PERFORMANCE ANALYSIS BY SIMULATION OF A WIRELESS SYSTEM ASSOCIATED WITH UWB

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Ultra Wideband transmission technique is supposed to be a promising candidate for fixed and mobile ad-hoc networks in short range scenarios. Ad-hoc networks are characterized by a lack of infrastructure, thus routing protocols are needed to establish connections between nodes. This thesis presents a performance analysis and evaluation for different routing protocols: On-Demand Distance Vector Routing protocol (AODV), Dynamic Source Routing protocol (DSR), Destination-Sequence Distance Vector (DSDV), and No Ad-hoc routing protocol (NOAH), considering two realistic scenarios. These scenarios were simulated using NS-2 with a 802.15.4a physical layer. The first scenario denoting a production line in a factory shows that the static routing protocol NOAH outperforms all protocols on the basis of packet delivery ratio and received throughput. In the second scenario designating a mobile ad-hoc network, routing protocols were compared in terms of packet delivery ratio, end-to-end delay and normalized routing load in different environments, in order to observe the influence of the network size, network load, and nodes mobility. Simulation results showed that DSR has performed well on the basis of packet delivery ratio while AODV has performed better in terms of average end-to-end delay. For normalized routing load we found that DSDV routing protocol is more stable than AODV and DSR.

Keywords: Ad-hoc network, AODV, DSDV, DSR, NOAH, UWB.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLOSSARY</td>
<td></td>
<td>VI</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td></td>
<td>VIII</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>BACKGROUND AND RELATED WORK</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>UWB BACKGROUND</td>
<td>5</td>
</tr>
<tr>
<td>1.1</td>
<td>INTRODUCTION</td>
<td>5</td>
</tr>
<tr>
<td>1.2</td>
<td>ULTRA WIDEBAND</td>
<td>5</td>
</tr>
<tr>
<td>1.2.1</td>
<td>Historical overview</td>
<td>5</td>
</tr>
<tr>
<td>1.2.2</td>
<td>Regulations</td>
<td>5</td>
</tr>
<tr>
<td>1.3</td>
<td>IEEE STANDARDIZATION</td>
<td>7</td>
</tr>
<tr>
<td>1.3.1</td>
<td>IEEE 802.15.3a</td>
<td>7</td>
</tr>
<tr>
<td>1.3.2</td>
<td>IEEE 802.15.4a</td>
<td>8</td>
</tr>
<tr>
<td>1.4</td>
<td>KEY BENEFITS OF UWB</td>
<td>8</td>
</tr>
<tr>
<td>1.4.1</td>
<td>Capacity</td>
<td>8</td>
</tr>
<tr>
<td>1.4.2</td>
<td>Power spectral density (PSD)</td>
<td>9</td>
</tr>
<tr>
<td>1.4.3</td>
<td>Material penetration characteristics</td>
<td>9</td>
</tr>
<tr>
<td>1.4.4</td>
<td>Pulse shape</td>
<td>10</td>
</tr>
<tr>
<td>1.4.5</td>
<td>Spatial Capacities</td>
<td>11</td>
</tr>
<tr>
<td>1.5</td>
<td>SUMMARY</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>UWB TECHNOLOGIES AND TECHNIQUES</td>
<td>14</td>
</tr>
<tr>
<td>2.1</td>
<td>INTRODUCTION</td>
<td>14</td>
</tr>
</tbody>
</table>
2.2 SINGLE BAND UWB ........................................................................................................... 14
   2.2.1 Modulation techniques ........................................................................................... 16
   2.2.2 Enabling Multiple Access in Single Band UWB ...................................................... 19
   2.2.3 Common and private acquisition preamble in IR-UWB [8, 9] .............................. 22
   2.2.4 Interference in IR-UWB networks ........................................................................ 23
2.3 MULTI-BAND APPROACH ................................................................................................. 24
   2.3.1 Multiband Orthogonal Frequency Division Multiplexing (MB-OFDM) ............... 25
2.4 SUMMARY ....................................................................................................................... 26

3 ROUTING PROTOCOLS AND NS SIMULATOR ................................................................. 28
   3.1 INTRODUCTION ........................................................................................................ 28
   3.2 WIRELESS AD-HOC ROUTING PROTOCOLS ........................................................ 29
       3.2.1 Destination-Sequenced Distance Vector (DSDV) .............................................. 29
       3.2.2 Ad-hoc On-Demand Distance Vector Routing (AODV) ................................. 29
       3.2.3 Dynamic Source Routing (DSR) ...................................................................... 30
       3.2.4 No Ad-hoc Routing Agent (NOAH) ................................................................. 31
   3.3 NETWORK SIMULATOR ............................................................................................... 32
       3.3.1 Network Simulator NS-2 ................................................................................ 32
   3.4 SUMMARY ................................................................................................................ 33

4 LINE SCENARIO SIMULATION AND ANALYSIS ........................................................ 35
   4.1 INTRODUCTION ..................................................................................................... 35
   4.2 NS-2 PARAMETERS ............................................................................................... 35
   4.3 SIMULATIONS ......................................................................................................... 36
   4.4 LINE OF NODES TOPOLOGY .............................................................................. 36
       4.4.1 Test 1: Influence of the type of acquisition preamble .................................... 37
       4.4.2 Test 2: Impact of the link distance ................................................................. 40
## GLOSSARY

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>AODV</td>
<td>Ad-hoc On-Demand Distance Vector</td>
</tr>
<tr>
<td>BPM</td>
<td>Bi-Phase Modulation</td>
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<td>CBR</td>
<td>Constant Bit Rate</td>
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<td>CDMA</td>
<td>Code Division Multiple Access</td>
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<td>DoD</td>
<td>Department of Defense</td>
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<tr>
<td>DSDV</td>
<td>Destination Sequenced Distance Vector</td>
</tr>
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<td>DSR</td>
<td>Dynamic Source Routing</td>
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<td>DSSS</td>
<td>Direct Sequence Spread Spectrum</td>
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<tr>
<td>DS-UWB</td>
<td>Direct Sequence Ultra-Wideband</td>
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<tr>
<td>EIRP</td>
<td>Effective Isotropic Radiated Power</td>
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<td>EXPOO</td>
<td>Exponential ON/OFF</td>
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<tr>
<td>FCC</td>
<td>Federal Communication Commission</td>
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<td>FTP</td>
<td>File Transfer Protocol</td>
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<td>GPR</td>
<td>Ground Penetration Radar</td>
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<td>GPS</td>
<td>Global Positioning System</td>
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<td>GSM</td>
<td>Global System for Mobile Communications</td>
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<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
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<tr>
<td>IP</td>
<td>Internet Protocol</td>
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<tr>
<td>IR</td>
<td>Impulse Radio</td>
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<td>IR-UWB</td>
<td>Impulse Radio Ultra Wideband</td>
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<td>MAC</td>
<td>Medium Access Control</td>
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<tr>
<td>MANET</td>
<td>Mobile Ad-hoc Network</td>
</tr>
<tr>
<td>MB-OFDM</td>
<td>Multiband Orthogonal Frequency Division Multiplexir</td>
</tr>
<tr>
<td>MUI</td>
<td>Multi-user Interference</td>
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<td>NAM</td>
<td>Network Animator</td>
</tr>
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<td>NOAH</td>
<td>No Ad-hoc</td>
</tr>
<tr>
<td>NS-2</td>
<td>Network simulator (Version 2)</td>
</tr>
<tr>
<td>OOK</td>
<td>On-Off Keying</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>OTcl</td>
<td>Object Tools Command Language</td>
</tr>
<tr>
<td>PAM</td>
<td>Pulse Amplitude Modulation</td>
</tr>
<tr>
<td>PDR</td>
<td>Packet Delivery Ratio</td>
</tr>
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<td>PN</td>
<td>Pseudorandom Noise code</td>
</tr>
<tr>
<td>POO</td>
<td>Pareto ON/OFF</td>
</tr>
<tr>
<td>PPM</td>
<td>Pulse-Position Modulation</td>
</tr>
<tr>
<td>PSD</td>
<td>Power Spectral Density</td>
</tr>
<tr>
<td>RERR</td>
<td>Route Error</td>
</tr>
<tr>
<td>RREP</td>
<td>Route Reply</td>
</tr>
<tr>
<td>RREQ</td>
<td>Route Request</td>
</tr>
<tr>
<td>RTh</td>
<td>Received throughput</td>
</tr>
<tr>
<td>RWP</td>
<td>Random Waypoint</td>
</tr>
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<td>Tcl/TK</td>
<td>Tool Command Language / Tool Kit</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission Control Protocol</td>
</tr>
<tr>
<td>TFC</td>
<td>Time-Frequency Code</td>
</tr>
<tr>
<td>THS</td>
<td>Time Hopping Sequence</td>
</tr>
<tr>
<td>THSS</td>
<td>Time Hopping Spread Spectrum</td>
</tr>
<tr>
<td>TH-UWB</td>
<td>Time-Hopping Ultra Wideband</td>
</tr>
<tr>
<td>UDP</td>
<td>User Datagram Protocol</td>
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<td>UWB</td>
<td>Ultra Wideband</td>
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<tr>
<td>WLAN</td>
<td>Wireless Local Area Network</td>
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<tr>
<td>WPAN</td>
<td>Wide Personal Area Network</td>
</tr>
<tr>
<td>WSN</td>
<td>Wireless Sensor Network</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 1.1: (a) The FCC spectral indoor mask (b) The FCC spectral outdoor mask ................................................................................................................................7

Figure 2.1: UWB pulse shape .................................................................................................................................15

Figure 2.2: (a) UWB pulse train (b) Spectrum of a UWB pulse train ..................................16

Figure 2.3: (a) Time representation of M-ary PPM modulation (b) Time representation of transmission bits “1” and “0” using the binary PPM modulation ................................................................................17

Figure 2.4: Time representation of transmission of bits “00”, “01”, “10”, “11” using the combination of binary PPM-PAM modulations .........................................................18

Figure 2.5: Example of transmission of bits “1 0 1 0 1” for a TH code of “3 5 2 5 1” using 2-PPM modulation ...........................................................................................................20

Figure 2.6: The DS-UWB spectrum ......................................................................................................................21

Figure 2.7: Packet format in IR-UWB ..............................................................................................................22

Figure 2.8: (a) Common acquisition preamble (b) Private acquisition preamble .................................................................................................................22

Figure 2.9: Near-far effect .................................................................................................................................24

Figure 2.10: Proposed MB-OFDM frequency band plan ................................................................................25

Figure 3.1: Ad-hoc network ..............................................................................................................................28

Figure 3.2: RREQ, RREP and RERR messages ..........................................................................................30

Figure 3.3: RREQ and RREP messages ........................................................................................................31

Figure 3.4: Simplified User's View of NS ...............................................................................................32

Figure 4.1: (a) Line topology (b) Example of line topology visualized in Nam..36

Figure 4.2: Line scenario: throughput versus number of nodes for link distances 1, 10 and 20m.........................................................38
Figure 4.3: Line scenario: throughput versus number of nodes for link distances 30, 40 and 50m

Figure 4.4: Received throughput versus the link distance for five different node numbers 2, 3, 5, 11 and 17

Figure 4.5: Line scenario: throughput versus number of nodes applied with different routing protocols for link distances 1, 5, 10, and 30m

Figure 4.6: Line scenario: packet delivery ratio versus number of nodes applied with different routing protocols for link distances 1, 5, 10, and 30m

Figure 4.7: Line scenario: throughput versus number of nodes applied with different routing protocols for link distances 1, 5, 10, and 30m

Figure 4.8: Line scenario: packet delivery ratio versus number of nodes applied with different routing protocols for link distances 1, 5, 10, and 30m

Figure 4.9: Throughput and Packet Delivery Ratio relationship

Figure 4.10: Packet Delivery Ratio in UDP versus Packet Delivery Ratio in TCP

Figure 5.1: Random mobile topology with 30 mobile nodes and one sink node fixed in the center of the area

Figure 5.2: Packet Delivery ratio as function of connections number using CBR, Pareto On/Off, and Exponential On/Off traffic sources (Both AODV and DSR were used)

Figure 5.3: Packet Delivery Ratio versus number of nodes

Figure 5.4: Average End-To-End Delay versus number of nodes

Figure 5.5: Normalized routing load versus number of nodes

Figure 5.6: Packet delivery ratio versus connections number

Figure 5.7: Average end-to-end delay versus connections number

Figure 5.8: Normalized routing load versus connections number

Figure 5.9: Packet delivery ratio versus nodes mobility

Figure 5.10: Average end-to-end delay versus nodes mobility

Figure 5.11: Normalized routing load versus nodes mobility
# LIST OF TABLES

Table 4.1: Results’ summary for the TCP case ......................................................53
Table 4.2: Results’ summary for the UDP case .....................................................53
Table 5.1: Simulation parameters .........................................................................60
Table 5.2: Scenarios parameters ............................................................................61
Table 5.3: Results’ summary .................................................................................76
INTRODUCTION

Wireless communication systems have been developed over the last few decades. Equipments and devices tend to operate in wireless mode, providing flexible data rates and wide variety of applications. Since the demand for wireless services is increasing, this must be done under the constraint of the limited available resources like spectrum and power. New generations of wireless mobile radio systems have appeared. Therefore, they have to find place in the overcrowded radio frequency spectrum and use it in a very efficient way.

Recently, wireless communication networks have witnessed the introduction of a promising technology called Ultra Wideband (UWB). UWB is a new technology which is different from conventional narrowband transmission technologies, based on spreading signals across a very wide bandwidth greater than 500 MHz. UWB communication systems are highly recommended for a variety of applications. They have been investigated intensively in the last few years due to their attractive properties such as high data rates, low transmission power, low equipment cost, spectrum reuse, multipath immunity and precise positioning capability.

In chapter 1, an introduction to UWB technology is provided. First, the fundamentals of UWB are overviewed, and then regulations and standardization are summarized. Also the key benefits of UWB are identified.

In chapter 2, the UWB signals and different data modulation schemes for UWB are described. Further, UWB technologies and techniques are studied, where a brief overview of Impulse Radio and Multi-band Orthogonal Frequency Division Multiplexing is presented.
In chapter 3, we present the different routing protocols used in our performance evaluation. Further, we provide a small overview describing the network simulator NS-2.

In chapter 4, we investigate the performance of UWB in a realistic scenario, denoting a line of production in a factory. First, we studied the performance of an Impulse Radio UWB network using private acquisition preambles with a network using common acquisition preamble. Then, a detailed study for a line scenario is provided on the basis of packet delivery ratio and received throughput, using both TCP and UDP transport protocols. Finally, a table with a brief comparison is presented.

In chapter 5, a random mobile ad-hoc network is studied. Routing protocols were compared in terms of packet delivery ratio, end-to-end delay and normalized routing load in different environments in order to observe the influence of the network size, network load, and nodes mobility. In the end, a table with a brief comparison is presented.

At the end, a final conclusion and recommendations for future work are presented.
BACKGROUND AND RELATED WORK

A remarkable step in the history of UWB communications was occurred in 2002, when the US Federal Communications Commission (FCC) allowed the commercial use of the UWB applications with restrict power limitations, thus new technologies were used. Further, industrial standards such as IEEE 802.15.3a (high data rates) and IEEE 802.15.4a (low data rates) based on UWB technology have been introduced.

In ad-hoc networks, nodes can communicate through a wireless channel without any existing network infrastructure. Communications are established directly between nodes or through intermediate nodes acting as routers. Therefore, a routing protocol is needed. A lot of work has been done for evaluating the performance of various routing protocols in different scenarios using IEEE 802.11, but there is still scope for IEEE 802.15.4a which is based on UWB technology. In our thesis, we have evaluated performances of the most widely used routing protocols namely AODV, DSDV, and DSR in addition to the static routing protocol NOAH using Network Simulator NS-2.
Chapter 1

UWB BACKGROUND
1 UWB BACKGROUND

1.1 INTRODUCTION

In this chapter the basic properties of UWB signals and systems are outlined. We will present the Federal Communication Commission (FCC) regulations and the IEEE standardization. In addition, we will discuss in details each of the key benefits of UWB, which make it attractive for consumer communication applications.

1.2 ULTRA WIDEBAND

1.2.1 Historical overview

The UWB has always denoted waveforms without carriers, which means impulse signals with duration in the order of a nanosecond. Firstly, UWB was basically used in radar systems. GPR was the first commercial success of the UWB system. One of its uses at that time was the detection of mines buried underground. It's in the 1989 that the UWB term was used for the first time in the American defense (DoD). Since that, until 2002, the UWB denotes mainly what we call impulse radio (IR) [1]. Later on, when the FCC issued a report allowing the commercial and unlicensed deployment of UWB with a given spectral mask, a substantial change occurred.

1.2.2 Regulations

Since UWB radio uses part of the spectrum, regulations must be set for having good spectrum management based on coexistence mechanisms instead of using conventional frequency sharing mechanisms. Regulations may differ between countries depending on existing technologies that occupy the spectrum.
This section introduces UWB regulations elaborated by the FCC (Federal Communication Commission) in the United States. The FCC is the organization that sets rules for the spectral usage. It has launched studies on UWB since 1998 and, in February 2002, regulations for UWB emissions were published in the "First Report and Order".

UWB signals are characterized by being extremely short pulses that have a very broad spectrum and very small energy content. This is the “traditional” way of emitting an UWB signal and goes under the name of Impulse Radio technique. As the radio frequency spectrum getting more crowded, UWB may interfere with existing communication and mobile systems. Among these systems we mention the GSM that has a bandwidth of 900 MHZ, and the GPS systems working at low levels of reception in a bandwidth of 1.2 - 1.5 GHz. For avoiding interference problems, the FCC approved a spectral mask from 3.1 to 10.6 GHz for operation of UWB devices for both indoor and outdoor masks, and assigned the Effective Isotropic Radiated Power (EIRP) allowed for each frequency band with a maximum set to -41.3 dBm/MHz as it is shown in Figure 1.1(a) and Figure 1.1(b) respectively [2] (“EIRP is the product of the power supplied to the antenna and the antenna gain in a given direction relative to an isotropic antenna”[3]).

For the indoor and outdoor spectral masks, the frequency range between 3.1 and 10.6 GHz has the same power spectral density. While between 1.6 and 3.1 GHz the outdoor radiation limits are 10dB below the indoor mask due to the pressure from some groups representing existing services [1].

According to the “First Report and Order”, any signal occupying a bandwidth greater than 500 MHz or having a fractional bandwidth larger than 0.2 is considered UWB. Fractional bandwidth is used to classify signals as a narrow band, wideband or ultra wideband. The fractional bandwidth is defined as the ratio of signal bandwidth to the center frequency. It can be determined using the expression 1.1
$$B_{f} = \frac{BW}{f_c} = \frac{2f_H - f_L}{f_H + f_L}$$

1.1

where $f_H$ and $f_L$ are respectively the upper and lower boundary [3].

![Figure 1.1: (a) The FCC spectral indoor mask (b) The FCC spectral outdoor mask [1]](image)

UWB is a technology that, respecting the FCC rules and regulations, can coexist in the same band with other existing technologies.

### 1.3 IEEE STANDARDIZATION

IEEE 802.15, a standardization of Bluetooth wireless specification defined by IEEE, is for wireless personal area networks (WPANs). IEEE 802.15 has characters such as short-range, low power, low cost, small networks and communication of devices within a Personal Operating Space. Between 2001 and 2002, IEEE launched two working groups: the IEEE 802.15.3a to be used for high data rate at short range applications, and the IEEE 802.15.4a aimed at communications with high precision ranging from an ultra low power.

#### 1.3.1 IEEE 802.15.3a

The IEEE 802.15.3a Study Group established in 2001 to define a new physical layer concept in order to serve companies’ requirements wishing to...
deploy high data rate applications, as video, imaging, and multimedia applications with a minimum data rate of 110Mbps at a short range of 10 meters. IEEE 802.15.3a was not specifically made to be an UWB standard group, but the best candidate for a new alternative was the UWB technology. The purpose of this study group was to provide a higher speed physical layer. At the same time, it should coexist with all existing 802.15 physical layer standards with a robust multipath performance [3, 4].

1.3.2 IEEE 802.15.4a

The IEEE 802.15.4 provides a framework for low data rate communication systems. In November 2002, the IEEE 802.15.4a task group was formed to investigate a UWB alternative physical layer to the 802.15.4 WPAN (Wide Personal Area Network) standard [5].

The main interest in developing the 802.15.4a compatible UWB impulse radio is to give scalability to data rates, longer range, high precision ranging and location capability, and low power consumption and cost [3].

1.4 KEY BENEFITS OF UWB

Characteristics of UWB lead the technology to have a great potential and open the door for new wireless applications that couldn’t be implemented until now. UWB has a number of advantages that make it attractive in communication applications.

1.4.1 Capacity

One of the biggest advantages of UWB is its high data rate. Hundreds of Mbps can be offered for a communication link. Comparing to current wireless and wired standards, UWB data rates are much higher. It can achieve 480Mbps and more for a transmission distance less than 1 m. A sample way to understand the
high capacity is in looking to the Shannon’s capacity equation, presented in expression 1.2

\[ C = B \log_2 (1 + \text{SNR}) \tag{1.2} \]

where \( C \) is the maximum channel capacity, \( B \) is the channel bandwidth, and \( \text{SNR} \) is the signal-to-noise ratio. To improve the channel capacity, we can increase the bandwidth, increase the signal power or decrease the noise. Since UWB has a large bandwidth, it can trade off some of the bandwidth to reduce signal power and interference with other sources [2, 3].

### 1.4.2 Power spectral density (PSD)

Energy is an important factor, especially for consumer of electronic devices. When the energy to be delivered is fixed, we can reach a low spectral density if it is transmitted on a large bandwidth instead of a small one [3]. In previous years, wireless communications have used a narrow bandwidth. For this reason they had a high spectral density. Since UWB has a very wide bandwidth, low PSD is achieved. This result can be seen in expression 1.3

\[ \text{PSD} = \frac{P}{B} \tag{1.3} \]

where \( P \) is the power transmitted in Watts (W), \( B \) is the bandwidth of the signal in Hertz (Hz), and the unit of PSD is in Watts / Hertz.

The low probability of detection caused by the low spectral density makes UWB efficient for secure and military applications.

### 1.4.3 Material penetration characteristics

UWB signals are characterized by their ability to penetrate walls. For earlier UWB systems, frequency components were mostly centered on 1 GHz. As the frequency decreases, the length of the UWB wave became much longer than
the wave length of the material that is passing through. But after 2002 and the new ruling of the FCC, the center frequency of UWB system increased, therefore the penetration characteristic of the signal has substantially decreased.

Expression 1.4 shows the relation between the wave length and the frequency.

$$\lambda = \frac{C}{f}$$  \hspace{1cm} 1.4

where $\lambda$ is the wave length in [m], $C$ is the speed of light in [m/s], and $f$ is the frequency in [Hz].

Propagation in indoor environments can take advantage of these situations due to several attenuations caused by obstacles that may be between the transmitter and the receiver [1, 6].

1.4.4 Pulse shape

In single band UWB or IR-UWB (described in Section 2.2), pulse width is very narrow, typically in a nanosecond.

This short duration of transmitted pulses provides a multipath immunity. Due to the different lengths of paths between the receiver and the transmitter, pulses will arrive at different times. Since used pulses are very narrow, it’s very difficult for a pulse to arrive within a pulse width. Therefore, if two pulses arrive separated by one pulse width, they will not interfere so they can be filtered or ignored in time domain.

Besides, IR-UWB signals can propagate without the need of a carrier and don’t require any Radio Frequency mixing stage. Unlike in conventional narrowband systems, pulses are injected into a carrier frequency. Consequently, low receiver equipments are used, thus reducing costs [3, 4].
1.4.5 Spatial Capacities

According to expression 1.5, UWB has a high spatial capacity. This means that the ratio between the maximum data rate and the transmission area is high comparing to other wireless communication systems.

\[
\text{Spatial capacity} = \frac{\text{Maximum data rate}}{\text{Transmission area}} \tag{1.5}
\]

where spatial capacity in [bps/m²], maximum data rate in [bps], and transmission area in [m²] where the transmission area is a circular area assuming a transmitter in the center [6].

Therefore, those characteristics and specially the very low power spectral density and the wide bandwidth make UWB communication almost recognizable as ground noise to other wireless communication systems.

1.5 SUMMARY

In this chapter, the basic characteristics of UWB were presented, starting with the essential regulations made by the FCC. The output power and spectrum are limited for indoor and outdoor systems. In addition, we have presented the two working groups, IEEE 802.15.3a and IEEE 802.15.4a.

We showed that because of the large bandwidth, UWB systems can achieve a high data rate and a low spectral density. Also, we explained the penetration characteristics provided by low frequencies. Since IR-UWB systems have short pulses, they can be filtered and unwanted multipath reflections can be ignored. This gives UWB systems a multipath immunity.
We also showed that UWB short pulses don’t need to be injected on a carrier frequency, thus removing complex components at the transmitter and the receiver.

Early implementation of UWB communication systems was based on transmitting and receiving short duration pulses. After 2002 and the new ruling of the FCC, new technologies are used and UWB shifts from the concept of single-band based on Impulse radio that occupy the whole allocated spectrum to the multi-band approach where the available UWB spectrum is divided into several sub-bands. Chapter 2 shows the basics of these two concepts.
Chapter 2

UWB TECHNOLOGIES AND TECHNIQUES
2 UWB TECHNOLOGIES AND TECHNIQUES

2.1 INTRODUCTION

This chapter presents UWB technologies with a comparison of different used techniques. The two most important UWB technologies that are being studied are Impulse Radio (IR), belonging to single-band category and Multi-band Orthogonal Frequency Division Multiplexing (MB-OFDM), belonging to multi-band one. IR encloses Direct Sequence Ultra-Wideband (DS-UWB) and Time Hopping Ultra-Wideband (TH-UWB).

This chapter also describes different pulse modulation techniques used in UWB. Pulse-Position Modulation (PPM), Bi-Phase Modulation (BPM), Pulse Amplitude Modulation (PAM) and On-Off Keying (OOK) are some of those techniques.

We will begin with the traditional impulse radio UWB and then move to the multiband UWB systems.

2.2 SINGLE BAND UWB

Single band UWB or Impulse Radio UWB (IR-UWB) is based on continuous transmission of extremely short pulses. Pulses used occupy an ultra wide spectrum in frequency domain with at least 500 MHz of bandwidth and don’t require the use of an additional carrier.

Usually Gaussian pulse is used in IR-UWB systems because it can be easily generated by pulse generators [1]. It is just a square pulse having the edges smoothed off. However, Gaussian doublet illustrated in Figure 2.1 is the most frequently used in IR-UWB. It is generated by a fast switching on and off that
leads to a Gaussian-like pulse (expressed in equation 2.1), then by applying two simultaneous derivatives yields:

\[ G(x) = \frac{A}{\sqrt{2\pi\sigma}} e^{-x^2/2\sigma^2} \]  

2.1

where A is the amplitude of the Gaussian pulse with a zero mean and \( \sigma^2 \) variance.

![Figure 2.1: UWB pulse shape [1]](image)

While Gaussian doublet is the typical UWB pulse shape, higher derivatives of Gaussian shape can be used. The aim in the pulse shape is to obtain a pulse waveform that meets the FCC emission limits, and maximizes the bandwidth. Infinite waveforms can be obtained by differentiating the original Gaussian pulse.

However, information cannot be sent in a single pulse, so data information is modulated into a sequence of pulses called pulse train, as illustrated in Figure 2.2(a).
When pulses are sent into regular intervals, unfortunately the peaks of power may limit the total transmit power due to the periodicity of transmitted pulses. These peaks appeared in locations which are the multiples of the inverse of pulses repetition interval. They are called “comb lines” shown in Figure 2.2(b) and they are unwanted since they go above the FCC limits and may interfere with other communication systems [1, 3]. The problem is resolved by “dithering” the signal or adding a small random offset or by delaying the transmission of each pulse to break the periodicity.

2.2.1 Modulation techniques

Many modulation techniques can be applied for impulse radio UWB systems. Pulse-Position Modulation (PPM), Bi-Phase Modulation (BPM), Pulse Amplitude Modulation (PAM) and On-Off Keying (OOK) are some of the most used techniques to modulate UWB pulses [2, 7].

2.2.1.1 PPM Modulation

PPM is the mostly used modulation technique used in single band approach. Pulse Position Modulation is a modulation where pulses have uniform height and width but are displaced in time.
By a simple shift in time, a binary communication can be established. Moreover, with \( M \) different delays a \( M \)-ary transmission can be done. Figure 2.3 shows an example of binary and \( M \)-ary PPM modulation.

![Figure 2.3: (a) Time representation of \( M \)-ary PPM modulation (b) Time representation of transmission bits “1” and “0” using the binary PPM modulation [2]](image)

2.2.1.1 BPM Modulation

Bi-Phase Modulation (BPM) is modulation of the pulse polarity where changes in the polarity represent the transmitting data.

2.2.1.2 PAM Modulation

Pulse Amplitude Modulation is a technique where the information is encoded in the amplitude of pulses. In binary PAM, bit “1” and “0” correspond to different amplitude values.
2.2.1.3 OOK Modulation

On-Off Keying (OOK) modulation is the simplest form of pulse modulation, in which the absence of a pulse represents a data bit “0” and its presence represents a data bit “1”.

2.2.1.4 PPM-PAM Modulation

A simple combination between PPM and PAM (PPM-PAM) can be considered for modulating UWB pulses, as presented in Figure 2.4.

![Figure 2.4: Time representation of transmission of bits “00”, “01”, “10”, “11” using the combination of binary PPM-PAM modulations [2]](image)

In Figure 2.4, we notice that the data is modulated in the amplitude as well as in the delay of the UWB pulses. For each transmitted symbol “00”, “01”,…, the odd bit represents a shift in time that account for the PPM modulation. The even bit of each symbol represents the pulse amplitude and account for the PAM modulation. For example, the odd bit “1” is represented by a shift in time, while the even bit “1” is represented by positive amplitude.
2.2.1.5 Comparison of UWB modulations

The most common Impulse Radio UWB modulation techniques are PPM and BPM. The main advantages of PPM modulation occur from its simplicity and from the ease with which the delay may be controlled. On the other hand, it is important to take into consideration the synchronization between the receiver and the transmitter, in addition to the large spectral peaks created. As well, simplicity and efficiency are the main advantages of BPM modulation. Unlikely, it is just used in binary communications.

No serious attempt has been made to use either PAM or OOK modulations for UWB. In OOK, the major difficulty is to detect the absence of a pulse in the presence of multipath. On the other hand, PAM has many disadvantages; “AM signal which has smaller amplitude is more affected to noise than that with larger amplitude. Furthermore, more power is required to transmit the higher amplitude pulse.” [2]

2.2.2 Enabling Multiple Access in Single Band UWB

In previous subsections, the described modulations do not provide multiple access capability. In order to achieve the multiple access, a randomization technique is applied to the transmitted signal. This randomization will minimize the interference by reducing spectral peaks.

Two important techniques for enabling multiple access in IR-UWB systems are studied: Time Hopping (TH) and Direct Sequence (DS) techniques. Both are used for low and high data rate UWB.

DS-UWB and TH-UWB may be considered to be similar to the well-known narrowband Direct Sequence Spread Spectrum (DSSS) and Time Hopping Spread Spectrum (THSS). Both technologies, UWB and spread spectrum take advantage of the expended bandwidth [2]. However in IR-UWB, the narrow UWB pulses are directly generated having an extremely large bandwidth, while in
conventional spread-spectrum sinusoidal signals are modulated with a carrier. In addition, the bandwidth for UWB signals has to be higher than 500 MHz, while for spread spectrum techniques much lower bandwidth is considered. Otherwise, the basic idea of both technologies is the same.

2.2.2.1  Time Hopping Ultra Wideband (TH-UWB)

Time Hopping Ultra Wideband (TH-UWB) is a random access spread spectrum technique. UWB pulses are transmitted having pseudo-random positions. TH-UWB can be combined with PAM, PPM, and PPM-PAM modulations.

Each data symbol is encoded by the transmission of multiple radio impulses shifted in time. To avoid collision of pulses, spread spectrum systems make use of a pseudorandom code generator. This code is referred to as periodic pseudorandom noise code (PN) [2]. It is used to determine the actual interval in which the output signal is transmitted. Each user is assigned by a code, thus UWB signals may be transmitted by multiple users without interference. Figure 2.5 shows an example of a binary PPM modulation for a specific user having “3 5 2 5 1” as pseudo random code.

![Figure 2.5: Example of transmission of bits “1 0 1 0 1” for a TH code of “3 5 2 5 1” using 2-PPM modulation [2]](image-url)
2.2.2.2 Direct Sequence Ultra Wideband (DS-UWB)

Direct Sequence Ultra Wideband is a single band technique based on the transmission and reception of short pulses. Many users can share the same spectrum without interfering by using orthogonal codes based on CDMA technique. Each user is assigned a different code. DS-UWB signals can be modulated using PAM, OOK or PPM-PAM modulations.

To achieve more efficiency, DS-UWB supports operations in two different bands: a low band of 1.75 GHz occupying the spectrum from 3.1 to 4.85 GHz and a high band of 3.5 GHz occupying the spectrum from 6.2 to 9.7 GHz (see Figure 2.6). Due to the possible interference from 802.11.a WLAN, the frequency range between 5 GHz and 6 GHz is avoided [2]. Both two bands can be used simultaneously or separately.

![Figure 2.6: The DS-UWB spectrum [2]](image-url)
2.2.3 Common and private acquisition preamble in IR-UWB [8, 9]

Correct packet reception in low data rate IR-UWB networks is an important issue because of the absence of global synchronization. Packet detection and timing acquisition are the first steps to a correct reception. Before determining exactly when the payload begins, first the destination must detect the packet on the medium. For this reason, a preamble is introduced at the beginning of each packet as illustrated in Figure 2.7 where time $t_0$ is the time to start decoding.

![Figure 2.7: Packet format in IR-UWB [10]](image)

Packet detection and timing acquisition for IR-UWB networks rely on the presence of an acquisition preamble (Time Hopping sequence THS) at the beginning of each packet. The way of choosing this preamble has an impact on the network performance. Two design choices of the acquisition preamble in the IR-UWB networks are possible: a common acquisition preamble for the whole network or an acquisition preamble that is private to each destination. Figure 2.8(a) shows that all destinations share a common acquisition preamble and Figure 2.8(b) shows that each destination has its own acquisition preamble.

![Figure 2.8: (a) Common acquisition preamble  (b) Private acquisition preamble [10]](image)
In private acquisition preamble, a source derives the acquisition preamble of sent packets from the MAC (Medium Access Control) address of the destination.

During time acquisition and when common acquisition preamble is used, a packet might contend with all sources that are transmitting in the whole network. In contrast, with a private acquisition preamble the contention is reduced to packets transmitted to the same destination. Hence, a network using a private acquisition preambles achieve higher throughput than a network with a common acquisition preamble. However, using private acquisition preambles require additional complexity to learn the acquisition preamble of the destination.

2.2.4 Interference in IR-UWB networks

“IR-UWB systems are subject to impulsive, non-Gaussian interference created by the system itself, or by other similar systems” [11].

In IR-UWB, pulse collisions between parallel transmitting sources are the main source of impulsive interference. In IR-UWB networks as in other networks, multi-user interference (MUI) occurs and consequently has to be dealt with to avoid its effect on the system [12]. In fact two or more IR-UWB systems that are not controlled by the same network may interfere between them causing pulse collisions. Even when nodes from different piconets have different THSs, thus those THSs are not orthogonal and collisions are not completely avoided. Still when THSs are orthogonal, a high synchronization should be maintained between all nodes from different piconets to prevent interference.

On the other hand, multipath propagation increases the probability of pulse collisions especially in indoor applications. In addition when the number of users transmitting simultaneously increases, the performance can be significantly affected even if the system has a low duty-cycle.
Finally, near-far effect is an important factor concerning interference. “It is a factor when a strong pulse and a weak pulse happen to collide” [11]. The power spectral density is no longer constant. The strong pulse will have much higher power than the weak one. For this reason it is important to ensure that high power signals do not pre-dominate other signals. Therefore, the near-far problem is solved by controlling the transmission power so received signals will have similar amplitudes. This process is known as power control. However, this is not well efficient in case when many piconets are completely uncontrolled.

2.3 MULTI-BAND APPROACH

Multi-band (MB) approach was first proposed to be used in IEEE 802.15.3a (high data rate). The idea behind MB-approach is that transmission of multiple signals at the same time is achieved by dividing the spectrum into multiple frequency bands that doesn’t overlap. Signals operating at different frequencies do not interfere among themselves [1]. In multiband UWB, pulses are modulated by carriers and transmitted through sub-bands of approximately 500 MHz bandwidth.

One advantage of using the multi-band UWB is the ability to utilize the entire spectrum available to UWB systems (7.5 GHz) with the use of appropriate multi-band widths. Multi-band Orthogonal Frequency Division Multiplexing (MB-OFDM) is one of the multi-band approaches.
2.3.1 Multiband Orthogonal Frequency Division Multiplexing (MB-OFDM)

MB-OFDM is based on multi-band and multi-carrier approach. The spectrum of UWB between 3.1 and 7.5 GHz is divided into 14 bands, each with 528 MHz bandwidth. OFDM modulation is used to transmit the information in each sub-band. The information is then interleaved across sub-bands and transmitted through multi-carrier (OFDM) techniques.

As the bandwidth is divided into sub-bands, and to avoid interference with other systems, sub-bands may be added or dropped. Figure 2.10 shows that the UWB spectrum is divided into 13 bands, where band between 5 and 6 GHz is not utilized to avoid interference with the existing IEEE 802.11a signals. For standard operation, the three lower bands are used, which is mandatory. The rest of the bands are allocated for optional use or future expansions [1,2].

Within each sub-band, information is transmitted using OFDM modulation. For differentiating between multiple users, MB-OFDM uses a time-frequency codes (TFC). “They provide a different carrier frequency at each time slot, corresponding to one of the center frequency of different sub-bands” [13].

![Figure 2.10: Proposed MB-OFDM frequency band plan [1]](image-url)
2.4 SUMMARY

In this chapter, the most important UWB technologies were presented: the Impulse Radio and MB-OFDM. IR-UWB is based on single band approach and MB-OFDM is based on multi-band approach.

IR-UWB encloses Direct Sequence and Time Hopping techniques. Many modulation techniques can be used, thus M-ary PPM and PAM modulations are the most used. For time acquisition and packet detection, two choices are available: a private or common acquisition preamble. Furthermore, interference, collision and near-far effect were presented. Then we showed the principle of MB-OFDM.

After presenting the major UWB modulation techniques and technologies, it is important to present our work. But before getting into details, we will discuss the network simulator used for our project and the different routing protocols applied in our simulations.
Chapter 3

ROUTING PROTOCOLS AND
NS SIMULATOR
3 ROUTING PROTOCOLS AND NS SIMULATOR

3.1 INTRODUCTION

Networks based on wireless technology allow users to access information and services via interconnections between nodes without the use of wires. There are two types of wireless networks. The first is the centralized network in which each mobile is connected to one or more fixed base stations. The second is the decentralized based on ad-hoc network. In this thesis, we are concerned with ad-hoc networks.

Ad-hoc networks are wireless networks where nodes don’t require any pre-existing infrastructure support for transferring data. All nodes behave as a router to forward packets to each other [14]. For this purpose a routing protocol is needed. Figure 3.1 shows an example of an ad-hoc network.

![Figure 3.1: Ad-hoc network [15]](image)

Therefore, routing protocols used in fixed networks do not have the same performance in ad-hoc networks where we have dynamic and random changing topology. For that reason, new routing protocols have been developed to maintain connections between nodes. Ad-hoc routing protocols are classified in many important categories:
Proactive Gateway Discovery: Each node in the network has to establish a route to every other node in the network all the time regardless of whether or not these routes are needed. Routes are calculated before one is needed [16]. The main advantage of proactive approach is that the route to any node is instantly founded in the route table. However, if the number of nodes increases, the routing table for each node increases in size. Proactive approach is not efficient for large networks.

Reactive Gateway Discovery: Reactive approach, known as on-demand routing, overcomes the disadvantages of proactive routing. Here the route is established as and when required. The source dynamically checks the route table when it wants to send to a specific destination [17].

So far, many routing protocols have been proposed. The most popular ones are the Ad-hoc on-demand distance vector (AODV), Destination-Sequenced Distance-Vector Routing protocol (DSDV), Dynamic Source Routing protocol (DSR), and the static protocol No Ad-hoc (NOAH) [18].

3.2 WIRELESS AD-HOC ROUTING PROTOCOLS

3.2.1 Destination-Sequenced Distance Vector (DSDV)

The DSDV is illustrated as a proactive protocol. Each node has a routing table that indicates the next hop and number of hops to the destination, in addition to a sequence number to tag each route. In case of two equal sequence numbers, the one with lower metric is the favorable. And in case of having two routes, the one with a higher sequence number is more favorable. As we have a varying topology, each node broadcasts periodically routing table updates [14, 17].

3.2.2 Ad-hoc On-Demand Distance Vector Routing (AODV)

AODV is a reactive routing protocol. Therefore, routes are determined only when needed; it reduces the number of broadcast. It uses routing table and
one entry per destination. As long as the communication connection between source and destination has valid routes, AODV does not play any role. Routes that are not used for a long time are deleted from the routing table. Also AODV uses sequence numbers to ensure loop freedom and to keep the freshness route to a destination. To discover the link, the protocol utilizes different messages: RREQ (route request), RREP (route reply), and RERR (route error).

When a node wants to discover a route to a destination, it sends a RREQ to all nodes, until the destination is reached or a neighbor node finds a fresh route to the destination. Then a RREP is sent back to the source and the route becomes available. Nodes are notified with RERR packets when it detects that a route for a neighbor node is not valid and the routing entry is removed.

An advantage of AODV is the routing overhead. It is relatively small compared to proactive protocols in high density networks. However, the delay in establishing a route could reduce the network throughput especially when we have high traffic or quick moving nodes [14, 17].

### 3.2.3 Dynamic Source Routing (DSR)

Dynamic Source Routing is a reactive protocol. In dynamic source routing each node has a cache where the routes are stored. This allows multiple route entries to be maintained per destination. Every sender knows the path to the destination. The data packets carry the source route in the packet header. The protocol is based on two concepts: route discovery and route maintenance. When a source is requesting to send a packet to a destination, it broadcasts a route request RREQ. If it is not received by the destination or either no node has a route

![Figure 3.2: RREQ, RREP and RERR messages][18]
to the destination in its cache, each node has to rebroadcast a RREQ packet. A RREP is sent back to the source where the route is stored in the cache for future use. If any link on the route is broken, the source node is notified by RERR packet and the source removes any link using this route from its cache [14].

![RREQ and RREP messages](image)

**Figure 3.3: RREQ and RREP messages [18]**

Once a route is discovered and placed in the route cache, it remains there until it breaks because DSR’s route cache entries have no lifetimes so all routing information are carried in the packet headers. For this reason, DSR performance decreases in large networks.

### 3.2.4 No Ad-hoc Routing Agent (NOAH)

No Ad-hoc Routing Agent (NOAH) is a static routing. It supports only direct communications between wireless nodes. Routes are manually entered into the routing table by a network administrator or by loading a pre-defined configuration file. It is a simple form of routing. As routes remain unchanged after they are configured, it is not recommended to be used in topologies where routing information has to be changed frequently. In case of failure or down connections, route must be reconfigured manually to overcome any loss in connectivity. NOAH does not send any routing packets [19]. In general, NOAH is used in scenarios where multi-hop wireless routing is undesired.

To evaluate different routing protocols in order to choose the best, a network simulator should be used.
3.3 NETWORK SIMULATOR

A network simulator is used to study the behavior of a network without the real presence of an actual network. Nowadays, there are many network simulators that can simulate the MANET. In this section, we will introduce the Network Simulator NS-2 to conduct simulations in our thesis because firstly NS-2 is an open source free software; it can be easily downloaded and installed. Also the programming language C++ is compatible with NS-2 [20].

3.3.1 Network Simulator NS-2

Network simulator (Version 2), known as NS2 is an object oriented, and a discrete event simulator used for studying different communication networks. It is often used for simulating TCP/IP networks. NS2 has the capability to simulate wired as well as wireless network functions and test large scale networks and new routing protocols that it is difficult to be deployed and tested in real world. It also supports simulation of TCP and UDP transmission protocols.

The code of NS2 is written in C++ to speed up the execution. The user interface is based on Object Oriented Tool Command Language (OTcl) script which is easy in use and in writing simulation scenarios [20]. When a topology is created with different objects, the configuration is passed to “ns” in a file written in the OTcl language. The OTcl interpreter located in “ns” translates the commands to their equivalence in C++.

![Figure 3.4: Simplified User's View of NS [21]](image)
NS-2 can generate trace information for: Agent, routing protocols, Mac layer and Movement mobiles. The analysis of trace files is used to generate graphs and tables showing results of simulations. We have two methods to analyze the simulation results: by removing the values listed in the file trace.tr and plotting graphs (using Matlab or Excel) or by using the ns capability of converting the trace file into xgraph format (xgraph is a tool that allows to plot the results of the simulation in the form of curves) [22]. To extract information from trace file, script in awk is needed to be written. The awk allows applying operations on data files to obtain different parameters and functions such as calculating average throughput, end-to-end delay, summing … AWK code can be written in a command line or in a file.

In addition, NS-2 contains a simulation tool called the network animator (nam). “Nam is a Tcl/TK based animation tool for viewing network simulation traces and real world packet trace data” [22]. Before generating nam, the trace file containing the topology information, nodes, links, packet traces should be created. After generating this file by ns, it is ready to be animated by nam.

### 3.4 SUMMARY

Mobile Ad hoc networks are wireless networks, where there is no need to any infrastructure support for transferring data packets between nodes. Network nodes work as routers. For this purpose, a routing protocol is needed. In fact, to study the performance of different routing protocols, a network simulator can be used. For our thesis, DSDV, AODV, DSR, and NOAH were used as routing protocols to be simulated in NS-2 simulator.

In next chapters, we will present the results of our simulations. Performance evaluations are based on two different scenarios. Many performance metrics were studied. Figures and results have been shown and analyzed.
Chapter 4

LINE SCENARIO

SIMULATION AND ANALYSIS
4 LINE SCENARIO SIMULATION AND ANALYSIS

4.1 INTRODUCTION

Ultra Wideband transmission technique is supposed to be a promising candidate for fixed and mobile ad-hoc networks in short range scenarios. Ad-hoc networks, considered as multi-hop networks, require routing protocol to establish connections between nodes. Our purpose is to study the performance analysis by simulation of a wireless system associated with UWB. For this reason, we present a performance evaluation of different routing protocols considering realistic ad-hoc network scenarios.

4.2 NS-2 PARAMETERS

The evaluation is accomplished through simulations using NS-2 version ns-allinone-2.29.3 running under Cygwin (a Linux-like environment for Windows) and an extension of low-rate IR-UWB which is available in [23]. The IR-UWB is based on the Time-Hopping Impulse-Radio technique. The MAC layer protocol is the DCC-MAC which is used to combat the effect of the strong impulsive interference. The propagation model used is Tarokh. The physical layer utilized is the 802.15.4a physical layer with a bit rate of 1 Mbit/s. The transmission range of the IR-UWB is in the order of 50 meters because of the low transmission power which is 0.28 mW. The center frequency is set to 4 GHz with a bandwidth of 1 GHz.
4.3 SIMULATIONS

For our performance evaluation we considered one proactive protocol, the Destination-Sequence Distance Vector (DSDV), two On-Demand routing protocols (Reactive) namely Ad-hoc On-Demand Distance Vector Routing (AODV) and Dynamic Source Routing (DSR) as well a static routing protocol No Ad-hoc (NOAH). For the ad-hoc networks we considered two realistic scenarios: one that can be implemented as an industrial indoor application denoting a production line in a factory represented in NS-2 by a line of nodes, and another scenario standing for a random mobile ad-hoc network used in many applications such as Wireless Sensor Networks (WSNs) applications. In this chapter we will present the line scenario.

4.4 LINE OF NODES TOPOLOGY

In this scenario, the topology consists of a line of \( n \) equidistant nodes (Figure 4.1(a)). The distance between neighboring nodes is \( d \) meters. In Figure 4.1(b) we can see an example of a line topology visualized in NAM where the sender and the receiver are placed at each extremity of the line.

![Diagram of Line Topology](image)

**Figure 4.1:** (a) Line topology (b) Example of line topology visualized in NAM
For this topology we will show the influence of the link distance (the distance between two adjacent nodes) on the received throughput for different numbers of nodes per line and for the two different types of preamble. Finally we will study the performance of different routing protocols based on different metrics for the two transport protocols TCP and UDP.

### 4.4.1 Test 1: Influence of the type of acquisition preamble

As was presented in chapter 2, the choice of acquisition preamble affects the received throughput of the network where the received throughput is the amount of data transferred over a period of time expressed in Kbit/s. For this reason, we will study the performance of an IR-UWB network using private acquisition preambles with a network using common acquisition preamble.

Therefore we choose different link distances between adjacent nodes. The link distances took the following values: 1, 10, 20, 30, 40, and 50 m. For each of these distances, the received throughput was drawn as a function of nodes number for both common and private acquisition preambles. Nodes number varies from 2 to 30 nodes per line. So, 108 simulations were performed.

For the private acquisition preamble, simulations were run five times for a duration of 210 seconds and their average was used. On the other hand, for the common acquisition preamble, more simulations are needed to obtain reasonable curves. The transport protocol is TCP with an FTP traffic generator having a packet size of 1000 bytes. Only the static routing protocol NOAH is considered in this case. To note that TCP and NOAH were chosen just to show the performance of the IR-UWB network for both common and private acquisition preamble. And later on, detailed studies are made for the line topology with different routing protocols using both TCP and UDP.

The performance metric used is the throughput. **Figure 4.2** and **Figure 4.3** show the throughput as function of nodes number for different link distances.
mentioned above for both common and private acquisition preambles. Figure 4.2 is considered for short link distances (1, 10 and 20m) while Figure 4.3 for long link distances (30, 40 and 50m).

**Figure 4.2**: Line scenario: throughput versus number of nodes for link distances 1, 10 and 20 m
For the three plots where link distances are relatively short (1, 10, and 20 m), we observe a big difference between the received throughput achieved by common acquisition preamble and the one achieved by private acquisition preambles. For more than 5 nodes, a stable throughput of approximately 70 Kbit/s is achieved using private acquisition preambles. In common acquisition preamble we observe a fast throughput reduction. For more than 6 nodes, the throughput reaches zero for some simulation runs. And in the case of 15 nodes, the network does not function at all.

As a conclusion, for relatively short link distances, a network with private acquisition preambles holds a higher throughput than a network with a common acquisition preamble.

For long link distances (30, 40, and 50 m) which are presented in Figure 4.3, the difference between the throughputs achieved by both acquisition preambles became very small. This result is due to the large link distance between nodes which eliminates the interference effect between them.

As conclusion when the common acquisition preamble is not affected by the internal interference between nodes, it performs like the private preamble. This shows that common preamble is bad in networks where there is a big interference. But it would perform better in lower density networks where we have negligible interference between nodes.
4.4.2 Test 2: Impact of the link distance

In this section, we evaluate the performance of an IR-UWB line network with the variation of the distance between adjacent nodes on the line. The link distance is varied from 1 to 50 m with 1 meter step increment. This evaluation is done for several numbers of nodes, where the values 2, 3, 5, 11, and 17 nodes are chosen. For this case we have 50x5 = 250 simulations, each one was run five times for duration of 210 seconds and their average was used. Note that the length

After this test, and based on the obtained results, in all our next scenarios private acquisition preamble is used to achieve better throughput.

Figure 4.3: Line scenario: throughput versus number of nodes for link distances 30, 40 and 50 m
of the line is equal to the distance between adjacent nodes times the number of nodes per line - 1.

\[
\text{Length of the line [m]} = \text{Distance between nodes} \times (\text{Number of nodes per line} - 1)
\]

To show the influence of the link distance, we choose the static routing protocol NOAH, the transport protocol TCP with an FTP traffic generator with a packet size of 1000 bytes and a private acquisition preamble. Figure 4.4 shows the variation of the received throughput as a function of the link distance for different nodes number.

![Graph showing the variation of the received throughput as a function of the link distance for different nodes number.](image)

**Figure 4.4:** Received throughput versus the link distance for five different node numbers 2, 3, 5, 11 and 17

For a fixed number of nodes, when the link distance increases, the received power at the destination decreases, causing a degradation in the throughput. This is clear in Figure 4.4 where the throughput is strongly reduced when the distance between nodes increases, to reach zero at a link distance higher than 50 m. Moreover, in case of 2 nodes per line, we notice that the throughput is higher than the throughputs of other cases. This is due to the fact that for 2 nodes, direct communication is established between the source and the destination, and there is no need to multi-hop between nodes. This justifies the higher and the big
difference in throughput comparing with other cases. To note that this difference becomes smaller as distance between nodes increases.

4.4.3 Test 3- Influence of routing protocols

In this section we present a performance evaluation between static routing protocol based on (NOAH), and dynamic routing protocols namely, On-Demand Distance Vector Routing protocol (AODV), Dynamic Source Routing protocol (DSR), and Destination-Sequenced Distance Vector routing protocol (DSDV) considering the line ad hoc network scenario.

The link distance is varied to take the values 1, 5, 10, and 30 m. For each of these values, the nodes number in the line is varied between 2 and 30 nodes (9 values are taken into consideration).

For our studies, we consider two transport protocols:

- Transmission Control Protocol (TCP) attached to a File Transfer Protocol (FTP) traffic generator used with a packet size of 1000 bytes.
- User Datagram Protocol (UDP). The traffic sources used are continuous bit rate (CBR) and 125 packets per second are sent with a packet size of 1000 bytes. The data rate is set to 1 Mbit/s.

As we have 4 different routing protocols and 4 link distances with 9 different values of nodes number varied between 2 and 30, thus 144 simulations were executed for each of the two transport protocols mentioned above and the collected data is averaged over 10 runs. To note that some simulations took 30 minutes when executed on a PC with a Pentium-4 CPU, especially in the case of higher number of nodes. Two important metrics were evaluated:
A. Received throughput (RTh): amount of data transferred over a period of time expressed in Kbit/s.

B. Packet delivery Ratio (PDR): the ratio between packets received and total packets sent.

4.4.3.1 Case 1: TCP transport protocol is used

A. Received throughput analysis

In this section our performance metric is the received throughput (RTh). Figure 4.5 shows the RTh as a function of the nodes number for different link distances taking the values 1, 5, 10, and 30 m. In each graph, the four routing protocols are plotted.
For link distance equal to 1 m, we can see that AODV and DSR perform better than NOAH because the transmission range of UWB is about 50 m, so the source can reach directly the destination without passing by intermediate nodes unlike the static protocol NOAH where routes are configured manually to pass by each node until reaching the destination. However, at higher number of nodes routing packets diffused by AODV and DSR increases because when a node wants to discover a route to a destination, it sends a route request to all nodes until the destination is reached or a neighbor node finds a fresh route to the destination.

Figure 4.5: Line scenario: throughput versus number of nodes applied with different routing protocols for link distances 1, 5, 10, and 30 m.
Therefore, less of the channel is used for data transfer and the throughput decreases. On the other hand in NOAH, we can observe that a stable throughput is reached for large number of nodes because the route is configured manually so no need to any routing control messages. For DSDV, we notice a fast throughput reduction to reach zero for more than 20 nodes. In addition to the routing packets diffused, in DSDV each node in the network establishes a route to every other node, so at higher number of nodes routing table for each node increases affecting the performance.

When link distances increases the throughput for all routing protocols decreases. The source node can’t reach the destination with a direct communication, so multi-hop is used and the performance of DSR and AODV decreases and NOAH becomes the leading protocol. At more than 5 to 10 nodes, the throughputs became approximately stable except for DSDV where at large number of nodes the throughput reaches zero. Figure 4.5 shows that NOAH performs better than all other protocols for large distances and for networks with large number of nodes. To note that AODV and DSR reach also an acceptable stable throughput compared to NOAH.

As conclusion, for small link distances AODV and DSR outperform NOAH. However, at higher number of nodes and large link distances NOAH is the leading protocol.

B. Packet delivery ratio analysis

In this part our performance metric is the packet delivery ratio (PDR) which is calculated at the transport protocol (end to end). Figure 4.6 shows the PDR as a function of the nodes number for the same link distances used for the throughput analyses. Also in each graph we show a comparison between the four routing protocols.
link distance = 1m

link distance = 5m

link distance = 10m
For very short link distances where a value of 1m is considered, AODV and DSR perform better than NOAH and DSDV. They deliver more than 95% data packets. However, NOAH’s performance is pretty good, it delivers about 80% data packets. For DSDV, it performs poorly as the nodes number increases and drops to 20% when nodes number is 30, because when using DSDV with large number of nodes, routing table for each node increases, as a result less and less of the channel will be used for data transfer, thus decreasing packet delivery.

As link distance increases the performance of NOAH and AODV became far superior compared to DSDV and DSR. We also observe a fast PDR reduction when using DSDV or DSR. However, a stable PDR is reached by NOAH and AODV by varying the number of nodes.

4.4.3.2 Case 2: UDP transport protocol is used

In this section the UDP transport protocol is used. The same parameters used for TCP protocol are taken into consideration and the same metrics RTh and PDR are studied for the different routing protocols.
A. Received throughput analysis

The four different link distances 1, 5, 10, and 30 m are used. Figure 4.7 shows the throughput as a function of nodes number for different link distances.
For a short link distance of 1 m, the static routing protocol NOAH is the worst, for the same reasons explained before in the TCP case where the source can’t reach the destination directly until passing through all intermediate nodes unlike other routing protocols.

At a higher link distances and large number of nodes it is evident that NOAH is the leading protocol. However, AODV and DSR achieve an acceptable stable throughput compared to NOAH. We also observe a very fast throughput reduction with DSDV to reach zero for more than 5 nodes, which justifies why DSDV is not efficient for large networks.

Comparing Figure 4.6 and Figure 4.7, we observe that routing protocols in both TCP and UDP cases have a comparable performance but with one major difference. For UDP, a higher throughput is achieved compared with TCP. For example if we take the case of a 1 m link distance with NOAH as routing protocol, we observe that we have a stable throughput at 200 Kbit/s in UDP while it’s 50 Kbit/s in the TCP case. For high link distances, the throughput in UDP is almost the double than in TCP.

Figure 4.7: Line scenario: throughput versus number of nodes applied with different routing protocols for link distances 1, 5, 10, and 30 m
B. Packet Delivery Ratio analysis

In this section we study the packet delivery ratio. Figure 4.8 shows the PDR as a function of nodes number for different link distances.
Looking at Figure 4.7 and Figure 4.8 we observe a relationship between the throughput and the packet delivery ratio curves.

Throughput = Received packets / simulation time;
Packet Delivery Ratio = Received packets / sent packets;

As Constant Bit Rate (CBR) is used, the number of sent packets is always constant for all simulations. For an interval of time the throughput will be equal to a constant multiplied by the Packet delivery ratio. This is shown in Figure 4.9.

*Throughput = Constant x Packet Delivery Ratio*

Figure 4.8: Line scenario: packet delivery ratio versus number of nodes applied with different routing protocols for link distances 1, 5, 10, and 30 m

Figure 4.9: Throughput and Packet Delivery Ratio relationship
Figure 4.9 shows the case of a 1 m link distance. The throughput achieved by AODV and DSR for low number of nodes is about 400 Kbit/s and 200 Kbit/s for NOAH. Or the packet delivery ratio is 40% for AODV and DSR and 20% for NOAH. It is clear from the figure that the curves for the packet delivery ratio and those for the throughput are proportional. Therefore, we can conclude from “4.4.3.2 A” that NOAH is the leading protocol for large link distances and for a big number of nodes. AODV and DSR have an acceptable stable packet delivery ratio, while in DSDV as number of nodes increases, the packet delivery ratio drops to less than 5% and reaches zero for long link distances.

As a result, the performance metrics used are not completely independent and they are proportional when CBR traffic is used, which let the throughput to vary linearly with the packet delivery ratio.

To finish, if we compare the packet delivery ratio between UDP and TCP, we observe that a lower packet delivery ratio is achieved in UDP. For example and as shown in Figure 4.10, for a link distance of 10 m and NOAH as routing protocol, when UDP is used we have a stable packet delivery ratio at 20% while it is more than 80% in the TCP case.

These results show that TCP is a reliable protocol because it guarantees packet delivery to the destination. In contrast, UDP is an “unreliable” protocol and there is no guarantee that the packets will be delivered to the destination host.
4.5 SUMMARY

Based on what we have evaluated, the performance of an IR-UWB network using a private acquisition preamble is better than a network using common acquisition preamble.

Also we have compared the three main ad-hoc routing protocols AODV, DSR and DSDV with the static routing protocol NOAH. A summary of the obtained results is presented in Table 4.1 and Table 4.2, where the outperformed routing protocols are shown in various cases.

**Table 4.1**

Results’ summary for the TCP case

<table>
<thead>
<tr>
<th>TCP</th>
<th>Short link distance d=1m</th>
<th>Long link distance d &gt;10m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Received Throughput</td>
<td>AODV-DSR</td>
<td>NOAH</td>
</tr>
<tr>
<td>Packet Delivery Ratio</td>
<td>AODV-DSR</td>
<td>NOAH</td>
</tr>
</tbody>
</table>

**Table 4.2**

Results’ summary for the UDP case

<table>
<thead>
<tr>
<th>UDP</th>
<th>Short link distance d=1m</th>
<th>Long link distance d &gt;10m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Received Throughput</td>
<td>AODV-DSR</td>
<td>NOAH</td>
</tr>
<tr>
<td></td>
<td>High nodes number &gt; 22:</td>
<td>NOAH</td>
</tr>
<tr>
<td>Packet Delivery Ratio</td>
<td>AODV-DSR</td>
<td>NOAH</td>
</tr>
<tr>
<td></td>
<td>High nodes number &gt; 22:</td>
<td>NOAH</td>
</tr>
</tbody>
</table>
Simulation results showed that NOAH outperforms all other protocols with long link distances for all performance metrics either using TCP or UDP. On the other hand, AODV and DSR perform better for short link distances and especially when low nodes number is used.

4.6 CONCLUSION

In this chapter, we compared the performance of different ad-hoc routing protocols which are AODV, DSR, DSDV and NOAH. We investigated two performance metrics: Packet Delivery Ratio (PDR) and Received throughput (RTh).

In the first part, we showed that networks using private acquisition preambles achieve higher throughput than networks using public acquisition preamble. Later on, we proved that when link distance between nodes increases, the throughput decreases, and at a link distance higher than 50 m the throughput reaches zero as the transmission range of UWB is about 50 m.

Then, for both transport protocols TCP and UDP, we showed that NOAH outperforms DSDV, AODV and DSR for large number of nodes and for large link distances. AODV and DSR have a good performance close to NOAH, while DSDV is the worst; its throughput decreases dramatically to reach zero in large networks and long distances. Comparing TCP with UDP, it is shown that delivery ratio is better in TCP than UDP caused by its natural reliability.

In the next chapter, we will expose the random mobile scenario. Performance comparison is done with regard to different parameters.
Chapter 5

MOBILE AD-HOC SCENARIO
SIMULATION AND ANALYSIS
5 MOBILE AD-HOC SCENARIO SIMULATION AND ANALYSIS

5.1 INTRODUCTION

One of the most active research fields in wireless communications networking is the Mobile ad-hoc Network (MANET) field. It is considered as a wireless system that connects devices anywhere and anytime without any infrastructure, which makes any node in the network acts as a router. MANET can be built around any wireless technology. IR-UWB is one of those technologies.

In this chapter, we will study the performance of different routing protocols in mobile ad-hoc networks using IR-UWB wireless technology. Simulations were performed using NS-2 simulator. The two On-Demand routing protocols namely Ad-hoc On-Demand Distance Vector Routing (AODV) and Dynamic Source Routing (DSR) were used for our evaluation in addition to the Destination- Sequenced Distance Vector routing protocol (DSDV).

There is no clear dominance of one protocol over the others. Some routing protocols are likely to perform best for some metrics, while others perform better for different metrics. For this reason, our performance comparison is done in different environments with regard to the network size, network load, and the mobility of nodes.

Before presenting our work done and the related analyses, it is important to show some tools and parameters used in our mobile ad-hoc network scenarios.
5.2 SYSTEM MODEL [24]

5.2.1 Random Waypoint model (RWP)

Random Waypoint (RWP) model is a commonly used model for mobility and especially in Ad Hoc networks. It is a model which describes the movement pattern of independent nodes. In the RWP model, each node moves along a zigzag line from one waypoint to another where positions are uniformly distributed over a given area. Nodes move with a constant speed randomly chosen from a waypoint to another. The nodes may have some pause time when they reach each waypoint before continuing on the next one. Such movement model is applicable in sensor networks or in situations where people walk as nodes.

5.2.2 Movement generator

To generate large number of nodes and their movements without manually specifying each node position and movement, we use a tool called “setdest”. The tool uses a random waypoint model. This movement generator script is available under ~ns/indep-utils/cmu-scen-gen/setdest.

The usage of this executable command is:

```bash
```

5.2.3 Traffic generator

To generate random traffic connections of TCP and CBR between mobile nodes, a traffic-scenario generator script is used. This traffic generator script is available under ~ns/indep-utils/cmu-scen-gen and is called “cbrgen.tcl”. This script can be easily read and modified, to generate what is suitable to our needs.
To create a traffic-connection file, the command line looks like the following:

```
ns cbrgen.tcl [-type cbr|tcp] [-nn num_of_nodes] [-seed seed]
               [-mc num_of_connections] [-rate rate]
```

In this command, we define the type of traffic connection needed (CBR or TCP), the number of nodes, the maximum number of connections to be setup between nodes and a random seed. In case of CBR connections, a rate parameter should be given which means how many packets per second, and it is seen as the inverse of the packet interval.

Since “cbrgen.tcl” can be easily read and modified, we made some modifications to become more suitable for what we need. The modifications made are the following:

- The packet size which is by default 512 Bytes is changed to 64 Bytes.
- The start times for traffic connections are set to be randomly generated between 0 and 20 seconds instead of 0 and 180 seconds.
- The traffic type is modified to handle the Exponential and Pareto traffics next to TCP and CBR.
- Instead of creating random destinations, the traffic generator was modified so all sources will have only one destination.

### 5.3 Scenario Model and Performance Metrics

In this chapter, we will simulate a mobile ad-hoc network to compare and evaluate the performance of routing protocols. Many different scenarios will be studied, and the evaluation is done according to different performance metrics.

For our simulation, we have setup a dynamic scenario with randomly moving mobile nodes in a square area of 200 x 200 m. A fixed node is placed in the center of the rectangular area which is considered as a base station node, receiving all traffics generated from different sources. This sink node did not
move during the whole simulation. To note that the reason of choosing one sink is that the number of mobile nodes in the area is too small and one base station can handle all events needed to be reported. An example of a topology is shown in Figure 5.1 with 30 mobile nodes distributed all along the area and a fixed node centered in the middle.

Mobile nodes in the simulation move according to the Random Waypoint (RWP) model. At the start of the simulation, mobile nodes are assigned some random positions within the specified area. Each mobile node moves in a straight line from a waypoint to a random destination in the 200m x 200m space at a constant speed. After reaching the destination, nodes may pause for a pause time seconds. Then they choose another destination and proceed by repeating the same behavior for the duration of the simulation.

Concerning the traffic model, only exponential On/Off (EXPOO) traffic sources are used. For achieving best results we did a test where we compare the performance of different traffic sources in a random static topology. In this test we studied the packet delivery ratio as a function of connections number. The result shows that the EXPOO traffic is the leading traffic and outperforms the others.

Figure 5.1: Random mobile topology with 30 mobile nodes and one sink node fixed in the center of the area
For this reason the EXPOO traffic is used for simulations. The experience will be exposed later in next paragraphs. Different scenarios were applied and diverse parameters were taken into consideration.

The basic settings that were fixed for all experiments are listed in Table 5.1.

Table 5.1
Simulation parameters

<table>
<thead>
<tr>
<th>Channel type</th>
<th>WirelessChannel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio propagation model</td>
<td>Tarokh</td>
</tr>
<tr>
<td>Network interface type</td>
<td>InterferencePhy (802.15.4a)</td>
</tr>
<tr>
<td>MAC type</td>
<td>IFControl (802.15.4a)</td>
</tr>
<tr>
<td>Modulation technique</td>
<td>CodedPPM</td>
</tr>
<tr>
<td>MAC data rate</td>
<td>1 Mbps</td>
</tr>
<tr>
<td>Interface queue (IFQ) type</td>
<td>CMUPriQueue (for DSR)</td>
</tr>
<tr>
<td></td>
<td>DropTail/PriQueue (for AODV, DSR, DSDV)</td>
</tr>
<tr>
<td>Link layer type</td>
<td>LL</td>
</tr>
<tr>
<td>Antenna model</td>
<td>OmniAntenna</td>
</tr>
<tr>
<td>Transmission range</td>
<td>50 m</td>
</tr>
<tr>
<td>Maximum number of packets in IFQ</td>
<td>50</td>
</tr>
<tr>
<td>Acquisition preamble technique</td>
<td>Private acquisition</td>
</tr>
<tr>
<td>Preamble time</td>
<td>64000 ns</td>
</tr>
<tr>
<td>Area</td>
<td>200x200 m²</td>
</tr>
<tr>
<td>Traffic</td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>Exponential On/Off</td>
</tr>
<tr>
<td>Burst time</td>
<td>500 ms</td>
</tr>
<tr>
<td>Idle time</td>
<td>500 ms</td>
</tr>
<tr>
<td>Packet size</td>
<td>64 Bytes</td>
</tr>
<tr>
<td>Start time</td>
<td>Randomly chosen in interval [0:20] seconds</td>
</tr>
<tr>
<td>Data rate</td>
<td>2 Kbit/s per connection</td>
</tr>
<tr>
<td>Simulation time</td>
<td>100s</td>
</tr>
</tbody>
</table>
5.3.1 Scenarios

The simulation is conducted in three different scenarios. In the first scenario, the performance of the routing protocols is compared in various numbers of nodes. The number of mobile nodes is varied from 10 to 60 with 5 step increment. The connections number is set to 10 connections. The node speed is fixed to 1 m/s with a pause time of 30 seconds.

In the second scenario, the performance of the routing protocols is compared where the connections number is varied to take the values 10, 20, 30, 40, and 50 connections. The node speed is set to 1 m/s with a pause time of 40 seconds and the number of mobile nodes is fixed to 50 nodes.

In the third scenario, the routing protocols are evaluated in different node speeds varied between 0 and 21 m/s. The number of mobile nodes is fixed to 50 nodes and the pause time is set to 0 second with 10 as connections number.

In these three scenarios some parameters with specific values are considered. These parameters are shown in Table 5.2.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Mobile nodes number</th>
<th>Nodes speed (m/s)</th>
<th>Pause time (s)</th>
<th>Connections number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60</td>
<td>1</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>50</td>
<td>1</td>
<td>40</td>
<td>10, 20, 30, 40, 50</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>50</td>
<td>0, 1, 2, 3, 6, 9, 12, 15, 18, 21</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>
The simulations were run 10 times, each for duration of 100 seconds and the figures reported are the mean results. To note that for each simulation the same mobility and traffic are generated for all tested routing protocols in order to perform an exact comparison.

5.3.2 Performance metrics [25]

In these scenarios, three routing protocols are evaluated based on three important performance metrics which are Packet Delivery Ratio, Average End-to-End Delay, and the Normalized Routing Load.

**Packet Delivery Ratio:** The ratio of the data packets delivered to the destinations to those generated by the traffic sources. This metric is important to show the reliability of routing protocols. The higher value give us better results. It will describe the loss rate that will be seen by the transport protocols, which in its turn affects the maximum throughput that the network can support. Packets that are sent but not received are lost in the network due to drops, route failures, congestion, and wireless channel losses.

**Average End-To-End Delay of data packets:** The averaged time needed for a data packet to be delivered from the source to the destination. This is the average delay of all the packets that are correctly received. Lost packets are obviously not included in this measurement since their packet delay is infinity. The lower the end-to-end delay the better the application performance.

**Normalized Routing Load:** The ratio of the total number of routing packets transmitted to the total number of data packets received at the destination. The normalized routing load metric evaluates the efficiency of the routing protocols.

In the next section we will present our simulation results.
5.4 SIMULATION RESULTS

Before presenting the simulation results for all scenarios, we will show the reason of choosing the Exponential On/Off traffic for our simulations.

5.4.1 Influence of the traffic type

Traffic sources tested in the experience are: Constant Bit Rate (CBR) traffic, Exponential On/Off (EXPOO) traffic, and the Pareto On/Off (POO) traffic.

CBR generates traffic according to a deterministic rate, where packets have constant size. EXPOO generates traffic according to an Exponential ON/OFF distribution. Based on this distribution, during ON periods, packets are sent at a fixed rate, while no packets are sent during OFF periods. POO traffic is identical to EXPOO, except the ON and OFF periods are taken from a Pareto On/Off distribution. Many parameters should be set for EXPOO and POO:

- “packetSize_” : the size of the packets generated.
- “burst_time_” : the average “ON” time for the generator.
- “idle_time_” : the average “OFF” time for the generator.
- “rate_” : the sending rate during “ON” times. [26]

For this experience, the packet delivery ratio as a function of connections number was studied. A fixed scenario was used with 50 nodes randomly distributed in an area of 200 m x 200 m and one node is placed in the center of the area (same scenario described in Section 5.3 with no mobility). The traffic sources are spread randomly over the network. All sources send data to only one destination which is the centered node. The packet size is set to 64 Bytes with a rate of 2 Kbit/s. The idle and burst times for both EXPOO and POO traffics are set to 500 ms. Simulations were run 10 times for duration of 100 seconds and their average was taken. Figure 5.2 shows the packet delivery ratio as a function of
connections number for the three traffic generators. Both AODV and DSR routing protocols are used.

The results show that, for both AODV and DSR routing protocols, the Exponential On/Off traffic outperforms Pareto On/Off and CBR traffics. For the Pareto On/Off traffic we observe that, at large numbers of connections, less than 30% of the generated packets are received. Same for the CBR traffic where the packet delivery decreases dramatically as the connections number increases to reach 10% for 50 connections. On the other hand, we can see that the Exponential On/On traffic has a relatively stable packet delivery ratio above 80% for DSR, and 60% for AODV.

![Figure 5.2: Packet Delivery ratio as function of connections number using CBR, Pareto On/Off, and Exponential On/Off traffic sources (Both AODV and DSR were used)](image)

Based on this experience, the Exponential On/Off traffic will be used as traffic generator in all our next scenarios.

The three different scenarios presented in 5.3.1 were performed and their results are presented in the successive subsections with respect to metrics like Packet Delivery Ratio, End to End Delay and Normalized Routing Load.
5.4.2 Scenario 1: Influence of the network size

An important parameter that affects the performance of routing protocols in a mobile ad-hoc network is the network size. In this scenario, the three routing protocols are evaluated based on the three performance metrics which are Packet Delivery Ratio, End-to-End Delay and the Normalized Routing Load in order to observe the influence of the network size.

A. Packet Delivery Ratio

Figure 5.3 shows the packet delivery ratio versus number of nodes.

![Figure 5.3: Packet Delivery Ratio versus number of nodes](image)

Based on the Figure 5.3, it is shown that at small number of nodes all protocols deliver less packets since no routes may be available and more routes breakage may occurs. As the number of nodes increases it is clear that DSR is the leading protocol, while DSDV is the worst. Since DSDV is a proactive protocol, it requires a regular and periodical update of its routing tables. For that reason it waits for a period of time to get new routing information. In this time, where no route is available, if nodes plan to transmit data, packets are queued and when the queue is full packets will be dropped.

The figure also shows that AODV delivers more data than DSDV but less than DSR. The reason of this behavior is that in case of link failure, DSDV waits for update packets while AODV broadcasts immediately a route request. With
DSR, in case of link failure, an alternative path from the cache is used, whereas AODV broadcasts a route request and waits for some time to get new information by receiving a route reply; during this time AODV queue the packets. This is an additional cause for DSR to drop less packets than AODV.

In addition, in Figure 5.3 we can observe that for the reactive routing protocol DSR, when the number of nodes increases, the packet delivery does not decrease because the additional nodes do not exchange routing information. On the other hand, as in proactive protocols each node in the network has to establish a route to every other node in the network all the time regardless whether or not these routes are needed, DSDV packet delivery ratio slightly decreases because when increasing the number of nodes, more routing traffic will be generated by DSDV so less of the channel will be used for data transfer.

B. Average End-To-End Delay

Figure 5.4 shows a comparison between the routing protocols on the basis of average end-to-end delay for different nodes number.

![Figure 5.4: Average End-To-End Delay versus number of nodes](image-url)
We notice that when the number of nodes increases, the average end-to-end delay increases. In general this is due to the more connections and congestions that appear in higher density networks.

From the graph above, we conclude that AODV has less average end-to-end delay when compared to DSDV and DSR. In AODV, routes are established on demand and destination sequence numbers are used to keep the freshness route to the destination. As a result, AODV didn’t produce so much delay even if the number of nodes increases.

The average end-to-end delay for DSDV is slightly more than AODV while DSR is far above. This is due to the periodic routing information sent by DSDV that allows the mobile nodes to update their route entries more often, resulting in fresher and shorter routes. With DSR, a mobile node continues to use a route to a gateway until it is broken. In some cases this route became long (in number of hops) and even if there is a new route much closer to the gateway, this route is not used and the source continues to send the data packets along the long route to the gateway until it is broken. Therefore, the end-to-end delay increases for these data packets, resulting in increased average end-to-end delay for all data packets.

C. Normalized Routing Load

Figure 5.5 shows the comparison of normalized routing load for AODV, DSR, and DSDV on varying number of nodes. For all routing protocols, we can observe that normalized routing load increased as number of nodes increased. This is obvious because when the network density increases, more routing traffic will be generated.

At low number of nodes, comparable performance is achieved by all routing protocols. However, at high node density, DSR outperforms the two protocols whereas DSDV performs poorer.
DSDV is not an On-Demand protocol, so it periodically broadcasts route updates regardless whether the source node requires the information or not. At high number of nodes, this can cause a high routing load.

DSR and AODV both use on-demand route discovery, but with different routing techniques. DSR uses route caches and maintains multiple routes per destination. On the other hand, AODV uses routing tables and maintains only one route per destination. For the normalized routing load with varied nodes number, it is found that for DSR it is less when compared to AODV. In the presence of mobility, link failures can happen very frequently. Link failures cause new route discoveries in AODV since it has one route per destination in nodes routing table. While the reaction of DSR to link failures is less and causes route discovery less often because it has multiple routes per destination and it is more likely to find a route in the cache, therefore route discovery is delayed until all cached routes fail. For this reason, resort to route discovery is less frequent in DSR than AODV, and that is why the routing load for DSR is less when compared to AODV.

Figure 5.5: Normalized routing load versus number of nodes

DSDV is not an On-Demand protocol, so it periodically broadcasts route updates regardless whether the source node requires the information or not. At high number of nodes, this can cause a high routing load.

DSR and AODV both use on-demand route discovery, but with different routing techniques. DSR uses route caches and maintains multiple routes per destination. On the other hand, AODV uses routing tables and maintains only one route per destination. For the normalized routing load with varied nodes number, it is found that for DSR it is less when compared to AODV. In the presence of mobility, link failures can happen very frequently. Link failures cause new route discoveries in AODV since it has one route per destination in nodes routing table. While the reaction of DSR to link failures is less and causes route discovery less often because it has multiple routes per destination and it is more likely to find a route in the cache, therefore route discovery is delayed until all cached routes fail. For this reason, resort to route discovery is less frequent in DSR than AODV, and that is why the routing load for DSR is less when compared to AODV.
5.4.3 Scenario 2: influence of network load

In this scenario, the three routing protocols are evaluated based on the three performance metrics which are Packet Delivery Ratio, End-to-End Delay and Normalized Routing Load in order to observe the influence of the network load.

A. Packet Delivery Ratio

Figure 5.6 shows the packet delivery ratio for the three routing protocols as function of the network load.

![Figure 5.6: Packet delivery ratio versus connections number](image)

Based on this figure, it is clear that DSR performs better. At low connections number, it delivers about 75% data packets. At higher connections number, many packets will be dropped due to the congestion which makes the packet delivery ratio decreases to reach 45% at 50 connections. For DSDV and AODV, they perform poorly and deliver less than 30% data packets.

DSR uses cache and maintains multiple routes per destination. Under heavy load, it may choose wrong routes. This will cause unnecessary bandwidth consumption and pollution of caches in other nodes. Consequently, packet
delivery ratio will decrease. As a result, DSR performs better for low traffic load, since caching provide significant benefits to a certain level.

Comparing the packet delivery ratio for AODV and DSDV, we can see that they have similar performance whereas there is a big difference in the performance compared to DSR. For the same reason mentioned in 5.4.2 in part A, in case of link failure, DSDV waits for a periodic update to get new information while AODV broadcasts immediately route request. In this time where no route is established, if nodes tend to send data, packets are queued and when the queue is full packets are dropped. In the other hand, DSR in case of link failure uses an alternative path from the cache (if found) to send data.

B. Average End-To-End Delay

Figure 5.7 shows a comparison between the routing protocols on the basis of average end-to-end delay for different network loads. It is clear that the delay is affected by large number of connections. In general, packets are queued into buffers and stay for a period of time before they are sent. When the network load increases, more packets are sent and the buffers are filled much quicker. Consequently, packets have to stay for a long time before they are sent, thus increasing the delay. This is seen with DSR where at high network load the delay becomes more than 5s.

![Figure 5.7: Average end-to-end delay versus connections number](image-url)
The graph shows that AODV outperforms DSDV and DSR. It has the shortest end-to-end delay of no more than 2 seconds. For the same reason mentioned in 5.4.2 in part B, AODV uses sequence numbers to maintain the fresher and shorter routes while DSDV uses periodic updates, which allows nodes to update frequently their route entries resulting in fresher and shorter routes. For DSR who has the worst end-to-end delay, a node continues to use a route until it is broken even if there is a best or a shorter route; causing additional delay.

C. Normalized Routing Load

Figure 5.8 shows a comparison between the routing protocols on the basis of normalized routing load for different connection numbers.

The normalized routing load is an important parameter that shows the scalability of a routing protocol. Based on this figure, it is shown that the proactive protocol DSDV is the less influenced by the connections number in terms of normalized routing load. A constant behavior is achieved by DSDV when the number of connections increases. The reason is that it is a proactive protocol; it periodically broadcasts route updates and a node does not need to find a route before transmitting packets.
When reactive protocols are used (DSR and AODV), the normalized routing load increases as the connections number increases. But it is found that for lower loads, DSR is more effective while for connections number greater than 30, DSDV is more effective. The poor performance of DSR at higher loads comes from its aggressive use of caching, thus using stale routes instead of determining the freshness of routes when multiple choices are available. However, it seems that at low loads caching routes help DSR and keep its routing load down. For AODV, when connections number increases, more nodes will be flooding the network with route requests and therefore more route replies are generated by nodes. This proves why normalized routing load increases with connections.

5.4.4 Scenario 3: Influence of nodes mobility

Mobility of nodes in mobile ad-hoc networks results in frequent changes of the network topology which makes routing a challenging task. In this scenario we examined the impact of mobility based on the performance of the mentioned performance metrics.

A. Packet Delivery Ratio

Figure 5.9 shows a comparison of packet delivery ratio for AODV, DSR and DSDV as function of nodes mobility.

![Packet delivery ratio versus nodes mobility](image-url)
As expected, the packet delivery ratio for all protocols decreases at high mobility since we will have more link failures and more number of packets will be dropped. Therefore more and more routing traffic are required and less of the channel will be used for data transfer. However, each routing protocol reacts differently during link failures. Those reactions lead to have different performances on the basis of the packet delivery ratio, average end-to-end delay and normalized routing load.

**Figure 5.9** shows clearly that DSR outperforms DSDV and AODV at low mobility nodes, while at high mobility AODV becomes the leading protocol. DSDV is the worst protocol; it performs poorer than the others for all mobility variations. This is because in rapid changed topology, DSDV is not adaptive to routes changes due of its periodical updating route table.

At low mobility, when link failures happen, new route discoveries in AODV are triggered. Thus, the frequency of route discoveries in AODV is directly proportional to the number of route breaks, while DSR protocol has a chance to find a route in its cache so less route discoveries are generated, for this reason it achieves higher packet delivery than AODV.

Under high mobility, topology changes rapidly. Under such situations, DSR may be inclined to choose wrong routes because it does not have any mechanism to know which route in the cache is out of date, so data packets are forwarded to a broken link, while AODV can adapt to the changes quickly since it only maintains one route and always chooses the fresh route, thus lower packet delivery ratio is achieved by DSR compared to AODV.

B. **Average End-To-End Delay**

**Figure 5.10** shows a comparison between the routing protocols on the basis of average end-to-end delay for different node speeds.
With respect to average end-to-end delays, AODV is the leading protocol while DSR is the worst. This is because DSR may not use optimum path always unlike AODV. In addition, one interesting observation is that the delay for DSR protocol increases with low mobility. This is due to a high level of network congestion and multiple access interferences at certain regions of the ad hoc network. The protocol does not have any mechanism for choosing routes in such a way that the data traffic can be more evenly distributed in the network. This phenomenon is less visible with higher mobility where traffic automatically gets more evenly distributed due to source movements. For this reason the end-to-end delay of DSR decreases at high mobility.

Also from Figure 5.10, we can see that average delay for the proactive protocol DSDV was pretty good as it uses a route already in the table, and no time is required to find a route.

C. Normalized Routing Load

Figure 5.11 shows a comparison of normalized routing load for AODV, DSR and DSDV as function of nodes speed.
The normalized routing load for DSR and AODV increases as the node mobility increases. This is because as the speed increases, mobility increases too. Thus we have more link failures which in turn will increase the number of route request from sources. For that reason, the routing load will increase. For DSDV, we can observe that routing load is almost constant with respect to nodes speed. This behavior of DSDV is due to its proactive nature which offers constant routing load in all cases.

At lower speeds DSR outperforms AODV since in case of failure in one route other route will be used rather than initiating route request. But at high mobility, the chance of the caches being stale is very high in DSR. Hence, the cache staleness results in significant degradation in performance for DSR in high mobility scenarios.

Figure 5.11: Normalized routing load versus nodes mobility
5.5 SUMMARY

A summary of the obtained results is presented in Table 5.3, where the outperformed routing protocols are shown in various cases.

Table 5.3
Results’ summary

<table>
<thead>
<tr>
<th></th>
<th>Influence of network size</th>
<th>Influence of network load</th>
<th>Influence of mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packet Delivery Ratio</td>
<td>DSR</td>
<td>DSR</td>
<td>Low speed DSR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High speed AODV</td>
</tr>
<tr>
<td>Average End-to-End Delay</td>
<td>AODV</td>
<td>AODV</td>
<td>AODV</td>
</tr>
<tr>
<td>Normalized Routing Load</td>
<td>DSR</td>
<td>Low load DSR</td>
<td>DSDV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High load DSDV</td>
<td></td>
</tr>
</tbody>
</table>

Simulation results showed that AODV outperforms all other routing protocols for average end-to-end delay performance metric in all cases. This is because, in AODV, routes are established on demand and destination sequence numbers are used to maintain the fresher and shorter routes to the destination.

On the other hand, with respect to packet delivery ratio, DSR outperforms DSDV and AODV in all scenarios expect in high speed. With extremely high mobility, AODV becomes the leading protocol because the topology changes rapidly, therefore DSR may be inclined to choose wrong routes so packets are forwarded to a broken link, while AODV can adapt to the changes quickly since it always chooses the fresh route.
When looking at the normalized routing load, at low loads, caching routes help DSR and keeps its routing load down. In contrast, at higher loads DSDV outperforms DSR. The poor performance of DSR comes from its aggressive use of caching, thus using stale routes instead of determining the freshness of routes when multiple choices are available.

5.6 CONCLUSION

In this chapter, we have presented a detailed performance comparison of important routing protocols for mobile ad hoc wireless networks based on the three performance metrics which are Packet Delivery Ratio, End-to-End Delay and the Normalized Routing Load.

AODV and DSR are On-Demand routing protocols, while DSDV is a proactive protocol. We have presented extensive simulation studies and compared these ad-hoc routing protocols, using a variety of workload such as network load, mobility and size of the ad hoc networks.
CONCLUSION AND RECOMMENDATIONS

Earlier, most of wireless technologies were based on the IEEE 802.11. Ad hoc wireless network, described as mobile stations communicating through wireless channels, is one example of these wireless technologies.

Recently, ad-hoc networking has been subjected to a lot of work, and several specific protocols have been developed and tested. Contrary, a very little work is done concerning the UWB technology and specifically the IEEE 802.15.4a physical layer, which is used in low data rate applications. Such networks are expected to play a very important role in future civilian and military setting.

The aim of our work was to study and evaluate the performance of a wireless system associated with UWB. For this purpose, many scenarios were considered and simulated using Network Simulator NS-2.

After introducing our work, we discussed in Chapters 1 and 2 the basic UWB characteristics. In addition, a brief overview of NS-2 and routing protocols was presented in Chapter 3. Later on, in Chapter 4, we showed that a network with private acquisition preamble achieve higher throughput than a network with common acquisition preamble. Then, a comprehensive study for a line scenario was provided. Simulation results showed that the static routing protocol NOAH outperforms AODV, DSDV and DSR. After that, we presented a detailed performance comparison of important routing protocols for mobile ad hoc wireless networks, using a variety of workload such as mobility, load and size of the ad-hoc networks. There was not a clear dominance of one protocol over the others. Some routing protocols were likely to perform best for some metrics, while others perform better for different metrics.
FUTURE WORK

We have limited the number of simulation nodes to a maximum of 60. We imposed this limitation because the execution time of simulations using the ns-2 simulator increases significantly as the number of nodes increases. In our future work, extensive complex simulations could be carried out in a bigger area with longer simulation time, in order to gain a more in-depth performance analysis of the ad hoc routing protocols. Furthermore, performance comparison with other routing protocols could be studied too.
REFERENCES


