The Impact of Antennas on the Bluetooth Link in Indoor Office Environments

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Abstract: 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. In this paper we present the results of measurement trails of the Bluetooth link employing different antennas in NLOS and LOS for indoor office environments. The results show the potential improvement in system performance gained from the use of directive antennas and the great dependency of the results on the antenna parameters (gain and efficiency) and the overall impact on the quality and coverage of the Bluetooth link.

Key words: Antennas, Bluetooth, Measurements, Wave Propagation.

1 Introduction

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, pagers, MP3 players, 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. Bluetooth devices operate in the industrial, scientific and medical (ISM) band at 2.4 GHz, and use 79 channels each occupying 1 MHz. The reader is refereed to (Bisdikian 2001, Haartsen 2000 and Bluetooth SIG.) for further information about this technology.

Propagation of radio waves inside buildings is a very complicated issue, and it depends significantly on the indoor environment (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 & al., 1998). A survey of indoor propagation measurement and models can be found in (Hashemi 1993), and electromagnetic propagation effects in (Sander & al. 1978). In this paper we show the measurements for indoor propagation of LOS and NLOS scenarios and access their effects on the Bluetooth link.

There is very little in the open literature on the measurements and performance evaluations of antennas for live Bluetooth links. In (Pedersen & al., 2000) the measurement trails using "omnidirectional antenna" was investigated for indoor and outdoor environments. Thus, further investigations about several types of antennas that might be used for Bluetooth devices and their performance in office environments were needed.

In this paper three types of measurements have been conducted: signal power measurements, bit error rate (BER) measurements and data rate measurements. All these measurements were performed indoors in a typical office environment by using two Bluetooth (BT) type class 3 modules Application Tool Kit. The range of these modules is expected to be around 10 meters in office environment and the sensitivity level of the input signal power is -70 dBm.

The organization of the reminder of the paper will be as follows. In Section 2 we provide a brief description of the building in the tested indoor office environment. The various types of antennas used in the measurement trails and their related parameters are presented in Section 3. In Section 4 we briefly outline the LOS and NLOS measurement scenarios and the results of these measurements are presented and compared in Section 5. Finally, Section 6 concludes the paper and present future research.
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 antenna types, in these indoor environments. Fig. 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 consist of a large single pane window in a wooden frame. The walls between the rooms consist 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.

![Fig. 1 Description of the indoor office environment used in the measurement scenarios for: a) NLOS and b) LOS.](image)

3 The Used Antennas

The antenna is the interface between the transmitter and the 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 BT 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 BT antennas have been developed significantly and since then many companies have entered the BT antenna market and others had already left it. The BT 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 antenna gain.

The radiation pattern of an antenna could be isotropic (a spherical pattern with the same radiation in every direction) 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 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 angle. 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 paper, both isotropic and directive antenna types will be 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 be also revealed in the measurement results section. The popular antenna types for BT devices are the external dipole, microstrip and planar inverted-F antenna (PIFA). In this paper the BT Application Tool Kit has been used in the measurements as we have mentioned above. In order to connect and measure with different antennas using the BT Application Tool Kit module, which has an originally microstrip PIFA antenna printed on a Printed Circuit Board, a cable with SMA connector has been connected to a feeding point with impedance of 50\(\Omega\) as a requirement for each BT antenna when it would be mounted on the board. The different antenna types used in these test are presented below; the operational frequency range for all antennas is 2.4-2.5 GHz and their nominal feeding impedance is 50\(\Omega\). 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 PIFA antenna used in the Master BT device has two galvanic contacts, one to the earth and the other as a feeding point with impedance of 50\(\Omega\) as a requirement for each BT antenna when it would be mounted on the board. The different antenna types used in these test are presented below; the operational frequency range for all antennas is 2.4-2.5 GHz and their nominal feeding impedance is 50\(\Omega\). 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 PIFA antenna used in the Master BT device has two galvanic contacts, one to the earth and the other as a feeding point with impedance of 50\(\Omega\). 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 relies on a reflection formed wave between the active element and a conductive plane. It is a big directional antenna. 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 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 at 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 Quat Wave Model 1 antenna has a small size of (18.2 x 3.9 x 1.6) mm, and it has surface-mounted embedded antenna. It can be integrated into PC cards, mobile phones, access points and BT enabled devices. It is a linearly polarized antenna with a peak gain of 2 dBi.

The Quat Wave Model 2 antenna is also small in size (21 x 4 x 3) mm and can be used as an embedded antenna for BT 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 Quat Wave Model 2 antenna is not omnidirectional.

The Half Wave Model 3 antenna has relatively small size (27 x 8 x 3) mm and can be used both as an embedded antenna and an external antenna for BT 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.

4 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 BT devices/antennas, respectively, as shown in Fig. 1.

A PC is connected to a BT device with PIFA antenna, have been used as a stationary BT device (Master). Another PC with a BT device (Slave), was rolled along the hallway in 1 m interval following the dotted line in Fig. 1. The various used antennas, which are described in the previous section, were replaced alternately on the Slave side.

In this paper, 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 a distance of 3 meters away from transmitter (see Fig. 1a) in order to avoid the direct LOS path.

5 Results of the Measurements

In this section we present the results of three types of measurement trails (signal power, bit error rate and data rate) in the NLOS and LOS scenarios described in the previous section.

The RSSI or signal power measurement results are shown in Fig. 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 Fig. 1. Increasing the distance ever further will ultimately produce a break in transmission 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 in NLOS scenario 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 other antennas produced intermediate results of the above two mentioned antennas. Similar conclusions can be withdrawn from LOS scenario.

Note that a successful data transmission was impossible after the coverage range of each antenna shown in Fig. 2. Another reason that has some impact on the behavior of each antenna is the number of obstacles between the Master and the Slave. The signal power measured at the received antennas was lower by increasing the number of obstacles between the Master and the Slave. The most important distance in this scenario is at 10 meters which is the anticipated range of the BT modules type class 3 used in these measurements.

An intriguing observation in Fig. 2 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. In NLOS, for example, this observation can be clearly seen from the RSSI results in Fig. 2a especially
at the distance from 9-12 meters. This result might sound somewhat surprising and thus requires further investigations. This observation is currently under study using FEMLAB simulations (COMSOL AB 2003) of the same building and the results will be explained in a forthcoming paper (Mohammed 2005).

An important observation that can be made from Fig. 2b 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. A forthcoming paper (Mohammed & al., 2005) using FEMLAB simulations plotting the distribution of power (the 2D fading pattern) inside the office building will show a clear explanation of this tunneling phenomenon.

In Fig. 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 $10^{-4}$ 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 as shown in Fig. 3. In addition, the effect of fast fading on the measurement results is evident from the rapid fluctuation of the measured BER values in Fig. 3 for all antennas. Again, the Half Wave Model 1 antenna provided the best results (lowest BER values) among the other used antennas, which is clearly related to its high gain and efficiency parameters.
For NLOS scenario in Fig. 3a, 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. On the other hand for LOS scenario in Fig. 3b, 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. The BER results of the other antennas (for both propagation scenarios) were in between the above mentioned values.

Finally, the results of the data rate measurements are plotted in Fig. 4. From these plots we notice only a very slight reduction of the BT link data rates with increasing the distance. The data rate results are also in agreement with the pattern of the BER results in Fig. 3; that is the higher the BER value, the lower 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 of about 306.3 kbps was obtained by the Half Wave Model 1 antenna and the lowest data rate value of 301.16 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.

![Data Rate Measurement Results for NLOS](image)

**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.

### Conclusions

In this paper we have presented the results of measurement trials of the Bluetooth link employing different antennas 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 BT 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 trails have revealed that a link with lower BER values provide higher capacity (data rate), less power requirements and better coverage. Future work comprises investigating the effects of different transmission angles, polarization and antenna diversity on the BT link performance. In a forthcoming paper we will validate the results using theoretical analysis and FEMLAB simulation. It is hoped that these result would provide an insight into the performance of antennas for other indoor wireless technologies such as the emerging ultra wideband (UWB) radio communications where the antenna design and impact is expected to be even more critical.

### References