Characteristics of Wireless Technology for Healthcare Applications: An Overview

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***Abstract*— The application of wireless technology in healthcare is increasing, not only it enhances the quality of patient care and patient mobility, but also it leads to accurate clinical decisions making. However, the electromagnetic energy emitted by the wireless transmitter devices may affects the operation of the medical equipment, especially those in close proximity with one another. In this study, we investigated the wireless technology that has minimal electromagnetic interference on the medical appliances and identified the characteristics of that particular wireless technology. From this review study, the establishment of wireless techniques in healthcare environment depends on the wireless frequency band, the wireless transmitter output power, distances between the wireless devices and the medical equipment, and also the surrounding environment of the hospitals.**

I. Introduction

Wireless technologies have provided a better communication environment in healthcare, in which medical information and services are able to be delivered over large and small distances. Reflecting back into the traditional application in hospitals, most medical equipment (ME) and devices were attached and wired to the hospital network. Each device was typically stand-alone and not networked together with the data management system. The existence of wires and cable systems tends to limit patient mobility and created inconveniences for nurses or physician staffs to have immediate access to the patient information [1, 6]. Introduction of the wireless communication technologies into healthcare environment has made bio-signals to be transmitted within seconds, thereby reduces restrictive wiring. Wireless technologies also have made electronic medical images, patient information and test results to be access easily and also accurate clinical decisions making.

During the mid of 1950s, commercial pagers were first applied and used in St. Thomas Hospital in London [17]. Until recent days, alphanumeric pagers and ground wired telephones are still in use in most hospitals [17]. Some hospitals have been using cordless phones or handheld devices to reach staff members in case of emergencies. Furthermore, in keeping with the wireless technology progression, many MEs are now available in wireless formats and settings. For example, the physiological monitors, infusion pumps, and ventilators [6, 7]. These devices can be grouped together and linked to the hospital-wide information system via wireless technology for further medical usage. Medical data can be accessed through mobile handheld devices such as Personal Digital Assistant (PDA) or any other mobile gadgets that are internet supported. Access to information regarding patient's conditions or certain MEs are faster, more systematic and convenient.

Even though wireless technology brings enormous benefits to healthcare, however, there occur restrictions on the use of the wireless devices after reports on malfunctions of the MEs in the late 80s and early 90s, due to the electromagnetic interference (EMI) from the electronic equipment or the wireless devices [17-21]. Therefore, a suitable wireless protocol must meet a set of functional requirements before it can be integrated into the hospitals. The requirements include the wireless frequency bands, the transmission power, minimum distances between the transmitter devices and the MEs, signal modulation type as well as the surrounding environment of the hospitals [1, 22]. In addition, the selected technology must be reliable in transmitting data, low data loss rate, immune to the disturbance by other wireless devices, secured patient data and patient safety, easy to be reconfigured, and also cost effective [1, 23].

This paper reviews some of today's wireless technologies that have been applied in healthcare environment and their EMI effects on the MEs. The objective of current study is to identify the characteristics of the wireless technology that has minimal EMI on MEs and are suitable for healthcare applications. Chapter II reviews about several wireless technologies. Chapter III explains about the coexistence of Wi-Fi, Bluetooth and Zigbee devices. Chapter IV and V portray about discussion and conclusion respectively.

II. Technology Overview

Today, there exist many different wireless technology systems around the world with all different formats and settings to fit the consumers' needs. New technologies keep entering and updating into the market. Wireless Local Area Networks (WLANs), Bluetooth, Zigbee, and Global System for Mobile communication (GSM), just to mention a few of the wireless technologies that are available and are partly implemented in hospitals today.

When choosing a wireless technology to be implemented into healthcare environment, there are many factors to be considered beforehand. One point is that the wireless

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technology devices emit electromagnetic energy, and most MEs contain electronic circuits that would be possible to be affected by the electromagnetic fields [13, 14]. This phenomenon is known as EMI. Plus, wireless devices work by transmitting and receiving radio signals. These signals might be misinterpreted as the electrophysiological signals by some MEs which are sensitive to external RF emissions such as pacemakers and ICDs [13].

Risks of EMI between the wireless transmitter devices and the MEs have to be controlled or eliminated for safety purposes. Potential problematic EMI-related hazards are lost or corrupted data and delayed or degradation in wireless transmissions, which lead to inaccurate results or even chances to cause MEs to silent malfunction [22]. All the mentioned hazards are harmful to patients and may threaten life. A test procedure based on the American Standard ANSI C63.18 – 2014 (revision of ANSI C63.18 – 1997) which recommends practice for an on-site, ad hoc test method to estimate immunity of MEs to electromagnetic radiated from specific RF transmitters [15]. This recommended practice is applicable to most MEs and RF transmitters with output power not higher than 8 W [14, 15, 17]. The test shall be performed in the laboratory, Intensive Care Unit (ICU), as well as operating room (OR). In this study, we reviewed the characteristics of four existing technologies, comprising the WLAN, Blueetooth, Zigbee and Radio Frequency Identification (RFID).

A. WLAN

WLAN, or IEEE 802.11 standard, or known as Wi-Fi in the market. In the earlier years, Wi-Fi was designed for data exchange and data communication, mostly used in laptops and portable personal computers [17]. Now, it is partly used in hospitals as well [16, 17].

Wi-Fi is categorized into low band mode, which is the IEEE 802.11b, g, and n technologies, and high band mode, which is the IEEE 802.1a and c [25]. In its low band mode, the data is transmitted at the speed of 11Mbps and up to 54Mbps in the Industrial, Scientific and Medical (ISM) 2.4 GHz band. While in the high band mode the data can transmit data up to Gbps in the 5GHz band. There are a total of 13 channels of Wi-Fi in the ISM 2.4 GHz band, and each channel is 22 MHz wide and overlapped. The range of coverage of the low band mode goes up to 32 meters indoors, and 95 meters outdoors [27]. The high band mode covers the range more than two times of the b and g technologies. The Enhanced Isotropic Radiated Power (EIRP) of Wi-Fi is limited to 20 dBm or 100mW [27].

Wi-Fi has slowly taken its move to be applied within hospital premises due to its low risk of EMI to MEs [5]. A number of studies have suggested that WLAN system can be implemented into different healthcare or medical applications to improve patient care [1-5]. A study of Paksuniemi et al. [1] on patient monitoring observed medical parameters such as changes in blood pressure, heart rate or respiratory rate, electrocardiography and temperature using wireless technologies. Lin et al. [2] also proposed a similar patient monitoring system but using the PDA integrated with the WLAN technology. The introduction of a medical video streaming over IEEE 802.11e in healthcare applications was done by Tan et al. [3]. While Kundu et al. [4] has proposed a system to support mobile diagnosis and treatment based on the WLAN network.

Fung et al. [5] performed an assessment on the EMI immunity of the MEs against WLAN IEEE 802.11 systems. Three major WLAN standards, the IEEE 802.11a, b and g were tested. Chosen MEs were of categories such as ECG monitors, ventilators, infusion pumps and fetal monitors, just to mention a few. Worst case scenario was set up with the transmission output power and data rates of the wireless transmitter devices were configured to the maximum value. During the assessment using IEEE 802.11b, only one of the tested ultrasonic fetal heart detector, out of 204 pieces of other MEs, which showed abnormality. Noise was heard from the speaker of the detector. There was no abnormal response observed when the MEs were exposed to both the IEEE 802.11a and g systems. Table 1 shows the results of the assessment as concluded from [5].

TABLE I. EMI IMMUNITY ASSESSMENT ON THE MES AGAINST THREE DIFFERENT WLAN SYSTEMS [5]

WLAN Standard	Total of MEs tested	Number of MEs operated normally	Number of MEs showed abnormality
IEEE 802.11a	204	204	0
IEEE 802.11b	204	203	1
IEEE 802.11g	204	204	0

Wallins et al. [17] also had performed a study to investigate if WLAN IEEE 802.11b transmission signal may cause abnormality on MEs operation in ICU and OR environments. The study showed that there was only two MEs out of the 76 were interfered, but were not considered as life-critical.

From the review, it can be revealed that the operation of MEs is less likely to be interfered by the WLAN systems, even at a very close proximity [16, 17]. Although WLANs have relatively low risk of EMI, the ad hoc test [15] to define immunity of MEs to EMI is still recommended to define the susceptibility of the wireless systems within hospital. The purposes of the testing are to identify if there is any ME that is sensitive to the chosen wireless system and determine the minimum distance where the interference starts to occur.

B. Bluetooth

Bluetooth, or IEEE 802.15.1 standard wireless technology, is basically designed to transfer and exchange data over a short range of distance. The IEEE 802.15.1 is based on the Wireless Personal Area Network (WPAN) standards, and it is a modern technology developed to solve tangle of cables and wires [1, 14, 25].

The maximum speed of transmission by Bluetooth vers.1.1 and 1.2 can reached up to 720 kbps and it is capable of transferring both audio and data. The transmission speed of Bluetooth vers.2.0 may reach up to 2.1 Mbps and may be enough for hospital environment [1]. Bluetooth occupies the entire ISM band in the 2.4 – 2.48 GHz, with a total of 79 channels [25]. Each channel is of 1 MHz wide. The range of coverage of Bluetooth varies with the transmission output power. For example, a device with output power of 100 mW

may cover up to 100 meters, while a device with output power of 25 mW is only capable of transferring data in the range of 10 meters. With aspects like high frequency, lower transmission power and robust configuration [14], Bluetooth is assumed to behave positively in healthcare environment.

Wallin and Wajntraub in [14] had performed a test to evaluate the performance of MEs in OR and ICU with a Bluetooth link powered up to transfer data. The Bluetooth link had a very low transmitting power of 1 mW. To ensure that the link did not cause hazard to any ME, the test was done in vitro before moving to the OR and ICU. The results showed none of the 44 tested MEs was affected by the Bluetooth communication link. In conclusion, Bluetooth did not cause any interference to MEs. Furthermore, the surrounding environment of the hospital did not affect the operation of the Bluetooth.

Although the test in [14] has shown that Bluetooth is not susceptible to MEs, however, this is not sufficient to prove that Bluetooth is completely not interrupting the operation of the MEs. While wireless technology and MEs keep advancing to the better version, it is suggested that hospitals should always conduct their own tests before implementing any wireless products into their hospital environment.

C. Zigbee

Zigbee or IEEE 802.15.4 standard wireless technology, is a popular wireless communication standard adopted for its low cost, low power, wider coverage, and security over data [23-25]. The data is transmitted at a rate of 250 kbps in the ISM radio band similar to that of Wi-Fi and Bluetooth technologies. Since the transmission power and data rate is much lower, Zigbee transmits data at a smaller coverage of 10 to 75 meters [1]. Zigbee technology has a total of 16 channels in the ISM 2.4 GHz band, and each channel is 2 MHz wide and not overlapped. The non-overlapping characteristic therefore enabled Zigbee network to coexist at the same period of time and area [25].

IEEE 802.15.4a is an amendment to the previous IEEE 802.15.4 technology [23]. The revision has given an alternative for low-data-rate physical layer, so that the new system is capable of providing precision and accuracy, high aggregation throughput, lower power consumption, wider coverage, and also adding scalability to data rates.

In the preliminary research of Kailas and Ingram [23], Zigbee is said to be one of the several standards that has been considered for medical application such as remote monitoring. Zigbee has low data rate solution, durable possibility and very low complexity. Paksuniemi et al. [1] has also stated that Zigbee is one of the applicable wireless technologies in healthcare for short-range data transmission besides Bluetooth. Additionally, Zigbee enables two-way communication, low cost of production and has lower power consumption.

D. Radio Frequency Identification (RFID)

RFID is a system that consists of a transponder or tag, and an interrogator or a reader. The readers tend to read and write data and information to the tags via a specific radio frequency. The tags are attached to any targeted physical objects or subjects while the readers can be any of a large portal antenna, workstations, or handheld portable readers [8]. Basically, RFID system is used to locate or track people, animals, products and assets [28]. The range of communication between the tags and the readers constrained by certain factors like output power and carrier frequencies. There are five different frequency bands operated in the RFID system [8, 9] and their respective applications are summarized as in Table 2. Overall, RFID system provides variety of benefits, including real time tracking, proximity to identification and a robustness for information storage.

TABLE II. SUMMARY OF RFID FREQUENCY BANDS AND THEIR APPLICATIONS [8]

RFID Frequency Band	Frequency Range	Usage
LF	125 – 134 kHz	For access control of animals and people
HF	13.56 MHz	For used in libraries, passports, payment emitters, and smart cards
433 MHz	433 MHz	For assets tracking
UHF	915 MHz	For used in retails and military supply chain tracking
2.4 GHz	2.4 GHz	For used limited to niche uses

RFID technology system has started to be adopted into healthcare application to improve delivery of patient care. RFID is also adopted to locate doctors, nurses, patients and the assets in the hospitals such as surgical equipment, drugs, blood and all [28]. Although RFID system has posed a variety of benefits, similar to other types of wireless devices, RFID could possibly cause EMI to MEs as it emits electromagnetic energy as well. A number of studies have been documented regarding interference of RFID to MEs [9-13].

Pantchenko et al. in [13] had tested the electromagnetic compatibility (EMC) of implantable neurotransmitter to RFID emitters. Six active implantable neurotransmitters were tested against 22 RFID emitters from different RF frequency bands. Only one exhibited output inhibition and inconsistent pulsing rate when exposed to 134 kHz RFID emitters at a distance from 2.5 cm to 15 cm. Active implantable neurotransmitter devices are claimed to be susceptible to EMI, similar to the implantable pacemakers and ICDs, although they do not have sensing capability. Implantable pacemakers and ICDs are sensitive to external low frequency RF signals because they have cardiac sensing capabilities and are likely to misinterpret the RF signals as electrophysiological signal input.

Seidman and Guag [8] on the other hand had tested the EMC of 11 units of the non-implantable medical devices against 19 RFID readers and one active tag. The RFID included the different frequency bands. Outcome of the test showed that only the RFID of 433 MHz band and 2.4 GHz band did not interfere with the operations of all the MEs.

III. Coexistence of Zigbee, Bluetooth and Wi-Fi Devices

Besides the characteristics of the wireless technology, the hospital environment is also a point that has to be taken note when implementing wireless system for healthcare applications [1, 22]. There is a possibility for coexistence to happen between several wireless technologies. For example, the WLAN is used for surgical conferences, Bluetooth is used to transfer images and Zigbee is used for healthcare monitoring at a particular period. The characteristics of WLAN, Bluetooth and Zigbee are summarized in Table 3 below.

TABLE III. Wireless Technologies and Their Characteristics [1, 23-25, 27]

Wireless Technology	Frequency Band	Data Trans. Speed	Total Channel	Trans. Power
WLAN (IEEE 802.11x)	ISM 2.4 GHz	11 Mbps – 54 Mbps (ISM 2.4 GHz)	13 (2.2 MHz wide, overlapped)	100 mW
	5 GHz	Up to Gigabyte bps		
Bluetooth (IEEE 802.15.1)	ISM 2.4 – 2.48 GHz	vers.1.1/1.2 – 720 kbps vers.2.0– 2.1 Mbps	79 (1 MHz wide)	25 mW to 100 mW
Zigbee (IEEE 802.15.4)	ISM 2.4 GHz	250 kbps	16 (2 MHz wide, non-overlapped)	Low power consumption [1]

WLAN, Bluetooth, and Zigbee wireless technologies are sharing the same unlicensed ISM frequency band, therefore there is possibility that mutual interference problem may occur, especially during close proximity [25]. The IEEE 802.11 Wi-Fi standards may affect the performance of Zigbee and Bluetooth if channels allocation is not taken into account. However, Bluetooth and Zigbee scarcely affect the performance of Wi-Fi. As Bluetooth is occupying the entire ISM band with 79 channels, while Zigbee has 16 channels with 2 MHz wide each and Wi-Fi has 13 channels with 22 MHz wide each, these channels are overlapped in the ISM band [25]. Hence, chances of getting interference problem are high. Fig. 1 shows the allocation of the Wi-Fi and Zigbee channels over the ISM band.

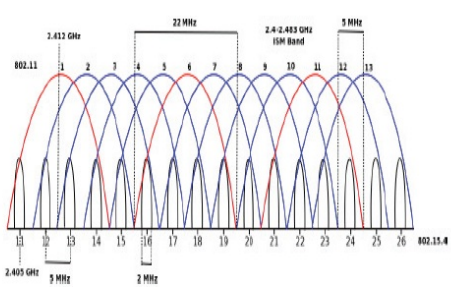

Figure 1. Allocation of Wi-Fi and Zigbee channels over the ISM band [27].

Due to the overlapping, Zigbee has left with channels 25 and 26 which are free from interference. Plus, the maximum transmission power of Wi-Fi may be 100 times higher than that of Zigbee, which makes these two technologies hardly to coexist at the same time in the same area [25].

An experimental assessment to determine the level of coexistence of the wireless devices had done by Garroppo et al. [27]. The results are shown from Fig. 2 to Fig. 5. Analyzing Fig. 2, the presence of Wi-Fi in proximity affects the frame error rate (FER) of Zigbee, where the FER drops to a value of 0.45. Conversely, Wi-Fi is practically less or none affected by the presence of Zigbee. The activity of Wi-Fi is shown in Fig. 3.

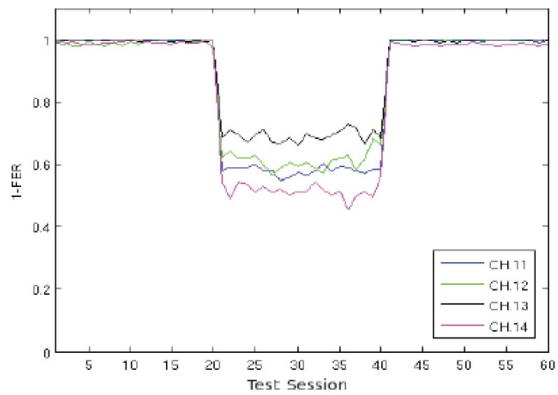

Figure 2. Performance of Zigbee under the presence of Wi-Fi in proximity [27].

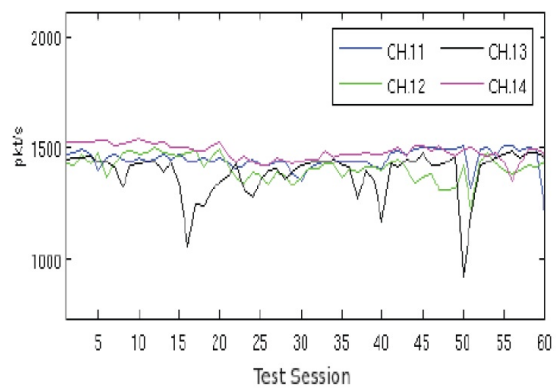

Figure 3. Performance of Wi-Fi under the presence of Zigbee in proximity [27].

The effect of Bluetooth over Zigbee was not obvious, as the FER dropped less than 10% [27]. However, under the presence of Zigbee, Bluetooth's performance showed rather an unstable network, as in Fig. 4. However, the degradation effect runs quite unnoticeable. The effect of Wi-Fi over Bluetooth showed high degradation on the Bluetooth signal. Fig. 5 illustrates the performance of Bluetooth under the interference of Wi-Fi. The data rate dropped from 1.12 Mbps to 0.59 Mbps, which was almost 50% of the drop for TT – RR scenario, while in TR –RT scenario, data rate dropped from 0.95 Mbps to 0.3 Mbps, which was more than 50%.

From the assessment in [27], Wi-Fi has proven to be scarcely affected by the presence of other wireless

technologies that operated in proximity. However, Bluetooth and Zigbee prompt to be interfered by the presence of Wi-Fi and suffered from serious signal degradation, especially Bluetooth [29, 30]. Zigbee is less likely to be interfered by Wi-Fi and Bluetooth, but Zigbee appeared to affect the performance of the Bluetooth. Therefore, Bluetooth networks require a more drastic separation from the existence of other wireless networks or devices. Appropriate encryption protocols are needed if Bluetooth-based system is chosen to be integrated into healthcare environment [14].

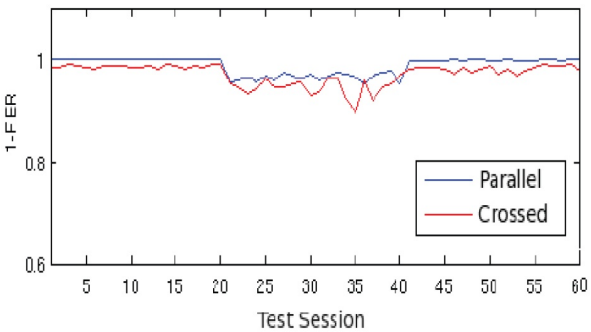

Figure 4. Performance of Bluetooth under the presence of Zigbee in proximity [27].

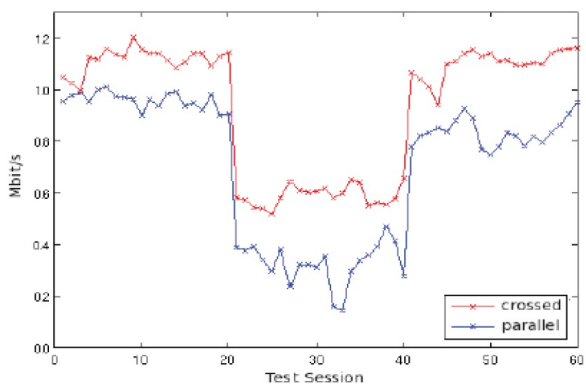

Figure 5. Performance of Bluetooth under the presence of Wi-Fi in proximity [27].

IV. Discussion

Implementing the wireless technology into healthcare environment requires consideration on the EMI and EMC between the wireless transmitter devices and the MEs. Previous studies have reviewed to determine the suitability of WLAN, Bluetooth, Zigbee and RFID in healthcare applications. Although previous studies have proven that these wireless technologies did not bring hazards to the MEs, however, they tend to interfere among others during the coexistence assessment [27]. Compatibility test of the RFID by [8, 13] have also proven that 433 MHz and 2.4 GHz frequency bands did not bring hazards to the MEs. However, there is no coexistence assessment done on 433 MHz bands up to date.

The establishment of wireless techniques in medical or healthcare environment is dependent on the wireless frequency band, wireless transmitter output power, distances between the wireless devices and the MEs, and the surrounding environment of the hospitals. Mostly occupied wireless frequency band, such as the 2.4 GHz may have higher chances to be subjected to interferences. Therefore, it is less likely to integrate the wireless technologies in 2.4 GHz band into healthcare environment. Relatively higher frequency and lower transmission power systems are believed to be less likely to interfere with the operation of the MEs [16, 17]. An ad-hoc test [15] can be conducted to determine the minimum distance of separation between the wireless devices and the MEs. This minimum distance of separation is where the interference started to take place. According to [31-33], it is uncommon for EMI affairs to occur at distances greater than 1 m. Surrounding environment of the hospitals such as building factors and other facilities may influence the degree of EMI [34, 35].

Further testing and assessment on the compatibility and the coexistence of the chosen wireless are suggested in order to assure the top performance is delivered in hospital and patient care.

V. Conclusion

In this paper, we have investigated the characteristics of the wireless technology with minimal EMI effects on the medical appliances that are suitable for healthcare applications. From the study, it can be concluded that the establishment of wireless techniques into medical or healthcare environment depends on the wireless frequency band, the wireless transmitter output power, distances between wireless devices and medical equipment, and the surrounding environment of the hospitals. In addition, the selected technology need to be reliable in transmitting data, low data loss rate, immune to the disturbance by other wireless devices, secured patient data and patient safety, easy to be reconfigured and also cost effective. Although some wireless technologies have been proven to be low risk of EMI, hospitals should always conduct an ad hoc test based on ANSI C63.18-2014 to define the compatibility of the involved MEs against EMI of specific wireless technologies. Medical staff shall always be aware of the fact that interference may occur anytime and shall always be prepared on how to react against it.

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