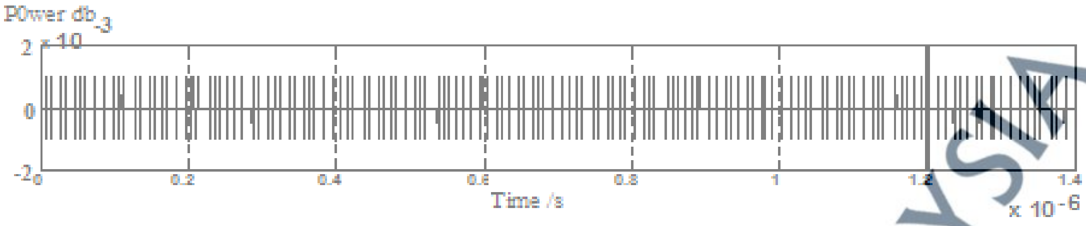

Figure 5.3: Simulink Simulation Of The Transmitted IR-UWB Signal In Real-Time Simulation DSP As M-Ary-PPM Modulation

A comparison between Figures 5.2 and 5.3 reveals that the data rate of the transmitted signal can be significantly increased by increasing the modulation binary order for M-Ary PPM.

5.2.2 Waveform Distortion Analysis of IR-UWB

Pulse distortion is crucial in IR-UWB due to its huge bandwidth. Such distortion should be analysed when evaluating the performance of a system as it differs from that of a narrowband system, especially in NLOS environments. System performance is evaluated under different propagation scenarios to analyse the effects of pulse distortion. The IR-UWB signal is simulated for different channel models under several conditions. The PPM signal propagated over an AWGN channel model is also analysed in the multipath fading channel model. The system performance is significantly degraded as the pulses travel, especially in indoor environments where these pulses are often reflected and scattered. This phenomenon superimposes the received signal with other signals and multipath components that require an advanced receiver structure to detect the transmitted signal.

5.2.3 AWGN Channel Simulation of the Attenuated IR-UWB Signal

Simulating the propagation of the reference IR-UWB signal over an AWGN channel by using MATLAB can determine the attenuation of signal energy along with distance in the time domain. The thermal noise at the receiver input is ignored by assumption for that sake of perfect synchronisation between the transmitter and receiver. Channel gain can be evaluated as a function of the distance (D) between the transmitter and receiver, and the two constants, power decay with distance (gamma) and reference attenuation (c0), are used to represent the power decay along with distance and the reference attenuation at 1 m, respectively. A simulated scenario of pulsed-based UWB is developed according to the parameters sittings for train of pulses in certain shape, modulation and coding as the communication link-budget shown in table 4.1 and appendix A .This reference transmited signal is shown first to determine the level of influence of each parameter on the quality of the received signal (as BER) in certain scenarios. The simulation starts from the simplest scenario (to highlight the effects of attenuations and distortions on the received pulses), where a transmitter and a receiver are placed at a distance of 10 m in a free-space environment with the following parameters: D (distance Tx/Rx) = 10 m, gamma (power decay with distance) = 2 and c0 (reference attenuation at 1 m) = 10^ (–30/20). The attenuated signal version of the transmitted signal is simulated as shown in Figure 5.4 and 5.5 (with the same signal parameters from Figure 5.1).

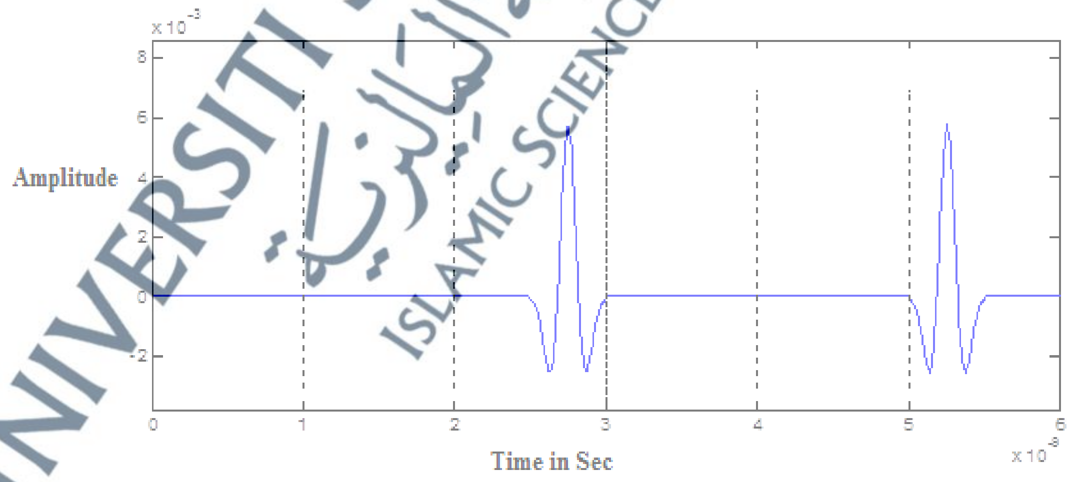

Figure 5.4: Transmitted TH With The PPM Modulation UWB Signal

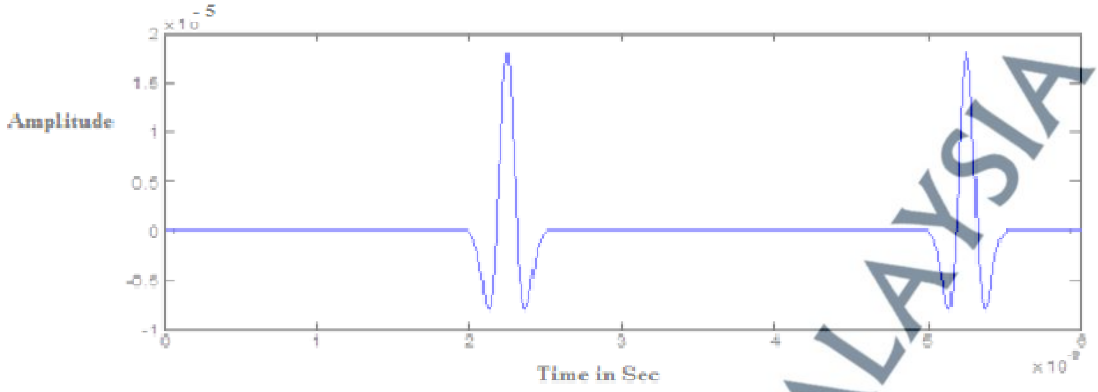

Figure 5.5: Attenuated Version Of The Transmitted Signal

The peak value of the transmitted signal is in the order of $6 * 10^{-3}$, whereas the peak value of the pulses in the received signal in Figure 5.5 is in the order of approximately $2 * 10^{-5}$. Therefore, the channel gain is $2/6 * 10^{-2}$ or approximately 0.0033.

5.3 MATLAB-Simulated Performance of the IR-UWB Receiver Over AWGN and Multipath Fading Channel Models

The performance of the proposed IR-UWB receiver is simulated to determine the effect of IR-UWB with the reference parameters on the transmitted signal over AWGN as shown in Figure 5.6. The performance of the proposed receiver in consideration of the reference signal parameters is taken as a reference scenario to evaluate the different IR-UWB signal parameters as a function of BER for the maximum SNR over the AWGN channel model. The objective of this evaluation is to determine the pulse parameter values that increase the transmission data rates and enhance the performance of the received signal in terms of BER to achieve a tunable impulse-based UWB for different application requirements.

The receiver activities are simulated according to the structure and mathematical model presented in Chapter 3 and the link budget of the proposed communication as in table 4.1 in chapter 4. Several MATLAB functions are used to analyse the proposed IR-UWB receiver as described in Chapter 3 and shown in Appendix A.

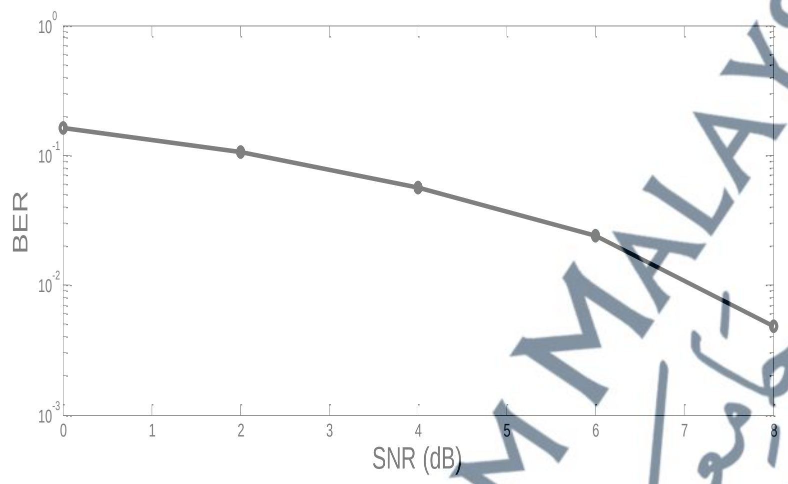

Figure 5.6: TH-PPM Receiver Performance

The rake receiver performance of UWB for the TH-PPM signal propagating over a multipath channel is then evaluated. The ARAKE (ideal RAKE) receiver processes all multipath components and their contributions, SRAKE (selective RAKE) contains eight multipath components, selects the multipath contribution that exhibits the best signal quality and chooses the transmitted symbol on the basis of this observation and PRAKE (partial RAKE) is the simplest receiver structure that contains two branches. The selection process in this receiver only considers the first two multipath components that arrive at the receiver.

The following results are obtained from the MATLAB simulation and are used to compare the performances of five different RAKE structures. Figure 5.7 compares the value of BER = $10^{-1.9}$ in the case of ARAKE, which processes multipath components, and that of BER = $10^{-0.9}$ in the case of SRAKE, which processes only two multipath components, and reveals that the BER performance can be significantly enhanced. Moreover, SRAKE, which processes eight components selectively, outperforms PRAKE, which randomly processes these same components, by almost

10% in terms of BER at an SNR of 9 dB. The complexity of the receiver is further reduced by using PRAKE, but its performance significantly degrades especially under a low number of processed channel components. The analysis results clearly show that when designing a tunable IR-UWB solution, a proper rake receiver structure with a good trade-off between receiver complexity and BER application requirements must be selected.

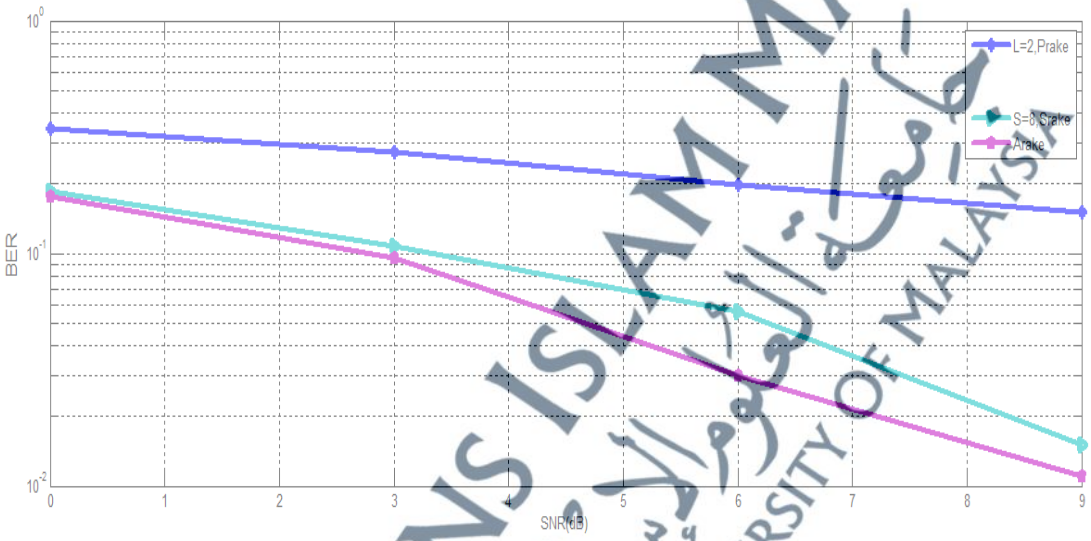

Figure 5.7: Rake Receiver Performance: ARAKE, SRAKE And PRAKE

5.4 Link Budget Design and Analysis of IR-UWB

This section investigates the BER of the system and presents the results obtained under different radio link settings for signal transmission. The effects of PRRs, widths, shaping factors and modulations are analysed. The different numbers of bits generated at the source and the numbers of pulses per bit are evaluated according to the BER criteria to highlight the significance of each parameter. This analysis aids the design of tunable IR-UWB transmission rates for different BER requirements and various distance scenarios.

The BER curve observations in Figure 5.8 show that the number of bits significantly affects BER. Specifically, as the number of generated bits increase from

1000 to 6000, the BER performance decreases from $10^{-2.7}$ to $10^{-1.7}$ at an SNR of 9 dB because as the number of bits increases, more bits become susceptible to noise, thereby introducing more errors. Therefore, a trade-off should be achieved when tuning the IR-UWB system based on the number of bits.

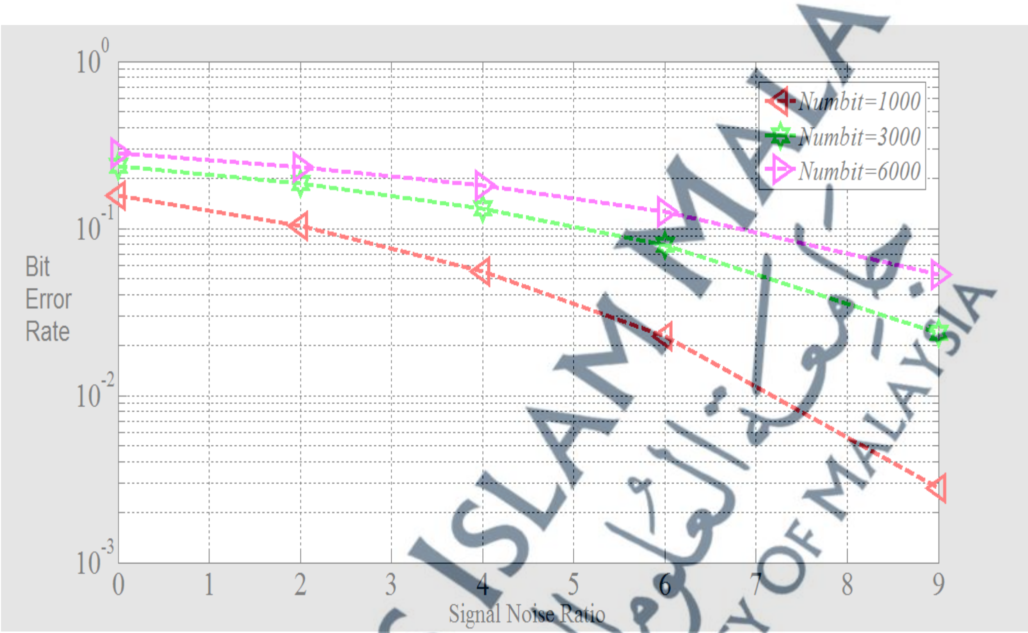

Figure 5.8: Receiver Performance With Different Numbers Of Source Bits Of TH-PPM

The BER performance is significantly enhanced as the number of pulses per bit increases as shown in Figure 5.9. As the number of pulses per bit increases by a multiple of 6, the BER performance increases from ($10^{-1.2}$ to $10^{-4.5}$) at an SNR of 9 dB. Therefore, the average BER of the system is proportional to the number of pulses. Designers can then achieve an optimum trade-off between the number of pulses per bit and the transmission rates suitable for the propagation condition. Such trade-off contributes to BER performance, given the difficulties in achieving a trade-off directly on an IR-UWB system with different transmission rates.

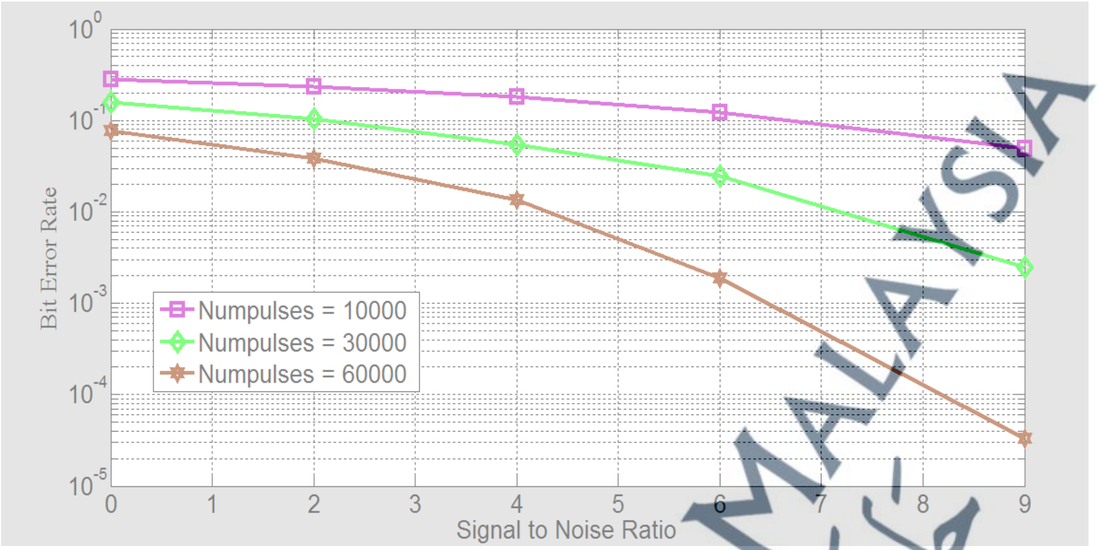

Figure 5.9: TH-PPM Receiver Performance For The Number Of Pulses Per Bit

Figure 5.10 shows the performance of the receiver with different average pulse repetitions. The period of different pulses depends on the data transmission, and its significant role in enhancing BER performance depends on the pulse repetition period. Reducing the pulse repetition period from 8×10^{-4} s to 3×10^{-9}s enhances the BER from 10^{-2} to $10^{2.9}$ at an SNR of 9 dB. BER performance improvements are also observed when the PRI decreases given that the system becomes more susceptible to noise and interferences when the pulse repetition period increases.

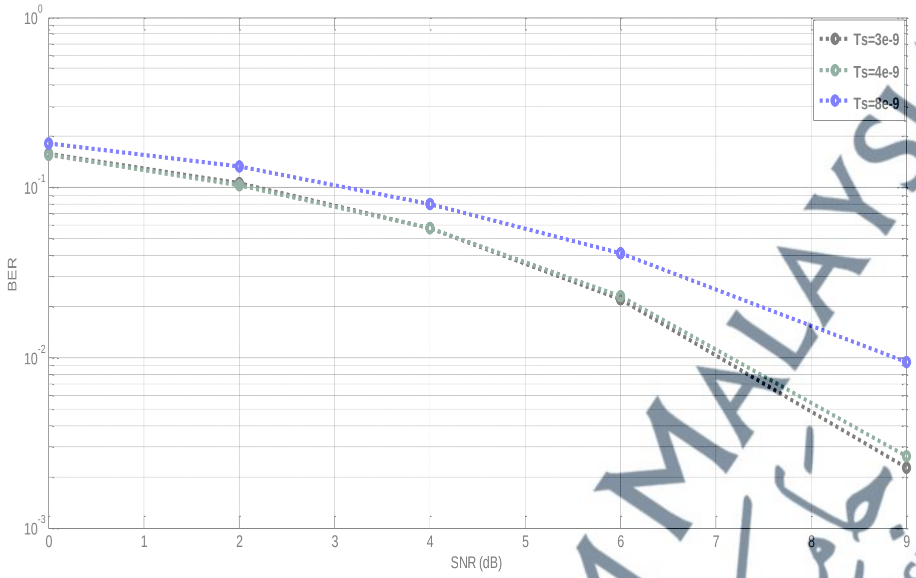

Figure 5.10: Effects Of Different Average Pulse Repetition Periods (Ts) On Receiver Performance

The generated bits per second can be determined as the reciprocal of code repetition rate Ns (the number of pulses per bits) multiplied by pulse average repetition period (Ts).

The values shown in Table 5.2 are obtained at different data rates. The data rate mainly depends on the number of pulses (Ns) per bit and/or the average pulse repetition (Ts). The following table shows that the data transmission rate increases when the average pulse repetition period is fixed to $1{\times}10^{-9}$, when the number of bits is fixed at 30000 bits and when the number of pulses per bit increases from 10000 to 25000 pulses.

Table 5.2: Data Rates Calculated As Functions Of Ts And Ns

Code repetition rate, Ns (Number of pulses per bit)	Frame time, Ts (Average pulse repetition period) in seconds	Data rate = $\frac{1}{N_s{\times}T_s}$ (Mbps)
Ns = 1/3 (NumPulse = 10000, Numbits = 30000)	$1{\times}10^{-9}$	$\frac{1}{0.333 \times 1\text{x}10^{-9}} = 333$ Mbps
Ns = 1/2 (NumPulse = 15000, Numbits = 30000)	$1{\times}10^{-9}$	$\frac{1}{0.5 \times 1\text{x}10^{-9}} = 500$ Mbps
Ns = 2/3 (NumPulse = 20000, Numbits = 30000)	$1{\times}10^{-9}$	$\frac{1}{0.666 \times 1\text{x}10^{-9}} = 666$ Mbps

Ns = 25/30 (NumPulse = 25000, Numbits = 30000)	1×10^{-9}	$\frac{1}{0.833 \times 1\text{x}10^{-9}} = 833 \text{ Mbps}$

Figure 5.11 shows the effect of increased data rate on BER performance. As indicated by the BER curves, decreased data rates result in a higher bit error probability. The BER increases by approximately 35% from 333 Mbps to 833 Mbps at the same SNR value of 9 dB.

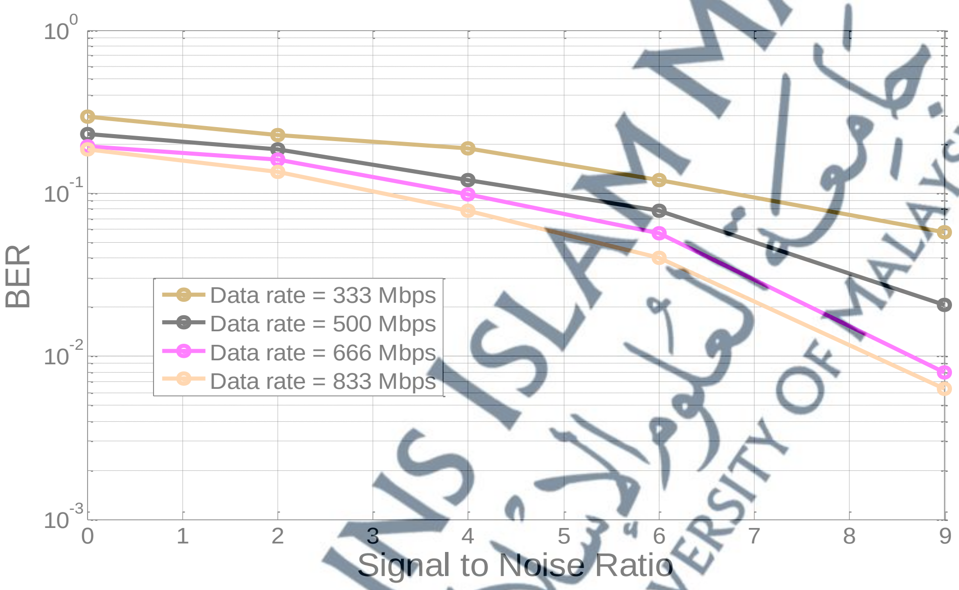

Figure 5.11: Effect Of Different Data Rates On Receiver Performance

The parameters introduced by PPM and PAM modulations, such as pulse shaping factors, timing, chip time and shift time, are analysed to determine whether the signal parameters related to a specific PPM modulation affect the average error probability. The pulse shaping and width in a certain position for coding by using the PPM modulation can be controlled by differentiating the Gaussian shape pulse for different pulse peaks and widths as discussed in Section 3.4.1.2.

Figure 5.12 shows that the pulse shaping factor (which depends on pulse width) has a minimal effect on BER performance. For the tuneable TH-UWB system, the best BER performance can be achieved at a pulse shaping factor (Tau) of $0.5\,x10^{-9}$ s.

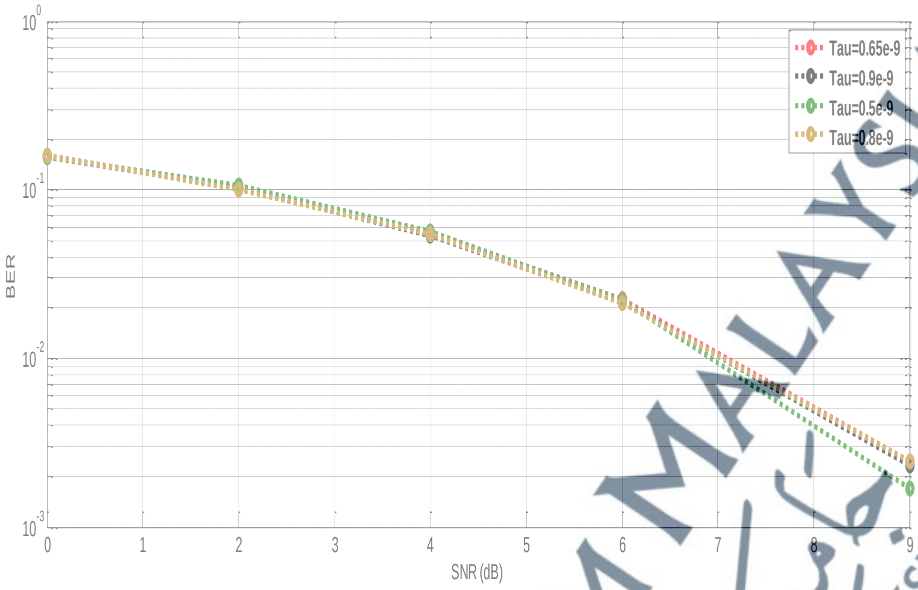

Figure 5.12: Effect Of Pulse Shaping Factor On Receiver Performance

Compared with pulse shaping factor, the pulse duration factor (Tm) has a more significant effect on BER performance. Figure 5.13 shows that the BER performance is enhanced when the pulse duration parameters are tuned into nanoseconds of around 0.2 x 10-9 ns. Specifically, BER increases from $10^{-1.8}$ to $10^{-2.7}$ for a pulse duration of 0. 9 ns to 0.2 ns at an SNR of 9 dB. Therefore, BER is significantly improved at a very small difference in time (in nanoseconds) because a shorter signal duration reduces the effect of noise on the signal.

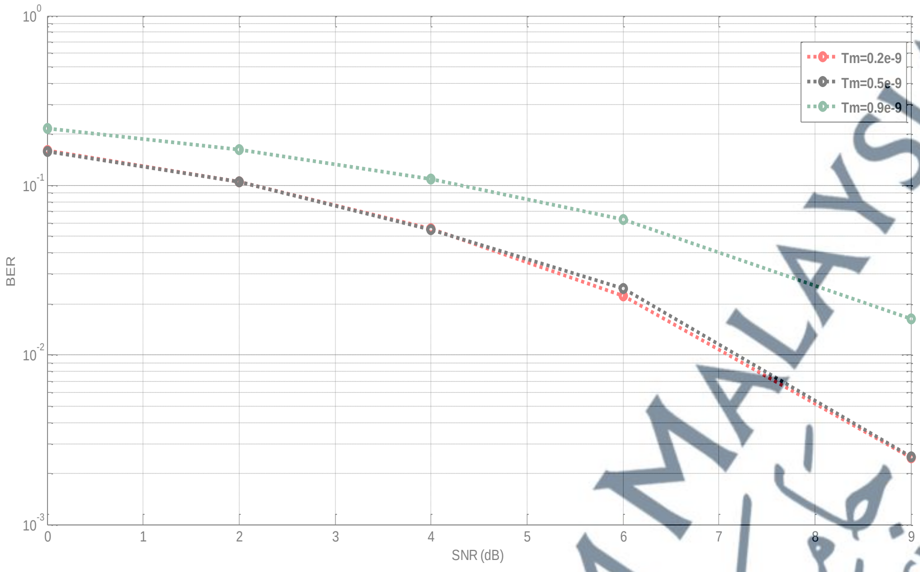

Figure 5.13: TH-PPM Receiver Performance at Different Pulse Durations

The change in chip time factor has a minimal effect on BER performance as shown in Figure 5.14:. The minimum chip time is measured on the basis of BER and SNR. A high BER is observed when the chip time is 10^{-9}.

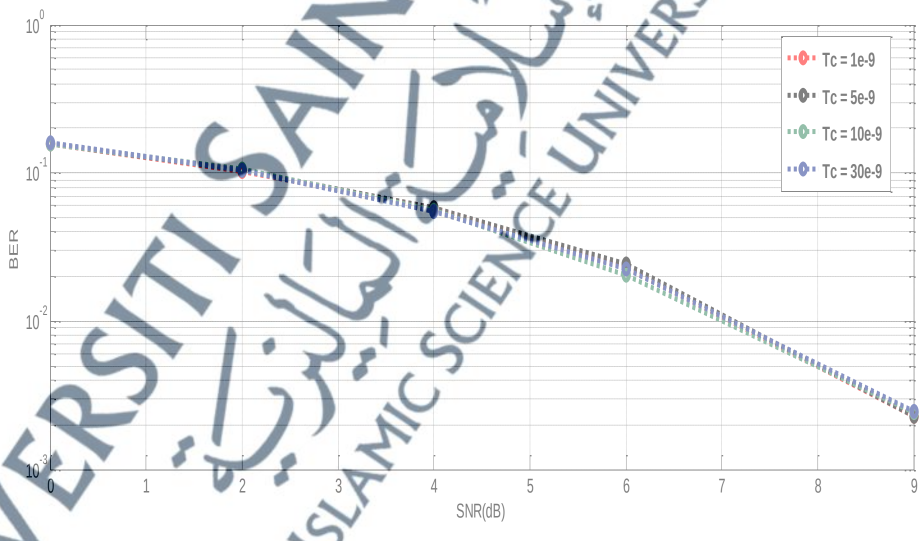

Figure 5.14: Performance Of The TH-PPM Receiver At Different Chip Times (T_c)

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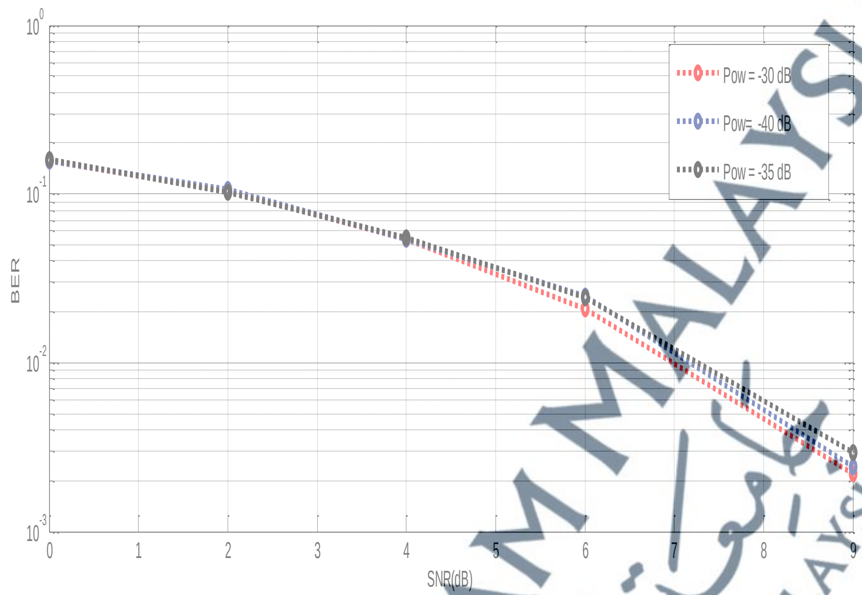

Figure 5.15: Effect Of Different Signal Powers On Receiver Performance

Figure 5.15 shows the effect of different signal powers on receiver performance. The average transmitted power for generating the pulses has no significant effect on the AWGN channel at the same communication and distance conditions. The receiver performance is then evaluated on the basis of the average pulse transmitted power. The BER decreases as the power of emitted pulses increases from –30 dB to –40 dB. The emitted pulses have very low power with a low duty cycle in narrowband and wideband signals. The emitted pulses increase along with interference yet produce a minimal effect due to the low duty cycle of the generated pulses.

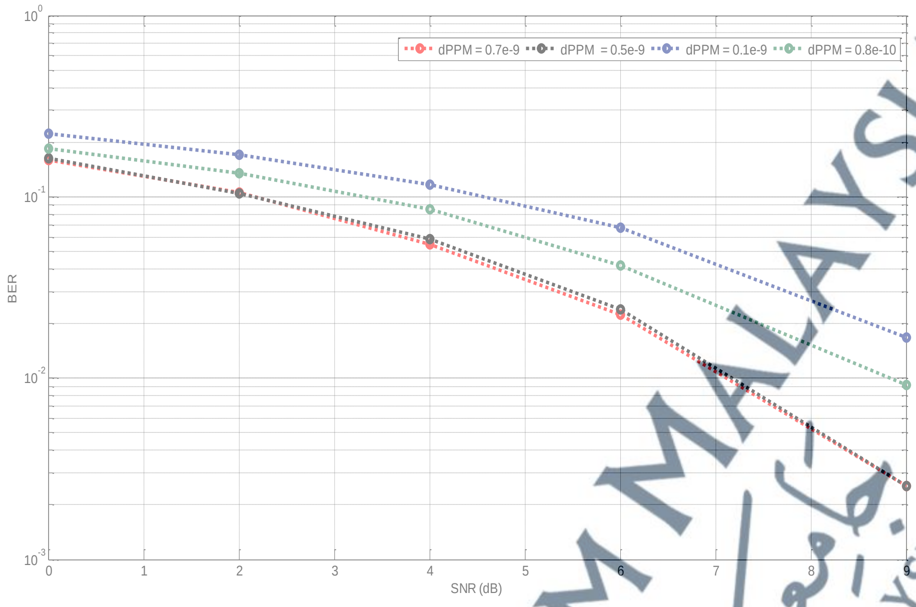

Figure 5.16: Effect Of Different dppm Values On TH-PPM Receiver Performance

Section 3.4.1.1 discusses the processes of generating pulse-based UWB by integrating TH into PPM. Firstly, the signal generates a TH code that is uniformly distributed at a certain interval. Secondly, depending on the value of the input bit, the PPM time shift is eventually introduced. The time-shifting introduced by PPM (dPPM) has a relatively significant effect on BER performance. The values of dPPM that are tuned between 0.5×10^{-9}s and 0.7× 10^{-9}s have a minimum error probability when the other parameters of the pulse generation are fixed as shown in Figure 5.16. The BER increases from $10^{-1.9}$ to $10^{-2.85}$s at an SNR of 9 dB because increasing the time shift introduced in the PPM of TH-UWB pulses decreases the signal self-interference due to the timing jitter that occurs when the pulses generated by a certain user of interest spills over the adjacent pulses as a result of the multi-path effects and interferences from other signals. This finding can help impulse-based UWB designers consider the proper value settings for the time-shifting introduced for PPM modulation to minimise interference and enhance BER performance.

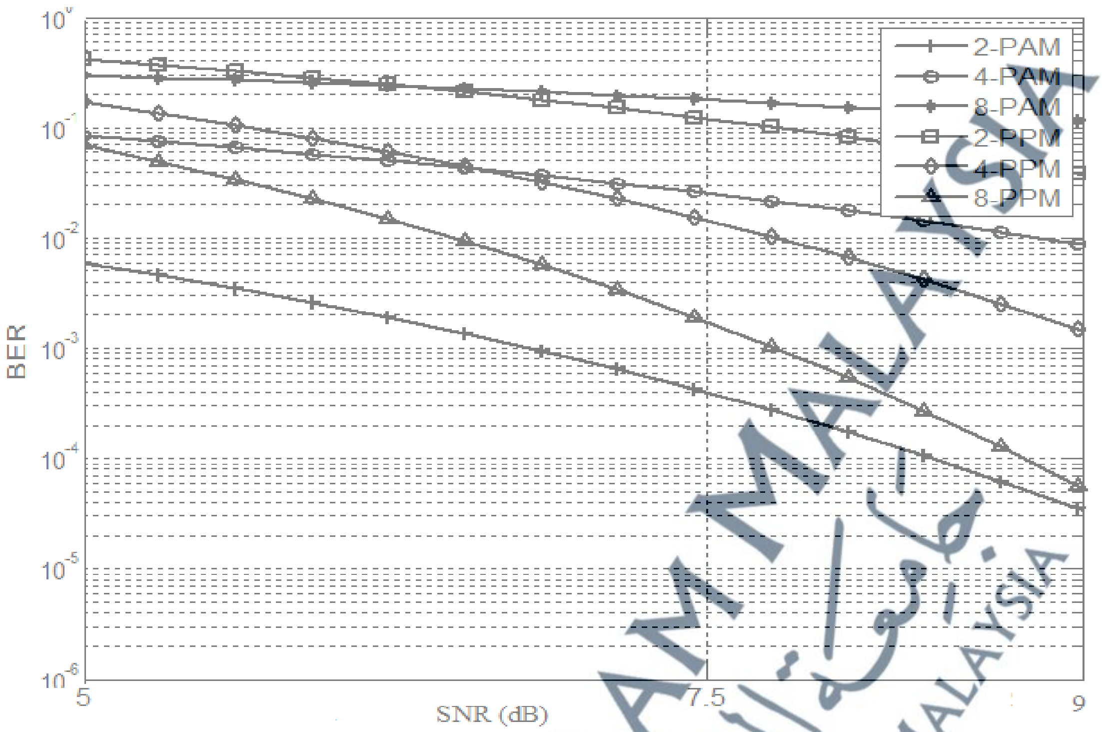

Figure 5.17: Comparison Of The Symbol Error Probabilities Of M-PAM And M-PPM

Figure 5.17 compares the symbol error probabilities of M-PAM and M-PPM. Modulation techniques are important in pulse design and in achieving an improved BER performance at different transmission rates. Higher-order M-PAM signals are then compared in terms of their BER of SNR values. PPM outputs are PAM with regard to the probability of symbol error. It is designed and tuneable UWB pulse-based solution is considered with the effect of a different spectrum.

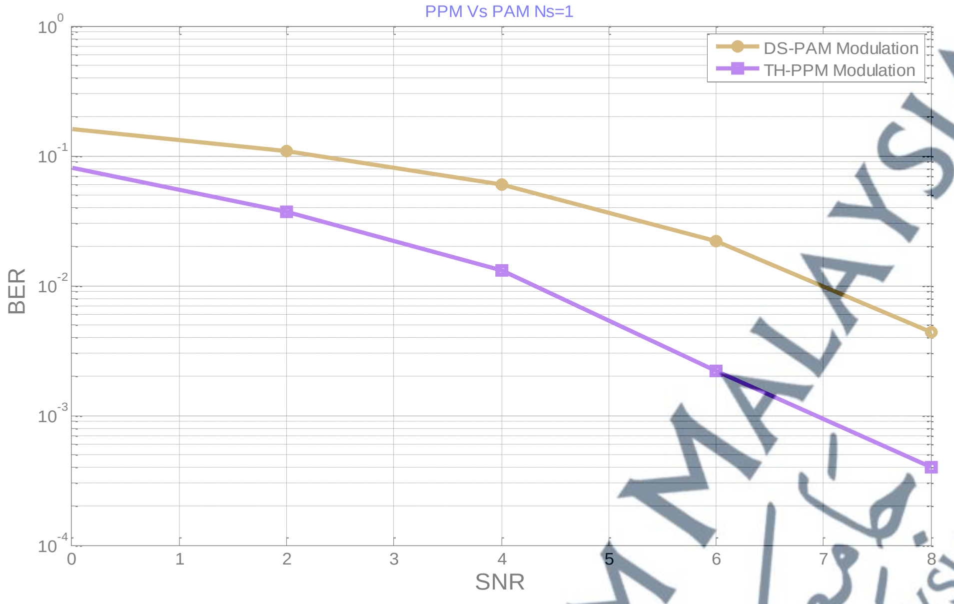

Figure 5.18: Comparison Between BER And SNR For 2PPM-TH-UWB And 2PAM-DS-UWB

Figure 5.18 compares BER and SNR with two PPM and two PAM. The TH-PPM output is improved in 27% at an SNR of 9 dB. DS and TH spectrum spreading techniques are used in the comparison, and TH-PPM emerges as the most efficient technique for the LDRs of UWB pulses.

MATLAB analysis is concluded with BER depends on application requirements. The different pulses of physical parameters are designed and tuned with different transmission rates. The physical parameters are designed in a link budget template and tuned with different data rates.

The previous MATLAB BER evaluation analysis reveals that different pulse physical parameters can be designed and tuned with different data transmission rates and BER performance levels. Some of these physical signal parameters, including modulation techniques, binary order of the modulations, spectrum spreading techniques, the pulse duration factor that determines the pulse shape, number of generated pulses per bit and time-shifting introduced for pulse position coding, have significant effects on BER or AWGN model propagation. Different physical parameters are designed in a link budget template and are tuned with matching data rates at various range scenarios. The proposed tunable system is designed with a link budget and evaluated by conducting a simulation and a statistical analysis of the received signal quality.

5.5 Link Budget Design of the Proposed TH-(PPM or PAM) UWB System in Simulink

The aim of the link budget design is to present an IR-UWB data link for application-specific QoS (BER requirements) at several distance environments as described in Section 4.3.1. The modelling design involves the tuning of multiband TH modulations (M-PPM or PAM) and the number of generated signal bits and pulses per bit at specific data rates. Signal timing and shaping factors are tuned to meet the BER requirements. The parameter settings of the designed communication model are shown as parts of the link design to meet certain performance requirements. Figure 5.19 shows the MATLAB simulation of the performance metrics trade-off, which is expressed as a function of the maximum distance between the transmitter and receiver for TH-UWB with PPM and PAM in various data rate environments for a pre-assumed BER requirement.

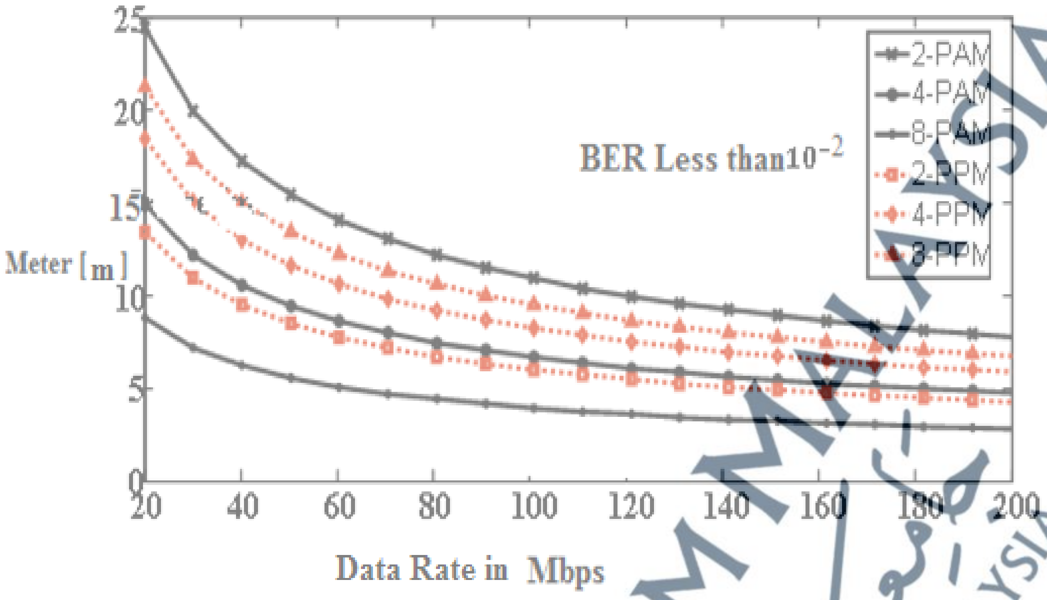

Figure 5.19: Trade-Off Flexibility Evaluated As Achieved Data Rates In Different Simulated Distance Scenarios For Different Modulations And Certain BER Requirements

Figure 5.19 shows that the data rates of the TH-IR system can increase at the cost of the coverage distance between the transmitter and receiver for specific BER requirements. This condition introduces the design concept of the IR-UWB system, wherein the parameters can be set to meet specific application requirements. As explained, Figure 5.19 shows that when the maximum coverage range is 25 m and when the BER does not exceed 10^{-2} according to the application requirements, the best performance can be achieved by tuning the pulse for a data rate of 20 Mbps via 2-PAM.

Figure 5.20 shows the system parameter settings in the real-time implementation of the Simulink model. These settings include the data transmission settings, the propagation channel model (AWGN) and the received signal detection settings. All values are obtained from the Simulink workspace during and after the system simulation as shown in Figure 5.20. The IR-TH PPM system is designed for specific data and predefined BER requirements and propagates over four AWGN LOS and NLOS channel model scenarios (C1 to C4) simulated at different distances as shown in Table 5.3. The required BER is within the range of 10^{-2}s and 10^{-4}s. The system is designed according to the parameter settings, including signal generation, shaping (at the data source level) and modulation (at the signal pilot level), to achieve the required radio link performance given that the BER is 2×10^{-2} are all shown as SIMULINK Model settings in Figure 5.20 as a translation of the BB level implementation shown in Table 4.1 in Chapter-4 of the IR-UWB communication link.

:

```
Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.

  Frame Time (uwb.MOD.Tf) = 10.000 ns
  Time Hopping Unit Time (uwb.MOD.Tc) = 1.000 ns
  PPM Modulation Unit Time (uwb.MOD.delta) = 0.156 ns
  Impulse width (uwb.MOD.tau) = 0.4000 ns
  Symbol Time in terms of Frame Time T/Tf (uwb.MOD.Ns) = 10
  PN Sequence Period (uwb.MOD.Np) = 31
  Average Signal Power (uwb.MOD.sigPower) = -40.0 dBm
  Pulse Energy (uwb.MOD.Ep) = 1.000000e-015 J
  Initial State of PN Code Shift Register [m=5] (uwb.MOD.xini) = [ 10001 ]
  Bits used to generate Hopping Code (uwb.MOD.bitsPerHop) = 3

  ------------ CHANNEL ------------

  Channel Delay (uwb.CHN.delay) = 0.000 ns
  AWGN Noise Power (uwb.CHN.noisePower) = -40.0 dBm

  ------------- RECEIVER ------------

  UWB Signal Detection Threshold (uwb.RCV.detectThreshold) = 95 percent
  Acquisition Threshold (uwb.RCV.acquisitionThreshold) = 70 percent
  False Alarm Threshold (uwb.RCV.falseAlarmThreshold) = 30 percent
  Initial State of Receiver PN Code Shift Register (uwb.RCV.xini) = [ 00010 ]

  ------------ SIMULATION ------------

  Sampling Time (uwb.Ts) = 0.1000 ns

  -----------END----------

  Warning: Could not find an exact (case-sensitive) match for 'uwbCom'.
  C:\Users\02070\Desktop\simulink-1-\UWB\simulink\uwbcom.mdl is a case-insensitive match and will be used instead.

fx >>
```

Figure 5.20: IR-UWB Communication Link With Parameter Settings Of The Generated Pulses

Figure 5.21 shows the system running in real-time simulation and the received signal that is detected with the delay threshold settings for system synchronisation. Acquisition coefficient and the tracking coefficient

```
Acquisition Coeffient=-0.059 percent
Acquisition Coeffient=24.803 percent
Acquisition Coeffient=-4.475 percent
Acquisition Coeffient=110.864 percent
PN Hopping Code acquired...!!
Acquired Frame Time=590.000 ns
Tracking Coeffient=104.394 percent
Tracking Coeffient=91.829 percent
Data Synchronized.. Demodulation begins.
Demodulation Start Time=810.000 ns
Tracking Coeffient=95.519 percent
Tracking Coeffient=97.975 percent
Tracking Coeffient=120.276 percent
Tracking Coeffient=104.327 percent
Tracking Coeffient=98.853 percent
Tracking Coeffient=98.393 percent
Tracking Coeffient=101.263 percent
Tracking Coeffient=100.428 percent
Tracking Coeffient=102.361 percent
Tracking Coeffient=101.989 percent
Tracking Coeffient=94.803 percent
Tracking Coeffient=97.204 percent
Tracking Coeffient=96.430 percent
Tracking Coeffient=110.554 percent
Tracking Coeffient=103.112 percent
Tracking Coeffient=93.954 percent
Tracking Coeffient=94.494 percent
Tracking Coeffient=102.325 percent
Tracking Coeffient=104.422 percent
Tracking Coeffient=92.262 percent
Tracking Coeffient=92.506 percent
Tracking Coeffient=99.301 percent
Tracking Coeffient=100.997 percent
Tracking Coeffient=101.348 percent
Tracking Coeffient=89.645 percent
Tracking Coeffient=112.038 percent
Tracking Coeffient=100.584 percent
fx >>
```

Figure 5.21: IR-UWB Communication Link Running In The Real-Time Simulation

Table 5.3 shows the results of the real-time Simulink Implementation of the template link budget of the table 4.1. The proper settings of the generated signal parameters are shown in Table 5.3 along with the BER for certain application requirements (not exceeding 10^{-2}).

Table 5.3: IR-UWB System Parameters And Real-Time Evaluation

Data source	
M-ary	2
Symbol time	100.000 ns
Link selector number [0 reserved for the pilot]	1
Promised data-loading state	[11000]
Modulation	
Frame time	10.000 ns
TH unit time	1.000 ns
PPM unit time	0.156 ns
Impulse width	0.2877 ns
Symbol time in terms of frame time T/Tf	10 ns
PN sequence period	31
Average signal power	–40.0 dBm
Pulse energy	1.000000e-015 J
Initial state of PN code shift register [m = 5]	[10001]
Bits used to generate hopping code	3
channel model	
Channel IEEE 802.15.3a	
UWB signal detection threshold	95%
Acquisition threshold	70%
False alarm threshold	30%
Initial state of receiver PN code shift register	[00010]
Simulation in real-time	
Sampling time (uwb.Ts) = 0.0500 ns; UWB signal detected; time = 4.550 ns; coefficient = 97.515	
Acquisition coefficient = 10.092%	
Acquisition coefficient = –3.805%	
Acquisition coefficient = 100.319%	
PN hopping code acquisition	
Acquired frame time = 590.000 ns	
Tracking coefficient = 101.779%	
Tracking coefficient = 100.507%	
Data synchronisation; demodulation begins.	
Demodulation start time = 810.000 ns	
BER command	Bercal
BER result	0.020000000000000

Table 5.3 shows that the optimised solution can be designed with the template link budget that can change the generated signal parameter values (shaded rows in the table) and suggests that this template design can be implemented in real time in a Simulink model.

5.6 Propagation Channel Model Description

The simulation results for the propagation models are evaluated according to the BER criteria with various Gaussian pulse shapes, coding and timing structures. The simulation and propagation models for UWB include

the CM1 residential LOS channel,

CM5 outdoor LOS channel,

Ghassemzadeh NLOS channel,

CM6 outdoor NLOS channel,

Ghassemzadeh LOS channel and

CM2 residential NLOS channel.

These channels are discussed along with BER,, which is considered a function of link distance with respect to the IEEE802.15.4A standard.

The physical parameters of the pulses are tuned to achieve different transmission rate requirements in various distance scenarios. The channel conditions of multipath fading channel models are considered in the simulation and in the indoor/outdoor experiments. System performance can be simplified as predetermined BER versus different data rate requirements in various distance scenarios.

5.6.1 IEEE802.15.4A Channel Model

The IEEE802.15.4A standard is issued as an amendment to IEEE802.15.4 for an alternative PHY that is completed by an IEEE802.15.4 low-rate alternative for a wireless system. The channel model was anticipated to be built during the period of improvements in the IEEE802.15.4A standard. The significant conditions for sensor network applications are summarised as follows:

Indoor office environments: Some rooms in this environment have a size similar to that in residential environments, whereas the other rooms are significantly larger. Those areas with small offices naturally include long corridors, and each office may have furniture or bookshelves on its walls.

Industrial environments: These environments are characterised by their large attachments, such as factory halls that are occupied by a large number of metallic reflectors, which lead to the development of several multipath channels.

Indoor residential environments: These environments are critical for home networking and is linked with various safety appliances, such as fire alarms and smoke sensors, that are installed in a small area. These environments are suitable for building structures and include thick indoor walls.

Outdoor residential environments: when various outdoor scenarios occur with large numbers, the recent model shelters only residential scenarios consisting of adequate ranges.

IEEE802.15.4A has two topologies, namely, the star topology and the peer-to-peer network topology, which are described as follows.

(a) The star topology suggests the initial format for an IEEE 802.15.4a network topology, includes the central node and has also been called a PAN.

(b) The peer-to-peer network topology is called a PAN coordinator, but some infrastructures may be present amongst multiple types of nodes. No communication is required to take place through the coordinator. The Ghassemzadeh model has been developed as a statistical path loss model for UWB propagation in LOS and NLOS residential environments. This model is based on some frequency-response measurements for pulses with a central frequency. The IEEE802.15.4a channel models are described in Table 5.4.

Table 5.4: IEEE802.15.4A Channel Models

Model	Description
CM1	Residential LOS
CM2	Residential NLOS
CM3	Indoor office LOS
CM4	Indoor office NLOS
CM5	Outdoor LOS
CM6	Outdoor NLOS
CM7	Open outdoor NLOS
CM8	Industrial LOS
CM9	Industrial NLOS

5.7 Performance Measurement

BER and throughput are used in the performance measurements and the simulations.

5.7.1 BER Performance for IEEE802.15.4A in Different Environments

The Ghassemzadeh model has been developed as an arithmetical loss of path model for UWB proliferation in domestic LOS and NLOS environments. Some pulses are based on frequency response measurements. The IEEE802.15.4a channel model is described in Table 5.4.

Throughput and BER are used in the simulation and performance measurements. By modern digital communication provide the end to end performance measurement. The bit error rate is a charity to the portion of the reliability system from bit to bit range i.e., bits-in to bits-out respectively. The BER performance can be given by

$$BER = \frac{Errors}{Total\ number\ of\ bits}$$

BER is defined as the ratio of errors to the total number of bits and is expressed as a base of 100 to a negative power. The sensitivity limit of BER can be defined as the received signal strength. The TH-modulated models that include BER demonstrate similar performance levels as the standard modulating models. The data rate of TH models is significantly higher than that of standard models because of the longer time frame and increased data bits per channel of the former. Therefore, even though the TH model has a similar BER compared with the standard model, the former is much more valuable to use because more information can be sent per frame at a low BER.

That BER can also be calculated by the orthogonal digital signals in a UWB communication system. In their work, BER was calculated by using the distinguishing function-based method, which measures the path gains of IEEE 802.15.4a channel models. BER can also be reduced by the quantisation error. The BER measurement is based on sending a data stream through the system and comparing the output with the input. BER can also be measured by the amplitude of the received signal. As mentioned earlier, BER can be used as a function of link distance with the IEEE802.15.4A standard for various channels, including the CM1 residential LOS channel, CM5 outdoor LOS channel, CM2 residential NLOS channel and CM6 outdoor NLOS channel

5.7.2 Throughput

Throughput is defined as the maximum production or processing rate. This chapter examines the throughput at three data rates. The corruption of data may affect throughput performance. The throughput may also be defined as the actual number of received packets at a certain distance. In general, throughput is directly proportional to the power of the transmitter, which increases indeterminately along with transmission power.

5.7.3 Analysis of BER and Throughput

The timing parameters of BER and throughput play key roles in evaluating BER and throughput. An appropriate bit rate and bandwidth selection contribute to the BER and throughput results.

i. BER and throughput are proportional to the bit rate, whereas a higher bit rate corresponds to a greater BER.

ii BER and throughput are inversely proportional to bandwidth size. A large bandwidth pulse enhances the multipath resistance and leads to a more precise ranging.

The parameters include distance (m) in the x-axis and BER in the y-axis. The parameter settings are based on some model effects, including the channel model, different bandwidth, different pulse duration, different distance, different maximum pulse, different PRF, different node, different data rate and different total packets sent effects.

5.8 Multi-Path Fading Channel Model in Simulated MAXIM Environments

5.8.1 Channel Model Effect

Figures 5.22 to 5.24 treat BER as a function of link distance with the IEEE802.15.4a.CM1 residential LOS and CM2 residential NLOS, CM5 outdoor LOS and CM6 outdoor NLOS, CM1 residential LOS and CM5 outdoor LOS that are corresponding to the distances between source and receiver. The receiver uses energy detection consisting of 3dB sensitivity. The six-channel models were evaluated as the residential LOS of CM1, the residential NLOS of CM2, outdoor LOS of CM5, outdoor NLOS of CM6 and the Ghassemzadeh residential LOS and NLOS models for IEEE 802.15.4a channel model. The NLOS channels show a significant performance degradation compared with LOS channels for the same model families. For example, the CM1 model shows a low range of BER between 0.0046 and 0.0048 at a distance of below 16 m, whereas the BER of the CM2 NLOS model transitions between 0.0037 and 0.01 at a distance of 7 m to 10 m. For outdoor CM6 NLOS, using the system becomes infeasible at distances exceeding 25 m, whereas CM6 LOS allows communications above 80 m. These differences can be attributed to the different path loss exponents of the channel models (CM1 residential LOS = 1.79, CM5 outdoor LOS = 1.76 CM2 residential NLOS = 4.58 and CM6 outdoor LOS = 2.5). Therefore, the path loss exponent value contributes to BER performance for the same model families. In sum, a smaller path loss exponent value corresponds to a greater BER performance. The same behaviour has been observed in all channels.

In the case of the residential LOS with a simulated distance of approximately 100 m, BER starts to significantly decline at distances beyond 20 m. Meanwhile, in the case of residential NLOS at the same distance, BER starts to decline at 6 m. Figure 5.22 shows the BER performance, which his considered a function of certain distances in the CM1 and CM2 residential LOS and NLOS channels, respectively.

The comparative analysis between the two simulated scenarios clearly shows that the residential NLOS has a better BER when the distances of CM1 and CM2 are less than 20 m (1/100) and 2 m, respectively. This can be explained as in residential NLOS; the pulses are expected to collide with obstacles that attenuate these pulses, thereby rapidly leading to a poor BER performance. The BER performance of impulse-based UWB is highly sensitive to NLOS environments and the attenuation factor in path loss, thereby limiting the signal within very short distances.

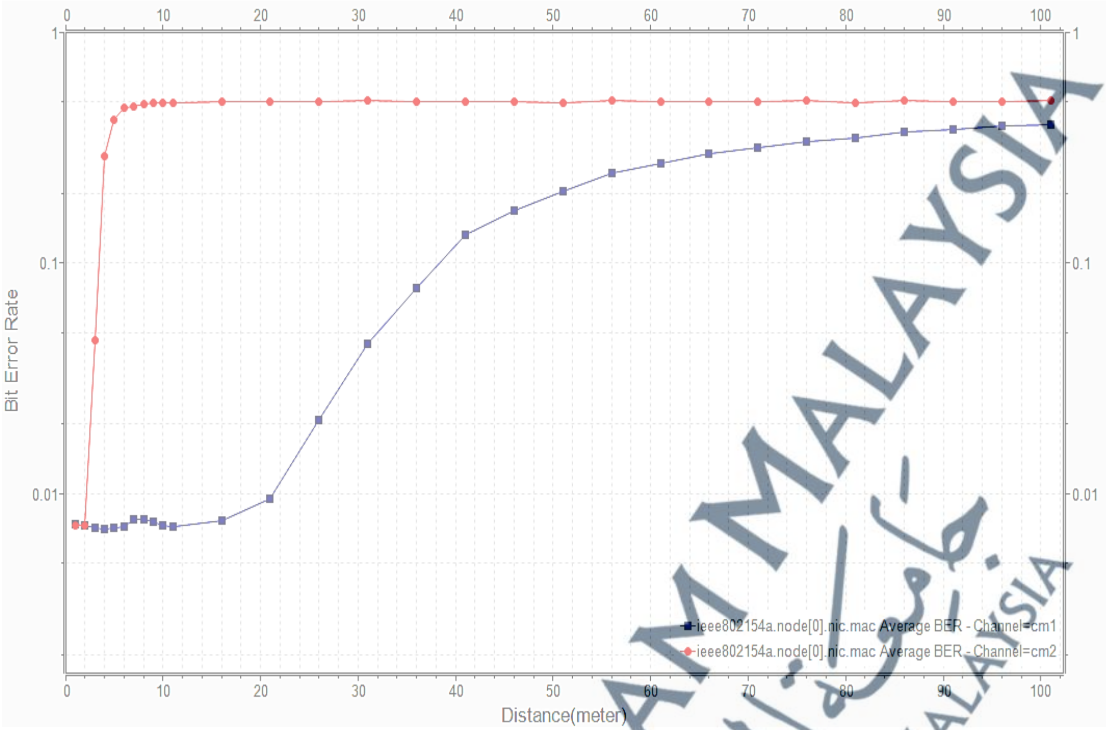

Figure 5.22: BER As A Function Of Link Distance With Channel IEEE802.15.4a CM1 Residential LOS And CM2 Residential NLOS

Figure 5.22 presents some key parameters that highlight an increase or decrease in two different channels. The blue and red lines indicate the average BER of channel CM1 residential LOS and channel CM2 residential NLOS, respectively. The simulation graph illustrates that at minimum and maximum (100 m) distances, the average BER of CM1 is equal to 0.009 and 0.5, respectively. In other words, CM1 residential LOS achieves a better BER performance at the maximum distance. Similarly, for CM2, the average BER increases by 0.009 and 0.55 at the minimum and maximum distances, respectively..

Figure 5.23 shows the BER of standard CM5 outdoor LOS and CM6 outdoor NLOS as a function of link distance. The blue and red lines denote the average BER of CM5 and CM6, respectively. The BER of CM5 and CM6 is simulated at a distance of 100 m. The BER of CM5 sharply decreases after 16 m and demonstrates a smooth decrease afterwards. And for the longer distance of 30 m with a probability of error in the received signal is less than 1/100.

These trends can be explained by the fact that the generated pulses in outdoor NLOS are prone to interferences and are less likely to be detected due to power loss after collision with the surrounding obstacles. Therefore, to prevent the corruption of packets, the alignment between the transmitter and receiver in outdoor environments must be considered.

The simulation result of CM5 outdoor LOS and CM6 outdoor NLOS consists of some keys such as blue and red path. The blue indicates the average BER of channel CM 1 residential LOS in which the BER is about 0.008 at a minimum distance 1m and gets increased to about 0.5 rates at a distance 100m for channel CM5 outdoor LOS.

The red line indicates that the average BER of CM6 is approximately 0.007 at a minimum distance of 1 m and increases to 0.8 at the maximum distance of 100 m. Therefore, CM5 and CM6 achieve a better BER at distances of 15 m to 100 m and 30 m to 100 m, respectively.

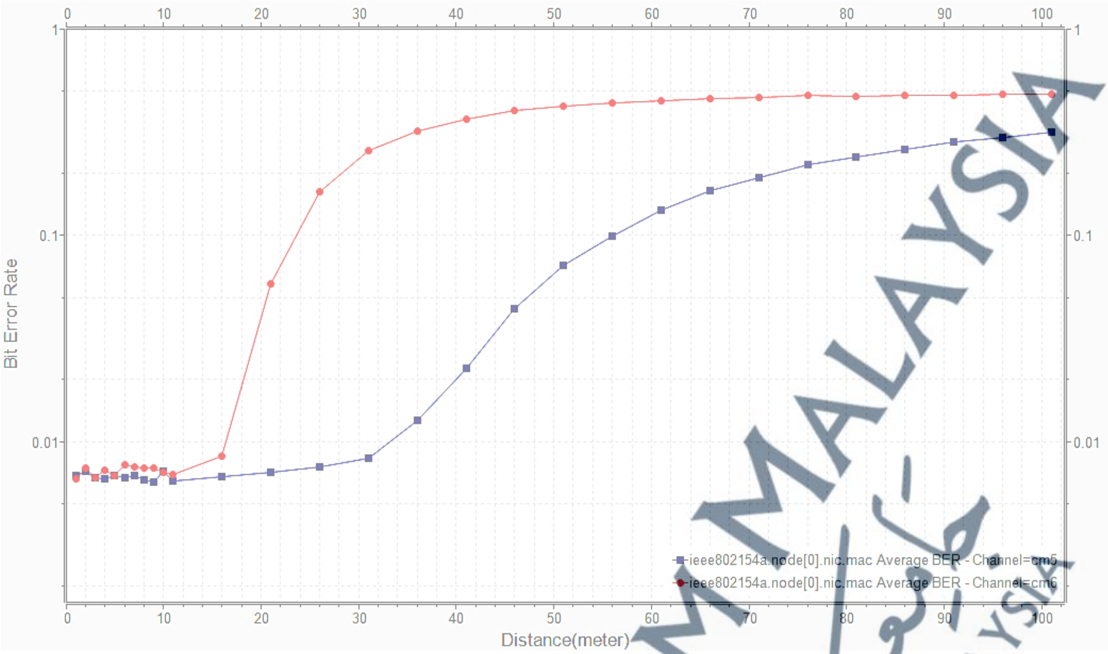

Figure 5.23: BER As A Function Of Link Distance With Channel IEEE802.15.4a CM5 Outdoor LOS And CM6 Outdoor NLOS

Figure 5.24 shows BER as a function of link distance with CM1 residential LOS and CM5 outdoor LOS. BER is simulated in both residential and outdoor environments at a maximum distance of 100 m. The BER performance for outdoor LOS is better than that for residential LOS with a probability of error of less than 1/100 at a distance of 35 m.

This finding can be explained by the fact that compared with indoor environments, outdoor environments have fewer obstacles, signal power decay and attenuation. Therefore, the obstacles and their types, which correspond to different degrees of power decay and path loss, must be considered as they can rapidly attenuate the signal in propagation environments. The red and blue lines in Figure 5.24 denote the average BER for CM1 residential LOS and CM5 outdoor LOS, respectively. The BER for CM1 starts at approximately 0.01 at a minimum distance of 22 m and increases to approximately 0.6 at a distance of 100 m. Meanwhile, the BER for CM5 increases from 0.01 at a minimum distance of 36 m to 0.5 at a distance of 100 m.

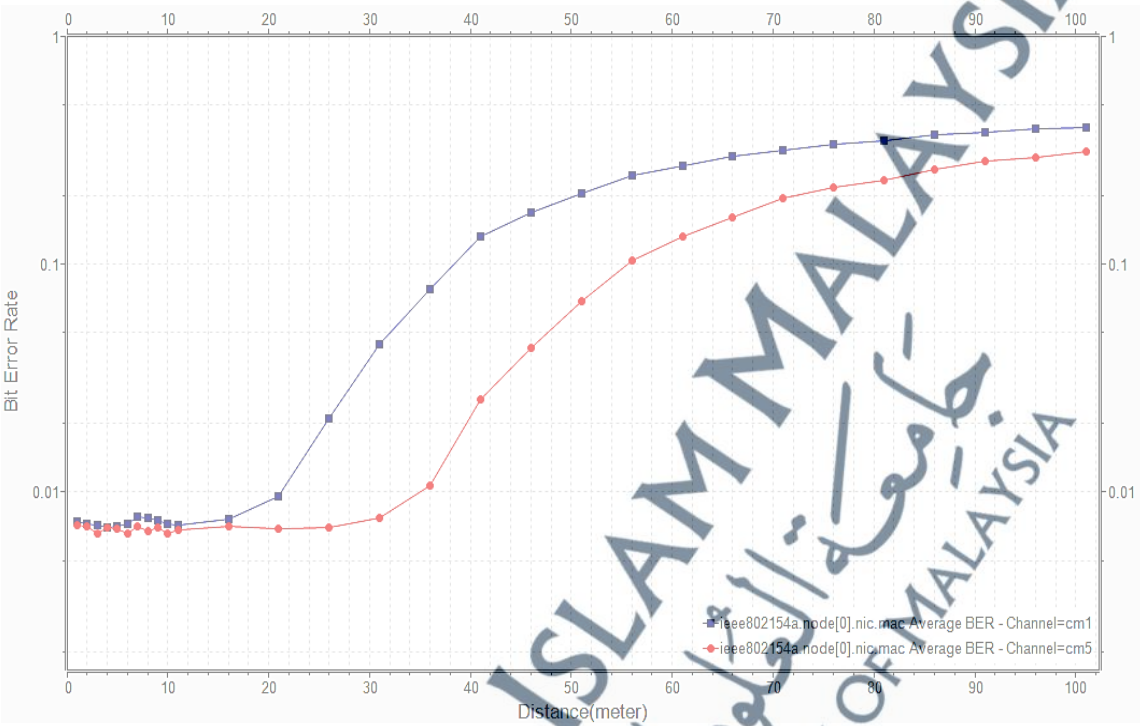

Figure 5.24: BER As A Function Of Link Distance With Channel IEEE802.15.4a CM1 Residential LOS And CM5 Outdoor LOS

Figure 5.25 shows the BER in residential and outdoor NLOS scenarios. The enactment is better in the case of the outdoor as in more stable with minimum BER of 1/100 for distance interval up to 18 m then the BER increased but still less increment than the sharp and exponential increase in the case of the outdoor NLOS.

The blue and red lines in Figure 5.25 indicate the average BER of CM2 residential NLOS and CM6 outdoor NLOS, respectively. Given the multiple obstacles in outdoor NLOS (e.g. thin and thick walls), the transmitted signal becomes prone to power decay and interference from dense wireless nodes in a small area.

The outdoor LOS of channel model can also be said that ranging errors increases when the antennas are closer to the ground and are more significant in NLOS conditions. Moreover, in NLOS conditions, ranging errors of more than 10 m are observed when the NLOS component is completely blocked by a building. Errors of such magnitude are typically not captured by the IEEE 802.15.4a CM6 (outdoor NLOS) channel model. The trends in Figure 5.24 also agree with those in Figure 5.23. The simulation results for CM2 residential NLOS and CM6 outdoor NLOS suggest that the BER for CM5 increases from 0.008 at a minimum distance of 1 m to 0.8 at a distance of 6 m.

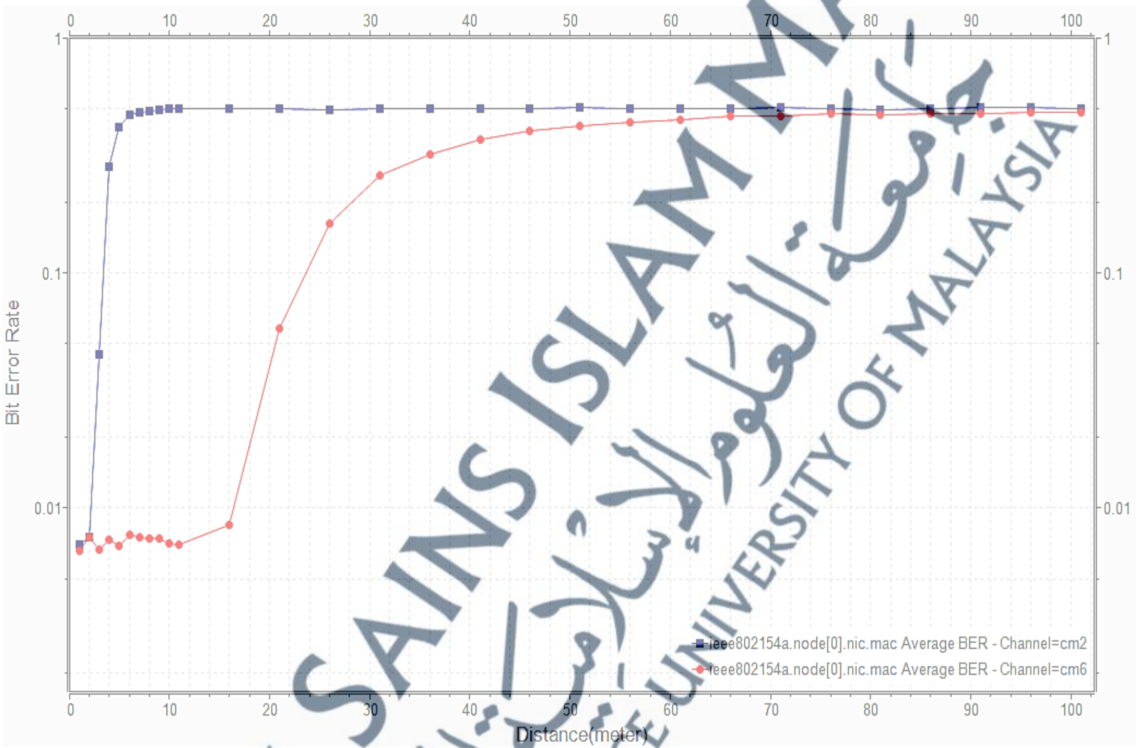

Figure 5.25: BER As A Function Of Link Distance With Channel IEEE802.15.4a CM2 Residential NLOS And CM6 Outdoor NLOS

Meanwhile, the BER for CM6 increases from 0.008 at a minimum distance of 1 m to 0.5 m at a distance of 36 m.

For the Ghassemzadeh multipath fading channel model, the blue and red lines in Figure 5.26 indicate the average BER of channel Ghassemzadeh residential LOS and channel Ghassemzadeh residential NLOS, respectively. The BER performance is then evaluated at a distance of 100 m. The BER of the channel Ghassemzadeh residential LOS is significantly higher than that of the channel Ghassemzadeh residential NLOS.

The signal can reach 18 m with a probability of error of less than 1/100. This finding inconsistent with that shown in the other figures given that LOS scenarios are less prone to interference and power-decay-causing signal attenuation. The BER for CM5 increases from 0.008 at a minimum distance of 1 m to 0.5 at a maximum distance of 100 m. Meanwhile, for CM6, the BER increases from 0.007 at a minimum distance of 1 m to 0.8 at a maximum distance of 100 m.

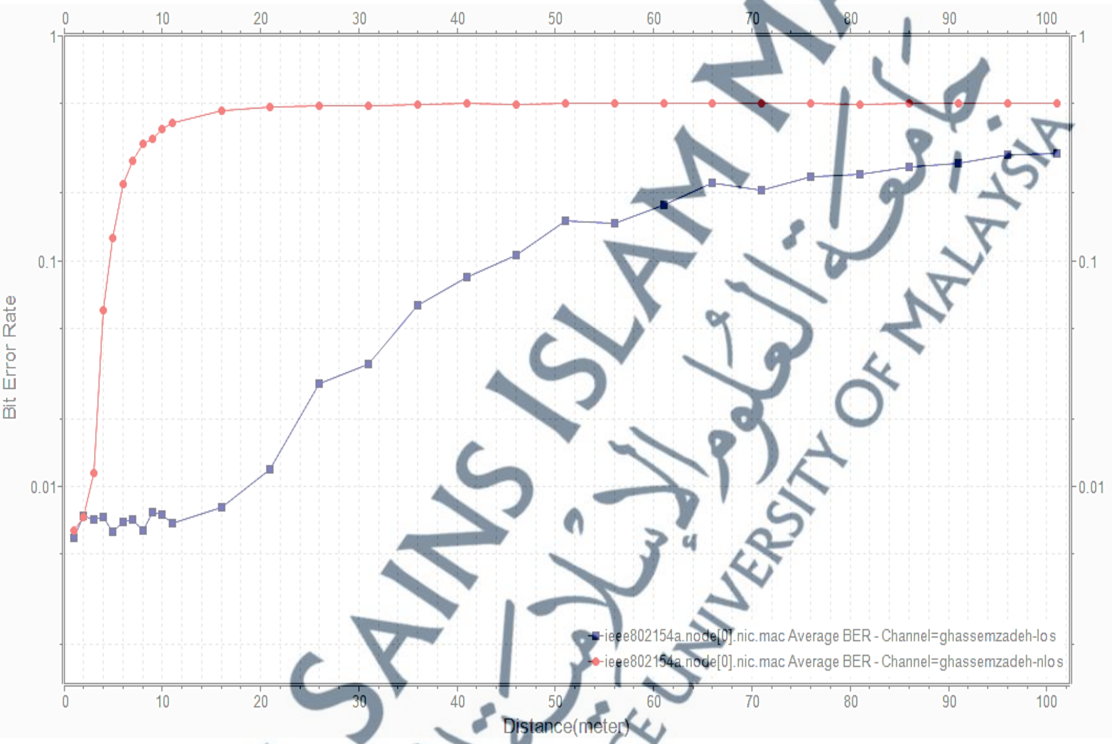

Figure 5.26: BER Over Distance For Ghassemzadeh Residential LOS And NLOS Channels

5.8.2 Different Bandwidth Effects

The BER performance of CM1 can be enhanced by increasing the channel bandwidth to 499.2 MHz (channel 3), 1081.6 MHz (channel 7) and 1354.97 MHz (channel 15). A larger bandwidth may allow the transmission of high power to a long communication range. The large bandwidth pulses indicate an enhanced multipath resistance. A greater bandwidth provides a more accurate range, and the IEEE802.15.4a standard defines various channels with high bandwidth. A greater bandwidth also allows for greater channel capacity and very high precision range measurements.

In other words, increasing the bandwidth can make the signal more resistant to the surrounding interferences and noise. The bandwidth of the transmission channel can be set to improve the received signal quality. Figure 5.27 shows the CM1 residential LOS BER performance at three bandwidths.

The simulated graph shows the BER performance of CM1 residential LOS at three bandwidths. The green, blue and red lines denote the average BER of channels 3, 7 and 15, amongst which channel 3 has a BER of 0.005 at a minimum distance of 16 m that increases to 0.5 at a maximum distance of 100 m. Meanwhile, for channel 7, the BER increases from 0.006 at a minimum distance of 21 m to 0.4 at a maximum distance of 100 m. The BER for channel 15 increases from 0.006 at a minimum distance of 21 m to 0.3 at a maximum distance of 100 m.

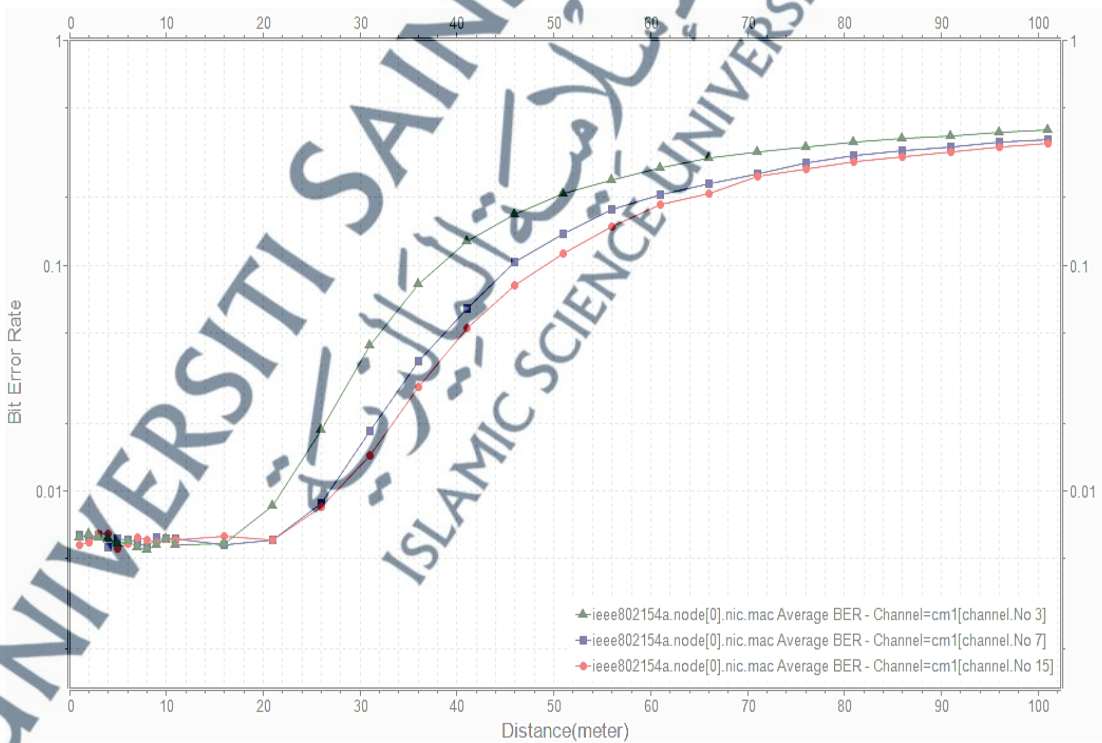

Figure 5.27: IEEE802.15.4a CM1 Residential LOS BER Performance At Three Bandwidths

Despite allowing for greater channel capacity and very high precision range measurements, a larger bandwidth also creates more noise in the channel. Large bandwidth pulses provide multipath resistance and accurate range. Therefore, the CM1 residential LOS achieves BER improvements at the three bandwidths.

5.8.3 Effect of Different Pulse Durations

The effect of different pulse durations on the BER performance of CM6 outdoor NLOS is illustrated in Figure 5.28, where the blue, green and red lines denote pulse durations of 0.75, 0.92 and 2 ns, respectively. When the number of nodes is two, decreasing the pulse duration will lead to a higher BER, thereby reducing the BER performance of CM6 between 20 m and 60 m.

This finding can be explained by the fact that shorter pulses are subjected to more power decay and that the received signal quality decreases as the signal attenuates. Reducing the pulse duration affects the quality of the received pulse as the attenuation will make the signal difficult to detect at the receiver side. The simulated graph shows the BER performance of CM6 at pulse durations of 0.75, 0.92 and 2 ns for the 2 nodes. At 2 ns, the BER performance of CM6 increases from 0.005 at a distance of 16 m to 0.8 at a maximum distance of 100 m.

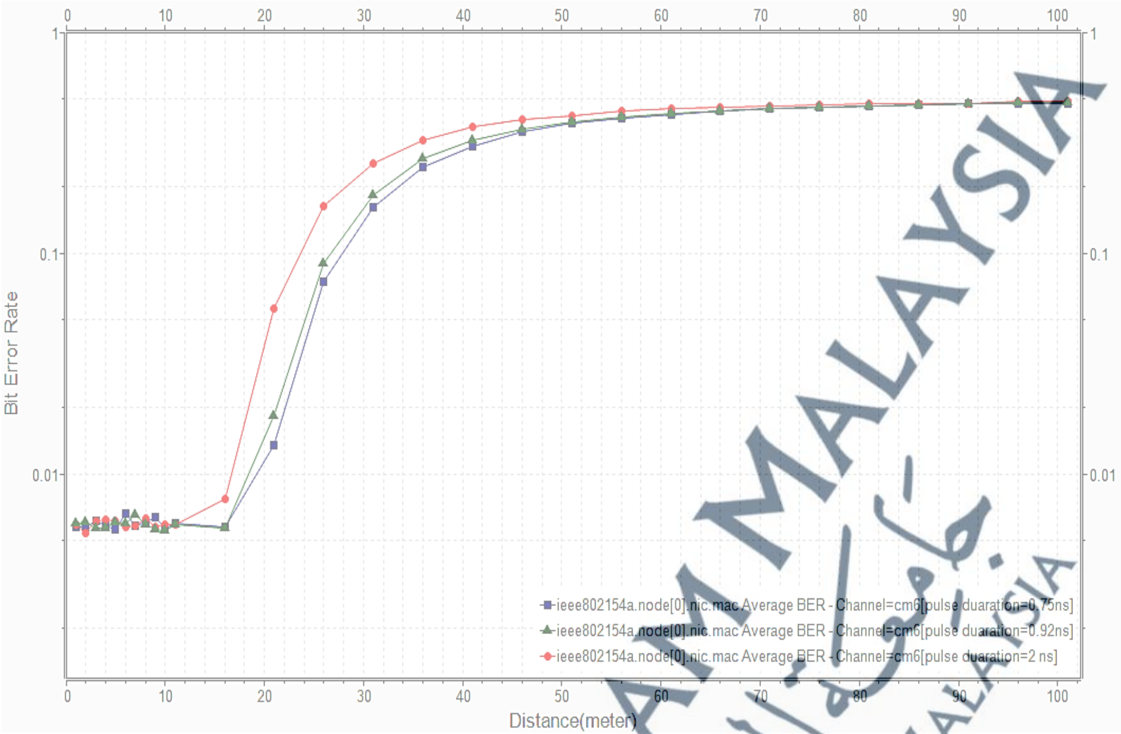

Figure 5.28: IEEE802.15.4a CM6 Outdoor NLOS BER Performance At Different Pulse Durations For Two Nodes

At 0.92 ns, the BER performance of CM6 increases from 0.005 at 16 m to 0.8 at 100 m. Meanwhile, at 2 ns, the BER performance increases from 0.006 at a distance of 16 m to 0.8 at a distance of 100 m.

5.8.4 Effect of Different Distances

Figure 5.29 shows the effect of different distances on BER performance. The red, blue and green lines denote 75, 150 and 200 m distances, respectively. In the case of CM5 outdoor LOS for channel 3, at 110 kbps for 2 nodes, increasing the distance will lead to a higher BER (and that is incompatible with the theory analysis). This trend can be observed at a distance of 30 m to 120 m and can be ascribed to the fact that a shorter pulse in a short distance has a better performance compared with that in a long distance. A longer distance is predicted to lead to a reduced received pulse signal quality, especially at distances of over 30 m. The simulated graph shows that the average BER is approximately 0.3 and 0.008 at distances of 75 m and 31 m, respectively, 0.4 and 0.75 at distances of 81 m and 150 m, respectively, and 0.76 and 0.8 at distances of 155 m and 200 m, respectively.

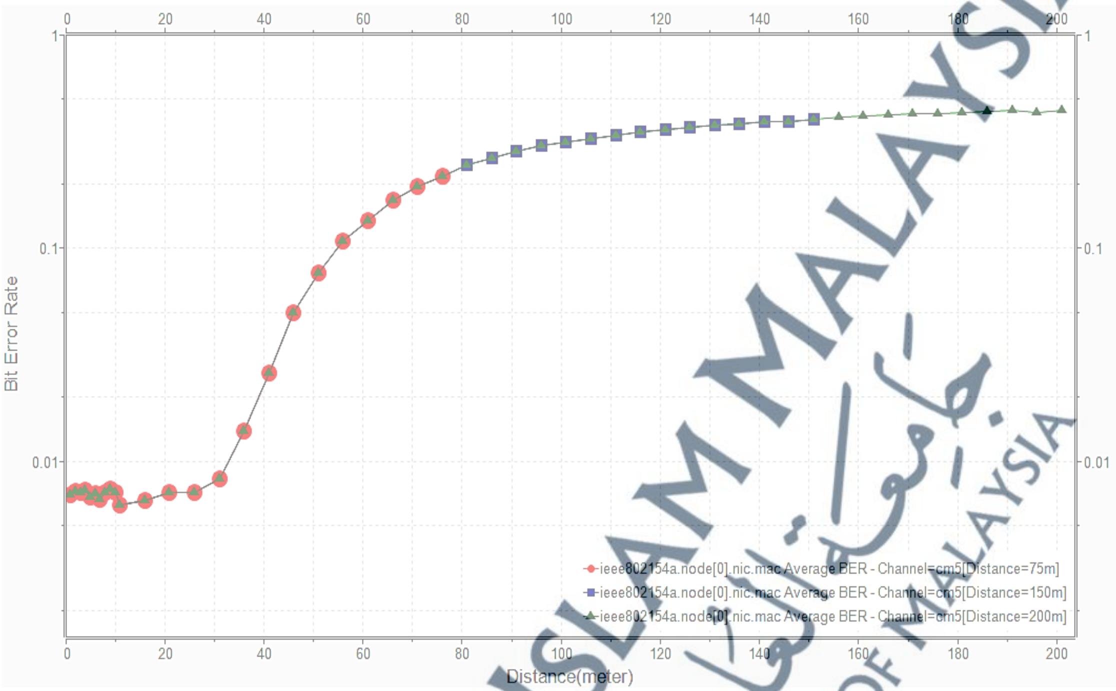

Figure 5.29: IEEE802.15.4a CM5 Outdoor LOS BER Performance At Different Distances For Two Nodes

5.8.5 Effect of Different Maximum Pulses

Figure 5.30 shows the maximum number of pulses and BER of the received signal quality for CM1 residential LOS at a data rate of 110 Kbps. Increasing the number of pulses at a certain data rate clearly improves the BER of the received signal quality in the case of three maximum pulses. A probability of error of 1/100 is observed up to a distance of 35 m.

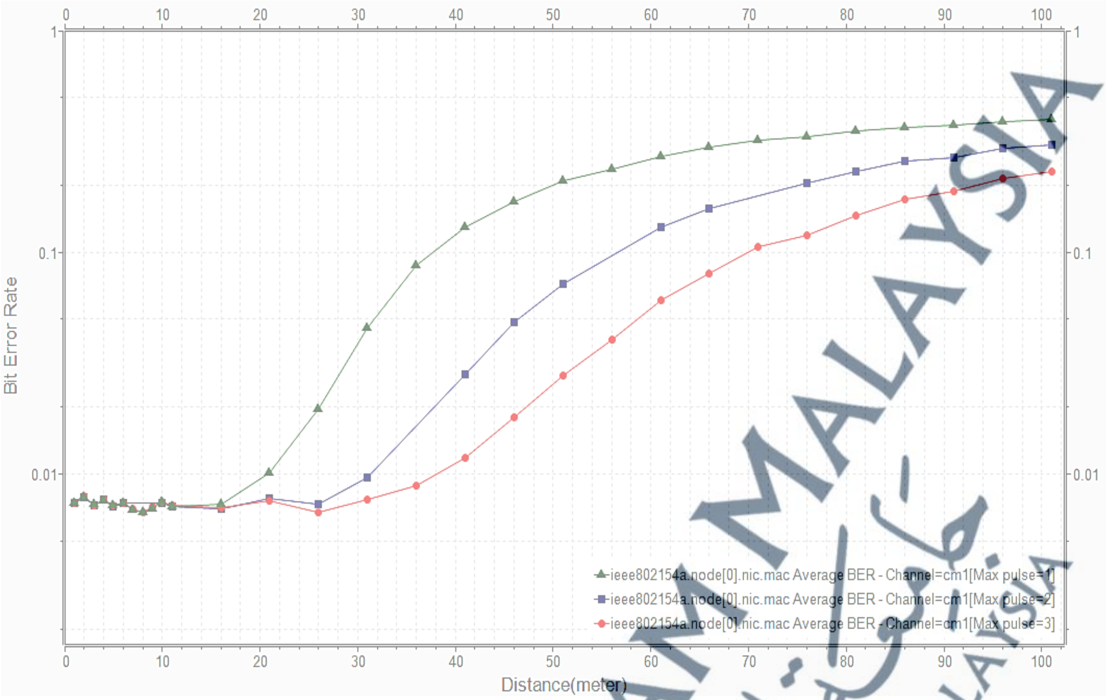

Figure 5.30: IEEE802.15.4a CM1 Residential LOS BER Performance At Different Maximum Pulses For Two Nodes

Increasing the number of pulses can cause more pulses to bounce when they hit surrounding obstacles. After bouncing, these pulses return to a certain power that can be detected at the receiver side. Therefore, tuning the number of pulses at a certain data rate can achieve QoS in terms of BER that meets certain requirements. In the simulated graph, the green, blue and red lines denote maximum pulse numbers of 1 to 3, respectively.

For a maximum pulse number of 1, the BER increases from 0.01 at a distance of 20 m to 0.75 at a distance of 100 m. For a maximum pulse number of 2, the BER increases from 0.01 at a distance of 31 m to 0.7 at a distance of 100 m. For a maximum pulse number of 3, the BER increases from 0.007 at a distance of 26 m to 0.65 at a distance of 100 m.

5.8.6 Effect of Different PRFs

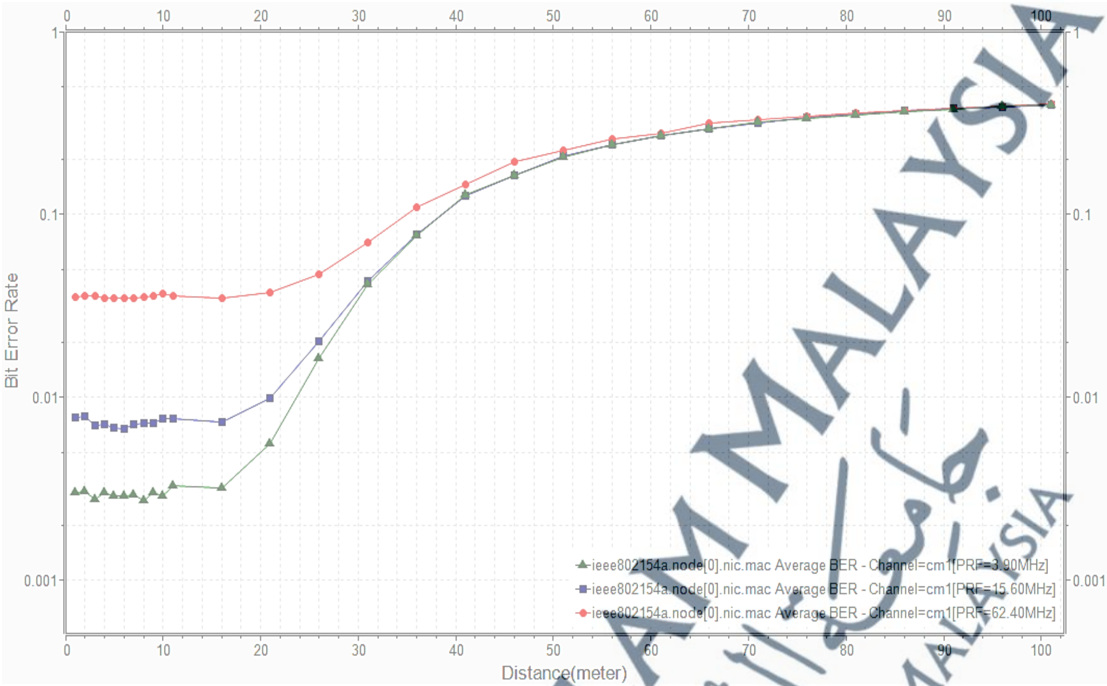

Figure 5.31: IEEE802.15.4a CM1 Residential LOS BER Performance At Different PRFs For Two Nodes

Figure 5.31 shows the effect of different PRFs on BER performance. The green, blue and red lines denote PRFs of 3.90, 15.60 and 62.40 MHz, respectively. The difference amongst these PRFs is captured by the number of burst positions, which is denoted by N burst. The results here are taken for BER performance over distance for channel 3 at 110kbps with different PRF as shown when decreasing the PRF will lead to higher BER, therefore, decrease the performance especially between distances of 15 to 30 meters. Compared with PRF, BER achieves a better performance specifically for LOS. The difference between the three specified PRFs is captured by the number of burst positions per symbol. Specifically, a lower number of bursts (Ncpb) leads to lower interference and bouncing of the generated pulses, thereby leading to a better synchronisation and improving the BER of the received signal. Table 5.5 shows the UWB number of burst positions for a given mean PRF.

Table 5.5: UWB Number Of Burst Positions For A Given Mean PRF

Mean PRF	3.90 MHz	15.60 MHz	62.40 MHz
NBurst	128	32	8

The reduced PRF enhances the quality of the received signal in terms of its error probability. The simulated graph shows different PRFs, such as 3.90, 15.60 and 62.40 MHz. At 3.90 MHz, the BER is 0.005 at a minimum distance of 16 m and 0.8 at a maximum distance of 100 m. At this frequency, the BER ranges from 0.005 to 0.8 at a distance of 16 m to 100 m. Meanwhile, at 15.60 MHz, the BER ranges from 0.01 to 0.8 at a distance of 22 m to 100 m. At 62.40 MHz, the BER ranges from 0.05 to 0.8 at a distance of 26 m to 100 m.

5.8.7 Effect of Different Nodes

Figure 5.32 presents a scenario where a different number of nodes is being transmitted in CM6 for outdoor NLOS at a maximum distance of 100 m. The number of nodes has minimal effects on the quality of the received signal. Meanwhile, in cases below 16 m, the signal has a very low BER of less than 0.01. Meanwhile, at a distance of 16 m to 66 m, the quality of the signal degrades exponentially. The number of nodes has no obvious effect on the received signal quality given the very low duty cycle of the generated pulses, which prevents them from overlapping and interfering with one another.

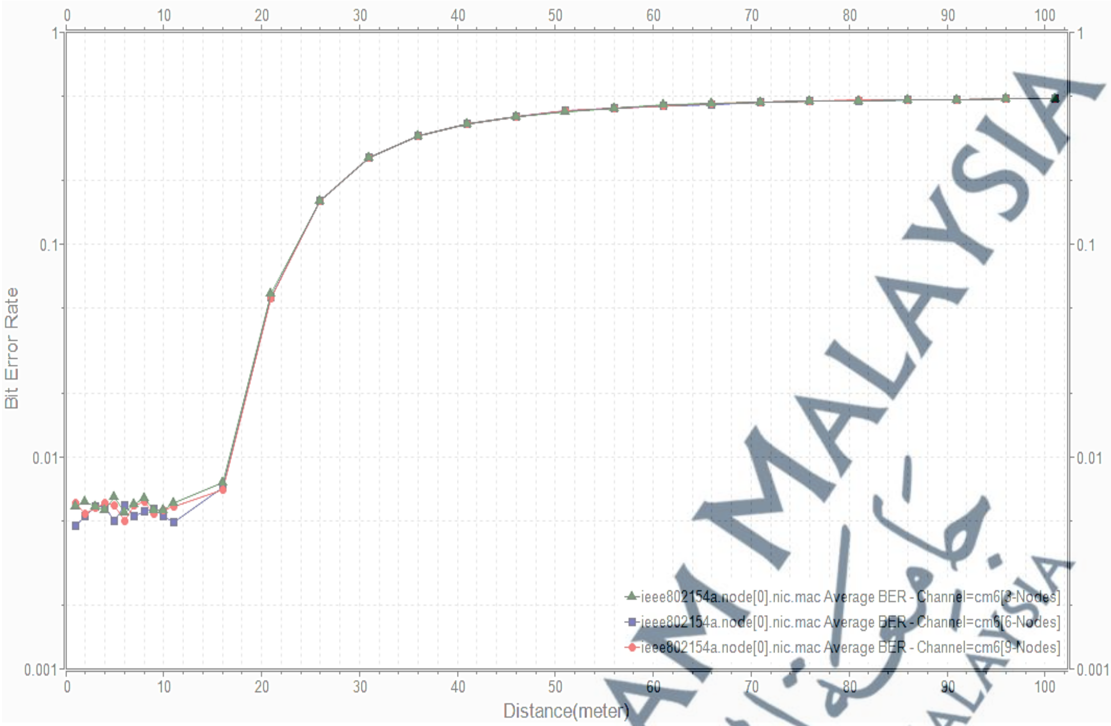

Figure 5.32: IEEE802.15.4a CM6 Outdoor NLOS BER Performance Of Different Nodes

The BER performance of CM6 outdoor at different node numbers (3, 6 and 9 nodes) is then evaluated. The blue, green and red lines in the simulated graph denote 6, 3 and 9 nodes, respectively. For 3 nodes, the BER ranges from 0.007 to 0.8 at a distance of 16 m to 200 m. For 6 nodes, the BER ranges from 0.007 to 0.8 at a distance of 16 m to 0.8. For 9 nodes, the BER ranges from 0.007 to 0.8 at a distance of 16 m to 200 m.

5.8.8 Effect of Different Data Rates

In chapter 4, table 4.4 in Section 4.7.3 shows the different data rate settings of the generated TH-UWB signal in a certain bandwidth and the parameters to be changed in order to achieve the desired data rate settings. The increased data rates are caused by congestion, and the transmitted pulses increase along with time. The main factor in this situation is the bandwidth size. Therefore, the same bandwidth is used for all data rates. The increments in data rate will cause congestion in traffic (bottleneck traffic) given that the transmitted bits increase every second yet the bandwidth remains the same. Therefore, bandwidth also affects BER and throughput by corrupting the data.

For example, the BER at 0.11 Mbps and 40 m is approximately 0.004, whereas that at 27.24 Mbps and 40 m is approximately 0.007. For throughput, the received packets at data rates of 6.81 Mbps and 0.85 Mbps start attenuating at 10 m and 60 m, respectively.

Figure 5.33 shows the IEEE802.15.4a CM1 Residentail LOS BER performance at multiple data rates and the relationship between different generated data rates of the conveyed pulsed signal and the received signal quality in terms of BER in the scenario where the maximum distance is 100 m. The trend analysis clearly shows that amongst all data rates, the lowest BER is achieved at 850 Kbps, especially at distances below 25 m where BER does not exceed 10^{-2}.

If the bandwidth remains the same and the data traffic increases, then congestion and bottleneck traffic both occur, thereby corrupting the received data especially for the HDR of 6.81 Mbps. In sum, increasing the data rate at a certain range will have a very obvious effect on the quality of the received signal. Meanwhile, if the data rate increases, then it may go to the extreme. The BER of CM1 residential LOS is simulated at data rates of 6.8 Mbps, 110 Kbps and 850 Kbps. At 6.8 Mbps, the BER increases from 0.02 at a minimum distance of 12 m to 0.75 at a maximum distance of 200 m. At a data rate of 110 Kbps, the BER increases from 0.007 at a minimum distance of 16 m to 0.75 at a maximum distance of 100 m. At a data rate of 850 Kbps, the BER increases from 0.01 at a minimum distance of 26 m to 0.7 at a maximum distance of 100 m. These measurements can be easily determined by using the key parameters denoted by the red, green and blue lines in the simulated graphs, which denote data rates of 6.8 Mbps, 110 Kbps and 850 Kbps, respectively.

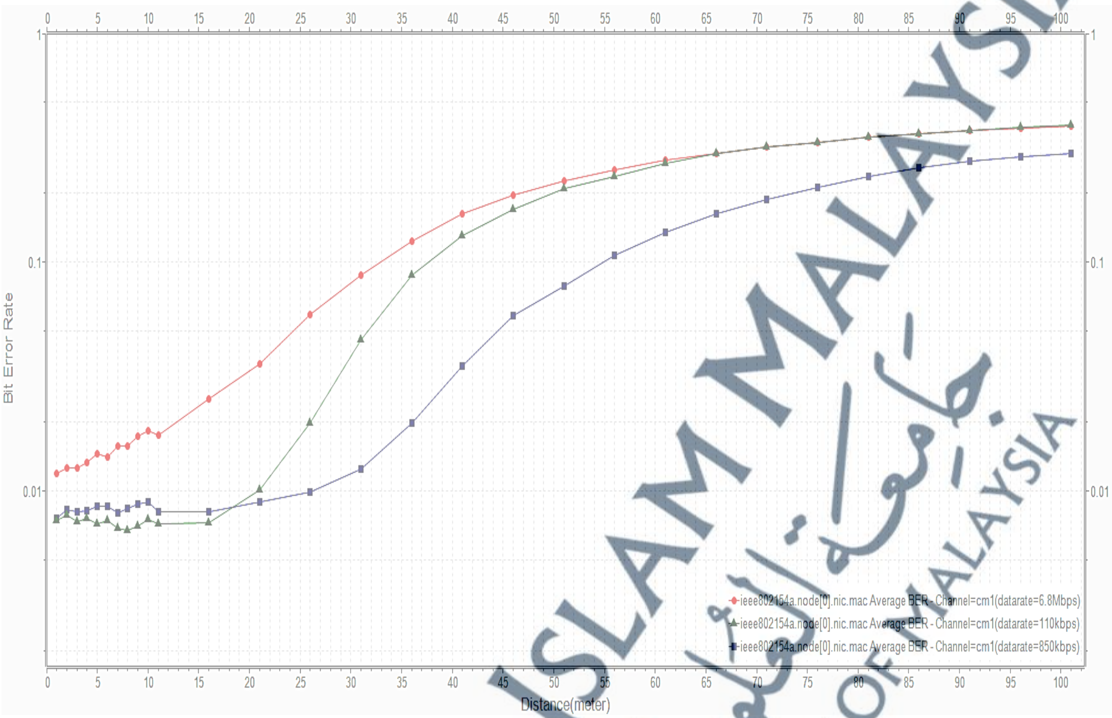

Figure 5.33: IEEE802.15.4a CM1 Residential LOS BER Performance At Different Data Rates

5.8.9 Effects of Different Numbers of Packets Sent

Figure 5.34 shows the influence of the increased number of total packets sent on BER at a simulated distance of 100 m. By increasing the number of total packets sent, the BER increases at a distance of 23 m or results in a low received signal error probability of 1/100. In other words, the more packets sent, the more packets can be detected and the more the received signal can recover its power.

The simulated graph analyses BER based on the number of packets sent. Each number of packets sent has a different BER. Specifically, when 150 packets are sent, the BER increases from 0.04 at a minimum distance of 25 m to 0.8 at a maximum distance of 100 m. When 250 packets are sent, the BER increases from 0.04 at a minimum distance of 25 m to 0.8 at a maximum distance of 100 m. When 350 packets are sent, the BER increases from 0.04 at a minimum distance of 25 m to 0.8 at a maximum distance of 100 m. The red, green and blue lines in the simulated graph denote the average BER of CM1 when 150, 250 and 350 packets are sent, respectively. The effect of total packets sent is simulated by using OMNET. The figure shows that a better BER is achieved under MIXIM.

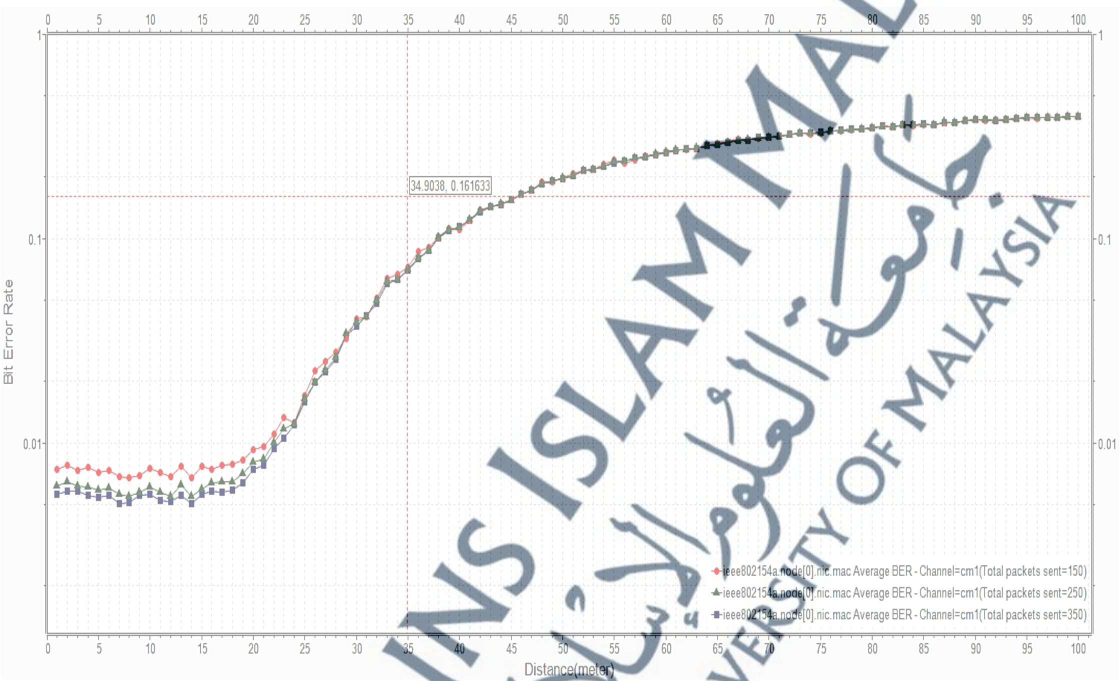

Figure 5.34: Effects Of Number Of Packets Sent On BER Performance

5.9 Throughput at Different Data Rates

Figures 5.35 to 5.37show the throughput at different data rates. Throughput is defined as the actual total received a packet in relation with a certain distance of 100 m at the 110 Kbps, 850 Kbps and 6.81 Mbps. Amongst these data rates, the best throughput is achieved at 850 Kbps, which agrees with the achieved BER at different data rates given that the probability of error in the received packets is the lowest at 850 Kbps.

In the simulated graph, the x-axis represents the distance (m) covered, whereas the y-axis represents the total number of packets received. It clearly describes numerous packet as a particular distance. The graph shows that 150 packets have been received at a distance of 31 m, thereby proving that a better BER performance can be achieved at distances of 0 m to 31 m. Figure 5.35 shows the throughput at a 110 Kbps data rate. The main difference between throughput and BER is that the former represents the transfer rate between two applications, whereas BER represents the speed at which two devices can transmit a change in state. The 110 Kbps data rate is simulated successfully by using OMNET++.

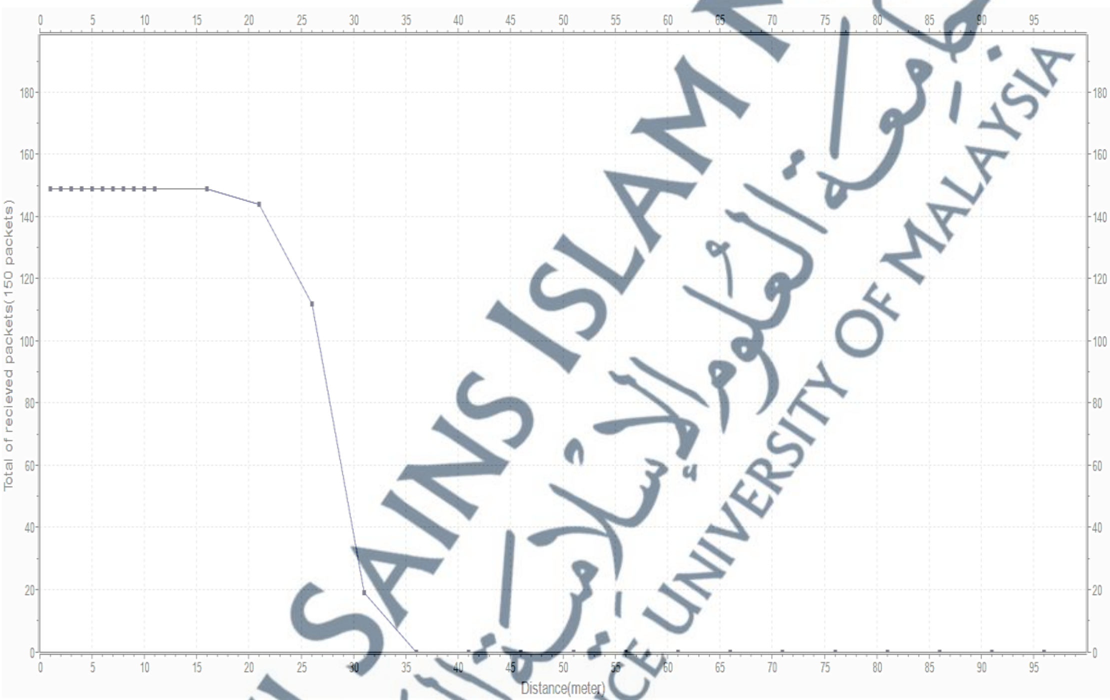

Figure 5.35: Throughput At Data Rate Of 110 Kbps

Figure 5.36 shows the throughput for the 850 Kbps data rate. At 150 packets, the distance covered is 41 m, which suggests that 150 packets have been received at a distance of 41 m, thereby proving that a better throughput is achieved at 850 Kbps.

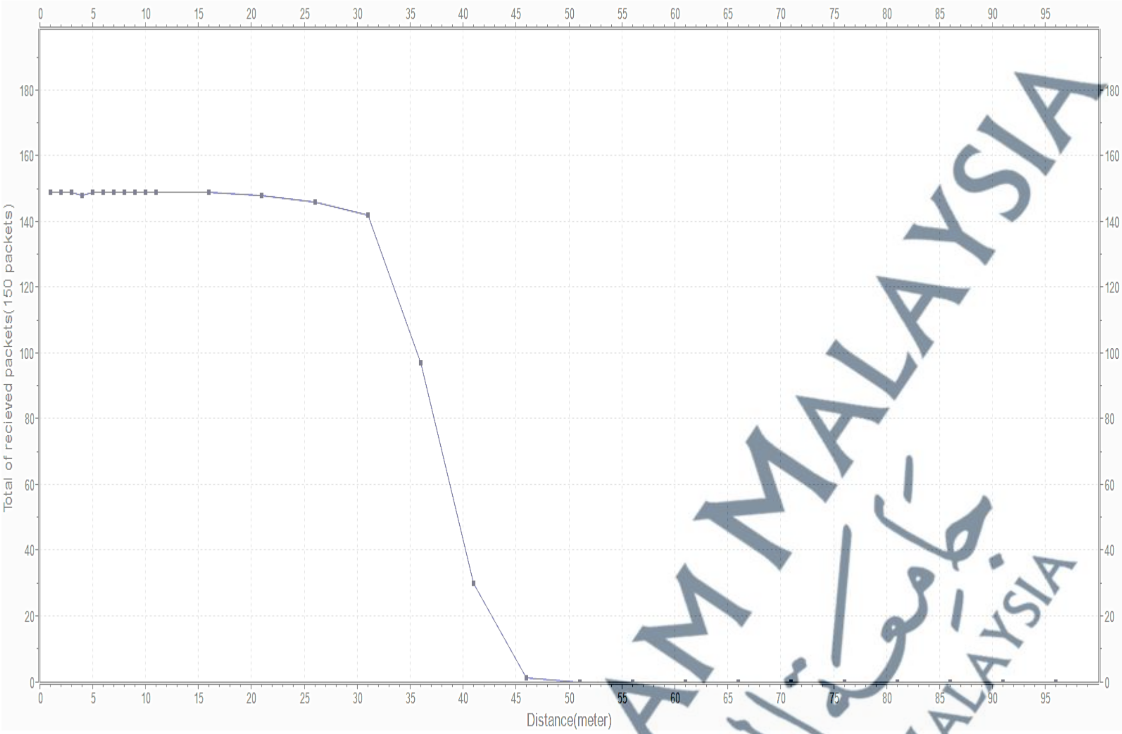

Figure 5.36: Throughput At Data Rate Of 850 Kbps

Figure 5.37 shows the throughput and BER achieved at a data rate of 6.81 Mbps. The simulated graph shows that 150 packets have been received at a distance of 26 m, thereby proving that a better throughput is achieved at a data rate of 6.81 Mbps.

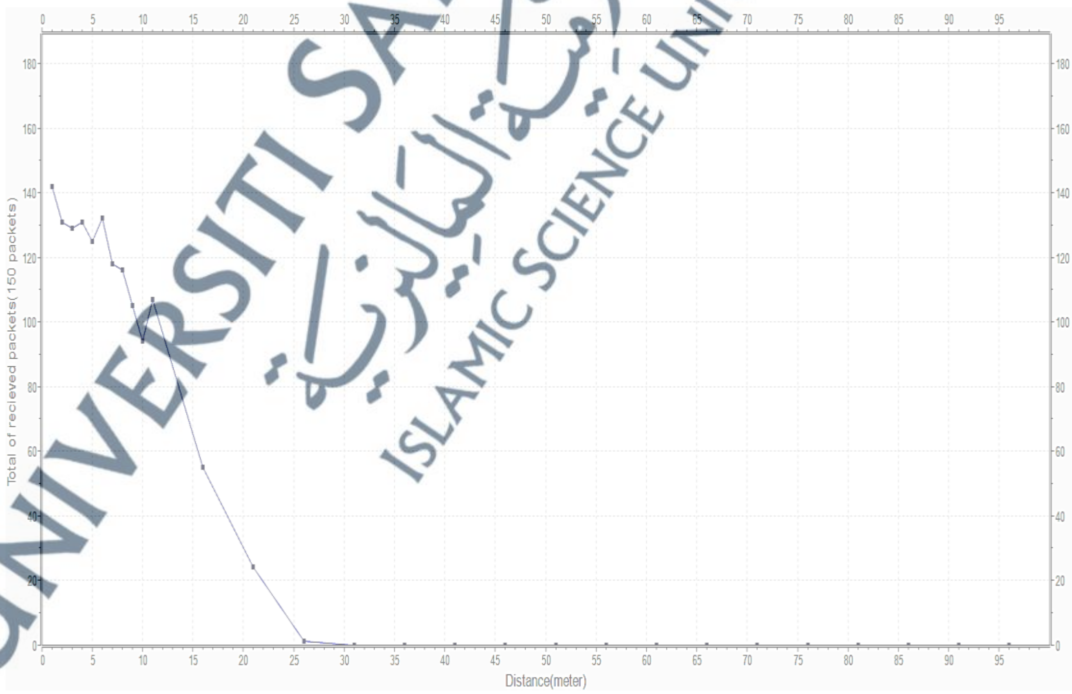

Figure 5.37: Throughput At Data Rate Of 6.81 Mbps

5.10 Summary

The reconfigurable capabilities of the IR-UWB communication system can support the scalability of this technology as a global solution for short/medium (from few meters to around hundred meters) distances and high/low (from a few hundred KBps to a few hundred Mbps) data rate wireless applications. The IR-UWB communication system provides better performance over BER as a function link distance with different channels IEEE802.15.4a. The channels are fully based on OMNET++ and MIXIM. BER performance and throughput are simulated at different data rates. The effect of channels is determined based on BER. The implementation and real (indoor/outdoor) environments are examined for validation purposes. The adaptive aspects of the system are then analysed across different data rate transmissions, BERs and distances.