Master's Thesis
석사 학위논문

An Adaptive Coexistence Mechanism between WLAN and WBAN in Wireless Medical Environments

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MS/IC 201123013

윤 솔. Sol Yoon. The study of An Adaptive Coexistence Mechanism between WLAN and WBAN in Wireless Medical Environments. Department of Information and Communication Engineering. 2013. 42P.
Advisors Prof. Kyung-Joon Park, Co-Advisors Prof. Sung Bae Lee.

ABSTRACT

Electronic health (E-Health) is being recognized as a method to improve the overall health status of the population. For this reason, medical wireless communication technology has been actively studied to realize E-health. Unlike wired communication, the use of wireless communication remains to provide ubiquitous connectivity; it allows better access and enables greater physical mobility to patients. Among the various wireless technologies, WLAN (IEEE 802.11/WiFi) and WBAN (IEEE 802.15.4/ZigBee) are widely used for e-healthcare system. However, interoperability and coexistence between these two heterogeneous networks are becoming key issues. ZigBee is potentially vulnerable to interference by WiFi in the same unlicensed ISM band. Most of all, the significantly different power level and asynchronous time slots result in significant unfairness between WLAN and WBAN. In this thesis, we focus on the coexistence environment beween WLAN and WBAN for e-healthcare systems in the ISM band.

We propose an adaptive coexistence CSMA mechanism which can mitigate interference and achieve efficiency channel sharing. By using an efficient throughput model, we control and find an appropriate adaptive contention window size of WLAN in order to give transmission opportunities to WBAN. This proposal can guarantee the required medical-grade QoS of WBAN without any significant degradation of the throughput of WLAN. The simulation results using MATLAB confirm that the proposed algorithm operate to make efficient channel sharing compare with conventional approach. As a result, the proposed coexistence CSMA protocol guarantee reliable healthcare system and provide better QoS of WLAN and WBAN in medical environments.

Keywords: Wireless Local Area Network (WLAN), Wireless Body Area Network (WBAN), Coexistence, E-health, CSMA

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Ⅰ. INTRODUCTION

The importance of medical services is being emphasized as elderly population increases. The rapidly aging population not only causes long hospital waiting times and expensive hospital stays, but also requires a lot of health manpower. Managing the cost and quality of treatment and caring for seniors is becoming big issues in both developed and developing countries [4]. For this phenomenon, electronic healthcare (e-healthcare) is coming into the spotlight and is greatly demanded in the medical environment [5]. According to the Food and Drug Administration (FDA), the global e-healthcare market is growing at a rate of 20 percent every year [6]. E-healthcare system integrates information processing and communications technologies for providing healthcare services. Specially, wireless communications technologies are used to support a variety of e-health applications. Wireless communication is a significant technology to improve mobility and service flexibility for various medical applications such as telemetry and telemedicine [7]. In addition, the installation and long term running cost of wireless systems will reduce the overall cost and easier to upgrade [4], [8]. However, wireless communication is less reliable than wired communication, which means that the wireless technology may delay and degrade of data transmission. Thus, we should overcome several challenges for successful deployment of wireless technology in medical applications [9] .

Among many wireless technologies that can be applied in medical environments, we focus on the wireless LAN (IEEE 802.11/WiFi) and wireless BAN (IEEE 802.15.4/ZigBee) for e-healthcare systems. WLANs and WBANs are becoming more and more popular with increasing presence in hospitals and homes because both are operating in the unlicensed frequency bands, which is called the Industrial Scientific and Medical (ISM) bands. WLANs are expected to be a major component to enable an integrated hospital and home networks. The reason is that it can provide higher capacity at a small cost in limited range scenarios [1]. WBANs are designed to provide connectivity between low power devices to be used for applications such as sensor networks [10]. Especially, IEEE 802.15.4/ZigBee, which is used for WBAN with a low data rate, is useful for real-time critical applications such as on-body sensors [8]. The increased use of WLAN and WBAN in medical application cause the coexistence issue when they use same frequency such as 2.4 GHz ISM band. In this thesis, we focus on the coexistence environment between WLAN (IEEE 802.11/WiFi) and WBAN (IEEE 802.15.4/ZigBee) for e-healthcare systems. The operation of WBAN with WLAN in the 2.4 GHz ISM band, brings challenges such as spectrum utilization, interoperability and the notable interference issue. Interference refers to frame collisions between mutual or same wireless technologies. This is a serious problem for health monitoring system which requires strict quality of service (QoS) guarantee. Interference degrades network throughput and hampers the deployment of multi-standard wireless communications in health monitoring systems.

In this thesis, we derive the optimal value of the physical carrier sensing threshold (CSTH) and propose adaptive control of the CSTH. We focus on the fair and efficient contention-based coexistence of heterogeneous networks that are asymmetric in terms of the transmission power and coverage. We propose CSMA protocol which adaptively controls the contention widow size for effective channel sharing. The rest of this thesis is organized as follows. In Section II, we review existing studies on the coexistence of heterogeneous wireless networks. In Section III, we deploy the background information of IEEE 802.11 WLAN and IEEE 802.15.4 for WBAN. In section IV, we study why the coexistence matters and state the main cause of unfair channel sharing among heterogeneous networks. There are several reasons such as asymmetry carrier sensing and different response time. We prove the problem situations by using MATLAB simulation. . In section V, We analyze the feasibility of CSTH control and derive an analytical model for the system throughput. Moreover, we propose a novel CSMA protocol for achieving efficient channel sharing. It can guarantee proper operation of WBAN with minimal degradation of the WLAN performance. Section VI presents simulation results in order to evaluate the performance of the proposed mechanism compared with preliminary simulation results. Then, we conclude this thesis in section VII.

Ⅱ. Related Work

2.1. Collision of ZigBee and WiFi

The interference between WiFi and ZigBee has been widely studied in both the industry and the research communities. According to these studies, WiFi is known to suffer less from collision with ZigBee and can recover loss via retransmission even under severe inference. However, in the meantime, ZigBee performance is severely degraded even with moderate WiFi traffic.

Pollin et al. [3] found that WiFi may interrupt ZigBee transmissions even when they are not located close to each other. Similar results have been observed in other measurement studies and real-world applications. The amount of WiFi traffic in a building or enterprise environment is increasing with the multiplication of WiFi devices and high rate of use of applications. Thus, the reliability of ZigBee WPANs used to monitor and control applications is severely affected by WiFi. Even when ZigBee is executing a listen-before-send, which should theoretically prevent interference, a significant WiFi performance degradation frequently occurs due to disparate slot sizes between two protocols [3].

Gummadi et al. [11] reported that ZigBee experiences a median packet-loss rate of 20%, and the loss could exceed 85% due to WiFi interference. This problem still occurs even when they enable carrier sensing and packet retransmission. Metronome exploits monitor mobility to scale up to a large metropolitan area while maintaining measurement accuracy of signal and interference levels experienced at the receivers. When they measured with testbed, WiFi did not have packet losses when co-located with multiple ZigBee devices. In the meantime, TCP latency increased by about 5% [11].

Yuan et al. [12] analyzed the packet error rate (PER) of IEEE 802.15.4 under the IEEE 802.11b interference with an assumption of blind transmissions. They reported that both IEEE 802.11b and IEEE 802.15.4 transmit packets regardless of whether the channel state is busy or not. To resolve this problem, they proposed a coexistence model of IEEE 802.15.4 wireless sensor networks (WSNs) and IEEE 802.11 b/g WLANs. Although the model depicted the coexistence behavior well in general, owing to some implementation factors that were not considered, it failed to precisely explain some coexistence performances in a real-life environment. The proposed model was experimentally validated, but only very limited quantitative analysis was given [12].

2.2. Existing Coexistence Mechanisms

We can expect to apply the frequency planning method for coexistence environments. However, this approach is ineffective when WLANs are unmanaged and may change channels unpredictably. The approach is also ineffective when WLANs are densely deployed, because there are only three non-overlapping channels between WiFi transmissions, and channels can opportunistically occupy the majority of 2.4GHz Industrial Scientific and Medical (ISM) bands. When WiFi traffic becomes intensive, ZigBee may adaptively switch to other idle channels. However, this approach does not solve bursty collisions, it responds only after a collision has already occurred. Adaptive channel allocation also causes a long “blackout time” due to scanning and re-association.

In [13], WISE is introduced, which is an alternative coexistence mechanism to resolve the problem. It aims to enhance coexistence in the temporal domain. WISE manages the white spaces between WiFi transmissions, and opportunistically schedules ZigBee traffic. However, WISE attempts to delay ZigBee transmissions when the WiFi channel experiences burst.

Therefore, it is not suitable for time division multiple Access (TDMA) mode or delay sensitive applications [13].

In WiCop, Y. Wang et al. proposed a policing frame work that can effectively control the temporal whitespaces between WiFi transmissions [14]. They propose two policing schemes i) Fake-PHY-Header, ii) DSSS Nulling. In the Fake-PHY-Header scheme, they add a policing node to the WBAN. The policing node runs the WiCop framework by properly sending policing signals and controlling the WBAN operations. Then, each WBAN polling period begins with a policing node broadcast in the temporal domain, which is called a Fake-PHY-Header. In the DSSS Nulling scheme, they generate a policing signal to create spaces for WBAN signals. By using these two schemes, WiCop raised WBAN packet delivery rates by up to 40%. However, if this proposal were applied to medical environments, we cannot guarantee reliability of the WiFi signal and the added policing node may make it unmanageable to use commercial off-the-shelf (COTS) [14].

Existing solutions focus on how much performance of WBAN can be improved. However, we will focus on the fair and efficient coexistence of heterogeneous networks that are asymmetric in terms of transmission power and coverage. Unlike the previous approaches, the proposed scheme adaptively controls the contention window for fair channel sharing without degrading the efficiency of channel sharing.

Ⅲ. Background

3.1. Wireless Networking in Healthcare

Recently, medical wireless communication technology has been actively studied to provide high quality services and reduce medical care costs for rapidly growing aging populations [8]. It has various benefits such as mobility, reliable performance, secure transmission for mission-critical applications, interoperability, etc. The IEEE 1073 group is currently developing guidelines for using wireless communication technologies for medical device communications in various healthcare environments [15]. In fact, there is a wide range of potential applications and use case scenarios, For example, from a patient's hospital bedside to a doctor's office. Medical applications such as real-time streaming data and alarm notifications have very strict requirements in terms of accuracy or latency. Accordingly, delivering the highest level of reliability and availability is a serious concern for communications infrastructure in healthcare environments. Table 3.1 summarizes the requirements of several medical applications. We can classify the medical applications in categories, according to their QoS requirements.

WiFi (IEEE 802.11 WLAN) and ZigBee (IEEE 802.15.4) are the most commonly used wireless technologies in medical networks. For instance, wireless telemetry sensors can be applied to WBAN which are attached to patients for sending a data to a PDA or laptop. The WBAN is generally used for real-time critical applications. The WLAN are used for real-time applications as well. However, in this thesis, we assume that WLAN is applied to non-medical applications. The devices, that used WLAN, can continuously transmit data to a central control workstation in our scenario. We consider that the requirements of WLAN and WBAN by following Table 3.1.

Table 3.1. Medical applications requirements [8].

Applications	Requirements				
	Bandwidth	Delay	Data loss	Reliability	Ubiquity
Remote control apps. (e.g., Control/settings)	Very low bandwidth. << 1kb/s	Require low delays. < 3-5 sec	Cannot tolerate data loss. No detectable loss.	These applications have very high reliability requirements.	Do not require mobility support, as the patient would be attached to some medical device that prevents mobility.
Real-Time critical apps. (e.g., Waveforms, physiological parameters)	Generally require continuous low bandwidth. 10 – 100 kb/s	Require low delays. < 300 msec	These are life critical applications and cannot tolerate data loss. $\sim 10^{-6}$	These applications have very high reliability requirements.	Require very efficient mobility support, as no data can be lost when the patient is moving or being relocated
Real-Time non-critical apps. (e.g., Video, audio)	Variable from low (voice) to high (video streaming) bandwidth. 10 kb/s - 1 Mb/s	Require low to moderate delays. 10 msec - 250 msec	These applications tolerate low data loss. $< 10^{-4}$	Reliability is important, but not critical.	Require efficient mobility support to avoid high delays and reduce packet loss.
Office/Medical IT (e.g., Web browsing)	Require high bandwidth. ~1 - 10 Mb/s	Tolerate moderate to high delays, although low delay is always desirable. < 1 sec	Tolerate some MAC data loss, which can be recovered by the transport layer. $< 10^{-2}$	Reliability is important, but not critical.	Require pervasive connectivity and mobility support inside hospital facilities, as well as outdoors.

3.2. IEEE 802.11 WLAN

WLAN based on the IEEE 802.11 standards is widely used in office buildings, homes, hospitals, and even outdoors in urban areas. It has several advantages such as low cost, mobility support, and service flexibility. WLAN is expected to be a major component to enable integrated hospital and home networks. Especially, IEEE 802.11 telemetry systems offer several benefits in terms of cost and a significant gain in the number of channels due to the large bandwidth of the ISM band. IEEE 802.11 has been recently reported through substantial deployment experiences and significantly outperform in medical facilities or home applications [9]. We introduce the IEEE 802.11 standards in more detail in the coming two sections; we briefly mention the concepts in the physical and medium access control (MAC) layer.

3.2.1 Physical Layer

IEEE 802.11b and 802.11g standards operate in the 2.4 GHz ISM band, which is divided into 13 overlapping channels spaced 5 MHz apart and the bandwidth of each channel is 22 MHz [1]. 802.11b was based on DSSS modulation and utilizes a channel bandwidth of 22 MHz, resulting in three non-overlapping channels, which are 1, 6 and 11. 802.11g was overlapping on orthogonal frequency division multiplexing (OFDM) modulation and utilized a channel bandwidth of 20 MHz. This occasionally leads to the belief that there are four non-overlapping channel, which are 1, 5, 9 and 13.

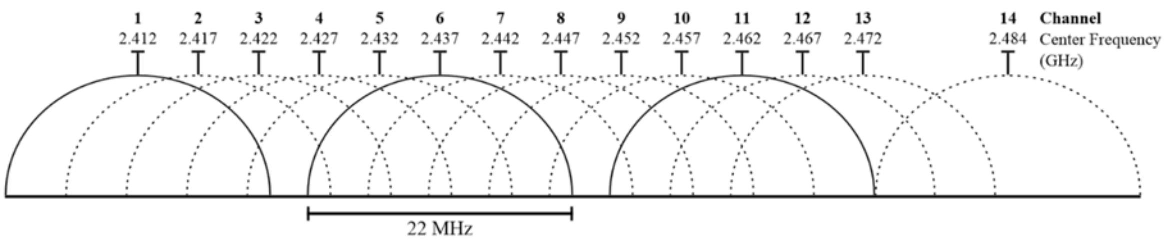


Figure 3.1. WiFi channels in the 2.4 GHz band [1].

Clear channel assessment (CCA) is used in the physical layer to determine the channel occupancy. Before initiating a transmission, an IEEE 802.11 node senses whether the channel is available or not by using either energy detection (ED) or carrier sensing (CS) or both. CS refers the ability of the receiver to detect and decode an incoming WiFi preamble signal. In addition, CCA must be informed as BUSY (busy condition) when another WiFi signal preamble is detected, and must be held as BUSY for the length of the received frame as indicated in the physical layer convergence protocol (PLCP) Header. Until it can be decoded it will cause CCA to report the medium as busy for the time required for the frame transmission to complete. The PLCP header length field indicates either the number of microseconds required for transmission of the full frame mac protocol data unit (MPDU) payload (DSSS), or the number of octects carried in the frame MPDU payload (OFDM). The following figure shows the PLCP frame header format for the DSSS PHY [1].

Energy detection (ED) refers to the ability of the receiver to detect the non-WiFi energy level present which is the current channel based on the noise floor, ambient energy, interference sources and unidentifiable WiFi signal. These may have been corrupted and cannot be decoded. Carrier sense can determine the exact length of time that the medium will be busy with the current frame. However, energy detection requires a pre-defined threshold which determines if the reported energy level is sufficient to report the medium as busy or idle. Typically, this is referred to as the ED threshold level or the CCA sensitivity level. The ED threshold is usually much lower for valid WiFi signals that can be decoded using carrier sense than it is for non-WiFi signals.

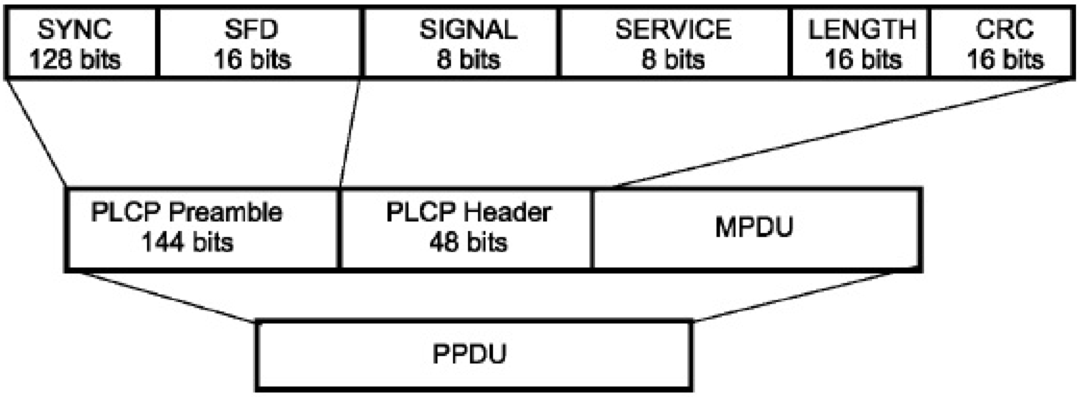


Figure 3.2. PLCP frame format [1].

According to the standard of IEEE 802.11, it operates with data rates of 6, 9, 12, 18, 24, 36, 48 and 54 Mbit/s. In addition, the back-off slot time is basically 9us (802.11 g/n) and transmit power is 15dBm to 20 dBm [1]. It is the main reason to cause the coexistence problem and we will introduce more detail later.

3.2.2. MAC Layer

The IEEE 802.11 medium access control (MAC) protocol employs the carrier sense multiple access with collision avoidance (CSMA/CA) mechanism. This access method wastes a significant percentage of channel capacity. However, it is still a necessary mechanism to provide reliability in data transmission. If the channel is sensed idle for a Distributed Coordination Function Inter-Frame Space (DIFS) time interval, the node will transmit a packet. Otherwise, the channel is sensed busy and the node defers its transmission. As the channel becomes idle for a DIFS time interval, the node will generate a random back-off delay based on an integer uniformly chosen in a contention window (CW, i.e., [0, CW]). Nodes initialize their CW to 15 or 31 slots, depending on the each IEEE 802.11 standard, and double it when they fail to access the medium until the CW reaches a maximum size of 1023 slots. The back-off timer decreases by one as long as the channel is sensed idle for a back-off time slot. The back-off counter will be frozen when a transmission is sensed on the channel, and resumed when the channel is sensed idle again for a DIFS interval. When the back-off timer counts down to zero, the node transmits a packet. After receiving a packet, the destination node waits for a Short Inter Frame Space (SIFS) interval and then sends an acknowledgement (ACK) back to the source node. If the source node receives the ACK, the size of CW remains the same value; otherwise, it will double.

There is another packet which can optionally supplement the exchange of Request to Send/Clear to Send (RTS/CTS). The distributed coordination function (DCF) access mechanism can be extended by the transmission of short RTS and CTS frames prior to transmit an actual data frame. A successful exchange of RTS and CTS frames allows the channel to be reserved for the time duration needed to transmit the data frame. If a node wishes to send a data packet, the node initially sends an RTS frame after the channel has been idle for a time interval exceeding DIFS. After receiving the RTS frame the receiver responds with a CTS frame, after the SIFS time. The CTS frame acknowledges the successful reception of RTS frame. After the successful exchange of RTS/CTS frames the data frame is sent by the transmitter, after waiting for a time interval of SIFS. If CTS frame is not received within the time interval, then the RTS is retransmitted after back-off [16].

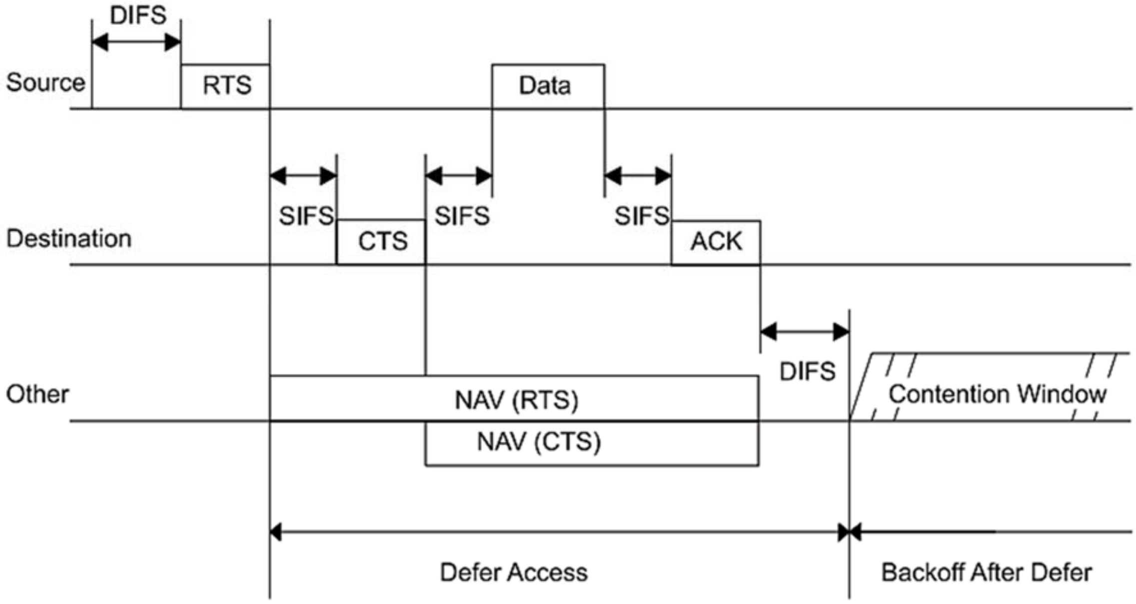


Figure 3.3. Channel access using RTS/CTS frames [16].

3.3. IEEE 802.15.4 for WBAN

The study of WBAN has been actively conducted as Healthcare becoming more and more important. A WBAN is a special purpose network, which can be exploited in medical environments to connect wearable telemetry sensors on the patient to a bedside monitor or to a doctor' PDA [17]. These wearable sensor nodes have wireless transmission capability and sense biological information of patients to remotely monitor and provide real-time feedback for medical diagnosis. It is expected to increase the functionality of lifestyle and healthcare devices to gradually match the needs of society. Sensor nodes should be low power and detect medical signals such as electrocardiogram (ECG), electroencephalography (EEG), electromyography (EMG), pulse rate, blood flow, pressure, temperature, etc. The collected data from the control devices are transmitted to remote destinations in a WBAN for diagnostic or other purposes. Generally, WBAN can use ZigBee, Bluetooth, or ultra-wideband (UWB) radio technologies. In this thesis, we will focus on ZigBee (IEEE 802.15.4). According to [18], market plans developed by ZigBee Alliance take into consideration several usage scenarios for medical applications; such as monitoring chronic disease, episodic patients, and patients' alarm. ZigBee was designed to provide low power compared with Bluetooth. The technology indeed offers significantly improved performance by reducing power 1 mW to 30 mW compared with the 100mW of Bluetooth. Such improvements are good match for the needs of low power sensor nodes used for WBAN.

We introduce IEEE 802.15.4 standard, which specifies the PHY layer and MAC layer for low-rate wireless personal area network (LR-WPANs) operating in the 2.4GHz ISM band. It is the basis of the ZigBee and focuses on low-cost, low-rate, low-power ubiquitous communication between devices [19].

3.3.1 Physical Layer

The standard defines 16 channels within the ISM band which are shared with the IEEE 802.11 WLAN, each 2 MHz wide with 3 MHz inter-channel gap-bands. Including the 2.4 GHz band width, there are three possible unlicensed frequency bands. The 868/915 MHz PHY is specified for operation in the 868 MHz band in Europe offering one channel with a raw data rate of 20 kb/s and the 915 MHz ISM band in North America offering 10 channels with a raw data rate of 40 kb/s. The low-band uses binary phase shift key (BPSK) modulation. The 2.4 GHz PHY (also called high-band) specifies operation in the 2.4 GHz ISM band, with nearly worldwide availability. This band spans from 2.4 to 2.483 GHz and offers 16 channels with channel spacing of 5 MHz, operating with a raw data rate of 250 kb/s using offset quadrature phase shift key (O-QPSK) modulation [19].

The IEEE 802.15.4 standard specifies a receiver sensitivity of -85 dBm for the 2.4 GHz band and -92 dBm for the 868/915 MHz band. Practical implementations are expected to improve this requirement. The standard specifies a transmit power capability of 1 mW, although it can vary within governmental regulatory bounds. Both PHY layers use a common packet structure, enabling the definition of a common MAC interface. Each packet, or PHY protocol data unit (PPDU), contains a preamble, a start of packet delimiter, a packet length, and a payload field, or PHY service data unit (PSDU). The 32-bit preamble is designed for acquisition of symbol and chip timing. The IEEE 802.15.4 payload length can vary from 2 to 127 bytes [19]. On the PHY layer, ZigBee's bit rate is limited to 350kb/s. Its CCA operation takes 128us, and the rx/tx switching time can be 192us, due to hardware limitations. The maximum transmit power of ZigBee is only 0 dBm. Hence, ZigBee has a much shorter interference range than WiFi. Therefore, ZigBee may not be effectively sensed by WiFi in coexistence environments.

Octects: 4	1	1		Variable
preamble	SFD	Frame length (7 bits)	Reserved (1 bit)	PSDU
SHR		PHR		PHY payload

Figure 3.4. PHY PPDU frame structure [1].

3.3.2 MAC Layer

Each ZigBee WBANs assigns a unique coordinator to perform association control and beacon scheduling for clients. The coordinator schedules a mixture of TDMA and CSMA frames periodically. Each scheduling period is called a super-frame, which starts with a beacon, followed by a number of CSMA slots (called CAP) and TDMA slots (called CFP or Guaranteed Time Slots(GTS)), and then an inactive period. The CFP slots are allocated on demand. In the CAP slots, ZigBee enforces slotted-CSMA access control, which differs from WiFi as follows. First, contention access must start from the boundaries of basic time units called back-off slots, each lasting 320us. Each back-off in ZigBee consists of two contention windows, i.e., a transmitter must ensure an idle channel for two slots (640us) before sending data [19].

There are two versions of IEEE 802.15.4 CSMA/CA: slotted and unslotted. In this thesis, we discuss only the popular unslotted one. Like IEEE 802.11 b/g WLANs, IEEE 802.15.4 wireless sensor networks also employ CSMA/CA for the medium access control. In IEEE 802.15.4, the channel is sensed only during a CCA period rather than during both a CCA and a back-off period like in IEEE 802.11b/g WLANs. The standard specifies that either ED or CS (or both) is used to check the channel state, but does not provide precise algorithms. If the channel is sensed busy during the CCA period, the size of CW in IEEE 802.15.4 WSNs doubles.

IV. Problem Statement

We focus on the coexistence issue between WLAN (WiFi/IEEE 802.11) and WBAN (ZigBee/IEEE 802.15.4) which are operating in the same 2.4 GHz ISM band. Their overlapping frequency allocations were illustrated in Fig. 4.1. The coexistence between WiFi and ZigBee poses a challenging problem for several reasons; first is a significantly different power level and second is asynchronous timing. The maximum transmit power of ZigBee is typically as low as 0 dBm, whereas the transmit power of WiFi is usually 15 dBm to 20 dBm [1]. For this reason, ZigBee has a much shorter interference and carrier sensing range than WiFi; hence, ZigBee may not be effectively sensed by WiFi when they are co-located. In addition, response time difference between WiFi and ZigBee makes collision hazards; WiFi has a shorter response time than ZigBee [2]. Accordingly, WiFi can prevent a ZigBee transmission when its carrier sensing in the rx/tx switching time of ZigBee transmitters, or the time spent in waiting for the next CSMA slot boundary. In this section, we develop what the problem is and why coexistence problems occur in our scenario.

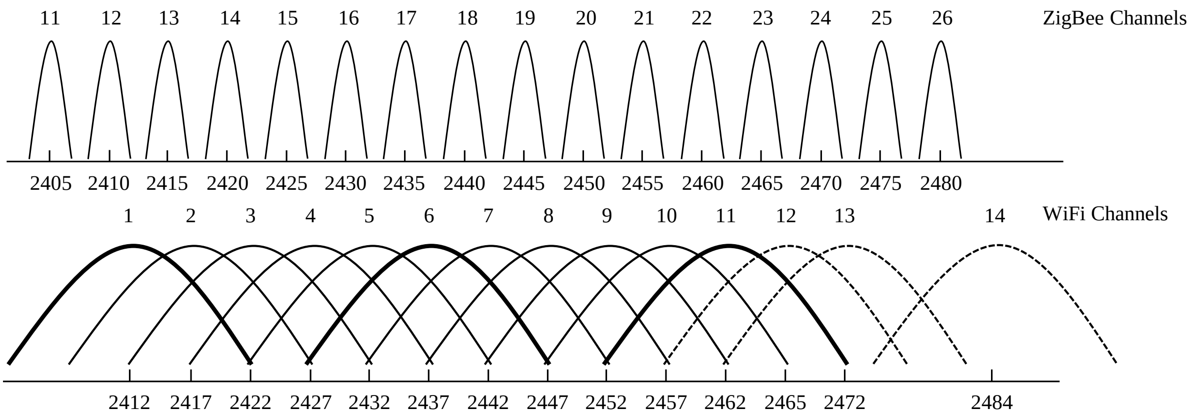


Figure 4.1. Frequency channel of 802.15.4 and 802.11b/g in the 2.4 GHz ISM band [3] .

4.1. Critical Data Transmission Issue in WBAN

If the problems mentioned earlier occur in medical environments, the result could be disastrous. Medical signals and information are critical and their transmission must be guaranteed. Therefore, we should consider the fact that the coexistence between WLAN and WBAN is extremely important in medical environments. In this thesis, we consider a general hospital wireless scenario which WBAN supports the ECG signal and WLAN supports the non-medical applications such as email and web browsing. Accordingly, WBAN must provide the required level of QoS because WBAN appliances deliver critical medical data to devices or central systems. In other words, WBAN with ECG signals requires low delays, high reliability, and little data loss. On the other hand, the reliability of WLAN is important but not critical.

4.2. Asymmetry of Carrier Sensing

The critical issue is that WBAN can detect transmission of WLAN, but WLAN may not detect transmission of WBAN in coexistence environments, even though both WBAN and WLAN deploy the CSMA protocol for channel access. This is because WLAN (WiFi/IEEE 802.11) and WBAN (ZigBee/IEEE 802.15.4) have different transmit power levels and physical carrier sensing thresholds (CSTH) respectively. WLAN has an extensive carrier sensing range due to its high transmit power. The WLAN signal cause interference for WBAN, while the WBAN's weak power intensity does not affect the transmission of WLAN. Consequently, asymmetry of carrier sensing occurs.

According to the CSTH interaction formula, if the receiver power P_r is bigger than CSTH as represented in the first equation, then, the transmitter can sense a busy channel. Let us define D_{cs} as the carrier sensing range within which the transmitter can detect a busy channel. The maximum transmission range with the most robust transmission rate D_{rx}, can be determined by the minimum receiver sensitivity P_{min}, and the transmission power. Considering the path-loss propagation model with the path-loss exponent of α, which is the most dominant factor for the channel model [20].

$$P_r = \frac{GP_{tx}}{D^{\alpha}} \geq CSTH$$

$$D_{cs\_wlan} = \left(\frac{G_{wlan}P_{tx\_wlan}}{P_{cs\_wlan}}\right)^{\frac{1}{\alpha}}$$

$$D_{rx\_\mathrm{wlan}} = \left(\frac{G_{wlan}P_{tx\_wlan}}{P_{min\_\mathrm{wlan}}}\right)^{\frac{1}{\alpha}}$$

$$I_{cs\_wlan} = \left(\frac{G_{wban}P_{tx\_wban}}{P_{cs\_wlan}}\right)^{\frac{1}{\alpha}}$$

All parameter values can correspond to both WLAN and WBAN, i.e., D_{cs_wban}, D_{rx_wban} and I_{cs_wban} are also applied with the same equations. It is known that $D_{cs} > D_{rx}$ since carrier sensing is available with the weaker signal required for successful decoding. This asymmetry of carrier sensing gives channel access priority to WLAN over WBAN [20]. There are three possible outcomes depending on the values of transmission power and the locations of WLAN or WBAN nodes. First, it is possible that I_{cs_wlan} is too small to cover the transmission range of WBAN at all. Second, the transmitter of WLAN hardly detects channel occupation by WBAN, and finally, I_{cs_wban} is large enough to cover the whole transmission range of WLAN. The transmitter of WBAN defers transmission whenever WLAN occupies the channel. Consequently, severe unfair channel access condition may occur between WLAN and WBAN; WLAN can access the channel regardless of whether WBAN occupies the channel or not.

4.3 Collision due to Different Response Time

Even when both WiFi and ZigBee are using the CSMA/CA mechanism and can hear each other, collisions may still happen. The reason is that WiFi has a much shorter response time and can easily preempt ZigBee transmission. The time slot of ZigBee is 320 μs, and it takes 128 μs to perform CCA and an additional 192 μs to switch from the CCA to transmission mode. This time period is referred to as the SIFS interval [19]. It takes a long time from receiving a packet to sending the ACK packet. On the other hand, the time slot of WiFi is only 9 μs, and the average back-off time is 72 μs with the default back-off window size of IEEE 802.11 b/g [2]. These parameter values are summarized in table 4.1. WiFi might finish carrier sensing or back-off process, while Zigbee is switching from CCA to transmission mode or data frame to ACK frame. WiFi may not aware of ZigBee signal and start transmission. Consequently, collision may occur as shown in Fig. 4.2. which clearly illustrates that ZigBee's performance is severely degraded by the WiFi signal resulting in an asymmetric coexistence problem.

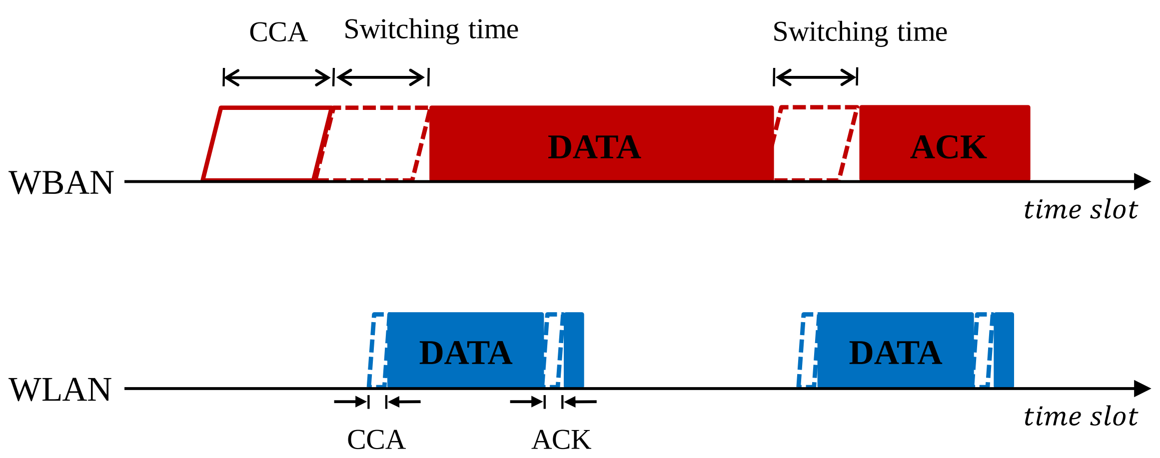


Figure 4.2. WiFi preempts WBAN transmission due to shorter response time of ZigBee [2].

Table 4.1. IEEE 802.15.4 and IEEE 802.11 b/g system parameters

	IEEE 802.15.4	**IEEE 802.11b**	**IEEE 802.11g**
Transmit power	0 dBm	20 dBm	20 dBm
Receiver sensitivity	-85 dBm	-76 dBm	-28 dBm
Transmit rate	250 kbps	11 Mbps	6 Mbps
Slot time	320 μs	20 μs	9 μs
SIFS	192 μs	10 μs	10 μs
DIFS	N/A	50 μs	28 μs
CCA	128 μs	15 μs	4 μs
Minimum value of Contention Window	7	31	15

4.4 Preliminary Simulation

We perform preliminary simulations to identify the coexistence problem which is unfair channel sharing and to verify that ZigBee fails to guarantee the reqired QoS when they share the same channel. We implement a simulator by using MATLAB. The wireless channel is modeled by considering the standard of both IEEE 802.11b/g and IEEE 802.15.4 as listed in Table 4.2. Considering the hospital or home environment, the path-loss exponent is set to 3. We are also considering the shadowing and multi-path fading; the Rayleigh fading model is used and set to 6 dB as a log-normal random variable with zero mean and standard deviation. We vary the number of nodes to two, five, or ten in our simulation. Our simulation does not consider node mobility and users are uniformly distributed in the cell. WLAN traffics are randomly generated such that its inter-arrival time follows a Poisson random variable with a mean value of 5 ms and we fix the packet size to 1000 bytes. WBAN traffics are generated periodically; it is mostly streaming data with low data rate with the packet size of 500 bytes.

Table 4.2. Parameters used in the simulations.

Parameter	Value	
	WLAN	WBAN
Transmission power	50 mW	1 mW
Minimum receiver sensitivity	-80 dBm	-85 dBm
Coverage	50 m	2m
Number of users per cell	2, 5, 10	2, 5, 10
Distance between the center of WLAN and WBAN	10 m	
Path-loss exponent	3	
Shadowing	6 dB	

Figure 4.3 shows the number of average channel access and transmission success per system with different numbers of users. When there are two users in the both WLAN and WBAN system, WLAN accesses the channel by 2361 times, which results in 1860 successful transmission. Note that this is an average value for 10 simulation runs. On the other hand, WBAN access only 1055 times with 740 successful transmissions. When there are five users in the WLAN and two users in the WBAN, WLAN accesses the channel 3065 times with 2059 successful transmissions. However, WBAN accesses the channel only 896 times and successes 578 times. As the number of WLAN users increases, WBAN behave conservative transmission and even the success rate is becoming lower. We can easily notice that WLAN make significantly more attempts to access, send or receive, than WBAN even when they have the same number of users. As expected, WBAN transmission opportunities will be lost, which results in degraded performance as the number of WLAN users increases. This unfairness issues will become even critical when WBAN has high priority medical traffic.

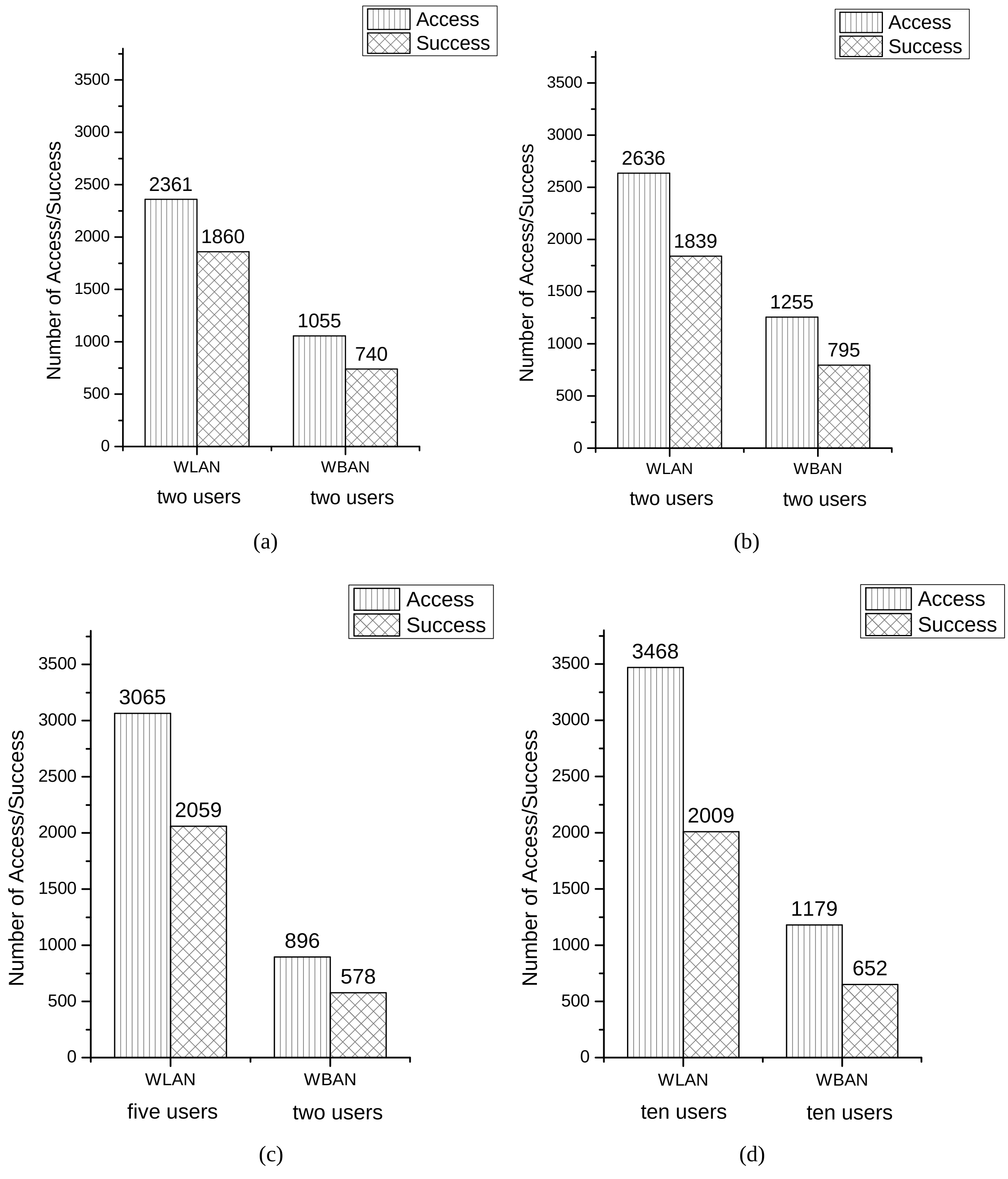


Figure 4.3. Number of channel access and success per system depending on the number of users. (a) Two WLAN users and Two WBAN users. (b) Two WLAN users and Five WBAN users. (c) Five WLAN users and Two WBAN users. (d) Ten WLAN users and Ten WBAN users.

V. Proposed Algorithm

In this section, we derive a simple analytical throughput model per system to evaluate how WBAN throughput satisfies the requirement and to observe the effect to several parameters on the fairness and efficiency of channel sharing. There is a very well-known throughput model for the CSMA protocol, which is proposed by Bianchi, it is based on distributed coordination function (DCF) of IEEE 802.11 [21]. However, Bianchi's throughput model cannot be directly applied to this thesis, because the transmission failure results from interference instead of collision. The purpose of deriving an analytic throughput model is to evaluate the effect of several parameters and to solve the unfairness problem between WLAN and WBAN. A throughput model depends on the transmission coverage, transmission rate, number of nodes, and contention window size [20]. Assume that there are N_{wlan} WLAN senders within the transmission coverage of WLAN and N_{wban} WBAN senders coexist with the WLAN nodes. We define CW_{wlan} and CW_{wban} as the contention window size of the WLAN and WBAN senders, respectively.

In this thesis, we make several assumptions for our scenarios. First, WLAN senders always have sending data and compete for channel access, and WBAN data is generated in periodic manner. The transmission round is defined as the time interval between two consecutive packet transmissions. Second, the WLAN senders can detect the WBAN's packet transmission with a probability of P_d, while the WBAN senders can completely detect the WLAN's packet transmission. Third, when both WLAN and WBAN initially start to transmission, their nodes select their own random back-off counters, b_{wlan} and b_{wban}, respectively.

5.1. Throughput Model per System

We define $p_{\mathrm{bo,wlan}}$ as the back-off probability of a WLAN sender as follows:

$$p_{\mathrm{bo,wlan}} \triangleq \Pr\{b_{\mathrm{wlan}} = k_{\mathrm{wlan}}\} = \frac{1}{\mathrm{CW_{wlan}}}, 0 \leq \mathrm{k} \leq \mathrm{CW_{wlan}}$$

$$p_{\mathrm{bo,wban}} \triangleq \Pr\{b_{\mathrm{wban}} = k_{\mathrm{wban}}\} = \frac{1}{\mathrm{CW_{wban}}}, 0 \leq \mathrm{k} \leq \mathrm{CW_{wban}}.$$

We consider two cases; (i) interference-free channel occupation by WLAN, which means that the minimum value of back-off counters of WBAN is bigger than the minimum value of back-off counters of WLAN. (ii) interference-prone channel occupation by WBAN, which means that the minimum value of back-off counters of WLAN is bigger than the minimum value of back-off counters of WBAN [20].

First consider case (i): First of all, we should understand the probability that a WLAN sender accesses the channel without intra system collision and inter system interference after back-off time of WLAN to obtain the average throughput, its denote $p_a^{(i)}$ and represented as

$$p_a^{(i)} = N_{wlan} p_{\mathrm{bo,wlan}} \big(1 - (k_{\mathrm{wlan}} + 1) p_{\mathrm{bo,wlan}}\big)^{N_{wlan}-1} (1 - (k_{\mathrm{wlan}} + 1) p_{\mathrm{bo,wban}})^{N_{\mathrm{wban}}}.$$

Let us define $\mathrm{TH}_{wlan,1}^{(i)}$ and $\mathrm{TH}_{wlan,2}^{(i)}$ as the WLAN throughput when a sender detects WBAN's transmission and does not, respectively. We can consider the second case in our scenario because $\mathrm{TH}_{wlan,1}^{(i)}$ is zero.

$$\mathrm{TH}_{wlan}^{(i)} = \sum_{k_{\mathrm{wlan}}=0}^{\mathrm{CW}_m - 1} p_a^{(i)} (1 - \mathrm{ber}_1)^L \frac{L}{k_{\mathrm{wlan}} t_s + \frac{L}{R_{wlan}} + t_{oh}}$$

In this equation, we define the several parameter values which are needed to obtain the average throughput of WLAN; CW_m is the minimum value of $\mathrm{CW}_{\mathrm{wlan}}$ and $\mathrm{CW}_{\mathrm{wban}}$. L is the packet size in bits. $\mathrm{R}_{\mathrm{wlan}}$ is the transmission rate of the WLAN nodes from 6 Mb/s to 54 Mb/s. The bit error rate (BER) can be obtained with a path-loss model in [22]. In addition, t_s is the slot time and t_{oh} is the overhead time. In this case, WBAN defers the channel access, and thus its throughput could be zero.

We consider case (ii) which the minimum value of back-off counters of WLAN is bigger than the minimum value of back-off counters of WBAN. The WBAN sender makes the channel access attempt before the WLAN sender attempts to channel access. In this case, we should distinguish the case where the WBAN sender detects WLAN's transmission from the case where the WBAN sender does not detect WLAN's transmission. Define two cases; $\mathrm{TH}_{wban,1}^{(ii)}$ is the WBAN throughput when the WBAN detects WLAN's transmission, and $\mathrm{TH}_{wban,2}^{(ii)}$ is the WBAN throughput when the WBAN does not detect WLAN's transmission. Accordingly, we can summarize the throughputs of the WLAN and the WBAN in case (ii) as follows.

$$\text{WLAN: } \mathrm{TH}_{wlan}^{(ii)} = (1 - p_d)\mathrm{TH}_{wlan,2}^{(ii)},$$

$$\text{WBAN: } \mathrm{TH}_{wban}^{(ii)} = p_d \mathrm{TH}_{wban,1}^{(ii)} + (1 - p_d)\mathrm{TH}_{wban,2}^{(ii)}.$$

The $\mathrm{TH}_{wban,1}^{(ii)}$, the WBAN throughput without interference by WBAN, can be obtain by the same equation with $\mathrm{TH}_{wlan}^{(i)}$. The throughput of the WLAN and WBAN is denoted as $\mathrm{TH}_{wlan,2}^{(ii)}$ and $\mathrm{TH}_{wban,2}^{(ii)}$, respectively.

Unlike case (i), the channel access probability of WLAN and WBAN senders can be represented as

$$p_a^{(ii)} = N_{wlan} p_{\mathrm{bo,wlan}} \big(1 - (k_{\mathrm{wlan}} + 1) p_{\mathrm{bo,wlan}}\big)^{N_{wlan}-1}$$

$$N_{wban} p_{\mathrm{bo,wban}} (1 - (k_{\mathrm{wlan}} + 1) p_{\mathrm{bo,wban}})^{N_{\mathrm{wban}}-1}.$$

We consider two WLAN and WBAN's back-off time are independent. When there exists interference to the WLAN and WBAN by the WBAN and WLAN, respectively, then the throughputs are represented as

$$\mathrm{TH}_{wlan,2}^{(ii)} = \sum_{k_{\mathrm{wban}}=0}^{\mathrm{CW}_m-1} \sum_{k_{\mathrm{wlan}}=k_{\mathrm{wban}}}^{\mathrm{CW}_m-1} p_a^{(ii)} (1 - \mathrm{per}_1) \frac{L}{n_{t,1} t_s},$$

$$\mathrm{TH}_{wban,2}^{(ii)} = \sum_{k_{\mathrm{wban}}=0}^{\mathrm{CW}_m-1} \sum_{k_{\mathrm{wlan}}=k_{\mathrm{wban}}}^{\mathrm{CW}_m-1} p_a^{(ii)} (1 - \mathrm{per}_2) \frac{L}{n_{t,2} t_s}.$$

The packet error rate (PER) of WLAN and WBAN, $\mathrm{per}_1^{(ii)}$and $\mathrm{per}_1^{(ii)}$ can be obtained in [20]. To obtained $\mathrm{per}_1^{(ii)}$and $\mathrm{per}_1^{(ii)}$ values, we should calculate the number of time slots with inter-system interference during both WLAN and WBAN send packet. In addition, we should calculate how may time slots occupied by the WLAN and WBAN senders without interference. The $n_{t,1}$ and $n_{t,2}$ mean that the number of time slots elapsed from the start of transmission round to the end of WLAN packet transmission [20]. All of these throughput equations, we can obtain final WLAN and WBAN throughput as

$$\text{WLAN: } \mathrm{TH}_{wlan} = \mathrm{TH}_{wlan}^{(i)} + \mathrm{TH}_{wlan}^{(ii)}$$

$$\text{WBAN: } \mathrm{TH}_{wban} = p_d \mathrm{TH}_{wban,1}^{(ii)} + (1 - p_d) \mathrm{TH}_{wban,2}^{(ii)}.$$

5.2. Optimal Contention Window Size

In order to guarantee the quality of service (QoS) of WBAN transmission with effective channel sharing, we propose the coexistence CSMA protocol. The main idea is to mitigate interference by decreasing the channel access attempt of WLAN and give more channel access opportunities to WBAN [20]. Coexistence CSMA protocol find optimal contention window size of WLAN to guarantee the QoS of WBAN transmission and without significantly degrading the throughput of WLAN. This idea can be realized by the dynamic control of WLAN's contention window. We establish the throughput ratio γ_{ratio} and total throughput η_{eff} as

$$\gamma_{\text{ratio}} = \frac{\text{TH}_{wlan}/N_{wlan}}{\text{TH}_{wban}/N_{wban}}$$

$$\eta_{\text{eff}} = \text{TH}_{wlan} + \text{TH}_{wban}.$$

Using the throughput model, we find an objective function for adjusting the contention window of WLAN as follows:

$$\mathcal{F}(\text{CW}_{wlan}) = w\frac{\eta_{\text{eff}}}{\text{C}_{\text{max}}} + (1-w)\mu_{\text{fair}},$$

$\eta_{\text{eff}}/\text{C}_{\text{max}}$ is the normalized efficiency of channel sharing and μ_{fair} is Jain's fairness index [23]. Here, w is a weight factor ($0 \le w \le 1$), which can be controlled according to the importance of efficiency or fairness in the channel sharing. The C_{max} is the ideal maximum capacity, which is calculated under the assumption that there is neither collision nor interference so that the transmission rate has the maximum value and contention window has the minimum value.

$$\mathrm{C_{max}} = \frac{L}{t_{oh} + \left(\frac{\mathrm{CW}_{min} - 1}{2}\right) t_s + \frac{L}{R_{max}}}$$

The μ_{fair} is considering the average throughput of the WLAN and the WBAN per nodes, and it represented as

$$\mu_{\mathrm{fair}} = \frac{(\frac{\mathrm{TH}_{wlan}}{N_{wlan}})^2 + (\frac{\mathrm{TH}_{wban}}{N_{wban}})^2}{2((\frac{\mathrm{TH}_{wlan}}{N_{wlan}})^2 + (\frac{\mathrm{TH}_{wban}}{N_{wban}})^2)}.$$

If the $\mathrm{TH}_{wlan}/N_{wlan} = \mathrm{TH}_{wban}/N_{wban}$, it is the best case. Either WLAN or WBAN is zero, then it might be the worst case.

$$\begin{gathered} maximize_{\mathrm{CW}_{wlan}} \quad \mathcal{F}(\mathrm{CW}_{wlan}) \\ \text{subject to} \quad \mathrm{CW}_{wlan} \in \Omega, \end{gathered}$$

where $\Omega = \{\mathrm{CW}_{wlan} | \mathrm{CW}_{min} \leq \mathrm{CW}_{wlan} \leq \mathrm{CW}_{max}\}$, and the optimal value of CW_{wlan} is

$$\mathrm{CW}^*_{wlan} = \mathrm{argmax}_{\mathrm{CW}_{wlan} \in \Omega}\, \mathcal{F}(\mathrm{CW}_{wlan}).$$

The coordinator of WBAN measures their aggregated throughput TH_{wban} and recognizes the number of relevant nodes N_{wban} in every monitoring interval. The coordinator sends a control message for resource management, which contains TH_{wban} and N_{wban}, to the access point (AP) of WLAN. Then, the AP measures the aggregate throughput and manages the number of nodes N_{wlan}. By using this information, AP estimates the objective function $\mathcal{F}(\mathrm{CW}_{wlan})$ for every monitoring interval. The CW_{wlan} is updated toward CW^*_{wlan} using the golden section search algorithm on the basis of the measurement of $\mathcal{F}(\mathrm{CW}_{wlan})$ [24]. The main goal of this algorithm is to find the local minimum or maximum of a one dimensional unimodal function in a closed interval without using the derivative of function.

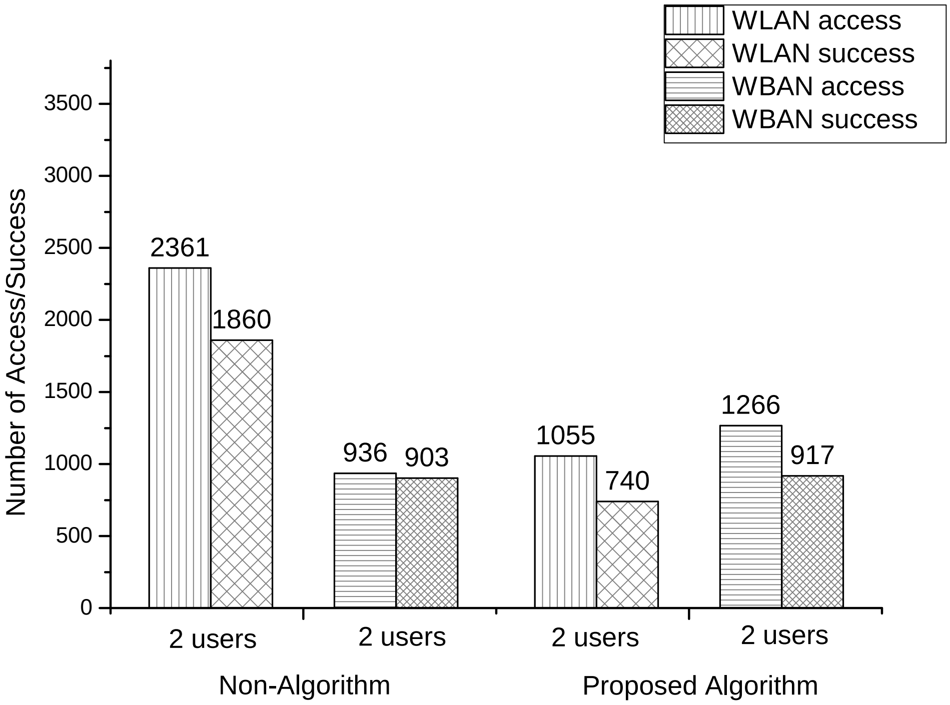
The proposed CSMA protocol is a flexible algorithm in that it can properly trade off the operating point between fairness and efficiency. More specifically, it can be achieved by tuning $w (0 \leq w \leq 1)$ in the objective function. For example, if we focus on the channel efficiency, then w might be set to a value close to 1. On the other hand, if we focus on the channel fairness, then w needs to be close to 0. In addition, the weighted fairness can also be supported, which means that γ_{ratio} could be achieved close to an arbitrary value of K by replacing TH_{wban} with $K\mathrm{TH}_{wban}$ in μ_{fair} equation. By applying this algorithm, we can expect that the QoS of WBAN is guaranteed without any significant degradation of WLAN throughput TH_{wlan} [20].

VI. Simulation

In this section, we evaluate the performance of the proposed algorithm. We apply the proposed algorithm to WLAN, and assume that WBAN recognizes the cause of failure is either collision or interference. If WBAN recognizes interference-driven transmission failure, BEB and link adaptation is not applied to WBAN. The BEB and link adaptation mechanism is only activated in the case of collision-driven failure. The design parameters of the proposed algorithm are set as follows: The time interval is 1 second and the weight factor of w is 0.5 (both efficiency and fairness are considered). The simulation time is set to 1 million time slots, the simulation results are averaged over 10 times of simulation runs, and nodes are randomly distributed in the coverage. The number of nodes of both WLAN and WBAN are varied to two, five, and ten. The channel model and parameters are the same with the preliminary simulation as listed in table 4.2.

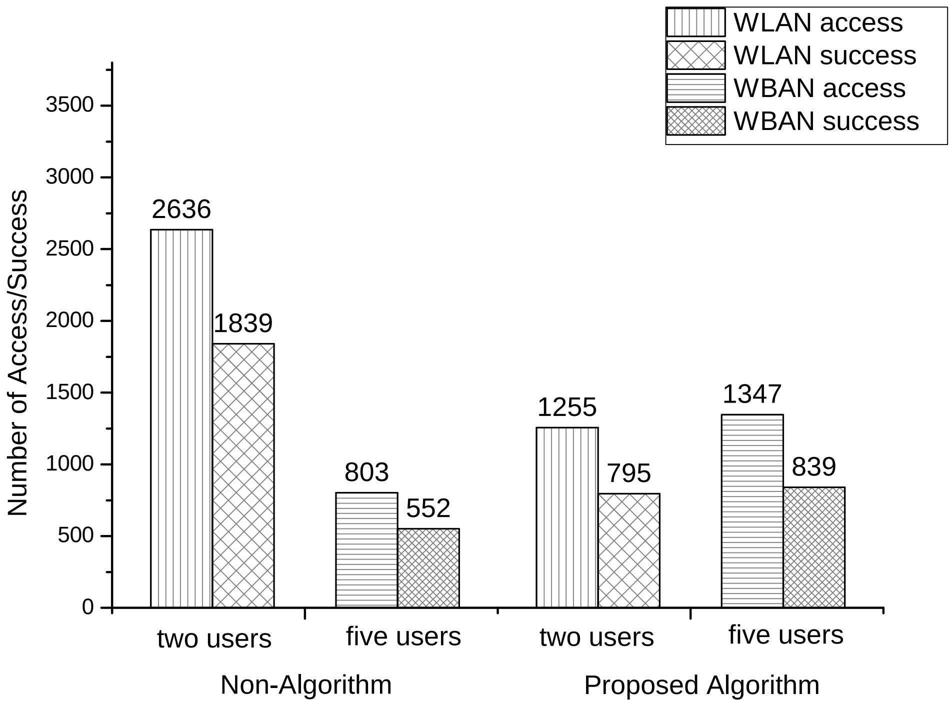
Compare with preliminary simulation results, the proposed mechanism can guarantee the WBAN's transmission and can enhance efficiency. These results confirm that CW_{wlan} is properly controlled to maximize the given objective function and that the proposed mechanism can control the trade-off between the fairness and efficiency of channel sharing by assigning a proper value to w. Fig. 6.1 shows how many times they attempt to transmit and receive successfully. The number of nodes is one of the most important factors affecting performance so that we compare two systems.

In case of Fig. 6.1 (a), we set two WLAN users and two WBAN users. Compare with Fig. 4.3 (a), WBAN's transmission opportunity is certainly guaranteed and WLAN's transmission success rate is increased. We can identify that the proposed algorithm can guarantee the WBAN's transmission compare with preliminary simulation results and maximize the throughput of WLAN to enhance efficiency in Fig. (b), (c), and (d).



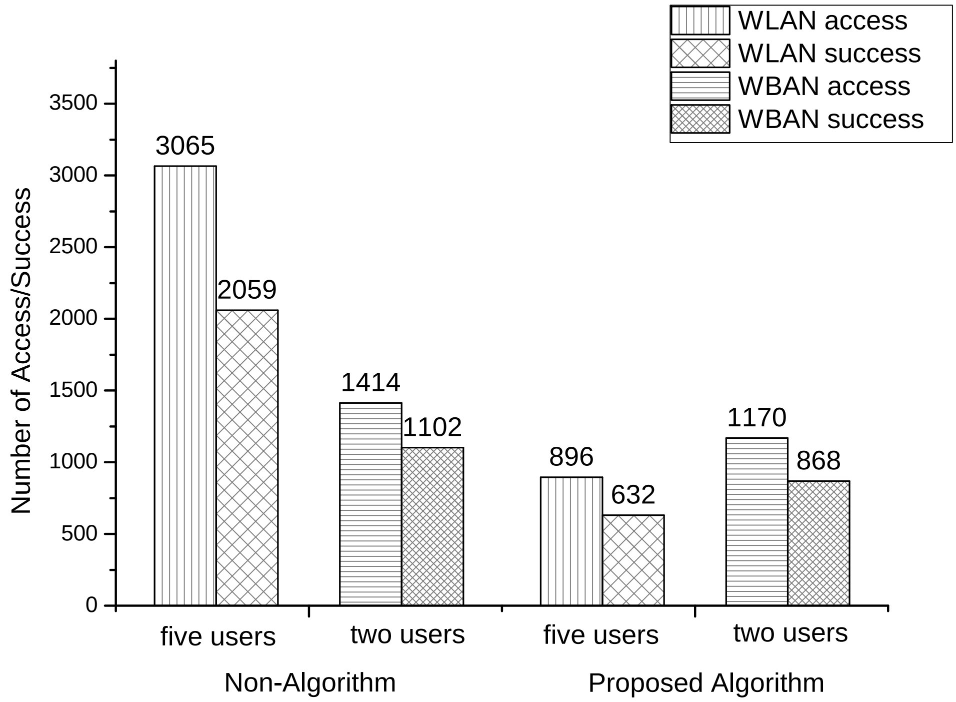
WLAN access
WLAN success
WBAN access
WBAN success
Number of Access/Success
3500
3000
2500
2000
1500
1000
500
0
2361
1860
936
903
1055
740
1266
917
2 users
2 users
2 users
2 users
Non-Algorithm
Proposed Algorithm

(a)

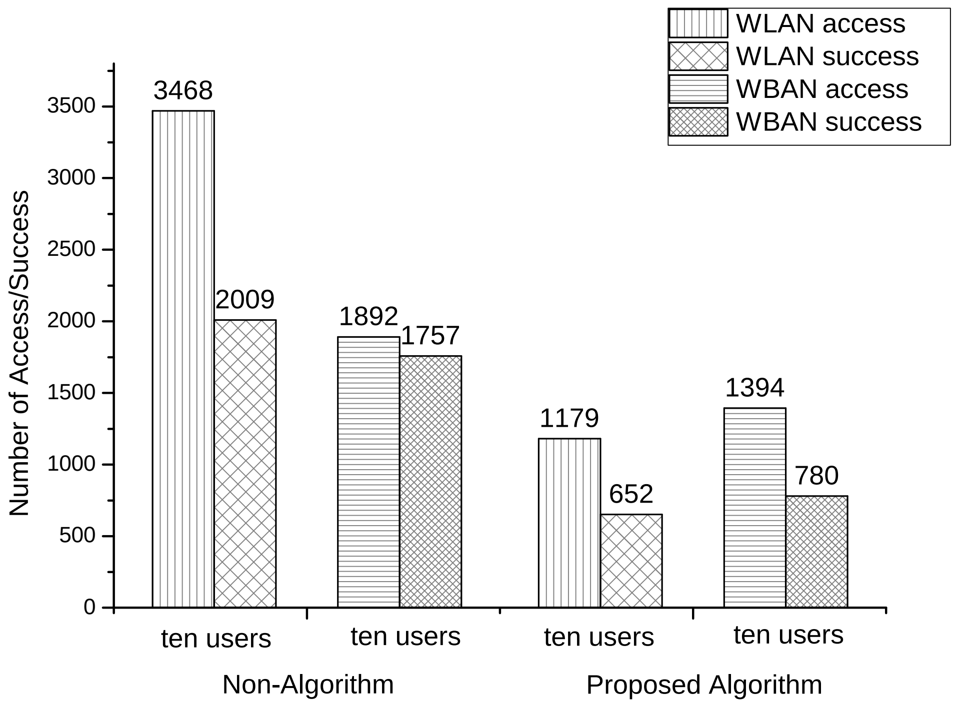


WLAN access
WLAN success
WBAN access
WBAN success
Number of Access/Success
3500
3000
2500
2000
1500
1000
500
0
2636
1839
803
552
1255
795
1347
839
two users
five users
two users
five users
Non-Algorithm
Proposed Algorithm

(b)



(c)

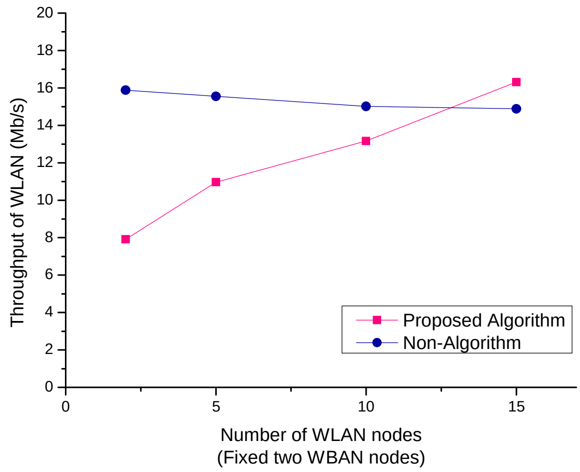


(d)

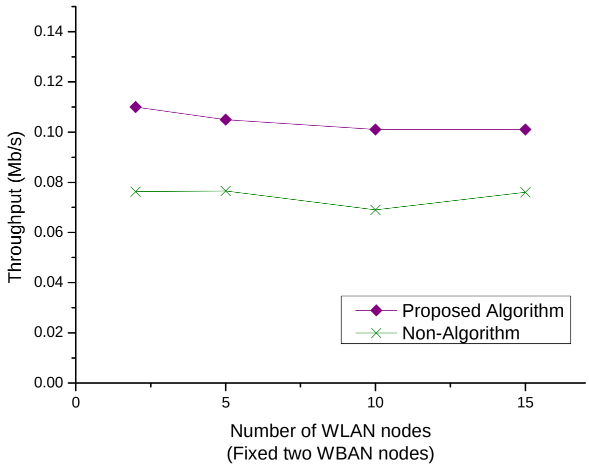
Figure 6.1. Number of channel access and success per system depending on the number of users. (a) Two WLAN users and Two WBAN users. (b) Two WLAN users and Five WBAN users. (c) Five WLAN users and Two WBAN users. (d) Ten WLAN users and Ten WBAN users.

We can verify that proposed algorithm can guarantee transmission of WBAN and manage more effective transmission of WLAN through Fig.6.1. As shown in Fig. 6.2, we can change the number of WLAN nodes from 2 to 15, while the number of WBAN nodes is fixed at 2, 5 and 10, respectively. Depending on the number of nodes, we can obtain different throughput of WLAN and WBAN. In case of WLAN, the conventional approach has higher throughput than the proposed algorithm. However, when the number of WLAN's nodes is bigger than 13, the proposed algorithm shows higher throughput than the conventional one. In case of WBAN, the proposed algorithm shows generally good performance than the conventional one.

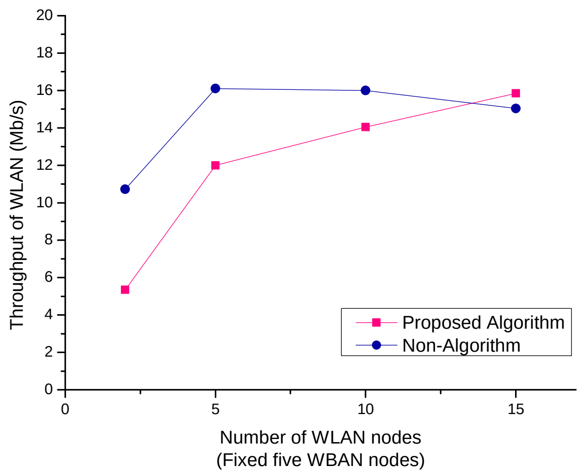
Table 6.1, 6.2, 6.3 and 6.4 list the performance indices of the proposed algorithm for the three cases of w=0.1, 0.5, and 0.9. In the case of w=0.1, the throughput of WLAN and the total throughput (η_{eff}) are smaller than the case of w=0.9. However, the throughput of WBAN is bigger than the case of w=0.9. The proposed algorithm can control the fairness and efficiency by using the weight factor value. These results confirm that the contention window of WLAN CW_{wlan} is effectively tuned to maximize the given objective function. The proposed algorithm can control the trade-off between the fairness and efficiency of channel sharing.



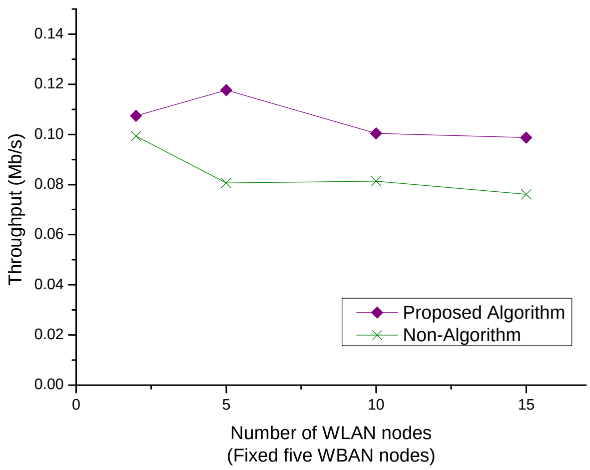
(a)



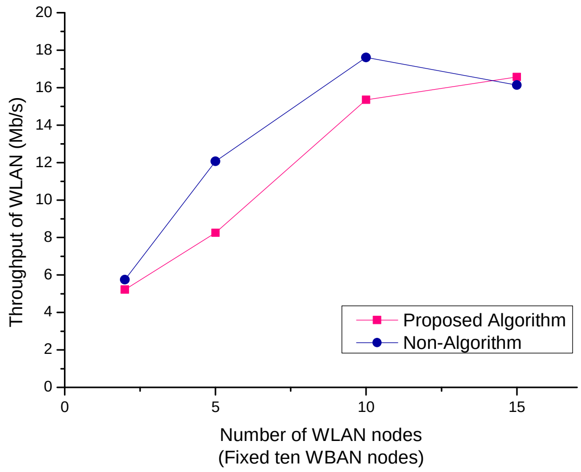
(b)



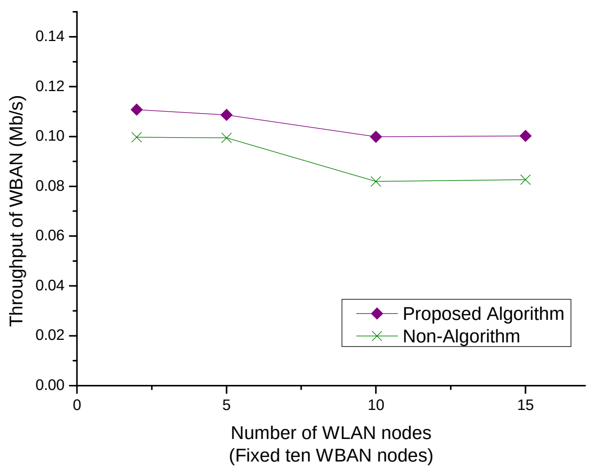
(c)



(d)



(e)



(f)

Figure 6.2. Throughput vs. Number of WLAN nodes.

Table 6.1. Several performance indices of the proposed algorithm with different values of the weight in the objective function when there are two nodes per system.

Weight	Per-system throughput (Mb/s)		Total throughput (Mb/s)
	WLAN	**WBAN**	
0.1 (fairness-centric)	7.6240	0.1097	7.7337
0.5 (balanced)	7.9104	0.1030	8.0134
0.9 (efficiency-centric)	8.1106	0.0999	8.2105

Table 6.2. Several performance indices of the proposed algorithm with different values of the weight in the objective function when there are two nodes for WLAN and five nodes for WBAN, respectively.

Weight	Per-system throughput (Mb/s)		Total throughput (Mb/s)
	WLAN	**WBAN**	
0.1 (fairness-centric)	5.1026	0.1112	5.2138
0.5 (balanced)	5.3451	0.1074	5.4525
0.9 (efficiency-centric)	5.8978	0.1002	5.9980

Table 6.3. Several performance indices of the proposed algorithm with different values of the weight in the objective function when there are five nodes for WLAN and two nodes for WBAN, respectively.

Weight	Per-system throughput (Mb/s)		Total throughput (Mb/s)
	WLAN	**WBAN**	
0.1 (fairness-centric)	11.6425	0.1072	11.7494
0.5 (balanced)	11.6822	0.1066	11.7888
0.9 (efficiency-centric)	12.2919	0.0936	12.3855

Table 6.4. Several performance indices of the proposed algorithm with different values of the weight in the objective function when there are ten nodes per system.

Weight	Per-system throughput (Mb/s)		Total throughput (Mb/s)
	WLAN	**WBAN**	
0.1 (fairness-centric)	14.7755	0.1014	14.8769
0.5 (balanced)	15.0038	0.1008	15.1046
0.9 (efficiency-centric)	15.7533	0.0996	15.8529

VII. Conclusion

In this thesis, we deal with the coexistence issue in medical environments, which is a critical issue, especially because of the increasing use of wireless communication technology in medical environments. We have addressed why coexistence matters when WLAN (IEEE 802.11/WiFi) and WBAN (IEEE 802.15.4/ZigBee) are operating in the same ISM frequency bands. Most of all, the significantly different power level and asynchronous time slots result in significant unfairness between WLAN and WBAN. WLAN cannot detect ongoing packet transmission by a smaller power system of WBAN. Consequently, WLAN attempts to access the channel even when WBAN has already occupied the shared channel, which will make WBAN suffer from frequent transmission failure. In this situation, WLAN is a significant interferer to WBAN, and WBAN become a victim of WLAN. This is a serious problem for health monitoring system which requires strict Quality of Service (QoS) guarantee.

To resolve this problem, we have proposed an adaptive coexistence CSMA mechanism which can mitigate interference and achieve efficiency channel sharing. Unlike the general network environment, medical network should guarantee transmission of WBAN and manage effective transmission of WLAN. By using an efficient throughput model, we control and find an appropriate adaptive contention window size of WLAN in order to give transmission opportunities to WBAN. By using the proposed scheme, unnecessary back-off mechanism as well as link adaptation mechanism will not be carried out when the cause of failure is interference. By applying this coexistence CSMA mechanism, we confirm via extensive simulation study that WBAN can attain the required transmission opportunity while WLAN can transmit more effectively. Hence, by using the proposed algorithm, we can guarantee the required medical-grade QoS of WBAN without any significant degradation of the throughput of WLAN. Consequently, we expect that the proposed coexistence CSMA protocol can realize a reliable healthcare system with the required medical-grade QoS.

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요 약 문

무선 의료 환경을 위한 WLAN과 WBAN의 적응 공존 기법

최근, 고령 인구의 증가와 만성 질환 환자의 증가로 인해 E-health 의 중요성이 강조되고 있다. 특히, E-health 를 실현시키기 위해 다양한 의료 무선 통신이 활발히 연구 중이다. 의료 환경 내에서 기존의 유선 통신과 다르게 무선 통신의 사용은 환자들에게 이동성을 보장하고 동시에 의료 서비스의 품질을 높일 수 있다는 장점이 있다. 본 논문에서 초점을 맞추고 있는 WLAN (IEEE 802.11/WiFi)와 WBAN (IEEE 802.15.4/ZigBee)은 다양한 무선 통신 기술 중 의료환경 및 가정 환경 내에서 가장 널리 사용되는 통신 기술이다. 하지만 WiFi 와 ZigBee 의 경우 동일한 2.4 GHz ISM 주파 대역을 사용함에 따라 두 시스템간 전송 세기의 차이로 인해 공존성 문제가 발생하게 된다. WiFi 는 상대적으로 전송 세기가 낮은 ZigBee 의 전송을 인지하지 못하고 ZigBee 가 전송하고 있는 도중 전송을 시작하며 그 결과, ZigBee 는 WiFi 로부터 간섭을 받아 전송을 실패하게 된다. 이러한 상황은 의료 환경에서 실시간으로 패킷을 전송하고 QoS 를 보장 받아야 하는 WBAN 에게 매우 치명적일 수 있다.

따라서 본 논문에서는 효율적인 채널 쉐어링을 제공하는 CSMA 매커니즘을 제안한다. 일반적인 무선통신망과는 달리, 의료 무선 통신망에서는 WBAN 의 전송을 보장하되 WLAN 이 나머지 시간을 효율적으로 활용하는 것이 목적이다. 이 매커니즘은 전체적인 시스템의 상황에 맞게 WLAN 의 contention window 크기를 조절하여 WBAN 에게 전송기회를 부여하는 방법으로서 WBAN 의 전송을 보장하는 범위에서 WLAN 의 throughput 을 최대화시킴으로써 WLAN 과 WBAN 의 효율적인 공존을 실현시킬 수 있다. 다양한 시뮬레이션을 통하여, WBAN 의 전송이 보장되는 동시에 WLAN 의 throughput 이 증가하는 결과를 확인할 수 있었다. 본 논문에서 제안한 공존 매커니즘은 의료 무선통신 망의 신뢰성을 향상시키고 QoS 를 보장하여 보다 높은 품질의 의료서비스를 제공할 수 있으리라 예상된다.

핵심어: E-health, 공존성, 무선랜, 무선 신체 영역 네트워크, CSMA

Acknowledgement

Foremost, I would like to express my sincere gratitude to my advisor Prof. Kyung-Joon Park for the continuous support of my thesis. He patiently provided the vision, encouragement and advice necessary for me to proceed through the master course. Without his guidance and persistent help this dissertation would not have been possible.

I would like to thank my thesis committee members, Prof. Sung Bae Lee and Prof. Ji-Woong Choi, whose work expanded my knowledge and encourage me to carry out for making my master degree thesis. My sincere thanks also goes to Prof. Wook Hyun Kwon, Prof. Sang Hyuk Son, Prof, Taejoon Park, Prof. Yongsoon Eun, Prof. Jae-Eun Jang, Prof. Min-Soo Kim, and Prof. Jihwan Choi. I am grateful to Prof. Eun-Chan Park as well. His guidance helped me in all the time of research and writing of this thesis. My research would not have been possible without his helps.

I thank my lab mates in CSI group: Sunghwa Son, Wonhong Jeon, Rojeena Bajracharya, Byeong Moon Cho, and Dohwan Kim. As a friend and colleague, they was always willing to help and give me best suggestions. Also I appreciate to other colleagues in ICE department.

I would like to thank my best friend Jihwan. He was a big support for me and he always gave courage. Last but not the least, I wish to thank my beloved family: father, mother, and grandmother for supporting me spiritually throughout my life.