model design of NetDevice, Interface and Node in the NS-3. The justification of choosing the NS-3, is that the RPL model, the 6LoWPAN adaptation model the LR-WPAN model (based on IEEE 802.15.4 MAC and PHY) have been developed and available to us for use.

4.2 Simulation of WSNs for Healthcare Using NS-3

Although there are many multi-hop routing protocols have been implemented such as the previously mentioned AODV, Dynamic Source Routing (DSR), Optimized Link State Routing (OLSR) on the NS-2 and NS-3 network simulators,

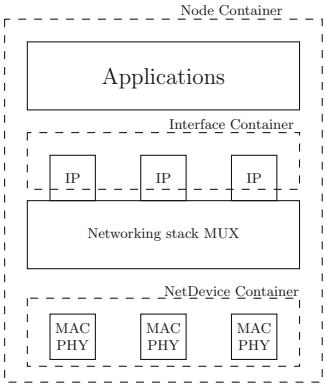

Fig. 4. NetDevice and Nodes Container in NS3

however, they are all developed for the Mobile Ad-hoc networks (a.k.a MANETs) and based on the IPv4 addressing schema. In the section, we adopt the RPL although both RPL and the AODV over IPv6 (ADOVv6) are in development stages, and have some bugs and wired behaviors that have to be fixed.

5 Configurations of WSNs for Health Care Scenarios

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

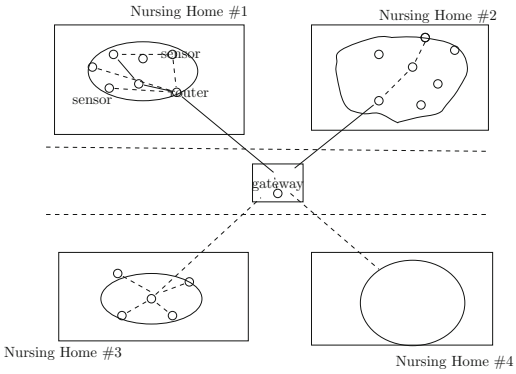

Fig. 5. A sketch of the healthcare system with four LoWPANs

5.1 The Application of WSNs in Hospitals

A WSNs based health care system has four LoWPANs and each LoWPAN in the settings consists of a mesh network of the ZigBee sensors and one ZigBee routers. All four ZigBee routers routes the patients data to a remote base station within hospital.

A hospital care giver 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. Figure 5 is a sketch of a nursing home with four LoWPANs in each patient's room. A LoWPAN comprised of 4 or more sensor nodes (or ZigBee nodes) and one router (ZigBee router) is responsible for monitoring the movement of the patient and collecting their physiological data such as the blood pressure and temperature, and then transmitting to the base station in the hospital corridor.

5.2 The Application of WSNs in Care Center

When it comes to the implementation of the WSNs applications, the overall application of the WSNs in care center 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 the ZigBee nodes or other types of low power sensors.

Figure 6 show data transmitting through the ZigBee sensors and the gateway within the simulated WSNs based health care system in the NS-3.

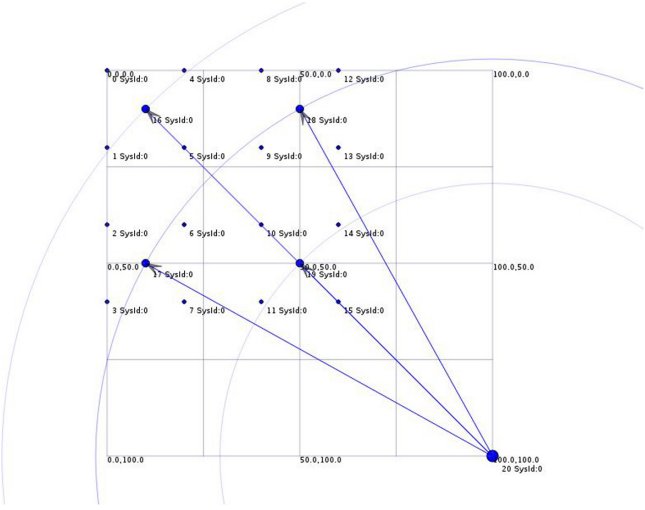

Fig. 6. The simulated WSNs based system in NS-3

The preliminary results about the performance of the WNSs based health care system have been achieved so far in terms of the latency of message delivery. A report of performance comparison with other studies will be presented shortly.

6 Conclusion

In this paper, we have proposed a framework of designing and developing efficient and low cost health care application systems based on the Wireless sensor networks.

The study has gone through from scrutinizing the requirements and characteristics of health care systems deployed in the two primarily environments. It has outlined a framework of layered protocol stack that can be applied while building the WSNs based systems to meet the requirements of health care services.

In accordance with the proposed framework, we have implemented a wireless patient monitoring and data collecting (WPMDC) system in the hospital environment. A prototype of the system has been simulated in NS-3, and some preliminary results shown that the framework be applicable to other health care related environments such as nursing home for aged care service.

After implementing the WPMDC systems, we have gained many insights into the requirements of health care services and deeper understanding of the communication protocols support the reliable communications on the wireless sensor networks with nature of low cost and noisy. In the future, we would continue the study on both the performance analysis and the security.

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