International Journal of Computer Networks and Applications (IJCNA)
DOI: 10.22247/ijcna/2021/207982 Volume 8, Issue 1, January – February (2021)

RESEARCH ARTICLE

Design and Analysis of a Reliable, Prioritized and Cognitive Radio-Controlled Telemedicine Network Architecture for Internet of Healthcare Things

Abhinav Adarsh
Electronics and Communication Engineering Department, Motilal Nehru National Institute of Technology Allahabad, Prayagraj, Uttar Pradesh, India
adarsh.abhinav@gmail.com

Shashwat Pathak
Department of Electronics and Communication Engineering, Meerut Institute of Engineering Technology, Meerut, Uttar Pradesh, India
pathak.shashwat@gmail.com

Basant Kumar
Electronics and Communication Engineering Department, Motilal Nehru National Institute of Technology Allahabad, Prayagraj, Uttar Pradesh, India
singhbasant@mnnit.ac.in

Received: 23 December 2020 / Revised: 29 January 2021 / Accepted: 10 February 2021 / Published: 23 February 2021

Abstract – This paper proposes and evaluates a reliable and efficient wireless telemedicine network architecture using cognitive radio network technology for e-Health applications. The proposed architectural framework is designed, to tackle congestion and inconsistency in network availability using the cognitive radio (CR) and to provide priority-based health services to distant primary health care centers. The proposed architectural framework utilizes the (1) dynamic prioritization scheme of the data, based on patient condition (2) prioritization based channel allocation using novel MAC protocol and (3) efficient utilization multiple wireless communication technologies using cognitive radio network. This paper utilizes the Data Sensitive Adaptive MAC (DSA-MAC) protocol for medical data prioritization and transmission at a body area network level (consist of multiple wireless medical sensors implanted on the single patient) of communication. Based on DSA-MAC, a novel MAC layer protocol, Node Sensitive Adaptive MAC (NSA-MAC) protocol is developed to prioritize the different patients based on their medical conditions and assist the prioritization based data transfer. Finally, the proposed architectural framework tackles congestion and inconsistency in network availability by shifting the data transfer process to any of the available networks (GSM, 3G-UMTS, WiMAX and 4G-LTE), with the help of cognitive radio technology.

Index Terms – Wireless Network Application, Internet of Healthcare Things, Cognitive Radio, MAC protocol, E-Health, Rural Health.

1. INTRODUCTION

Different diagnostic devices together with patients, healthcare assistants and expert doctors form a Healthcare Network which is connected through different networks and form an Internet of Healthcare Things for the delivery of telemedicine. Telemedicine can be stated as the delivery of healthcare through a doctor at a distance, digital medical equipment and telecommunications technologies. It covers the diagnosis of a wide range of diseases such as Cardio-vascular [1], Parkinson [2], Alzheimer [3], diabetes [4], post-operation care [5], elderly care [6]]and eye-related conditions [7].

Rural and remote locations lack the presence of advance healthcare system. Telemedicine or e-health is a handy tool to deliver decent healthcare services at these locations. Seventy-five percent, of India's health system, including doctors and other health services, is situated in metropolitan areas, where just 27 percent of country’s population resides, as per United Nations survey [8]. An effective telemedicine system needed to be developed to deal with this uneven distribution of healthcare facilities and patients. In addition, the recent covid 19 pandemic situation is a big motivation for the development of a reliable telemonitoring system, which can be able to provide priority-based guidance to a large number of infected people according to their medical condition. However, the inconsistency of communication networks and fluctuation in bandwidth availability due to lack of infrastructure make it difficult to design and implement an e-healthcare framework. Reliability, efficiency and accuracy of all of the existing telemedicine networks are dependent on the stability and consistency of network connection between patients and doctors. Generally, in a rural or remote location, the presence of network connection is inconsistent and sometimes lacks in bandwidth availability. Thus, a flexible network architecture design for e-healthcare system is required, which can be able to adapt its transmission process according to the condition of communication network strength. With the recent growth in modern wireless communication, a reliable, cost-effective, and easy to install wireless network architecture based on the popular, easy to use, and easily available wireless links of GSM, UMTS (3G), WiMAX and 4G LTE can be developed.

1.1. Research Objective and Brief Description of Proposed Work

The main aim of this article is to present a complete framework of the telemedicine system for remote area, where the presence of the mobile network is a challenging issue. The proposed architectural framework is designed to tackle major issues in creating e- Healthcare or telemedicine system

- Medical data prioritization based on their sensitivity and MAC layer design for body area network for prioritization based channel allocation**.**
- Patient prioritization based on the medical condition and MAC layer design for local area network for prioritization -based channel allocation.
- Congestion and inconsistency in network availability at remote/discrete locations.

The cognitive radio has the capability to sense its surrounding environment for vacant/available spectrum band and modify the transmission parameters (modulation, network protocols routing etc.) accordingly, such that it can communicate data over any vacant/available spectrum band. SDR is the main building block of cognitive radio technology, which is responsible for its automatic functionality. This paper exploits the SDR capability to sense, adapt and transmit over any of the available networks of different communication technologies. The proposed scenario works in four stages. In the first tier, biomedical data from each patient is collected using sensors; data is sent to the central control node and local storage unit using Body Area Network Controller (BANC). Prioritization of sensor node and channel allocation in the first tier is done according to the sensitivity of medical data as defined by Data Sensitive Adaptive Medium Access Control (DSA-MAC) protocol. The second tier consists of a central control node, which is connected to multiple BANCs. Here, prioritization of patient node and channel allocation is done based on proposed node sensitive adaptive medium access control (NSA-MAC) protocol, which is the modification of DSA-MAC. Third-tier is Software Defined Radio (SDR), which is responsible for sensing and selecting the best possible spectrum band for data transmission; it changes the network parameters in accordance with the selected band. This step is very crucial to deal with inconsistency in network availability at rural and remote locations. The fourth tier contains the main hospital, specialist doctor and cloud storage. All sensor devices are connected to the central node at the primary care centre (PCC) via a short-range wireless communication technology and a priority-based channel allocation protocol. PCC is connected to the Base Care Center (BCC) or a doctor through Software Defined Radio using long-range wireless communication networks like GSM, UMTS, WiMAX and 4G LTE. SDR senses and selects the best available network connection for data transmission. Although the presented system has the capability to jump across the different communication technologies for data transmission, there is still a chance that all the networks are down altogether. In that case, there is a local storage unit where data get stored for transmission in the future, when network connectivity with sufficient bandwidth becomes available.

The remaining paper is organized as follows: Section 2 describe the different published research, related to the topic of the paper. Section 3 contains a description of the complete scenario, network architectures and protocol associated with different stages of the proposed telemedicine network. In section 4, simulation parameters related to Medium Access Control (MAC) and simulation results are presented and analyzed. Finally, section 5 provides the overall conclusion.

2. RELATED WORK

Recently, there are many telemedicine /e-health models being presented and adopted all over the world. Some examples in India are the project of Madras Diabetic Research Foundation (MDRF) [9], in collaboration with the World Diabetes Foundation (WDF). The teleophthalmology project being conducted by Sankara Nethralaya [10] Medical Research Foundation at Chennai. Apollo Hospitals Group, in alliance with NIIT Ltd, has started a “Medvarsity” [11]. It is a platform to deliver online medical training and education. It provides a wide range of courses for doctors, nurses, and other paramedical personnel. The recent advances in telemonitoring/telemedicine/eHealth focus on specific health issues. Interactive and video supported elderly veteran care application is presented in reference [12].

Application for treatment of “opioid use disorder” is also presented [13]. Application to provide immediate guidance and care services for allergic symptom in patients in a rural area using telemedicine is presented in reference [14]. More flexible and customized telemedicine scenario development using emerging mobile communication environment [15] and provision of real-time health monitoring [16] are the main challenging tasks for healthcare delivery in the rural areas. Some of the theoretical applications are proposed by the researchers in this field using the recent developments in communication technologies. Development of the Internet of things (IoT) [17] and SmartPhone [18] open new opportunities for e-healthcare. IoT based tele-healthcare architecture is designed by [19], specifically for rural and distant area of developing world and data management system for IoTs based healthcare architectures is presented by [20]. [21] Proposed a teleophthalmology network scenario based on various available wireless links such as GSM, UMTS and WiMAX; it was demonstrated through simulation that WiMAX network could be deployed for low latency applications such as teleconsultation and remote patient follow-up. One of the major limitations of this paper is that the performance of 4g/LTE technology has not been evaluated for the proposed teleophthalmology model. Development of 4G technology has opened a huge scope for the implementation of ICT enabled services in the areas of e-banking, e-governance, eHealth etc. Availability of higher data rate and maximum reach can be utilized in designing newer telemedicine scenarios to provide interactive and good quality healthcare facility.

The idea of 4G network-based wound care model with the help of smart glasses is presented in reference [22]. Video codec for the doctor-patient conference and live telecasting sensors, all based on 4G, is presented by [23]. Scenario using 4G network form-health is presented by Yair E. Rivera [24]. Although 5G is not available all over but some optimistic telemedicine scenario using 5G is presented by the researchers [25] [26]. The main limitation for 5G based network is, it’s shorter range. 5G requires a very dense plantation of server nodes [27]. In addition, high-frequency signal of 5G can travel only in direct line of sight and even small blocks like tree, wall, and rain can cause termination of network connection. In the present scenario, limited presence and access capability of a 5G network to the general population, make it impractical to realize as an application.

The core objective of 4G is to ensure availability of larger bandwidth for data transfer, to lower the latency and to provide packet optimized radio access technique, which can assist the use dynamic bandwidth [28]. Its network architecture is designed to achieve high Quality of Service (QoS) through assisting packet-switched data transfer process in flawless mobility. 4G can provide up to 75 Mbps of data rates in uplink and 300Mbps of data rate in the downlink. In case of, very decent environmental conditions, 300 Mbps of data rate can be achieved with the help of 20 MHz carriers. All 4G units are equipped to work perfectly with Multiple Input Multiple Output transmissions (MIMO) technology, which allows the base station to transmit multiple data streams over the same carrier, simultaneously. Based on a literary survey following problems are identified which are needed to be addressed in the proposed work:

- Most of the network applications lack the flexibility and depend on single communication technology (2G, 3G, WiMAX and 4G etc.) and hence, in case of, failure or unavailability of that specific technology makes the whole system crumble.
- Many of the presented researches are not considering the prioritization of medical data or patients and prioritization based channel allocation scheme. This is critical for telemedicine scenario as it makes sure that during the scarcity of bandwidth, the more critical patients get the access of channel.
- Mobility is another crucial issue that makes the network architecture design difficult for telemedicine application.

3. PROPOSED COGNITIVE RADIO BASED NETWORK ARCHITECTURE FOR PRIORITIZED E-HEALTH SERVICES

A new telemedicine model based on heterogeneous wireless network architecture is proposed utilizing cognitive radio communication. The overall network architecture of the proposed telemedicine scenario is illustrated in Figure 1. In primary care center (PCC) data from the patient is collected through bio-sensors, the data transfer procedure from the sensors is administered by a body area network controller (BANC). The data sensitivity-based body area network protocol has been used by BANC, for channel allocation. Each patient is equipped with multiple biosensors administered by a body area network controller. In order to administer the multiple patients at PCC, there is a central control node. The center node collects data packets from different nearby patient nodes and performs two tasks; firstly, it stores the data to a local storage unit and secondly, according to the priority of node, based on patient condition, it connects the patient node to SDR. After collecting data from different nearby patient nodes through the center node, SDR sends the data to BCC main server.

The function of SDR is to sense and establish a suitable communication link between center node at PCC and BCC main server. The 4G LTE is the latest technology among all the available communication links but there are other alternatives such as UMTS, WiMAX etc. After receiving the data from center node, the BCC main server checks for new case. If there is a new case, it is assigned to an expert/doctor who is free. The assigned doctor examines the data, can demand more data from PCC and generates a report, containing diagnosis results and subsequent prescription. All these data will be sent to the BCC main server. From BCC main server, the data is sent to center node in Primary Care

Center (PCC) as shown in Figure 2. A final report is sent to the respective PCC as well as patient's smartphone. If the patient case is called again, BCC main server recognizes it and forwards the case to the pre-assigned doctor, who has access to the diagnostic information available at BCC main server. This scenario describes a four-stage communication model for remote/rural area

1. A Patient is wearing multiple sensors and Body Area Network Control (BANC).
2. Center control node connected to multiple BANC. Another end of this node is connected to SDR and Local Storage Unit.
3. The third stage contains the SDR, which is responsible for choosing the best available spectrum band and setting the communication parameters accordingly.
4. Finally, the last stage is consisting of the main medical center, specialist doctor and the cloud storage.

The overall working process of the proposed telemedicine network scenario at different tiers is presented in Figure 2.

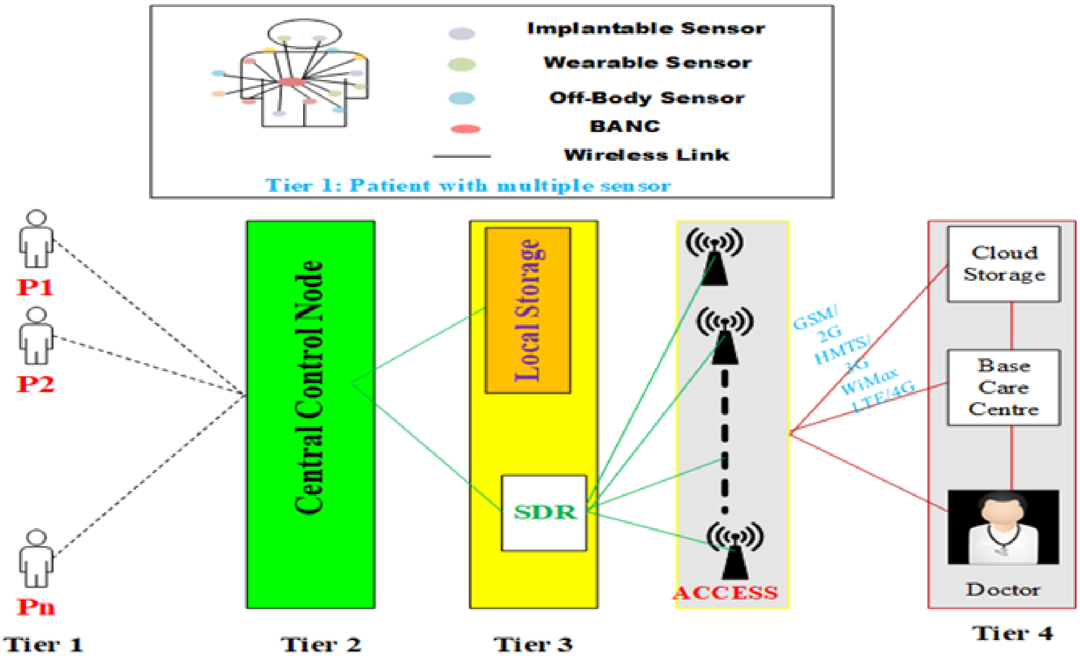

Figure 1 Architecture of Proposed Tele-Monitoring Network

A body area network of multiple bio-sensors contains a patient equipped with multiple wearable, implantable and of-body bio-sensors to gather data from patient's body. There is a primary care-taker available to monitor that all the sensors are placed and working properly. Patient's medical data are transmitted to a center control node kept in each PCC, through short-range communication technologies (ZigBee, Wi-Fi, Bluetooth, etc.). The data transfer process is administered by body area network control (BANC) which utilizes the data sensitive adaptive MAC (DSA-MAC) protocol [29] for data transfer. Medical data are categorized into four groups as per Table 1. DSA-MAC protocol has distinguished feature that it allocates channel basis of priority based on the sensitivity of data from the sensor node, i.e. if the data shows the critical condition, then it gets higher priority and transferred immediately.

At a center control node, Central control node is responsible for data transfer from patient's node to BCC through SDR, according to the priority of patient's conditions. Patients with a greater number of high priority data according to table 1, assigned as a higher priority node. Central control node saves all data, from all the patient to a local storage unit. Patient's personal information along with hosting Primary Care Center (PCC) identity code can be embedded into the medical data for secure, compact, and bandwidth-efficient transmission of medical information. The central control node is wirelessly connected to multiple patient nodes or BANC controller and manages the data transmission over the shared channel. Thus, prioritization based medium access control is needed, such that critical patient gets immediate access to the channel, in case of traffic overload. This paper proposes the use of the node sensitive adaptive MAC protocol (NSA-MAC) at central control node.

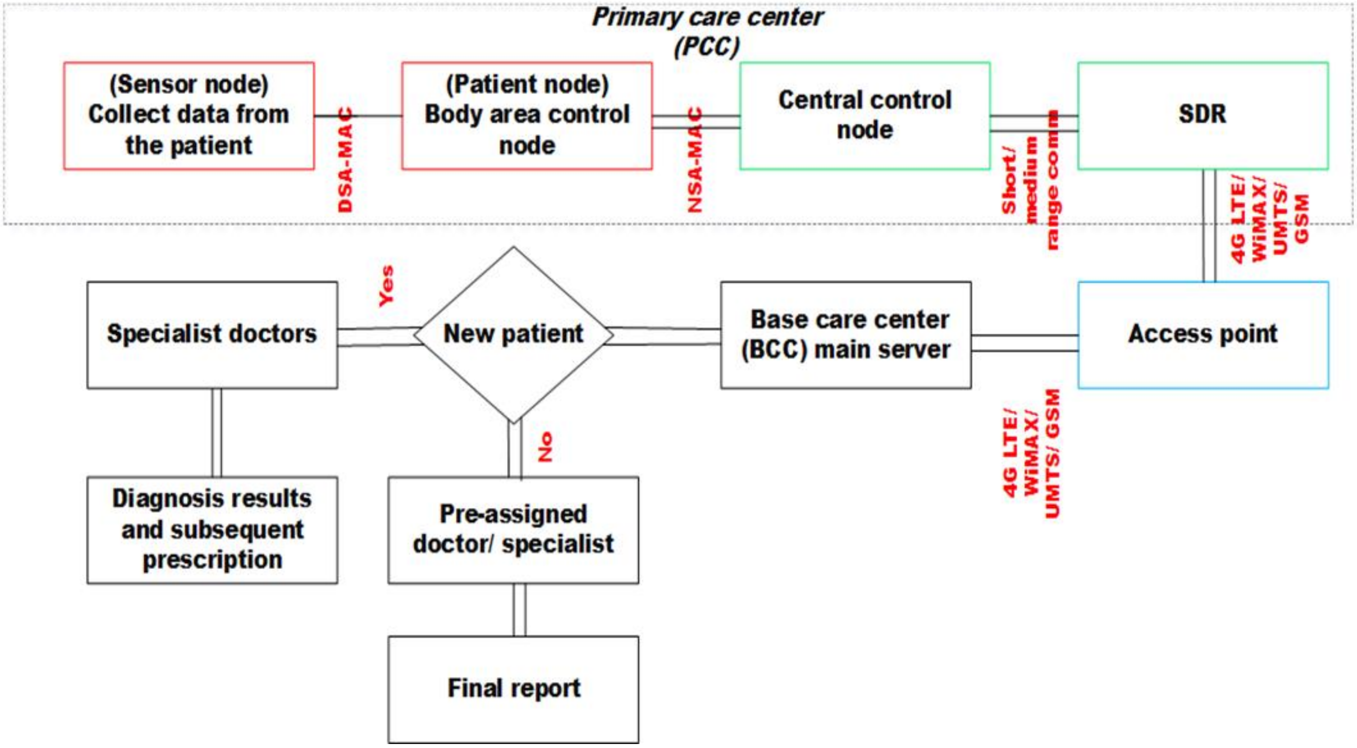

Figure 2 Schematic Workflow Diagram of the Proposed Telemedicine Network Scenario

Data type	Example	Priority level
Life-Threatening Data (Pr1)	Any medical data which fall in the range, that indicates life-threatening situation for the patient	Maximum
Continuous Monitoring Data (Pr2)	EEG, EMG, ECG	2nd
Periodic Routine Data (Pr3)	Air holding capacity of lungs, substances in the blood, blood pressure	3rd
Non-Medical Data (Pr4)	Audio/video conversation, on-demand data like nerve reflection, weight, urine colour etc.	Minimum

Table 1 Different Priority Level of the Medical Data as Per DSA-MAC

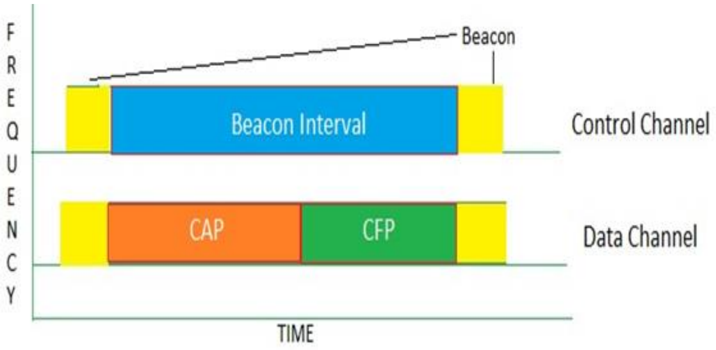

Figure 3 Time Slot and Frequency Band of Two Channels of the Proposed Algorithm

This protocol exploits the four technique to provide medium access control to multiple patient's nodes working together, in the proposed telemedicine system. The main techniques used in this protocol are (1) Node prioritization (2) Dual channel implementation (3) Dynamic slot length determination and (4) Dynamin slot allocation to the sensor node according to their priority.

Figure 3 depicts the time and frequency division of two channels. Control channel is reserved for the communication of control-data, like a request for channel allotment by sensors and confirmation of channel allocation by BANC. Nodes switched from the control channel (cc) to the data channel (dc) after the control signal is exchanged between the sensors and the controller. The switching of the channel is done during the beacon period.

3.1. Patient Node Prioritization

The priority of patient's node is set on the basis of two factors; firstly, the level of maximum priority of data that has to be communicated and secondly, the volume of the utmost priority data. First part depends on maximum sensitivity of the data (according to Table 1) needed to be communicated by any of the sensors attached to the patient. Whereas, the second part depends on the total number of sensors possessing the highest priority data for transmission. The prioritization can be done through Algorithm 1.

Step 1: Form a "Group 1" of the nodes, which has at least one data packet with the highest priority level.

Step 2: Form a "Group 2" of the nodes, which is not the part of Group 1 and has at least one data packet with the 2nd highest priority level.

Step 3: Form a "Group 3" of the nodes, which is not the part of Group 1 as well as Group 2, and has at least one data packet with the 3rd highest priority level.

Step 4: Form a "Group 4" of the nodes, which is not the part of Group 1, Group 2, or Group3 i.e. rest of the nodes left.

Step 5: Arrange the nodes inside all the groups, according to number of maximum priority data packets they have.

Step 6: Finally set the priority for all the nodes in the following manner:

Highest Priority (P1):	Nodes from Group 1
2nd priority (P2):	Nodes from Group 2
3rd Priority (P3):	Nodes from Group 3
Last priority (P4):	Nodes form Group 4

Algorithm 1: Prioritization of Patients Nodes

Dynamic sub-period determination and allocation by central control node: - The superframe design of proposed node sensitive adaptive Medium Access Control (NSA-MAC) protocol is shown in Figure 4.

Based on the patient's condition, the node (BANC node/Patient node) priority has been set. Based on the node's priority, a number of sub-periods of dynamic length are allotted to patient's node, to access the channel. In order to minimize the wastage of time slots; each sub-period is given a variable-length instead of constant length, which is determined by phase partition portion of Contention-based MAC Protocol algorithm running at the central control node. This algorithm is implemented only for contention access period (CAP) duration, not during the contention-free period (CFP). BANC node of priority order P1 is allowed to access the channel in all the sub-periods; the BANC of priority order P2 can access the sub-period two to four, whereas, BANC node assigned to priority order P3, is permitted to use sub-periods three and four. The node of priority level P4 can transmit during the sub-period four only. The dynamic determination of the length of the sub-period is done by equation (1) [30].

$$L_i = \sum_{k=0}^{i-1} L_k + l_{cap} * (N_i / N_t) \qquad (1)$$

Where L_i is the length of ith sub-period, N_i is the number of nodes with an ith priority level, N_t is the total number of nodes and value of L_0 is taken as 0.

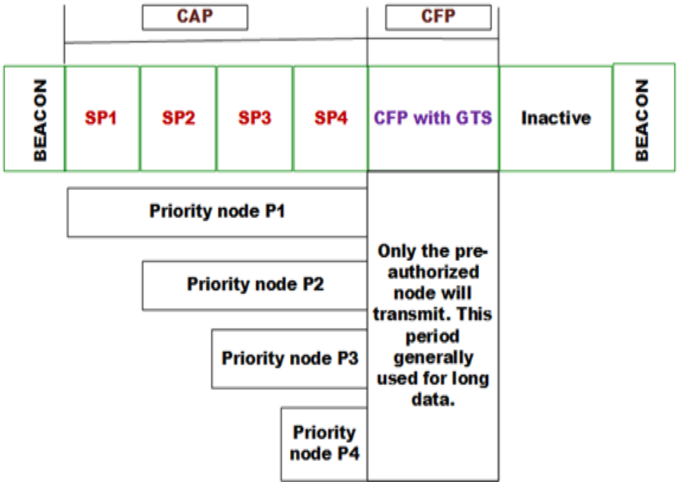

Figure 4 Dynamic Time Slot Partition of the Superframe Structure of the Proposed NSA-MAC for Control Node

For the CAP duration, all the BANC node can transmit their data packets in their corresponding sub-period, implementing the CSMA/CA protocol. For the CFP duration, only pre-authorized BANC nodes can transmit their data, using the pre-allocated guaranteed-time slots (GTS). During GTS, only pre-authorized nodes transmit using the allotted band, and there is no interference from any other node in the PCC.

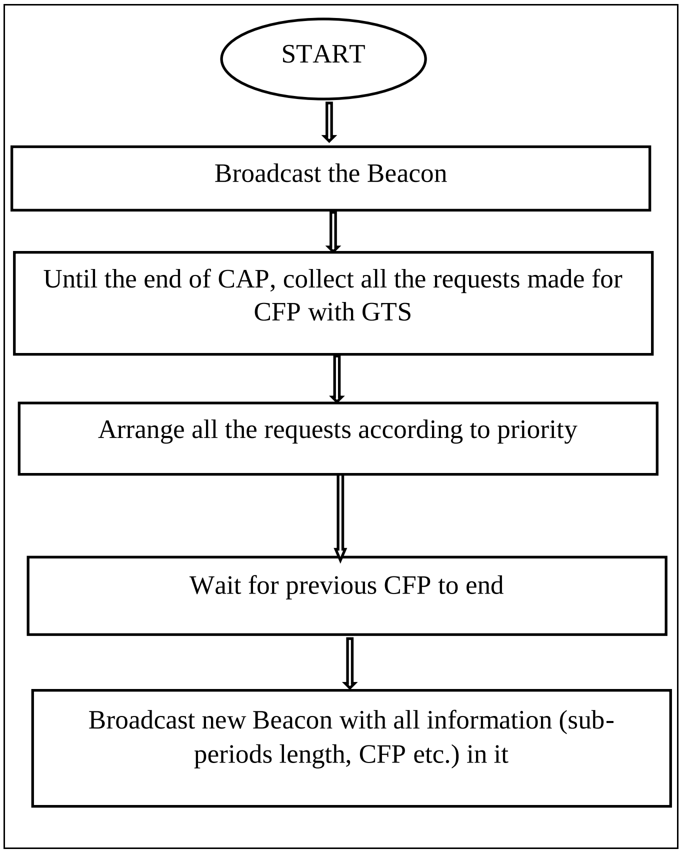

Figure 5 Flow Diagram of Working of the Central Controller

For transmitting data during the CFP, the concerned node transmits the request signals during CAP, to the central control node (PCC controller), to get an allocation of CFP; carrier sensed collision avoidance (CSMA/CA) MAC protocol is utilized in this process. Once the entire request signal is successfully transported to a central controller, it assigns the GTS to the patient's nodes, according to the given priority. During CAP, all nodes fight for the channel for data transmission using CSMA/CA, during the different number of sub-periods, according to their priority levels. After accessing the channel, all the small size data are transferred instantly. For large data, request for allocation of GTS slot during CAP is sent to central controller using the control channel. Generally, the BANC nodes having priority level P1 and P3, contain smaller data size and nodes associated with priority level P2 and P4 have big size data. In Figure 5 and Figure 6, the workflow diagram at the controller end and node end, are shown respectively.

3.2. Software Defined Radio Functionality

SDR sends the patient data over a wireless link to the main server at base hospital (BH) or base care center (BCC). Suitable communication links can be established between a center node at a PCC and a BH for providing reliable, appropriate bandwidth connectivity. Various communication network options such as GSM, UMTS (3G), WiMAX and 4G LTE are available.

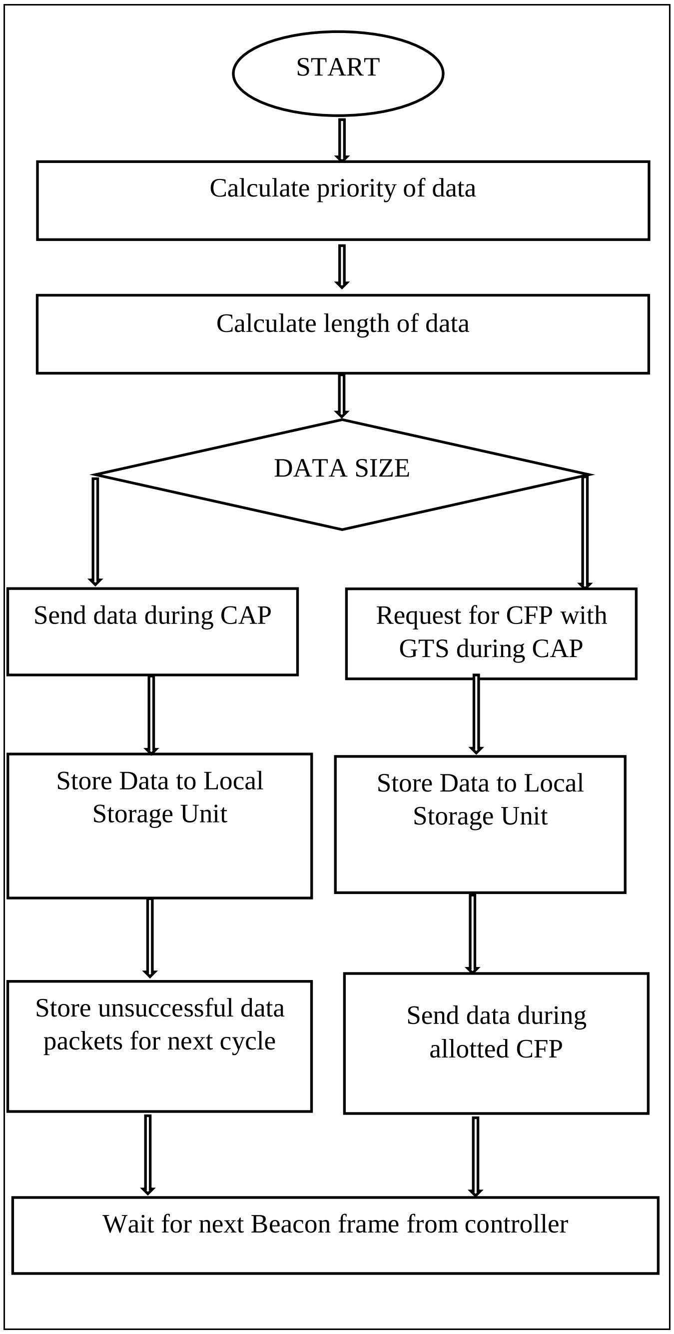

Figure 6 Flow Diagram at Patient's Node (BANC) End

Main work of SDR is to check the availability of the network and modify the transmission parameters (signal modulation, channel coding, protocols etc.) according to available network and transmit the data over it. The SDR keeps on sensing for the availability of different networks so that in case one of the networks is disconnected or overloaded. Then it will jump to the next best available network. There is a need to evaluate and compare the performance of each type of network considering the proposed scenario.

The BCC main server, located in the hospital, receives medical data from various PCCs. The server hosts the software platform and keeps the record of patient's ID, PCC ID and patient's personal information. The server generates an alert message regarding receipt of diagnostic data and forwards it to an expert/doctor. This software platform enables the doctor to record his opinion regarding diagnosis with the particular patient's data. Doctors examine the medical data and can also further access the historical data of the patient, which is stored at a local storage unit and cloud storage. After examining the data, expert/doctor generates a report containing diagnostic results.

Along with a report, a prescription is also generated. All these generated data, report and subsequent prescription are sent to BCC main server. From BCC main server, the data is sent over to center node in Primary Care Center (PCC). A final report is sent to the respective PCC as well as patient's smartphone. If the same case is registered again, the server forwards it to a pre-assigned expert/doctor, who has access to the relevant diagnostic information available at BCC main server.

In the second telemedicine scheme, patients do not need to be monitored regularly. Still, they need to update their medical data at regular interval of time, and they do not require to visit the nearby Primary Care Center (PCC). Here, patients need to send their captured medical data to BCC main server through a mobile app. For that, they need to register over a mobile hosting application (App). This scenario is beneficial in post-operative healing and wound care model. The rest of the process follows the same path as mentioned in the above scenario. The BCC main server communicates with the medical experts for a final opinion. In this scenario, medical experts may be static or mobile. The proposed telemedicine model adds a lot of flexibility if it considers true mobility of the medical expert. This gives liberty to medical experts to analyze and generate medical reports even when they are travelling. Incorporating this kind of flexibility in the model requires reliable, low delay, bandwidth-efficient mobile networks. GSM, UMTS (3G), WiMAX and 4G LTE are some of the possible communication standards that can fulfil the desired requirements. This work evaluates the performance of GSM, UMTS (3G), WiMAX and 4G LTE networks for medical data transmission between the BCC main server and distant medical expert.

4. RESULTS ANALYSIS AND DISCUSSIONS

The simulation results of the proposed telemedicine scenario are presented in two parts. First part presents the performance evaluation of the proposed new node sensitivity (patient condition) based adaptive MAC (NSA-MAC) protocol, used by central control node to monitor the data coming from multiple patients at Primary care center (PCC). The performance of NSA-MAC is compared against the traditional standard IEEE 802.15.4. In the second part of this section, the link between PCC and BCC is considered, where patients to doctor communication link using large distance communication technologies like GSM, UMTS(3G), WiMAX and 4G LTE is analyzed.

4.1. NSA-MAC VS Standard IEEE 802.15.4. at Central Control Node of PCC

NS-3 Network Simulator, version 3.28, installed on operating system UBUNTU 14.20 version for assessing the performance of the proposed NSA-MAC protocol. Multiple groups of data packets are used to perform the simulation. All the parameters related to physical layers used for simulation are fixed as per IEEE 802.15.4. Standard protocol. Supposing that all patients BANC nodes are inside the range of fifty meters from the central control node stationed in the PCC building. The star network topology is the best fit for the given scenario. Thus, star topology is created for the simulation to evaluate the MAC layer protocol performance. All the patient's nodes are positioned in a random way in the circular plane of 50m radius with central control node stationed at the center, and the data is transmitted by each patients-node or BANC to the SDR through central control node. The data packets of emergency and normal medical data are equal in size. Value of network parameters defined for simulation is given in Table 2.

Simulation Parameter	Value
Channel Bandwidth	250 kbps
Frequency	2.4 GHz
Bit duration	16 µs
Superframe length	122.80 ms
Transition time	191 µs
Unit Back-off Period	20 sym
Maximum CSMA Backoffs	5
Minimum BE	3
Maximum BE	5

Table 2 Value Assigned to Different Network Parameters for Simulation of NSA-MAC

Comparison between the standard IEEE 802.15.4 and the proposed NSA-MAC protocol is made with respect to average transmission time, emergency traffic transmission time and the network throughput. Figure 7 shows the average transmission time for a data packet while a different number of nodes are present in the network.

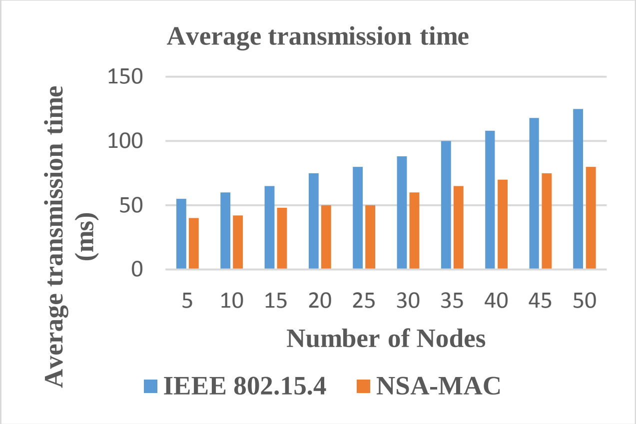

Figure 7 Average Transmission Time

The NSA-MAC protocol accomplishes improvement over the IEEE 802.15.4 since the average transmission time for NSA-MAC is smaller for transmitting the same number of data packets. In addition, the performance of NSA-MAC increases with an increase in the number of patients nodes. The relative performance of NSA-MAC against the IEEE 802.15.4 advances with the rise in the number of patient's nodes, by virtue of priority based dynamic access. When a large number of nodes try to transmit data simultaneously, using a shared channel; then a higher number of collisions between the data packet takes place, and as a result, a massive number of retransmission of data packets produces additional collisions. This is the reason for a big increase in average transmission time in IEEE 802.15.4 MAC protocol with a small increase in the number of nodes. On the contrary, in the NSA-MAC protocol, the duration of CAP differs for the nodes with different priorities, as shown in Figure 4. This process reduces the number of nodes competing for data transmission over a shared channel simultaneously; as a result, lower number of collisions occur, and lower number of retransmissions of data packets are required.

Figure 8 shows the relative average transmission time, taken by the highest priority data packets for the protocols. The highest priority medical data packets are smaller in size (as per DSA-MAC). The transmission time for these packets is almost the duration of the time that a patient's node has to spend to get access to the channel for transmission of the highest priority medical data packets.

Throughputs corresponding to both protocols for a different number of patient's nodes has been shown in Figure 9. Throughputs corresponding to both the protocols are approximately equal when the number of patient's nodes in the network is less than 10. Initially, throughputs increase with the increase in the number of nodes in the network due to an increase in inefficient utilization of total bandwidth. The throughput decreases as the high number of nodes added to the network; this is due to large contention density and therefore, a high packet collision rate.

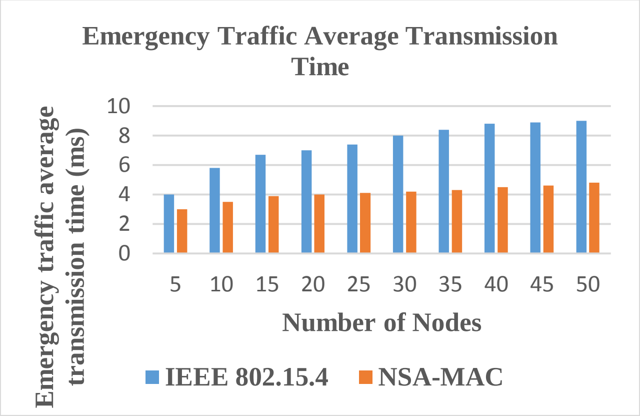

Figure 8 Average Transmission Time for Highest Priority Data

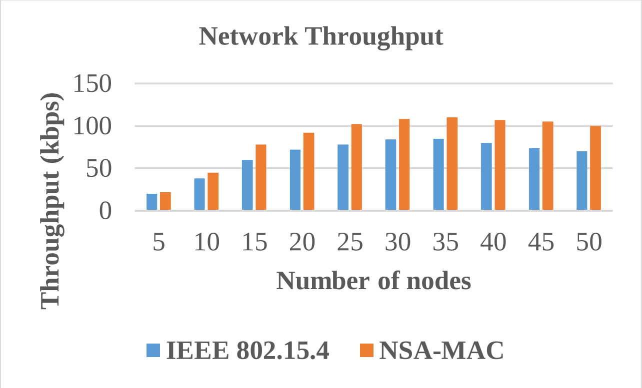

Figure 9 Throughput Corresponding to Protocols under Consideration

4.2. Performance of SDR FOR Different Wireless Technologies (GSM, UMTS(3G), WIMAX and 4G LTE)

Parameter	Value
Number of patient nodes	100
Number of center nodes	8
number of doctor nodes	2
data packets size	512 kb to 2 Mb

Table 3 Simulation Parameters used for Communication between SDR and BCC Main Server

The proposed telemedicine scenario is simulated using Network Simulator (NS 3.26). A BCC campus, an area of 1,000 square meters, is connected to 8 PCC center nodes.

Each PCC center nodes acquire medical data from five patient nodes through a ZigBee network. Medical data required for diagnosis are assumed to have data packets sizes of 512 Kb to 2 Mb. The maximum permissible end-to-end delay for real-time transmission is less than 350 ms. For store-and-forward schemes, it is something lower than 1s. The simulation parameters used, for performance evaluation of data transmission between SDR and main server of base care center are mentioned in Table 3.

4.2.1. Performance Analysis of Various Wireless Network Links between PCC and Static BCC

Performance of GSM, UMTS (3G), WiMAX and 4G LTE based network connection between the PCC and BCC is evaluated by considering network parameters such as throughput, average end-to-end delay, and average jitter.

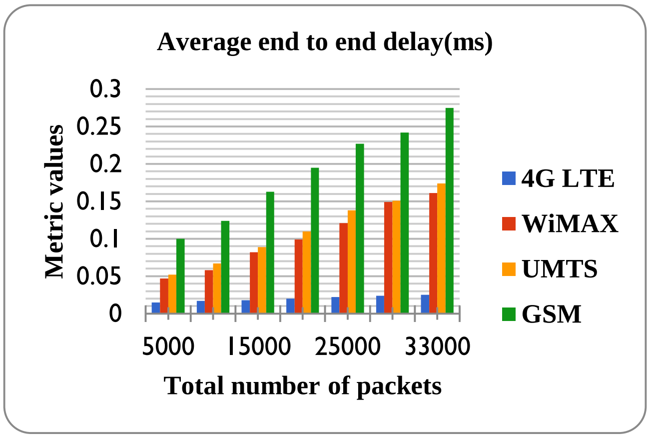

Figure 10 Average End to End Delay (ms) between Nodes and BEH Main Server with Varying Number of Packets

Figure 10 shows that average end-to-end delay between patient nodes and the BCC main server using wireless networks by varying the total number of packets in the range of 5000–33,000. 4G LTE gives the lesser end-to-end delay, when compared to GSM, UMTS (3G) and WiMAX. Another observation is that change in delay with respect total no of packets is almost constant for 4G LTE. Performance of GSM is worst among the considered wireless networks both in terms of total delay and consistency in delay. Although WiMAX and 3G produce an equal end to end delay for 3000 packets, but WiMAX have a little edge over 3G.

Figure 11 shows that average jitter between patient nodes and the BCC main server for the considered wireless networks by varying the total number of packets in the range of 5000–33,000. Here, average jitter increases with the increase in the load in all considered networks, because increased load causes more contention in the Transmission Control Protocol/ Internet Protocol (TCP/IP) network as different packets follow different paths, to arrive at the destination. In the GSM network, between patient nodes and the BCC main server, average jitter observed is much more than that of the 4G LTE network.

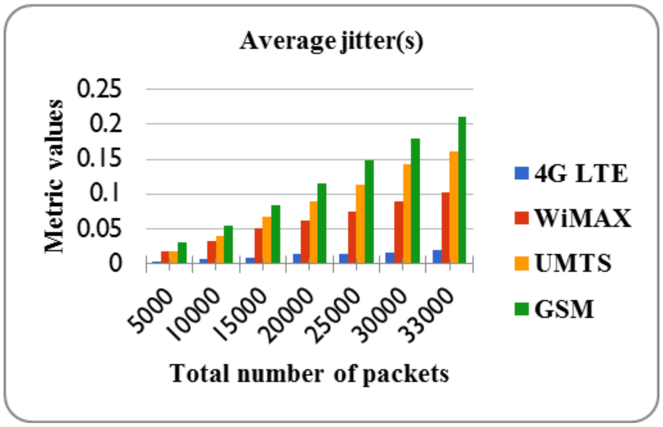

Figure 11 Average Jitter (s) between Nodes and BEH Main Server with Varying Number of Packets

Throughput at the BCC main server is calculated between patient nodes and the BCC main server and is shown in Figure 12. It is found that the 4G LTE network has the highest throughput, followed by WiMAX, UMTS (3G) and GSM. Also, the throughput almost remains constant with the variation in the number of packets.

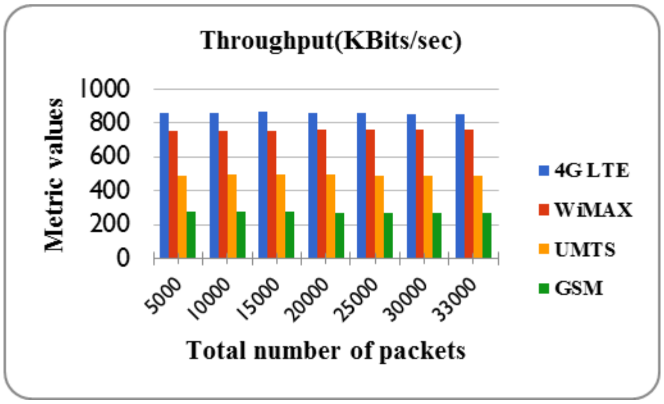

Figure 12 Throughput (kb/s) between Nodes and BEH Main Server Varying Number of Packets

4.2.2. Performance Analysis of Wireless Network Links between the BCC and Doctor in the Mobile Environment

In this simulation, patient nodes are connected to the center nodes through Zigbee network. These PCC nodes are linked to the BCC main server via one of the networks among the considered GSM, UMTS (3G), WiMAX and 4G LTE links (through SDR). Figure 13 shows that average end-to-end delay between the main server and doctor. Transmission through GSM fails at the speed of 20 Kmph, as the end-to-end delay parameter exceeds the threshold.It is also observed that the UMTS (3G) network fails to perform in considered simulation environment when the speed of doctor exceeds 150 Kmph. WiMAX can deliver packets successfully at speeds beyond 160 KPH. It is also estimated through simulation that WiMAX performs well, even up to the speed of 300 Kmph. Whereas, 4G LTE can perform well even at speed beyond 300 Kmph. Figure 14 shows that 4G LTE experiences the lowest jitter, followed by WiMAX, at the same time, it is also observed that the jitters are almost constant beyond the mobility speed of around 50 Kmph. In a GSM network, observed average jitter is much more than that of the 4G LTE network. Therefore, medical data packets in a GSM network suffer severe delay with the increase in mobility.

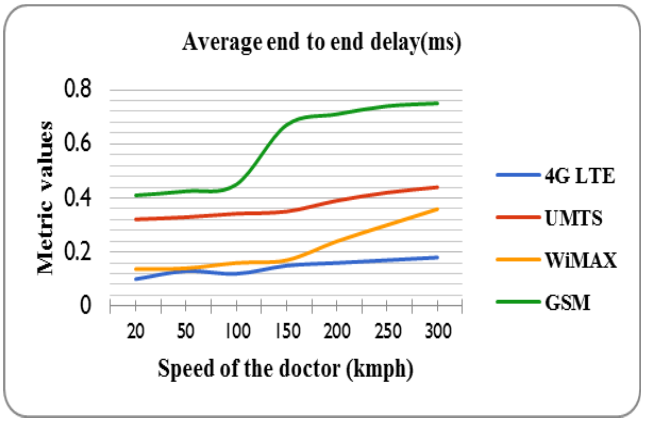

Figure 13 Average End to End Delay (ms) between the BEH Main Server and Doctor (While the Doctor is Moving)

Figure 15 shows that 4G LTE offers far better throughput in the network between the main server and doctor, as compared to GSM, UMTS (3G) and WiMAX networks. It is also observed that throughput decreases slightly with the increase in mobility speed of doctor, for all considered networks. WiMAX and UMTS (3G) show moderate throughput followed by GSM.

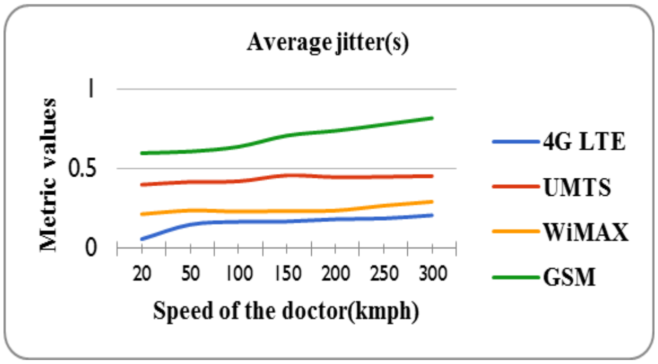

Figure 14 Average Jitter (s) between the BEH Main Server and Doctor (When Doctor is Moving)

Therefore, the observed simulation results clearly confirm that the 4G LTE is the preferred network for high bit-rate applications, even in high mobility scenarios. Finally, the results obtained suggest that average end-to-end delay is the most critical performance parameter in the proposed telemedicine scenario and it decides the load capacity of central node at PCC and maximum mobility speed of the doctor for GSM, UMTS (3G), WiMAX and 4G LTE networks considered in this work.

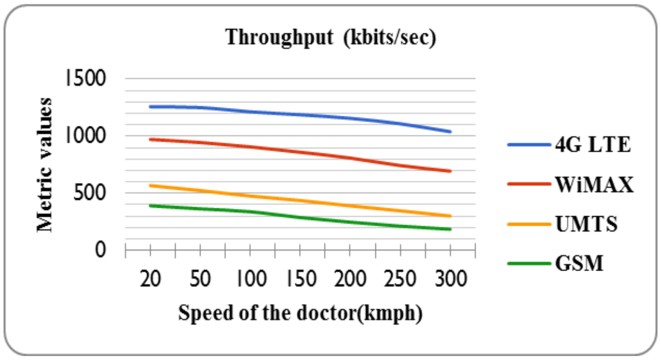

Figure 15 Throughput (kb/s) between the BEH Main Server and Doctor (While the Doctor is Moving)

4.3. Discussion

In the previous sub-sections, results for different layers of proposed telemedicine architecture have been presented and analyzed. The proposed four-tier architecture assists the medical data transfer from sensor nodes to the specialist doctor on a priority basis. From technical point of view, the four critical nodes could be defined as sensor nodes, Body Area Control Node (BANC), Central Control node (at Primary Care Center) and Base Hospital or Specialist Doctor.

Number of node	Avg. Transmission Time (ms) for Data packets	Avg. Transmission Time (ms) for Critical Data packets	Throughput (Kbps)
10	42	3.5	46
20	50	4.0	92
30	61	4.2	108
40	73	4.5	107
50	82	4.8	99

Table 4 Performance Major of Proposed NSA-MAC

The proposed framework utilizes the Data Sensitive Adaptive MAC protocol to assist the priority-based data transfer between the sensor node and BANC. In order to assist the communication between serval BANCs and central control node, a Node Sensitive Adaptive MAC protocol is proposed, and its efficiency is analyzed in term of average transmission time for data packets, the average transmission time of critical data packets, and throughput with respect different number of nodes. The overall performance of the proposed NSA-MAC scheme is listed in Table 4.

Again, in order to assist the communication between multiple central control nodes placed at the base care center and base hospital main server or the specialist doctor cognitive radio based solution has been prosed and analyzed. The introduction of cognitive radio not only improves bandwidth efficiency but also increases the reliability of the system. Here, two scenarios have been taken into account. In the first case, there are multiple base or primary care center monitored and guided by the base care center. In the second scenario, patient is directly involved with doctor and doctor may be static or mobile with different velocities. The evaluation of the performance of different long-distance communication technology for both scenarios is done in term of end-to-end delay, jitter and throughput. Although the 4G-LTE technology is superior to other available technologies but in case of congestion or connection failure, the cognitive radio technology allows the data transfer process to shift to another working network. This increases the reliability of the system. For real-time medical application, end-to-end delay, which represents the latency of the network, is a very critical parameter. It can be concluded from the result analysis that for real-time application 4G by far is the best choice for real-time application, but WiMAX and 3G technologies can be a temporary substitute.

5. CONCLUSION

An implementation model for enabling Internet of Healthcare Things leading to a flexible telemedicine solution for providing primary and secondary care services in rural and remote areas was proposed and evaluated in the presented research work. The proposed heterogeneous telemedicine network scenario can potentially be implemented for remote diagnosis, monitoring, and follow-up for patients having different health issues (common as well as specialized). Proposed network architecture consisted of a heterogeneous wireless network controlled by cognitive radio. This architecture was supported by reliable, agile and medical-prioritization based MAC protocols (DSA-MAC and NSA-MAC) at PCC and SDR supported GSM/UMTS (3G)/WiMAX/4G LTE links. On the basis of the obtained simulation results, it is concluded that 4G LTE network can be effectively used as preferred network for low latency applications such as image transfer and high-quality video teleconferencing applications (such as teleconsultation and patient follow-up also real-time patient follow-ups). LTE has been able to deliver a high data rate of 1.2 Mbps in the practical scenario where relative speed between doctor and primary care center (PCC)/ patient is 150km/hour. All LTE units are equipped to work perfectly with Multiple Input Multiple Output transmissions (MIMO), which allow the base station to send multiple data streams simultaneously, using the same carrier. Alternatively, a WiMAX link can also be considered for deployment by SDR in the proposed scenario for the mobility speed of less than 300 kmph (for the mobile doctor). The performance of the proposed network scenario can be improved further by incorporating the latest 5G along with other available wireless technologies. Wideband technology possesses more bandwidth than ZigBee; it also suffers less interference in short-range applications. Therefore, another improvement can be done at PCC level by replacing traditional sort range communication networks (ZigBee, Bluetooth, Wi-Fi, etc.) with emerging Ultra-Wide Band (UWB) and Short-Range Devices (SRD) technologies.

REFERENCES

[1] J. Fontecave-Jallon, P.-Y. Guméry, P. Calabrese, R. Briot and P. Baconnier, 2013. "A Wearable Technology Revisited for Cardio-Respiratory Functional Exploration," International Journal of E-Health and Medical Communications, vol. 4, no. 1, pp. 12-22.

[2] M. A. Lones, J. E. Alty, J. Cosgrove, P. Duggan-Carter, S. Jamieson, R. F. Naylor, A. J. Turner and S. L. Smith, 2017. "A New Evolutionary Algorithm-Based Home Monitoring Device for Parkinson's Dyskinesia," Journal of Medical Systems, vol. 41, no. 11, pp 1-8.

[3] Costanzo, M. C., Arcidiacono, C., Rodolico, A., Panebianco, M., Aguglia, E., & Signorelli, M. S. (2020). Diagnostic and interventional implications of telemedicine in Alzheimer's disease and mild cognitive impairment: a literature review. International journal of geriatric psychiatry, 35(1), 12-28.

[4] H. Mushcab, W. G. Kernohan, J. Wallace, R. Harper and S. Martin, "Self-Management of Diabetes Mellitus with Remote Monitoring, 2017." International Journal of E-Health and Medical Communications, vol. 8, no. 1, pp. 52-61.

[5] Moghimi, H., Schaffer, J. L., & Wickramasinghe, N. (2016). Intelligent home risk-based monitoring solutions enable post acute care surveillance. In Contemporary Consumer Health Informatics (pp. 399-412). Springer, Cham.

[6] Tuna, Gurkan, Resul Das, and Ayse Tuna. 2015. "Wireless sensor network-based health monitoring system for the elderly and disabled." International Journal of Computer Networks and Applications (IJCNA) 2, no. 6 pp: 247-25.

[7] S. Kumar, A. Adarsh, B. Kumar and K. A. Singh, 2020. "An automated early diabetic retinopathy detection through improved blood vessel and optic disc segmentation," Optics & Laser Technology, vol. 121, p. 105815.

[8] Dasgupta, P. (2013). The shameful frailty of the rural healthcare system in India. Future Challenges, 2.

[9] Prathiba, V., & Rema, M. (2011). Teleophthalmology: a model for eye care delivery in rural and underserved areas of India. International journal of family medicine, 2011.

[10] S. John, S. Sengupta, S. J. Reddy, P. Prabhu, K. Kirubanandan and S. S. Badrinath, 2012. "The Sankara Nethralaya Mobile Teleophthalmology Model for Comprehensive Eye Care Delivery in Rural India," Telemedicine and e-Health, vol. 18, no. 5, pp. 382-387.

[11] Apollo-hospital. [Online]. Available: https://www.medvarsity.com/.

[12] S. V. Adams, M. J. Mader, M. J. Bollinger, E. S. Wong, T. J. Hudson and A. J. Littman, 2019. "Utilization of Interactive Clinical Video Telemedicine by Rural and Urban Veterans in the Veterans Health Administration Health Care System," The Journal of Rural Health, vol. 35, no. 3, pp. 308-318.

[13] R. Rubin, 2019. "Using Telemedicine to Treat Opioid Use Disorder in Rural Areas," Jama, vol. 322, no. 11, p. 1029.

[14] L. Taylor, M. Waller and J. M. Portnoy, 2019. "Telemedicine for Allergy Services to Rural Communities," The Journal of Allergy and Clinical Immunology: In Practice, vol. 7, no. 8, pp. 2554-2559.

[15] M. Batistatos, G. Tsoulos and G. Athanasiadou, 2012. "Mobile telemedicine for moving vehicle scenarios: Wireless technology options and challenges," Journal of Network and Computer Applications, vol. 35, no. 3, pp. 1140-1150.

[16] P. Najera, J. Lopez and R. Roman, 2011. "Real-time location and inpatient care systems based on passive RFID," Journal of Network and Computer Applications , vol. 34, no. 3, pp. 980-989.

[17] Magesh, S., Indumathi, J., Nadu, T., & Prabha, P. S. (2020). Concepts and Contributions of Edge Computing in Internet of Things (IoT): A Survey. Int. J. Comput. Netw. Appl, 7 (5), 146-156.

[18] C. Chakraborty, 2019."Performance Analysis of Compression Techniques for Chronic Wound Image Transmission Under Smartphone-Enabled Tele-Wound Network," International Journal of E-Health and Medical Communications, vol. 10, no. 2, pp. 1-20.

[19] Bagula, A.; Mandava, M.; Bagula, H.; 2018. "A framework for healthcare support in the rural and low income areas of the developing world," Journal of Network and Computer Applications, vol. 120, pp. 17-29.

[20] Y. Yangab, X. Zhenga and C. Tangb, 2017. "Lightweight distributed secure data management system for health internet of things," Journal of Network and Computer Applications, vol. 89, pp. 26-37.

[21] S. Pathak and B. Kumar, 2017. "Wireless Teleophthalmology: A Novel, Low-Cost, Flexible Network Architecture and Its Performance Evaluation for Remote Eye Care Solutions," telemedicine and e-Health, vol. 23, no. 9, pp. 753-762.

[22] J. Ye, Y. Zuo, T. Xie, M. Wu, P. Ni, Y. Kang, X. Yu, X. Sun, Y. Huang and S. Lu, 2016. "A telemedicine wound care model using 4G with smart phones or smart glasses," Medicine, vol. 96, no. 31, e4198.

[23] S. M. S. A. Majeed, S. K. Askar and M. Fleury, 2014. "H.265 Codec over 4G Networks for Telemedicine System Application," 2014 UKSim-AMSS 16th International Conference on Computer Modelling and Simulation.

[24] Rivera-Julio, Y.E., 2016, September. Design of a Telemedicine Ubiquitous Architecture Based on the Smart Device mHealth Arduino 4G. In Workshop on Engineering Applications Springer, Cham. Vol 657 pp. 345-356.

[25] W. D. D. Mattos and P. R. Gondim, 2016. "M-Health Solutions Using 5G Networks and M2M Communications," IT Professional, vol. 18, no. 3, pp. 24-29.

[26] Sodhro, A. H., & Shah, M. A. (2017, April). Role of 5G in medical health. In 2017 International Conference on Innovations in Electrical Engineering and Computational Technologies (ICIEECT) (pp. 1-5). IEEE.

[27] Sharma, Vishal, Kathiravan Srinivasan, Han-Chieh Chao, Kai-Lung Hua, and Wen-Huang Cheng. 2017. "Intelligent deployment of UAVs in 5G heterogeneous communication environment for improved coverage." Journal of Network and Computer Applications vol-85, pp: 94-105.

[28] H. Holma and C. Sartori, 2012. "Self-Organizing Networks (SON)," LTE-Advanced, pp. 135-152.

[29] Adarsh, A., Tiwari, A., & Kumar, B. (2019, July). Performance Analysis of Data Sensitive Adaptive MAC Protocol for Intra-Hospital Scenario. In 2019 10th International Conference on Computing, Communication and Networking Technologies (ICCCNT) (pp. 1-6). IEEE.

[30] B. Kim and J. Cho, 2012. "A novel priority-based channel access algorithm for contention-based MAC protocol in WBANs," Proceedings of the 6th International Conference on Ubiquitous Information Management and Communication - ICUIMC '12.

Authors

Abhinav Adarsh is currently pursuing his Ph.D in “Cognitive radio based E-healthcare” from Department of Electronics and Communication Engineering, Motilal Nehru National Institute of Technology Allahabad, Prayagraj, India. He obtained his Bachelor of Technology degree in Electronics and Tele-communication from College of Engineering Roorkee, Roorkee, Uttrakhand and M. Tech. degree in Digital Communication from ABV-IIITM Gwalior, in year 2012 and 2015 respectively. His area of research includes wireless communication, cognitive radio, telemedicine, multimedia communication and medical image processing. He has published 6 research papers in reputed international journals/conferences.

Dr. Shashwat Pathak is currently associated with Meerut Institute of Engineering and Technology, Meerut as Associate Professor in the Department of Electronics and Communication Engineering. He is also leading Innovation Cell of the Institute. He has received PhD degree (Dec. 2017) in Wireless Communication from Department of Electronics and Communication Engg., Motilal Nehru National Institute of Technology Allahabad. He has worked in the field of telemedicine and development of portable healthcare diagnostic devices. His invention from PhD work has secured seed funding from Ministry of Electronics and IT (MeiTY), GoI. He has filed three Indian patents on diagnostic healthcare devices. He has 11 publications in reputed International Journals and Conferences and a book chapter published in Springer. He has co-founded a startup " Electro Curietech Pvt. Ltd.", in the year 2017, which is currently being incubated at Incubation Center IIT Patna. His startup works in the domain of Telemedicine, Healthcare electronics and custom made IT solutions using AI and data analytics.

Dr. Basant Kumar is currently working as Associate Professor in Department of Electronics and Communication Engineering, Motilal Nehru National Institute of Technology Allahabad, Prayagraj, India. He has more than 15 years of teaching and research experience. He obtained his B.Tech. degree in Electronics and Instrumentation Engineering from Bundelkhand Institute of Engineering and Technology, Jhansi, Uttar Pradesh, and M.E. degree in Communication Engineering from Birla Institute of Technology and Science, Pilani, in 1999 and 2002 respectively. He received Ph.D. in Electronics Engineering from Indian Institute of Technology, Banaras Hindu University, Varanasi, India (IIT-BHU) in 2011. His area of research includes telemedicine, data compression, data hiding, multimedia communication, medical signal & image processing, and medical instrumentation. He has published more than 64 research papers in reputed international journals/conferences.