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Performance Evaluation of Existing Interference Mitigation Techniques under Designed Interference Environment

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Abstract:

According to the latest report, 10% people in India die because of cardiovascular diseases. This mortality rate can be reduced by using state of art technology which can give early warning signs of such attacks. Thus, Wireless Body Area Network (WBAN) arrangements where remote patient monitoring is made possible can help in this context. Also, WBAN can reduce the cost of hospitalization and ensure comfort level of the patient. This paper is an outcome of our ongoing research to design robust Wireless body area network for remote patient health monitoring system. Our previous work confirmed that designed WBAN can be extremely useful for remote patient monitoring, however WBAN are prone to interference. Interference is a phenomenon of overlapping wireless ranges of WBANs thus there is a need to test performance of designed WBAN under interference. Interference reduces the reliability of the transmission of the data, the throughput and increases the power consumption. In WBAN vital body parameters are sensed and transmitted wirelessly to the health service provider. Any delay in transmission of the data due to interference could be dangerous for patients' health. Thus, the efforts should be made to mitigate interference.

Thus, performance of the designed WBAN under the influence of interference is reported in this paper. For performance analysis, three parameters i.e. delay, power consumption and throughput are considered. Also, effectiveness of two existing, concurrent Interference Mitigation Techniques (IMT) is evaluated for the interference reduction for Designed WBAN. First, the designed WBAN is tested under Interference environment without mitigation technique. Later on, a performance of SCA (Smart Channel Assignment) and ITLS (Interference Aware Traffic Priority Based Linked Scheduling) interference mitigation algorithms are tested under same interference environment and comparative statements are made. Purpose of such comparative analysis is to find the scope of development of new or better IMT for designed WBAN.

Keywords:*Interference Mitigation, ITLS, SCA, WBAN.*

I. INTRODUCTION

The health monitoring is useful to monitor condition of critical organs and to provide immediate medical attention to reduce undue risk of life. Traditionally, this is being done at hospitals by using on body wired sensors [1]. For such wired monitoring patient has to be admitted in hospital, and wear various on body sensors; limiting the movement of the patient. The wireless health monitoring provides remote sensing and enhanced mobility [1], and comfortable life for a patient as need to get hospitalized is minimized [1],[2]. A Wireless Body Area Network (WBAN); which is a subset of Wireless Sensor Network (WSN) is composed of a short range communication and low power sensors placed on or around a human body. A WBAN system consists of biomedical sensor nodes for monitoring physiological data such as temperature, blood pressure, electrocardiography (ECG), electroencephalography (EEG), electromyography, and heart rate. These sensors may be wearable or implanted devices that collect and transmit vital signals to the coordinator. The collected data can then be forwarded to health service provider for necessary action [1].

Considering the population of India, health infrastructure is always going to be limited. Thus, alternative arrangements where remote patient monitoring is made possible can help to reduce burden on health infrastructure. Moreover, Wireless Body Area Network (WBAN) can reduce the cost of hospitalization and ensure comfort level of the patient. In India, 10% of people die every year, because of heart attack [3] and it is considered as a leading cause of death in India [4, 5]. The severity of the problem can be minimized by efficient heart rate monitoring; to give early warning signs of the heart attack. *Thus, the main motivation of this research is to design WBAN as per the IEEE 802.15.6 standard for the heart rate monitoring.*

It is the fact that the humans are active and for daily routines they move from one place to another place. Thus, the sensor devices associated with arms, legs, et al., on a human body are also mobile. Thus, having static WBAN is almost impractical. Thus for realistic studies, mobility of the WBAN must be considered. It can also be understood that the mobility can be anywhere; say in hospitals, offices or market place. It is the great possibility in near future that in many practical environments such as hospitals, offices, schools etc. multiple WBANs can co-exist. Such coexistence of WBAN assisted due to mobility causes overlapping of communication ranges. This is called as interference. Interference reduces the reliability of the transmission of the data, the throughput and increases the power consumption. In WBAN, vital body parameters are sensed and transmitted wirelessly to the health service provider. Any delay in transmission of the data due to interference could be dangerous for patients' health. Thus, the efforts should be made to mitigate interference. *Since, interference causes degradation of a network performance, there is a need to test performance of designed WBAN under interference and to mitigate it.*

From the referred literature [3, 4, 5], it is understood that heart rate and pulse rate are the good indicators of heart disease. *Accordingly, we have designed WBAN consisting three sensors and one hub (discussed in detail in the section 3).* Our experiments and simulation with designed WBAN confirmed that it can be really useful for remote patient monitoring, however it has to be tested under interference environment. *Thus, performance of the designed WBAN under the influence of interference is investigated and reported in this paper.* For network performance analysis, three parameters viz. delay, energy consumption and throughput are considered. *In addition, an effectiveness of two existing, concurrent Interference Mitigation Techniques (IMT) (discussed in detail in the section 3) is evaluated for the interference reduction for Designed WBAN.* The designed WBAN is first tested under interference environment without any mitigation technique. Later on, SCA (Smart Channel Assignment) and ITLS (Interference Aware Traffic Priority Based Linked Scheduling) interference mitigation algorithms are applied and performance is tested under the same interference environment and comparative statements are made. *An objective of such comparative analysis is to find the scope of development of new or better IMT for designed WBAN.* The rest of the paper is arranged in the different sections. In the section II, previous interference mitigation studies are reported with important interference mitigation techniques. In the section III, methodology and simulation environment used for this research is discussed. Simulation results are discussed in the section IV followed by concluding section V.

II. LITERATURE REVIEW

In the literature many studies have reported that the interference of any form causes data collision [6],[7], beacon loss [8],[9] and affects on signal quality which results in loss of reliability and increases power consumption of the network. Overall the interference causes network performance degradation. It is understood that the researchers have used various parameters to identify interference; average packet reception ratio (PRR) and SINR values [6], the SINR, emitting power, and temporal model [7], beacon delivery ratio (BDR) [8], The transmission efficiency (TE) and BDR [9], The received power of each sensor and packet length [10], the network traffic [11], and transmission schedule [12]. Different authors have proposed different IMTs, in the following section we have listed out few which are applicable for the current research.

Authors [13] proposed an Almost Blank Subframe (ABS) algorithm. The proposed algorithm measures the load of network and provides load balancing technique. It has two gateways called as healthy gateway and WBAN gateway. It has a subframe called as a mandatory ABS subframe used for load management. System performance was improved due to load balancing technique.

In this algorithm interference caused by other nearby devices can also be avoided by using ABS gateway. In this Technique Range Extension (RE) index is used to show Range Extension which is an indicator of availability of devices. When more devices enter in the range of WBAN, RE will increase and which will indicate interference.

In [14] authors described a tress based collection protocol (CTP) which is used for interference reduction and performance improvement. In this technique expected transmission (EXT) routing is used and results were presented by changing Packet size and transmission power.

In [15] authors presented a parameter adjustment method for improving reliability of communication in WBAN which suffers high interference. This method includes packet size reduction, bake off time and CCA period reduction. In [16] authors presented a Dynamic channel assignment scheme for interference avoidance named as Dynamic Channel allocation Scheme for Interference Mitigation (DCAIM). In this paper, authors classified area of each WBAN as relay region which was synchronized by relay. In this technique each Regional Group creates a table of Interference Sensors and this will be broadcasted to all nearby sensors. So sensors from Interference sets were allocated orthogonal channels and all other may use same time slot. In this technique time division multiplexing was used.

In [17] authors divided data transmitted by sensors in two types as Primary Users (PU) which are delay sensitive and other as Secondary Users (SU) which are throughput sensitive. All bandwidth was divided for PU and SU. The bandwidth was fairly allocated for critical data. Particle Swarm Optimization (PSO) approach was utilized for transmission power optimization. It was modeled as mathematical model as a Linear Programming Problem (LPP) and PSO was implemented for interference mitigation.

In [18] authors, presented a Smart Channel Assignment (SCA) interference mitigation algorithm. This algorithm considered co-existing WBANs. In these algorithm coordinators of coexisting WBANs offers orthogonal channels for each WBAN. So total channel bandwidth was divided equally into time slots equal to total WBAN numbers and each slot of respective WBAN was further sub divided in to sensor nodes of that WBAN network. After orthogonal channel assignment interference set was formed based on table of received power of each sensor. Then coordinator broadcasts its interference list to form interference set. Nodes with interference were arranged with same time slot as per their previous allocation. Remaining time slots are equally divided into other nodes without interference.

In [19] authors, presented Interference Aware Traffic Priority Based Link Scheduling (ITLS). This is an interference mitigation algorithm used for coexisting WBAN environment. In this algorithm orthogonal transmission was used between all WBANs and total time slots were equally divided into sensors. All WBAN coordinator creates Interference Sensor Group (ISG) and Non Interference sensor Group and initialize a scheduling vector. All sensors are assigned with priority. Along with traffic priority weighted interference of each sensor was calculated.

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ITLS algorithm was executed at coordinator of each WBAN, Contention Value (CV) used to define weight constraints at each time slot. The active sensor with highest CV and priority was selected.

In summary, the purpose of the mitigation schemes is to guarantee that WBANs operate stably even in highly populated and interference-prone situations. These schemes must be suitable equipped with interference detection as well as overcoming techniques to ensure network performance. The interference mitigation technique must be designed or satisfy the needs to be effective. These parameters mainly include system throughput, power consumption, Quality of Service and Reliability. One by one these parameters are discussed below.

A. System throughput

The system throughput is related to the data rate and packet delivery ratio. In general it is understood that the higher system throughput leads to the more reliable communication. It is a fact that the Mobile and high-density WBANs adversely affect bandwidth utilization. Thus, the signal loss may result in a dangerous situation for patients in healthcare applications. Thus reliability in sending vital signals from a human body to the server is critical. *So, a requirement of any mitigation scheme is to maximize system throughput.*

B. Energy Consumption

For a long lifespan for the sensor nodes, energy efficiency or consumption is important. The power capacities of WBAN sensor nodes are limited due to the small size of their batteries. In interference scenarios, the power consumption of a WBAN increases because of contention to access the channel, retransmission, and the idle listening channel. *Thus, interference mitigation algorithms must consider the minimization power in a WBAN as a main objective.*

C. Quality of Service (QoS)

All WBANs have specific QoS requirements for each type of sensor or application. QoS depends on bit error rate (BER) or the nature of transmitted signal (Heart rate). In interference, WBANs with a high QoS constraint should have a high priority to access the channel and low BER.

D. Reliability

Reliability is considered in terms of packet delay and probability of packet loss. It should be as low as possible. The convergence time is a time in which WBANs return to normal operation. For the more effective the interference mitigation scheme; the convergence time must be low to reduce delay

. From above discussion, it is concluded that the best interference mitigation technique will have *maximum system throughput, minimization power, a high QoS or low BER and low convergence time. Considering above discussion, we have considered three parameters to compare performance of Interference mitigation technique viz. throughput, delay and energy consumption.*

In this research, we have used IEEE 802.15.6 MAC protocol which supports dynamic resource allocation based interference mitigation techniques. We found SCA and ITLS are channel allocation methods which have been recently tested for Interference studies. Thus, for practical convenience, we chose to compare these two concurrent methods for mitigation performance for designed WBAN.

III. METHODOLOGY

Following flowchart shows methodology used for the research. In the subsequent section each part is discussed in detail.

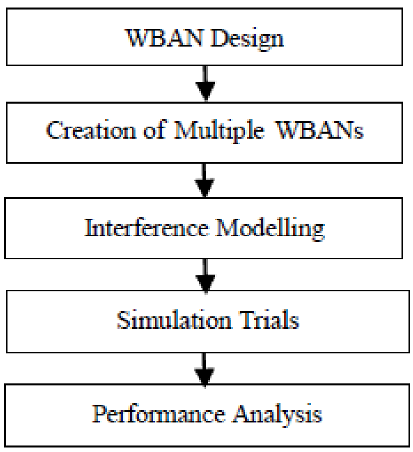


Fig.1 Flowchart for Methodology

A. WBAN Design

The main motivation of this research is to contribute to heart rate monitoring by developing WBAN as per the IEEE 802.15.6 standard. Since, the heart rate and pulse rate are the good indicators of a heart disease, we selected these two sensors. In addition, the third sensor for body temperature monitoring is introduced to the network. Each sensor, thus independently monitors vital signatures and communicates to the central Hub as shown in fig. 2a. A single hop star topology was found suitable and selected for connecting all sensors with the hub. These three sensors nodes will be communicating with a single hub as shown in fig. 2a.

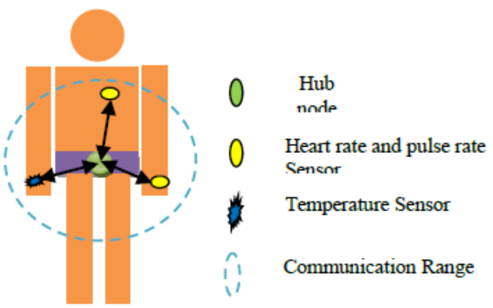


Fig. 2 (a) WBAN network placed on a human body

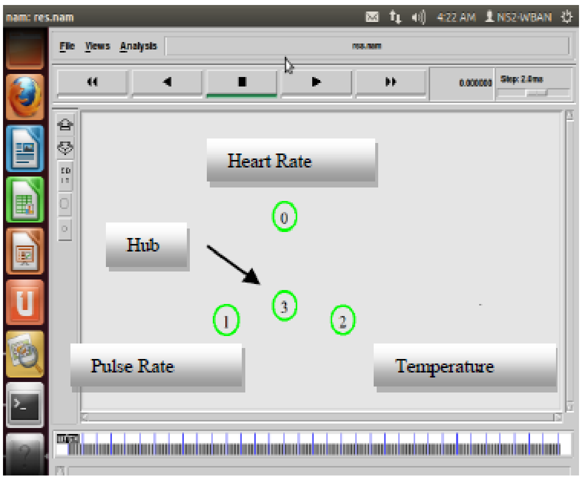
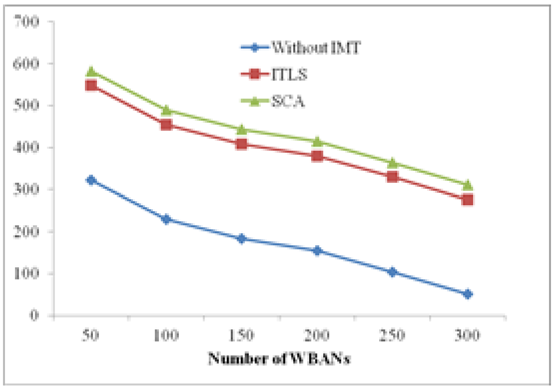


Fig. 2 (b) WBAN in NS2

The node-0 is a heart rate sensor mounted close to heart, node-1 is a pulse rate sensor mounted near to right-hand wrist and node -2 is a temperature sensor mounted on the left hand. A central node 3 represents Hub. Accordingly, the WBAN network is designed in NS2 (simulated environment) as shown in fig. 2b. Accordingly, a program for four nodes is written.

B. Creation of Multiple WBANs and interference Modelling

Since the paper focuses on effect of interference on network performance, thus it was necessary to create an interference environment. The interference environment is created by considering multiple WBANs coexisting at a single place having area of 100 x100 meters. We considered 50 coexisting WBANs initially in the first set of simulation to create interference environment. Each WBAN in the interference environment was similar to the model discussed in WBAN design section. However, every WBAN has different mobility pattern. For example, some WBANs are static where person is standing at a particular place and some are moving with different speeds to replicate walking. To simulate real time crowd environment, we kept on adding 50 WBANs in each trial up to 300 WBANs. This replicates the situation where many WBANs communication ranges overlaps with each other. Thus, we tried to replicate real life situation where 300 WBANs can co-exist; thus we created interference model.



C. Simulation Studies

Network design in NS2 contains a Frontend and Backend structure. The frontend is used to design a WBAN. The designed network contains three nodes and one hub, thus four nodes are created. We used

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MAC 802.15.6 protocol. Following Table I show all simulation parameters. The simulation environment consists of 100 m x100m area. As discussed in previous section, initially 50 WBANs with random mobility scenario were created. Initial energy, transmitter and receiver energy values were maintained as mentioned in the Table I. We conducted the simulation trial for 100 seconds and then analyzed the results by applying the awk script to the output file of the program. We fixed the same data rate for all sensors. To check the network configuration a test run was carried out. The designed network worked successfully and the desired output is obtained which confirmed that all nodes, hub and wireless links are working properly. Simulations are carried out for three parameters viz. throughput, delay, and power consumption.

Table I Network Simulation Parameters

Network Area	1000 x 1000
Type of Network	WBAN
Number of WBAN	50-300
Number of Body Sensors in Each WBAN	3
Velocity	1.5 m/s
MAC	802.15.6
Simulation Time	100 second
Initial Energy	0.5 J
Transmitter energy consumption	16.7 nJ
Receiver energy consumption	36.1 nJ
Interference Mitigation techniques	SCA, ITLS

D. Performance Analysis

Objective of the paper is to evaluate effectiveness of interference mitigation techniques to mitigate or minimize interference. As discussed in section II, the best IMT would improve throughput with less energy consumption and less delay. Thus the first trial run was conducted without any IMT and the results are tabulated for throughput, delay, and power consumption and this data was used to compare with results obtained by trial run by applying SCA, ITLS interference mitigation techniques.

IV. RESULT AND DISCUSSION

In this section, we will discuss network performance under interference environment with and without interference mitigation techniques. The performance parameters are throughput, energy consumption and delay analysis.

A. Throughput Analysis

Following fig. 3 shows throughput analysis and Table 2 shows throughput analysis comparative for different Interference Mitigation Techniques. From fig. 3, it was observed that as we increase number of WBANs, the throughput goes on reducing. We have taken readings by varying number of WBANs from 50 to 300. Due to coexistence of these many numbers of WBANs in particular area, 84% decrease in throughput for AODV protocol was observed. Thus, we can conclude that co-existence of multiple WBANs decreases throughput. However, efforts should be made to improve throughput by applying interference mitigation technique. So, we took reading by applying mitigation techniques and checked whether it has an impact on throughput. When we applied ITLS mitigation technique throughput reduction was improved and it was 49.55% and for SCA throughput was even better and reduction was observed up to 46.66%. With these results, we can conclude that throughput will be better if we use mitigation technique for better performance. In general, SCA has shown marginally better throughput performance than ITLS.

Fig. 3 Effect of increasing number of WBANs on throghput for different Interference Mitigation Techniques

Following table II provides throughput analysis for multiple WBANs in interference environment. It can be seen that throughput is increased considerable with IMT as compared to without IMT. SCA has shown better performance than ITLS.

Table II Through put analysis comparative for different Interference Mitigation Techniques

Number of WBANs	Without IMT	ITLS	SCA
50	322.1	547.66	581.54
100	229.45	455.01	488.89
150	182.92	408.48	442.36
200	154.26	379.82	413.7
250	104.44	330	363.88
300	50.72	276.28	310.16

B. Delay analysis

Following fig.4 shows Delay analysis and Table III shows Delay analysis comparative for different Interference Mitigation Techniques. From fig. 5, it was observed that as we increase number of WBANs the delay goes on increasing. From readings, when no mitigation technique was applied then there was 7.167% increase in delay without IMT. We intended to check effect of applying mitigation techniques. We found improvement in delay due to IMT. When we applied, ITLS mitigation technique, delay was improved to 6.05% and for SCA delay was 6.1%.

With these results, we can conclude that delay goes on increasing as we increase number of WBANS. By applying mitigation technique, delay was reduced and performance was enhanced. ITLS and SCA have similar effect on delay, so no clear distinction can be made between these two techniques. Both techniques can be tested for more number WBANs beyond 300 to get this distinction; which is beyond the scope of this research. From fig. 4 it was observed that there was gradual increase in delay up to 250, whereas sudden increase in delay is observed beyond 250 WBANs

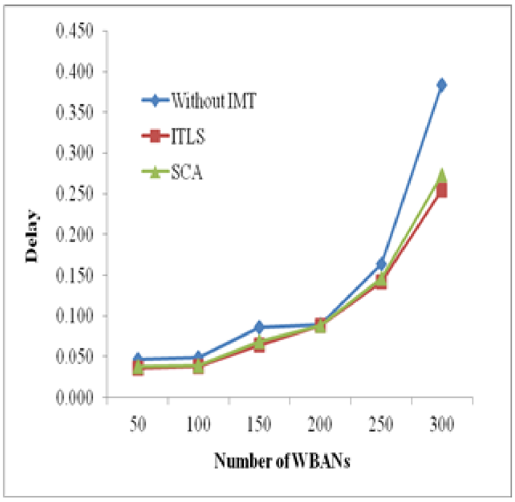

Fig. 4 Effect of increasing number of WBANs on delay for different Interference Mitigation Techniques

Following table III provides delay analysis for multiple WBANs in interference environment. It can be seen that delay is decreased considerably with IMT as compared to without IMT. ITLS has shown marginally better performance than SCA.

Table III Delay analysis comparative for different Interference Mitigation Techniques

Number of WBANs	Without IMT	ITLS	SCA
50	0.047	0.036	0.038
100	0.049	0.038	0.039
150	0.087	0.065	0.068
200	0.089	0.089	0.089
250	0.164	0.142	0.146
300	0.383	0.255	0.273

C. Energy Consumption Analysis

Following fig. 5 shows energy consumption analysis and Table IV shows energy consumption analysis comparative for different Interference Mitigation Techniques.

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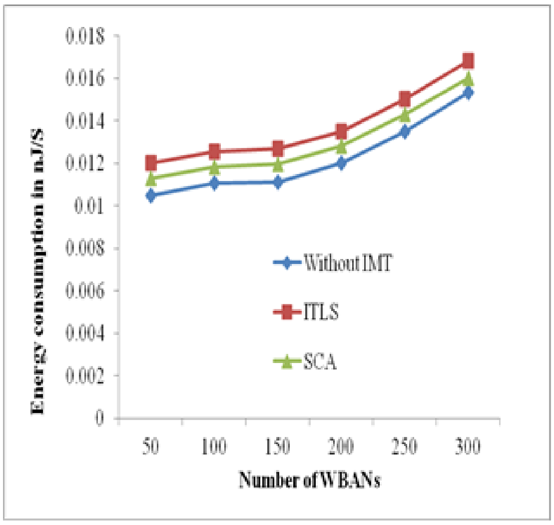

Fig.5 Effect of increasing number of WBANs on energy consumption for different Interference Mitigation Techniques

Initially energy consumption was more in all cases. As WBANs are increased, then it becomes stable. Then gradual increase in energy consumption was observed beyond 200 WBANs. Same trend was observed for all three sets of readings.

From fig. 5, it was observed that with increase number of WBANs the energy consumption was increased. *It is also observed that when no mitigation technique was applied then there is less energy requirements for the network as compared with IMT.* This is understandable, because IMT is an added feature of the network which will require extra energy for its functioning. However, this extra energy requirement is justified because there is more network throughput and lesser delay in the network. Also, it is observed that network required comparatively less power when SCA is used as compared to ITLS. Thus it is recommended to use IMT for better network performance.

Following table IV provides energy consumption analysis for multiple WBANs in interference environment. It can be seen that energy consumption is increased marginally with IMT as compared to without IMT. SCA has shown better performance than ITLS.

Table IV Energy consumption analysis comparative for different Interference Mitigation Techniques

Number of WBANs	Without IMT	ITLS	SCA
50	0.011	0.012	0.011
100	0.011	0.013	0.012
150	0.011	0.013	0.012
200	0.012	0.014	0.013
250	0.014	0.015	0.014
300	0.015	0.017	0.016

V. CONCLUSION

Without Interference Mitigation Technique (IMT), we observed large reduction in the throughput. With the application of IMT, considerable improvement in throughput is observed. Thus, it is concluded that for better network throughput in interference environment use of IMT is recommended. From delay analysis, it is concluded that delay goes on increasing as we increase number of WBANS. With an application of IMT delay was reduced considerably as compared to without IMT. Thus, we can conclude that with mitigation technique delay can be reduced and network performance can be improved.

It is understood that IMT improves throughput and delay however it increases energy consumption of the network. Results have shown that this increase in energy is marginally more with IMT than without IMT. Considering, importance of WBAN for monitoring the patient’s vital parameters, it is essential to have lesser delay, and better throughput. Although, energy consumption is compromised with IMT, it is strongly recommended to use IMT. Comparing SCA and ITLS, we found that both techniques were effective to maintain better throughput, lesser delay, and marginally higher energy consumption. However, difference between these two IMTs is marginal. Thus, we see need of better improved IMT which can have comparatively better results for designed WBAN.

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