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Assessment of Indoor Propagation and Antenna Performance for Bluetooth Wireless Communication Links

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Over the last decade the world has witnessed explosive growth in the use of wireless mobile communications. Looking around we find users with mobile phones, wireless PDAs, MP3 players, keyboards etc. and wireless headphones to connect to these devices - a small testament of the impact of wireless communications on our daily lives. In addition the burst of new technologies such as Bluetooth and other short-range wireless communications are encouraging the further development of a wide variety of distributed wireless devices (Mohammed, 2002).

Bluetooth is one of those short range wireless communication technology systems which aims at replacing many proprietary cables that connect one device with another with one universal short-range radio link. Recently, many mobile devices (e.g., mobile phones, PDAs, computer mice) with integrated Bluetooth modules have been introduced. Their wireless technology is used to transfer any kind of data onto these devices.

Propagation of radio waves inside buildings is a very complicated issue, and it depends significantly on the indoor environment (home, office, factory) and the topography (LOS: line of sight and NLOS: non-line of sight). The statistics of the indoor channel varies with time due to movements of people and equipment (Obayashi & Zander, 1998). A survey of indoor propagation measurement and models can be found in (Hashemi, 1993), and electromagnetic propagation effects in (Sander & Reed, 1978). There are limited investigations in the open literature on the measurements and simulations of multipath wave propagation effects on the performance of live Bluetooth links.

In this chapter we present measurement campaigns (signal power, bit error rate and data rate) in an indoor office building for LOS and NLOS propagation scenarios and assess their effects on the Bluetooth link. These measurements were carried out using various antennas (omni-directional and directive antennas), and we will present comparative analysis to access the potential improvement in system performance gained from the use of directive antennas. We will also show the effect of antenna parameters (gain and efficiency) on the results and the overall impact on the quality and coverage of the Bluetooth link.

The organization of this chapter is as follows. In section 2 we provide a brief description of the building in the tested indoor office environment and the various types of antennas used in the measurement trials and their related parameters. In section 3 we present the results of these measurements. Finally, section 4 concludes the chapter.

1. Bluetooth

Bluetooth devices operate in the unlicensed industrial, scientific and medical (ISM) band at 2.4 GHz, and with a total bandwidth of 83.5 MHz (Bisdikian, 2001; Bluetooth, 2002; Haartsen, 2000). According to the IEEE 802.11 standard, this band is globally available, license-free and follow a basic set of power, spectral emission and interference specifications.
There are two types of connections depending on the number and functions of the Bluetooth system. These connections form a piconet topology which is either point-to-point or point-to-multipoint networks. In the point-to-point connection, only two Bluetooth devices are involved, while several Blutooth devices are connected in the point-to-multipoint connection. In these configurations the Bluetooth device that first creates a connection is designated as the *master* device and the others would then become *slave* devices. The maximum number of eight Bluetooth devices can be connected into a piconet, (i.e.,1 master and 7 slaves).
The topology of the connection can be extended to involve more piconets depending on the function of each Bluetooth device. This extended net is called a scatternet, in which a Bluetooth device could be active in more than one piconet.
The Bluetooth radio utilize spectrum spreading through the use of frequency hopping between 79 channels displaced by 1 MHz, from 2.402 GHz to 2.481 GHz, although in some countries the frequency hopping range is reduced to 23 hops (McDermott-Wells, 2004). The frequency hopping provides a redcution of interference from other devices in the busy ISM band. Even though the Bluetooth technology includes a retransmission scheme for lost data packets, the frequency hopping will minimize the possibility of data blocking when there are many Bluetooth devices within range of each other. The gross data rate of the Bluetooth technology is 1 Mbps (Bisdikian, 2001; Bluetooth, 2002; Miller & Bisdikian, 2001).
Each Bluetooth device is classified into 3 power classes,

- class 1 with a maximum transmit power of 20 dBm.
- class 2 with a maximum transmit power of 4 dBm.
- class 3, with a maximum transmit power of 0 dBm.

To obtain the most efficient use of the bandwidth within a channel while maintaining an acceptable bit error rate, the digital bit stream is modulated using Gaussian Frequency Shift Keying (GFSK).
The power emission is controlled at the receiver side by monitoring the Received Signal Strength Indicator (RSSI) and sending Link Manager Protocol (LMP) control commands to the transmitter asking for the transmit power to be reduced if the RSSI value is higher than the necessary threshold required to maintain a better link quality. If the RSSI value is too low, then the receiver may request the power to be increased (Bisdikian, 2001; Bluetooth, 2002; Miller & Bisdikian, 2001).
The Bluetooth protocol uses a combination of circuit and packet switching. Slots can be reserved for three supported synchronous voice channels and one asynchronous data channel. In addition there is a supported channel for both asynchronous data and synchronous voice.

2. The tested indoor office environment

The measurement trials were performed indoors in typical office environments. In this section we will describe the building structure and material where the measurements took place and later in the results section we show the sensitivity of the Bluetooth link, employing different

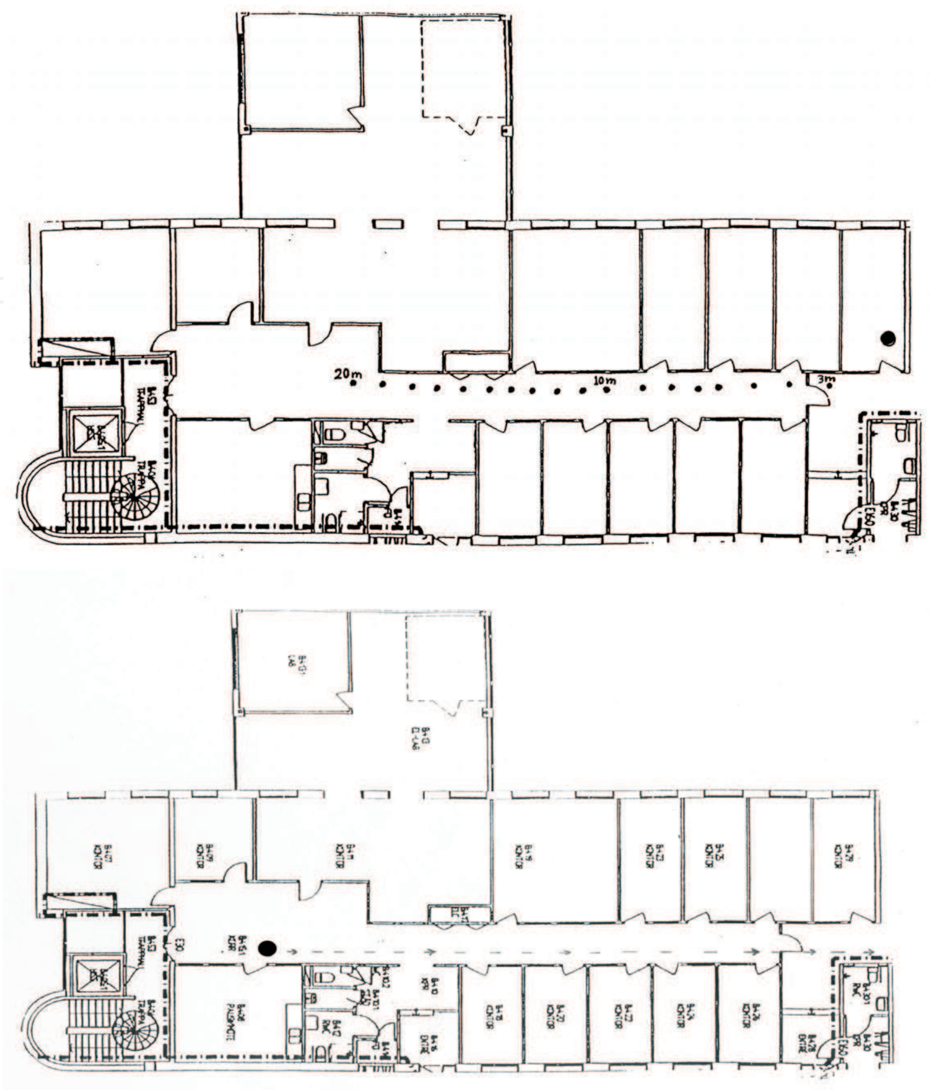


Fig. 1. Description of the indoor office environment used in the measurement scenarios for: NLOS (top figure) and LOS (bottom figure).

antenna types, in these indoor environments. Figure 1 shows a typical example of office environment which is quite common all over the world. The dimensions of the hallway of the building in this figure are (45 x 1.85 x 2.30) meters. Most doors are mainly made of wood except of the two outer doors, one at each end of the hallway, which are made of metal. The inner walls in the hallway consists of a large single pane window in a wooden frame. The walls between the rooms consists of two plasterboards supported by two vertical steel crossbars and the plasterboards are nailed to vertical wooden crossbars that are situated at regular intervals inside the wall. Mostly all the furniture in the office are made of wood and plastic. The outer walls of the building are made of concrete isolated with thermal material and dual pane windows surrounded by wooden/metal frames.

2.1 The used antennas

The antenna is the interface between the transmitter/receiver and the propagation medium, and it therefore is a deciding factor in the performance of a radio communication system.

To improve and develop the design of Bluetooth antenna, the Bluetooth Special Interest Group (SIG) has left the antenna part as an open door for the antenna manufacturers. In the past few years, the designs of Bluetooth antennas have been developed significantly and since then many companies have entered the Bluetooth antenna market and others have already left it. The Bluetooth radio module has to be connected to an antenna to transport the electromagnetic energy from the radio module to the antenna (transmitter), or from the antenna to the radio module (receiver). In addition, there are three important parameters concerning both the propagation of electromagnetic waves and the definition of the coverage of the wireless devices. These parameters are the receiver sensitivity, output power and antenn a gain.

The radiation pattern of an antenna could be *omnidirectional* (a circular pattern with the same radiation in every direction in one plane) or *directional*. Therefore the radiation pattern in a particular direction determines if the antenna has a directive gain or not. Fixed network devices such as LAN Access Points (LAP) could use antennas that are directed as they are installed. Conversely, mobile devices such as cellular phones, laptops, cameras, etc. need to transmit and receive at any direction and angel. As a consequence, in the choice of an antenna for a product, its position as well as its parameters (gain, efficiency and radiation pattern) should be taken into account and investigated properly.

In this chapter, both omnidirectional and directive antenna types have been used and tested. The range of the Bluetooth antenna is much different in practical measurements than the theoretically anticipated range especially in an office environment; this observation will also be revealed in the measurement results section. The popular antenna types for Bluetooth devices are the external dipole, microstrip and *planar inverted-F antenna* (PIFA). In this chapter the Bluetooth Application Tool Kit has been used in the measurements as we have mentioned above. In order to connect and measure with different antennas by using the Bluetooth Application Tool Kit module which has an originally microstrip PIFA antenna printed on a Printed Circuit Board (PCB), a cable with SMA connector has been connected to a feeding point with impedance of 50 ohm as a requirement for each Bluetooth antenna when it would be mounted on the board. The different antenna types used in these tests are presented below; the operational frequency range for all antennas is 2.4-2.5 GHz and their nominal feeding impedance is 50 ohm. It is worth mentioning at this point that generic names have been given to the different antennas used in these measurements rather than their specific names. The various tested antennas and their radiation patterns are presented in the appendix. The PIFA antenna used in the Master Bluetooth device has two galvanic contacts, one to the earth and the other as a feeding point with impedance of 50 ohm. The structure of the PIFA antenna is optimized for small size requirements, large bandwidth and efficient gain. The size of the PIFA antenna is (25 x 7) mm.

The *Half Wave Model 1* antenna (Appendix figure 5) relies on a reflection formed wave between the active element and a conductive plane. The gain value of this antenna is 9.2 dBi and its efficiency is 95%. Because of its large size, this antenna can be used as an external antenna for some applications like a printer server and measuring instruments. The return loss, which has been measured with a network analyzer, is 14.4 dB.

The *Half Wave Model 2* antenna (Appendix figure 6) is an external antenna which was supplied with an adjustable radiator angle. This antenna could take different positions (vertical, horizontal, etc.). The *Half Wave Model 2* antenna is characterized by a radiation pattern which is almost the same in all directions (omnidirectional). The gain value of this antenna is 1.6 dBi, the efficiency is 75% and the return loss is 15 dB.

The *Quart Wave Model 1* antenna (Appendix figure 9) has a small size of (18.2 x 3.9 x 1.6) mm, and it is a surface-mounted embedded antenna. It can be integrated into PC cards, mobile phones, access points and Bluetooth enabled devices. It is a linearly polarized antenna with a peak gain of 2 dBi.
The *Quart Wave Model 2* antenna (Appendix figure 8) is also small in size (21 x 4 x 3) mm and can be used as an embedded antenna for Bluetooth enabled devices. The gain value of this antenna is 4.1 dBi, its efficiency value is 68% and the return loss is 10.784 dB. The radiation pattern of the *Quart Wave Model 2* antenna is not omnidirectional.
The *Half Wave Model 3* antenna (Appendix figure 7) has relatively small size (27 x 8 x 3) mm and can be used both as an embedded antenna and an external antenna for Bluetooth enabled devices. The radiation pattern of this antenna indicates that the *Half Wave Model 3* antenna is not an omnidirectional antenna. The gain value of this antenna is 4.0 dBi, its efficiency is 62% and the return loss is 13.46 dB.

2.2 The measurements setup

Measurement campaigns were conducted so that we can get an understanding of how the signal power, BER and the data rate are affected by NLOS and LOS propagation scenarios for the different Bluetooth antennas that have been used in the indoor office environment. The antennas used in these measurement trials and their parameters have been described in the previous section.
One room (back room marked with a dot) and part of the hallway were used in the measurements to provide NLOS and LOS scenarios between the two Bluetooth devices/antennas, respectively, as shown in figure 1. A PC is connected to a Bluetooth device with PIFA antenna, have been used as a stationary Bluetooth device (Master). Another PC with a Bluetooth device (Slave), was rolled along the hallway in 1 m interval following the dotted line in figure 1. The various used antennas, which are described in the previous section, were replaced alternately on the Slave side. In this chapter, the Receiver Signal Strength Indicator (RSSI) is used in the measurements; this term and signal power has been used interchangeably here. The Bluetooth RSSI measurement compares the received signal power with two threshold levels, which define the Golden Receive Power Range (Bisdikian, 2001). Note that all the results for signal power measurements were registered after measuring it 10 times to ensure that a stable signal is being measured. For the fast fading dip identification, the measured return value of RSSI was flickering (or hopping) from 0 dB to -20 dB and back again to 0 dB and so on (i.e., a stable result couldn't be measured).
Note that the door in the back room, where the master was placed for NLOS scenario, was open and other doors in the hallway were also open during the measurements. In addition, people in the office were allowed to move freely during the measurements, and the results of these measurements were registered after a successful data transmission. For the NLOS measurement scenario all the measurements have been started at the range of 3 meters (see figure 1) in order to avoid the direct LOS path.

3. Results of the measurements

Antennas that are able to direct the transmitted and received signals' energy are of great interest for future wireless communication systems. The directivity implies reduced transmit power and interference and hence potential for increased capacity, quality and range. In this section we present the measurement trials using different directive antennas and compare with isotropic antenna for NLOS and LOS propagation scenarios described in the previous

section. The results of three types of measurement trials (signal power, bit error rate and data rate) will be presented in this section.
The RSSI or signal power measurement results are shown in figure 2. It is evident from this figure that a significant reduction in signal power is achieved with the gradual increase of both the distance and the number of the obstacles between the Master and the Slave along the dotted line in figure 1. Increasing the distance even further will ultimately produce a break in transmission; that is a disconnection between the radio modules at different distances depending on the parameters (gain and efficiency) of the different used antennas and the propagation scenario. This is the reason why the *Half Wave Model 1* antenna (9.2 dBi, 95%) has the highest signal power and best range (19 meters) while the *Half Wave Model 3* antenna (4 dBi, 62%) has the lowest signal power and range (9 meters). The results of the other antennas are intermediate between the results of the above two mentioned antennas.
Note that a successful data transmission was impossible after the coverage range of each antenna as shown in figure 2. The most important distance in this scenario is at 10 meters which is the anticipated range of the Bluetooth class 3 modules used in these measurements.
An interesting observation in NLOS scenario is the reception of stable (or constant) signal power level (in some distances for all the used antennas) in spite of increasing the distance between the Master and the Slave. This can be clearly seen from the RSSI results in figure 2 for example at the distance from 9-12 meters.
An important observation that can be made from figure 2 regarding LOS scenario is that the signal still exists in the hallway much farther beyond the operating range of 10 meters (see for example *Half Wave Model 1*). This phenomenon could be explained by the tunnelling effect where the hallway acts as a waveguide to the reflected radio waves from the walls along the hallway. Hence the increased coverage ranges as compared to NLOS scenario.
In figure 3 we show the results of BER measurements for the different antennas. BER is defined as the number of errors in the system that occurs within a given sequence of bits. For example, a BER of 0.001% means that in average one bit out of 10000 bits is corrupted. Generally, the BER becomes higher by increasing the distance between the transmitter and the receiver, and by increasing the number of obstacles in the communications path. However, the effect of fast fading on the measurement results is evident from the rapid fluctuation of the measured BER values for all antennas as shown in figure 3. Again, the *Half Wave Model 1* antenna provided the best results (lowest BER values) among the used antennas, which is clearly related to its high gain and efficiency parameters.
For NLOS scenario in figure 3 (top plot), the highest BER value of 1.964% was obtained by the *Half Wave Model 3* antenna at a distance of 12 m, while the lowest BER value of 0.378% (at the same distance) was obtained by the *Half Wave Model 1* antenna. The BER results of the other antennas were in between the above mentioned values. On the other hand, for LOS scenario in figure 3 (bottom plot), the results of BER measurements show a minimum value of 0.0% (no errors) and a maximum value of 0.905%. In other words, the BER is lower in LOS as compared to NLOS scenario as expected. Again, the *Half Wave Model 1* antenna has the best results (lowest BER values) among the used antennas, which is clearly related to its high gain and efficiency parameters.
Finally, the results of the data rate measurements are plotted in figure 4. From these plots we notice only a very slight reduction of the Bluetooth link data rates with increasing the distance. The data rate results are also in agreement with the pattern of the BER results in figure 3; that is the higher the BER value, the lower the data rate that can be achieved and vice versa. This can be clearly seen in the distance of 12 m for NLOS scenario, where the highest data rate value

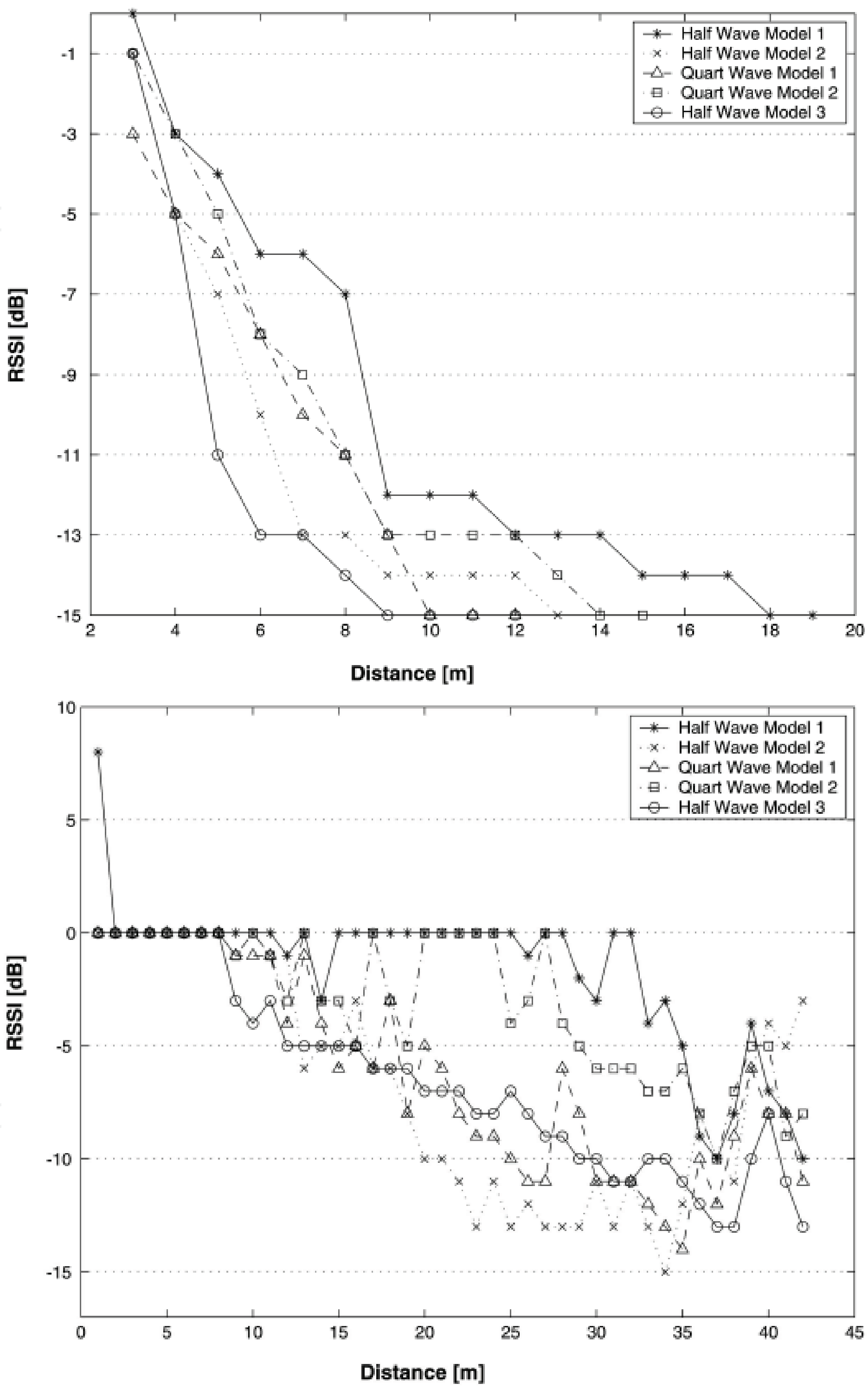


Fig. 2. The signal power measurements results for: NLOS (top figure) and LOS (bottom figure). The RSSI generally drops with increasing the distance between the Master and the Slave.

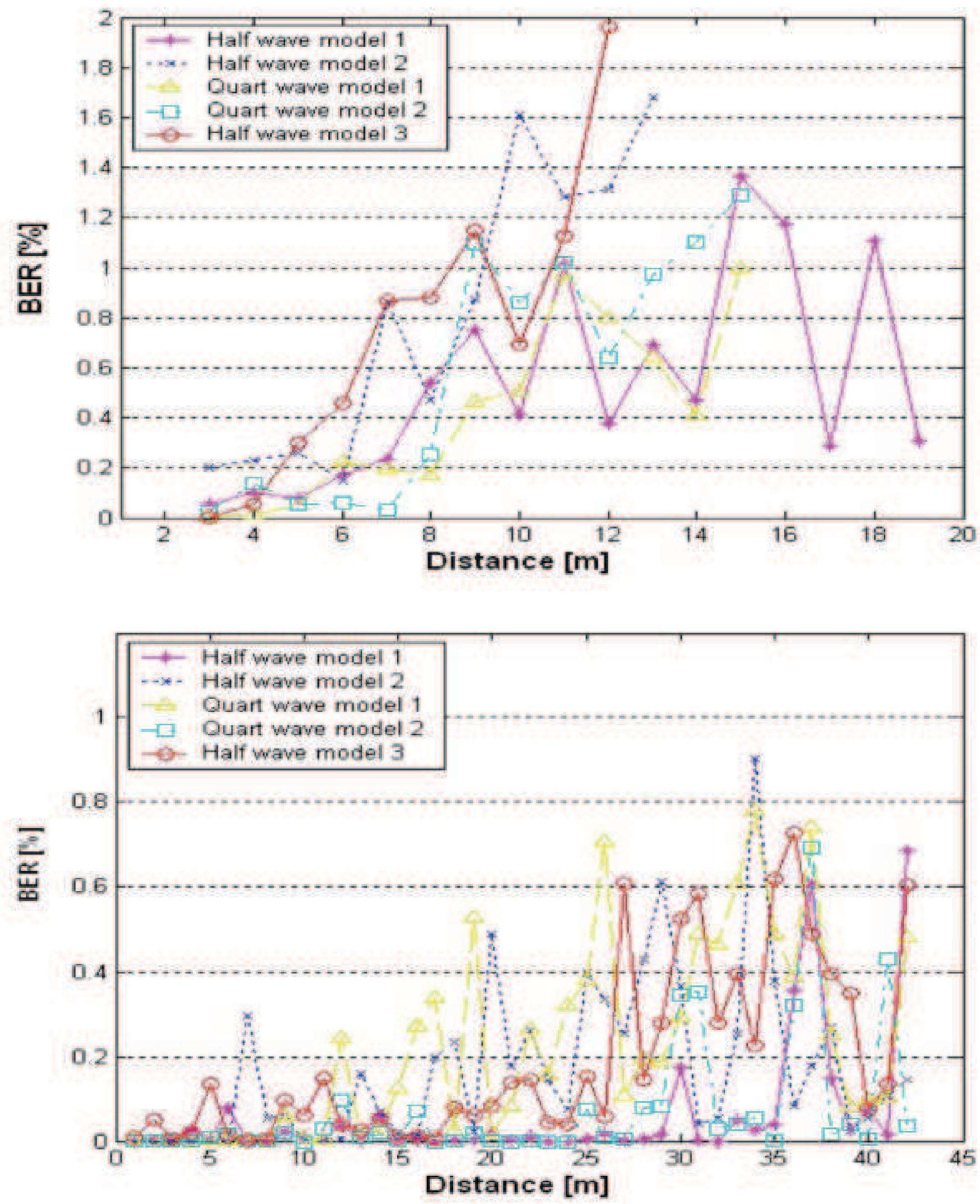


Fig. 3. The BER measurement results for: NLOS (top figure) and LOS (bottom figure). The BER increases with distance and the rapid fluctuations are due to fast fading.

of about 172.2 kbps was obtained by the *Half Wave Model 1* antenna and the lowest data rate value of 169.4 kbps was obtained by the *Half Wave Model 3* antenna. The results of the *Quart Wave Model 2*, *Quart Wave Model 1* and *Half Wave Model 3* antennas has followed a similar pattern by giving intermediate data rate values as was the case for RSSI and BER scenarios. A similar pattern of results (not shown) were obtained from LOS scenario.

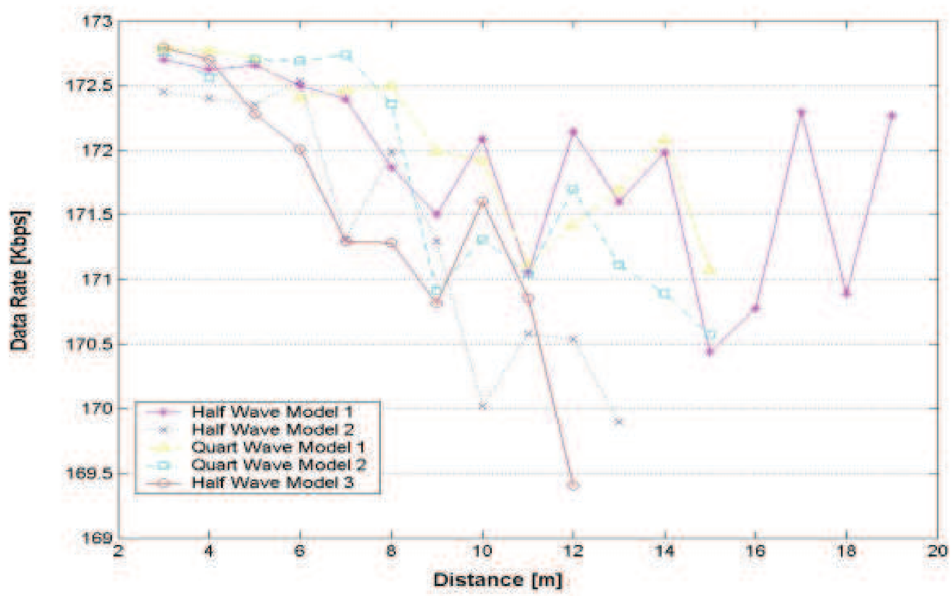


Fig. 4. The data rate measurement results for NLOS. Only a slight drop in data rates is obtained with increasing distance between the transmitter and receiver.

4. Conclusions

In this chapter we have presented the results of measurement trials of the Bluetooth link employing different antennas operating at 2.4 GHz in NLOS and LOS propagation scenarios for indoor office environments. The measurement results have shown a noticeable degradation in performance by increasing the distance between the Master and the Slave. It was also shown that a disconnection in the Bluetooth transmission link was obtained at different distances for each antenna, which in turn was dependent on the antenna parameters (gain and the efficiency). We have also explored the effect of the antenna parameters and the relation between BER, signal power and data rate. The indoor trials have revealed that a link with lower BER values provide higher capacity (data rate), less power requirements and better coverage.

5. Appendix: Antenna types

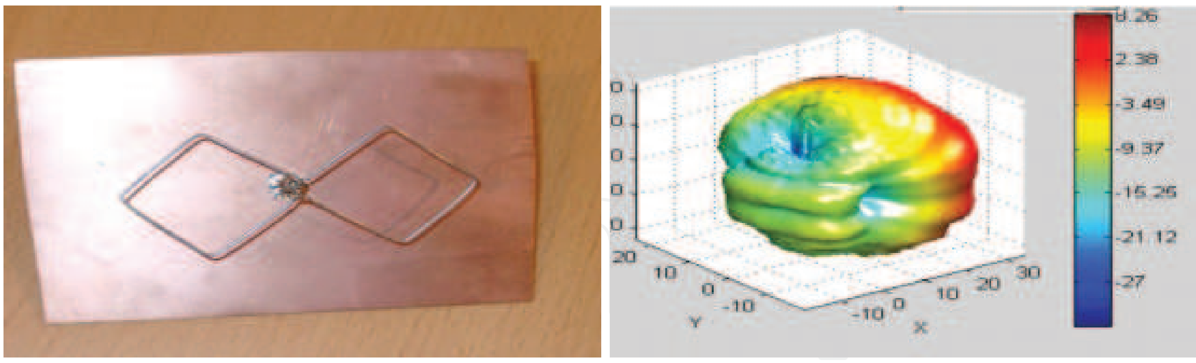


Fig. 5. Antenna type: *Half wave model 1*

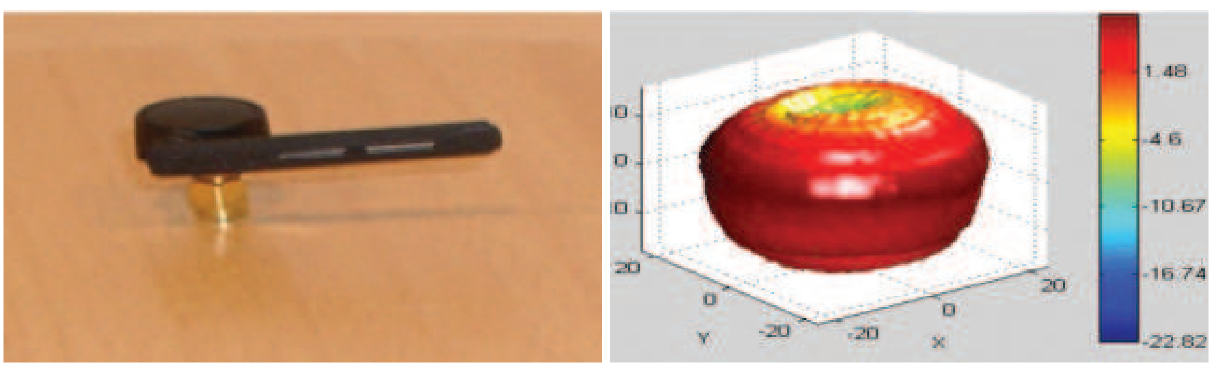


Fig. 6. Antenna type: *Half wave model 2*

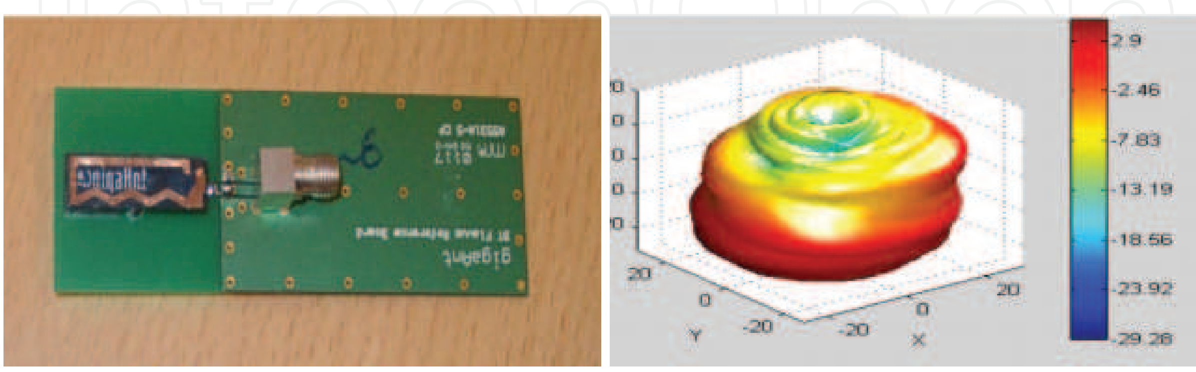


Fig. 7. Antenna type: *Half wave model 3*

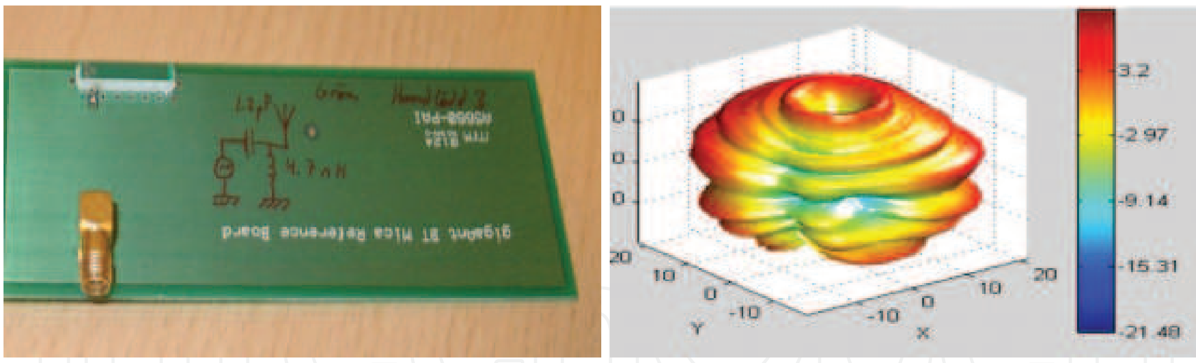


Fig. 8. Antenna type: *Quarter wave model 2*

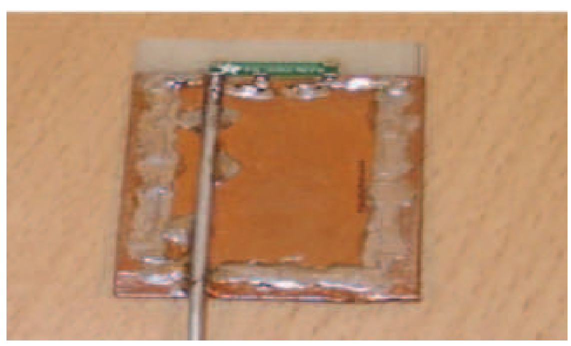


Fig. 9. Antenna type: *Quarter wave model 1*

6. References

Bisdikian, C. (2001). An overview of the bluetooth wireless technology, *IEEE Communications Magazine* Vol. 39(No. 12): 86–94.

Bluetooth (2002). http://www.bluetooth.com, *Bluetooth SIG* .

Haartsen, J. (2000). The bluetooth radio system, *IEEE Personal Communications* Vol. 7(No. 1): 28–36.

Hashemi, H. (1993). The indoor radio propagation channel, *Proceedings of the IEEE* Vol. 81(No. 7): 943–968.

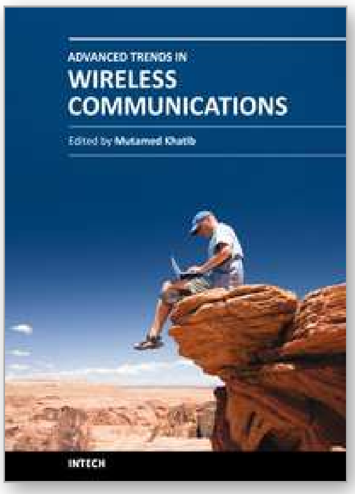
McDermott-Wells, P. (2004). What is bluetooth?, *IEEE Potentials* Vol. 23(No. 5): 33–35.

Miller, B. A. & Bisdikian, C. (2001). *Bluetooth Revealed*, Prentice Hall PTR, Upper Saddle River, NJ.

Mohammed, A. (2002). Advances in signal processing for mobile communication systems, *Special Issue of Wiley's International Journal of Adaptive Control and Signal Processing* Vol. 16(No. 8): 539–540.

Obayashi, S. & Zander, J. (1998). A body-shadowing model for indoor radio communication environments, *IEEE Transactions on Antenna and Propagation* Vol. 46(No. 6): 920–927.

Sander, K. F. & Reed, G. A. (1978). *Transmission and Propagation of Electromagnetic Waves*, Cambridge University Press.



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Physical limitations on wireless communication channels impose huge challenges to reliable communication. Bandwidth limitations, propagation loss, noise and interference make the wireless channel a narrow pipe that does not readily accommodate rapid flow of data. Thus, researches aim to design systems that are suitable to operate in such channels, in order to have high performance quality of service. Also, the mobility of the communication systems requires further investigations to reduce the complexity and the power consumption of the receiver. This book aims to provide highlights of the current research in the field of wireless communications. The subjects discussed are very valuable to communication researchers rather than researchers in the wireless related areas. The book chapters cover a wide range of wireless communication topics.

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