A new Network Coordinator Node Design Selecting the Optimum Wireless Technology for Wireless Body Area Networks

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Abstract

This paper proposes a new network coordinator node design to select the most suitable wireless technology for WBANs by using fuzzy logic. Its goal is to select a wireless communication technology available considering the user/application requirements and network conditions. A WBAN is composed of a set of sensors placed in, on, or around human body, which monitors the human body functions and the surrounding environment. In an effort to send sensor readings from human body to medical center or a station, a WBAN needs to stay connected to a local or a wide area network by using various wireless communication technologies. Nowadays, several wireless networking technologies may be utilized in WLANs and/or WANs each of which is capable of sending WBAN sensor readings to the desired destination. Therefore, choosing the best serving wireless communications technology has critical importance to provide quality of service support and cost efficient connections for WBAN users. In this work, we have developed, modeled, and simulated some networking scenarios utilizing our fuzzy logic-based NCN by using OPNET and MATLAB. Besides, we have compared our proposed fuzzy logic based algorithm with widely used RSSI-based AP selection algorithm. The results obtained from the simulations show that the proposed approach provides appropriate outcomes for both the WBAN users and the overall network.

Keywords: WBAN, Fuzzy Logic, Network Coordinator Node, Cognitive Radio

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1. Introduction

Latest advances in wireless communications and sensors have led to the development of Wireless Body Area Networks (WBANs). A WBAN is a type of Wireless Sensor Network (WSN) technology that interconnects small-size, lightweight, and low-power nodes with sensing capabilities in, on, or around a human body. The main task of wireless sensor nodes in WBANs is to continuously monitor human physiological activities, vital signs (such as body temperature, heart-rate, blood pressure etc.), actions, and the surrounding environment [1], [2]. The specific biological signals acquired from the human body are processed and sent to the Network Coordinator Node (NCN) as needed or periodically. Then, the NCN aggregates the signals from all body sensor nodes [3]. Wireless communications is more widely used for the sensor nodes to communicate with the NCN due to the human's need for mobility. The aggregated signals from the sensors are monitored by an NCN, i.e., a PDA, laptop or smart phone which acts as a sink. NCN transmits the data collected from sensor nodes to control center. In brief, a WBAN architecture consists of body sensor nodes, an NCN, and wireless links for intra-body and extra-body communications. WBANs are mostly used in biomedical applications; but they are also used in a number of new applications namely interactive gaming, entertainment, fitness monitoring, and military applications [4]. Essentially, a WBAN is similar to the WSN in that it first collects signals from the human body, and then processes the sensor signals and lastly transmits them to the NCN [5].

The NCN within WBANs needs to send the gathered signals to a control mechanism (a medical center or a control unit). It sends them to the sink through a wireless technology. As there is no standard technology developed for WBANs, wireless technologies such as cellular networks (e.g., GSM/GPRS, UMTS), Wireless Local Area Networks (WLANs) (e.g., IEEE 802.11a/b/g/n), Metropolitan Area Networks (MANs) (e.g., IEEE 802.16, WiMAX), and Personal Area Networks (WPANs) (e.g., Bluetooth) can be used in WBAN applications [6]. So, one of these wireless technologies can be exploited by the NCN to transmit the sensor readings to the control center. In an example, with the utilization of wireless technologies in a large transmission range, the patients are not confined in a hospital and they may be monitored in a wide geographical area. Therefore, the selection of the most appropriate wireless technology should be considered first by the NCN. Current short-distance wireless communication technologies such as Wi-Fi and cellular networks such as GSM could be easily applied into these systems in order to provide seamless connection between NCN and control center.

Wireless technologies are different from each other in terms of bandwidths, frequencies, modulation techniques, coverage areas, etc. For mobile users, only one of these wireless technologies is not able to provide cost-effective, wide coverage area, and low packet latency. For example, while WLANs provide cost-effective connections, they have a small coverage area, and cannot support outdoor connections and high speed users. Cellular networks have a large coverage area and support high speed users, but they do not provide cost-effective connections and have a number of problems in indoor applications giving rise to customer dissatisfaction [6]. Consequently, it is expected for the NCN to able to select and connect to the most suitable wireless technology available according to the parameters it utilizes. For this reason, the NCN must scan the wireless environment for all possible wireless technologies and change its working parameters such as data rate, bandwidth, modulation scheme and frequency to dynamically adopt any possible wireless technology. This operation introduces the Cognitive Radio (CR) theory as well [7]. A CR is a transceiver that periodically modifies its working parameters in order for wireless communications to have spectrum agility to choose an appropriate wireless technology. For this purpose, a CR based Network Coordinator Node (CRNCN) is considered in this study. It senses the wireless environment for all possible wireless technologies and changes its transmission and reception parameters in order to get connection to an optimum wireless technology.

In order to choose the optimum wireless technology, CRNCN must evaluate some parameters about wireless technologies available. CR operations with different wireless technologies are usually performed in a similar way to the vertical handoff operations. Taking into the account the parameters such as; user's speed, data rate, monetary cost, coverage area in addition to the Received Signal Strength Indicator (RSSI), CRNCN gets connection to the one of the wireless technology which most fits its requirements [8].

In this paper, a new fuzzy logic based NCN design approach for WBANs are presented. Our NCN selects the optimum wireless technology among the several available technologies according to the input parameters for both in-door and out-door applications. Data rate, monetary cost, speed of mobile, coverage area and RSSI are considered as system parameters while choosing the optimum technology. We have developed, modeled, and simulated some networking scenarios utilizing our fuzzy logic-based NCN with several body sensor nodes by using OPNET and MATLAB software. Further, we have compared our proposed fuzzy logic based algorithm with widely used the RSSI-based AP selection algorithm. The results obtained from the simulations show that the developed fuzzy logic-based CR approach provides appropriate outcomes for both the WBAN users and the overall network.

The main contributions of our study can be summarized as;

(i) to make a novel NCN design to select the most appropriate WLANs or WANs by using CR scheme in the WBAN architecture utilizing fuzzy logic,

(ii) to compare the results of the proposed scheme with those of RSSI-based algorithm,

(iii) to develop, model and evaluate several WBAN scenarios utilizing our developed CRNCN and

(iv) to cooperate OPNET and MATLAB simulation tools together to make more realistic performance evaluation.

2. Related Work

Although the WBAN concept is relatively new and interesting, a volume of studies can still be found in literature. There are also a few studies including CR in WBAN architecture. CR Based Medium Access Control (CR-MAC) protocol for WBANs that utilizes CR transmission is proposed in [9]. In this protocol, the network nodes are assumed to have the capability of dynamically tuning their transmitter power according to their monitored traffic urgency level. The NCN in proposed work may process the received sensor results before reporting them to the Tele-health server via other networks such as a cellular system or WLAN where health authority can access such information.But, there is no information about how the NCN selects the wireless technology.

In [10], CR technology is used to "*Detect and Avoid*" interference to primary users. They described the architecture of the WBAN for medical applications based on ultra wideband technology. This architecture defines the communication requirements that integrate both on-body and in-body medical sensors into a single system. The same authors discuss CR for medical WBANs in [11]. In this study, they emphasized that all the wireless users collocated with a cognitive WBAN must be cognitive devices as well. In [12], a survey is presented about CR in WBAN applications, ranging from smart grid, public safety and broadband cellular to medical applications. It explains the benefits that CR would bring, and also some challenges that are yet to be resolved. The effects of applying CR into WBAN system are explained in [13]. This work aims to improve the performance of the proposed system by taking advantage of CR capabilities such as sensing the spectrum hole and rebuilding its connection in new frequency band. In [14], a CR approach enabling WBAN services in the 2360-2400MHz band, where lower interference levels are expected when compared to the more crowded 2.4 GHz ISM band is proposed. It shows an improvement in the performance of the radio link along with primary user protection.

A fundamental WBAN architecture shown in **Fig. 1** consists of one or more body sensor nodes, an NCN and communication channels for transmitting gathered signal information over a wireless network to the control center [5]. Sensor nodes continuously measure the vital signals (i.e. electrocardiography-ECG, electroencephalography-EEG, electromyography-EMG) and activities, such as body temperature, heartbeat, respiratory and glucose level in blood and send them to the NCN such as a cell phone or a PDA. Sensors together with NCN consist of a network topology. In WBANs, different network topologies such as star, tree, and mesh can be used according to the user/application requirements. The most common is a star topology where nodes are connected to a central coordinator in star manner [3], [4].

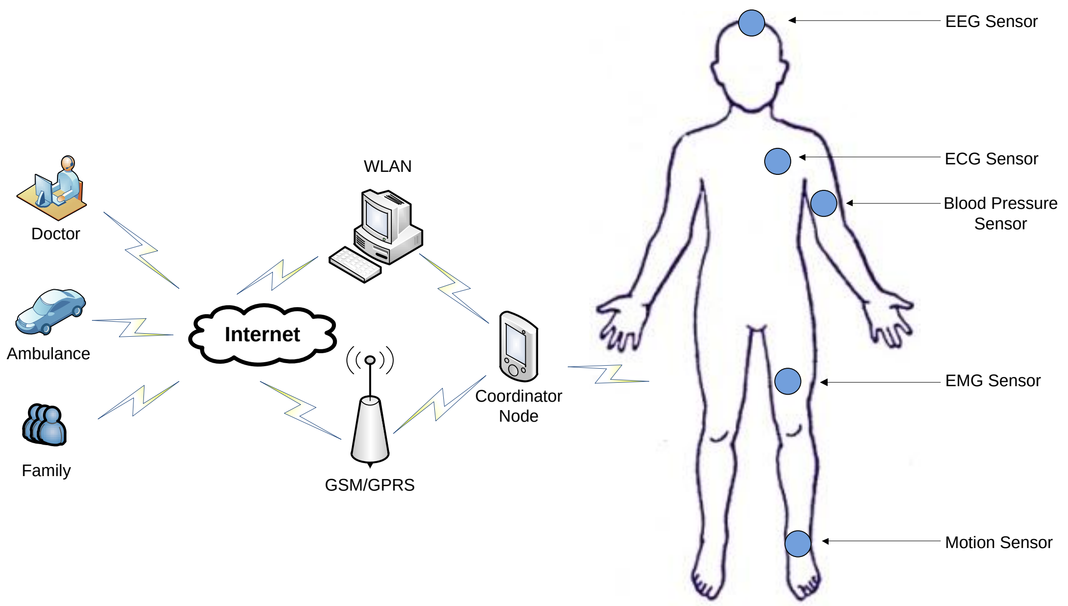

Fig. 1. A fundamental WBAN architecture

The NCN in WBANs sends the sensor data over the WLANs (i.e. Wi-Fi) or cellular networks (i.e. GSM) to a remote location such as emergency center or a caregiver. It can also process the sensor data and make decisions regarding the mobility of the patient and measurements of the body. There are mainly two communication channels used in the WBANs, namely; intra-body and extra-body communication channels. The first one is used to connect WSNs to the NCN and the latter one is used to connect NCN to a wireless technology.

Consequently, the capability of connecting to a local or wide area networks is a requirement for WBANs [15-19]. In order to accomplish a connection to a local or a wide area network, WBANs need to have effective and well-organized network architecture. Current short-distance wireless communication technologies such as Wi-Fi and cellular networks (i.e. GSM) could be exploited by the WBANs to transmit their sensor readings to the patient observer. However, the standards of WBAN have not been published yet [14].

In general, access point selection methodologies need to consider many parameters including user profiles, application requirements and network conditions such as handoff decision algorithms [6], [8]. Handoff, in wireless networks, occurs when a mobile user switches from one Base Station (BS) to another BS both using the same technology or from one technology to another. While moving out from one point to another, mobile users may come across different types of networks each has specific characteristics that need to be considered when choosing the best candidate serving node. When a mobile user moves between two adjacent cells (e.g. GSM cells), generally, only one parameter such as RSSI or Signal-to-Noise Ratio (SNR) is used. If RSSI or SNR drops below a predefined threshold, the mobile user changes its serving BS. Using only one parameter for choosing the wireless technology available is not efficient since existing networks overlap with each other. When more performance parameters, such as; data rate, monetary cost, user speed, RSSI and etc., are considered, more realistic performance results can be achieved for these heterogeneous wireless networks. Therefore, switching to the optimum wireless technology according to the user/network requirements is vital especially for WBANs as they can have the critical sensor data to transmit.

Artificial intelligence based systems such as Fuzzy Logic and Artificial Neural Networks are good candidates for pattern classifiers due to their non-linearity and generalization capability [20]. In this work, a fuzzy logic-based access point selection algorithm within NCN which combines data rate, monetary cost, speed of mobile, coverage area and RSSI parameters is utilized in order to satisfy both user and network requirements of the proposed WBAN. We adopt fuzzy logic approach as it has an inherent strength of fuzzy logic in solving problems exhibiting imprecision. Besides, many of the terms used for describing radio signals are fuzzy in nature [21, 22]. In the proposed approach, NCN is able to connect to different wireless technologies with perception and adaptation capabilities. Selection of the optimum wireless technology by the NCN within the WBAN has vital effects on the network stability, quality of service (QoS) provision, resource utilization, and user satisfaction. The following section describes in detail the proposed NCN design.

3. The Proposed NCN Designed by Using Fuzzy Logic

A WBAN consists of several sensor nodes which are capable of sensing and processing the vital signals and of communicating with the NCN for the transmission of these signals for remote monitoring. The NCN aggregates and processes the vital biological signals from all wireless sensor nodes. The sensor nodes are required to communicate with the NCN in wirelessly. In WBANs, for short range wireless technologies between sensor nodes and NCN, ISM band (2.4 GHz to 2.4835GHz) like Zigbee (802.15.4) and Bluetooth (802.15.1) are utilized [2], [23]. Wireless sensor nodes generally need to transmit data at a wide range of data rates from 1kb/s to 1Mb/s. But having restricted power supply, these nodes are expected to consume as little power as possible [24].

Since the NCN within the WBANs needs to communicate and gather the signals from the sensor nodes, there must be a Medium Access Control (MAC) protocol which defines how to be accessed to the channel by sensor nodes. The main tasks of a MAC protocol are considered to achieve maximum throughput, minimum delay, and to maximize the network lifetime by controlling the main sources of energy wastage, such as collision and over listening. The MAC protocols mainly used for WSNs are Carrier Sense Multiple Access / Collision Avoidance (CSMA/CA) and Time Division Multiple Access (TDMA). As CSMA technique experiences more collision and consume more energy, it is not suitable for WBANs, on the other hand, TDMA having time synchronization among sensor nodes experiences no collision and has better bandwidth utilization when compared to the CSMA system [24].

In our WBAN scenarios, TDMA MAC is used between wireless sensor nodes and the NCN at 2.4 GHz ISM band. After gathering sensor signals from sensor nodes, NCN must send the gathered signals over one of the wireless technologies to the control center. There are large varieties of wireless technologies such as Wi-Fi, GSM, GPRS, UMTS, WiMAX, and etc. Also, the next generation wireless network concepts need to be considered for a collaboration of these different wireless technologies in order to provide QoS support and cost efficient connections.

A NCN needs to be aware of any wireless technologies around and to provide connection to the optimum access point considering user/application requirements and network conditions. NCN must have the ability to dynamically adapt its configuration to the various working conditions by exploiting deployments with pre-installed components. This requirement introduces the CR concept defined as a self aware communication system that efficiently uses available spectrum in an intelligent way [7].

The NCN proposed in this study is in complete charge of managing the wireless technology selection process as well as its other functions with the capability of the CR methodology. The CRNCN senses the medium periodically by scanning the frequency spectrum to get the available Access Points (APs) parameters. These parameters are utilized in a fuzzy logic-based access point selection algorithm. Because of the variety of parameters considered for Multi Attribute Decision Making (MADM) processes, a decision making process must be used in wireless technology selection operation. Therefore, in this work, a fuzzy logic-based wireless technology selection algorithm which combines data rate (DR), monetary cost (C), speed of mobile (S), coverage area (CA) and RSSI (RS) parameters is utilized in order to satisfy both user and network requirements of the WBAN. The block diagram of the proposed algorithm is given in **Fig. 2**.

Applications of fuzzy logic are used in a wide range of fields including artificial intelligence, computer science, pattern recognition, engineering and etc. A fuzzy logic-based system is designed by using a set of "If/Then" linguistic rules determined by the expert regarded as a knowledge base. The first step of the fuzzy system is to feed the aforementioned parameters into a fuzzifier as can be shown in Fig. 2. The aim of the fuzzifier is to convert the real-time measurements into fuzzy sets. For example, if mobile speed is considered in crisp set, in the corresponding fuzzy set, the signal can be represented as low, medium or high. The membership values are obtained from membership function by mapping the input values with a particular parameter. Then, fuzzy conversion is performed by using a reverse engine named as defuzzifier to generate an output which describes the candidacy value of wireless technologies. For example; if a wireless technology is able to support a data rate of 50 Kbps with pedestrian speed, having a cost of 0.1 unit, short range coverage area (150 m) and RSS of -60 dBm, then the output of this wireless technology is calculated as 9.3 for a walker patient. But, this output is about 2 for a faster patient (a driver or a voyager).

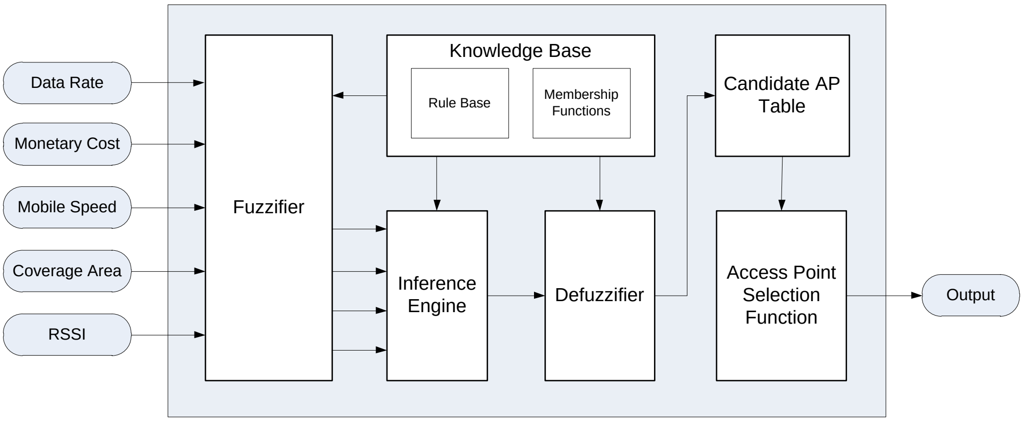

Fig. 2. The block diagram of the fuzzy logic based NCN system

There are 81 rules used for producing a new set of fuzzy linguistic variables. Some of the fuzzy rules in the rule base are tabulated in Table 1. For instance, Rule 1 corresponds to the following IF–THEN structure: if the potential AP supports low data rate, it has a low monetary cost, its RSSI is weak, its velocity is low, and it has a small coverage area, then the output value of the AP is 1, which means that it is not a strong candidate. On the other hand, Rule 20 outputs a greater output value, i.e. 9, which implies the AP's output value is quite high.

Table 1. Example fuzzy rules

Rule	Data Rate	Cost	RSSI	Velocity	Coverage	Output
1	Low	Low	Weak	Low	Small	1
11	Medium	Low	Medium	Low	Small	4
20	High	Low	Medium	Velocity	Small	9
30	Low	Low	Medium	Medium	Small	2
74	High	Medium	Strong	Medium	Large	8
78	High	High	Medium	Medium	Large	5
81	High	High	Strong	High	Large	6

Membership functions of the fuzzy system are given in **Fig. 3**, **Fig. 4**, **Fig. 5**, **Fig. 6**, and **Fig. 7**. In the figures, the horizontal axis indicates the crisp values (i.e. 0.75, 10, -75) of the related parameters, and the vertical axis (i.e. l values) depicts the membership values of the parameter. Trim and trapezoid fuzzy functions are chosen as fuzzy membership functions due to their capability of achieving better performance for especially real time applications [25]. The data rate membership functions are shown in **Fig. 3**.

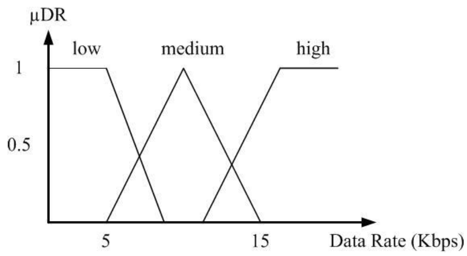

Fig. 3. Fuzzy membership functions for data rate (DR)

In the simulation scenario, it is assumed that all the networks have a specific unit price (cost values are expressed proportionally) information. The monetary cost membership functions are shown in **Fig. 4**.

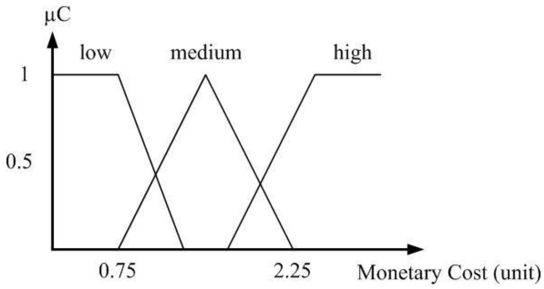

Fig. 4. Fuzzy membership functions for monetary cost (C)

The RSSI input of the fuzzy system has also the ability to change its structure according to the network requirements. The RSSI membership functions for GSM and Wi-Fi networks are illustrated in **Fig. 5. a)** and **Fig. 5. b)**, respectively.

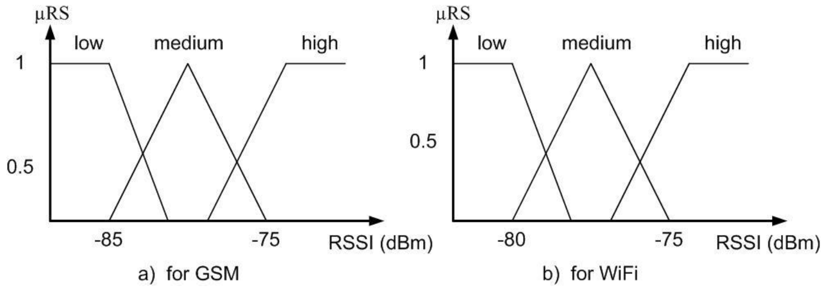

Fig. 5. Fuzzy membership functions for RSSI (RS)

Wi-Fi access point supports only mobile devices with pedestrian speed, but GSM base stations support not only pedestrian users but also fast mobile users. The mobile speed input of the fuzzy system has been obtained from trajectory attribute of the mobile terminals used in the OPNET simulation. The membership functions of mobile speed are shown in **Fig. 6**.

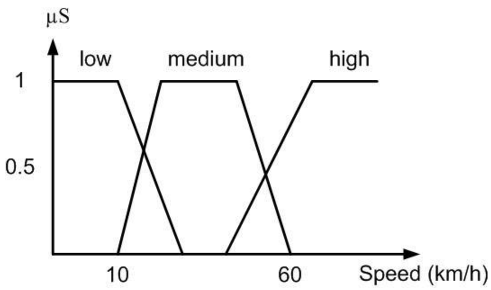

Fig. 6. Fuzzy membership functions for mobile speed (S)

Wi-Fi hotspots have a small coverage area at about 100-300 meters, but GSM base stations have a large coverage area at about 3-10 Km [26]. The membership functions of the access points' coverage area (CA) are shown in **Fig. 7**.

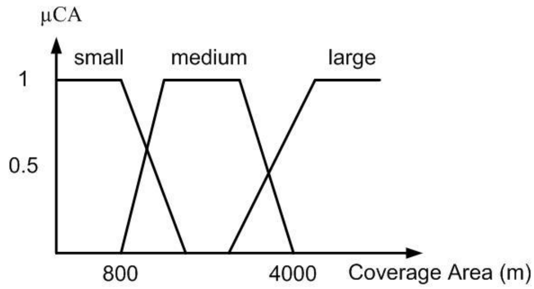

Fig. 7. Fuzzy membership functions for coverage area (CA)

4. Simulation Results of The Case Studies

In our simulation scenarios, we have designed a WBAN consisting of a group of wireless sensor nodes and an NCN shown in **Fig. 8**. As seen in the figure, GSM with GPRS serving and Wi-Fi technologies each having specific working parameters coexist in the same networking environment with WBAN nodes. The network part of simulations is modeled by using OPNET Modeler simulation software. The implementation of our fuzzy logic based algorithm which is incorporated into the NCN is completed by MATLAB FIS editor. Both MATLAB and OPNET work together for more sensible estimation and substantiation during the simulation.

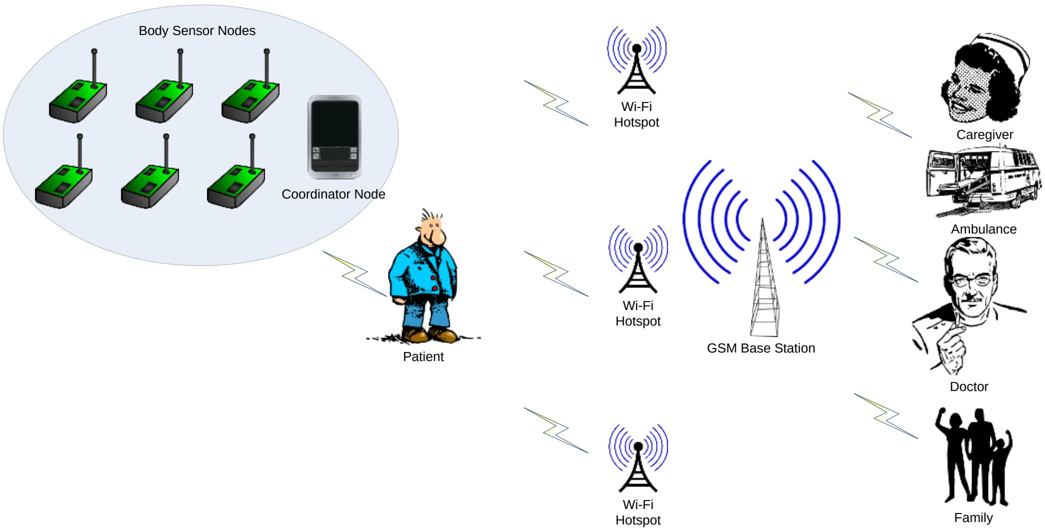

Fig. 8. The proposed WBAN structure

In the simulation scenarios, body sensor nodes are assumed to continuously check the vital signals and activities of patient, such as body temperature, heartbeat, and respiratory. Sensor nodes each having a distinct time slot in a TDMA frame send their packets to the NCN in their own time slots. Star topology in which the body sensor nodes are connected to an NCN in star manner is adopted for our simulation scenarios. The CRNCN proposed in this study is in complete charge of managing the access point selection process as well as its other functions with the CR capability. The CRNCN senses the medium by scanning the frequency spectrum to get the available wireless technologies. During the listening period, the CRNCN changes its working parameters such as frequency, modulation, data rate, and bandwidth to adapt any possible wireless technology. Then the available APs' parameters are utilized in the fuzzy logic-based wireless technology selection algorithm for deciding and switching the optimum serving AP. When any AP is found in the vicinity, CRNCN gets its parameters in order to use them as inputs of the proposed AP selection algorithm. The CRNCN calculates the APs' output values according to its input parameters using its fuzzy inference system, and stores all the information required. Once the scan process is completed, the output values of each available AP are compared to one another. If the newly found AP's output is equal or greater than that of the present, the new AP is chosen as a serving node. Otherwise, existing AP is not changed. The performance evaluations of developed algorithm are illustrated with case studies. Simulation time for all the simulation scenarios is one hour and the other simulation parameters are shown in **Table 2**.

Table 2. Simulation parameters

Parameter	Value
Sensors Data Rate	5* Kb/s
Supported Data Rate	Wi-Fi=1 Mb/s, GSM=270,833 b/s
Frequency Band	Wi-Fi=2.4 GHz, GSM=890-935MHz Sensors= 2.4 GHz
Transmitter Power	Wi-Fi= 100 mW , GSM=1.5 W
Modulation Type	Wi-Fi= QPSK, GSM=GMSK
Speed of Mobile	5Km/h, 50 Km/h
Coverage Area	Wi-Fi=300m, GSM=10000m
Area Size	5 km X 5 km
Scan Period	100 ms
Monetary Cost	Wi-Fi=0.1 GSM=1.8
*Generated using Exponential Distribution Function Exp (Mean).	

4.1 Case Study 1

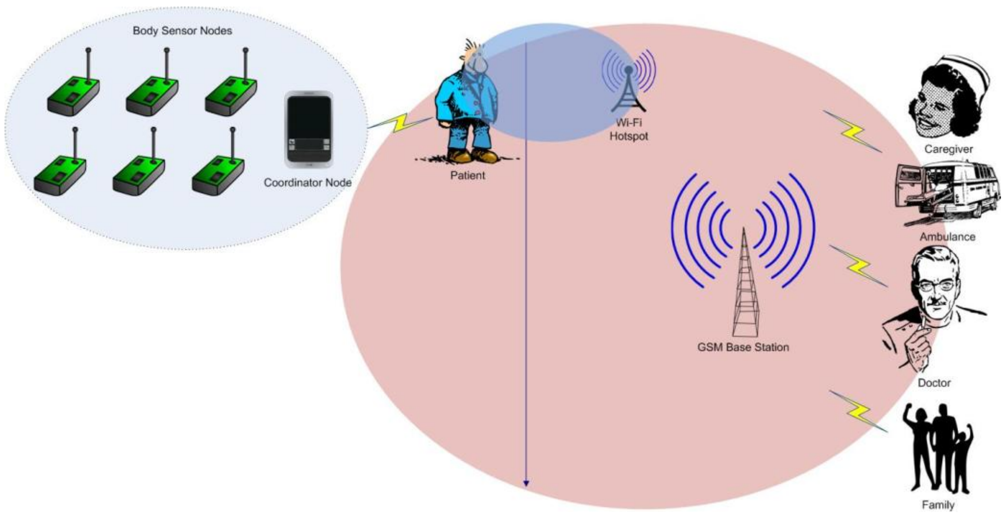

Fig. 9. The proposed WBAN structure for case study 1

In the first case study, there are two APs, a Wi-Fi AP and a GSM AP serving GPRS with specific working parameters placed in the communication area as shown in **Fig. 9**. The patient equipped with WBAN moves with pedestrian (5 km/h) speed during the simulation run time along the trajectory shown in blue line in the same figure. The CRNCN senses the environment periodically for any possible wireless technologies and choices the most appropriate wireless technology by using its fuzzy logic-based AP selection algorithm.

At the beginning of the simulation, the CRNCN firstly utilizes the Wi-Fi hotspot since it has high RSSI, sufficient bandwidth and extremely low cost with pedestrian speed (5km/h). After 300 seconds has elapsed around the Wi-Fi hotspot, data rate of Wi-Fi decreases dramatically. Fuzzy logic-based NCN on patient decides to switch from the existing Wi-Fi AP to GSM AP in spite of the fact that the Wi-Fi has appropriate RSSI and cost parameters considering the application requirements. The GSM AP with GPRS serving is able to provide appropriate bandwidth for the applications preferred. When compared with the Wi-Fi, the GSM AP has a larger coverage area and higher RSSI value. Therefore, it is chosen as new serving AP, as illustrated in **Fig. 10**.

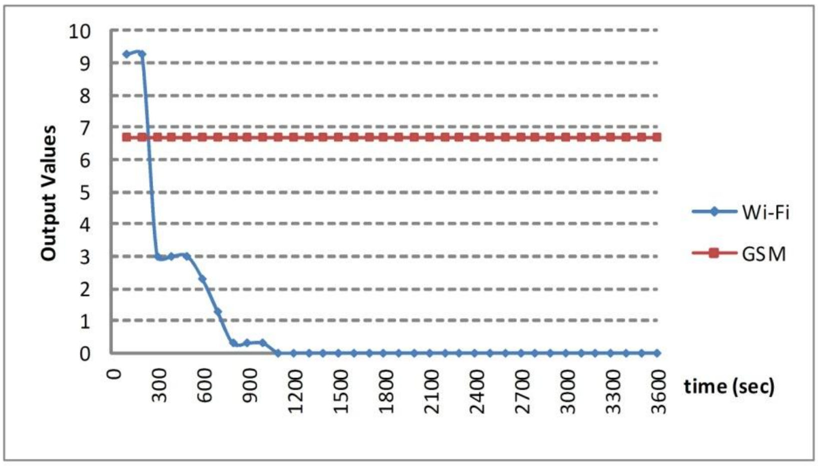

Fig. 10. Output values of APs for case study 1

In traditional RSSI based-AP selection algorithms as in [27], the RSSI value is the only parameter to select the appropriate AP. However, only the RSSI value to choose the AP can sometimes be misleading. This condition is shown in **Fig. 11**. In the figure, the measured RSSI values of the Wi-Fi and GSM are shown as a function of the simulation run time. As GSM has greater RSSI values than those of Wi-Fi along with the simulation run time, the algorithm always selects the GSM AP. But GSM may be more expensive and have lower bandwidth than Wi-Fi and, so Wi-Fi may be more appropriate for the connection. Therefore, some other parameters must be taken into account in order to select the most appropriate AP. For instance monetary cost, coverage area, data rate and speed have also been considered in our proposed models. As a consequence, in the same conditions, the proposed fuzzy logic based algorithm chooses the Wi-Fi AP, whereas the RSSI-based traditional algorithms choose the GSM AP which is not the most appropriate one.

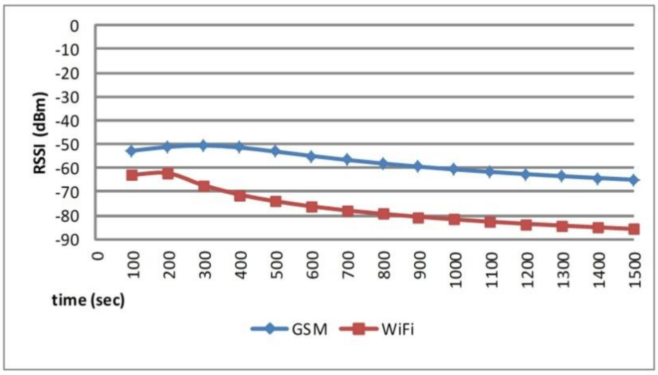

Fig. 11. RSSI-based performance evaluation chart

In **Fig. 12**, end-to-end delay (EED) results of the proposed CRNCN for the case study 1 are presented. Until 300 seconds, CRNCN communicates with Wi-Fi hotspot with large bandwidth, thus the EED results are very low. After 300 seconds, CRNCN switches to communicate with the GSM AP. As the GSM connection has the limited bandwidth when compared to Wi-Fi, the EED results are a little higher than those of Wi-Fi previously connected to.

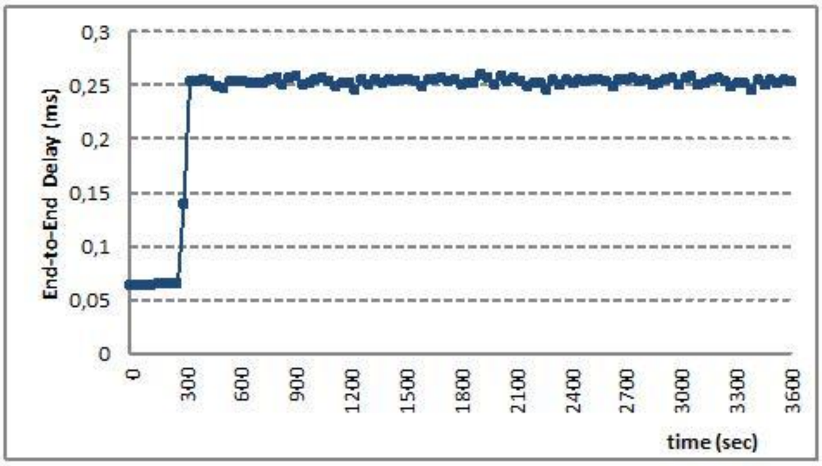

Fig. 12. EED results for case study 1

4.2 Case Study 2

In the second case study, there are four APs, three Wi-Fi and one GSM serving GPRS with specific working parameters, placed in the communication area as shown in **Fig. 13**. The patient equipped with WBAN moves with pedestrian (5 km/h) speed during the simulation run time along with the trajectory. CRNCN senses the environment periodically for potential wireless technologies and choices the most suitable one by using the fuzzy logic based AP selection algorithm.

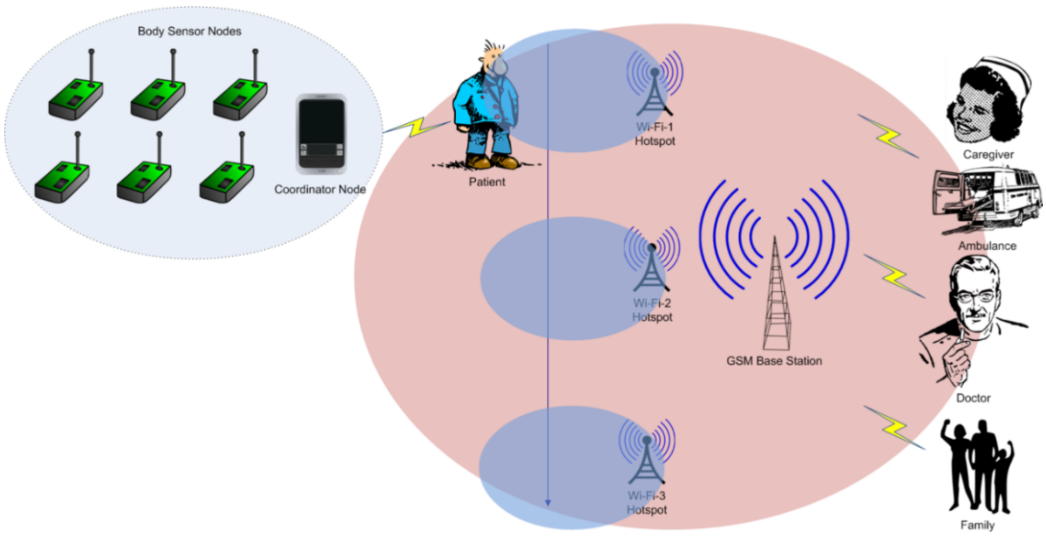

Fig. 13. The proposed WBAN structure for case study 2

The patient equipped with WBAN firstly camps on Wi-Fi hotspot as in the first case study. Then, it connects to GSM AP. As shown in **Fig. 13**, the CRNCN with pedestrian speed switches to the other two Wi-Fi APs one after the other because of their high RSSI, sufficient bandwidth and extremely low cost. The output values of the APs are illustrated in **Fig. 14**.

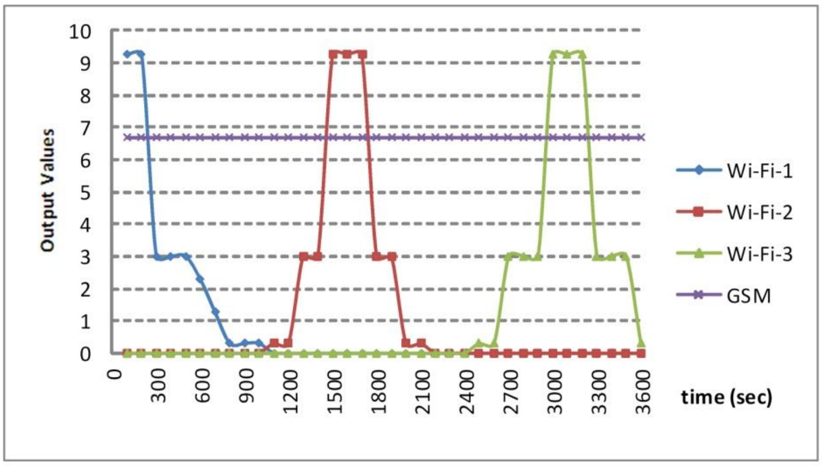

Fig. 14. Output values of APs for case study 2

In **Fig. 15**, the EED results of the proposed CRNCN for the case study 2 are presented. The CRNCN utilizes three Wi-Fi APs one after the other along the trajectory during the simulation time.

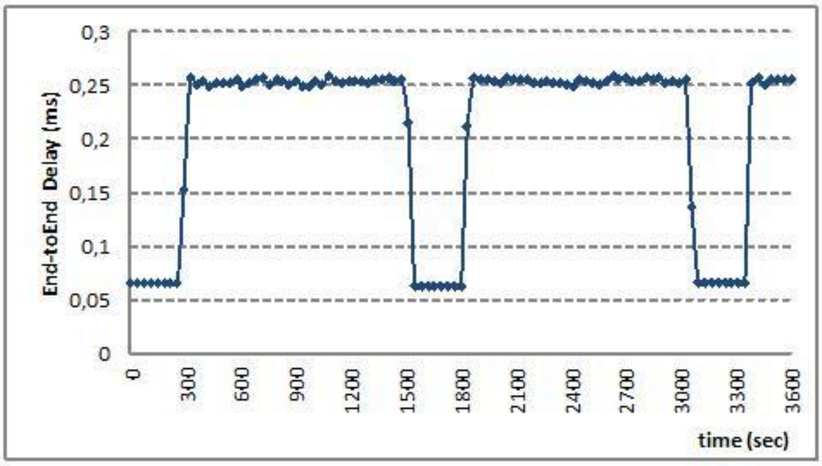

Fig. 15. EED results for case study 2

4.3 Case Study 3

In the third case study, all the parameters are the same as the second case study except for the patient speed. At the beginning of the simulation, the patient has a speed of 5 Km/h, so the CRNCN camps on the Wi-Fi hotspot. After 500 seconds, the patient gets on the bus with 50 Km/h speed. As Wi-Fi connections support only pedestrian speed, the CRNCN does not connect to the second Wi-Fi AP because of its high speed (50 Km/h). This condition is shown in the **Fig. 16** with the first bus from the top. Therefore, the CRNCN keeps on connected to the GSM base station. After two km, the patient gets off the bus, and this time CRNCN is able to connect the third Wi-Fi hotspot because of pedestrian speed.

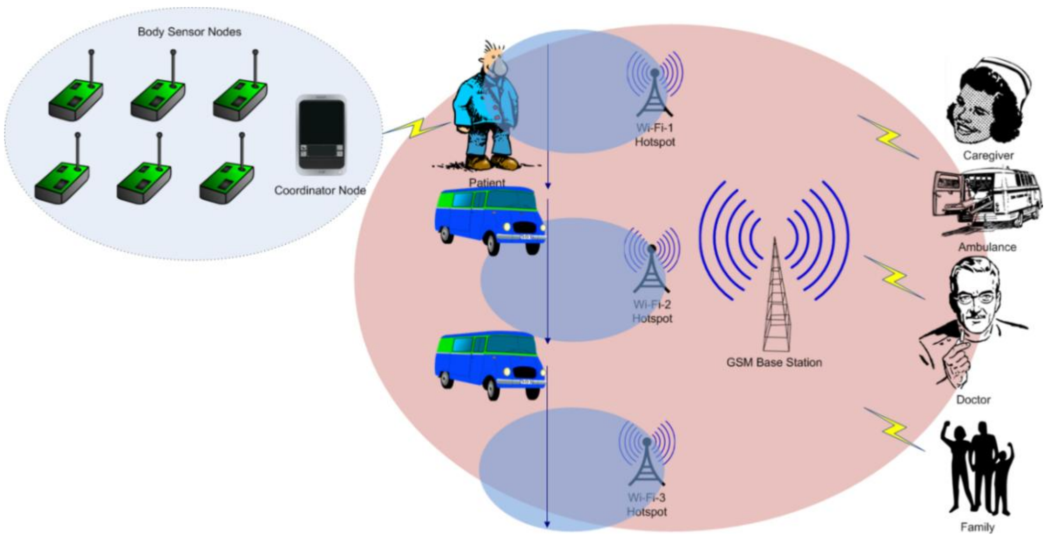

Fig. 16. The proposed WBAN structure for case study 3

The output values of the APs and the EED results of the proposed CRNCN for the case study 3 are presented in **Fig. 17** and **Fig. 18,** respectively.

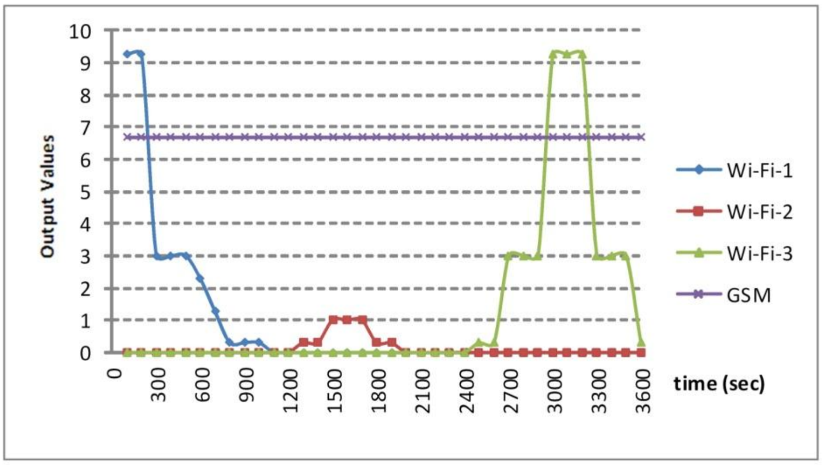

Fig. 17.. Output values of APs for case study 3

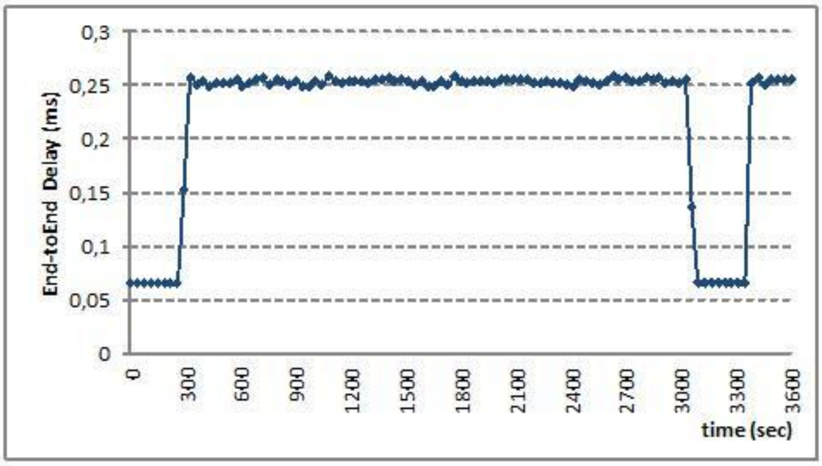

Fig. 18. EED results for Case Study 3

5. Conclusion

The CR-based WBANs are relatively new and there are a few studies on this subject. In this study, a new WBAN architecture and its CRNCN choosing the optimum wireless technology (access point) according to some parameters are developed, modeled and evaluated. The proposed CRNCN has a fuzzy logic-based wireless technology selection algorithm which combines such parameters as data rate, monetary cost, the speed of mobile, coverage area and RSSI. The fuzzy logic-based algorithm gives better results than widely used RSSI-based algorithm. Simulation results show that the proposed CRNCN is able to determine and switch to the most appropriate communication network under different dynamic working conditions.

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