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Indoor 60 GHz wideband communication channel prediction based on 18 GHz channel measurements

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Abstract. Due to the trends for new wideband services we decided to analyse the behaviour of the 60 GHz communication channel. In this paper we presented our conclusions of the 60 GHz communication channel behaviour based on the behaviour of 18 GHz communication channels. Due to the lack of very expensive and necessary equipment we decided to assume the behaviour of 60 GHz channel based on measurements at 18 GHz that have been available to us. Measurements at 18 GHz that were performed inside the building were taken from the literature for the time and frequency domain. Based on these measurements, we found out for new services at 60 GHz that we have to take into account factors which influence on the quality of the received signal. Factors such as moving people, echoes from the walls of the building, echoes of the lift shafts, stairways, etc. influence non negligible on the level of the received signal.

Keywords: 60 GHz communication channel, 18 GHz communication channel, channel measurements, transmitting antenna, receiving antenna

Predikcija lastnosti 60 GHz širokopasovnega kanala na podlagi meritev 18 GHz komunikacijskega kanala

Povzetek. Danes se vse bolj uveljavljajo širokopasovne storitve na majhnih razdaljah, kar pomeni razvoj storitev na čedalje pomembnejšem področju 60 GHz komunikacij. Pri razvoju novih storitev v delovnem in domačem okolju moramo upoštevati obnašanje kanala v zaprtem prostoru. Zaradi nam nedostopne in drage merilne opreme in nedostopnih meritev 60 GHz kanala smo iz literature povzeli nam dostopne meritve 18 GHz kanala. Na podlagi povzetih rezultatov meritev 18 GHz kanala, izvedenih v stavbi, smo predvideli obnašanje 60 GHz širokopasovnega komunikacijskega kanala.
V prvem delu so predstavljene meritve in obnašanje signala 18 GHz kanala. Iz teh karakteristik smo sklepali na časovno obnašanje signala 60 GHz kanala v merjenem prostoru hodnika stavbe. V drugem delu članka smo na podlagi omenjenega 18 GHz kanala sklepali na obnašanje 60 GHz kanala v frekvenčnem prostoru. Na podlagi teh meritev smo ugotovili, da moramo pri novih storitvah mobilnega 60 GHz komunikacijskega sistema upoštevati tudi dejavnike vpliva na kakovost sprejetega signala, kot so gibajoče osebe, odboji od sten stavbe, odboji od jaškov dvigal, stopnišč itd.

Ključne besede: 60 GHz komunikacijski kanal, 18 GHz komunikacijski kanal, meritve kanala, oddajna antena, sprejemna antena

1 Introduction

A huge bandwidth of up to several gigahertz was set aside for unlicensed wireless communication. This continuous block of millimeter-wave frequency spectrum has become of special interest for high data rate WLAN for several reasons. Firstly, this spectrum is unlicensed, meaning that there is no need to buy a license before operating equipment within that spectrum. The licensing process is typically very time-consuming.

The millimeter-wave spectrum is a portion of the electromagnetic spectrum where the wavelength varies from ten millimeters (30 GHz) down to one millimeter (300 GHz). This spectrum enables two-way wireless communications at data rates that previously could only be accomplished with fibre optic cable.

The interest for this frequency band analysis comes from a phenomenon of nature: the oxygen molecule (O_2) absorbs electromagnetic energy at 60 GHz. This absorption is much higher at 60 GHz than at lower frequencies that are typically used for wireless communication. The absorption attenuates 60 GHz signals over distance, so that they cannot travel far beyond their intended recipient. Another consequence of O_2 absorption is that radiation from one particular 60 GHz radio link is quickly reduced to a level that will not interfere with other 60 GHz links operating in the same geographic vicinity. This reduction enables higher frequency re-use.

As mentioned above, this frequency band is suitable for short-distance communication, especially in indoor environments. This is due to severe additional absorption attenuation at a range of 10-15 dB/km

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(compared to free-space attenuation) by oxygen molecules in the atmosphere. Also, both brick walls and concrete floors in an indoor environment can cause an additional attenuation of several tens of decibels, which limits an indoor cell to one floor in a building or even one room. This gives an advantage that the frequency band can be re-used at a short distance.

Highly focused antennas minimise the possibility of interference between links in the same geographic area and the risk that the transmission will be intercepted. They also maximise performance. Operating at higher frequencies results in a more focused antenna. Antenna directivity is limited by the physical principle of diffraction which states that the beam width is inversely proportional to the operating frequency. Therefore at 60 GHz, the beam width is far narrower than at the lower frequency unlicensed bands. Table 1 shows the beam width for several unlicensed frequency bands.

Frequency	Beam Width
2.4 GHz	**117 degrees**
24 GHz	**12 degrees**
60 GHz	**4.7 degrees**

Table 1. Beam width for several unlicensed frequency bands (for 1 – foot diameter antennas)

On the other hand, radio communication in the 60 GHz frequency band is limited by the transmitted signal power since the free-space loss is very high compared to that in the low-frequency band of 2-5 GHz. Furthermore, if the receiver is located in the non line-of-sight region, even more signal power is required due to the shadowing effect and the diffraction feature. Nevertheless, in a small indoor environment, reflective objects and walls will induce more reflections and may therefore benefit the level of the received signal power.

The 60 GHz band is an excellent choice for high-speed Internet, data, video and audio indoor communication. It offers numerous benefits such as: unlicensed used, highly secure operation, excellent immunity to interference, high level of frequency re-use, possibility of fibre optic data transmission speeds, mature technology – this spectrum has been used for secure communication such as satellite-to-satellite communication.

Characteristics like high security, excellent immunity to interference and a high level of frequency re-use result from the short transmission distance due to oxygen absorption and a narrow antenna-beam width.

2 Definition of the problem

The problem which we wanted to analyse was the characterization of the signal propagation in indoor communication systems at 60 GHz. However, due to the lack of very important and expensive equipment we decided to analyse all available articles and documented measurements made by other laboratories. Our problem of analysing the communication channel at 60 GHz was then aided by using the results of already existing articles where measurements had been made at 18 GHz only. Our assumption was that relative differences between 18 GHz and 60 GHz signal are small and that differences are mainly in the beam width and in the level of the received signal. The 60 GHz signal has bigger attenuation due to the oxygen absorption. Also, due to the narrower beam width the number of multipaths at the receiver site was expected to be smaller. If we take that into account, the level of the 60 GHz signal at the receiver site should be smaller compared to the 18 GHz signal under the same conditions. We summarised the articles given in the references for the 18 GHz in the following text.

3 The indoor channel Radio Propagation Measurements and Modelling

3.1 Statistical model of the channel in the time domain

The results presented in this subchapter [3] provide a prediction of the signal behaviour in indoor corridor environments including the dynamic effects of people. In-building structures strongly affect the signal transmission, and the purpose of this measurement campaign was to derive a path loss model considering site specific information. Indoor radio propagation is very complex and difficult, because the shortest path between transmit and receive locations is usually blocked by walls, floors, ceilings, doors or other objects. The variability of architectural configurations, the internal layout and the building materials drastically influence the indoor radio channel.

The variation in the received signal level in indoor areas can be characterized by a slow fading and fast fading component. The slow fading describes the fact that the average signal level decreases, as the distance from the transmitter increases. The fast fading component describes the fluctuation of the received signal power due to the movement of the receiver over small distances.

As is the case with the outdoor mobile systems, there are several important parameters that have to be examined. The path loss and statistical characteristics of the received signal envelope are the most important for coverage planning. Another basic parameter that was investigated is the effect of the human presence and movement in the area of radio paths.

During the first measurement, the transmitting system T_x was stationary and the receiving equipment R_x was moved along a predefined direction of the corridor. The configuration of the corridor is shown in Figure 1. The transmitting system was placed at one end of the corridor, 2 m before the intervening door. The distance of 1 m from the transmitting antenna in the direction of other measurement sites was chosen as the reference distance (calibration procedure). The purpose of the calibration procedure is to obtain the transfer function of the receiving system. Since, at 1 m T_x-R_x separation distance it is expected for signal to have a strong LOS (Line Of Sight) component which predominates any signal components scattered by the local environment.

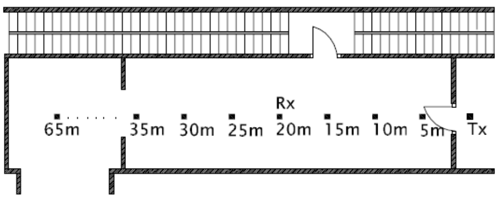

Figure 1. Configuration of the corridor

Starting 5 m from the transmitting antenna, measurements are taken at equal intervals of 5 m. To obtain the average signal power at each measurement position, the receiving antenna was moving with a constant velocity at a distance of 1 m in front and behind the fixed measurement position. A total corridor distance of 65 m was covered in this experiment. This first measurement, at 5 m from T_x antenna, was conducted in LOS conditions in the main corridor. However, there were strong reflection conditions because of the geometry of the location.

The same measurement procedure was followed for the second set of measurements at 10 m from T_x antenna. The measurements were taken in the corridor with the intervening door closed. In that case it was a partial LOS, because of the attenuating of the LOS component through the door.

The variation of the received power in the case of turning the corner between two corridors, in NLOS (Non Line Of Sight) conditions, was also measured. The measurements sites were 2 m before and 2 m after the turning point (see Figure 1). The diffraction area of the corner is highly absorptive, containing walls of brick and concrete. Another set of measurements was done with T_x-R_x antennas located on different floors, followed by the same procedure mentioned above.

All measurements were performed during times of typical activities.

3.1.1 Data Analysis and Results

The rapid variation in the signal power while the receiving antenna is moving over small distances toward or away from the transmitting system is called fast fading. Fast fading is the main reason for the degradation in the performance of an indoor system because of the rapid changes in the level of the received signal envelope.

Figure 2 shows these signal fluctuations, known as envelope fading. The receiving antenna is moving within 2 m toward and away from the transmitting antenna. The T_x-R_x distance separation is 30 m and 50 m. The dynamic range on the receiving side, over a small distance, is typically 5-20 dB. The signal fading contributes to the interference of received multipath signals. It was measured in LOS and NLOS conditions.

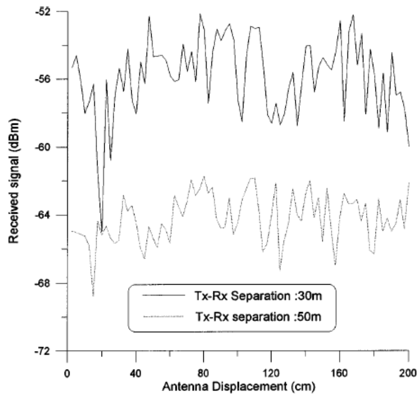

Figure 2. Received signal envelope in 2 m track antenna displacement for Tx-Rx separation 30 m and 50 m. [3]

Movement of the receiving system over small distances influences the amplitude of each multipath component of a transmitting system. In that way it influences the received signal envelope. The fluctuation of the received signal envelope (its velocity and amplitude) depends on the speed of the receiving system and the measurement environment.

A signal transmitted through an indoor wireless channel will typically experience random variation due to blockage from objects in the signal path. Such variations are also caused by changes in the reflecting surface and scattering objects due to the movement of the receiving system. Changing the position of the receiver, multipath signals will experience different attenuation conditions and due to that will cause variations in the received signal envelope.

First, the corridor measurement data was analysed at different distances from the transmitting site. The standard deviation of the measured signal level at different distances from the transmitter is shown in [3] (page 100). It can be observed that the standard deviation of the signal level is relatively small when the receiver is close to the transmitter. As the T_x-R_x separation distance decreases, so does the number of multipath components. In that case, multipath components across about the same distances provide nearly the same received powers. All this results in a small standard deviation. In such conditions the LOS power component is dominant.

3.1.2 Dynamic effects of indoor moving people

Personnel activity affects multipath signal components so that the received signal envelope varies with respect to the reference value without any personnel activities. Signal amplitude variations caused by people's activities when both antennas are fixed is called temporal fading.

Several data signals were measured in a hallway with different T_x-R_x separation distances, during personnel activities in the vicinity of two antennas. The transmitting and receiving antennas were fixed at the same height above the ground, and up to 5 people were randomly moved at a distance of 2-3 m away from them. Figure 3 presents a typical plot over a time period of 30 seconds. The percentage of deep fades is generally low and it depends on the number of active people during the measurement period.

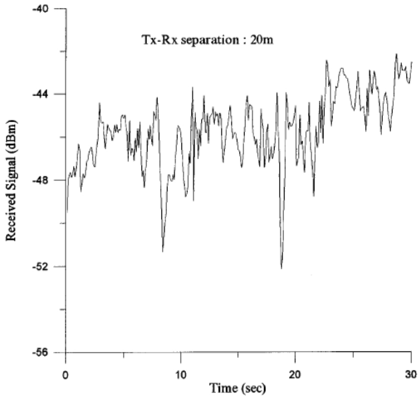

Figure 3. Received signal level due to personnel movement in a 30 second time period. [3]

3.1.3 Path-loss corridor models

The case where the average signal level decreases as the distance from the transmitter increases is called slow fading.

Path loss generally increases logarithmically with the distance. The Single-Slope Model (1SM) can be described by the following equation:

$$L(dB) = L_0(dB) + 10n\log d \tag{1}$$

Where L_0 represents the path loss at 1 m, n represents the propagation loss exponent and d is the T_x-R_x separation distance in meters. The measured data were fitted to a linear function in order to derive a mathematical expression of the model mentioned above. The value for n was found to be around 2 (open hallways within buildings). However, the proposed mathematical model does not include losses dictated by walls and floors which obstruct the direct ray between the transmitter and receiver. The model which includes the aforementioned additions is given by:

$$L = L_{FS} + L_C + \sum_{i=1}^{I} K_{wi}L_{wi} + K_f^{\left[\frac{k_f+2}{k_f+1}-b\right]}L_f \tag{2}$$

where:

- L_{FS}: free-space loss between transmitter and receiver
- L_C: constant loss
- K_{wi}: number of penetrated walls of type I
- K_f: number of penetrated floors
- L_{wi}: loss of wall type I
- L_f: loss between adjacent floors
- b: empirical factor
- I: number of different wall types

Walls were categorized in two types: *light walls* made of brick, wood, simple glass or light concrete, and *heavy walls* made of brick stone or reinforced concrete.

The following cases are considered:

1) T_x and R_x antennas on the same floor with LOS conditions.
2) T_x and R_x antennas on the same floor without LOS conditions between them (intervening door closed). A typical result, obtained from fitting the data is shown in Figure 4a.
3) T_x and R_x antennas on the same floor - path loss model due to temporal fading (caused by personnel movement). A typical result, obtained from fitting the data, is shown in Figure 4b.
4) Rx antenna turning from one corridor to another (Figure 5).
5) Tx and Rx antennas on different floors - a one floor separation case (Figure 6).

The measurements that were taken in the main corridor show a higher level of the received signal power compared to those in a free space. This is because of the wave-guided effect, a process where reflections are canalised by certain wall configurations and can bring significantly higher signal levels compared to the case of free-space propagation. This effect was observed in long and narrow corridors with LOS assumption. For the propagation measurements in the main corridor the propagation loss exponent n was found to be smaller than in the free space, where n = 2. This is because the long and narrow corridors with walls up to the ceiling result in a strong wave-guided effect. It was observed that diffraction areas are negligible when turning from one corridor to another. The corner effect is shown in Figure 5. The dynamic signal range drops from 10 dB 2 m before the turning point to 5 dB 2m after the turning point. The decrease in the average signal level at the moment of turning the corner is 15 dB.

In the one floor separation case in Figure 6, there is a strong evidence that the signal is being channelled up by stairwells and lift shafts. The building configuration provides ways to bring the low but not negligible signal level to a location close to the receiving site that should be taken in consideration.

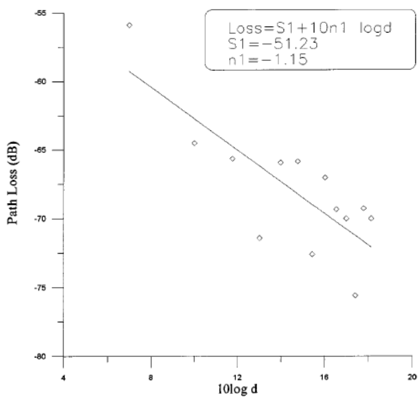

Figure 4a. Tx-Rx on the same floor without LOS conditions between them (intervening door closed). [3]

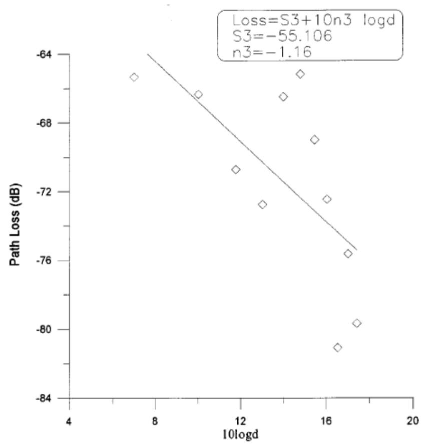

Figure 4b. Tx-Rx on the same floor – path-loss model due to temporal fading. [3]

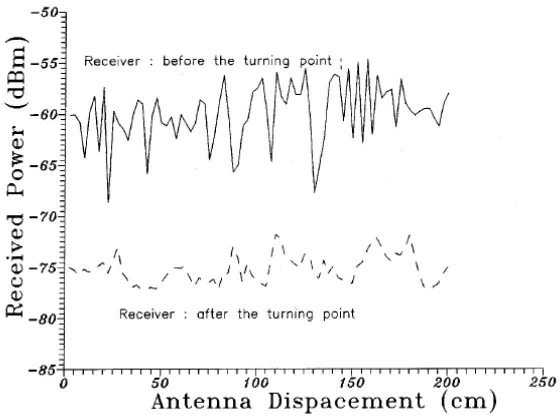

Figure 5. Comparison of envelope fading before and after the turning point in the corridor. [3]

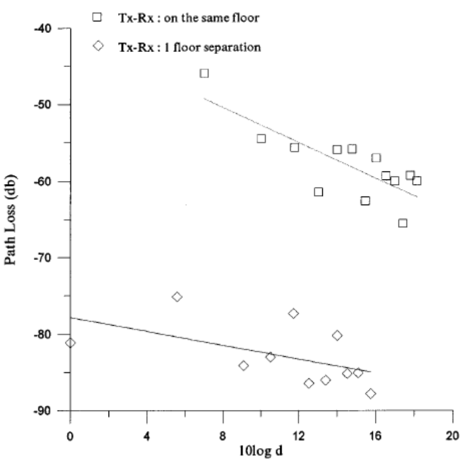

Figure 6. Comparison of measurement results for corridor and floor cases. [3]

3.2 Statistical model of the channel in the frequency domain

The present greatest challenge in the design of wireless local area networks (WLAN) is perhaps overcoming the restriction of the transmission rate due to the multipath dispersion of the radio waves. Since it is impractical to attempt to eliminate the multipath disturbances, an accurate channel model is desirable to minimise the effect of multipath propagation.

The deployment of omni-directional antennas ensures a good area coverage of the radio waves. However, it also generates many multipath components at the receiving site. Thus, the low transmission rate of the system has to be imposed.

Some researches have proposed the use of directional antennas in order to increase the transmission data rate. In order to explore the potential of high data rate transmission (high speed WLAN), measurements of indoor radio channels in the frequency domain were carried out in a laboratory at 18-19 GHz using directive antennas.

3.2.1 Measurement technique

The frequency-sweeping technique was chosen for the measurement. The frequency range swept was 18-19 GHz in steps of 1.25 MHz (801 points). Each sweep took 400 ms. Within this short period, the channel could be assumed as static. Due to this, the time-invariant model was used for channel modelling.

In order to analyse frequency characteristics of the channel, the frequency response was collected. Both antennas were placed at a height of 1.8 m. Before data collection, the measurement setup was calibrated in an empty room with an antenna separation of 1.06 m. The frequency response of the channel in [4] (page 23) shows that within a 35 dB range below the strongest path (the direct path), no other multipath components were detected. Therefore, the dynamic range of the power delay profile was chosen to be 30 dB. This guaranteed that the multipath components detected in the measurements were caused by the channel instead of the measurement setup.

3.2.2 Measurement plan

The measurement data were divided into two categories: the mid-scale; and large-scale measurements. The mid-scale measurements were taken at antenna separations of 5 m, 8 m and 12 m. Only LOS data were collected at antenna separations of 5 m and 8 m. At an antenna separation of 12 m, both LOS and NLOS locations were tested. Two hundred profiles were recorded for each antenna separation. The large-scale measurements were also composed of 200 profiles with antenna separations varying from 1.5 m to 20 m.

In order to get enough profiles in the mid-scale measurement, the transmitter and receiver were not fixed at one location but all the time keeping the distance between them. During the large-scale measurement, the receiver was fixed at the corner of the laboratory, and the transmitter was moved in the channel. These two antennas were always aligned to ensure the strongest power reception.

The statistical properties of the channel parameters, such as the power attenuation, the arrival times and the amplitudes of the multipath components are described. The theoretical probability distributions (specified in [1]), are compared with the empirical result and the best theoretical model is chosen.

The characteristics of the power attenuation are presented in two ways. Firstly, as the statistics of the average power attenuation for all three groups of the mid-scale measurement. Secondly, as the dependency of the power attenuation on the antenna separation. The average power attenuation for each power-delay profile is calculated by taking the mean of the frequency response amplitude at each frequency point swept as given in the following equation:

$$PL(dB) = \frac{1}{801}\sum_{k=1}^{801}\left|a_f(k)\right| \qquad (3)$$

where $a_f(k)$ is the amplitude of the frequency response of the k-th point. From the average power attenuation obtained for each profile, the statistical distribution is calculated for each antenna separation. The empirical data show a very close fit to the theoretical lognormal distribution as shown in [4] (page 24).

The power-distance dependency is a parameter to predict the coverage range of the radio waves. This dependency (power loss) can be expressed as:

$$PL(dB) - PL_0(dB) = \left|10n\log_{10}\frac{d}{d_0}\right| \qquad (4)$$

where *PL*(dB) represents the power loss at the measurement point in decibels, PL_0(dB) is the power loss at the reference point, *d* is the T_x-R_x distance separation, d_0 is the reference T_x-R_x distance separation and *n* is a propagation loss exponent. In the last equation only the parameter *n* is unknown. *PL*(dB) is the power loss of one profile and is calculated from equation (3) as the mean of the frequency response amplitude at each frequency point swept. PL_0(dB) is calculated in the process of calibration in the empty room for the antenna separation of 1.06 m.

To calculate the exponent *n*, the large-scale measurements must be computed to find [*PL*(dB)-PL_0(dB)] and [10 $\log_{10}d/d_0$] for all measurement points (profiles). The large-scale measurements were composed of 200 profiles (measurement points) with antenna separations varying from 1.5 m to 20 m. The results are then plotted in the coordinate of the power loss expressed in dB versus the distance expressed in the log-scale. The relationship should be described by a line starting from the origin point with the slope equal to the exponent *n*.

The method of comparing the broadband and the narrow band power loss can be approximated by comparing their propagation loss exponents, *n*. The reason lies in the fact that increasing the propagation loss exponent *n* results in an increase in the Power Loss *PL*(dB), and vice versa.

The *n* value was calculated using the least mean-square error technique for the average power loss and for the CW (constant wave) power loss and was presented in Table 2 for several cases. The calculation of the average power loss was given by the equation (3). The CW power loss is the frequency response amplitude at a single frequency point. In this calculation, the frequency point of 18.5 GHz was chosen. The *n* for the average and CW power losses is shown in Figures 8a. and 8b., respectively.

	Average Power Loss	**CW Power Loss**
LOS data	**1.9454**	**1.8256**
NLOS data	**2.7651**	**2.6515**
All data	**2.2966**	**2.2047**

Table 2. Average and CW power losses for several cases.[4]

It should be noted that the power loss is not only determined by the propagation loss exponent *n*, but also by the wavelength of the microwave. For the 18 GHz microwave, its wavelength is only 1.6 cm. Thus, for a 30 m antenna separation, the power loss will be about 100 dB.

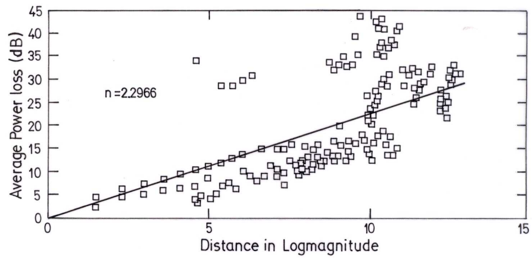

Figure 8a. Average power loss vs. Distance. [4]

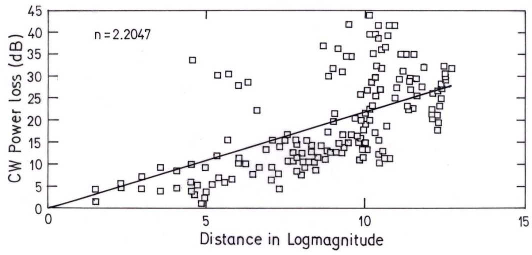

Figure 8b. CW power loss vs. Distance. [4]

Therefore, the cell size of the WLAN must not be too large, otherwise the power loss can not be recovered at the receiver end. However, this provides an advantage when using this frequency band: the possibility of reusing the same frequency in the nearby cells.

4 Conclusion

There exists a great interest in new applications and services in the 60 GHz radio frequency channels for indoor communication. Due to the fact that we focused our activities on new services in small mobile communication cells, we should have analysed the 60 GHz channel characteristics. Due to the lack of very important measurement equipment, we were forced to analyse characteristics of the 18 GHz communication channel, the nearest frequency communication channel for which we had measurement results.

Our focus was on the frequency and time analysis of the communication channel in indoor environments. The biggest influence on characteristics of the 60 GHz channel is the atmospheric oxygen absorption, which results in additional attenuation of 15 dB/km compared to free-space attenuation. Therefore, it is not convenient for long-range radio communication applications. Comparisons between 60 GHz signals and signals at much lower frequencies (2 – 5 GHz) showed severe differences. The most important one is that 60 GHz signals penetrate walls less easily. Therefore, this frequency is usable for transmission in confined places only. Attenuation through walls is big enough to minimise the influence on the receiver sites in adjacent places. The configuration of the building influences the levels of the received signals on the lower floors through the reflected signals channelled by stairwells and lift shafts. Those levels are low but not negligible even at 60 GHz. Therefore, their possible influence should be taken into consideration.

The nearest future home and office networking environment is predicted to be dominated by a variety of multimedia services like wireless HDTV, wireless home entertainment, or virtual wireless office. To support these applications, the required data rate offered to the user has to be in the order of hundreds of Mb/s, justifying the need for developing a short-range gigabit wireless system supported by optical network. More attention has recently been paid to the 60 GHz band as a potential candidate for radio layer of future indoor networks as it provides a 7 GHz continuous bandwidth for unlicensed operations worldwide. This huge bandwidth coupled with the mentioned signal attenuation beyond a few meters makes the 60 GHz mm Wave band a suitable candidate for supporting short-range applications.

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5 References

[1] Homayoun Hashemi, The Indoor Radio Propagation Channel, Proceedings of the IEEE, Vol. 81, No. 7, July 1993.

[2] Hirofumi Suzuki, A Statistical Model for Urban Radio Propagation, IEEE Transactions on Communications, Vol. Com-25, No. 7, July 1977.

[3] N. Papadakis, A. Economou, J. Fotinopoulou and P. Constantinou, Radio Propagation Measurements and Modeling of Indoor Channels at 1.8 GHz, Wireless Personal Communications, No.9, 1999, pp. 95-111.

[4] M. A. Do and Sumei Sun, Statistical Modeling of Broadband Wireless LAN Channels at 18 GHz Using Directive Antennas, International Journal of Wireless Information Networks, Vol. 4, No.1, 1997.

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