Characterization of the Spatial Distribution of RMS Delay Spread in Indoor LOS Wireless Environments at 5.2GHz

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ABSTRACT

Results from ray-tracing modelling and measurements of RMS delay spread in indoor line-of-sight (LOS) environments at HIPERLAN/U-NII frequencies (5.2 GHz) with omni-directional antennas have shown that the maximum RMS delay spread in a room is dependent on the dimensions of the room and the reflectivity of the walls. Under these conditions the RMS delay spread increases with distance from the transmitter up to a maximum value that is thereafter constant with distance over the remainder of the room.

I. INTRODUCTION

The emergence of the HIPERLAN standard and the allocation of the U-NII bands in the USA have enabled the development of high bit-rate (>20Mbps) indoor wireless products at 5 GHz. This has prompted the need to characterize the indoor wireless propagation environment at this frequency. The rms delay spread is a parameter that is often used to quantify the time dispersion introduced by a multipath wireless channel. Practically, the delay spread has been found to be directly related to the minimum symbol duration [1] and therefore the transmission rate that can be used in order to avoid excessive intersymbol interference. The delay spread is therefore an essential parameter in the design of wireless communication systems.

This paper presents rms delay-spread results from 2D ray-tracing modelling and from measurements made in various rooms. A characteristic and common pattern of LOS delay spreads has been observed in all cases. Results are also presented that link room size and wall materials with observed LOS delay spread measurements.

II. MODELLING DELAY SPREAD

A simple model for the delay spread in a rectangular room has been reported elsewhere [2]. This yields a characteristic plateau in the delay spread over much of the room area. The model involves summing the multiple reflection contributions to the power arriving at the receiver to calculate the rms delay spread, τ_{rds}:

$$\tau_{rds} = \sqrt{\overline{\tau^2} - \overline{\tau}^2}$$

The summation in the *l-th* power of the propagation time, given by $\overline{\tau^l} \equiv K^{-1}\sum_i \tau_i^l P_i$, is over all paths (the direct and the multiple reflection) from transmitter to receiver. τ_i is the propagation time over the *i*-th path and P_i is the power in this ray (the normalization factor is the total received power, $K = \sum_i P_i$).

For the omni-directional antennas used, it is appropriate to sum only over the paths in a 2D plane. Constructing images of the receiver, it is clear that there are 4*N* (*N* > 0) possible paths to it which undergo *N* reflections. Although it is possible to consider arbitrary transmitter and receiver positions [2], for an estimate of the height of the delay spread plateau it suffices to place the transmitter at the centre of the room and the receiver at a corner. Then for a room of sides a and ηa, centred on the origin the receiver and all its images lie at the points $((0.5(-1)^n + n)a, (0.5(-1)^m + m)\eta a)$. The distance to the *nm-th* image is thus $d_{nm}^2 = a^2((0.5(-1)^n + n)^2 + (0.5(-1)^m + m)^2\eta^2)$ and the time taken for a ray to reach this is $\tau_{nm} = d_{nm}/c$. Assuming that the power is attenuated by a factor of α at each reflection and an inverse-square law fall-off for propagation, the power in a ray at the *nm*-th image is $P_{nm} = P\alpha^{|n|+|m|}d_{nm}^{-2}$ (the constant P is set by the transmitter power and clearly has no effect on τ_{rds}).

For a channel sounder with a short capture-time, the summations to calculate τ_{rds} should run over the receiver images reachable in that time. For a sounder with a very long capture-time, the summations essentially extend over all images. In the latter case, for very highly-reflective walls (α very close to unity) the summations have to run over hundreds of reflections to converge. For more absorptive walls ($\alpha < 1$), of the order of ten reflections is sufficient and for highly absorptive walls ($\alpha << 1$) just a few reflections are necessary.

The actual value of the plateau in τ_{rds} clearly depends on a number of parameters. However, in all of the cases mentioned above, there exists a simple scaling result. For rooms of fixed aspect ratio (fixed η) and wall reflection α, the height of the delay spread plateau (*DS*) scales with the linear dimension, so $DS = ka$ where k depends on α , η and the sounder capture time if this is short. In order to compare rooms of different aspect ratio (but not too extreme so $0.5 \le \eta \le 2$ approx.) but the same α, a reasonable approximation is that $DS = k\sqrt{floor\ area}$ where k is set by α .

A. Modelling results

Figure 1 below shows the delay spreads obtained by 2D ray-tracing in a metal-walled square room of side 20m. This simulated room was a completely enclosed 2D structure and there were no openings or gaps in the walls. The transmitting antenna was placed in the centre of the room.

The concentric rings of monotonically increasing delay spread radiate out from the transmitting antenna up to a maximum 'plateau value'. The plateau of delay spread is approximately flat over the remainder of the floor area of the room. This characteristic pattern of delay spread distribution was also observed in all other square metal-walled rooms. In rooms other than those with metal-walls the spatial distribution of rms delay spreads followed a similar pattern except for a scaling factor. This scaling always had the effect of reducing the height of the plateau. Such a decrease in delay spread is to be expected as wall materials other than metal will be partly absorptive and not totally reflective.

III. MEASUREMENT RESULTS

Delay spread measurements were undertaken in six commercial and residential properties. The following sections describe three representative examples of the results obtained in LOS situations. The first example is of a large rectangular meeting room and the others are of rooms in residential properties with brick/stone walls.

The channel sounder used to calculate the rms delay spreads was developed at Bristol University. A detailed description of its operation was reported elsewhere [3]. Briefly however, the sounder uses a 2047-bit PN sequence to modulate a 5.2 GHz carrier (for HIPERLAN and U-NII compliance). The transmitter and receiver antennas were quarter-wavelength monopoles with a square ground-plane of side 10cm. The PN generator is clocked at 100MHz which gives the sounder a resolution of approximately 10ns. At the receiver a correlation is performed with a replica PN sequence running 4 kHz slower than at the transmitter. The outputs of the correlation were sampled by a 16 bit adc and processed off-line to obtain estimates of the rms delay spread.

A. Large Meeting Room

This windowless room measures 16.6 m x 11.5 m. The floor is made of carpet-covered square metal tiles of side 60cm that are themselves suspended above a concrete sub-floor. All the wall surfaces have a cloth-covered metal facing except for one wall along the 11.5m side of the room. Above the suspended ceiling there is a fine wire mesh (chicken-wire) which extends over the whole ceiling area. The room was filled with metal-framed chairs arranged in rows.

In the measurements the omni-directional transmitter was located near one corner of the room at a height of approximately 1.5m above the floor

The actual delay spreads obtained from measurements in the meeting room (figure 2) follow the general shape described in plan view by figure 1 particularly the plateau of delay spreads which occurs away from the transmitter.

B. Rooms in residential properties

The measured variation of in-room rms delay spread with distance from the transmitter is shown in figure 3 for a room in a Victorian apartment conversion and in figure 4 for a room in a Victorian house.

The apartment occupies one level of a converted four-storey Victorian town house. The external walls of the house are substantial (3'7" thick) and made of stone. The walls which enclose the room where the measurements were conducted are 30 cm (12") thick. The windows are all single glazed with clear glass. The dimensions of the room are 4.7m x 4.6m which does not include the area of the bay window (semi-circle of radius 1.7m).

The dimensions of the room in the Victorian house are: 3.5m x 4m. The internal walls are constructed of red-brick and the external walls are stone. There was a large single-glazed window in the room.

In both instances the 5.2 GHz omni-directional transmitter was situated near a corner at a height of approximately 1m above floor level.

In LOS conditions the characteristic spatial plateau of delay spreads is apparent. Delay spread measurements conducted in the other residential scenarios investigated exhibited the same characteristic pattern.

IV. DISCUSSION

The spatial distribution of LOS rms delay spreads has a characteristic pattern. This pattern was observed to good agreement in both ray-tracing simulations and measurements. In a given room with LOS to the transmitter, the delay spread increases radially with distance from the transmitter up to a maximum 'plateau' value. This plateau of delay spreads is maintained over the remainder of the room.

Delay spreads in LOS conditions in the metal-walled meeting rooms are greater than in LOS conditions in the residential room. This is due to the highly-reflective metal surfaces on the sides of the meeting rooms and the lower reflectivity and high absorptiveness of the internal brick and stone walls and the room furnishings in the residential rooms.

From the results of simulations and measurements the following empirical relationship is proposed for the value of the 'plateau' of the rms delay spread in a LOS environment in an enclosed room:

$$DS(ns) = k\sqrt{floor\ area}$$

The variable k depends on the reflectivity of the enclosing walls. In metal-walled rooms k ranges from 3 ns/m to 4 ns/m, whereas in brick/stone-walled rooms it is around 1.5 ns/m. The value of the rms delay spread plateau using a value of k for metal-walled rooms provides an upper limit to the extent of rms delay spread that can be expected in a particular indoor room LOS condition. Any given room therefore should fall somewhere below this limit depending of the reflectivity of the walls.

For the non-LOS situations which were measured in the residential scenarios only, there does not appear to be a plateau-like pattern to the delay spread distribution nor a linear relationship between delay spread and distance or area. This is attributable to the propagation environment that is effectively a complex arrangement of reflectors, shadowing walls, and doorway and window openings. This is in contrast to the homogeneous and regular environment that characterized the meeting rooms and produced the plateau distribution of rms delay spread.

V. CONCLUSIONS

Several new and important results have become apparent from this study of delay spreads in indoor LOS conditions. These results are summarised below:

1. In indoor LOS conditions in a given room the rms delay spread increases with radial distance from the transmitter up to a maximum value which then remains constant across the remainder of the room

2. The maximum delay spread in a room is determined by the dimensions of the room and the reflectivity of the material of the walls and the furnishings The following empirical relationship is proposed for the value of the 'plateau' of the rms delay spread (DS) in nanoseconds in a LOS environment in an enclosed room:

$$DS(ns) = k\sqrt{floor\ area}$$

the variable k depends on the reflectivity of the enclosing walls. In metal-walled rooms k ranges from 3 ns/m to 4 ns/m, whereas in brick/stone-walled rooms it is around 1.5 ns/m.

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[3] P. Hafezi, D. Wedge, M.A. Beach, M. Lawton, "Propagation Measurements of the 5.2 GHz Radio Band in Commercial and Domestic Environments", PIMRC 1996.

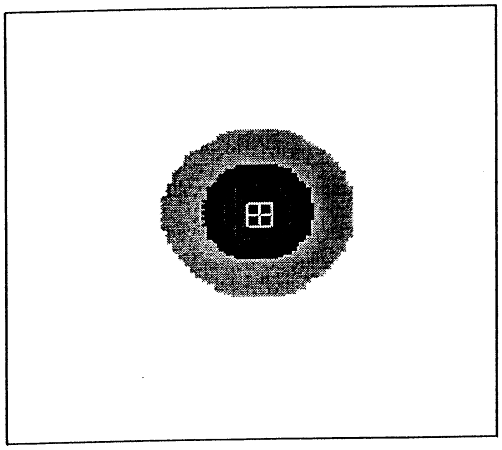

Figure 1. RMS delay spreads in a square metal-walled room found from 2D ray tracing. The transmitter is in the centre of the room. The lowest delay spreads are found in the centre and increase with distance from the transmitter up to a maximum 'plateau' value.

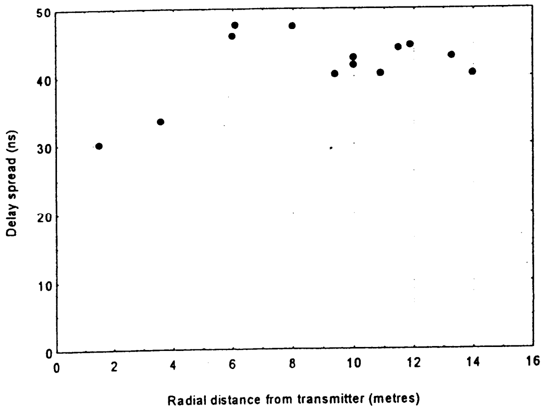

Figure 2. Measured LOS delay spreads in a large metal room

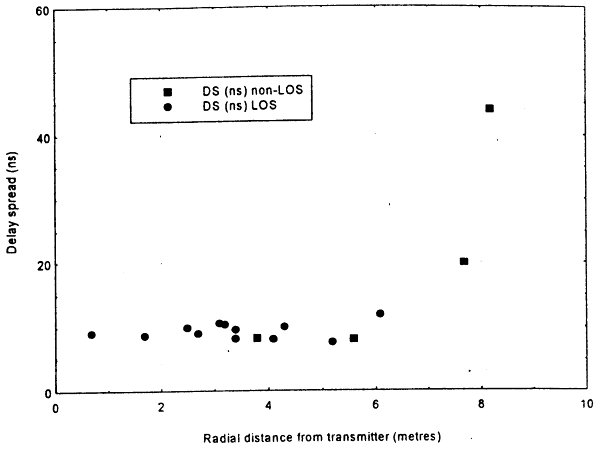

Figure 3. Measured delay spreads in a room in a Victorian apartment conversion.

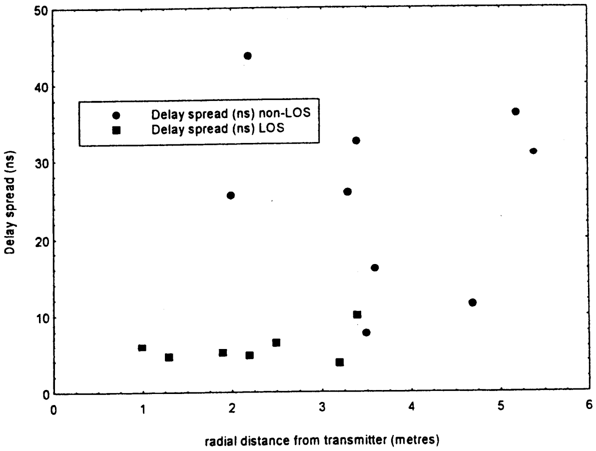

Figure 4. Measured delay spreads in a room in a Victorian house.