Radio transmission at 1800 MHz into, and within, multistory buildings

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Abstract: Investigations of propagation into, and within, buildings at 1800 MHz have been undertaken using buildings in the University of Liverpool precinct. Measurements of the mean signal level have been made in rooms and corridors of four different buildings and, where appropriate, these have been compared with measurements at street level outside. 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 13 dB. The rate of change of penetration loss with height was −1.4 dB per floor. For floor levels higher than the sixth floor, it was found to be 0.4 dB per floor. The rate of change of the mean signal level for signals travelling within buildings was, on average, 8.3 dB per floor. The best coverage was obtained by locating the transmitter in a large room at the centre of the building. The path loss attenuation factor n that best modelled the within-building measurements was found to be 5.6.

1 Introduction

The introduction of cellular systems has brought awareness of the possibilities of radio-connected communications terminals not only to the closed communities of specialist users, but also to the public at large. The general expectation is now virtually boundless, and pressure to create the 'personal communications' environment in which every adult carries a universal personal terminal to meet most of his or her communications needs is already being felt in the international telecommunications planning community [1]. Such a system will have to be based on a microcellular structure leading to cells possibly as small as a single building. It has long been realised that radiocommunication systems are both convenient and cost-effective solutions for providing data and speech services in an indoor environment owing to their inherent advantages over the conventional wire links. Some of these advantages are the elimination of wiring around buildings, providing services for a larger number of users, flexibility in shifting terminals and equipment around, relatively easy maintenance, increased quality of service and flexibility in introducing or changing communication services in existing buildings without the need for expensive and time consuming rewiring [2]. The full economic potential of cellular radio systems is only likely to be reached if there is extensive use of portable and hand-held terminals.

The use of such equipment inside buildings, however, involves a radio propagation environment that differs from the more familiar street-level situation that has been so extensively studied in connection with vehicle-borne transceivers [3, 4]. Propagation models that adequately describe the signal in open and urban areas are no longer adequate, since there will be a building penetration loss associated with the indoor environment [5]. This additional loss will depend on various factors including the transmission frequency, the range of the transmitter, the building construction, the nature of surrounding buildings and the position of the transceiver within the building.

In this paper we describe measurements, at 1800 MHz, into buildings with the transmitter located on the roof of one building and the receiver located in a different building. The paper also describes measurements that have been undertaken with both transmitter and receiver situated within the same building. These latter measurements are classified as propagation within buildings.

2 Experimental procedure

The tests were undertaken using a fixed base station transmitter and a mobile receiver. The signal transmitted from the base station was received using a purpose-built data logging system which was wheeled around the building on a trolley. A block diagram of the data logging system is shown in Fig. 1. The main components are a measuring receiver, a microcomputer and a distance transducer. The receiver typically yields a 70 dB dynamic range and has a noise floor equal to −125 dBm. To accommodate those areas of high signal strength where the receiver may become overloaded, an external (10 dB/step) attenuator is used between the antenna and the receiver input terminal. Spatial sampling was considered important for this propagation study because the length of the data record that could be obtained in each room or corridor of a building was limited. In order to sample spatially the voltage output of the receiver, a slotted disc was attached to a fifth wheel on the mobile trolley. By interruption of an optoisolator, a train of marker pulses could be produced at a rate proportional to the number of slots per disc and the speed of motion of the trolley.

It is well known that, in the mobile radio environment, fades of 40 dB or more below the mean signal level are not uncommon, with successive minima occurring about every half wavelength of the carrier frequency [6]. The

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data logging system, sampling at every 7.8 mm, can collect 22 samples per wavelength at 1800 MHz, and this ensured that the sampled signal was an accurate representation of the received signal.

within buildings. The into-building experiments, four in total, were conducted with the transmitter located on the roof of the Department of Mechanical Engineering, at a height of 40 m. 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 and the Departments of Computer Science and of 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. In this context, the term 'partial line of sight' means that line-of-sight existed only to some parts of these buildings. A general description of each building is given in Table 1. Offices on all floors of all buildings were crowded with typical office furniture, and the teaching or research laboratories contained experimental equipment according to the specialised demands of each area of study. Fig. 2 shows the locations of the buildings within the University precinct.

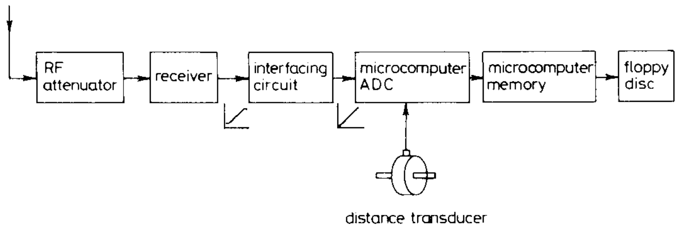

Fig. 1 *Block diagram of data logging system*

The base station consisted of a continuous wave (CW) transmitter feeding a collinear antenna, raised clear of local obstructions. It produced an effective radiated power of 32 dBm. A vertically polarised omnidirectional collinear antenna mounted on a ground plane 1.4 m above the floor was used at the mobile.

3 Data processing

In order to investigate the distribution of the small- and large-scale signal variations, the penetration loss, and the distance dependence of the mean and to assess the effect of the height of the building on the penetration loss, the following analysis procedure was adopted.

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

Building penetration loss for a given floor within a building was defined as the difference between the average of the measurements taken on that floor and an average of measurements at street level outside the building [7]. Outside signal strength was measured at street level around the perimeter of the building, along the closest available path to the building's outside walls.

The large-scale signal distribution can be determined by testing the departure (in decibels) of the average signal strength of each room from the average signal strength for the whole building. The effect of height and transmitter–receiver location can be determined by examining the penetration loss relevant to each floor of the building.

As an aid to collating and analysing the data, each room and corridor within a building was treated as a discrete survey and a separate data file was produced. All measurements were coded to associate them with major marker characters/numbers. The coding identifies the building (for both transmitter and receiver), the floor number (or outside street-level data), the room (or corridor), the frequency, and repeated measurements.

In addition, other information required in the subsequent analysis was also stored in each data file, e.g. the number of samples, the external attenuation level and the minimum detectable signal.

4 Experimental results

15 experiments were conducted to assess the effect of transmission conditions on signals transmitted into and

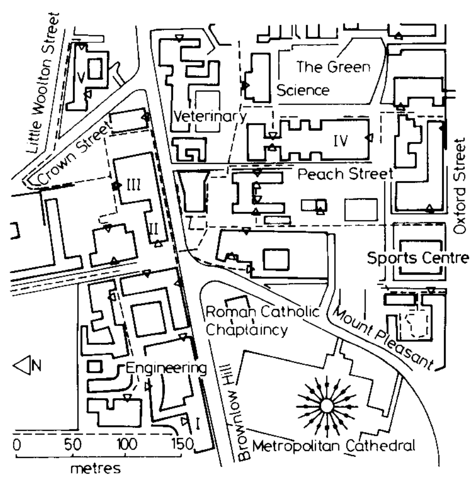

Fig. 2 *Partial plan of the University of Liverpool precinct*

I Mechanical Engineering
II Electrical Engineering Block A
III Electrical Engineering Block B
IV Computer Science
V Life Sciences

4.1 Into-building experiments

In the four into-building experiments, a total of 525 locations were surveyed, with the number of samples approaching half a million. It is therefore evident that, on average, 1000 samples were undertaken in each surveyed location. Since the data logging system sampling rate is

Table 1: General description of buildings

Building	Number of floors	Height	Floor area		Construction and other details
Electr. A	7	27 m	936 m^2	(i)	Steel-framed
				(ii)	Floors 5 and 6 offices
				(iii)	Floors 3 and 4: large laboratories
				(iv)	Floor 2: lecture rooms
				(v)	Floors 1 and ground; open areas
				(vi)	Floors 2 to 6: large glass windows
				(vii)	Ground and floor 1: Outside walls all glass
Electr. B	4	15 m	700 m^2	(i)	Steel-framed
				(ii)	Floors 2 and 3: offices with research rooms
				(iii)	Floor 1: workshops
				(iv)	Ground floor: workshops and large laboratories
				(v)	Large windows
Computer science	10	33 m	280 m^2	(i)	Reinforced concrete
				(ii)	Floors 1 to 8: offices and laboratories
				(iii)	Large windows
Life sciences	11	43 m	729 m^2	(i)	Reinforced concrete
				(ii)	Floor 9: plant and common rooms
				(iii)	Floors 3 to 8: offices andlaboratories
				(iv)	North and South faces: large windows

22 samples per wavelength, it means that each survey covered a linear distance of around 45 wavelengths. Thus this survey length and the 22 samples per wavelength ensured an accurate estimate of the local mean value as well as a good representation of the small-scale signal variations in every location. The cumulative distribution of the small-scale signal variations within the Computer Science building, plotted on Rayleigh graph paper, is shown in Fig. 3. This is typical of the four experiments.

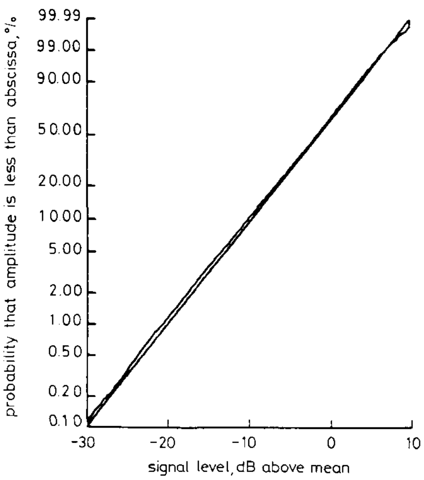

Fig. 3 *Typical cumulative distribution of the small-scale signal variations: into building transmissions*

The cumulative distributions of the large-scale signal variations (in decibels) within the Electrical Engineering Block B, plotted on Gaussian graph paper, is shown in Fig. 4. The large-scale variations can be approximately represented by a log-normal distribution (the straight line), the slope of the distribution being related to the standard deviation. The standard deviations obtained for the four experiments are given in Table 2.

The transmission conditions seem to have a strong effect on the standard deviation and also on the departure of the distribution from log-normal. Fig. 4 represents the situation when no line-of-sight path exists and in this case the large-scale signal variations exactly fit a log-normal distribution with a standard deviation of approximately 5 dB. For other experiments where there is a partial line-of-sight path, the large-scale signal variations depart somewhat from the log-normal and have higher standard deviations. Nevertheless, the results show that, overall, the large-scale signal variations are adequately modelled by a log-normal distribution. The measured values of standard deviation are close to those reported by Cox [5] and Turkmani [8] at 900 MHz.

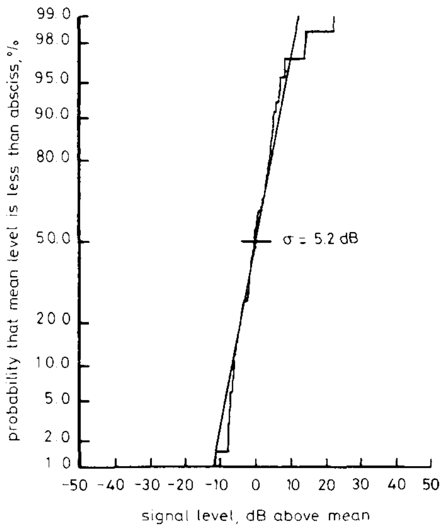

Fig. 4 *Typical cumulative distribution of the large-scale signal variations: into-building transmissions (no line of sight)*

Table 2: Standard deviations σ for the CDF of large-scale signal variations in into-building experiments

Experiment	Receiver location	σ dB
1	Electr. Eng. A	8.38
2	Electr. Eng. B	5.20
3	Computer science	8.71
4	Life sciences	8.11
For the four experiments	Mean, dB	7.60

4.2 Building penetration loss

The effect of height within the building on the penetration loss was calculated by averaging the penetration losses measured on each floor of the buildings being used. The penetration losses on the first floor of Electrical Engineering, Block A, and Computer Science were ignored because of the limited number of data files that it was possible to collect on these particular floors of the two buildings.

The average building penetration loss values on each floor were plotted as a graph (see Fig. 5) showing the relationship between the penetration loss and height. The building penetration loss at the ground floor was 13.38 dB. Previous measurements undertaken at the University of Liverpool [8] had shown that the building penetration loss at 900 MHz was 14.24 dB. Therefore, and as reported in References 7 and 8, the penetration loss decreases as the frequency of transmission increases. 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 from 900 MHz (TACS and GSM systems) to 1800 MHz (DCS 1800 and DECT systems), some of the additional path loss can be compensated for by lower building penetration loss values. Defining the building penetration loss as the difference between the signal measured inside the building and the signal at street level outside, provides a factor that can be directly added to signal levels measured or predicted by any of the well known propagation prediction models (such as Okumura [3]) to account for the fact that the receiver is inside the building.

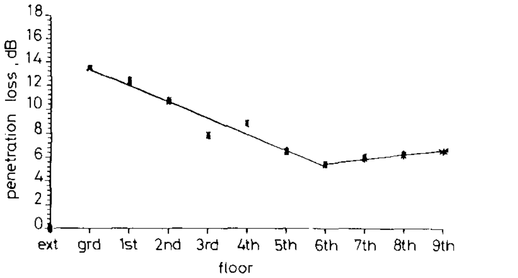

Fig. 5 *Regression estimate of building penetration loss as a function of floor level height*

Using the method of least squares, the best regression lines were fitted to the measured values. Examination of the graph in Fig. 5 shows the existence of two distinct slopes with a turning point around the sixth floor level. It has been found that the rate of change of the penetration loss with height within the building, up to the sixth floor, is −1.4 dB per floor. For higher floor levels, however, the penetration loss increases again, at a rate of about 0.4 dB per floor.

A possible explanation for the change in the value of penetration loss regression coefficient is given in Reference 8. A tentative conclusion drawn is that the increase is a function of the relative height of the transmitter and receiver locations, especially when the separation between them is small.

The statistical significance of the regression lines can be assessed using the F-test [9]. It has been found that the regression line is statistically significant (significance level equal to 0.5%) between the ground and the sixth floors. For floors from the sixth to ninth, the level of significance was found to be 2.5%. A reasonable explanation for the increasing of the level of significance for the F-test on the higher floors is that there were not enough locations at those heights.

4.3 Three-dimensional representation of the radio wave intensity

Fig. 6 shows the isometric projection views of the mean signal levels measured at the different floors of the Electrical Engineering Block A. The mean signal levels have been normalised to the highest measured value.

Recalling that the transmitter antenna was located at the roof of the Mechanical Engineering building which is 40 m in height and 180 m distant from the building under test, it can be observed from Fig. 6 that the signal levels measured in the building sides which are closer to the transmitter are, in general, higher than the signal levels

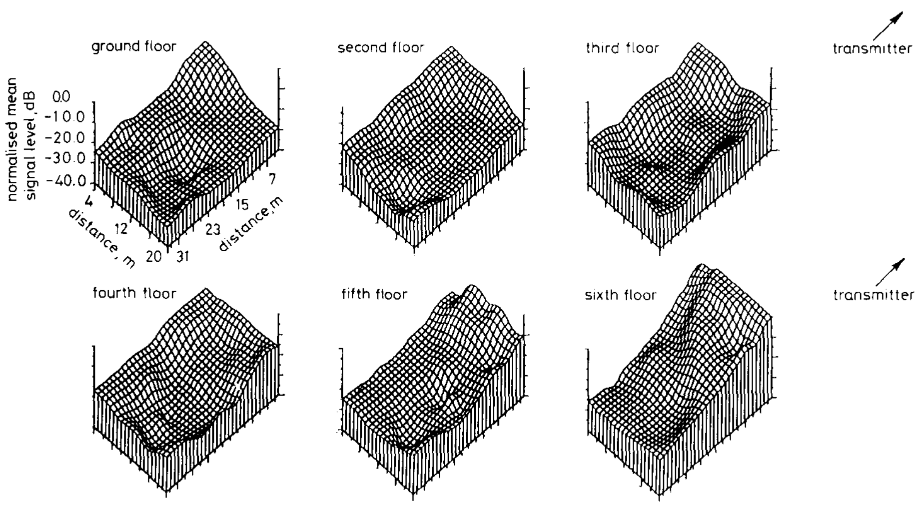

Fig. 6 *Isometric projection views of normalised mean signal levels (transmitter in Mechanical Engineering building)*

measured at other locations. The differences of mean signal levels measured at the two opposite sides facing the transmitter are more significant at the top floors. The measured mean signal levels are higher in the perimeter of the building (i.e. close to the windows). It should be noted that, during the experiments, all the doors in the floor under test were kept closed.

5 Within building experiments

11 experiments have been conducted within the four buildings in the University precinct. A total of 1329 locations were surveyed.

5.1 Large-scale and small-scale statistics

The cumulative distribution function of the small-scale signal variations within the Electrical Engineering Block A, with the transmitter located in the same building, room 306, plotted on Rayleigh graph paper is shown in Fig. 7, this being typical of the 11 experiments. It is clear

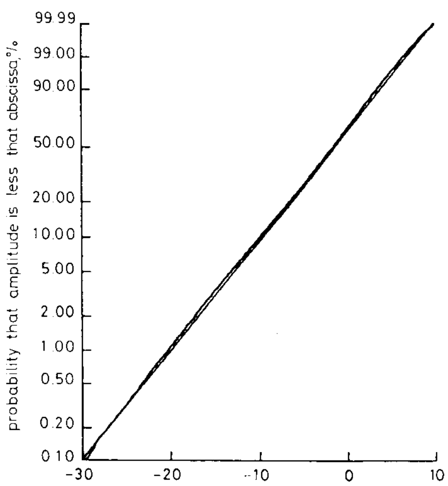

Fig. 7 *Typical cumulative distribution of small-scale signal variations: within-building transmissions*

that the small-scale signal variations can be very closely represented by a Rayleigh distribution and, overall, the transmission conditions hardly affect this distribution.

The cumulative distribution of the large-scale signal variations (in decibels) in the same building is plotted on normal-scaled graph paper, as shown in Fig. 8.

The standard deviations are high, mainly because the mean signal level 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. Nevertheless, the results suggest that the large-scale signal variations can reasonably be modelled by a log-normal distribution with a standard deviation of approximately 16.5 dB.

5.2 Transmitter location inside buildings

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

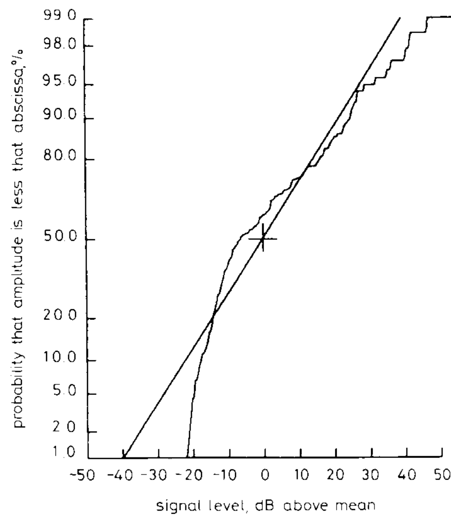

Fig. 8 *Typical cumulative distribution of large-scale signal variations: within-building transmissions*

in the Computer Science, were plotted and are shown in Figs. 9 and 10, respectively.

Fig. 10 shows, for example, that the median signal strength was approximately −78 dBm when the transmitter was located in room 802 (eighth floor) of the Computer Science building. However, this increased to

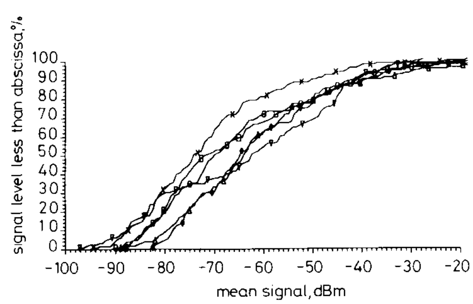

Fig. 9 *Comparison of the cumulative distribution function of large-scale signal variations for different transmitter locations within Electrical Engineering Block A*

△△△ room 403
▽▽▽ room 6CR
✕✕✕ foyer
⊟⊟⊟ room 306
◇◇◇ room 302
⊖⊖⊖ room 602

−68 dBm when the transmitter was located in room 413 (fourth floor) of the same building. The transmitter in the foyer yielded a median signal strength of −74 dB. This result shows that, by choosing a room in the middle (room 413) of the Computer Science building, the overall coverage improved and the median signal level within the building increased by approximately 10 dB and 6 dB when compared with the results for room 802 and foyer, respectively.

As an item of further information, the Computer Science can be loosely described as a building where most of the rooms are of similar size. That is not the case

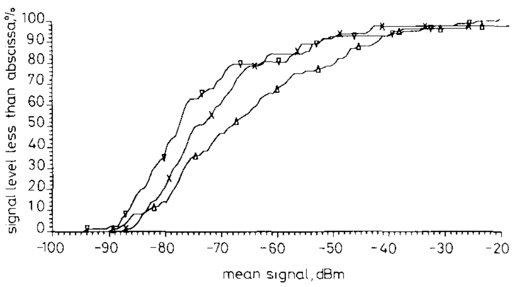

Fig. 10 *Comparison of the cumulative distribution function of the large-scale signal variations for different transmitter locations within the Computer Science building*

ΔΔΔ room 413
∇∇∇ room 802
××× foyer

for the Electrical Engineering Block A, which has one very large room occupying the centre between the fifth and sixth floors and much smaller rooms on the perimeter of each floor. On the other hand, on the third and fourth floors the large rooms are on the perimeter and the smaller ones are in the centre.

Fig. 9 shows the cumulative distribution function for the six transmitter locations in the Electrical Engineering Block A. It can be observed that, when the transmitter was placed in the very large room near the top of the building (room 6CR), the median signal level increased by about 12 dB compared with the value measured when the transmitter was in the foyer. When the transmitter was located in the very large room (302) with a large window area, near the centre of the building, the median was 7 dB higher than when it was located in a small room (306), with no windows, in the centre of the same floor.

Although the very large room at the top of the building (room 6CR) yielded the highest median signal strength (−62 dBm), considering the overall cumulative distribution function, it can be observed that room 302 provided the best coverage since all the measured mean signal levels (i.e. 100%) where higher than −82 dBm. When the transmitter was located, however, in room 6CR only 78% of the mean signal levels were higher than −82 dBm. In general, the worst coverage was when the transmitter was located in the foyer.

The above results suggest that, by locating the transmitter in a very large room in the middle of the building, the signal coverage can be increased substantially. This is desirable in a one cell per building signal coverage. For a multicell per building radio system, other aspects beside signal coverage should be considered, such as capacity and interference.

5.3 Floor mean signal level

For convenience, the mean signal level of each floor was normalised by the average signal level of the floor where the transmitter was located. As expected, the average signal level decreases, as the distance from the transmitter increases. However, the gradient of this variation from floor to floor is strongly affected by the conditions of transmission. As an example, by comparing the results of the two experiments from Electrical Engineering Block A (rooms 602 and 6CR), it can be observed that, because of the existence of a large window in room 602, the average signal levels on the third, second, first and ground floors were higher (−24.49 dB, −27.61 dB, −16.60 dB and −31.24 dB) than the averages obtained in the second experiment (room 6CR) (−36.26 dB, −42.87 dB, −43.13 dB and −47.06 dB). The overall results for the second experiment, however, were found to be superior (Fig. 9) because of the strategic location of the transmitter between the fifth and sixth floors, i.e. the transmitter was located exactly in the middle of the very large split-level room 6CR. Of the floor area of that room, 80% is on the fifth floor and its ceiling coincides with the ceiling of the sixth floor. In addition, that particular room has a very large volume and is in close proximity to approximately 50% of the rooms within the building (64 of the 128 rooms in the Electrical Engineering Block A, are on the fifth and sixth floors). On the other hand, room 602 has a very large window area and, since the lower floors of the building comprise only large rooms with open areas and large windows, signals can propagate easily from inside to outside and back to inside. Thus it seems evident that the nonuniform distribution of the rooms throughout the building had the effect of biasing the results shown in Fig. 9.

The influence of windows on the results of another two experiments where the transmitter was located on the third floor, i.e. rooms 306 and 302, was also evident. The presence of large windows in room 302 yielded stronger average signals on almost all the floors.

Because the basements of buildings experienced much lower signal levels, they were not considered in the calculations of the averages for each floor in order to avoid anomalies caused by the averaging of signal strengths on floors above, and below, ground level in different buildings. In fact, basements will probably need to be considered separately in designing portable radio systems [10].

The differences between ground floors and outside building measurements for the Electrical Engineering Block A, were also analysed. It is interesting to note that, when the transmitter was on the sixth floor (rooms 602 and 6CR), the signal levels outside the building were 11 dB and 9 dB higher, respectively, than that measured on the ground floor. This difference was of the same order of magnitude as that measured for propagation into the same building (12.1 dB). This suggests that, when the transmitter was on the sixth floor, the transmitted signal propagated from inside the building to outside, through the windows, and was then reflected back into the same building by the surrounding buildings. The majority of the energy that reaches the ground floor is therefore due to outside reflections. This is similar to the case of propagation into buildings. However, when the transmitter was on the fourth floor (room 403), or on the third floor (rooms 306 and 302), only some of the signals on the ground floor were due to reflections from outside, the remainder were from propagation within the building itself. The differences between the signals at ground floor level and the outside were reduced to 7 dB, 4 dB and 5 dB, respectively.

Fig. 11 shows the isometric projection views of the mean signal levels when the transmitter was located in room 302. It is evident that, as the distance between the transmitter and receiver increases, the mean signal level decreases. Fig. 11 also shows the exact location of the transmitter in room 302 (i.e. the region of the highest mean signal level on the third floor). It is interesting to note that the signal levels in all floors are, in general, higher in the side of the building where the transmitter was located.

The transmitted signal spreads within the building as a volume, and the signal strength decreases more or less uniformly as the distance from the transmitter increases. This means that floors just below, and above, the transmitter will receive stronger signals than, for instance, a region far away from the transmitter on the same floor.

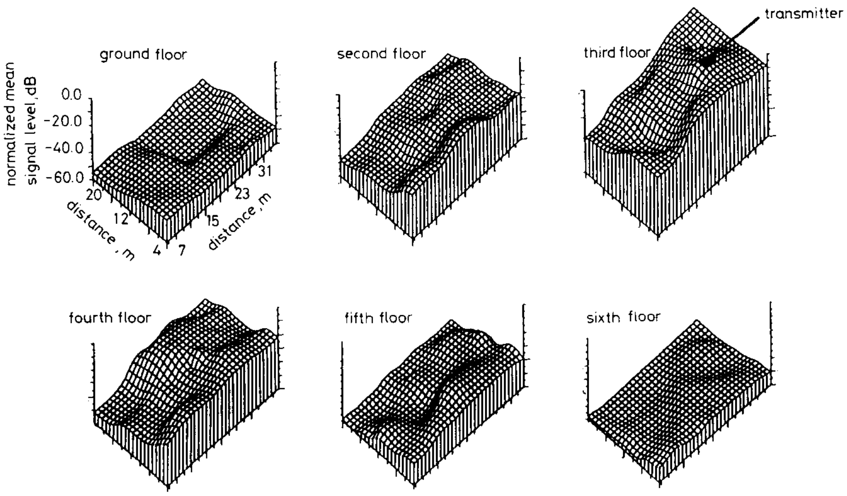

Fig. 11 *Isometric projection views of normalised mean signal levels (transmitter in Electrical Engineering Block A, room 302)*

Comparing Fig. 11 (within-building measurement) and Fig. 6 (into-building measurement) it was observed that the mean signal levels spread over 65 dB in the first case whereas, in the second case, the spread was reduced to 40 dB.

The mean signal levels on all the floors, for the 11 experiments, are shown in Fig. 12. The linear least square regression line to the mean signal level of those floors is also shown. Examination of the graph reveals two different slopes: 6.1 dB per floor when considering floors below that on which the transmitter was located and the −10.4 dB/floor, when considering the measurements conducted on floors above the transmitter location. Therefore the average rate of change of the mean signal level was 8.3 dB per floor.

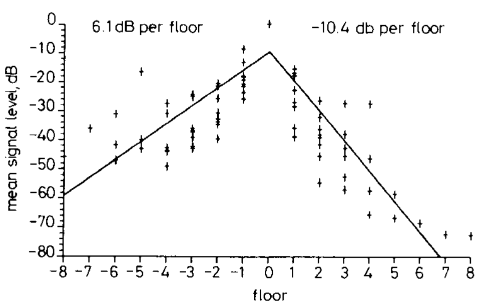

Fig. 12 *Normalised floor mean signal level against number of floors separating the receiver and transmitter*

The statistical significance of the regression lines were again assessed using the F-test [9]. Both lines are statistically significant with a significance level of 0.5%.

The different slopes may be due to the greater density of rooms on the higher floors. Note that six of the 11 experiments were carried out in the Electrical Engineering Block A, where 50% of the rooms are concentrated on the fifth and sixth floors.

5.4 Distance/power-law relationship

The data points in Fig. 13 represent the mean signal levels in each room of the Electrical Engineering Block A,

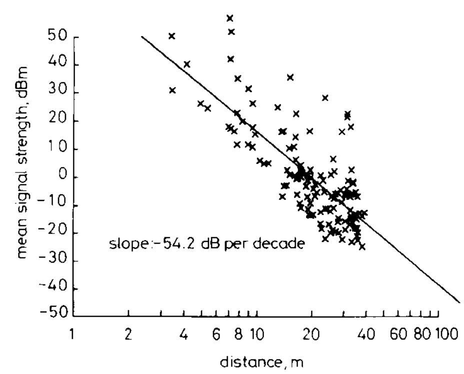

Fig. 13 *Normalised floor mean signal level against distance separation between receiver and transmitter (transmitter located in Electrical Engineering Block A, room 602)*

with the transmitter in room 602. The signal levels were normalised to the overall mean signal level. The normalised signal levels were plotted as a function of the distance between the transmitter and receiver. The method of least squares was used for fitting the line which best estimates the average value for the mean signal strength corresponding to each value of distance d. The regression coefficient yields the path loss attenuation factor n as given by the following equation:

$$\text{mean signal level} = \text{intercept} - 10n \log_{10} d \quad (1)$$

Fig. 13 shows that, when the transmitter was located in room 602, the path loss attenuation factor n was 5.4.

Considering the 11 within-building experiments, the average value of n was found to be 5.6. The statistical significance of the regression lines for the 11 within-building experiments were assessed using the F-test. All regression lines were found to be statistically significant with a significance level of 0.5%.

Although the regression coefficient for the experiment carried out with the transmitter located in room 6CR was found to be -53.4 dB per decade (i.e. $n = 5.3$), it was observed that, on isolating the measured mean signal levels according to the floor level, the values of the regression coefficients at the lower floors were found to be positive. This is further evidence that the transmitted signals propagate from inside the building to outside, through the windows, and are reflected back into the same building by the surrounding buildings. Because the transmitter was located in the middle, and on the top of, the building in that experiment, areas on the perimeter of the lower floors, located at further distances from the transmitter, received stronger signals than areas in the middle of those same floors, located at shorter distances from the transmitter.

The variability of the path loss attenuation factor n for the different buildings was also considered. For the same building (Electrical Engineering Block A), using six different locations for the transmitter, it was found that n varies from 4.8 to 6.9. For the whole group of experiments, this range was found to be 3.2 to 7.9, and the average value was 5.6.

Cox [11] reported path loss attenuation factor (measurements made in the 800–900 MHz frequency band) ranging from 2 to 6 with values of 4 or 5 appearing to be typical. The slight discrepancy may be the result of the particular conditions surrounding the experiments reported in the literature as well as the frequency of transmission. The value n is related to factors such as the grade of emptiness of the places surveyed and the relationship between signals travelling inside, and from outside to inside, buildings, and this may be extremely variable.

6 Conclusions

Experimental work, which has been undertaken to characterise propagation within, and into, buildings at 1800 MHz has been described in this paper.

The signal statistics within buildings can be modelled as small-scale signal variations (multipath), superimposed on large-scale variations (shadowing). Two different sets of experiments have been conducted, using buildings within the University of Liverpool precinct. Four experiments were conducted to assess the effect of propagation conditions on signals transmitted into buildings, and a further 11 experiments were carried out to assess the effect on signals transmitted within buildings.

The significant conclusions related to propagation into buildings are as follows:

(i) The small-scale variations are Rayleigh distributed.

(ii) The large-scale variations are log-normally distributed with a standard deviation related to the condition of transmission. Examination of the results for the four experiments 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. The average value was 7.60 dB.

(iii) The rate of change of penetration loss with height for signals travelling into the building was about -1.4 dB per floor. It was found, however, that the penetration loss increased for floor levels higher than the sixth floor, with a rate of change of 0.4 dB per floor.

(iv) The average penetration loss at ground floor level was found to be around 13 dB.

The significant conclusions related to propagation within buildings are as follows:

(*a*) The small-scale variations are Rayleigh distributed.

(*b*) The large-scale variations are, reasonably, log-normally distributed with a standard deviation value of about 16.5 dB.

(*c*) The rate of change of mean signal level per floor for signals travelling within the building was approximately 8.3 dB/floor (6.1 dB/floor for floors below the transmitter and -10.4 dB/floor going upwards).

(*d*) It was found that the best signal coverage could be obtained by locating the transmitter at the centre of the building, preferably in one of the larger rooms.

(*e*) The path loss attenuation factor n was approximately equal to 5.6. It is assumed that the slight differences in the values of n reported in this study, and others reported in the literature, are due probably to the particular conditions surrounding the experiments.

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