PROPAGATION INTO AND WITHIN BUILDINGS AT 900, 1800 AND 2300 MHz

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ABSTRACT

Investigations of propagation into, and within, buildings at 900, 1800 and 2300 MHz have been undertaken. The composite Rayleigh-plus-log-normal distribution successfully modelled the measured cumulative distributions of all measurements. The average measured penetration loss at ground floor level was found to be 14.2, 13.4 and 12.8 dB respectively at 900, 1800 and 2300 MHz. The rate of change of penetration loss with height was -1.4 dB per floor. The rate of change of mean signal level for signals travelling within buildings was, on average, 8.5 dB per floor. The path loss attenuation factor, n, that best modelled the within-building measurement was found to be 5.3, 5.5 and 6.0 respectively for 900, 1800 and 2300 MHz.

1. Introduction

The dramatic changes in the nature of mobile radio technology in the past decade have had a very clear impact on the general communications environment. The relatively unsophisticated technology of the early 1970's has given way to much more advanced components and equipment, and the demand for mobile communication services has led to the development of new systems that operate in higher frequency bands. The move towards 'personal communications', i.e. communication with hand-held rather than vehicle-borne equipment, has led to the realisation that not enough is known about radio propagation either into or within buildings. In this context, *into* is used to identify the scenario where a conventional base station on a hilltop site or atop a high building communicates with a radio receiver that is inside another building. On the other hand *within* is used to identify the case when both transmitter and receiver are inside the same building.

This paper contains the results of an investigation of radio propagation into and within buildings at 900, 1800 and 2300 MHz. Measurements of the average signal strength and the signal variability have been made using buildings within the University of Liverpool precinct. These tests were intended, inter alia, to establish whether the *Rayleigh-plus-lognormal* statistical model that successfully describes the signal received at street-level outside buildings still applied, or whether it would be necessary to devise an alternative model. The signal variability is discussed in both *into* and *within* building measurements. The building loss factor, which is included in the vehicular mobile model to account for the increase in attenuation of the received signal observed when the *mobile* is moved from outside a building to inside, is discussed in the *into* building measurements. The variation in signal strength as a function of distance is described in the *within* building measurements.

2. Experimental procedure

One readily accessible property of the signal transmitted over a mobile radio propagation path is the variation of its envelope as the position of the mobile terminal is changed. It is well established that the signal statistics can be modelled as a combination of a small-scale quasi-stationary process (multipath), superimposed on a large-scale process (shadowing). The scattering model which describes the local, i.e. small area statistics, follows a Rayleigh distribution, and the local mean (i.e. the signal strength averaged over the Rayleigh fading) is log-normallly distributed.[1]

For a given distance from the transmitter, the difference between the mean signal strength on one floor of the building and the mean signal strength measured in the streets, immediately outside, can be defined as the penetration loss for that floor.[2] One purpose of the current propagation study has been to determine the building loss and its variation in a form that can be combined with vehicular mobile studies to give an estimate of coverage *into* buildings.

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It has been also shown [3] that the local mean varies with the distance between the base station and the receiver and, is given by a law of the form

$$mean\_signal\_strength = intercept + 10\log_{10}(d^{\,n}) \qquad (1)$$

The obtained values for the *path loss attenuation factor*, n, are given in the *within* buildings measurements.

The method used to obtain the results was to transmit a continuous wave (CW) signal from a fixed base station; this was received and recorded for subsequent analysis by mounting a receiver and data-logging system (DLS) on a trolley which could be moved around within the building concerned. Spatial sampling was facilitated by attaching a slotted disc to a fifth wheel on the trolley.

In order to process the data collected in a particular room in the building, each sample was normalised by the average signal strength within that room. The normalised data for each room was then collated to form a data file consisting of the fast-fading component only. The distribution of this fast-fading signal describes the small scale signal variations.

The large scale signal distribution was determined by testing the departure (in dB) of the average signal strength of each room from the average signal strength for the whole building. The difference between the average of the measurements carried out in all rooms of one particular floor and the average of the measurements at street level was treated as the building penetration loss for that floor.

3. Into building measurements

Measurements of the received signal strength were undertaken within buildings in the University of Liverpool precinct. The buildings were Blocks A and B of the Department of Electrical Engineering & Electronics and the Departments of Computer Science and Life Sciences, these buildings being at 180, 240, 300 and 350 m, respectively from the transmitter. No line-of-sight existed between Electrical Engineering Block B and the transmitter. Partial line-of-sight existed, however to the three other buildings. A general description of each building was given in reference 4. The transmitter was located on the roof of the Mechanical Engineering building, at a height of 40 m.

Twelve experiments, four for each frequency setting, were conducted. The cumulative distribution of the small scale signal variations and of the large scale signal variations for 1800 MHz were discussed in references 4 and 5. Nevertheless the significant conclusions, considering all three frequency settings, are:

1. The small scale variations are Rayleigh distributed.
2. The large scale variations are log-normally distributed with a standard deviation related to the condition of transmission. The standard deviation were found to be 8.09, 7.60 and 7.56 dB for 900, 1800 and 2300 MHz respectively, i.e. the values of standard deviation decreased slightly as the carrier frequency increased. Examination of the results also shows a value for the standard deviation of around 5 dB when no line-of-sight existed, whereas, for a partial line-of-sight condition, the standard deviation increased to approximately 8.5 dB.

References 4 and 5 describe in some detail the *building penetration loss* for 1800 MHz. The average penetration loss at ground floor level was found to be around 14.2, 13.4 and 12.8 dB respectively at 900, 1800 and 2300 MHz. It has also been found that the penetration loss decreases with height at a rate of 1.4 dB per floor in average (-1.38, -1.36 and -1.50 dB for 900, 1800 and 2300 MHz). It was noticed however, that the penetration loss increased for floor levels higher than the sixth floor, with a rate of change of 0.2 dB per floor in average (0.45, 0.36 and -0.22 dB). These anomalies, which had also been reported in the literature, were attributed to the relative position of base station, measured and obstructing buildings or other physical structures. It should be finally noted that, as reported in reference 2, the penetration loss decreased slightly as the frequency of transmission was increased. This is in contrast to the well known fact that path loss increases with the transmission frequency. In free space propagation, for example, the path loss increases by 6 dB when the frequency of transmission is doubled. Therefore, as far as propagation into buildings is concerned, by increasing the frequency of transmission, some of the additional path loss can be compensated by lower building penetration loss values.[4]

4. Within building measurements

Personal Communication Network (PCN) systems are expected to utilise a small cell structure in order to meet the very large demand expected for mobile radio services. In dense urban areas (e.g. the city of London), microcells, or even picocells, may be used. In some situations one large building alone can comprise a microcell and in this case the base station will be situated within the building. An understanding of the propagation mechanism within buildings is therefore very important and essential.

Twenty two experiments for 1800 and 2300 MHz, and six experiments for 900 MHz have been conducted within the four buildings of the University precinct. In order to determine the transmitter location which gives the best signal coverage, six different rooms in the Electrical Engineering Block A, and three in the Computer Science were selected as base station for 1800 and 2300 MHz.

The small-scale signal variations, at the three frequencies, were very closely represented by a Rayleigh distribution and overall, the transmission conditions hardly affected this distribution. Although, the results suggest that the large-scale signal variations can also be modelled by a log-normal distribution, the standard deviations are high: 16.0 dB, 16.5 dB and 17.8 dB respectively for 900, 1800 and 2300 MHz. The values are high, mainly because the mean signal strength on the floor where the transmitter is situated is very high, while the mean signal levels on floors further away from the transmitter are much lower.

In order to compare the dependence of the median (50%) signal level on the position of the transmitter inside the same building, the cumulative distribution of the large-scale signal variations, for the six experiments in the Electrical Engineering Block A, and for the three experiments in the Computer Science, were plotted and the results for 1800 MHz are shown in reference 4. Similar results were found for the 2300 MHz setting (see Fig. 1); considering, for example, the Electrical Engineering Block A, it can be observed that, when the transmitter was placed in a very large room, which occupies the centre of the building between the fifth and the sixth floor, the median signal level increased by about 15 dB compared with the value measured when the transmitter was in the foyer. When the transmitter was located in a very large room, with a large window area, near the centre of the building, the median was 7.5 dB higher than when it was located in a small room, with no windows, in the centre of the same floor. Although, the very large room at the top of the building yielded the highest median signal strength, the large room in the middle of the building, with large window area, provided the best coverage: the minimum mean signal value of its distribution was found between 7 dB and 10 dB higher than the minima of the other distributions.

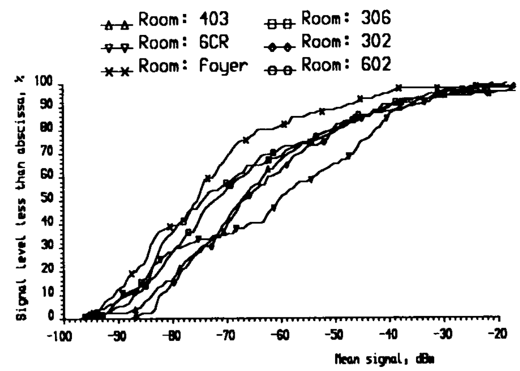

Figure 1 : Comparison of the cumulative distribution function of large-scale signal variations for different transmitter locations within Electrical Engineering Block A, at 2300 MHz

The floor mean signal levels were calculated and the values plotted in a graph which shows the gradient of their variation from floor to floor. Fig. 2 gives, for example, the results for 2300 MHz. Examination of those graphs, for each frequency, reveals two different slopes: 6.5, 6.1 and 6.7 dB per floor, respectively for 900, 1800 and 2300 MHz, when considering floors below that on which the transmitter was located and, similarly, -10.5, -10.4 and -10.8 dB per floor, when considering the measurements conducted on floors above the transmission location. The results may be attributed again to the relatively different positions of base station and obstructions around the lower and upper floors. However, changing the frequency, has scarcely affected the value obtained in either event, i.e. receiver below or above the transmitter. Therefore, the global average rate of change of the mean signal level calculated, was 8.5 dB per floor.

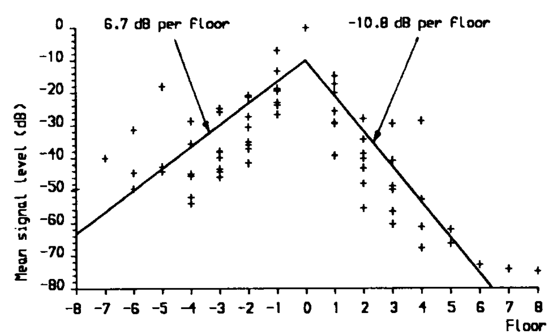

Figure 2. : Normalised floor mean signal level against number of floors separating the receiver and transmitter

The regression analysis applied to the scatter diagram of the mean signal strengths, calculated for each room in one particular experiment, yields the *path loss attenuation factor*, n, defined in eqn. (1), This factor describes the association between the mean signal strengths and distances from the transmitter. The *correlation coefficient* of the scatter diagram also indicates the degree of association between the two variables, i.e. a *correlation coefficient* close to 1 indicates a strong association, which means that knowing one variable helps in predicting the other, whereas a *correlation coefficient* close to 0 indicates a weak association, and information about one variable does not give much information about the other.

The path loss attenuation factors were found equal to 5.3, 5.5 and 6.0 respectively for 900, 1800 and 2300 MHz, i.e. increasing slightly with frequency. The correlation coefficients have been determined around 0.7.

5. Conclusions

It has been confirmed that the Rayleigh plus lognormal model is adequate to describe the signal envelope variations, the standard deviation of the lognormal component being between 5 and 8.5 dB depending on the transmission conditions and frequency. The average penetration loss at ground floor level was found to be 14.2 dB at 900 MHz, 13.4 dB at 1800 MHz and 12.8 dB at 2300 MHz. As the receiver was moved to the upper floors of a building, the penetration loss decreased at a rate of about 1.4 dB per floor. Anomalies, which had also been reported in the literature, were found at levels above the 6th floor where the loss again started to increase.

The Rayleigh plus lognormal statistical model can also be used to model propagation totally within buildings although the standard deviation of the lognormal component is much higher at about 16.8 dB. Coverage within buildings is highly variable depending on the location of the transmitter and the number of obstructions between it and the receiver. Although difficult to draw firm conclusions, it has been found that the coverage of a building can be maximised by locating the transmitter near the centre of the building and in as large a room as possible.

The rate of change of mean signal level for propagation totally within a building has been measured at approximately 8.5 dB per floor. The signal attenuates quite rapidly and according to regression analysis the best-fit regression line has a path loss attenuation factor, n, equal to 5.3, 5.5 and 6.0 for 900, 1800 and 2300 MHz respectively. This is somewhat higher than values reported in the literature, which are themselves quite variable, and is an example of the difficulties involved in arriving at definitive conclusions in a highly-variable environment. Nevertheless, sufficient results have been obtained to justify the conclusions drawn, and the results should be useful to system designers and frequency planners.

6. Acknowledgment

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7. References

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