Bulletin of Electrical Engineering and Informatics
Vol. 11, No. 2, April 2022, pp. 893~900
ISSN: 2302-9285, DOI: 10.11591/eei.v11i2.3219

Wireless body-area network monitoring with ZigBee, 5G and 5G with MIMO for outdoor environments

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Article Info

Article history:

Received Oct 3, 2021
Revised Feb 6, 2022
Accepted Feb 23, 2022

Keywords:

5G MIMO
Outdoor communications
Path gain
Received power
WAN
WBAN
ZigBee

ABSTRACT

Wireless body area network (WBAN) works near or inside the human body and is characterized by its accuracy in sending and receiving data. It works for long hours and must be low in energy consumption. One of its problems is that the transmission and reception distance is few and does not exceed a few meters. We worked on simulations based on a network consisting of ZigBee or fifth-generation (5G) and 5G with multiple-input and multiple-output (MIMO) nodes to deliver information to the center (hospital) at a 2.4 to 2.8 or 5 GHz frequency to solve this problem. Suppose the sensors are connected to the Arduino, which in turn is connected to the transmitter connection. The proposed method transmits data obtained from the sensor that touched the patient by multi-node to the hospital. The suggested method shows the best scenario to reduce energy consumption based on the number of active nodes. Based on the results obtained, we have noticed that ZigBee devices reduce energy use, perform better, and significantly extend the life of the nodes. While 5G devices increased the response speed in transferring data. In addition, MIMO antennas have the advantage of adding more stability in the connection between nodes.

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1. INTRODUCTION

The tremendous progress in science and the development of communication methods up to the 5G technology made it easy to deliver enormous amounts of data in record times relative to older technologies [1]-[3]. It also developed with it the use of more than one technology simultaneously, such as using ZigBee with WiFi and with high-speed communication networks, which led to the invention of innovative, high-efficiency, convenient wireless devices more than its predecessors and also opened more horizons for the use of this technology in more expansive fields such as information technology, industry, and medicine [4], [5]. Where many types have been used as an experiment to transfer data and with different technologies and at the same time work to reduce energy consumption by using hardware or software, and it cannot be ignored with each increase in the transmission distance, the percentage of energy consumption increases and the transmission efficiency decreases [6]-[8].

In recent years, several methods have been proposed in the field of wireless communications in order to increase the accuracy and efficiency of data transmission and also reduce the consumption of special energy in communications systems [9]. For this, a large number and a variety of methods and techniques were presented, which need a clear and accurate study in order to solve all the problems facing medical technologies. For example, the future healthcare system needs a set of updates and improvements in various scenarios in order to receive patient data more efficiently [10]. In addition, management and tracking of the patient and hospital assets conditions for remote monitoring using special applications that are necessary to be used in the health field to monitor and track patients' cases remotely for their data [11], [12]. The new 5G infrastructure companion is implemented within the WBAN network, which will open wide horizons in terms of higher bandwidth for communication, through which the largest amount of data is transmitted, as well as increase the speed of response and access to receiving systems, and also improve complex processing solutions and security for systems that carry this type of generation. In addition, health systems carrying this generation will be able to use the internet of things (loT) and use high-speed machine-to-machine (M2M) communications [13], [14].

In recent research, the focus has been on the most important technologies used in the 5G and presenting modern methods that will focus and promise in this generation. For example, researchers in [15] presented and discussed several technologies that can be expected to be the core of 5G using their properties such as millimeter waves (MmWaves) and MIMO antennas, making a system using these technologies able to transmit data more securely and transmit it in the fastest way possible using multipoint techniques. While the researchers suggested in [16], [17], the latest technologies used in WBAN combined with 5G technologies as well presenting their advantages and disadvantages. In addition, 5G healthcare applications have recently been discussed which are expected to be introduced on most WBAN systems. Moreover, there is a recent study in [18], where the researchers in this study focused on building an algorithm based on the Tx power control (TPC) algorithm [19], [20]. The goal of building this algorithm is to provide better power in WBAN networks, as well as to evaluate the power and also get the high transmission power in terms of network metrics. This algorithm is characterized in determining the state of the channel in WBAN networks and also determines the extent of fading, shadowing, and path loss encountered by the WBAN. The researchers proved that this algorithm is suitable for medical applications as it was tested through simulation results in the MATLAB software. Whereas the authors suggested in [21] a protocol stack for 5G-CCN (content-centric network) WBAN that the goal of this protocol is to allow sharing of medical data collected from a patient to any physician who needs this data in order to treat the patient's condition as quickly as possible. The best feature of this technology is that each router in the network has a cache that makes data access faster than in previous generation networks and also does not need direct access to the database stored in hospital servers.

In this paper, we will present a design for a WBAN based on three technologies, the first is ZigBee, the second is 5G with MIMO, and the third is 5G with non-MIMO. This network was designed in (Al-Asader Hospital, Najaf, Iraq). In addition, we tested several frequencies for an energy-efficient network of sensors used to regulate the external environment and compared them to extend the range and life of the multi-hop sensor. The goal of this work presented in this paper is to design a WBAN through which patient states can be monitored remotely. In addition, we will focus on providing a WBAN network characterized by three main parts: the first part is to monitor patients' cases automatically and store all their case data and send it to a doctor to follow up their condition accurately. The second part is to provide the shortest way to send and receive patient data if the doctor is outside the hospital so that choosing the shortest route will extend the life of the sensors used in the network. The third and most important part is to focus on choosing the best frequency that makes the network more stable and broader in transmitting patient data as quickly as possible. So, we focused on the most important parameters that measure the performance of the WBAN network presented in this paper, and these parameters are the strength of the received power (R_{P}), the losses of the paths transmitted from the devices connected to the patient for the device installed near the doctors, and also the path gain (G_{P}) strength.

The rest of the sections for this paper are organized as; section 2 presents relevant recent work and compares it with our proposed work in this paper. Section 3 presents the main parameters that determine the efficiency and performance of the proposed WBAN work. Section 4 presents the concepts of WBAN elements and the external environment simulation proposed in this paper. While section 5 presents the most important results and discusses these results in detail. Finally, section 6 presents conclusions for the proposed work and also presents future work.

2. RELATED RECENT WORKS

In a recent study presented in [22], the researchers proposed a model scheme for compressing all of the patient's electroencephalogram (EEG) data without wasting a portion of the data using fog computing in order to enable the downsizing feature of IoT EEG data that is raised above the cloud. This scheme consists of two stages: the first stage is data collection so that the data is grouped into hierarchical groups, while the second stage is data compression, merging with small groups and uploading them over the cloud. According to several experiments conducted, the researchers observed that the hierarchical clustering method based on Huffman reduces the volume of large EEG data in order to upload it to the cloud platform. Therefore, Huffman's method achieved an average compressive strength ratio is 4.33, and this ratio doubles the compressive strength for some of the scenarios proposed by other researchers.

In another recent study presented in [23], the authors proposed a system for monitoring patients' disease risk by installing sensors to collect data for monitoring their health. The proposed model depends on three stages that lead to patient monitoring, the first stage is an adaptation to sampling in order to save energy, the second stage is the combined data taken from the samples, while the third stage is the decision-making procedure. According to the proposed scenario, the authors note that it is appropriate in terms of energy consumption as well as providing a clear approach to monitoring the health status of patients.

In another recent study proposed in [24], researchers introduced a technique for remote monitoring of patients. The mechanism of this technology works to collect patient data in order to save energy and at a high rate of adaptation. Based on the simulations conducted on the proposed technique, the researchers noted that this technique reduces the volume of collected data, and this leads to providing adequate energy for all sensor samples installed on the patient's body.

Also, in another recent study proposed in [25], a model was introduced and implemented for compressing potential EEG fractals, the main goal is to reduce EEG data traffic sent from the patient data collector (PDA) to the clinician destination. The researchers confirmed that the proposed model improves the flow of data from the patient to the nearest health clinic. In addition, the researchers confirmed that the size of the fractals block plays a major role in producing the highest compression ratio for the data collected from the sensors to facilitate traffic through the sensor network as well as to reduce energy consumption in order to extend the sensors' work for a longer period of time.

In this paper, we implement a new scenario in order to introduce a WBAN for remote patient health monitoring. The idea of the scenario was based on three stages in order to obtain the shortest path to receive or transmit data from the patient to the doctor in the hospital or vice versa from the doctor to the patient. The first stage should determine the location of the hospital, the second stage is to determine the number of nodes between the hospital and the patient. While the third stage is to determine the patient's location. In addition, we relied on three technologies which are 5G normal, 5G with MIMO, and ZigBee. The main objective for using these techniques is to determine which is the best efficient and least losses in the transmission or receipt of data between the patient and the doctor. For this, three parameters are relied on in order to determine the efficiency of these techniques, as well as the efficiency of the proposed WBAN, these parameters are the R_{P}, the G_{P}, and the L_{P} in free space. By carefully comparing between these technologies, we noticed that 5G with MIMO gives the best results in terms of stability and reliability for the work of a WBAN, as well as giving the best receiving capacity, the strongest G_{P}, and the least L_{P} in free space. The reason that 5G with MIMO is better because that MIMO antennas prevent interference and noise between the paths because they contain a set of channels that operate in different frequencies and bands.

3. THE MAIN PARAMETERS OF THE PROPOSED WBAN

In this section, the main parameters to determine the efficiency and performance of the WBAN work proposed in this paper will be presented.

3.1. Received power

In most wireless networks, the received signal power parameter is considered essential to determine the signal strength of the proposed network. This parameter is affected by several influences that make it degraded at some times for the designed networks. This effect is due to the environmental nature in which the network was designed. For example, barriers and obstacles are made of different materials that work on reflection, refraction, absorption, collision, or multiple paths. Therefore, all these effects make the signal power weak and deteriorated in the event that the devices of the transmitters and receivers are not installed in good locations. This parameter can be calculated based on (1) [1].

$$R_{\text{P}} = \sum_{i=1}^{N_{Path}} \left(\frac{\beta\lambda^2}{8\pi\eta_{Fs}}\right)\left(\left|E_{i,\theta}\sqrt[2]{|G_\theta(\theta_i,\Phi_i)|}e^{j\varphi_\theta} + E_{i,\Phi}\sqrt[2]{|G_\Phi(\theta_i,\Phi_i)|}e^{j\varphi_\Phi}\right|\right)^2 \quad (1)$$

Where β is the amount of the frequency band spectrum overlap for the transmitted waves, λ is the wavelength of a path, $G_\theta(\theta_i,\Phi_i)$ is the transmit antenna gain component, $G_\Phi(\theta_i,\Phi_i)$ is the receive antenna gain component, η_{Fs} is free space impedance, $E_{i,\theta}$ and $E_{i,\Phi}$ are the electric field components (theta and phi) for each path that reaches each receiving point, θ_i and Φ_i are to give the arrival direction for path, φ_θ and φ_Φ are the electric field relative phase to the components (theta and phi) of the far region, and N_{Path} is the number of paths between the two antennas (transmitting and receiving).

3.2. Path losses (L_P)

This parameter is considered one of the most important parameters through which it is possible to determine the losses encountered by the path transmitted from the transmitter stations to the receiving points. Also, this parameter is affected by several effects that make the signal path encounter many interferences with a loud noise. These effects are the same that affected the R_P parameter. Therefore, this parameter can be calculated through (2) [9].

$$L_P\,(dB) = P_{Transmit} - P_{Receive} + G_{Transmit,Max} + G_{Receive,Max} - L_{System} \tag{2}$$

Where $P_{Transmit}$ is the transmitted power for paths in dBm, $P_{Receive}$ is the received power for each receiving point in dBm, $G_{Transmit,Max}$ and $G_{Receive,Max}$ are the maximum gain for transmitting and receiving in dBi, and L_{System} is the losses in (dB) that accompany wireless systems.

3.3. Path gain

The concept of this parameter is the same as that of the L_P parameter in terms of effects and calculations, but the sign is the opposite as shown in (3) [10].

$$G_P(dB) = -L_P(dB) \tag{3}$$

4. WBAN CONCEPTS AND SIMULATION FOR OUTDOOR ENVIRONMENT

The basic parts of a WBAN network depend on the elements of the transceivers as well as their characteristics. The data transmission process is subject to many environmental factors, so we have relied on reducing the impact of these factors by manipulating the power of transmitters and choosing the shortest distance to transmit data from the patient to the doctor and vice versa. In addition, any number of sensors can be added along the path in order to obtain the best result of data transmission over long distances. Figure 1 illustrates the basic elements used in a WBAN and wireless area network (WAN).

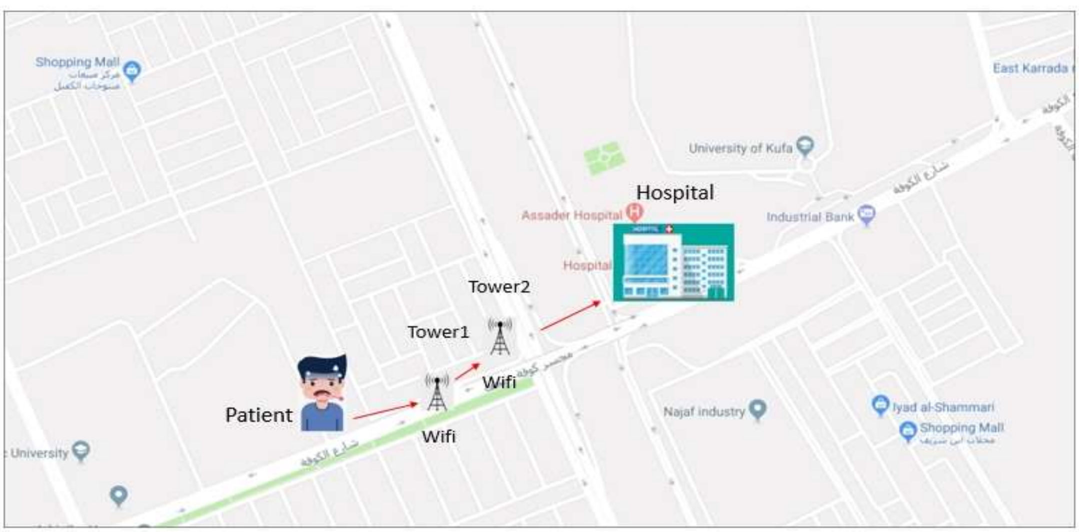

Figure 1. The basic elements of the WBAN network connected from the patient to the hospital in order to follow up the patient's condition remotely

Moreover, the flowchart of the parameters for all the scenarios that were worked in the simulation and that achieved the results is shown in Figure 2. This flowchart depends on several steps, the first step must determine the location of the hospital, the second step is to determine the number of nodes between the hospital and the patient, and the third step is to determine the patient location. The final step is to create the connection path and calculate the collected data to give results at the end of the process.

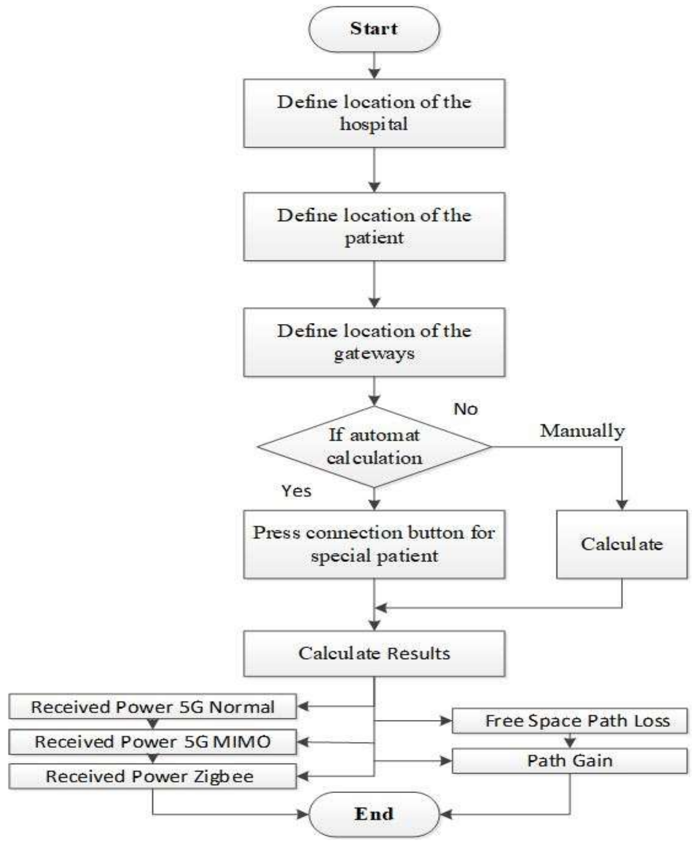

Figure 2. The flowchart shows the steps involved in the simulation model for sending and receiving data between patient and hospital for ZigBee, 5G normal, and 5G MIMO antenna

5. RESULTS AND DISCUSSION

Most of the institutions and telecommunications companies relied on a set of equations to calculate the results obtained so that we applied them taking into account the differences between the technologies used in 5G and 5G networks with MIMO and ZigBee. So that every technology has a method of work that differs from the other technology. Therefore, the work of each technology has been taken into account in order to obtain the optimal technology capable of communication to monitor the patient's condition with the least problems. The instructions used in this paper are written in C# language and these instructions are used for calculating equations based on the parameters of all techniques. The main equation for calculating the advantage of any technology is reserved power.

The system has introduced wireless technology that is able to monitor and send the largest number of physiological data from the patient's implanted nodes to the hospital in real-time response. For this, patients will wear wireless sensors whose function is to sense the physiological state and send it to their doctors in a quick real-time response. In addition, in the simulation scene, several network hops were used in order to allow physicians to monitor the patient's condition periodically and remotely as shown in Figure 3. As a result, the external environment model is designed to simulate and explore the best approach to the patient monitoring process. Moreover, this simulation with the three-component map shows the location of the patient (for three patients and each patient in a different place) as well as the location of the hospital and the node between WiFi and the hospital endpoint as shown in Figure 3.

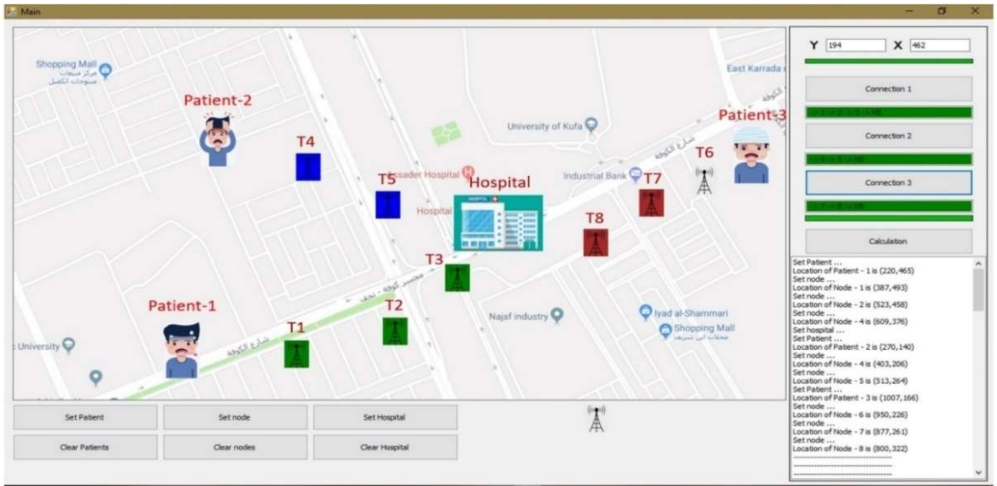

Figure 3. A simulation scene platform for all WBAN scenarios and elements

The end result of all the technologies proposed in this paper which are 5G and 5G with MIMO and Zigbee is shown in Figure 4. We noticed that ZigBee devices reduce energy use, last longer, perform better, and significantly extend the life of the contract. While 5G devices increased the speed of response and transmission to achieve rapid data delivery. In addition, MIMO antennas have added more reliability and stability to the consumption of R_P as shown in Figure 5.

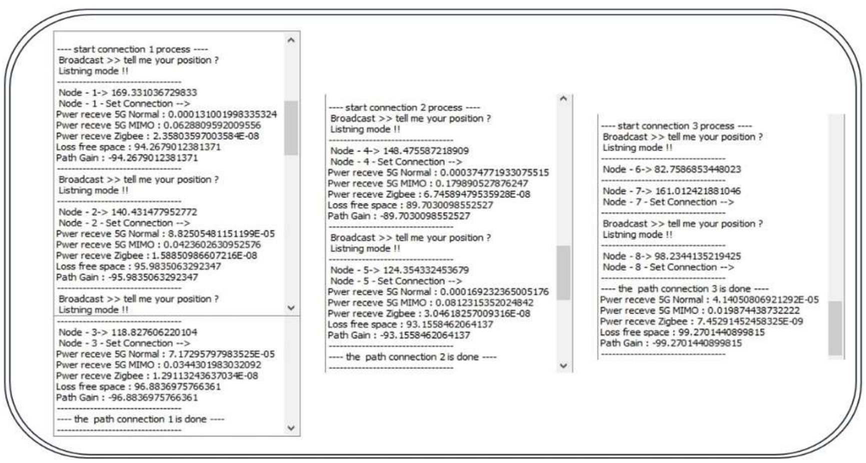

Figure 4. Results of all 5G and 5G technologies with MIMO and ZigBee

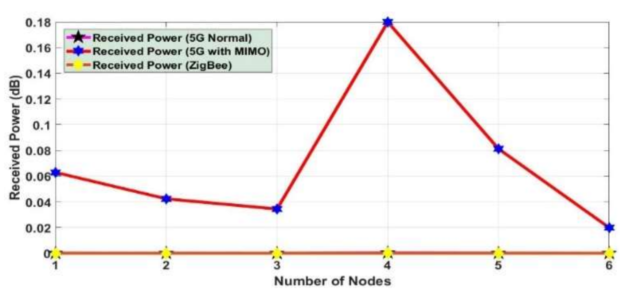

Figure 5. The received power strength for each receiving node at a frequency of 5 GHz for the various techniques proposed in this paper (5G normal, 5G with MIMO, and ZigBee)

6. CONCLUSION

This paper presents the best methods for communication between patient-installed and hospital-installed nodes to control the energy consumed in the network due to changes between ZigBee, 5G Normal, and 5G with MIMO technology and also fast data delivery to be more effective for use in real-time response. The Zigbee devices minimize the energy used to perform better and significantly extend the nodes' life cycle. While the 5G device increased transmission speed to achieve the fast delivery of data. Then MIMO added more stability for the consumption of R_{P}. The effect of the transmitter can be significantly and effectively reduced by using combined devices. Cell phone towers can be used to reduce knots and increase the area covered to make the movement of patients more comfortable. In future work, we will optimally cover the area of the outdoor environment using an optimization algorithm to determine the optimal paths in wireless sensor networks.

ACKNOWLEDGEMENTS

We express our sincere gratitude and thanks to the Islamic University (https://iunajaf.edu.iq/) for their continuous support to complete this academic work in the standard period because of its importance in the development of the field WBAN communications and Wireless Sensor Networks in the near future.

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