Delay Spread Requirements for Wireless Networks in the 2.4 GHz and 5 GHz Bands

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ABSTRACT

This paper starts with a brief overview of radio channel models. The most important parameter in these models is the delay spread, since this is directly related to the complexity of a modem. Various measurement results reported in the literature are summarized, showing that for most office buildings, the delay spread is the range of 40 to 70 ns, while larger delay spreads up to 300 ns can be expected in large buildings like shopping centers and factories.

1 INTRODUCTION

Fundamental work on modelling of the indoor radio channel is published in [1,2]. One of the results of this work, which is also supported by many other measurements reported in the literature, is that the average received multipath power is an exponentially decaying function of the excess delay. Further, the amplitudes of individual multipath components are Rayleigh distributed. This observation has led to simplified channel models as used in [3,4]. These models assume a fixed number of paths with equidistant delays. The path amplitudes are independent Rayleigh variables, while the path phases are uniformly distributed. Figure 1 shows an example of an average and an instantaneous power delay profile which were generated using this approach.

Compared to the more extensive models in [1,2], the simplified model of [3,4] may give somewhat optimistic results because the number of multipath component is fixed to the maximum possible amount. In the models of [1,2], the number of paths is random. Paths arrive in clusters with Poisson distributed arrival times. Within a cluster, the path amplitudes are independent Rayleigh variables. The average power delay profile, averaged over a large number of channels, is an exponentially decaying function, just as for the models in [3,4]. Thus, the only difference between the models is that the instantaneous power delay profiles have a slightly different shape, and channels generated by the method of [3,4] generally show more multipath components than channels generated according to [1,2]. This may give a somewhat optimistic diversity effect, because diversity is proportional to the number of paths. However, it probably does not make a difference when the models are used to determine the delay spread tolerance of a particular transmission system, since that is not depending on the number of paths, but rather on the amount of power in paths exceeding a certain excess delay. So, the channel models of [3,4] seem a good basis for comparison of different modulations, also because their simulation complexity is much lower than the models of [1,2]. One of the most important things that has to be sorted out is what the minimum delay spread value is that the modulation scheme must be able to cope with. To get an answer on this question, the next section presents some measurement results obtained from the literature.

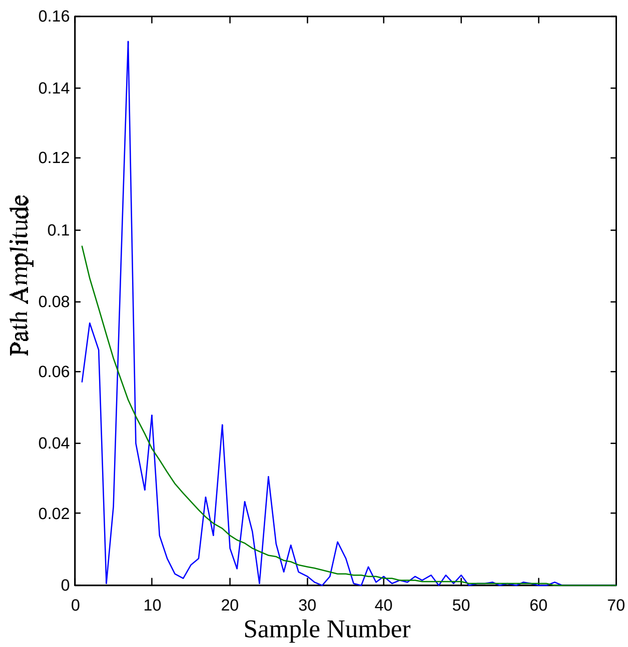

Figure 1: Example of generated average and instantaneous power delay profiles for a delay spread of 10 sampling intervals.

2 DELAY SPREAD VALUES

Tables 1 and 2 summarize some delay spread results obtained from literature for frequencies around 2 and 5 GHz. Two delay spread values are given; the *median* delay spread is the 50% value, meaning that 50% of all channels has a delay spread that is lower than the median value. Clearly, the median value is not so interesting for designing a wireless link, because there you want to guarantee that the link works for at least 90% or 99% of all channels. Therefore the second column gives the measured *maximum* delay spread values. The reason to use maximum delay spread instead of a 90% or 99% value is that many papers only mention the maximum value. From the papers that do present cumulative distribution functions of their measured delay spreads, it can be deduced that the 99% value is only a few percent smaller than the maximum delay spread.

Median Delay Spread [ns]	Maximum Delay Spread [ns]	Reference	Remarks
40	120	[5]	Large building (New York stock exchange)
40	95	[6]	Office building
40	150	[7]	Office building
60 106	200 270	[10]	Shopping center Laboratory
19	30	[11]	Office building: single room only
20 30 105	65 75 170	[12]	Office building Canteen Shopping center
30	56	[14]	Office building
25	30	[19]	Office building: single room only

Table 1: Measured delay spreads in frequency range of 1.8 to 2.4 GHz

Median Delay Spread [ns]	Maximum Delay Spread [ns]	Reference	Remarks
40	120	[5]	Large building (New York stock exchange)
50 35 10	60 55 35	[8]	Office building Meeting room (5mx5m) with metal walls Single room with stone walls
40	130	[7]	Office building
40 65 25	120 125 65	[9]	Indoor sports arena Factory Office building
20	30	[19]	Office building: single room only

Table 2: Measured delay spreads in frequency range of 4 to 6 GHz.

Measurements done at several frequencies simultaneously show that there is no significant difference in the delay spreads when the frequency changes from 850 MHz to 4 GHz [5, 7]. Therefore, below some additional results are included from measurements in the range of 800 MHz to 1.5 GHz.

Median Delay Spread [ns]	Maximum Delay Spread [ns]	Reference	Remarks
25	50	[2]	Office building
30	56	[14]	Office building
27	43	[15]	Office building
11	58	[16]	Office building
35 40 80 120	80 90 120 180	[17]	Office building Shopping mall Airport Factory
50 120	129 300	[18]	Warehouse Factory

Table 3: Measured delay spreads in frequency range of 800 MHz to 1.5 GHz.

Interesting results that can be derived from the measurements and the references are:

- The delay spread is related to the building size; largest delay spreads (up to 270 ns) were measured in large buildings like shopping centers and factories.
- For most office buildings, the maximum delay spread is in the range of 40 to 70 ns. Smaller delay spreads around 30 ns occur when both transmitter and receiver are within the same room.
- Even small rooms (5mx5m) can give significant delay spreads around 50 ns when there are metal walls [8].

REFERENCES

[1] H. Hashemi, ‘The Indoor Radio Propagation Channel’, Proceedings of the IEEE, vol. 81, no. 7, July 1993, pp. 943-968.

[2] A.A.M. Saleh and R.A. Valenzuela, ‘A Statistical Model for Indoor Multipath Propagation’, IEEE Journal on Selected Areas in Communications, vol. SAC-5, no. 2, February 1987, pp. 128-137.

[3] G. Halls, ‘HIPERLAN Radio Channel Models and Simulation Results’, RES10TTG 93/58.

[4] N. Chayat, ‘Tentative Criteria for Comparison of Modulation Methods’, IEEE P802.11-97/96.

[5] D.M.J. Devasirvatham, ‘Multi-Frequency Propagation Measurements and Models in a Large Metropolitan Commercial Building for Personal Communications’, IEEE PIMRC ’91, September 23-25, London, pp. 98-103.

[6] D.M.J. Devasirvatham, ‘Time Delay Spread Measurements at 850 MHz and 1.7 GHz inside a Metropolitan Office Building’, Electronics Letters, February 2, 1989, pp. 194-196.

[7] D.M.J. Devasirvatham, M.J. Krain and D.A. Rappaport, ‘Radio Propagation Measurements at 850 MHz, 1.7 GHz and 4 GHz inside two dissimilar office buildings’, Electronics Letters, vol. 26, no. 7, March 29, 1990, pp. 445-447.

[8] P. Hafesi, D. Wedge, M. Beach, M. Lawton, ‘Propagation Measurements at 5.2 GHz in Commercial and Domestic Environments’, IEEE PIMRC ’97, Helsinki, September 1-4, pp. 509-513.

[9] D.A. Hawbaker and T.S. Rappaport, ‘Indoor Wideband Radiowave Propagation Measurements at 1.3 GHz and 4.0 GHz’, Electronics Letters, vol. 26, no. 21, October 11, 1990, pp. 1800-1802.

[10] I.T. Johnson and E. Gurdenelli, ‘Measurements of Wideband Channel Characteristics in Cells Within Man Made Structures of Area Less Than 0.2 km^2’, COST 231 TD(90)083.

[11] J. Lahteenmaki, ‘Indoor Measurements and Simulation of Propagation at 1.7 GHz’, COST 231 TD(90)084.

[12] P.C. Anderson, O.J.M. Houen, K. Kladakis, K.T. Peterson, H. Fredskild and I. Zarnoczay, ‘Delay Spread Measurements at 2 GHz’, COST 231 TD(91)029.

[13] R.J.C. Bultitude et al., ‘The Dependance of Indoor Radio Channel Multipath Characteristics on Transmit/Receive Ranges’, IEEE Journal on Selected Areas in Communications, vol. 11, no. 7, September 1993, pp. 979-990.

[14] R.J.C. Bultitude, S.A. Mahmoud and W.A. Sullivan, ‘A Comparison of Indoor Radio Propagation Characteristics at 910 MHz and 1.75 GHz’, IEEE Journal on Selected Areas in Communications, vol. 7, no. 1, January 1989, pp. 20-30.

[15] K. Pahlavan and S.J. Howard, ‘Frequency Domain Measurements of Indoor Radio Channels’, Electronics Letters, vol. 25, no. 24, November 23, 1989, pp. 1645-1647.

[16] R. Davies and J.P. McGeehan, ‘Propagation Measurements at 1.7 GHz for Microcellular Urban Communications’, Electronics Letters, vol. 26, no. 14, July 5, 1990, pp. 1053-1055.

[17] E. Zollinger and A. Radovic, ‘Measured Time Variant Characteristics f Radio Channels in the Indoor Environment’, COST 231 TD(91)089.

[18] T.S. Rappaport and C.D. McGillem, ‘Characterization of UHF Multipath Radio Channels in Factory Buildings’, IEEE Transactions on Antennas and Propagation, vol. 37, no. 8, August 1989, pp. 1058-1069.

[19] P. Nobles and F. Halsall, ‘Delay Spread and Received Power Measurements Within a Building at 2 GHz, 5 GHz and 17 GHz’, IEE Tenth International Conference on Antennas and Propagation, Edinburgh, April 14-17, 1997.