Contention Window Adaptation for Coexistence of WBAN and WLAN in Medical Environments

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***Abstract*—The increasing use of wireless networks and the constant miniaturization of electronic devices have empowered the development of wireless body area networks (WBAN). In this paper, we focus on the coexistence problem of WBAN and wireless LAN (WLAN) in medical environments. In order to resolve the unfairness issue caused by coexistence, we propose a novel contention window adaptation scheme for achieving efficient channel sharing by considering network performance and fairness at the same time.**

I. Introduction

The dramatic use of wireless networking technologies as well as the constant miniaturization of electronic devices have enabled the development of wireless body area networks (WBAN). In addition, electronic healthcare (e-healthcare) is coming into the spotlight and is widely adopted in various medical environments [1].

In medical environments, WLAN can also be used in addition to WBAN, both of which usually operates in the same 2.4 GHz ISM band. Furthermore, both technologies adopt the CSMA/CA mechanism to access the channel. WBAN is typically used to collect vital signals from on-body sensors while WLAN is used to transmit collected data to remote destinations. Consequently, a fundamental coexistence issue between WBAN and WLAN arises in medical environments.

In this paper, we deal with the problem of coexistence between WLAN and WBAN. In particular, coexistence of WLAN and WBAN results in performance degradation of WBAN because WBAN adopts smaller transmit power level than WLAN, i.e., 15 dBm for WLAN and 0 dBm for WBAN. Consequently, a WBAN node can hear transmissions of WLAN and defer its transmission while a WLAN node may ignore those of WBAN, which is called asymmetric interference. Another problem is collision due to different response times. The time slot of WBAN is 320 μs while that of WLAN is 9 μs [2], [3]. Therefore, a WLAN node often terminates its carrier sensing within the switching time of a WBAN node, which results in collision.

In order to resolve these two key issues in coexistence of WLAN and WBAN, we propose a novel contention window adaptation scheme for WLAN in order to achieve efficient channel sharing by considering performance and fairness at the same time. Then, we conduct simulation to show the effectiveness of the proposed scheme over the conventional one.

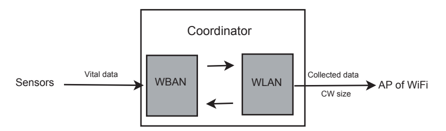


Fig. 1. Proposed coordinator architecture for WLAN and WBAN coexistence in medical environments.

II. Problem Formulation

As shown in Fig. 1, we consider a coordinator, which makes a signal path between WBAN and WLAN in our system architecture to exchange information in every monitoring interval of T_{ae}. This information includes the aggregate throughput of WLAN, TH_{wlan}, the number of nodes of WLAN, N_{wlan}, the aggregated throughput of WBAN, TH_{wban}, and the number of nodes of WBAN, N_{wban}. Using these information, the coordinator calculates the total throughput η_{eff} as follows:

$$\eta_{eff} = TH_{wlan} + TH_{wban}.$$

Also, we introduce an objective function $\mathcal{F}$ for adjusting the contention window of WLAN as follows:

$$\mathcal{F}(CW_{wlan}) = w\frac{\eta_{eff}}{C_{max}} + (1-w)\mu_{fair}, \quad (1)$$

which is a linear function of normalized efficiency η_{eff}/C_{max} and a jain's fair index μ_{fair} both of which are less than one [4]. Here, C_{max} is an ideal maximum capacity calculated under the assumption that there are no collision and interference, which corresponds to the case of the transmission rate and the minimum contention window. Also, μ_{fair} in (1) is calculated as

$$\mu_{fair} = \frac{\left(\frac{TH_{wlan}}{N_{wlan}} + \frac{TH_{wban}}{N_{wban}}\right)^2}{2\left[\left(\frac{TH_{wlan}}{N_{wlan}}\right)^2 + \left(\frac{TH_{wban}}{N_{wban}}\right)^2\right]}. \quad (2)$$

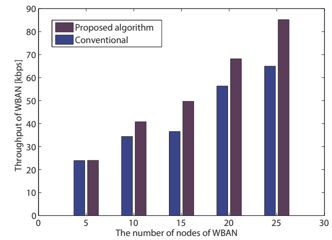
Here, we use a weighted fairness, i.e., TH_{wban} is replaced with $K \cdot TH_{wban}$ where K is an arbitrary value in order to balance between TH_{wban} and TH_{wlan} because TH_{wban} is too smaller than TH_{wlan}. In the meantime, w is a weight factor with $0 \leq w \leq 1$, which can be controlled according to the tradeoff between efficiency and fairness in the channel sharing.

Since $\mathcal{F}(CW_{wlan})$ is unimodal and concave with respect to CW_{wlan}, there exists an unique optimal value that maximizes $\mathcal{F}$ [5]. In addition, due to the dynamic nature of wireless channels, it is important to adaptively control the contention window size of WLAN. Therefore, the weight factor is controlled according to the measured delay of WBAN T_d. More specifically, if the current value of T_d is smaller than the delay requirement of T_{req}, the weight factor will be increased to give more transmission opportunity to WLAN. On the contrary, if T_d exceeds T_{req}, the weight factor will be decreased to give more fairness to the networks. Then, the coordinator estimates the objective function (1) and uses a golden section search algorithm [6] to find the optimal contention window size of WLAN in every T_{ae}.

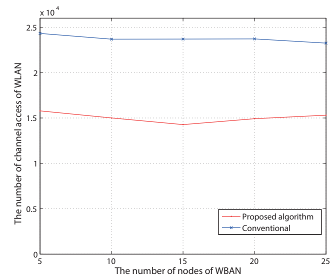
III. Performance evaluation

We conduct numerical simulations to validate the performance of our proposed algorithm. We develop a customized simulator which includes the CSMA/CA mechanism. Here, in order to incorporate medical applications, we assume that the WBAN nodes carry the Electrocardiogram (ECG) data with the data rate of 4 Kbps. In the meantime, the inter-arrival time of WLAN traffic follows a Poisson random variable with a mean value of 5 ms. Also, we set T_{req} as 50 ms for adjusting the contention window size of WLAN nodes. And weighted fairness factor K is set to 1000 and initial value of w to 0.5 in simulations.

As performance metrics, we measure the throughput and the delay of WBAN nodes. First, we show the throughput of WBAN nodes with respect to the number of WBAN nodes when there are 10 WLAN nodes. Fig. 2(a) shows that our proposed algorithm increases WBAN throughput, which results from the fact that the increased contention window size of WLAN gives more channel access chances to WBAN nodes. Also, Fig. 2(b) shows total number of channel access that the performance of WLAN is insignificantly affected. Second, Fig. 3 shows the average packet delay of WBAN traffic with respect to the number of WLAN nodes when there are 20 WBAN nodes. The required quality of service (QoS) for ECG traffic is that the ECG packet delay should be less than 300 ms [7]. We observe the delay of the proposed algorithm is less than 100 ms, which validates the effectiveness of the proposed scheme.



(a)



(b)

Fig. 2. The performance of the proposed algorithm when there are 10 WLAN nodes. (a) Throughput of WBAN (b) The number of WLAN channel access

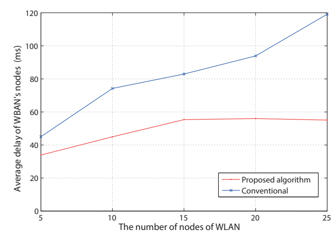


Fig. 3. Average packet delay of WBAN with respect to the number of WLAN nodes when there are 20 WBAN nodes.

IV. Conclusion

In this paper, we focus on the coexistence problem for medical environments of WBAN (IEEE 802.15.4) and WLAN (IEEE 802.11) in the 2.4GHz ISM band. Under coexistence, the performance degradation of conventional WBAN is inevitable because of asymmetry of the transmission power and the response time. In order to resolve the asymmetric performance and to guarantee the required medical QoS, we propose a novel contention window adaptation scheme. The proposed method adaptively tunes the contention window size of WLAN by observing the delay of WBAN so that the performance of WBAN is maintained at a certain pre-specified level. Simulation results show that our proposed scheme provides better throughput and smaller delay of WBAN without significantly affecting the performance of WLAN.

Acknowledgments

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