Indoor Propagation of Bluetooth Waves, Effect of Distance on Bluetooth Data Transmission, and Simulation of Wave Propagation

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Abstract: - This paper describes a study of how 2.45GHz electromagnetic waves propagate indoors. 2.45GHz is a typical Bluetooth frequency. Propagation models with both one and several transmitters have been made using an advanced computer program. Furthermore, a model of the propagation of 433MHz radio waves has been made and used as a standard point of comparison. To make sure that such models are reliable the study was renewed using a real 2.45GHz transmitter and receiver and then comparing the results to those given by one of the propagation models. In addition, the results of a study of Bluetooth traffic have been compared to the outcome of a propagation model created to represent a similar situation. Finally, the suitability of Bluetooth for indoor use is discussed.

Key-Words: - Bluetooth, propagation model, receiver sensitivity, data transmission, packet retransmission

1 Introduction

Bluetooth, the low cost technology to replace inconvenient cables, has been one of the most hyped technologies in the area of wireless communications lately. Bluetooth operates on the 2.4GHz (2,400.0 – 2,483.5) Industrial Scientific and Medical (ISM) band worldwide. Offices and other indoor facilities are considered to be especially suitable surroundings for Bluetooth.

In order to be a sufficient Bluetooth link the receiver sensitivity must be at least -70dBm with BER 0.1%. Bluetooth devices are divided into three classes by their power output:

Class 1	+20dBm	100mW,
Class 2	+4dBm	2.5mW,
Class 3	0dBm	1mW.

In this paper the question of how many 2.45GHz transmitters are needed to produce a receiver sensitivity of at least -70dBm everywhere in an apartment (circa 15m * 25m in size) is considered. The same has been done using common 433MHz transmitters to better illustrate the results. A comparison between the results of a Bluetooth traffic study and a propagation model is presented as well. The transmitters used in this study are omni-directional and belong to the third class (0dBm or 1mW). Such transmitters are used because their popularity in the area of personal area networks seems to be increasing day by day. Also, the results raise a question regarding the threshold frequency, namely whether -70dBm is a good minimum value or not. This matter is discussed as well.

2 Propagation Models

The computer program that was used to create the propagation models – computer programs and propagation models were discussed in [4] – shown in Fig.1, 2, 3 and 4 is based on an algorithm called Multi-Channel-Coupling. Basically, Multi-Channel-Coupling does not deal with individual rays but considers a propagation environment to be an assembly of attenuators and reflectors whose geometry defines a huge number of possible modes of interaction.

The only differences between Fig.1 and Fig.2 are the number and frequency of transmitters (the little crosses). In Fig.1 the frequency of all individual transmitters is 2.45 GHz while in Fig.2 the frequency is 433MHz. Otherwise the pictures are similar. All the transmitters are omni-directional (0dBm or 1mW) and placed at the height of 0.80m, and the floor plans are on the same scale. Furthermore, different wall materials are also represented in the pictures.

Fig.1 and 2 show that although a rather small apartment is in question, it takes at least five 2.45GHz transmitters to cover the whole apartment with receiver sensitivity of at least -50dBm

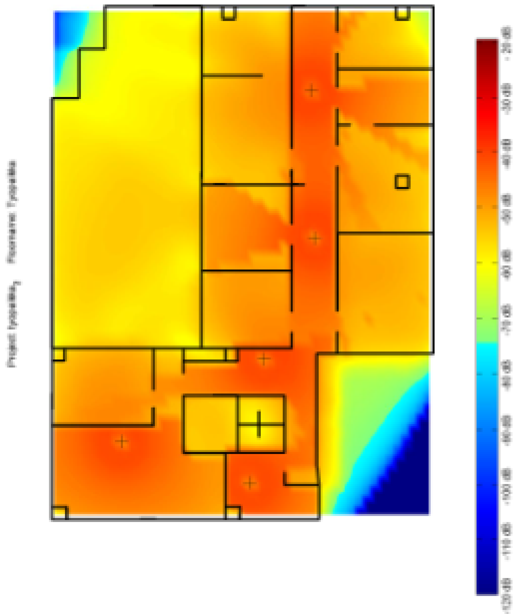

Fig.1 *Five omni-directional, 1mW, 2.45GHz transmitters are needed to secure that receiver sensitivity doesn't drop under -50dBm in the apartment.*

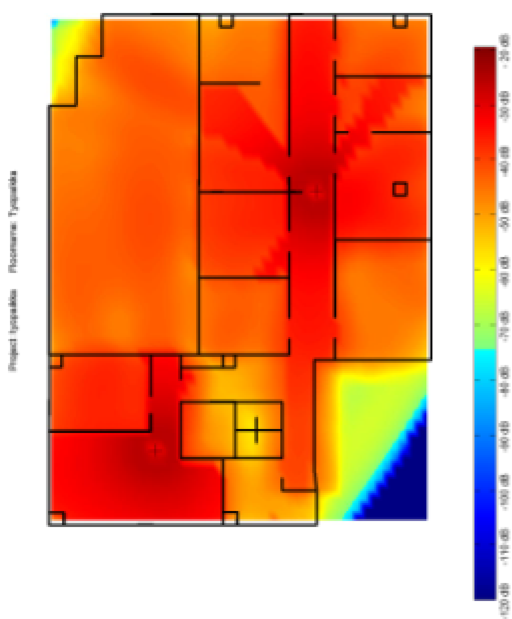

Fig.2 *Two omni-directional, 1mW, 433MHz transmitters are more than enough to produce even better results than in Fig.1.*

whereas only two 433MHz transmitters are needed to do the same. (The reason why -50dBm has been regarded as minimum receiver sensitivity here is explained in the next chapter.) As a matter of fact, a single rightly placed 433MHz transmitter can almost satisfy the requirements.

3 Experimental Validation

To verify the validity of the two propagation models described above a third model was created in which only a single transmitter was used. Fig.3 shows this propagation model. The transmitter of Fig.3 is exactly similar to the ones in Fig.1 (2.45GHz, 0dBm or 1mW, omni-directional) and it is also placed at the same height, 0.80m.

The next step was to use a signal generator and an omni-directional antenna as a transmitter and a spectrum analyzer and a similar antenna as a receiver. The transmitter was placed in the same place where it is in Fig.3 and at the same height, of course. The receiver was then moved around the apartment and results were taken in several places in every room and the corridors. No significant movement occurred during a single sweep of frequencies except that required to operate the equipment. In reality the surroundings where Bluetooth devices operate are dynamic, people move around a lot, for example. A typical result of movement during a sweep of frequencies is shown in Fig.4. The impact of multipath propagation, considered in [1], was taken into account as well, and its effects were brought to average by changing the position of the receiver in a standard way.

At first the experimental results seemed to differ quite a lot from those predicted in Fig.3. However, a closer look revealed that the difference was quite stationary everywhere in the apartment. The experimental results showed always roughly 20dBm lower receiver sensitivity than the propagation model. This suggested that in reality the transmitted signals might attenuate a little more than propagation models of Fig.1 and 2 indicate as well. Nevertheless, the figures can be considered fairly reliable because such models can only be suggestive at best. In addition, there are always people around whose movement in the line of transmission causes increased signal attenuation. This is why -50dBm has been regarded as the minimum receiver sensitivity in Fig.1 and 2.

4 Bluetooth Data Transmission Study

In order to provide further proof of the reliability of propagation models and also just out of general interest, a study of Bluetooth traffic was done using a real Bluetooth transmitter and a receiver. The focus of this study was in data transmission speeds and the time required for a successful transmission when the distance between the transmitter and the receiver was not kept the same. Packet retransmission was also studied. A similar situation was then depicted in a propagation model and the results were compared. Fig.5 shows the propagation model in question. As in all the other measurements the used transmitter was once again omni-directional and its power output was 0dBm or 1mW.

Let's have a closer look at Fig.5. The shorter distance between the transmitter (represented by the cross) and the receivers (the dots) is 5.80m while the longer distance is 8.90m. There is also a relatively thin plaster board wall in the direct line between the transmitter and the receiver that are separated by 8.90m distance.

A 1MB file was sent repeatedly to the receiver and finally a mean value for the required time, transmission speed and packet retransmission per cent was obtained. These mean values were then normalized using the average value obtained from the shorter range as a standard point of comparison. This way the comparison between the results of the Bluetooth traffic study and the propagation model is clearer and easier to understand than by comparing absolute values.

The normalized values indicated that it took on an average 1.20 times longer a time to transmit successfully when the distance was 8.90m instead of 5.80m. At the same time data transmission speed was only 0.83 times the speed obtained with a shorter range and even 9.89 times more packets had to be retransmitted. These results show that by lengthening the distance between the transmitter and the receiver a successful transmission becomes harder and harder. Data transmission speed becomes slower which makes the time required to transmit successfully longer. Also, a lot more packets have to be retransmitted. It is also noteworthy that no significant movement took place during the transmissions. In reality there usually is some sort of movement which makes transmissions even more difficult.

When the results of the Bluetooth traffic study were compared to the results shown in Fig.5 it could be seen that propagation models really can give a good idea of what to expect in reality. The receiver sensitivity is about -60 dBm around the receiver placed at a distance of 8.90m from the transmitter. Around the receiver that is nearer the transmitter the sensitivity is about -50dBm. This indicates that it takes somewhat more effort to transmit a file to the more distant receiver than to the nearer which it indeed does. Furthermore, if we use -50dBm as a standard point of comparison, it means that the receiver sensitivity is 1.20 times worse around the more distant receiver. The ratio between the average transmission times was exactly the same. Although comparing receiver sensitivity and transmission times is not that orthodox the two are closely related and this further establishes the reliability of propagation models.

5 Conclusions and Discussion

This paper has described a study of how 2.45GHz electromagnetic waves propagate indoors. Three different propagation models have been made using an advanced computer program. In order to make sure that the models are reliable, experiments have been done using a real transmitter and receiver. The experimental results have then been compared to those given by one of the propagation models. Also, a Bluetooth traffic study has been made and the reliability of propagation models has been discussed by comparing the results of the traffic study to those shown in Fig.5.

Based on the results it has to be said that while Bluetooth has indisputable advantages it is certainly not flawless. Five 2.45GHz omni-directional transmitters (0dBm or 1mW) are required to produce a receiver sensitivity of at least -70dBm everywhere in a quite small apartment. If the frequency was 433MHz, only two, perhaps only one transmitter would be needed to do the same. Furthermore, in offices and other places in which Bluetooth devices are designed to operate there are practically always people who move around from place to place which increases signal attenuation. Hence, even five 2.45GHz transmitters with 0dBm power output may not be enough in practice. It is tempting to use transmitters with higher power output but low power output has its advantages also, frequencies can be reused, for example. Because of this only a single transmitter and receiver was used in the experiments instead of many and focusing on the radio network performance of Bluetooth considered in [3]. On the other hand, with the help of smart antennas [1] – [2], for instance, the results might be significantly better than in Fig.1.

Finally, the results of this study raise the question of whether -70dBm is a suitable minimum receiver sensitivity or not. Taking into consideration the fact that the characteristics of the transmitter in use and coupling loss may attenuate the signal even up to 20dB, -70dBm leaves only so much scope for the "real" attenuation. The experimental results of this study, for example, suggested that already in the room next to the one where the transmitter was, the receiver sensitivity exceeded the minimum receiver sensitivity only just.

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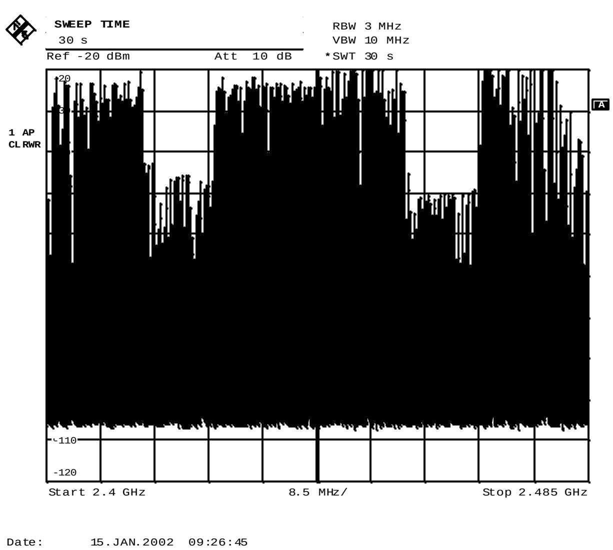

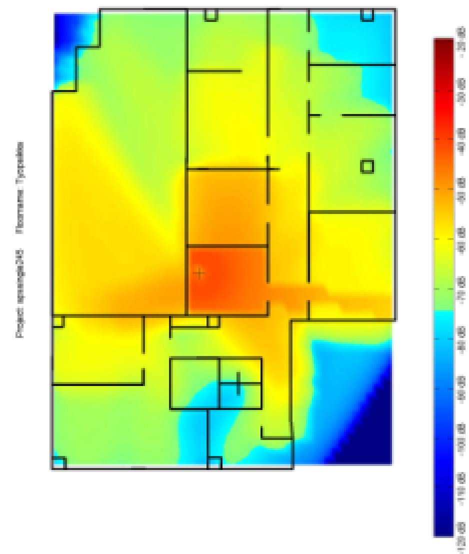

Fig.3 When only a single omni-directional, 1mW, 2.45GHz transmitter is used the attenuation of the signal can be seen very clearly.

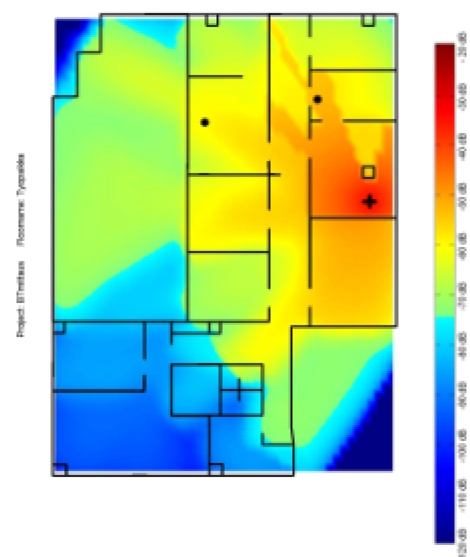

Fig.5 Distance clearly affects the receiver sensitivity. The distances between the transmitter and the receivers are 5.80m and 8.90m. The result is a 10 dB difference in the receiver sensitivities.

Fig.4 When people move in the line of transmission it normally results in a weakened signal like in the picture to the left.