Mobile Wi-Fi based Scheduling for Body Area Networks

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ABSTRACT
Recently, Wireless Sensor Networks (WSNs) have significantly helped in evolving the provision of healthcare services. Wireless Body Area Networks (WBANs) have helped in healthcare service improvement. However, this has also created various research challenges such as Quality of Service (QoS) support. IEEE 802.11e Wireless Local Area Networks (WLANs) based on CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) specify standards for MAC (Medium Access Control) protocols to support QoS in wireless networks. EDCF (Enhanced Distributed Coordination Function) is a contention-based channel access scheme. In this paper, an Optimized QoS (OQ) scheduling scheme with Mobile Wi-Fi connectivity is proposed for QoS differentiation. The scheme makes use of two different biosensors types and the optimum CW (Contention Window). Initially at MAC layer, CW is set to optimize CW_{min} based on the sensor priority class for patient monitoring. Furthermore, less end-to-end packet delay is ensured for high priority critical sensor data, which improves QoS performance. Through simulation, it is shown that the proposed approach provides QoS guarantee to high priority sensor data traffic. Results obtained indicate that OQ outperforms the DQ (default Quality of service) other conventional approaches.

General Terms
Wireless Body Area Networks, Contention Window

Keywords
IEEE 802.11 MAC, IEEE 802.11, QoS, EDCF, CW_{min}, Mobile Wi-Fi, Scheduling

1. INTRODUCTION
The fast advances in electronics and wireless communication technologies have enabled the Wireless Sensor Network (WSN) to help in developing economically viable solutions for several applications such as military reconnaissance and healthcare monitoring etc. Predominantly, the WSN technology has been applied in the healthcare domain, where Wireless Body Area Network (WBAN) can efficiently support healthcare services [1]. This can provide better services to patients in hospitals, workplaces or homes, using limited resources. A WSN is a group of miniaturized sensor nodes, which can be up to hundreds or thousands in number, attached to patient bodies [2]. In WBAN, the wireless technologies usage (e.g. 4G/5G, Wi-Fi or Mobile Wi-Fi etc.) over network can create various network related challenges. Among these challenges, a major issue is the need of Quality of Service (QoS) support due to biosensors' limited power and narrowband real time WBAN applications. Compared to WSNs, WBANs have fewer and smaller nodes, which imply small batteries with limited power leading to stricter energy consumption. This paper addresses body sensor data traffic scheduling in WBAN. Therefore, an OQ scheduling approach is proposed in WBAN based on Enhanced Distributed Coordination Function (EDCF) via Mobile Wi-Fi connectivity. The approach provides service differentiation at MAC layer. The rest of this paper is organized as following. Section II & III present the WBAN system, Mobile Wi-Fi system architecture and the associated work that has been done in the QoS support area. Section IV evaluates the proposed scheme performance. Section V includes the simulation experiments and the result analysis. Finally, a conclusion is provided.

2. BACKGROUND
The section presents the operational principle of WBAN, Mobile Wi-Fi system architecture and the associated work that has been conducted to address QoS support in the last few years.

2.1 WBAN System
It consists of body sensors implanting the sensor nodes on a human body or inside it to measure vital signs like Blood Pressure (BP), electrocardiogram (ECG), and temperature (temp) etc. It provides a low power, short range and reliable wireless communication in a close immediacy to or inside the human body [3].

2.2 Mobile Wi-Fi Device
The Mobile Wi-Fi acts as a relay to connect a cellular network (i.e. 2G/3G/4G) to a Wi-Fi system. The device is used to share a 3G or 4G mobile Internet access to Wi-Fi enabled peripheral devices, e.gs smart phones, laptops. It operates on 2.4GHz or 5GHz and provides Wi-Fi access within 10 meters for up to 5 STAs [4,5,6]. The Mobile Wi-Fi device consists of a modem and Wi-Fi router. The modem is used for establishing connection between mobile Wi-Fi and cell phone devices while the Wi-Fi router is used for Wi-Fi connections. It supports different cellular standards like LTE, HSPA etc. and provides connectivity in the coverage area [7].

2.3 System Architecture
The system architecture comprises of a group of huge number of small sensor nodes attached to a patient's body: sensor nodes, base station (Access point), Mobile Wi-Fi device and medical server as illustrated in Fig 1. Body sensors sense and persistently monitor the patient's health data from the body, which is sent to the Base Station (BS) outside the body, where BS is, connected to the hospital server via Mobile Wi-Fi device and WLAN. The patients' data forwarded to hospital database can be accessed by hospital team.

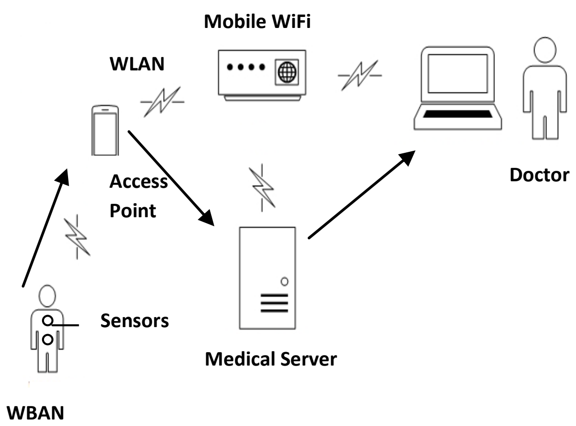


Fig 1: System Architecture

3. RELATED WORK

This section explains briefly some work that had been conducted by the researchers to address QoS problems in this domain. In [8], a class based model facilitates QoS provisioning by defining two bits added inside the flag header to differentiate three classes of services. A Dynamic multi threshold priority packet scheduling algorithm is proposed [9] for better QoS provision to low priority packets. The algorithm also makes use of dynamic thresholds for loss efficiency of high priority packets. The authors of [10] extended the Distributed Coordination Function (DCF) by incrementing Contention Window (CW) using two functions i.e. taking two bit left shift. The scheme reduces delay, packet loss ratio and increase the transmission channel efficiency. In [11], the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol is presented for IEEE 802.15.6 in the beacon communication mode. It allows rapid and prioritized right of entry to the channel by distinguishing CW. According to the priority classes, CW_{min} (CW minimum) and CW_{max} (CW maximum) values are chosen. The dynamic control backoff time algorithm (DCBTA) proposed in [12] enhances both delay and throughput of IEEE 802.11 DCF performance. Using CW threshold ($CW_{Threshold}$), the traffic is categorized in DCBTA. A novel CW control scheme proposed in [13] analyzes IEEE 802.11 DCF parameters effect such as CW and RL (Retry Limit) in industrial applications including short packet and noisy environment [14].

4. OPTIMIZED QOS SCHEDULING SCHEME

The Optimized QoS (OQ) scheme is divided into two parts: Optimized CW size using priority class and CW_{min} increment.

1. In the first part, an optimized CW size is obtained using priority class and backoff time calculation. In the OQ scheme, two body sensor types are used: ECG and temp. These two sensor types are given different priorities: highest to ECG and lowest to temp. Both the sensor types are based on video application type traffic with each having different access category (AC) and type of service (TOS). Each AC has its own default CW size. Initially in OQ, based on the priority sensor class, the optimized CW_{min} is calculated from the default CW_{min} value for sensors by keeping CW_{max} same as default. This is because each state of a sensor node "s" is initially set to the minimum CW size (CW_{min}), which is the initial successful transmission attempt. Therefore, an optimized CW_{min} size plays a major role in providing priorities to the sensors. The CW_{min} and CW_{max} for ECG sensors are set as default in proposed approach. Whereas, the optimized CW_{min} value for temp sensors (background AC) is obtained from default CW_{min} value by calculating backoff time interval β_i using formula as below in Equation 1.

$$\beta i = 2^{i+k} - 1 \qquad (1)$$

Where, i is the number of retransmission attempts, k depends on the PHY layer type. Then, three bit left shift plus 7 for Temp from the backoff value is obtained in equation (1). For example; CW_{min} value for temperature sensors (background effort AC) was selected to be [15] to be 31. In this case, the OQ CW_{min} is set to 255. The proposed OQ scheduling scheme enables the highest priority class to have smaller CW size and largest CW size for lowest priority.

2. In the second part, an OQ CW_{min} is set as above for a successful initial transmission. Else, it is incremented using formula in Equation 2.

$$newCW[AC] = (oldCW1) * 2 \ ) - 1 \qquad (2)$$

This increment procedure applied to all the two sensor classes (ECG and temperature) from optimized CW_{min} size till it reaches CW_{max}. In addition, each AC has its own AIFS (Arbitrary Interframe Space) value which is obtained by calculating SIFS (Short interframe Space), AIFSN [AC] (Arbitrary Interframe Space Number) and slot time. They are selected as default for all two sensors in OQ scheduling scheme. For example, the AIFSN [AC] value of different ACs in optimized approach is selected to be as default that is 2 for video AC and 7 for background AC. The slot time duration in 802.11b as the PHY layer is selected as 20 μs and SIFS as *10* μs [16]. Hence, AIFS [AC] for ECG (Video AC) is selected to be 50μs and temp (Background AC) is selected as 150μs.

5. RESULTS AND ANALYSIS

The proposed scheme is evaluated in simulation environment that includes network model and simulation scenarios. The network model consists of body sensors based wireless nodes, one access point and one server as shown in Fig 2. Body sensor wireless nodes consist of temp and ECG nodes. The temp nodes are labeled as Temp1, Temp2, Temp3.., whereas the ECG nodes are denoted as ECG1, ECG2, ECG3… and so on.

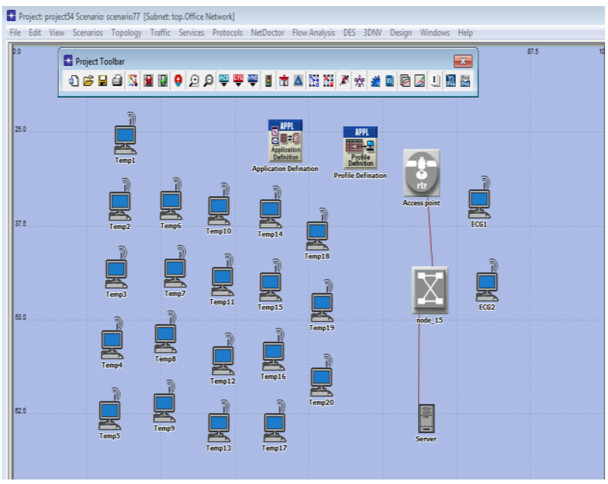


Fig 2: Network Model

In simulation evaluation, in case of EDCF, from higher layer the two traffic classes are fed into the MAC layer corresponding to respective AC to illustrate how efficiently the new protocol works for service differentiation. Application based profiles of simulation scenarios for different ACs are shown in Table 1.

Table 1: AC and Corresponding ToS

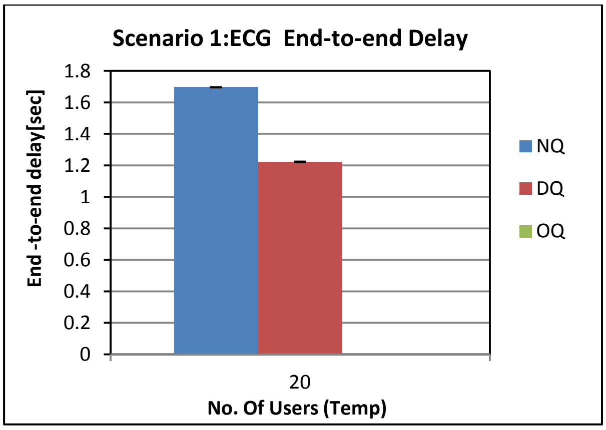
AC	Application Type	ToS (Type of Service)
AC(0) Background	Video Conferencing	Background
AC(2) Video Conferencing	Video Conferencing	Interactive Multimedia

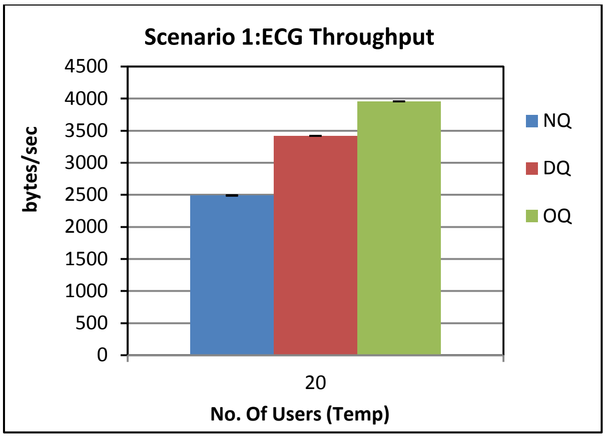
The inter-arrival time of ECG and temp data frames is set as 0.001 sec and 5 sec respectively, whereas frame size is of 2 bytes. The OQ scheduling scheme performance is evaluated via Mobile Wi-Fi connectivity. 802.11b is selected as the PHY layer where the data rate is 11 Mbps. The sensor nodes transmit for a simulation time of 1000 sec and each scenario is simulated with 10 different seeds. The three scheduling schemes used in this paper are: No QoS (denoted as NQ), Default QoS (DQ), and Optimized QoS (OQ). NQ scheme has no HCF (Hybrid Coordination Function) parameters that are defined by IEEE 802.11e (WLAN QoS) MAC standard. The DQ scheduling scheme in which EDCF parameters values are defined as per IEEE 802.11e standard for QoS mechanism. In OQ scheduling scheme, the default EDCF parameters are remodeled.

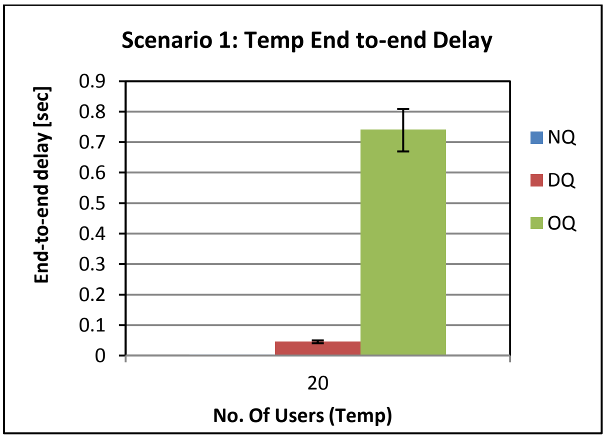
5.1 Scenario 1

The first scenario comprises of 22 wireless LAN nodes or sensors where two are ECG and rest temp nodes. The QoS parameters such as end-to-end delay and throughput are evaluated for NQ, DQ and OQ. The results are obtained with 95% confidence interval calculated for 10 seeds also shown in the graphs as error bars.

Fig 3 describes results of the first scenario.







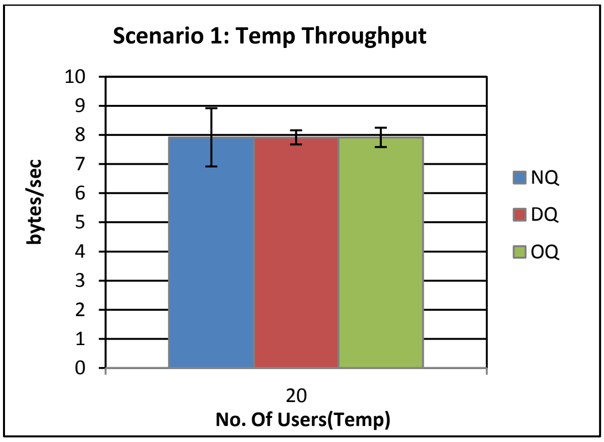


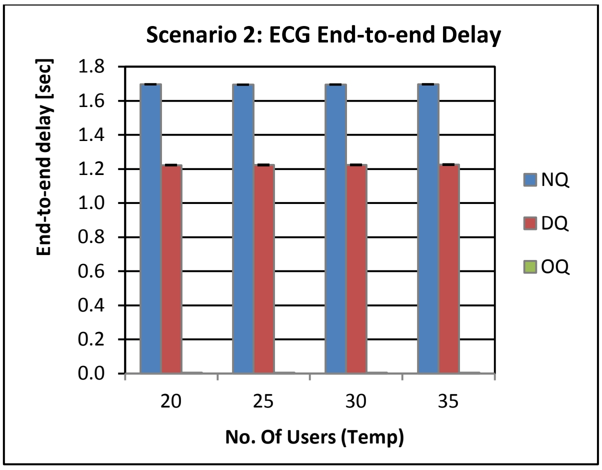
Fig 3: QoS parameter for ECG and Temperature

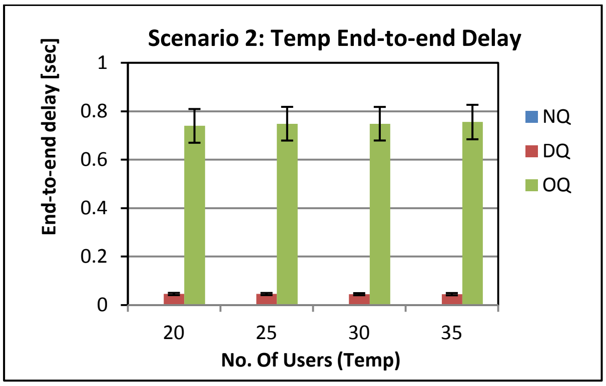
5.2 Analysis of Scenario 1 Results

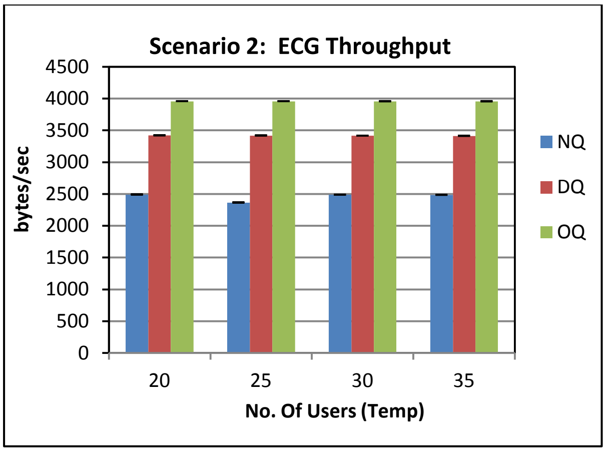
The results in Fig 3 show that the OQ scheme performs better as compared to DQ and NQ by achieving low end-to-end delay for ECG devices, however high for temp devices. In addition, high ECG throughput is achieved as compared to ECG throughput of other schedulers. The average end-to-end delay for ECG devices of NQ, DQ and OQ scheduling scheme is also depicted in Fig 3. It shows that in case of OQ scheduler, ECG data is transmitted with high priority, thus achieving low end-to-end delay of just above 0 sec not visible in graph as compared to DQ scheduler where end-to-end delay is above 1.2 sec. In case of NQ scheduler, end-to-end delay is about 1.7sec. Fig 3 depicts the end-to-end delay of temperature devices for NQ, DQ and OQ schemes. The temperature devices in case of OQ scheduler have maximum end-to-end delay of above 0.7 sec as compared to DQ of almost 0 sec and NQ of below 0.1 sec. In Fig 3, the OQ scheme achieves higher ECG throughput when compared with NQ and DQ schemes as it transmits data at 3900 bytes/sec. In case of DQ scheduler, data is transmitted at 3400 bytes/sec and NQ with 2500 bytes/sec due to the fact that OQ gives scheduling priority to ECG devices, thus manages to transfer more ECG data with higher spectral efficiency resulting increase in the overall cell throughput performance. The average temperature throughput remains the same for all the three schedulers due to the strict ECG user priority.

5.3 Scenario 2

The temperature sensors are increased in each subsequent sub-scenario and the number of ECG devices kept constant. The network model comprises of sensors where two are ECG and rest temp (20, 25, 30 and 35). Fig 4 describes the results of second scenario.







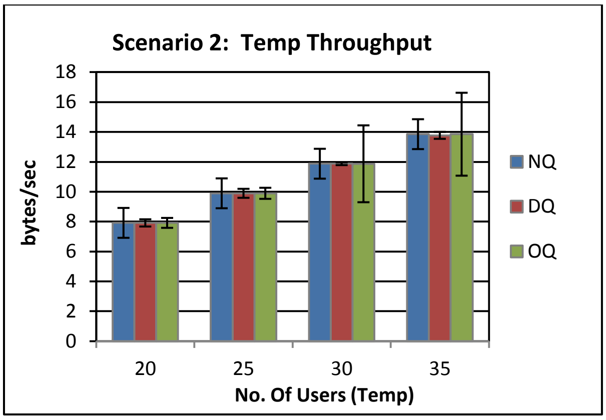


Fig 4: QoS parameter for ECG and Temperature

5.4 Analysis of scenario 2 Results

The results in Fig 4 show that with OQ scheduler, end-to-end delay results for ECG traffic do not vary even if the number of temp users is increased. Also, end-to-end delay results remain almost the same for temperature users with increase in the number of temperature users. The OQ scheduler satisfies the users' requirements, achieving a packet end-to-end delay of almost 0 sec for ECG and below 0.8 sec for temperature. This is because the OQ scheduler tries to distribute sufficient resources in each TTI to serve both ECG and temperature users.

In comparison with NQ and DQ schedulers, the ECG traffic users for OQ scheduler have the best performance with increasing temperature traffic users in subsequent sub-scenarios. OQ achieves the ECG traffic user end-to-end delay of almost 0 sec. However, the worst performance is achieved by NQ with the highest end-to-end delay of around 1.7 sec. This is because NQ scheduler gives priority to users with good channel conditions without considering any other factor. The range of 95% confidence interval for temperature end-to-end delay is around 0.7-0.8 sec. On the other hand, ECG end-to-end delay values achieved are just above 0 sec. The average ECG throughput for the OQ scheduler remains unchanged for these traffic sub-scenarios when the temperature users are increased. It is because the number of ECG devices remains the same in all sub-scenarios. The OQ scheduler satisfies the users' requirements by achieving maximum throughput of 4000 bytes/sec when temperature users are increased. On the other hand, the average temperature throughput for OQ scheduler increases when temperature users are increased. The temperature throughput increases gradually with increasing number of temperature devices and the scheduler satisfies the QoS requirements by achieving maximum throughput at 14 bytes/sec. The results of average ECG throughput of users with NQ, DQ and OQ schedulers show that the OQ scheduler users manage to achieve data rate of 4000 bytes/sec compared to DQ scheduler achieved rate of 3500 bytes/s and NQ scheduler users transmit at approximately 2500 bytes/sec. The reason for this is that the OQ scheduler gives better scheduling priority to the video ECG users that manage to obtain higher data rates with improved spectral efficiency and thus increase the overall cell throughput performance. The average throughput of temperature users is same for all three schedulers NQ, DQ and OQ. The throughput increases when the number of temperature users is increased. Despite the fact that guaranteed bit rate bearers are served with strict priority before the non- guaranteed bit rate users, there are enough resources to serve even the non-guaranteed bit rate users. Also, the greater interarrival times of temperature users' data packets mean that increasing the number of temperature sensors would not increase the throughput drastically.

6. CONCLUSIONS

WBAN involve sensor nodes implanted in a human body or inside the body measures vital signs like blood pressure, respiration rate, glucose level etc. for patient health monitoring. This usage creates various challenges such as the need of QoS support, biosensors' limited power and narrowband real time applications using broadband networks. Also, non-availability of DSL in remote areas for patient monitoring is an issue in WBANs.

To resolve these problems, using Mobile Wi-Fi, EDCF based (OQ) scheme was proposed in this paper for WBAN. The proposed scheme ensures QoS differentiation. In this approach, scheduling of body sensor data under IEEE 802.11e MAC layer of WLAN in WBAN was investigated. MAC assigns different contention window sizes to three sensor priority classes considered in this work.. The results obtained using OPNET modeler 14.5 simulator for QoS parameters i.e. throughput and end-to-end delay performance show that the proposed scheme outperforms other approaches. Comparative analysis show that our approach works much better than the default 802.11e EDCF scheme. Furthermore, our approach not only improves the performance of real-time packets, but also provides internet facility in remote areas using Mobile Wi-Fi for patient monitoring. The proposed scheme provides higher service differentiation along with minimum end-to-end packet delay and high throughput.

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