

Electromagnetic Interference Immunity Testing of Medical Equipment to WLAN IEEE 802.11 Systems

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Abstract— Studies have proposed that wireless local area networks (WLAN) can be applied in medical applications to enhance the quality of patient care, such as patient monitoring systems and hospital admission systems. However, there has been concern regarding the effect of electromagnetic interference (EMI) on medical equipment from wireless communication devices, especially those at close proximity to vital medical equipment. As a result, an investigation to examine the medical equipment due to interference from the WLAN devices was carried out. The outcomes have indicated that a WLAN system is safe for installation inside hospital premises, with only one of the fetal heart monitors found to be susceptible to the interference of an IEEE 802.11b WLAN system.

Key words: EMI, hospital, immunity test, medical equipment, WLAN.

I. INTRODUCTION

The effects of electromagnetic interference (EMI) from wireless communications devices on medical equipment, especially on life-critical medical equipment, have been a major concern raised by hospitals and the general public in the last decade. In 1994, a radiofrequency susceptibility test on medical equipment was carried out by the Medical Devices Bureau in Canada. Some kinds of medical equipment, such as ventilators, infusion pumps, defibrillators with an electrocardiogram (ECG) monitor and fetal monitors, were found to be quite susceptible to EMI within the frequency band of interest. The study suggested that care be taken when operating VHF radios, UHF radios and cellular phones within one meter of these devices [1]. In 1997, the Medicines and Healthcare Products Regulatory Agency (MHRA) in the United Kingdom carried out an EMI test on medical equipment using different mobile communication devices, such as analog phones, global systems for mobile communications (GSM), personal communication networks (PCN) and two-way radios. These results showed that anesthesia machines, respirators, external pacemakers, ECG monitors, defibrillators, infusion pumps and ventilators were also sensitive to EMI [2]. In 1999, a study of EMI effects due to walkie-talkies, GSM 900 and digital cellular systems (DCS

1800) on external pacemakers was carried out; results have shown that pacemaker inhibition and asynchronous pacing were caused by EMI in some cases [3]. In 2004, there was a study of EMI on infusion pumps from GSM mobile phones; results have shown that infusion pumps and syringe pumps were stopped and an alarm was triggered due to the EMI from GSM 900 and PCS 1800 mobile phones [4]. It has been concluded that certain types of medical equipment, including fetal monitors, infusion pumps, syringe pumps, ECG monitors, external pacemakers, respirators, anesthesia machines and defibrillators, are sensitive to mobile communication devices, such as analog and digital mobile phones and two-way radios [1-4]. Short-range wireless communications systems such as Digital Enhanced Cordless Telecommunications (DECT) and WLAN are commonly considered to be relatively less risky within hospital premises due to their comparatively low transmission power.

Nowadays, the newly developed medical equipment shall meet the immunity requirements as stated in the EMC standard, for example, EN60601-1-2 [5]. In the latest version of EN60601-1-2, the immunity test levels have been increased to 3 V/m and 10 V/m for non-life support devices and life-support devices, respectively, in order to provide further protection to medical equipment against the interference from wireless devices. The testing frequencies have also been extended to 2.5 GHz to provide better immunity performance and better coverage in the operating frequencies of existing wireless communication equipment. However, the test level can also be different from the standard immunity levels provided that the specific immunity level is clearly stated by the manufacturer in the equipment instruction manual.

Considering that the risk of a WLAN system is comparatively low and the improvement in EMC design of medical equipment to be more immune to electromagnetic interference, WLAN has become one of the most suitable technologies for installing within hospital premises in recent years. Various studies have suggested that a WLAN system can be used at different medical applications for improving

the efficiency of patient's health care in hospital [6-12]. Lin et al. [6] proposed a mobile patient monitoring system for vital signs such as heart rate, three-lead electrocardiography and SpO₂, which integrated a current personal digital assistant (PDA) technology and wireless local area network technology. Tan et al. [7] presented a medical video streaming over 802.11e-WLAN in m-health applications and the corresponding issues of this application. Baker et al. [8] discussed that standards-based 802.11 networks with published reliability tenfold higher than conventional telemetry already met the requirements for supporting life-critical applications, such as electronic medical record updates through a direct connection to clinical information systems, in today's healthcare environment. Soomro et al. [9] discussed that Wireless Personal Area Networks (WPAN) and WLAN technologies will play a fundamental role in enabling the integration of IT and medical applications, such as real-time and remote control of medical equipment for improving health care efficiency. Kundu et al. [10] proposed a system that has the potential to support mobile-diagnosis and treatment within hospital premises based on a WLAN network. Golmie et al. [11] evaluated the performance and suitability for medical applications on cable replacement to remove tethering devices and allow for flexible configurations for mobile units through low-rate WPAN technology, as specified in the IEEE 802.15.4 standard. Paksuniemi et al. [12] performed a study on using wireless technologies for patient monitoring of medical parameters such as blood pressure, electrocardiography, respiration rate, heart rate and temperature.

Although WLANs pose a relatively low risk for medical application, ad-hoc immunity measurements of medical equipment in a real hospital environment against the interference from wireless communication devices are required by hospital authorities, in Hong Kong, in consideration of the particular interference scenarios in hospitals, such as specific immunity levels, interference source at close proximity, reflections and resonance. In this paper, the EMI effects on medical equipment caused by the WLAN including IEEE 802.11a at 5GHz and IEEE 802.11b/g at 2.4 GHz in Hong Kong are discussed. The purpose is to identify any sensitive medical equipment with regards to different WLAN's systems and also to find out their corresponding distances to where interference ceases.

II. METHODOLOGY

Although the immunity electric field test level of the type tests in EN 60601-1-2 [5] provides a relatively good radiated immunity margin for the medical equipment of concern, it does not guarantee the satisfactory operation of the equipment in certain *in-situ* circumstances such as using a notebook or personal computer station with a WLAN in the near vicinity of the medical equipment. In order to study the EMI effects on medical devices under the *in-situ* hospital environment, it is necessary to characterize the EMC performance of the existing medical devices due to wireless telecommunications

devices in the hospitals. The EMI immunity assessment on medical equipment was carried out in a hospital in Hong Kong. The assessment procedures have followed the ideas mentioned in the ANSI C63.18 standard [13], which specifies the on-site and ad hoc testing in evaluating the radiated immunity of medical equipment to mobile transmitters. In this assessment, three major WLAN standards, including IEEE 802.11a, IEEE 802.11b and IEEE 802.11g are reviewed. The corresponding operating frequency, maximum data rate and maximum transmit power of these WLAN systems are summarized in Table I.

The schematic diagram of the test setup is shown in Figure 1. This includes the medical device under test, and a WLAN Network. The WLAN Network consists of a wireless Access Point (AP) that is to be installed in the hospital, a notebook computer (i.e. Server) to control the wireless AP and another notebook computer (i.e. Client) for receiving and transmitting data, completing an operational WLAN system. In general, both vertical and horizontal polarizations of the WLAN antenna are to be tested. As shown in Figure 2, the antenna of the access points for IEEE 802.11a (i.e. 5.18 GHz) and IEEE 802.11b/g (i.e. 2.412 GHz) are located at different positions of the AP, the configurations for the test set up of the same polarization for IEEE 802.11a and IEEE 802.11b/g are hence correspondingly different in the polarization of the client's notebook computer. The corresponding setups of the client's notebook and wireless AP for different antenna polarizations of IEEE 802.11a and IEEE 802.11b/g in this assessment are illustrated in Figure 2 through Figure 5. For each WLAN standard, the transmission frequencies are set at the lowest channel frequency, as recommended in the Cisco guideline [14]. In order to generate the highest transmission power to the medical equipment to represent a worst-case scenario, transmission powers are set to the provided maximum output power when transmitting data. All the transmission data rates are also set to the highest data rates corresponding to the standards. Medical devices shall be placed and operated in a condition of normal-use, as discussed and agreed with the medical staff in the hospital. All four sides of the medical equipment shall be tested, except under some particular conditions such as wall mounted or fixed, installed medical equipment.

The WLAN antenna is placed firstly at 10 cm from the edge of the medical device. If any abnormal responses were observed at 10 cm, the WLAN's interference would be turned off to confirm that the abnormal response was caused by the WLAN system. The symptom of the abnormal responses and the electric field strength at the medical device are recorded at that particular distance, and the test shall be repeated for separation distances increasing from 10 cm to 3 m, until the abnormal response ceased. The electric field strength is measured by a dipole antenna connected to a spectrum analyzer (Model: R&S FSEK30: Spectrum Analyzer, 20Hz to 40GHz).

In the immunity assessment, there is a total of 204 pieces of

medical equipment, covering categories such as fetal monitors, infusion pumps, ventilator, ECG monitors, physiologic monitor, respirators, anesthesia machines and defibrillators, etc., which were selected and tested against the WLAN's operating frequencies in each WLAN system mentioned. Two main types of abnormal responses, including visual response (i.e., image and waveform distortion on the monitor, error code and power turn off) and audio response, (i.e., alarm sound and noise generation in the speaker) of the medical equipment were studied.

TABLE I
CHARACTERISTICS OF WLAN SYSTEMS IN THE ASSESSMENT

System	Operating Frequency (GHz)	Max. Data Rate (Mbits/s)	Max. Transmit Power (W)
IEEE 802.11a	5.18 – 5.25	54	0.2
IEEE 802.11a	5.25 – 5.32	54	1
IEEE 802.11b	2.412 – 2.472	11	1
IEEE 802.11g	2.412 – 2.472	54	1

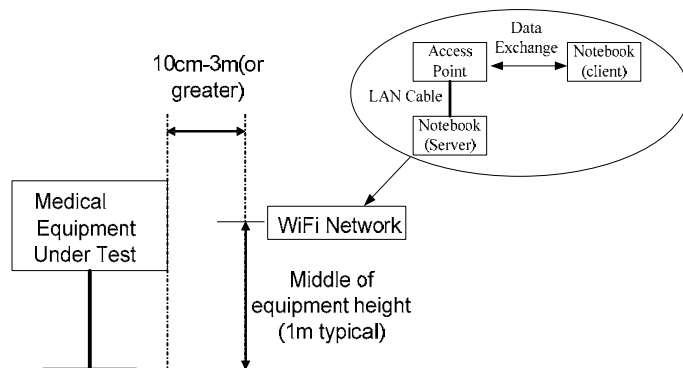


Fig. 1 Block diagram of test set up

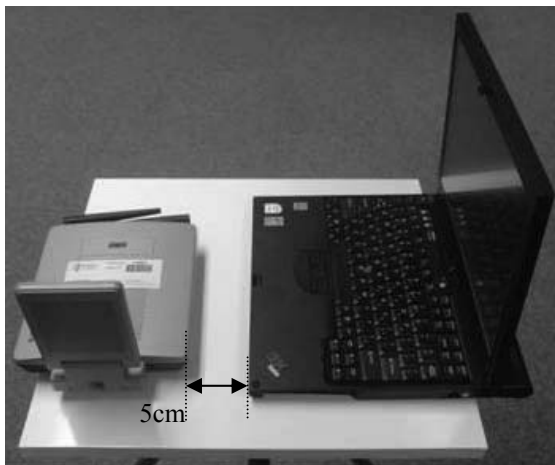


Fig. 2 Setup for IEEE 802.11a – Vertical polarization

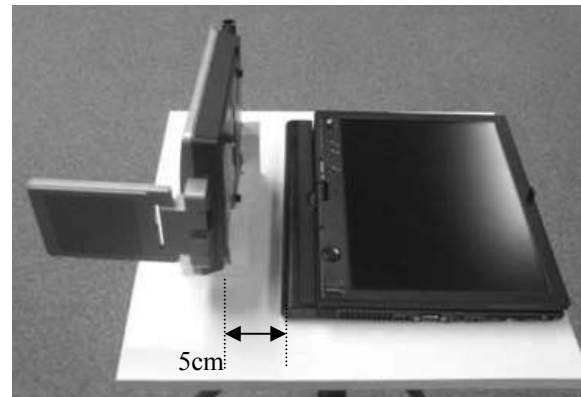


Fig. 3 Setup for IEEE 802.11a – Horizontal polarization

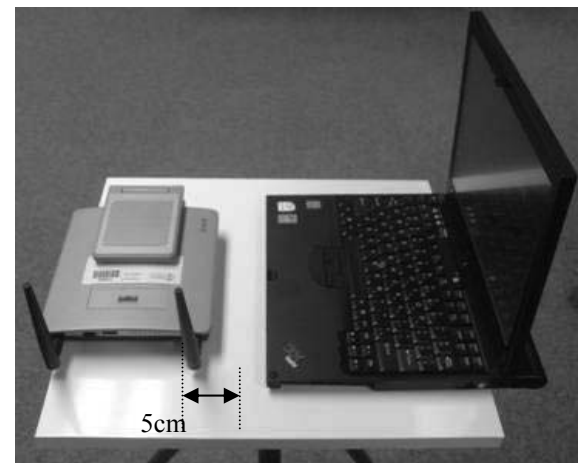


Fig. 4 Setup for IEEE 802.11b/g – Vertical polarization

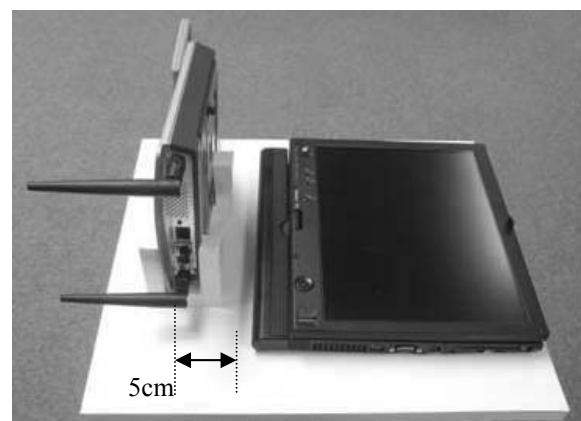


Fig. 5 Setup for IEEE 802.11b/g – Horizontal polarization

III. RESULTS AND DISCUSSION

The immunity assessment was conducted for a total of 204 pieces of medical equipment. A total of eight different

departments, including Central Nursing, Medical and Geriatric, Neurosurgery, Obstetrics and Gynaecology, Operating Theater, Paediatrics, Radiology and Surgery, were involved in this assessment. A summary table of the test results of the EMI immunity assessments on the medical equipment against three different WLAN systems is shown in Table II. Of these, 203 pieces passed the assessment while only one failed when exposed to the interference of IEEE 802.11b corresponding to a 0.5% of failure rate. No abnormal response was observed during the immunity test with IEEE 802.11a and IEEE 802.11g systems. An ultrasonic fetal heart detector was found to be susceptible to IEEE 802.11b at all four sides and at both vertical and horizontal polarizations of the AP and notebook computer. During the assessment, noise is found to be generated in the speaker of the detector at 10 cm distance, and the abnormal response ceased when the distance was increased to 60 cm. Electric field strengths of 0.22 V/m and 0.24 V/m measured at the cease distance were recorded at vertical and horizontal polarization, respectively.

TABLE II
TEST RESULT OF THE EMI IMMUNITY ASSESSMENT ON THE MEDICAL EQUIPMENT AGAINST THREE DIFFERENT WLAN SYSTEMS

System	Number of Tested Equipment	Number and Percentage of Equipment Passed	Number and Percentage of Equipment Failed
IEEE 802.11a	204	204 (100%)	0 (0%)
IEEE 802.11b	204	203 (99.5%)	1 (0.5%)
IEEE 802.11g	204	204 (100%)	0 (0%)

IV. CONCLUSION

In this study, the immunity assessment for 204 pieces of medical equipment against three different WLAN standards, including the IEEE 802.11a, b and g, were carried out. In summary, no particular life-critical abnormal response was observed in the assessment indicating that the WLAN systems are not likely to affect the performance of medical equipment, even operating at a very close proximity of the medical equipment (i.e 10cm). Only one of the tested ultrasonic fetal heart detectors was found to be susceptible to the IEEE 802.11b signal, and the abnormal response ceased with a separation distance larger than 0.6 m.

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