Design of Adaptive IEEE 802.11 WLAN in Hospital Environments

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***Abstract*—In this paper, we propose an adaptive tuning scheme of IEEE 802.11 WLAN for healthcare applications. Our proposed method can significantly improve medical-grade quality of service (QoS) and network performance at the same time. Though the conventional IEEE 802.11e protocol supports a certain level of QoS, it does not provide medical-grade QoS due to its relative priority among different traffic classes. Our proposed scheme adaptively tunes the arbitrary inter frame space number (AIFSN) of the IEEE 802.11e protocol for enhancing the overall network performance while providing the required medical-grade QoS. In our healthcare scenario, we consider the following three medical traffic categories: medical alarm, real-time electrocardiogram (ECG) transmission, and TCP connection. Our simulation results show that the proposed scheme improves the performance of low-priority TCP traffic while protecting high-priority medical alarms from lower priority traffic.**

I. Introduction

Today's hospitals are adopting more and more wireless technologies, not only to reduce the deployment cost and provide patients increased mobility, but also to improve the system reliability over the so-called "malignant spaghetti" (crisscross of cables from various medical devices) [1], [2]. However, due to the unpredictable wireless channel condition, the main obstacle to successful deployment of wireless technologies in healthcare facilities is how to guarantee the required quality of service (QoS) of medical applications, i.e., *medical-grade QoS*.

Currently, the leading companies in healthcare IT are suggesting IEEE 802.11 WLAN as a feasible solution for healthcare applications [3]–[5]. However, there has been little research efforts on how to efficiently design medical-grade WLAN. One exception is an enhanced WLAN protocol in [2], which can provide absolute priority among different medical traffic that are categorized according to their urgency. However, the scheme in [2] does not pay much attention to the overall network throughput performance.

In this paper, our objective is to design adaptive IEEE 802.11 WLAN for healthcare facilities. We focus on the following medical traffic classes: medical alarm, real-time monitoring data, and TCP transmission. We assign priority to each of the above traffic according to their urgency as shown in Table I. Then, we propose an adaptive tuning mechanism for IEEE 802.11 WLAN, which can improve the overall network throughput performance while providing the required medical-grade QoS at the same time.

TABLE I
PRIORITIZATION OF MEDICAL APPLICATIONS.

Access Category	Priority	Medical application
AC0	Highest	Medical alarm
AC1	High	Real-time monitoring
AC2	Medium	TCP transmission
AC3	Lowest	Non-medical applications

The rest of the paper is organized as follows: In Section II, we show that the conventional IEEE 802.11e protocol is insufficient in medical environments due to its relative priority among classes. Then, in Section III, we describe our algorithm for tuning the arbitrary inter frame space number (AIFSN) of IEEE 802.11 WLAN. Performance comparison with the conventional IEEE 802.11e protocol and the absolute priority scheme in [2] is given in Section IV. Our conclusion with future research avenues is given in Section V.

II. Motivation

In Table I, we map medical applications into the access categories of the conventional IEEE 802.11e protocol, which is a natural categorization of the medical traffic according to their urgency. The actual protocol parameter values for each category can be found in Table II.

In order to show that the conventional IEEE 802.11e is insufficient to provide medical-grade QoS, we carry out simulation with the coexistence of all the three categories of medical alarm, real-time monitoring, and TCP transfer. Fig. 1 shows that the ratio of delayed alarm significantly increases as the number of nodes increases. Here, the critical issue is that the absolute priority of medical alarm is not guaranteed with the conventional IEEE 802.11e even when the network is unsaturated.

The main reason is the priority inversion caused by the AIFSN and the contention window (CW) assignment given in Table II. According to the categorization in Table I, alarms and real-time monitoring have the same AIFSN with different CW values. This assignment implies that alarm and real-time monitoring have the same chance to go into the backoff state.

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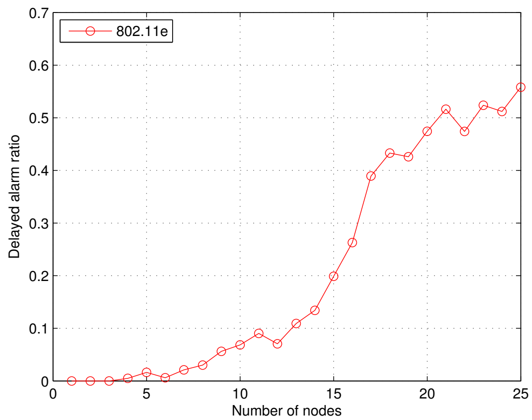

Fig. 1. Ratio of delayed alarm packets over total received alarm packets.

TABLE II
DEFAULT VALUES FOR ENHANCED DISTRIBUTED CHANNEL ACCESS (EDCA) PARAMETERS AND ACCESS CATEGORIES.

	AIFSN	CW_{MIN}	CW_{MAX}
AC0 (high)	2	7	15
AC1	2	15	31
AC2	3	31	1023
AC3 (low)	7	31	1023

Since the backoff timer is randomly chosen according to CW, there exists a certain probability that real-time monitoring traffic takes the channel if it picks up a smaller CW value than alarm.

In the meantime, the scheme in [2] can provide absolute priority for high priority medical traffic. However, this absolute priority scheme does not consider the network throughput performance. Consequently, it is required to develop an adaptive scheme that can give more chance to lower priority traffic if possible while guaranteeing the absolute priority of urgent traffic as the network traffic increases.

III. PROPOSED ALGORITHM

There exist quite extensive studies for improving performance of the conventional IEEE 802.11e, e.g., [6], [7]. However, most of existing algorithms adjust the CW value mainly because they do not need absolute priority among traffic classes. Unlike these existing work, we focus on tuning the AIFSN to consider both the network throughput performance and priority guarantee. In IEEE 802.11e, AIFS is determined as follows:

$$\text{AIFS}_i = \text{SIFS} + \text{AIFSN}_i * \text{Slot time}.$$

Fig. 2 shows the proposed algorithm. In a nutshell, it tunes the AIFSN value with respect to network traffic condition. We introduce two metrics for changing the AIFSN, i.e., delay of alarm and ratio of delayed ECG. According to the QoS requirements for medical applications in [1], we assign 200 ms as the maximum allowable latency for alarms. In order for

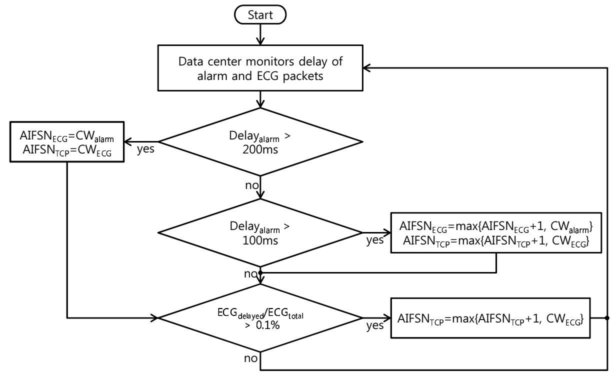

Fig. 2. Proposed algorithm for tuning the AIFSN value.

early handling of priority inversion situation, we set 100 ms as the threshold for alarm delay. Similarly, we assign 0.1 % as the threshold for the ratio of delayed ECG. If either the delay of alarm or the ratio of delayed ECG is larger than the threshold, we adjust the AIFSN of lower priority traffic in order to give more priority to alarm and ECG. In addition, if the situation is serious with alarm delay larger than 200 ms, the AIFSNs of all the traffic priority lower than alarm are set to the pre-defined maximum values.

IV. PERFORMANCE EVALUATION

In our simulation, we consider alarm, ECG transmission as real-time monitoring traffic, and TCP file transmission in each category of medical applications. We use ns-2 [8] as a simulator to compare the performance of the following three schemes: the conventional IEEE 802.11e, absolute priority scheme [2], and the proposed algorithm.

For completeness, we briefly explain the main idea of the absolute priority as given in (1).

$$\text{AIFS}_i = \begin{cases} \text{AIFS}_0, & \text{if } i = 0, \\ \text{AIFS}_{i-1} + \text{CW}_{i-1}, & \text{otherwise.} \end{cases} \quad (1)$$

For the highest priority traffic, i.e., $i = 0$, it gives the smallest AIFS. Hence, lower priority traffic has to wait its higher priority's AIFS plus CW. In this manner, high priority traffic does not have to contend with low priority and will always be a winner in channel access regardless of the amount of the lower priority traffic. However, absolute priority is so strict that lower priority traffic should wait for a large AIFS even without any high priority traffic, which is a waste of network resource.

Fig. 3 shows the ratio of delayed alarm packets for the conventional IEEE 802.11e, absolute priority, and proposed algorithm. As we have already shown in Section II, the IEEE 802.11e protocol gives poor performance as the number of nodes increases. On the other hand, both the absolute priority and the proposed algorithm give no delayed alarm at all, which shows the effectiveness of the proposed algorithm in terms of medical-grade QoS.

In Fig. 4, the ratio of delayed ECG packets is shown. The ratio of the IEEE 802.11e protocol significantly increases with

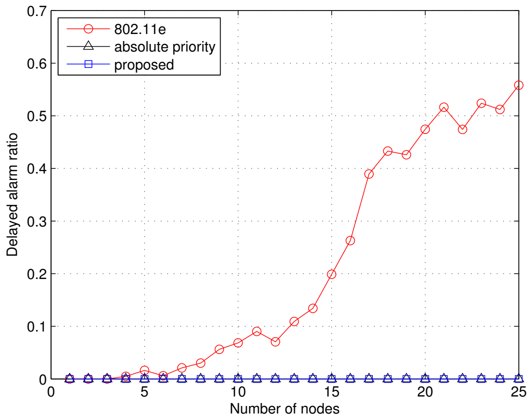

Fig. 3. Ratio of delayed alarm packets over total received alarm packets.

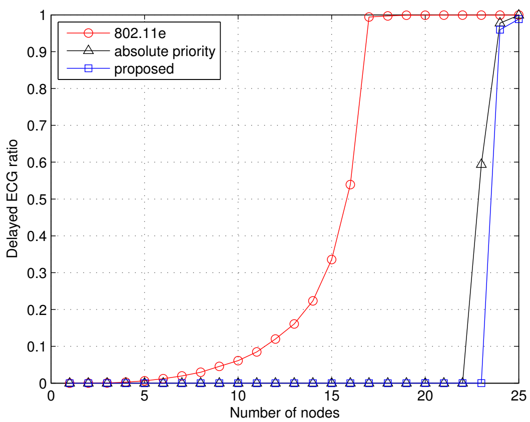

Fig. 4. Ratio of delayed ECG packets over total received ECG packets.

more than 15 nodes, which saturates with 17 nodes. In the meantime, absolute priority and the proposed algorithm remain around zero until 22 and 23 nodes, respectively. We speculate that the increase of the ratio after these points may imply the saturation of network capacity. We will further investigate this issue in our future work.

Fig. 5 shows the TCP performance. It should be noted that absolute priority and the proposed algorithm gives larger AIFS for TCP transmission than IEEE 802.11e. However, even with shorter AIFS, IEEE 802.11e gives worse TCP performance due to more frequent collisions. Because the absolute priority scheme suppresses low priority, our proposed algorithm gives better performance for TCP transfer. In summary, we can conclude that the proposed scheme can provide medical-grade QoS with improved lower priority performance.

V. Conclusion and Future Work

We have proposed an adaptive scheme for tuning the AIFSN value according to network traffic condition. The proposed method improves the overall network throughput performance while maintaining the required medical-grade QoS. We have

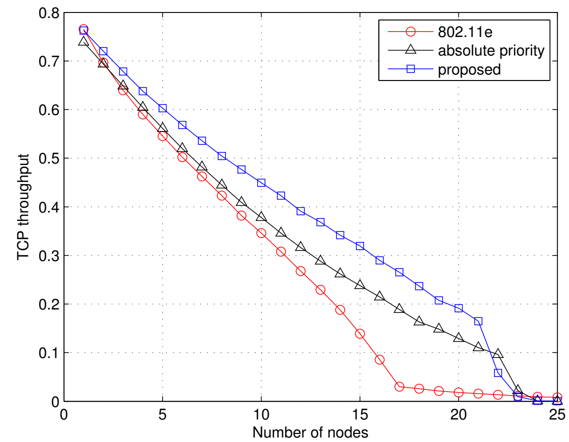

Fig. 5. TCP throughput performance.

compared the proposed algorithm with the conventional IEEE 802.11e protocol and the absolute priority scheme proposed in [2]. Our simulation results show that our scheme gives better TCP performance and also provides the required QoS for medical alarm. In our future work, we will investigate the capacity of IEEE 802.11 WLAN for medical applications in an analytical manner. With the analysis, we expect that we can further develop an admission control algorithm on top of the proposed scheme to further enhance the performance of medical WLAN.

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