QoS Provisioning in Sensor Enabled Telemedicine Networks

Chunxiao Chigan, Michigan Tech, USA
Vikram Oberoi, Highmark Inc., USA

ABSTRACT

Enabled by the advances of the wireless sensor network technologies, wireless LANs will play a critical role in providing ubiquitous connectivity for future telemedicine applications. This paper focuses on how to provide QoS over the wireless channel between the Body Sensor Network (BSN) Gateway and the wireless Access Points (AP). Telemedicine applications require the periodic report data and the emergency messages transmitted to the remote health care center in a timely manner. However, unlike the voice and multimedia applications which can be supported by traditional QoS techniques, the sporadic nature of the emergency data in telemedicine systems makes it nontrivial to provide sufficient QoS. This article investigates several alternative schemes for QoS support in the telemedicine systems, and an express dual channel (EDC) based QoS mechanism is proposed. Not only is the proposed mechanism simple and resource efficient, but also it provides the bounded maximum delay guarantee for the unpredictable emergency data transmission for telemedicine applications.

Keywords: body sensor networks (BSNs); bounded maximum delay; delay intolerant; express dual channel (EDC) based QoS provisioning; telemedicine system; wireless LAN

INTRODUCTION

With the advances in wireless technology, the realization of seamless connectivity to support "anywhere" and "anytime" communications becomes more and more plausible. One of the most important advancements is the development of low cost wireless sensors networks to collect data in various environments. In this paper, we explore one such environment, namely the telemedicine systems. Chronic diseases such as diabetes and heart attacks are the most common and costly health problems in the United States. Fortunately, with the help of adequate support infrastructure and seamless connectivity, many fatal situations may be prevented. If the data related to the periodic monitoring reports and potential emergency situations of the patients can get across to medical facilities in a timely manner, even though the patient is free to roam about, many life-death critical situations can be taken care of.

A telemedicine system which can support such application, is depicted in Figure 1, where the data regarding various physiological
parameters such as heart rate, blood pressure, and so forth, collected by the in-body sensors, is fed to and aggregated by the Body Sensor Network (BSN) gateway which can be some handheld device (e.g., a modified palmtop or PDA). This BSN gateway then sends this data to a wireless Access Point (AP, supported by IEEE 802.11) connected to the Internet, which further relays the data to the remote medical facilities. In such a telemedicine system, the BSN gateway fuses information from wearable, ingestible, and implantable sensors to provide continuous diagnostic monitoring and generate early warnings. It may also provide control over critical implantable devices such as drug delivery pumps. The emergency or the periodic data fused by a BSN gateway is then relayed via a WLAN access point to remote health care centers. The communication between the WLAN access point and remote health care center takes place via an all IP-based network.

To deploy such a telemedicine application which is life-death critical, certain QoS guarantees have to be provisioned so the data can reach the remote health care center in a reliable and timely manner. This paper focuses on the QoS provisioning between the BSN gateway and the wireless access points (e.g., IEEE 802.11 based Hot Spots) in the telemedicine applications.

We assume that the underlying media access control (MAC) protocol of the WLAN access point network is the IEEE 802.11e standard which supports the traditional QoS service to various classes of applications. Compared to the baseline IEEE 802.11 which does not support any QoS service, IEEE802.11e provides a basic platform to support different priority of the wireless media access to different data traffics if the traffic pattern is of certain predictability. However, the occurrence of emergency events in telemedicine application is extremely sporadic and its traffic pattern is totally unpredictable.
Therefore, the QoS provisioning for such applications is not trivial. Rather, it can be an extremely difficult task if the traditional scheduling-based QoS approaches or the traditional contention based on-demand QoS approach patterns are applied for the QoS provisioning in telemedicine systems.

In this article, we propose a completely new method of providing QoS support for telemedicine applications with very little complexity and cost-effective QoS guarantees. The rest of the article is organized as follows. In the second section, we present the related work and discuss the uniqueness of the QoS requirements in telemedicine applications. In addition, four alternative potential approaches to support QoS in telemedicine applications are also investigated in this section. The third section presents the details of our proposed Express Dual Channel (EDC) based QoS solution for telemedicine applications. In the fourth section, we present our simulation results, and the fifth section concludes the paper by presenting conclusions and future work.

RELATED WORK
In this section, we present the existing approaches providing traditional QoS services and identify the unique challenges of QoS provisioning in telemedicine systems. We then explore the potential approaches to meet these unique QoS requirements in telemedicine applications.

Current QoS Approaches (Traditional QoS)
There are many solutions proposed to support the traditional wireless QoS applications where different classes of data demands are known in advance. For example, it is known that some applications (e.g., video, voice) are more delay sensitive than the others (e.g., data). Because the traffic patterns of these delay sensitive data (video and voice) have been extensively studied and well understood, we refer to the solutions providing QoS to applications of predictable traffic patterns as traditional QoS approaches. The current approaches to support traditional QoS requirements can be grouped into various categories. We have classified (refer to Figure 2) some of these approaches which are closely related to our work into three categories. The following is a brief overview of these approaches.

Service Differentiation and Priority (SDP) Based QoS Schemes
The schemes under this category basically use different values of various contention parameters such as contention window size and so forth, to assign different priorities to different services. The work by Ada and Castelluccia (2003), Xiao (2003), and Veres, Campbell, Barry, and Sun (2001) belong to this category. One such scheme has been proposed in Ada and Castelluccia (2003), wherein the authors present four service differentiation schemes for IEEE 802.11. The first scheme is based on scaling the contention window according to the priority of each flow or user. For different users with different priorities, the second, the third, and the fourth mechanisms assign different minimum contention window values, different interframe spacing and different maximum frame lengths, respectively. The SDP-based QoS approach can also be used to provide priorities to real-time applications (Xiao, 2003). By differentiating the initial window size, the window-increasing factor and the maximum backoff stage, an analytical model for assigning priorities to real-time applications was proposed in Xiao (2003).

In the SDP-based QoS approach, service differentiation can also be introduced using a fully distributed approach. In Veres et al. (2001), based on the IEEE 802.11 Distributed Coordination Function (DCF) mode, two distributed estimation algorithms are proposed. A Virtual MAC (VMAC) algorithm passively monitors the radio channel and estimates locally achievable service levels. VMAC estimates key MAC level statistics related to service quality such as delay, delay variation, packet collision, and packet loss.

In all of the above schemes, priority is assigned to different services by assigning fa-
vorable contention parameters. Therefore, data demanding high priority can only achieve best-effort QoS with unbounded maximum delay. This is due to the fact that the high priority data still has to contend for channel access with the lower priority and equal priority services.

**Fair and Real-Time Scheduling (FRS) Based QoS Schemes**

The protocols under this category use fair queue scheduling principles to attain QoS. Vaidya, Bahl, and Gupta (2000), Adamou, Khanna, Lee, Shin, and Zhou (2001), and Ranasinghe, Andrew, Hayes, and Everitt (2001) fall into this category, wherein the scheduling can be done based on the traffic analysis for different applications.

Using one or more parameters, such as finish time for a packet, some scheduling policies are developed. One such approach presented in Vaidya et al. (2000) is based on the Self Clocked Fair-Queuing approach of transmitting the packet whose finish tag is the smallest, as well as its mechanism for updating the virtual time. A distributed approach for finding the smallest finish tag is employed, using the back off interval mechanism of IEEE 802.11 MAC. The essential idea is to choose a backoff interval that is proportional to the finish tag of the packet to be transmitted.

The approaches under this category try to attain a specific scheduling goal depending upon the nature of the application. For instance in Adamou et al. (2001), the authors present four different algorithms designed to attain certain specific scheduling goals. The first two are EDF (Earliest Deadline First) and GDF (Greatest Degradation First) that consider only one aspect of the scheduling goal, respectively. EDF is naturally suited for maximizing throughput, while GDF seeks to minimize the maximum degradation. The next two are algorithms, called EOG (EDF or GDF) and LFF (Lagging Flows First), which consider the two aspects of the scheduling goal. EOG simply combines EDF and GDF, whereas LFF tries to favor lagging flows in a nontrivial manner.

Similar to different scheduling goals, the QoS objectives can also be differentiated according to the nature of the application (Ranasinghe et al., 2001). One QoS objective could be to maximize the number of customers receiving good service for real time data services such as multimedia data, MPEG, video streaming, IP telephony, and so forth. In Ranasinghe et al. (2001), a new scheduling scheme called the Dual Queue discipline is proposed which has the flexibility to satisfy a variety of QoS objectives, ranging from existing notions of

---

**Figure 2. Diagrammatic representation of classification of QoS various approaches**

---

![Diagram](image-url)
fairness to maximizing the number of customers receiving good service.

All the schemes under this category, however, require the prior knowledge of the different traffic patterns, which is unavailable in telemedicine applications wherein the traffic pattern of emergency messages is highly unpredictable.

**Multi Channel (MC) Based QoS Schemes**

In MC-based QoS schemes, usually separate dedicated messages are used to set up a separate dedicated channel or reserve the primary channel for data transmission. Dedicated Channel for Streaming Services (DCSS) (Tsai & Wang, 2005) uses some new control frames to assign a new dedicated channel for heavy traffic or streaming services. On the other hand, Dynamic Channel Assignment (DCA) (Wu, Lin, Tseng, & Sheu, 2000) divides the overall bandwidth into one control channel and “n” data channels. Whenever a node wants to communicate with another node, it sends control packets over the control channel to obtain rights to access one of the data channels. The data channels carry only the Data and the Acknowledgements packets.

Another QoS mechanism is to use different reserved channels for communicating with different neighbors. Sequenced Neighbor Double Reservation (SNDR) (Cai & Lu, 2000) is one such MAC protocol for Multi-Channel Ad Hoc networks. The basic idea is that, for a given node A, if one of its neighbors B wants to send data to A, B must use the same code sequence preassigned to A to send data. In other words, A can receive data only on the channel it has been preassigned. If more than one neighbor wants to send data to A, then they use TDM over that channel.

One of the drawbacks of the schemes mentioned in this category is the delay caused in setting up the separate channel or gaining access to the main data channel. In addition, valuable resources may be underutilized because of reservation of separate channels for separate nodes.

**Alternative Approaches (QoS in Telemedicine Applications)**

In this section, we first discuss the unique QoS requirements and challenges for telemedicine applications. Then we discuss why the previously surveyed existing approaches may not work well to provide QoS support for such applications. Certain approaches that may be employed for providing QoS guarantee for telemedicine applications are then explored. We use the sensor enabled telemedicine systems illustrated in Figure 1 as an example in the rest of the paper for discussion purpose. The QoS issues and principles discussed in this paper, however, are applicable to a variety of sensor enabled telemedicine systems.

**Unique QoS Requirements of Telemedicine Applications**

As described above, there are many traditional solutions proposed to support the traditional wireless QoS applications where different classes of data demands are known in advance. However, as shown in Figure 3, telemedicine application usually comprises of two types of data: the regular periodic report data which are sent at fixed time intervals and are of predictable nature, and the emergency messages that have highly erratic natures. Therefore, providing QoS support for emergency situations can be very tricky because of this erratic nature.

To highlight the uniqueness of QoS requirements for emergency data, let us compare its properties with that of traditional QoS applications such as voice streaming and multimedia traffic.

*First, the emergency events in telemedicine application are extremely sporadic and unpredictable, therefore may occur just once in several months/years. However, although emergencies occur sporadically, emergency telemedicine data is extremely delay-intolerant and demands bounded maximum delay guarantee. Hence, traditional resource reservation and the scheduling-based QoS approach cannot be applied to this kind of telemedicine applications efficiently. On the other hand, the traditional on-demand*
QoS approaches are contention-based and may lead to unbounded maximum delay, and therefore cannot ensure the QoS requirements of the delay intolerant telemedicine applications either. Thus, all traditional QoS approaches (resource reservation and scheduling based, or contention based on-demand approach) can hardly suit the telemedicine applications.

Indeed, none of the traditional QoS approaches discussed previously can work well in telemedicine applications. The SDP Based QoS Schemes may experience unbounded maximum delay for gaining the channel access due to the contention among different and same priority services. The FRS Based QoS Schemes require traffic analysis and thus demand the prior knowledge of traffic patterns that is not available for telemedicine applications. And the MC Based QoS Schemes may require unbounded maximum delay in establishing a separate channel or gaining access to one of the data channels. This is also due to the contention and collisions that may occur over the control channel.

**Alternative Approaches for Telemedicine QoS**

Next, we explore potential approaches that might be applicable for QoS in telemedicine applications.

1. **Allocate Resources On-the-Fly:** Anytime a device with emergency message to be delivered via the access point (AP), it probes the availability of an AP in its vicinity (or passively listens for a beacon from an AP). Then it associates with the AP. After the association phase, it contends for the channel and can only send the emergency data after obtaining channel access. The obvious limitation of this approach is the nondeterministic delay introduced. In the worst case (with unbounded maximum delay) the device with emergency event may not get the channel access in the acceptable delay period.

2. **Dedicated Emergency Channel Approach:** Another approach could be to reserve a whole separate channel for transmitting the emergency data. However, as emergencies occur rarely and follow the bursty pattern, this often leads to significant wastage of the resources.

3. **Dedicated Emergency Slot Approach:** A similar approach is that the AP reserves a slot of channel access for the telemedicine application by the periodic beacon signal it sends out. If the application indicates that there is an emergency event in this slot, the AP grants the channel to the telemedicine application. However, the beacon is sent...
4. **QoS Support Based on IEEE 802.11e:**

   This approach uses the Hybrid Coordination Function (HCF) in the IEEE 802.11e standard (refer to appendix for details) to provide higher priority for the telemedicine applications. Under the HCF mode, because the AP is given the highest priority for the wireless media access, it can grant access to nodes with different priorities based on certain criteria. During the Contention Free Period (CFP), the AP can issue a QoS Contention Free (CF) Poll to a particular station to grant it a channel access. The AP schedules these polls based on the traffic analysis sent to it by each station regarding their queue length, and so forth. During the Contention Period (CP), all the stations contend for channel access via Enhanced Distributed Coordination Function (EDCF). In this case, if the AP is triggered properly by the emergency demands, it can grant channel access to the telemedicine stations by sending out a beacon signal. However, for telemedicine applications, the traffic is of a highly unpredictable nature which could render the traffic analysis/predication a very complex issue. Therefore, it would be very difficult to design a scheduling algorithm that can capture the unpredictable nature of the emergency data.

   In this paper, we propose a novel mechanism to provide QoS for telemedicine applications. Not only is this mechanism simple and resource efficient, but also it provides bounded maximum delay for the unpredictable emergency data transmission.

**EXPRESS DUAL CHANNEL (EDC) BASED QOS PROVISIONING FOR TELEMEDICINE APPLICATIONS**

In this section, we present an entirely new and radical approach for providing QoS support in telemedicine applications. We use the telemedicine system depicted in Figure 1 as an example for explanation, but the proposed approach is applicable to most of the telemedicine applications where wireless media access controls are involved.

As described in the first section, for a sensor enabled telemedicine system, the patients are equipped with in-body or wearable sensors which can send the data from different parts of the body to the Body Sensor Network (BSN) Gateway (e.g., modified handheld devices such as PDAs or Palmtops). The BSN gateway sends the aggregated data (periodic reporting data, and unpredictable emergency data) to the remote health care centers via the public Wireless Access Points (APs, e.g., WiFi) which are connected to the Internet. Because APs often support many other applications in the public domain, there are contentions among different applications to gain the wireless channel access from different nodes. Furthermore, multiple telemedicine applications within one AP also contend among each other to gain channel access. In this context, our paper focuses on the QoS support for telemedicine applications by guaranteeing maximum (worst) delay of the public APs access, and at the same time minimizing the resource wastage due to the unpredictability of the emergency data.
Assumptions and Notations
The assumptions that were made are listed below:

- The AP is able to transmit and receive data simultaneously.
- The level of interference experienced by two nodes is the same in both directions (transmission and receiving). The interference level does not change during the transmission period.
- Nodes send association and disassociation messages to the AP when they enter and leave the network, respectively.

The following is the summary of the notations (IEEE 802.11e compatible) used in this paper:

- SIFS—Short Interframe Space
- PIFS—Point Interframe Space
- DIFS—Distributed Interframe Space
- HC—Hybrid Coordinator
- AP—Access Point
- TXOP—Transmission Opportunity
- TBTT—Target Beacon Transmission Time

Network Dynamics in Telemedicine Applications
To enable the BSN gateway sending data to remote health center seamlessly, APs at different locations (different spots on campus, shops, airports, etc.) can be used to provide pervasive network connection. In this case, the individual wireless local area network is in infrastructure mode. However, the telemedicine applications supported by enormous numbers of APs are still of ad hoc nature because the BSN gateway can be one time within the coverage of one AP, and another time move to the vicinity of a different AP. This demands a perfect hand-off technology for the WLAN networks, which is beyond the scope of this article.

The above situation is depicted in Figure 4. The network configuration (in which a telemedicine device connected to) at time t1 is different from that at time t2 when some telemedicine applications have moved from the coverage area of AP1 to the coverage area of AP2.

Revisit: Traffic Patterns and Unique QoS Requirements in Telemedicine Applications
As discussed previously, the QoS support required by the telemedicine applications is

Figure 4. Network configuration at time t1, t2
different to that of conventional applications due to the extreme unpredictability of the emergency data pattern. Conventional techniques for providing QoS, which are based on analyzing the traffic patterns of different flows, do not suit such kinds of telemedicine applications due to the highly unpredictable nature of the traffic. In general, for such applications, the emergency events occur very infrequently, and therefore often it is desirable to have the periodic report messages (probably with a slow repetition cycle) sent for event monitoring/predication purpose and to maintain the presence of the telemedicine devices and their association with the network access point.

**Supporting Emergency QoS in Telemedicine System: Express Dual Channel-Based Mechanism**

To provide QoS guarantee for telemedicine applications supported by wireless LAN, we propose the use of an unsymmetrical dual channel mechanism. With such a dual channel mechanism, the primary channel is dominated for all data transmission, and the secondary channel is very slim, which is dedicated to the short emergency alert message (EAM) transmission.

Figure 5 depicts a scenario where such a dual channel mechanism is used to provide QoS support for a telemedicine application in case of an emergency. Before an emergency occurred, a general application device A was sending data to an AP. Now, as soon as the emergency occurred, the telemedicine application device T sends out a short Emergency Alert Message (EAM) through the reserved secondary, or alert channel. Upon receiving the EAM alarm, the AP schedules (with the highest priority) to send out a beacon to all the applications in the network, indicating the reservation of resources for device T.

The AP can gain access to the channel anytime because of its highest priority to access the channel under the Hybrid Coordination Function (HCF) mode supported in IEEE 802.11e. Upon receiving the beacon frame, telemedicine device T can send out the emergency data over the primary data channel. At the same time, the regular application device A loses its access to data transmission channel. Only devices with telemedicine requirements are equipped with this dual channel. A separate secondary channel is reserved for sending the short EAM to the AP. Whenever an emergency occurs, the BSN gateway sends a short EAM over this reserved channel to the AP to request the channel access.
for its emergency data. With this reserved secondary channel, the short EAM can arrive in a timely manner at the AP. Upon receiving the EAM, the AP can schedule to send out a beacon frame indicating an instant/highest priority reservation of resources for this station over the primary (normal) channel for its emergency data transmission. Once the requesting station is granted to access the medium, it can then send the complete emergency data over the primary data transmission channel.

The reserved secondary channel therefore requires a very small amount of bandwidth as the EAMs are very short messages to report the occurrence of the emergency event. Consequently, such a static secondary channel reservation at the APs for the telemedicine applications will not be costly even when there are no devices of telemedicine applications associated with the APs.

Because there could be more than one device of telemedicine applications within one AP’s coverage, there can be a contention over this reserved secondary channel too. To resolve such a complication, the AP can apply a Time Division Multiplexing (TDM) scheme over the reserved secondary channel to allow a fixed number of such applications that it can accommodate to associate with itself. This number will depend on the maximum delay these telemedicine applications can tolerate and the statistics of the specific telemedicine applications. Once the EAM reaches the AP through the reserved secondary channel, the primary data channel access will then be scheduled for that application, and thus emergency requests can be processed within a certain time, and hence the delay in processing multiple such requests will be deterministic. To allocate the available bandwidth between the dominant primary data channel and the slim secondary emergency alert channel, Orthogonal Frequency Division Multiplexing (OFDM) (Tutorial: Multi Carrier Modulation and OFDM. http://zone.ni.com/devzone/cda/ph/p/id/150), (Lawrey, 1997) or Frequency Division Multiplexing (FDM) (Tutorial: Multi Carrier Modulation and OFDM. http://zone.ni.com/devzone/cda/ph/p/id/150) or Code Division Multiple Access (CDMA) can be used. Details of these methods can be found in Lawrey (1997). Because these are all mature commercial technologies, the cost of the hardware introduced to support our proposed express dual channel (EDC)-based QoS solution will be rather low.

Figure 6 gives an in-depth description of the wireless channel acquisition for the proposed dual channel-based QoS support for telemedicine applications. Station 1 is a telemedicine application device and is equipped with two channels. Stations 2 and 3 are regular application devices and can send messages over the primary data channel only. The whole process is divided into two periods, the Contention Free Period (CFP) and the Contention Period (CP). The CFP is fixed and bounded by two TBTT (Target Beacon Transmission Time). During the Contention Free Period (CFP), the AP or the Hybrid Coordinator (HC) polls the stations for data transmission by sending a beacon, whereas during the CP, the nodes contend for channel access (refer to appendix for details).

First, let us have a look at channel access during CFP. Let us assume at time 0, the AP has polled and given the Transmission Opportunity (TXOP) to station 2. Station 1 and 3 set the Network Allocation Vector (NAV) to the next Target Beacon Transmission Time TBTT, assuming that all the polling slots are full and it will not have the TXOP during this period. Thus, station 2 can send its data to the AP during its TXOP over the primary data channel.

Now let us consider the Contention Period (CP). During the Contention Period (CP), all
the stations contend for channel access via Enhanced Distributed Coordination Function (EDCF) (refer to appendix for details). But the AP still can grant access to the channel by broadcasting a beacon. Thus, when station 1 detects an emergency, it sends an EAM over the secondary emergency channel. Upon receiving this EAM, AP broadcasts a beacon over the primary channel. Now, station 1 can send its emergency data over the primary data channel.

To provide QoS support for regular report data for telemedicine applications, we apply the IEEE 802.11e standard. For details of IEEE 802.11e MAC, please refer to the appendix. Such periodic data reports of telemedicine applications are grouped into a separate category with the second highest access priority at the primary data channel. The number of retransmission of such periodic report data is limited by the time after which the report will be outdated and not by a certain threshold number as in IEEE 802.11e standard. When operating in the EDCF mode, the telemedicine applications get the second highest priority to access the primary data channel and when operating in the Hybrid Coordinator (HC) mode, the Hybrid Coordinator (HC) located at the Access Point (AP) polls the telemedicine applications first. As the regular report data will be generated in a periodic manner, the AP can schedule its polling for these applications after it analyses their traffic patterns.

Queue Formation and Processing of Queue Entries at the AP

There are 3 classes of queues maintained at the AP in the proposed telemedicine QoS mechanism. The emergency data queue (EAM queue) has the highest priority. The queue with the second highest priority is dedicated to the periodic report data of the telemedicine applications. The
queue dedicated to the other messages (regular applications) has the lowest priority. As shown in Figures 7 and 9, the entries in the EAM queue at the AP are given the highest priority. As long as there is an entry in the EAM queue it will be processed first, thus resulting in very small processing delay for such applications. Thus, as soon as an emergency occurs, the EAM can be sent to the AP without further access contention. When a station leaves the network, it sends a disassociation message to the AP and the AP can release the resources that were allocated to this station.

The proposed Hybrid “Emergency First” and “Fair Queue” algorithm works as follows (refer to Figure 8): the AP processor always checks the EAM queue first. If there is a message in this queue, it processes it; otherwise it goes on to check the queue of the periodic reports. Upon the completion of any message processing, the AP proceeds to check the EAM queue first and then the other queues.

In Figure 7 of case “a”, at the starting point, there was an entry in the EAM queue, so the processor at AP processes it. In case “b”, as there is no entry in the EAM queue, the processor moves on to periodic data reports queue, and processes one entry and then again proceeds to check the EAM queue. If there is an entry in EAM queue, the AP will process it first and then move on to other queues. This is depicted in case “c”. Notice that there can never be more than one message in the output queue at a time. This is due to the fact that the processor only processes one message at a time and then checks the different queues first before processing the next message. Thus, the maximum delay experienced by the emergency data after it reaches the AP is the time required to process one single data message request.

Figure 9 depicts the Finite State Machine (FSM) of our Hybrid “Emergency First” and “Fair Queue” Algorithm, which is described in detail in Figure 8. The FSM diagram and the algorithm (refer to Figure 8) depict the processing flow of queue entries at the Access Point. An EAM basically triggers the AP to reserve resources for its telemedicine application. As soon as an EAM reaches the AP, it sends out a beacon indicating the reservation of resources for the telemedicine application associated with the EAM.

This beacon also acts as an acknowledgment for the telemedicine station that its EAM has reached the AP. For periodic reports, the standard ACK packets can be used as the confirmation of their reception. Once the emergency data reaches the AP, it is placed in Emergency data queue. This queue is given the highest priority. All the queues are scanned by the AP in a round robin fashion, as described in Figure 8.

**SIMULATIONS**

As discussed in the second and third sections, our proposed Express Dual Channel Based QoS Mechanism can guarantee bounded maximum delay experienced by the emergency message transmission, and it can therefore ensure the QoS requirement of the telemedicine applications wherein the occurrence of the emergency event is rare and highly unpredictable. Indeed, without a prior knowledge of the traffic pattern of the emergency messages available, it is impossible for the traditional schedule-based QoS approaches to prereserve channel resources for telemedicine applications efficiently. On the other hand, the traditional on-demand QoS approaches are contention-based and may lead to unbounded maximum delay, and therefore cannot ensure the QoS requirements of the delay intolerant telemedicine applications either. In this section, we will evaluate the performance of our proposed QoS scheme in terms of the average end-to-end transmission delay, and the percentage of the dropped data bits via simulation.

We used OPNET, version 8.1A, for simulating the proposed QoS solution in WLAN networks. Various parameters used and their values are shown in Table 1. A total of 10 nodes were placed randomly, but all within the transmission range of the Access Point (AP). The underlying MAC protocol is the IEEE 802.11. IEEE 802.11e has not been simulated in OPNET. For the time being, we used IEEE
Figure 7. Hybrid “Emergency First” and “Fair Queue” scheduling at the AP

Case a) AP processes the entry in Emergency data queue
Case b) AP processes the entry in Periodic Reports queue
Case c) AP processes the entry in Emergency data queue

Figure 8. Hybrid “Emergency First” and “Fair Queue” algorithm

1. Check Emergency data Queue
   a. If entry exists,
      • retrieve data, go to Process,
      • go to step 1
   b. Else, go to step 2.
2. Check Periodic Reports Queue
   a. If entry exists,
      • retrieve data, go to Process,
      • go to step 3
3. Check Regular messages Queue
   a. If entry exists,
      • retrieve data, go to Process,
      • go to step 1
   b. Else, go to step 1

Figure 9. Finite state machine (FSM) of queue processing at AP

CEQ: Check Emergency data Queue (also the start state)
CPQ: Check Periodic data Queue
CRQ: Check Regular data Queue
REQ: Retrieve Emergency Queue data
RPQ: Retrieve Periodic Queue data
RRQ: Retrieve Regular Queue data
PRO: Process data
802.11 standard as the underlying MAC. The network is operating in infrastructure mode where all the nodes have PCF functionality enabled. For telemedicine stations, only the emergency data is considered, and the periodic report data is not included.

Figure 10 shows the average dropped data bits (kilobits) for the telemedicine stations and the regular stations vs. the average load for a station. Our proposed scheme is compared with the baseline scheme, which is the IEEE 802.11 standard in the PCF mode without priority given to any station. We used this scheme to form a benchmark for the performance of a regular station. Therefore, in the baseline scheme, all the stations are considered as regular stations as opposed to our proposed scheme, in which stations are divided among telemedicine stations and regular stations. ES (EQoS) (10%) denotes Enhanced Telemedicine Stations in our proposed telemedicine QoS scheme, and they are 10% of the total stations in the simulated WLAN network. Similarly, RS (BS) denotes Regular Stations in the Baseline Scheme. ES+RS (EQoS, 10%) denotes the overall performance of all telemedicine and regular stations in our proposed EQoS scheme when there are 10% telemedicine stations in the simulated WLAN networks. Conversely, when there are 10% telemedicine stations, then there will be 90% regular stations, and when there are 20% telemedicine stations, there will be 80% regular stations. We can see that the percentage of the dropped data bits are considerably less for the telemedicine station in our proposed scheme, as expected.

It is also shown in Figure 10 that although the percentage of the dropped data bits for a regular station in our scheme is greater than that in the baseline scheme, this difference is not much larger as compared to that in the baseline scheme. Hence, even though in our proposed scheme we concentrate on the telemedicine stations, the performance degradation for a regular station is not that large. The graph also shows that there is a slight increase in the percentage of the dropped data bits for the telemedicine stations when their number is increased from 10% to 20%. However, for overall performance of all regular and telemedicine station, this increase is negligible. This may be due to less contention experienced by regular stations as the number of regular stations contending for the same channel has decreased.

We can also see that there is a steady increase in the percentage of the dropped data bits with the increased load for the telemedicine stations. This is due to the fact that EAMs reach the AP through a time division multiplexed channel. Hence, when one telemedicine station gains the channel access, the other telemedicine station has to wait until the first one completes its transmission. Thus, with an increasing load, more data bits will be dropped as the waiting time will increase.

Table 1. Simulation parameters and their values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid size</td>
<td>100*100 meters</td>
</tr>
<tr>
<td>Transmission range</td>
<td>30 meters</td>
</tr>
<tr>
<td>Traffic</td>
<td>Bursty</td>
</tr>
<tr>
<td>Network Scale</td>
<td>Office</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>900 seconds</td>
</tr>
<tr>
<td>No. of stations</td>
<td>10</td>
</tr>
<tr>
<td>No. of stations equipped w/ emergency channel</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 11 shows the average delay of the end-to-end transmission for the telemedicine stations and the regular stations vs. the average load for the station. As the load for the station increases, the average delay experienced by both the telemedicine and the regular station increases. However, the delay experienced by the telemedicine station is much less than the delay experienced by the regular station in our scheme. This is due to the fact that whenever a telemedicine station needs to send data to the AP, it can send an EAM over the emergency channel and get the channel access scheduled in a deterministic and negligible time period.
Figure 10. Percentage of dropped data vs. average load

Figure 11. Average delay vs. average load
However, regular stations have to contend with other regular applications (which results in non-deterministic delay) or wait to be polled by the AP before they can start sending their data.

Again, even though in our scheme we concentrate on improving the performance of the telemedicine stations, the performance degradation for a regular station is not much as compared to the regular station in the baseline scheme. This can be inferred from the curve showing the overall average delay experienced by all the telemedicine and the regular stations, which is slightly higher for our scheme as compared to the baseline scheme. The average delay experienced by the telemedicine stations increases when their number is increased from 10% to 20%. This is again due to the fact that at higher loads a telemedicine station will have to wait for a longer period until the telemedicine station, which has gained channel access earlier, has finished its data transmission.

CONCLUSION AND FUTURE WORK

Due to the highly erratic nature of the telemedicine emergency events, designing mechanisms to provide QoS based on traditional methods is not trivial, if not impossible. This is mainly because the traffic pattern based traditional scheduling QoS solutions cannot be used for telemedicine application. If resources are pre-reserved, it will result in a highly inefficient solution. On the other hand, the traditional on-demand QoS approaches are contention-based and may result in unbounded maximum delay, and therefore cannot ensure the QoS requirement of the delay intolerant telemedicine applications either. In this article, we proposed a novel mechanism to provide QoS for telemedicine applications. Our proposed dual channel-based QoS approach, where the slim express secondary channel is dedicated for transmitting short Emergency Alert Message (EAM), is an effective and simple method of providing QoS in ubiquitous telemedicine applications. The proposed solution uses the IEEE 802.11e standard as its baseline mechanism (Deng & Haas, 1998). The simulation results show that not only is this mechanism simple and efficient, but also it results in bounded maximum delay for the erratic emergency data transmission in telemedicine applications.

In the future, we will simulate and compare our proposed mechanism with the traditional QoS methods to estimate the overall performance improvements. We will also carry out an analysis on the maximum number of devices for telemedicine and general applications that an AP can accommodate simultaneously, given specific QoS requirements (e.g., maximum tolerable delay) of various telemedicine applications.

REFERENCES


c

APPENDIX A.

OVERVIEW OF IEEE 802.11E MAC

IEEE 802.11e (IEEE Std 802.1 WD3.3., 2002) has been proposed specifically to support QoS requirements. It introduces the concept of a Hybrid Coordination Function (HCF), which basically consists of two access schemes:

- The Enhanced Distributed Coordination Function (EDCF), which is an extension to the DCF in 802.11 to provide service differentiation via priorities, and
- The Hybrid Coordinator (HC), which is a modification to the existing Point Coordinator (PC) for more efficient polling schemes.

When using EDCF, multiple Access Categories (ACs) have been defined to provide QoS. Each AC uses the DCF; however with different values of the contention parameters DIFS, now called Arbitration IFS (AIFS). ACs with lower parameter values will experience lower mean waiting and backoff times and thus will have a relatively higher access priority to the medium. A station or a node which has multiple ACs in parallel will have internal contention between its own ACs in addition to the access contention with other stations.

According to the draft standard (IEEE Std 802.1 WD3.3., 2002), four different types of
services, voice, video, video probe, and best effort, are considered with each of them having their own AC. Table 2 lists the parameter values which have been assigned to each of the four ACs. The values are chosen in such a way that the highest access probability is given to the “voice” AC and the lowest one to the AC supporting the best effort data traffic.

Table 2. Contention parameter values for different ACs

<table>
<thead>
<tr>
<th>AC</th>
<th>AIFS</th>
<th>CW&lt;sub&gt;min&lt;/sub&gt;</th>
<th>CW&lt;sub&gt;max&lt;/sub&gt;</th>
<th>Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>15</td>
<td>1023</td>
<td>Best effort</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>15</td>
<td>1023</td>
<td>Video probe</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>7</td>
<td>15</td>
<td>Video</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>voice</td>
</tr>
</tbody>
</table>

In addition to the EDCF contention mechanism providing service differentiation, a polling-based access mechanism similar to the IEEE 802.11 PCF is also included in the 802.11e draft standard (IEEE Std 802.1 WD3.3., 2002). This polling scheme is controlled by a centralized hybrid coordinator (HC) located at the access point (AP). The HC can start a controlled access period (CAP) whenever needed, in order to poll traffic from the stations.

An important new attribute of the IEEE 802.11e MAC is that the station that obtains the medium access cannot utilize it longer than the duration greater than a specified limit. This attribute is known as a transmission opportunity (TXOP). A TXOP is defined by its starting time and duration. TXOPs obtained via contention-based medium access are referred to as EDCA-TXOPs, and TXOPs obtained by the HC via controlled medium access is referred to as HCCA-TXOP or polled TXOP. The duration of an EDCA-TXOP is limited by a TXOP-limit. This TXOP-limit is distributed regularly by the HC within an information field of the beacon.

Another enhancement is that no station can transmit across the target beacon transmission time (TBTT). This means that a station can send its frame only if it can be completed before the upcoming TBTT. This reduces the expected beacon delay, which gives the HC better control over the medium, especially if the optional contention free period (CFP) is used after beacon transmission.
Figure 12. Structure for the periodic superframe in IEEE 802.11e

Chunxiao Chigan is presently an assistant professor of electrical and computer engineering at Michigan Tech. Her research interests include vehicular ad hoc networks, wireless ad hoc and sensor networks, wireless network security, adaptive network protocol design for cognitive radio networks, dependable computing and communication systems, and network resource allocation and management. Prior to joining Michigan Tech, Dr. Chigan was a visiting scholar with the department of high performance communications system at Bell Labs, Lucent Technologies (Holmdel, NJ). She received the MS and PhD degrees in electrical engineering from the State University of New York, Stony Brook, in 2000 and 2002 respectively. Dr. Chigan is a recipient of the National Science Foundation CAREER Award (2007).

Vikram Oberoi is presently a senior systems consultant at Highmark, Pittsburgh, PA. He conducted his research in the areas of vehicular ad hoc networks, wireless ad hoc and sensor networks and wireless network security under the guidance of Dr. Chigan. Vikram Oberoi received his master’s degree in electrical engineering from Michigan Tech, Houghton, MI in 2005. He received his bachelor’s degree in electronics engineering from BDCOE, India in 2002.