Integration of Wireless Body Area Networks (WBANs) and WAN, WiMAX and LTE

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Abstract

Nowadays, wireless communication has a great advantage in technology. We use wireless devices almost in all expected life such as: entertainment, working and recently in the healthcare area, where Wireless Body Area Networks (WBANs) become a hot topic for researchers and system designers. Recent work on WBANs focus on related issues to communication protocol, especially ZigBee network is fine tuned to meet particular requirements in healthcare area. For example, some papers present real-time patient monitoring via ZigBee communication given the short distance between body sensors and remote devices, while the other work solve the limited coverage problem of Zigbee by designing mechanisms to relay Zigbee data to other types of wire or wireless infrastructure. However, very few of them investigate the scenarios of ZigBee coexisting or integrated with other networks. In this paper, we present the real-time data transmission from ZigBee end devices to Wide Area Network (WAN), Worldwide interoperation for microwave access network (WiMAX) and Long Term Evolution network (LTE). We provide in detail the ZigBee gateway components. Our simulation is conducted by OPNET, we visualize many topology network scenarios in ZigBee hybrid system. The results in simulation show that ZigBee end devices can successfully transmit data in real-time to other network end devices.

Keywords: Wireless Body Area Networks (WBANs), ZigBee, hybrid system

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1. Introduction

Great advantage in micro-electronics and wireless communication have changed the world. That is an innovation for scientists to propose ubiquitous healthcare application. Nowadays, patient status can be captured, stored and transmitted to doctors any-time and any-where in real-time fashion. For this purpose, the new type of network architecture generally known as Wireless Body Area Network (WBAN) has been developed. In WBAN, sensors continuously monitor human body such as health status and activities . The intelligent wearable sensor typically has three main functions: retrieving sensory data from environment and human body, local processing, and routing to the next hop while avoiding data loss. Sensors are made feasible by novel advances on lightweight, very small-size, ultra-low-power, and intelligent monitoring . There are many protocol and radio technologies provided for WBAN, including Bluetooth, Bluetooth Low Energy, ZigBee and IEEE 802.15.4, Ultra-Wide Band (UWB) and IEEE 802.15.6. Among these radio technology, ZigBee is the best choice for WBAN. ZigBee Alliance is an association of companies working together to develop standard and products for reliable, very low power wireless networking consumption, and cost-effective. Several monitoring wearable sensors on a patient are ZigBee end-devices. All data from sensors will be transmitted to ZigBee coordinator node. Due to the ultra-low power in sensor node, a short-range communication is established between sensor ZigBee end-device and ZigBee coordinator. We call ZigBee network is the first last-mind network. The second last-mind network can be intergrated with ZigBee network. Many different technolohies and wireless infrastructure networks are proposed to integrate with WBANs and improve the transmission efficiency and energy efficiency of hybrid wireless networks [1], [2], [3]. The existing infrastructure networks such as Wide area network (WAN), WiMAX or LTE are selected to be analyzed in this paper. They are widely used to offer my type of services [3]. Over the second last-mind network, data from ZigBee end devices are transmitted far away. So, ZigBee network needs a gateway for enable inter-operation with different kind of networks.

The remainder of this paper is organized as follows. We review the communication architecture of WBAN and co-existing networks in Section 2. In Section 3, we explain three kinds of ZigBee coordinator gateway to WAN, WiFi, WiMAX and LTE respectively. Section 4 presents several topology networks for simulation and determine the results. Finally, Section 5 concludes this paper.

2. Review WBAN Communication Architecture and Co-existed Networks

2.1 WBAN Communication Architecture

In [4], they proposed two definitions: intra-body communication and extra-body communication. The intra-body communication includes the former which controls the information handling on the body between the sensors or actuators and the personal device. The extra-body communication is the latter which ensures communication between the personal device and an external network. They also presented a multi-tiered telemedicine system, tier-1 encompasses the intra-body communication, tier-2 is the extra-body communication between the personal device and the Internet and tier-3 represents the extra-body communication from the Internet to the medical server. The combination of intra-body and extra-body communication can be seen as an enabler for ubiquitous health care service provisioning.

In [4], M. Chen also provides three-tier architecture based on the Body Area Network (BAN) communications system but in more detail and clearly. He introduced the terminology of "*intra-BSN communication*" known as tier-1 to define the communication that directly relates to the user with the radio coverage of about 2 meters, which consists of two categories: (1) the communication among the body sensors, which are deployed strategically on the human body or planted inside the body, as well as attached within the human's clothing; (2) the communication between the body sensors and the portable Personal Server (PS). He defined "*inter-BSN communication*" known as tier-2 is the communication between the PS and one or more multiple access points (APs). The AP can be deployed as a part of the infrastructure, or strategically placed in dynamic environment for handling emergency situation. As with the terminology of "inter-BSN", the functionality of a tier-2-network (as shown in **Fig. 1**) is used to interconnect BSNs with various networks that are easy to access in daily life, such as internet and cellular networks. Tier-3 is the *"beyond-BSN communication"* which helps to enhance the application and coverage range of E-healthcare system a step further by enabling authorized healthcare personnel (e.g., doctor or patient's immediate family) to remotely access a patient's medical information by means of cellular network or the Internet. Further details on BAN are given in [1A]-[1C].

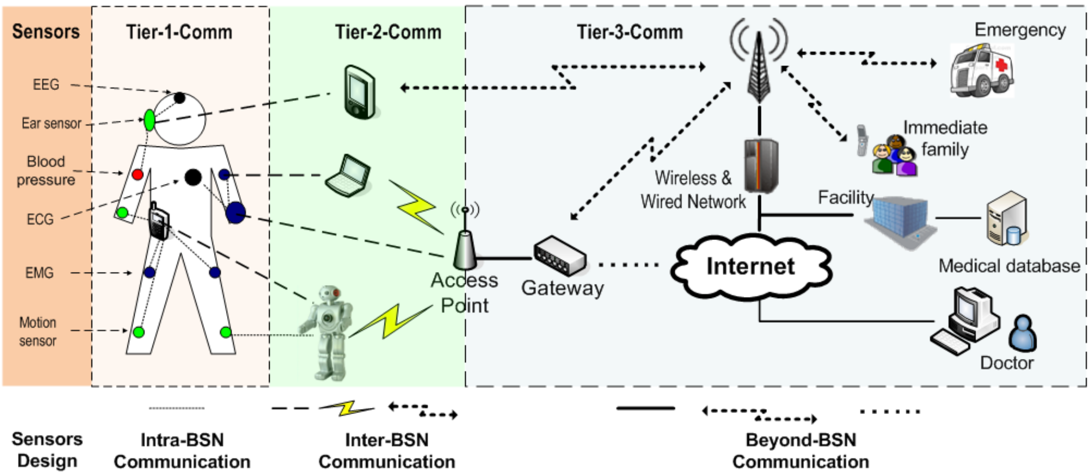

Fig. 1. A three-tier architecture based on a BAN communication system [4]

2.2 Co-existing Network

There are multiple solutions from existing BSN projects for three tiers BSN communication. In [4], M. Chen had summarized and comparison some existing BSN projects. For intra-BSN communication , ZigBee star topology network is used in [5]. A hop-count number in star topology network is one, it ensures that the data rate can be achieved at maximum while minimum end-to-end delay. For inter-BSN communication, ZigBee mesh topology network is used in CodeBlue [6], AID-N [7]. At tier-2, personal devices such as Personal Digital Assistance (PDA), Laptop or smart phone are mobility and usually move around the tier-1, mesh structure can helps mobile devices stay far away from body sensors by multi-hop communication. For beyond-BSN communication, Internet/WiFi/Cellular networks are used in AID-N, CareNet [8], WHMS, WiMoCA [9], MIMOSA [10]. In tier-3 area, we propose two novel infrastructure networks that are WiMAX and LTE.

The ZigBee physical layer supports three frequency bands: a 2450 MHz band (with 16 channels), a 915 MHz band (with 10 channels) and a 868 MHz band (1 channel), all using the Direct Sequence Spread Spectrum (DSSS) access mode. **Table 1** summarizes the main features of the three bands [11]

Table 1. ZigBee physical layer specifications

Carrier frequency	2450 MHz	915 MHz	868 MHz
Gross data rate	250 kbps	40 kbps	20 kbps
No. of Channel	16	10	1
Modulation	O-QPSK	BPSK	BPSK
Chip pseudo-noise sequence	32	15	15
Bit per symbol	4	1	1
Symbol period	16 micro-sec	24 micro-sec	49 micro-sec
Access scheme	DSSS	DSSS	DSSS

Key physical parameters of WiFi, WiMAX and LTE are must be considered to determine whether having radio interference between different kind of networks or not. **Table 2** lists some key physical specifications. A carrier operation frequency is one of the most important specification that we should consider at first. Idustry, Medical and Scienentic (IMS) band is an atractive carrier frequency because it is a free bandwidth, but a payment is the interference happenning if user is not careful to build up communication system[12].

Table 2. WiFi, WiMAX and LTE with key physical specifications comparison

	IEEE 802.11g (WiFi)	IEEE 802.16e (WiMAX)	LTE
DL/UL Peak Data Rate (Mbps)	54 / 54	45 / 13	100 / 50
Carrier Frequency	2.4 GHz	2.3 - 3.6 GHz	700 MHz - 2.6 GHz
Duplexing Schemes	CSMA/CA	TDD and FDD	TDD and FDD
Typical range	150 m	3-5 km	5 km
Access schemes	OFDM/DSSS	OFDM	OFDM

Base on the physical characteristics statistic in **Table 2**, we recognize that there is no radio interference from WiMAX or LTE radio to ZigBee radio if they co-exist together with WBAN. For WiFi, the access point must be configured in OFDM access schemes to avoid the collision between ZigBee network and WiFi network. Moreover, WiFi devices can be roaming to WiMAX network in case that they move from indoor to outdoor area [3]. Moreover, some published works demonstrate that QoS can be guaranteed between WiMAX and other systems [15]. In the next section, we will explain in detail the WiFi device, WiMAX device and LTE device which are integrated to ZigBee device.

3. ZigBee Gateway

A ZigBee protocol standard includes 4 layers [11]. An overview of the ZigBee protocol stack is shown in **Fig. 2**. The physical (PHY) layer operates on or off radio communication, it supports functionalities for channel selection, link quality estimation, energy detection measurement and clear channel assessment. The Medium Access Control (MAC) layer defines three types of node: network coordinator, network router or network end-device [16][17]. Each PAN only has one coordinator node and it is recognized by the identification (ID) number, this number is called PAN-ID. Child nodes are known as end-devices or routers needed to have the same PAN-ID with the coordinator.

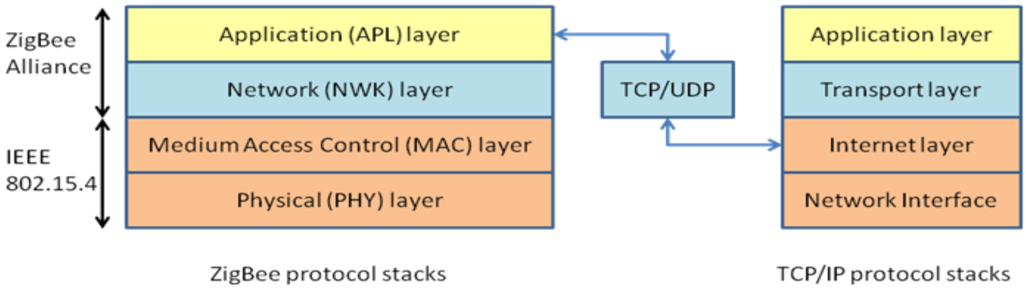

Fig. 2. Interconnection between ZigBee and TCP/IP protocol

At a network (NWK) layer, the topology of PAN network is configured. Besides the star topology that naturally maps to the corresponding topology in IEEE 802.15.4, the ZigBee network layer also supports more complex topologies like a tree and a mesh [14]. The network layer is in charge of organizing and providing routing over a multi-hop network (built on top of the IEEE 802.15.4 functionalities).

An Application Layer (APL) intends to provide a framework for distributed application development and communication. The application profile framework allows different developers to independently build and sell ZigBee devices that can interoperate with each others in a given of application profile. Based on this characteristic in application layer, we can build up the gateway component in the point of view application profile. We propose the layers connection inside the ZigBee coordinator device. **Fig. 2** illustrates the layers connection in detail.

Pseudo code for the application layer profile:

```
BEGIN
        Get_packet (from network layer);
        If ( packet's destination equals "To Internet")
                { Encapsulate the packet with destination IP address;
                  Delivery packet to internet layer in TCP/IP protocol;
                }
        Else    If ( packet's destination is different in PAN_ID)
                        { Drop the packet;
                        }
                Else { save packet to Data-base
                        }
                End If
        End If
END
```

We use OPNET Modeler [13] to implement our proposition. We take a gateway device from ZigBee network to Internet as a example explanation, the other types of gateway have the same structure and operation as described in the Pseudo code. A ZigBee coordinator node model is showed in the **Fig. 3**.

In the application layer, we add new attribute which is named "To Internet". When ZigBee end-device chooses "To Internet" as the destination in the traffic application attributes configuration, all traffic generated by this node will be routed to the Internet via ZigBee coordinator gateway. The destination IP address is established by ZigBee coordinator. It also means that each PAN can only communicates with one specific IP address defined by ZigBee coordinator. If ZigBee end-device chooses a name of other nodes inside its PAN, the traffic from this node will be routed in local PAN and reach the end-device destination. We do not maintain the situation that ZigBee end-device chooses the name of other node outside its PAN because it is out of scope in this paper.

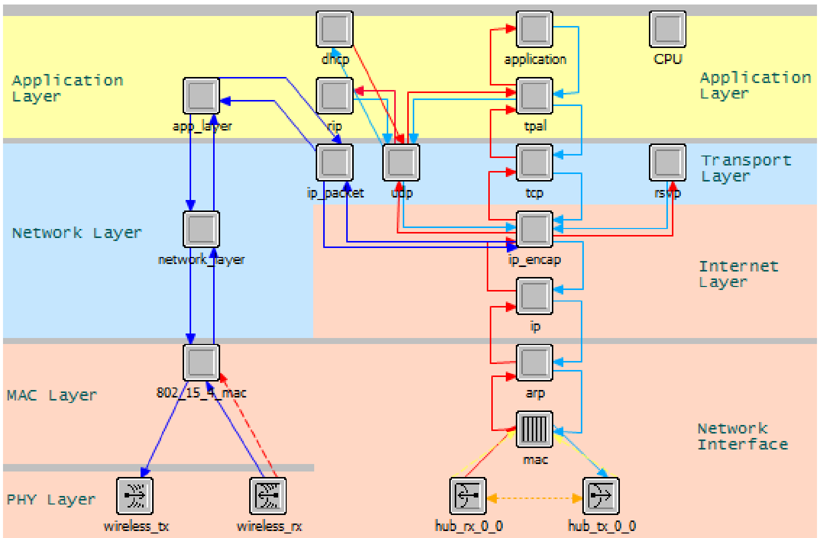

Fig. 3. ZigBee Ethernet gateway model node

4. Network Simulation

In this section, we propose 4 kinds of inter-operation between ZigBee network with WAN, WiFi, WiMAX and LTE network. At first, we introduce the meaning and the function of our proposed devices used in simulation for better understanding our scheme in **Table 3.**

Table 3. Symbol's name, type and function meaning

Symbol's name	Type	Function
Sensor[i]_user[j]	ZigBee end device	Sensor environment and send data to ZigBee coordinator.
PDA_ ZigBee _PAN[i]	Personal Digital Assistant with ZigBee end device intergration	Receive data from sensor1_user[i]
Router_[i]	ZigBee router	Route data for multi-hop network.
ZigBee_Eth_gw_PAN[i]	ZigBee coordinator and Ethernet station hybrid	Coordinator roles and gateway to the Ethernet.
ZigBee_WiFi_gw[i]	ZigBee coordinator and	Coordinator roles and gateway to WiFi access

	WiFi station hybrid	point.
ZigBee_WiMAX_gw[i]	ZigBee coordinator and WiMAX mobile station hybrid	Coordinator roles and gateway to WiMAX base station.
ZigBee_LTE_gw[i]	ZigBee coordinator and LTE mobile station hybrid	Coordinator roles and gateway to e-nodeB base station.

4.1 WBAN Configuration

A physical configuration and application traffic in WBAN unify in all scenarios simulation. A strategy of send and receive data traffic for each PAN is the same for all WBANs and also unify in all scenarios simulation. **Table 4** and **Table 5** list detail configuration for ZigBee network.

Table 4. ZigBee's application traffic attributes

Application traffic attributes		Value
Destination	Sensor1 _user[i]	PDA_ ZigBee _PAN[i]
	Remaining sensors	To Internet
Packet interval time		Poisson(1)
Packet size		Constant(1024)
Start time		Uniform(20,21)
Stop time		Infinity

Table 5. ZigBee's physical attributes

ZigBee parameters		Value
Transmit power	Coordinator	1 mW
	PDA device	1 mW
	Router	0.1 mW
	Sensor	0.05 mW
Packet reception-power threshold		-85 dB
Transmission band		2450 MHz

We suppose that a WBAN includes 6 sensors node and 1 PDA device. **Fig. 4a,b,c** represent WBAN co-existing with WiFi, WiMAX and LTE, respectively. There are 2 consideration WBAN structures. If the coordinator is a hybrid mobile device, star structure is used, otherwise tree structure or mesh structure will be considered.

4.2 ZigBee and WAN Integration Network

In the first scenario, a room with dimension 50x50 meters contents 3 patients, each patient is wearing 6 sensor nodes to establish a WBAN in star topology network structure as presenting in **Fig. 4a**. A detail for a WBAN configuration has been described in **Table 4** and **Table 5.** WiFi access point (AP) is placed at the middle of the room. WiFi AP is used IEEE802.11g standard with OFDM access scheme to avoid radio collision with ZigBee network. Outside the room, we illustrate a WAN with a IP cloud, 3 gateways and 3 PC workstations. We also suppose that the IP cloud does not affect to data packets. We assume that the transmission cable is perfectly with none delay, jitter and drop packet. The network topology is illustrated in **Fig. 5.**

In this scheme, each WBAN generates data with 2 separated data streams should be considered. One traffic stream is from sensor_1 to PDA device, the other traffic stream is from remaining 5 sensors to PC workstation. Data generated from each WBAN will be transmitted to correlative PC workstation in separately.

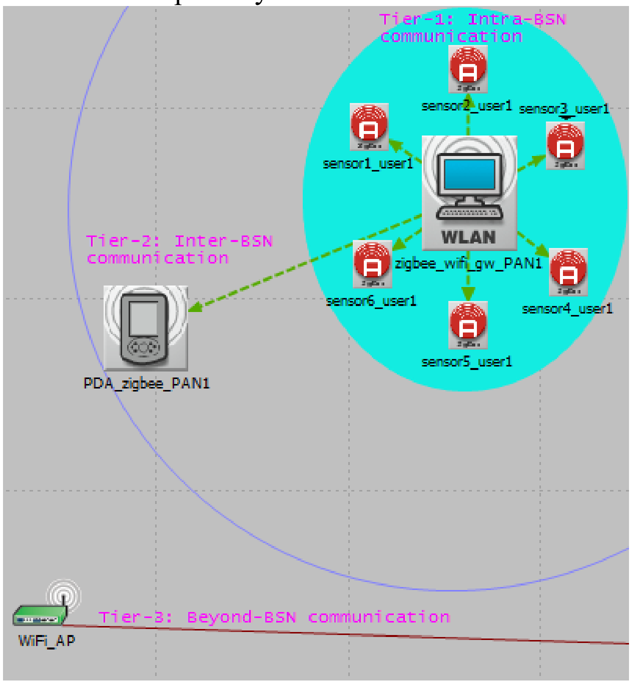

Fig. 4a. WBAN with ZigBee coordinator and WiFi station intergration

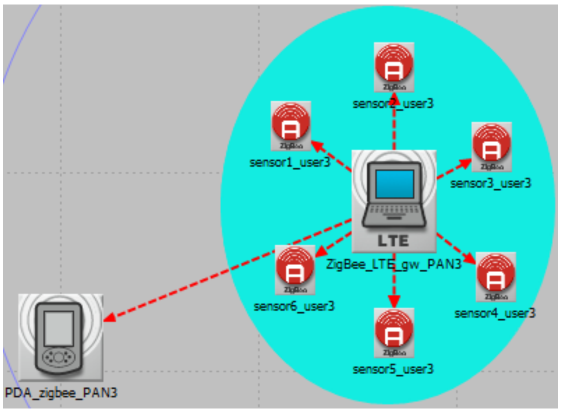

Fig. 4b. WBAN with ZigBee coordinator and LTE station intergration

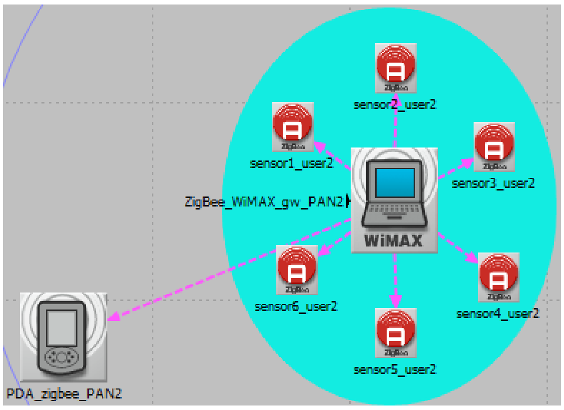

Fig. 4c. WBAN with ZigBee coordinator and WiMAX station intergration

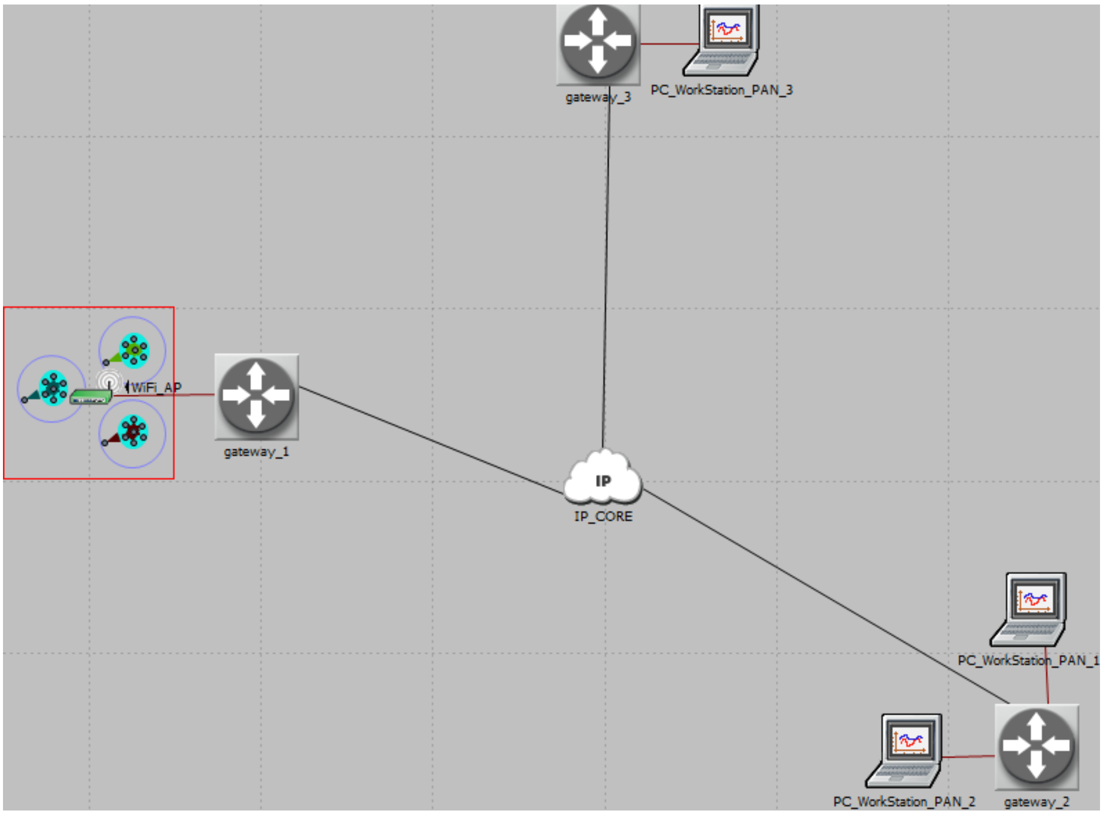

Fig. 5. WBAN and WAN co-existing with ZigBee star topology network

The PDA_ZigBee device which receives data from sensor_1 is not only used by the patient but also used by another person such as doctor, nurse. Moreover, a transmission power for both ZigBee coordinator and PDA_ZigBee are set at 1 mW. It means that the distance communication between them cannot over 25 meters for ensured reliability connection. It must has a solution for the mobility problem of PDA_ZigBee or WBAN in a large room. Tree/mesh topology network can be suitable solutions. So, we simulation and determine all types of topology network.

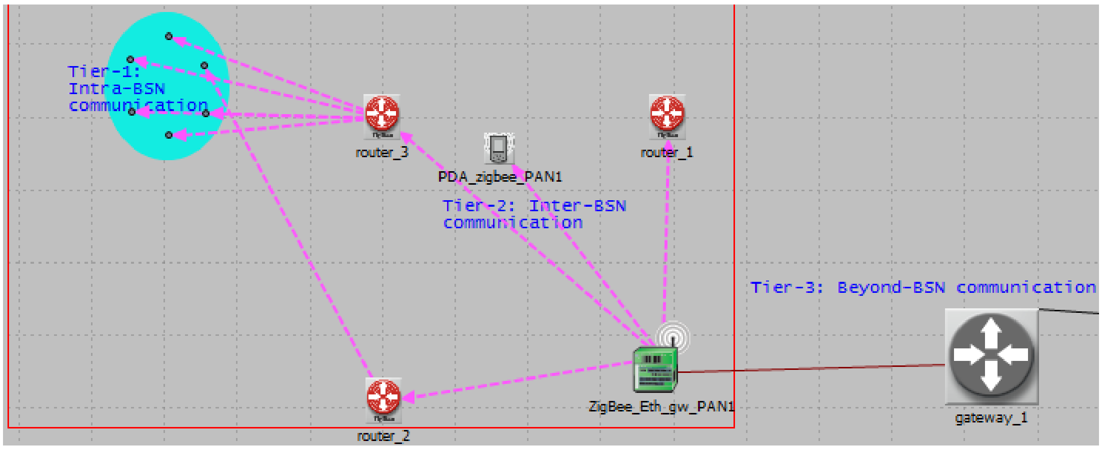

Fig. 6a. WBAN and WAN co-existing with ZigBee tree topology network

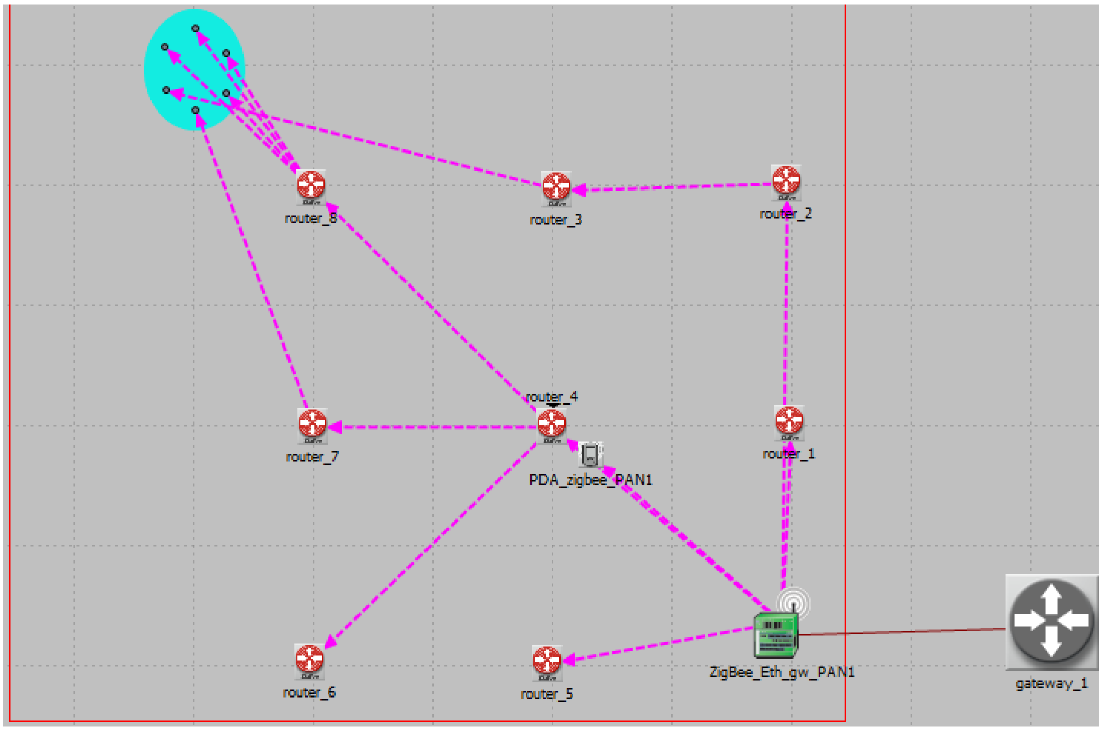

Fig. 6b. WBAN and WAN co-existing with ZigBee mesh topology network

The first schemes is presented in **Fig. 6a**, tree topology network is deployed inside a room with 50x50 meters, there're 1 ZigBee Ethernet hybrid, 3 ZigBee routers and 1 WBAN for a patient. ZigBee routers are arranged with 20 meters apart. The second scheme is presented in **Fig. 6b**, mesh topology network is deployed inside a larger room with 70x70 meters. In this case, 8 ZigBee routers have been used with 20 meters apart between 2 adjacent routers . A patient is free to move around the room without lost data traffic from sensor_1 to PDA_device.

A comparison results simulation for 3 types of ZigBee topology network are displayed in **Fig. 7a,b** and **Fig. 8a,b**, respectively.

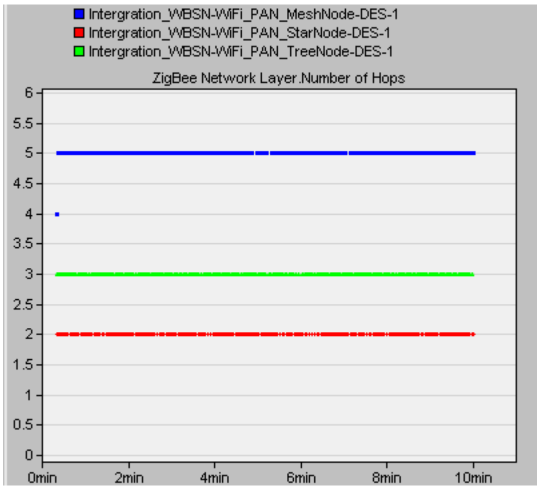

Fig. 7a. Number of hop-count from sensor_1 to PDA device

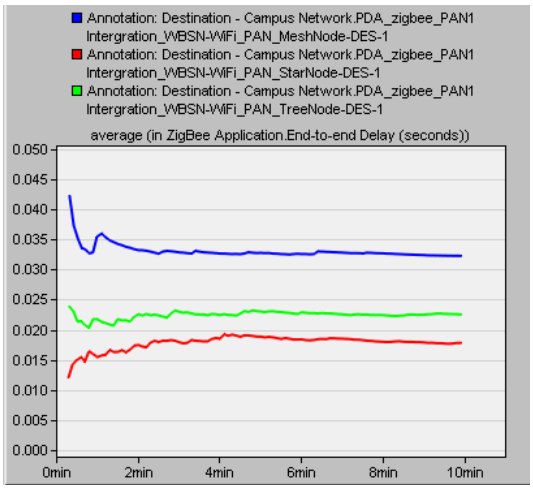

Fig. 7b. End-to-end delay from sensor_1 to PDA device

A simulation results of sensor1_user1 is showed in **Fig. 7a** and **b**. These results are presented for the inter-BSN communication. The end-to-end delay value increases symmetrical with the number of hop-count. Data traffic from sensor1_user1 to PDA_device has a minimum hop-count as well as end-to-end delay in case of star topology network, and these values increase symmetrical in case of tree topology and mesh topology network, respectively.

The results for beyond-BSN communication provide in **Fig. 8a** and **b**. We consider 2 aspects: end-to-end delay and system data throughput. For end-to-end delay, this value is measured from ZigBee end devices in WBAN through WAN and reach to PC workstation. Similarly, end-to-end delay value is symmetrical with the number of hop-count. For system data throughput, this value is strong affected by the type of ZigBee topology. Star topology is very good performance with burst of data traffic while tree and mesh topology are weaker. In our simulation scenario, 5 sensors generate packet with rate 1024 bit per second (bps) at the same time. It means that the total traffic which ZigBee gateway pushes on the WAN is about 5000 bps. Only the PC workstation in case of star topology can received maximum throughput, these others is fewer in throughput clearly. This is the trade-off between the mobility and the throughput in the inter-BSN communication.

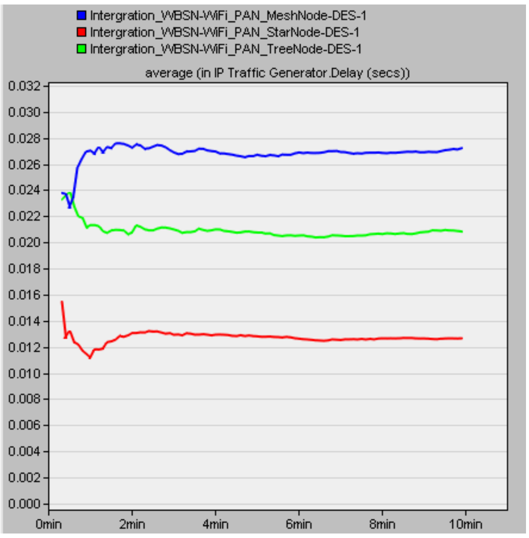

Fig. 8a. End-to-end delay from WBAN to PC workstation

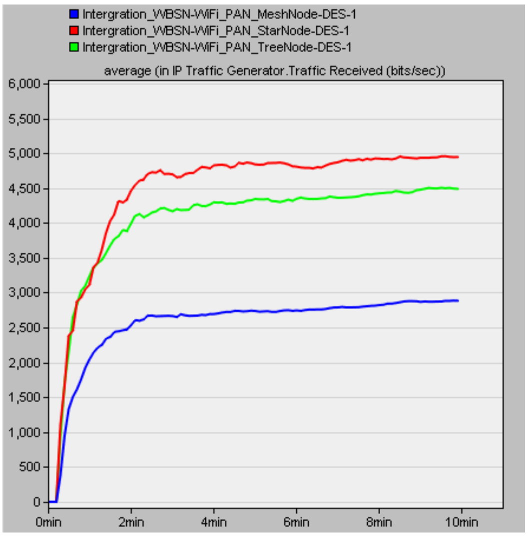

Fig. 8b. Throughput from WBAN to PC workstation

4.3 ZigBee and WiMAX or LTE Integration Network

In this scenario, we apply 2 novel wireless technologies WiMAX and LTE. We show that they can be used as the second last-mind network in assisting WBSN effectively. ZigBee and WiMAX/ LTE coexisting network is presented in **Fig. 9a** and **b.** The network topology is the same for both hybrid system. Inside a room, ZigBee star topology is used for each PAN. A ZigBee coordinator is a WiMAX hybrid as in **Fig. 4b** and LTE hybrid as in **Fig. 4c** for each scenario, respectively. Outside a room, a beyond-BSN communication is simply network that both ZigBee coordinator hybrid and mobile device are served by the same radio base station.

About data traffic flows, there are 2 flows similar with ZigBee and WAN integration network. One traffic flow from sensor_1 to PDA device, the other traffic flow is from remaining 5 sensors to mobile station device.

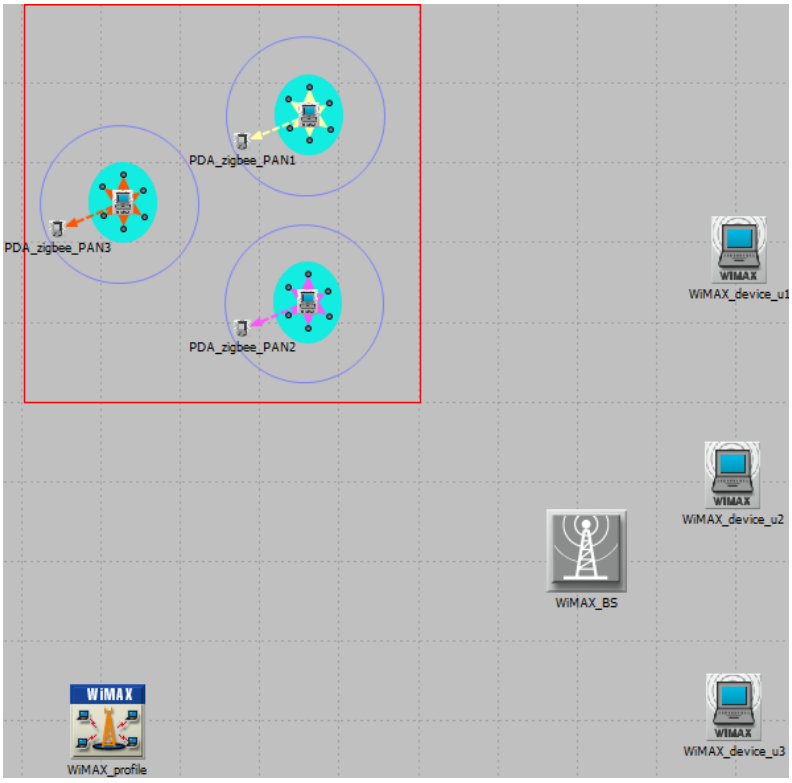

Fig. 9a. WBAN and WiMAX co-existing with ZigBee star topology network

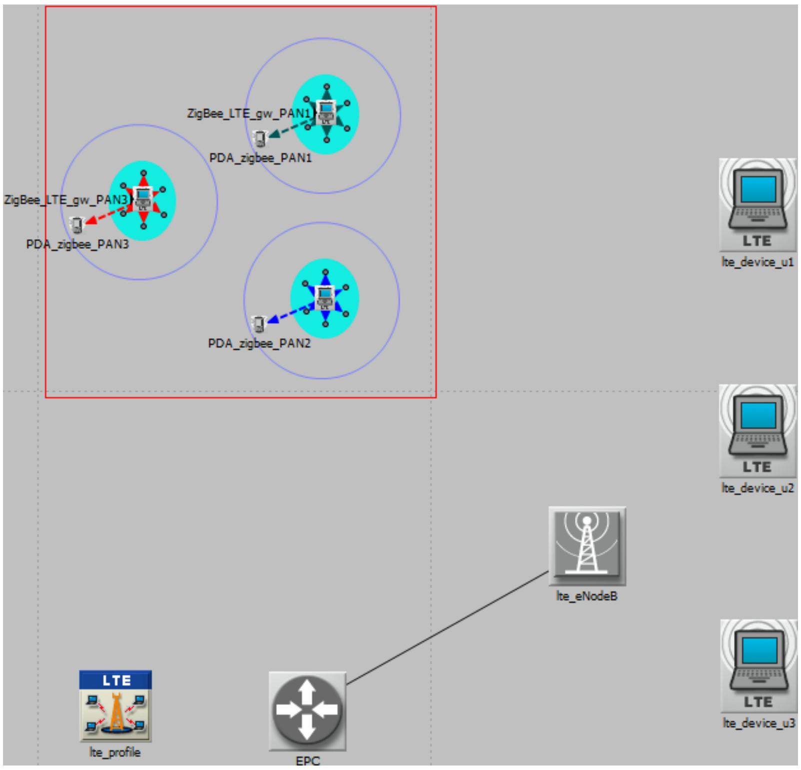

Fig. 9b. WBAN and LTE co-existing with ZigBee star topology network

Comparison the simulation results between using WiMAX and LTE as the second last-mind assisting to WBAN are displayed in **Fig. 10a** and **b**. There is no big different in this situation. Both of them support very well for a high burst of data stream over wireless communication. A different in peak data rate has caused a little different in end-to-end delay value because a requirement bandwidth for WBAN is much smaller than available WiMAX or LTE bandwidth. With higher peak data rate, LTE can achieved lower delay in transmission than WiMAX.

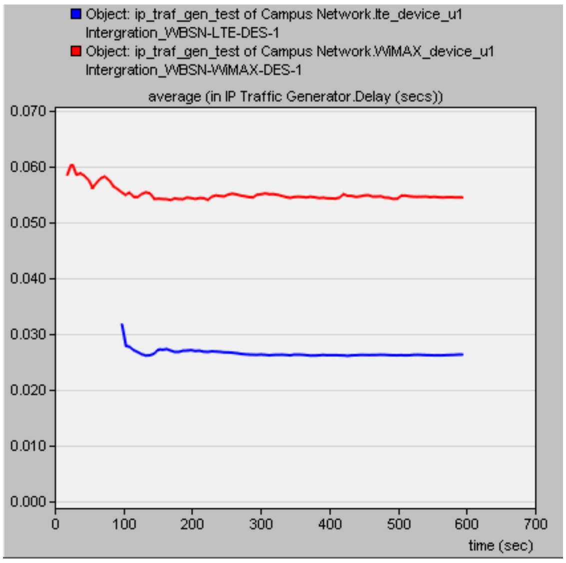

Fig. 10a. End-to-end delay from WBAN to WiMAX/ LTE mobile station

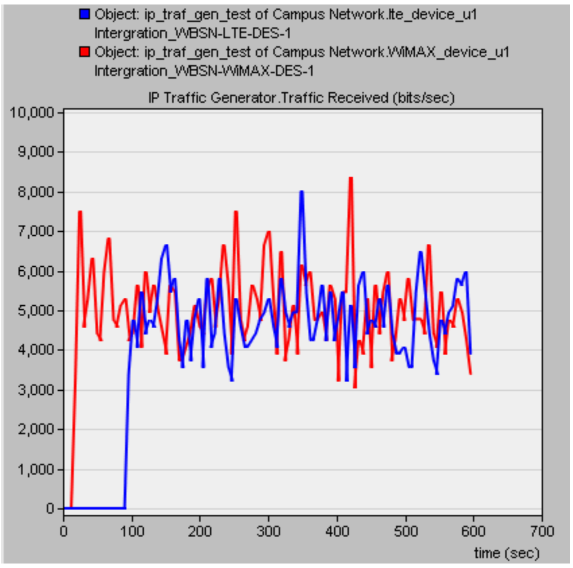

Fig. 10b. Throughput from WBAN to WiMAX/ LTE mobile station

In the next scenario of LTE network, we suppose that patient 1 is be moved from place to place and his/her WBAN still enable to keep in touch with LTE mobile station in real-time. A network scenario is displayed in **Fig. 10**. A LTE network has 2 e-nodeBs and the distance between them is 2000 meters. Each e-nodeB has a unique ID number. In our scheme, patient 1 moves with a speed 3 m/s (or 10.8 km/h) from e-nodeB has ID 0 to e-nodeB has ID 1.

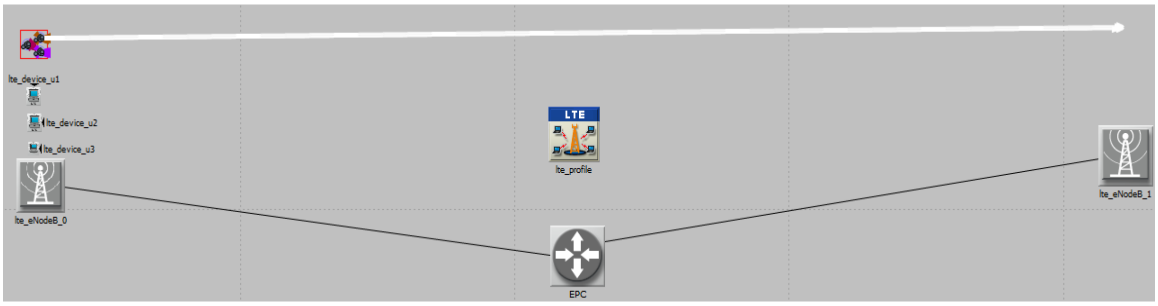

Fig. 10. WBAN with ZigBee LTE gateway moving and handover within LTE network

A final simulation results consider the mobility effect of WBAN from place to place in **Fig. 11a** and **b**. At the first time, ZigBee_LTE_gw registered and transceiver radio signal with e-nodeB ID 0 because it had stayed closely to e-nodeB ID 0. When a patient moved far away from e-nodeB ID 0, the signal strength is received by ZigBee_LTE_gw grows weak. Until it recognizes that a power of received signal below a threshold value while e-nodeB ID 1 gives better signal strength, handover from e-nodeB ID 0 to ID 1 happening. In **Fig. 11b,** totally data traffic about 5000 bps which is generated by WBAN were transmitted to LTE mobile station. With a successful handover, data traffic flow from WBAN to LTE device is not be dropped or corrupted.

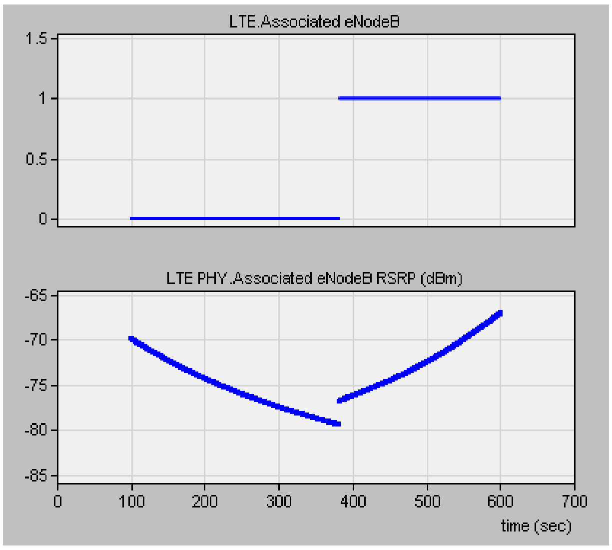

Fig. 11a. e-nodeB ID and radio signal strength received by ZigBee LTE gateway device

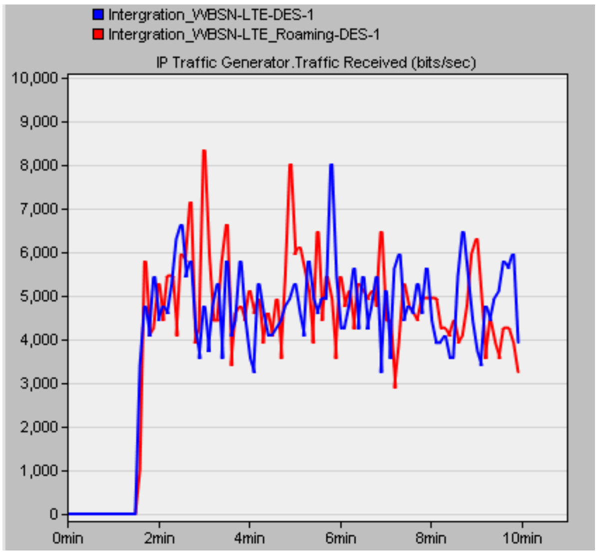

Fig. 11b. Throughput from WBAN to LTE mobile station in 2 cases: static and moving.

5. Conclusion

The hybrid system is proposed to provide remote wireless monitoring in healthcare system. Real time monitoring is critical consideration because it strongly affects to the patient's health status when data is lost, corrupted or delayed. With a long distance data transmission, healthcare system needs reliable and guarantee from transmission network. Nowadays, a solution of using WiFi AP seams unsuitable for real-time data transmission in spite of AP point is cheap and widely existed. WiMAX or LTE has engaged the best choice in the second last-mind transmission for healthcare system. In this paper, we have presented several kind of ZigBee hybrid devices and have evaluated the effect of real-time data to our proposed hybrid system. In future works we will study how sensor localization algorithms can improve the proposed system for indoors [18][19] and for any other type of environment [20-25].

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