Providing QoS in Ubiquitous Telemedicine Networks

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***Abstract* —Wireless LANs will play a critical role in providing anywhere and anytime connectivity for ubiquitous 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 (e.g., wireless hotspots in various locations). In the telemedicine application, it usually requires the periodic data and the data related to the occurrence of emergencies to be reported to the remote health care in a timely manner. Unlike the traditional QoS techniques which support voice and data applications, the sporadic nature of the emergency data in telemedicine systems makes it nontrivial to provide sufficient QoS support.**

In this paper, we first investigated several alternative schemes for emergency QoS support in the telemedicine systems. An express dual channel (EDC) based QoS provisioning mechanism is then proposed. Not only is the proposed mechanism simple and resource efficient, but also it provides the minimum delay for the unpredictable emergency data transmission. Simulation results show the proposed EDC based solution provides satisfactory QoS for ubiquitous telemedicine applications.

Keywords— Wirelesss LAN, Body Sensor Networks (BSNs), QoS, Access Point (AP), Delay intolerance.

I. INTRODUCTION

With the advances in ubiquitous networking technology, the realization of seamless connectivity to support "anywhere" and "anytime" communications becomes more and more plausible. In this paper we explore the telemedicine systems based on the ubiquitous networking. If the data related to patient's periodic monitoring reports and potential emergency situations 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 off. 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 etc. 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 central database. In detail, the BSN gateway fuses information from wearable, ingestible and implantable sensors to provide continuous diagnostic monitoring and generate early warnings. It also provides control over critical implantable devices such as drug delivery pumps. The emergency or the periodic data is then fused by a BSN gateway and relayed via a WLAN access point to remote health care centers. The communication between the WLAN access point and remote health care takes place via an all IP-based network.

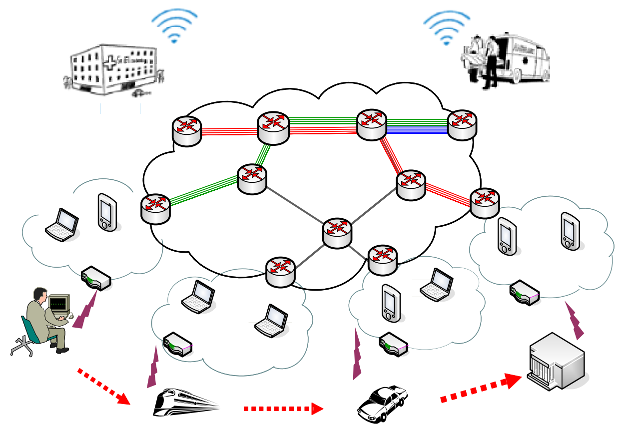

Figure 1: Example of Ubiquitous Telemedicine Application

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 in a *reliable* and *timely* manner. This paper focuses on the QoS provisioning between the BSN gateway and the wireless access point 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 these traffic are of certain predictability in terms of the traffic patterns. 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 a very difficult task if the traditional approaches of scheduling based on certain traffic patterns are applied for the QoS provisioning in telemedicine systems.

In this paper 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 paper is organized as follows. In section II, we present the related work and discuss the challenges and uniqueness of the QoS requirements in telemedicine applications. In addition, four alternative potential approaches to support QoS in telemedicine applications are

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also investigated in this section. Section III presents the details of our proposed Express Dual Channel (EDC) based QoS solution for telemedicine applications. In section IV, we present our simulation results and section V concludes the paper by presenting conclusions and future work.

II. UNIQUE QOS REQUIREMENTS IN UBIQUITOUS TELEMEDICINE APPLICATIONS

In this section we first discuss the unique QoS requirements and challenges for telemedicine applications. Then we discuss why the existing conventional approaches are not suitable to provide QoS support for such applications. Potential approaches that can be employed providing QoS support for telemedicine applications are then investigated.

A. UNIQUE QOS REQUIREMENTS

There are many solutions proposed to support the traditional wireless QoS applications where different classes of data demands are known in advance [1-9]. However, as shown in figure 2, 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 nature. Therefore, providing QoS support for emergency situations can be very tricky because of this erratic nature.

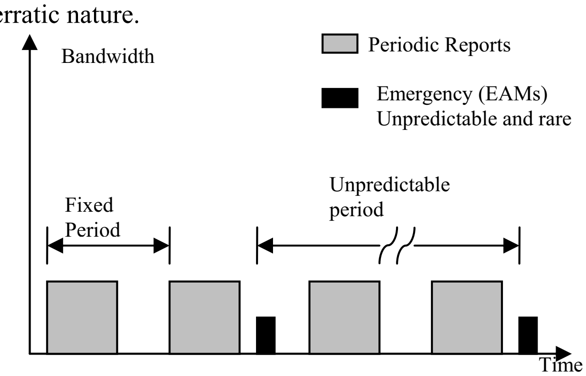

Figure 2: traffic pattern for a telemedicine application

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 of all, the emergency events in telemedicine application are extremely sporadic and may occur just once in several months/years.*** Hence, pre-reserving resources specifically for this kind of data can result in significant wastage of resources. On the other hand, ***although emergencies occur sporadically, emergency telemedicine data is extremely delay-intolerant.*** The telemedicine data traffic is indeed of bursty nature and it demands to be sent across as soon as possible. ***Therefore, the telemedicine application needs to have smooth network connectivity irrespective of the fact that telemedicine events occur sporadically.*** Thus, the traditional QoS solutions hardly suit the telemedicine applications.

B. POTENTIAL ALTERNATIVE QOS APPROACHES

Here we explore some potential approaches that might be suitable for QoS support in telemedicine applications.

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

2. *Dedicated Emergency Channel Approach:* This is an approach which reserves a whole separate channel for transmitting the emergency data. However as emergencies occur sporadically and follow the erratic pattern, this often leads to significant wastage of the resources.

3. *Dedicated Emergency Slot Approach:* Another 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 access to the telemedicine application. However, the beacon is sent out following the scheduled (determined) intervals, whereas emergencies are of highly unpredictable nature. Thus, if the emergency event occurs after the beacon was sent out, the emergency data cannot be transmitted until the next beacon period. In addition, since the emergency data has to be transmitted within the reserved slot, the periodic share of wireless channel access needs to be large enough to support at least one telemedicine application at a time. With the unpredictable nature of the emergency message, this *slot reservation based approach* is therefore subject to the wastage of resources as the *dedicated channel based approach*. In general, the larger the reserved slot, the less access delay the telemedicine applications (one or more) experience and the more significant the resource wastage is.

4. *QoS Support Based on IEEE 802.11e*: this approach uses the Hybrid Coordination Function (HCF) of the IEEE 802.11e standard to provide higher priority for the telemedicine applications. Under the HCF mode, since 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 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 etc. During the Contention Period (CP), all the stations contend for channel access via Enhanced Distributed Coordination Function (EDCF) (refer to appendix for details). 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

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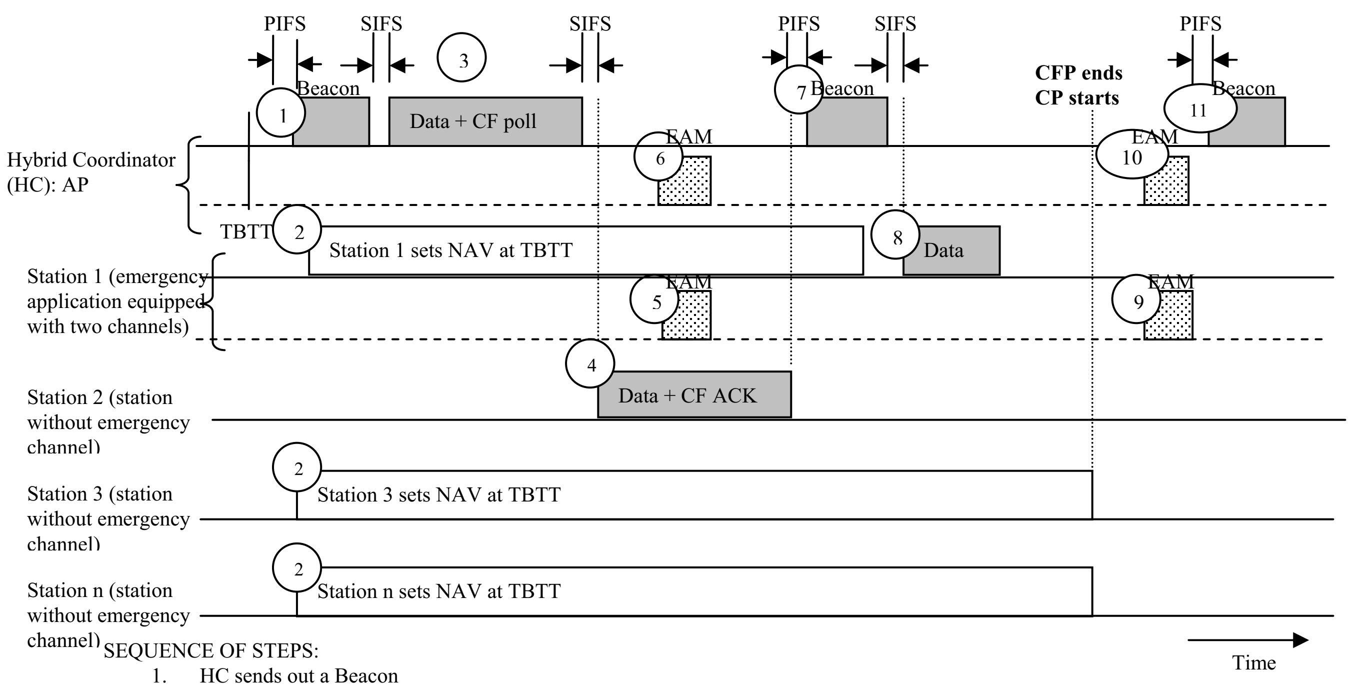
of highly sporadic nature which could render the traffic analysis and predication a very complex issue. Therefore, it would be very difficult to design a scheduling algorithm that can capture the sporadic nature of the emergency data.

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 the minimum delay for the unpredictable emergency data transmission.

III. EXPRESS DUAL CHANNEL (EDC) BASED QOS PROVISIONING FOR EMERGENCY APPLICATIONS

As described in section I, for the 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. 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) which are connected to the internet. Since 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/devices, In this context, our paper focuses on the QoS support for emergency applications by guaranteeing minimum delay of the public APs access, while at the same time minimizing the resource wastage due to the unpredictability of the emergency data.

To provide QoS guarantee for emergency applications supported by wireless LAN, we propose an Express Dual Channel (EDC) based QoS provisioning mechanism. To distribute the available bandwidth among the dominant primary data channel and the slim secondary emergency alert channel, Orthogonal Frequency Division Multiplexing (OFDM) [10], [12] or Frequency Division Multiplexing (FDM) [10] or Code Division Multiple Access (CDMA) can be used. With such a dual channel mechanism, the primary channel is dedicated to all data (both emergency and regular) transmission; the express secondary channel is very slim which is dedicated to the short emergency alert message (EAM) transmission. Therefore, as soon as the emergency occurred, the telemedicine application device sends out a short Emergency Alert Message (EAM) through the express secondary channel. Upon receiving the EAM alarm, the AP schedules (with the highest priority) to broadcast a beacon to all the applications in the network, indicating the reservation of resources for the emergency device. The AP itself can gain access to the primary channel



SEQUENCE OF STEPS:

1. HC sends out a Beacon
2. Stations 1 and 3 set their NAV accordingly
3. After SIFS, sends out the Data+CF Poll for the polled station (2)
4. Station 2 sends out the Data+CF ACK
5. Station 1 sends out an EAM over the emergency channel at the same time
6. HC receives EAM over emergency channel, terminates current transmission
7. Sends out a Beacon
8. Station 1 starts transmitting DATA after SIFS.
9. In CP all nodes use CSMA/CA to contend for the channel, station 1 sends out EAM over emergency channel
10. HC receives EAM over emergency channel
11. HC sends out a beacon over primary channel, now station 1 can start sending data

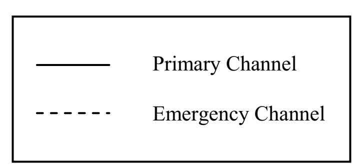


Figure 3: channel access during the Contention Free Period (CFP) and Contention Period (CP)

with the highest priority under the Hybrid Coordination Function (HCF) mode supported in IEEE 802.11e [11]. Only devices with emergency requirements and the AP are equipped with the dual channels. With this reserved secondary channel, the short EAM can arrive in a timely manner at the AP. The reserved secondary channel therefore requires very small amount of bandwidth.

Figure 3 gives an in-depth description of the wireless channel acquisition for the express dual channel based emergency applications. Station 1 supports telemedicine application 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).

Let us first have a look at channel access during CFP. 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 when an emergency happens at emergency station 1, it sends out an EAM over the secondary express emergency alert channel to the AP. Once the AP receives this EAM, it terminates the TXOP of station 2 and sends out a beacon frame over the primary channel after waiting for the Point (coordination function) Interframe Space (PIFS) duration. This beacon indicates the reservation of the primary channel for emergency station 1 and grants the TXOP to station 1 for the required duration. Stations 2 and 3 can set their NAVs' accordingly.

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 periodic reports we apply the IEEE 802.11e standard. For details of IEEE 802.11e MAC, please refer to [11]. Such periodic data reports of telemedicine applications are grouped into a separate category with the second highest access priority at the primary data channel.

There are 3 classes of queues are maintained at the AP in the proposed telemedicine QoS mechanism. The emergency data 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. The proposed Hybrid "Emergency First" and "Fair Queue" algorithm works as follows: the AP processor always checks the Emergency data 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 completion of any message processing, the AP proceed to checks the Emergency data queue first and then the other queues.

IV. SIMULATIONS

We used Opnet 8.1A for simulating the proposed QoS solution. Figure 4 shows the average percentage of the dropped data for the telemedicine stations and the regular stations versus 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 stations. In the baseline scheme all the stations are considered as regular stations as opposed to our scheme in which stations are divided among telemedicine stations and regular stations. ES (Emergency QoS, or EQoS) (10%) denotes Telemedicine stations 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 combined performance of 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.

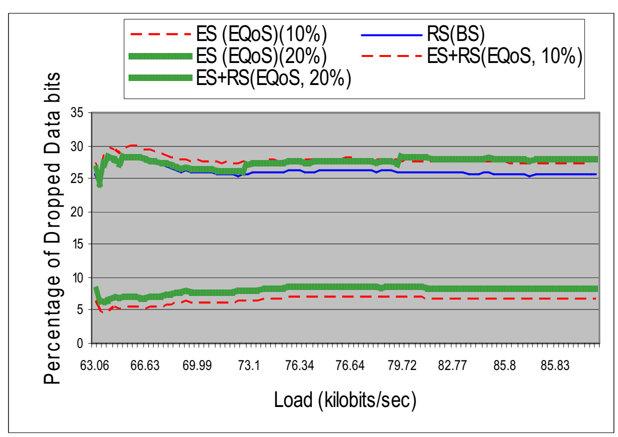


Figure 4: percentage of dropped data bits versus average load

It is also shown in figure 4 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 our scheme concentrates 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 station when their number is increased from 10 to 20%. However, for regular and telemedicine station combined case, 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 dropped data bits with the increased load for the telemedicine stations. This can be 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 increasing load more data bits will be dropped as the waiting time will increase.

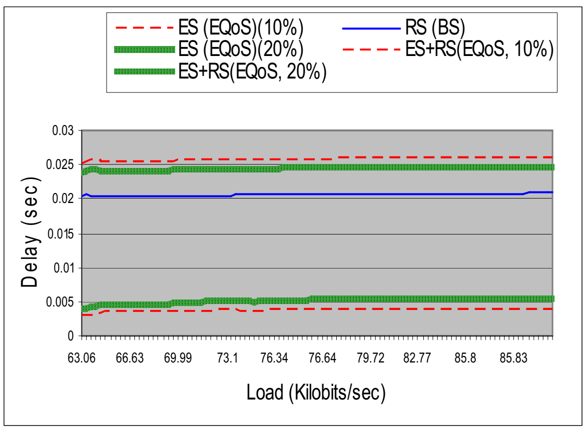


Figure 5: average delay versus average load

Figure 5 shows the average delay of the end-to-end transmission for the telemedicine stations and the regular stations versus 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 increase. However the delay experienced by 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. However, regular stations have to contend with other regular applications 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 combined delay experienced by the telemedicine and the regular station, which is slightly higher for our scheme as compared to the baseline scheme. The 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.

V. CONCLUSION

In this paper, we propose a novel mechanism to provide QoS for telemedicine applications. Due to the highly erratic nature of these events, designing a protocol to provide QoS based on conventional methods is not trivial. This is mainly because the facts that traffic pattern based scheduling traditional QoS solutions can not be used for telemedicine application. If resources are pre-reserved, it will result in a highly inefficient method. Thus, our proposed dual channel based approach, where the slim express secondary channel is dedicated for transmitting short Emergency Alert Message (EAM), can be a very effective and simple method of providing QoS in ubiquitous telemedicine applications. The proposed solution uses the IEEE 802.11e standard as its baseline mechanism [11]. The simulation results show that not only is this mechanism simple and efficient, but also it results in the minimum delay demanded by the erratic data transmission in telemedicine applications.

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