

EXPERIMENTAL INVESTIGATION OF UWB SIGNAL INTERFERENCE EFFECT BETWEEN UWB COMMUNICATION DEVICE AND VSAT

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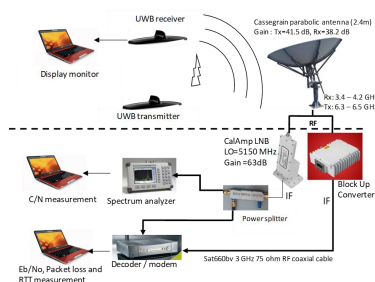
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Graphical abstract



Abstract

This paper presents the experimental investigation of the Ultra Wideband (UWB) signal interference effect between commercialized UWB communication device (UCD) and Very Small Aperture Terminal (VSAT). Recent research trend shows increase of interest to make use of UWB signal for Internet of Things (IoT) application. It is expected that IoT devices based on UWB technology increases in the future and can become unattended jammer to other services. The analysis involves two sets of experimental set up: i) UWB communication system is the interference victim from narrow band signal and other UWB transmission and ii) signal radiated from UCD devices using UWB signal interfere to other existing radio communication services which in this case a VSAT. The level of interference is evaluated based on the measured bit error rate (BER), round trip time (RTT) and carrier over noise ratio (C/N). The finding from this paper can be used as a guide for new interference mitigation techniques and spectrum planning purposes.

Keywords: UWB communication, IoT devices, Interference study, UWB signal, VSAT, IoT-UWB

Abstrak

Kertas penyelidikan ini membincangkan tentang ujikaji yang dilakukan dalam mengkaji kesan isyarat jalur lebar ultra (UWB) di antara peranti komunikasi UWB peranti komunikasi (UCD) dan VSAT. Perkembangan semasa menunjukkan peningkatan minat dalam menggunakan isyarat UWB dalam aplikasi IoT. Dijangkakan pada masa hadapan peralatan IoT berasaskan UWB akan meningkat serta berkemungkinan akan mengganggu peralatan/perkhidmatan yang lain. Analisis yang dijalankan merangkumi 2 set ujikaji iaitu: i) sistem komunikasi UWB sebagai mangsa hingar daripada isyarat jalur sempit dan isyarat UWB yang lain serta ii) kesan isyarat UWB daripada peralatan UCD terhadap perkhidmatan sistem radio komunikasi yang lain dalam kes ini VSAT. Beberapa parameter telah dianalisis untuk mengkaji aras gangguan isyarat antaranya BER, RTT and C/N. Hasil kajian daripada kertas penyelidikan ini boleh digunakan sebagai panduan dalam penghasilan teknik pengurangan hingar dan perancangan frekuensi.

Kata kunci: Komunikasi UWB, Peranti IoT, Kajian Gangguan Isyarat, Isyarat UWB, VSAT, IoT-UWB

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1.0 INTRODUCTION

It has been more than a decade since the first paper on Ultra Wideband (UWB) was considered for

application in wireless communication. The wireless communication system which based on UWB technique is emerged from the time-domain electromagnetic concept [1]. It thus can provide a

diverse applications that benefits researchers, consumers, industries and businesses. In general, UWB signal is designed for a low power digital data communication over a broad frequency bands, hence ensuring the public safety. In many countries, UWB signals are allowed to operate in the frequency band between 3.1 GHz to 10.6 GHz with bit rates greater than 100 Mbps [2]. UWB signal can be generated from the analogue waveform including a typical pulse signal then it is radiated into the air for transmission [3]. Hence, the technique could be materialized without using expensive electronics/radio frequency components thus reduces the system cost. The broad spectrum bandwidth operated by UWB inevitably will occupy other existing radio services frequency range. As a consequence, an obligation to reduce significant interference to other systems is imposed. This challenging requirement seems to be an opportunity for UWB for many applications. Many works are still in progress to increase the utilization of UWB technology for consumer sectors.

Currently, the inherent advantages of UWB steered the increase in its applications such as in home entertainment [4] and define as UWB communication device(UCD). Recent development in UWB with new standard that can support the requirement of Internet of Things (IoT) [17] create diverse emerging applications as supported in [5] on the hybrid between UWB/Radio-frequency identification(RFID) towards IoT which in this case a wireless sensor network(WSN). A research paper [6] highlights the reborn of UWB technology as a technique to add localization for a wide range of uses in the WSN. The paper shows the development of an advanced prototype of impulse radio, allowing accuracy within inches for indoor and outdoor localization. As a result this paper foresees that UWB will be very useful in many IoT applications namely constrained sensor nodes communication, radar and positioning as provided in the following Table 1. Thus, in the near future, it is expected that many IoT based consumer devices will adopt UWB technology.

The nature of the UWB signals characteristics and transmission may cause interference between the UWB devices and also to other radio communication services. There are some studies that focused on the UWB performance in the environment with dense multipath and with additive of white Gaussian noise [11]. Since the signal's characteristic of UWB technique uses a broad bandwidth, it is worthwhile to study the interference effect from a narrow bandwidth (NB) signal on the UWB signal itself. Although some studies have been performed to analyse the interference level on the UWB system from NB signal [12], this paper extends the experiment to the commercialized UWB device. A study on the impact of UWB signal to wireless local area network(WLAN) and global system for mobile communication(GSM) are explained in [13] and [14], respectively. However, these studies did not conduct the complete UWB devices and there is still lacking in

literature for the interference from commercialized UWB devices to other communication services.

Table 1 Summary of selected UWB application (current and future) based on UWB technique composition

Category	Features	Descriptions
Communication	Communication in dense environment	Robust indoor environment is due to UWB resistant to multipath fading which limit indoors communications. UWB also scales well in dense deployments [7]
	One-to-many communication	The unique nature of the UWB can support one-to-many communication at the physical layer [7]
	High data rate with battery powered	High definition television for example requires excess of 30 Mbps over a distance of at least few meters
	Low power	UWB low data-rate transceiver suitable for battery-less operation [8]
Radar	Secure wireless transmission	The large bandwidth of UWB also enable secure communication with special modulation at the physical layer [8].
	Passive object identification and inspection	UWB radar devices is very small in size, low-cost, low-power and have an excellent range resolution [9].
Positioning	Positioning performed between active devices	High positioning accuracy (mm) is possible even indoors [10].

Thus the aim of this paper is to analyse the interference that can be caused by the commercialized UWB consumer communication devices using UWB signal to other consumer devices including Very Small Aperture Terminal (VSAT) services. In addition the interference to the UWB system is also studied. The analysis is divided into two parts:

- i) interference to UWB communication devices from other services, and
- ii) interference from UWB communication devices to other radio communication services eg. VSAT (as a victim).

In the first part, a set of UWB-based devices which share the same carrier frequency range were tested. Two experimental configurations for measuring the link quality between the two UWB devices were set up. The single NB channel and signal from other UWB devices were used as the source of interference. The bit error rate (BER) were recorded and evaluated for each measurement to analyse the level of interference. In the second part, an electromagnetic wave interference from the UWB devices towards the VSAT radio communication services is analysed. The results from the experimental analysis can gain insight information on the interference issues when later many IoT UWB-based devices were made available as consumer devices. Regulators, researchers and engineer can benefit from this information for current and future planning. As the first part, this paper presents the general background on UWB techniques, its standard and current IoT devices development based on UWB techniques.

The availability of IoT consumer devices based on UWB in the market is increasing year by year. It has been developed for various applications. To respond to this demand, the Federal Communications Commission (FCC) in United States for example and some other countries allocate frequency range between 3.1 to 10.6 GHz to UWB system. According to the recommendation in [2], the maximum operating power for UWB devices is kept to be lower than -41.3 dBm. The reason is to reduce any effect of interference to other primary radio communication services. The initial power spectral mask proposed for UWB devices to be operated either for outdoor and indoor applications is shown in Figure 1 [2].

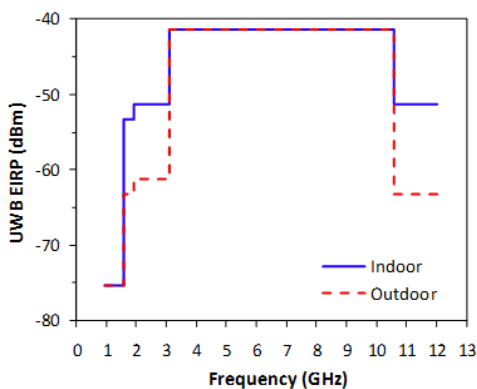


Figure 1 Proposed spectrum mask for UWB system operating in indoor and outdoor environment

For UWB signal design in time domain, few options can be chosen such as a short-pulse waveform and comprises of few cycles of RF energy [13]. These

waveform can be mathematically modelled easily. As an example equation in (1) illustrates the polycycle waveform model for UWB pulses with N numbers of sinusoid cycles [5]. Figure 2(a) shows typical waveforms for this type of UWB signals.

$$S(t) = \begin{cases} \sin(\omega t) & 0 < t < NT \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

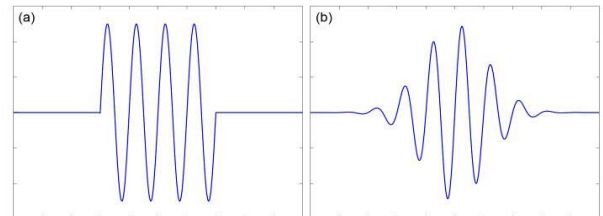


Figure 2 Typical UWB pulses in time domain. (a) polycycle and (b) Gaussian waveform

Another typical model for UWB signal is Gaussian which can either be monopulse or polycycle as illustrated in Figure 3 [3]. The mathematical definition for the latter modelled is given in (2) which shows the integration of sinusoidal waveform into a Gaussian function.

$$S(t) = \sin(\omega t)e^{-\frac{1}{2}x^2} \quad (2)$$

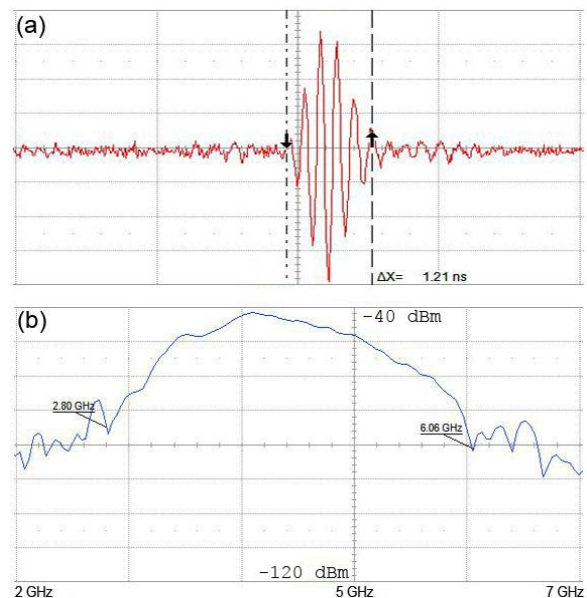


Figure 3 Initial sampling of UWB device A in (a) time domain and (b) frequency distribution

In terms of modulation that can be integrated with UWB signals, typical modulation options such as pulse position modulation (PPM) or binary phase shift keying (BPSK) are possible. Thus, the bit error rate for binary modulations in an additive white Gaussian

noise(AWGN) channel $n(t)$ with double-sided spectral density of $N_0/2$ is shown in (3).

$$BER = P_b = Q \cdot \sqrt{\frac{d_{12}^2}{2N_0}} \tag{3}$$

where d_{12} is the Euclidean distance between two different symbols on a constellation, and the $Q(x)$ given in (4) [14],

$$Q(x) = \frac{1}{2} \operatorname{erfc} \left(\frac{x}{\sqrt{2}} \right) \tag{4}$$

From hardware point of view, the attractiveness of the UWB systems lies in the fact the same system can have identical circuit front-end but can perform multi-function of communication, radar and positioning. It also a carrier less system meaning that the transceiver can be fabricated using all digital architecture technique without analogue components. The multi-function capability and the carrier less property of UWB reduce complexity, cost, weight, size and power consumption. The advantage of the UWB systems is due to the nature of its signal which acquires very fine time duration. This provides high bandwidth and penetration capability that is useful in diverse applications. Together with the fact its feature can mitigate the effect of multi-path problem, it works well in dense environment i.e. indoor.

2.0 METHODOLOGY

This section is divided into two sub-section. The first one elaborates the interference analysis to UWB communication from narrowband signal and from other adjacent UWB signal. The next sub-section presents the analysis of VSAT radio services interference from UWB signal.

A. The Effect of Interference to UWB Devices

This section explains the experimental set-up and measurement that was conducted to study the interference to the commercialized consumer devices based on using UWB technology. Three types of UWB device for different applications were used with detail as below and summarized in Table 2. The specific brand is not available to ensure the integrity of the paper. However, the information on the technique and specification for each of the UWB devices is more important for interference measurement.

Table 2 Summary of commercial UWB devices used for interference measurement

Name	Device A	Device B (Band 1)	Device B (Band 2)	Device C
Frequency range	3.1-6.3 GHz	3.168 to 4.752 GHz	6.336 to 7.976 GHz	3.1 to 4.8 GHz

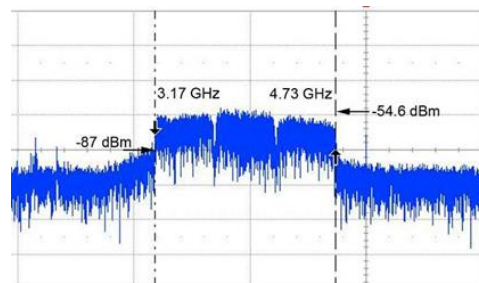
Name	Device A	Device B (Band 1)	Device B (Band 2)	Device C
Measured output Power density	-23.1 dBm/MHz	-39.1 dBm/MHz	-39.1 dBm/MHz	-49.5 dBm/MHz

1. UWB device A (UWB Transceiver)

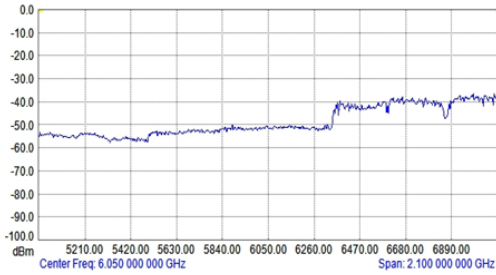
UWB device A is a complete UWB Transceiver radio device that sends the UWB pulse. It is equipped with the evaluation kit which includes two radios and system analysis software (SAM). The device is connected to the computer and uses a fixed IP address to access and control the device through the monitoring software. The radio part of the UWB device as well as the communication parameters can be easily configured by the software. The device is set up by selecting one UWB radio part as a transmitter and the other one is configured as the receiver. This device transmits a UWB pulse with the centre frequency of 4.7 GHz and the 3 dB bandwidth is 3.2 GHz. The Pulse Repetition Frequency (PRF) is selected to be 9.6 MHz. Figure 3 illustrates the signal waveform and its frequency spectrum of the device that were captured using a digital oscilloscope. The output power of transmission is less than -41 dBm.

2. UWB Device B (Wireless Audio Video (A/V) Extender)

The latest applications of UWB system is the wireless home entertainment. A commercially off-the-shelf wireless audio/video extender UWB device for extra screen (eg. liquid crystal display(LCD) and television) is selected which includes a UWB transmitter connected to the signal source and a receiver equipped with AV/high definition multimedia interface(HDMI) connected to the screen. Currently, this device is available for two UWB frequency bands: 3.11 – 4.8 GHz, 6.3 – 7.9 GHz (denoted as UWB device B: band-2 and band-1 respectively). Figure 4 illustrates the snapshot from the spectrum analyser for frequency distribution of UWB device B, it can be seen that it overlaps with the UWB device A. This device uses a direct sequence spread spectrum as the modulation technique. The maximum power emission level of this device is -39.1 dBm/MHz.



(a)

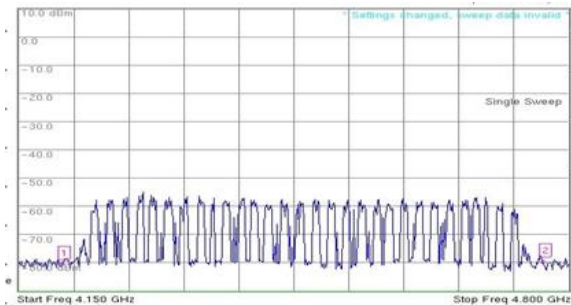


(b)

Figure 4 Frequency distribution of wireless A/V extender. (a) UWB device B (band-1) (b) UWB device B (band-2)

3. UWB Device C (Wireless for HDMI)

The third consumer electronics based on UWB devices that was selected is the wireless for HDMI. Figure 5(a) shows the spectrum plot for this device at single sweep with operating frequency band between 4224 – 4752 MHz. Multiband single carriers pulse-based technique is used for this device. Single-carrier multiband systems transmit information by modulating the phase of a very narrow pulse. The bandwidth for each carrier/narrow pulse is 6.818 MHz as shown in Figure 5(b). This device has 3 sub-bands but it operates in one sub-band at a time. The carrier frequency can shift between 3.168 – 3.696 GHz, 3.696 – 4.224 GHz and 4.224 – 4.752 GHz.



(a)



(b)

Figure 5 Spectrum plot of UWB device C (Wireless for HDMI)

B. Interference Measurement Set-Up

This section discusses the effect of interference to UWB devices by narrow band signal (NBI) and other UWB signal. Separate experimental layouts were done and three different data rate transmissions (9.6 Mbps, 600 Kbps and 75 Kbps) were tested for each measurement. The experiment was performed separately with each measurement was taken for 600 sec duration of continuous transmission. The BER measurement is used to indicate the significant effect of interference to UWB communication. The BER measures the number of received bits of a data stream over a communication channel that has been distorted due to interference.

Figure 6 shows the interference measurements set-up from NBI at two different central frequencies ($f_c = 3.1$ GHz and 4.7 GHz) to the UWB system. The distance between the UWB devices pair, D_d is fixed to 3m, but the distance of the jammer, R (range of NB to the midpoint between the UWB devices) is varied from 1 to 6 m. The BER of the UWB communication system is measured for each distance and shown in Figure 7. The measurement result shows that the BER increases as the distance between the UWB signal on air and source of jammer reduces. The level of interference is more significant for higher data rate, from figure indicates that communication data rate with 9.6 Mbps is more affected as compared to more robust lower rate data transmission of 75 kbps. Another point is that, since the NBI carrier frequency of 4.7 GHz overlaps with the UWB centre frequency, resulting higher interference.

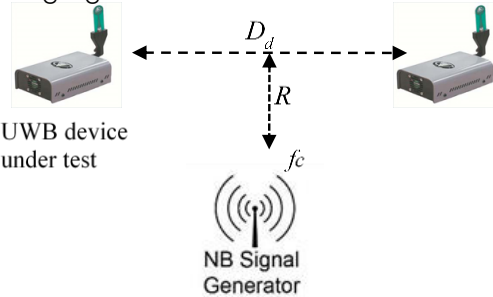


Figure 6 Measurement set-up to measure interference to UWB devices by narrow band signal (NBI)

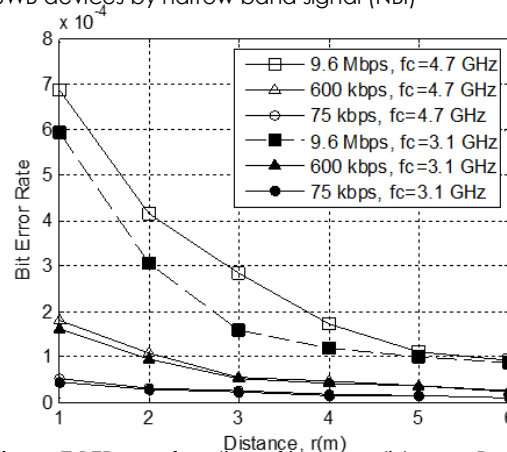


Figure 7 BER as a function of jammer distance, R with fixed $d = 3$ m for UWB device A pair

C. UWB Signal Interference to VSAT

The effect of interference from UWB based devices to other existing radio communication services is analysed in this section, specifically a VSAT system operating in Malaysia (as a study case for typical active VSAT services) was chosen as the victim as the case. VSAT system provides various applications, including: telephony, fax, television, Internet broadband access, satellite news gathering (SNG), high-speed data communication services, location and others. In general, VSAT offers a high-quality communication services for both business users and residential. Many of VSAT services offered in Malaysia are used for mission critical applications. Oil and gas industries, supervisory control and data acquisition (SCADA), automated teller machine (ATMs), Point of Sales and other banking related services are some of the example of common users of VSAT services in Malaysia. Since the services are of commercial services offered to various clients, there are concerns from the industry on the possibility of interference from the UWB consumer devices towards the VSAT services. In addition, broadcasting satellite services that are utilizing C band frequency range in Malaysia are overlapping with UWB operating frequency range of 3 to 10 GHz. Hence, there were also concerns from satellite TV service providers on possible interference from UWB devices to their household consumer satellite dishes reception.

A VSAT communication system use for academic purposes and placed on the roof top of fourteen stories building located in Faculty of Engineering, Universiti Putra Malaysia is used for the testing. In general, VSAT consists of the inbound (remote terminal) and the outbound (hub station), the measurement is established at the inbound part where it is more prone to interference. The experimental setup on the roof top can reduce any scattering or diffraction effect and scattering that might exist and it eliminates interference from other sources. Figure 8 illustrates the experimental set up configuration for measuring the level of interference to the VSAT system from the UWB signal. The VSAT link uses Measat-3 satellite operating at C-band frequency (3956 MHz to 3958 MHz) for downlink. It utilizes vertical polarization with an inbound information rate of 128 Kbit/s, applying QPSK modulation technique and used 5/6 rate Forward Error Correction (FEC). A Cassegrain dish antenna with 2.4 m diameter and 38.2 dB gain is use at the inbound terminal. The system is equipped with Low Noise Block (LNB) and Block Up-Converter (BUC) with typical gain of 63 dB and 61 dB respectively. The LNB converted the C-band frequency to intermediate frequency (IF) frequency (1000 MHz in this case). The signal is later routed to the satellite modem for signal demodulation. During the measurement, the IF signals is monitored by the spectrum analyser for visual appreciation of its spectrum characteristics and level of received power. The UWB devices were positioned near to the VSAT and are set to be

continuously in the active mode while measurement of the VSAT parameters was taken. The parameter for some main equipment is given in Table 3.

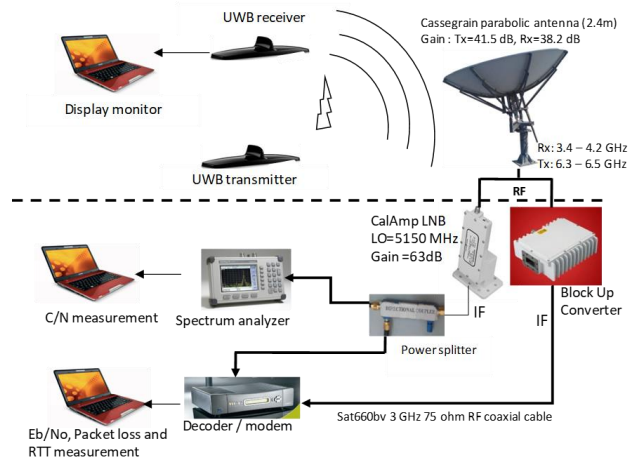


Figure 8 BER as a function of jammer distance, R with fixed d = 3 m for UWB device A pair

Table 3 Equipments used during the measurement

No.	Equipment	Specification
1	Cassegrain dish antenna	Rx Freq: 3.625-4.2GHz Tx Freq: 5.850-6.425GHz Gain: 38.2dB - 41.5dB Aperture: 2.4 meter
2	Extended C-band Phase-locked loop(PLL) LNB (Low-noise block)	RF Freq: 3.4 to 4.2 GHz IF Freq: 0.950 – 1.750 GHz Gain: 63 dB Typical LO: 5.15 GHz
3	C band 5W BUC (Block up-converter)	RF Freq: 5.85 - 6.725 GHz IF Freq: 0.950 – 1.825 GHz Gain: 61 dB nom. LO: 4.9 GHz
4	Power Splitter	Operating frequency: 3 – 8 GHz

D. VSAT Interference Level Measurement

The aim of the testing is to measure the interference effect from UWB signal to the VSAT link. Thus, a UWB device is located at the vicinity of the VSAT dish antenna. This is to make sure the signal from UWB directly interrupt the VSAT signal. Figure 9 shows the position of the UWB devices with respect to the dish antenna. As can be seen from the figure, two parameters were considered, the distance, D and angles, θ of the UWB device to the centre point of the dish. As an example, for a fixed distance of D = 2 m, the UWB device can be positioned at three different angles $\theta_1 = 0^\circ$, $\theta_2 = 15^\circ$ and $\theta_3 = 30^\circ$.

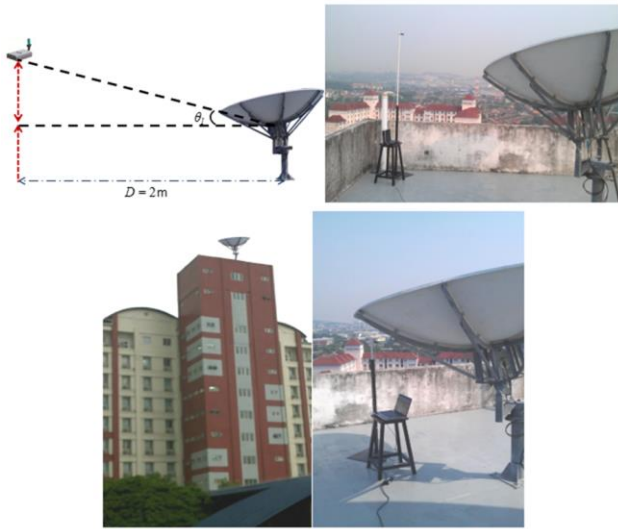


Figure 9 VSAT system located on the top of building and snap shot of interference measurement set up

3.0 RESULTS AND DISCUSSION

A. BER Performance in the Presence of Other UWB Signal

The experimental set up to investigate the BER performance in the presence of another UWB device (UWB device B band-1) with the slightly overlapped bandwidth is illustrated in Figure 10. The obtained result of the experiments is depicted in Figure 11. The results show the presence of another UWB signal reduce BER of UWB device under test. The communication status of the Devices B is not accessible, hence this paper focused on the effects of signal from this device on the UWB Device A. However, the communication quality of UWB Device B can be visually analysed by looking at the video streaming on the screen. From the observation, it shows that the video showed some discontinuity (almost freeze) when the distance, R lower than 3 m.

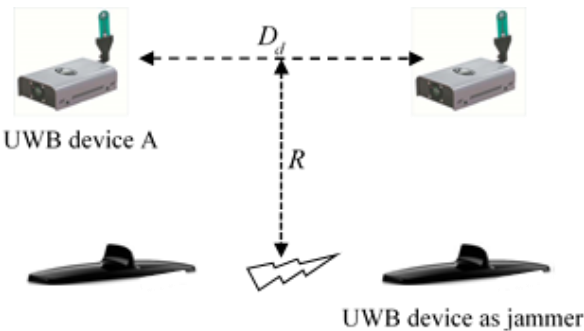


Figure 10 Measurement set-up to measure interference to UWB device A by other UWB signal

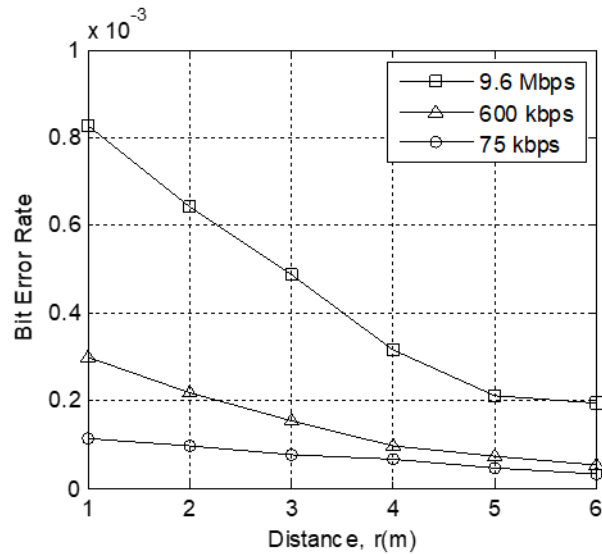


Figure 11 BER performance as a function of UWB jammer distance, R for different transmission rates

As a summary for this section, few main observations from the interference measurement to the UWB system is given below:

- the effect of interference can be seen if the carrier frequency of the interferer signal (NB signal source) fall within the UWB signal frequency range. As a result, the BER increases,
- the UWB communication signal is affected by the transmission of a sinusoidal narrow band signal. The severity of interference increases for higher data rate and
- the system performance for the UWB device under test decreases as the signal from other UWB device present as the interference.

B. UWB Signal Interference to VSAT

Three UWB devices explain in section 3 (UWB device B (sub band 1 and 2) and UWB device C) were used for the measurement. It comprises a USB dongle (transmitter) connected to a notebook computer via a USB port and a UWB receiver connected to a display monitor. UWB transmission occurred by playing a video at the notebook computer and the monitor displayed the video. Four parameters were measured to evaluate the effect of interference from UWB signal to VSAT link namely:

- E_b/N_o – energy per bit to noise power spectral density ratio. The energy per bit, E_b can be determined by dividing the carrier power by the bit rate. It is measured at the input to the VSAT receiver and is used as the basis to determine how strong the signal is.

- ii. C/N – carrier over noise ratio. Also known as the signal-to-noise ratio (SNR) of a modulated signal. High C/N ratios show good quality of reception.
- iii. Round trip time (RTT) is measured using ping command. In this regard, full ping command is utilized and after each experiment the number of lost packet is counted. RTT is the length of time it takes for a signal to be sent plus the length of time it takes for an acknowledgment of that signal to be received.
- iv. Packet loss (%)

The UWB device signal acts as a noise, N to VSAT signal. Therefore, the increment of UWB device signal's power transmission causes E_b/N_o and C/N of VSAT signal to decrease its values. Lower value of E_b/N_o and C/N shows poor quality of reception. Before the interference's effect from UWB signal is analysed, a reference reading of E_b/N_o to is first observed. Figure 12 shows the continuous measurement of E_b/N_o for seven days without any external electromagnetic interference to the VSAT. It can be suggested that the value of 8dB is used as the average of E_b/N_o . From the measurement, seems like the value of E_b/N_o never reach the lowest value which is 4dB. So, the $E_b/N_o = 4$ dB is selected as the threshold before the VSAT communication is said to be disconnected.

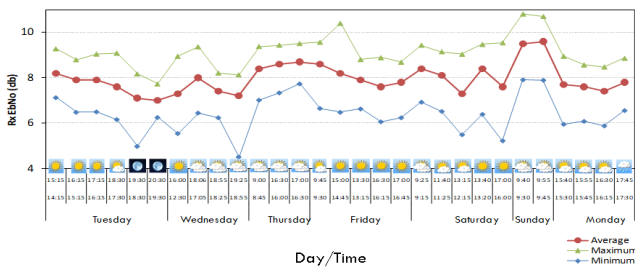
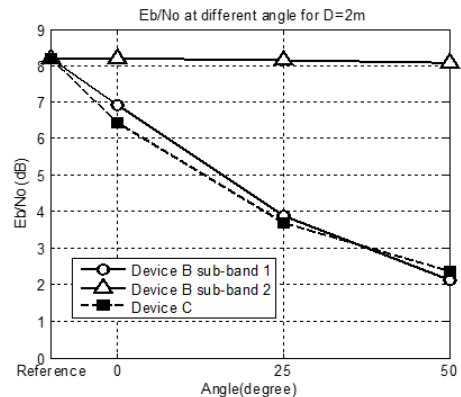


Figure 12 Rx E_b/N_o seven days duration without UWB interference

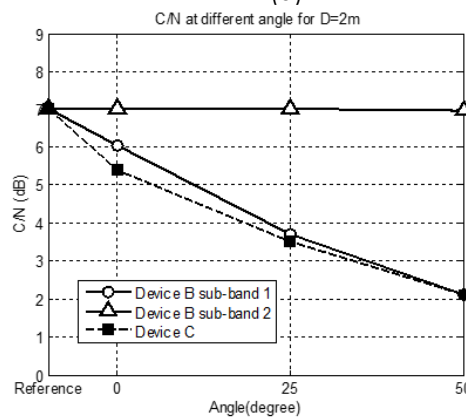
C. VSAT Interference Level

Figure 13 shows the observed E_b/N_o and C/N when the UWB devices positioned at $D = 2$ m for different angles, θ . Each line in the graph represents each type of UWB device. Clearly from the figure, the effect of interference increases when the UWB device is getting close to the main lobe. Hence, angle, $\theta = 50^\circ$ shows the highest interference. UWB Device C shows less interference effect due to the different operating frequency as compared to the VSAT link. High value of E_b/N_o and C/N indicates less interference. For UWB devices B and C, the graph shows a significant interference to the VSAT link and it reached beyond the threshold value of E_b/N_o , which may result the VSAT link to be disconnected. Although UWB device C use 3 sub-bands technique, but it does not give any advantages as it still

interferes the VSAT link. This may due to VSAT service operates from 3.8 to 4.2 GHz while this UWB device operates with 3 sub-bands from 3.1 to 4.8 GHz.



(a)



(b)

Figure 13 VSAT interference level measurement for (a) E_b/N_o and (b) C/N for UWB devices located at $D=2$ m at different angles

In addition, the effects of UWB on the quality of the internet service were investigated. Figure 14 reveals the results for this measurement. Clearly, this device interferes the internet service in near distances that results in losing the internet connection. In case of $\theta = 50^\circ$, the rate of packet loss is high consequently the service is disconnected. Although UWB device B sub-band 2 did not interfere the VSAT services, the RTT and PLL from Figure 14(b) shows little decrement of performance when it is near to the main lobe of the antenna. Next testing measures the interference to the VSAT services at different distance, D for UWB Device B sub-band 1 only as shown in Figure 15. Obviously, as the distance increases, the level of interference decreases with linear pattern.

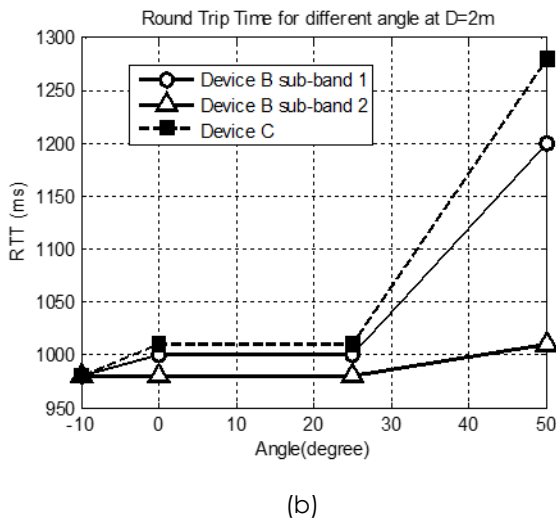
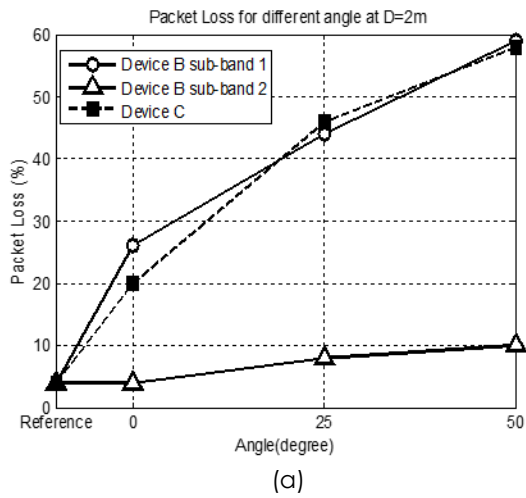


Figure 14 VSAT interference level from signal of UWB devices measured in (a) Packet loss and (b) RTT

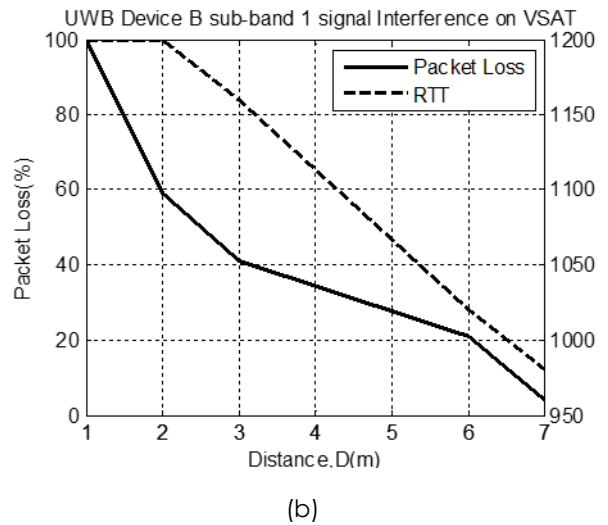
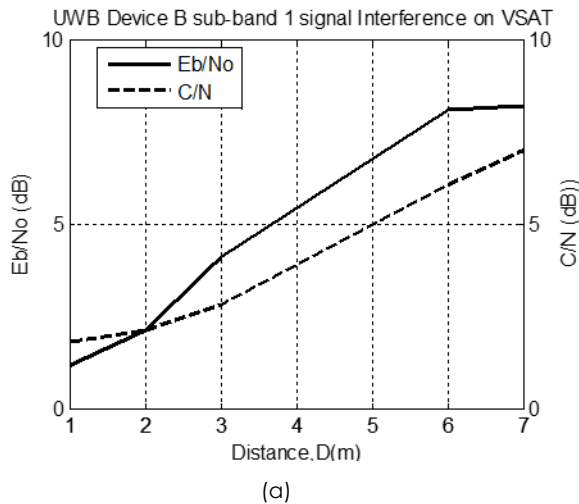


Figure 15 VSAT interference level from UWB Device B sub-band 1 at different distance, D

To complete the analysis, interference measurement was taken for two UWB devices that were activated simultaneously as shown in Figure 16. Results indicates that a strong interference occurred when two UWB devices were put side by side and the signals were propagating at the vicinity of the VSAT antenna dish. The angle θ was fixed to 50°. Mainly the service was on re-connected for distance more than 5 m.

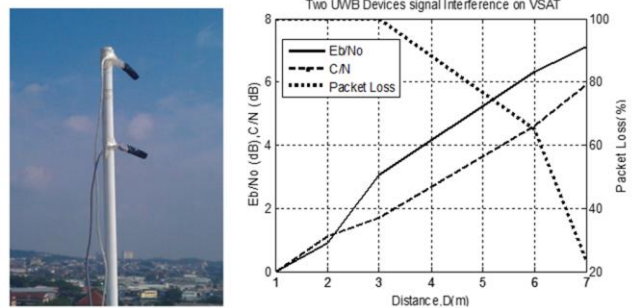


Figure 16 VSAT interference level from signals of two UWB devices activated simultaneously

4.0 CONCLUSION

Two sets of the interference measurement related to UWB communication devices were successfully implemented. The first measurement analysed the interference to the UWB device and followed by the second set which analyse the effect of UWB emission to VSAT system. The result for the former experiment illustrates that, NB or UWB signal interference effect the average BER of the UWB system under test. It was shown that if the frequencies are overlaps, then the interference effect is significant. The interference of the UWB devices towards the VSAT service verify

significant interference towards the VSAT service especially for UWB device B (sub-band 1) and UWB device C. The position and location of the UWB signal source from the antenna dish effect the level of interference. As the initial findings, this paper recommends that the power density of the UWB device is limited to -41.3 dBm/MHz in the distance farther than 3 m from VSAT antenna dish. However, this limitation is only applicable for UWB device that operate at VSAT band, which is 3.8 to 4.2. The finding from this paper can be used as a guide for new interference or jamming mitigation techniques as well as spectrum planning purposes.

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