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Title: **Radio Wave Propagation Characteristics at 5 GHz with Mode-lingSuggestions for HIPERLAN/2**

Agenda Item:

Document for:

Decision	
Discussion	**X**
Information	**X**

1 Introduction

The purpose with this report is to assess the current knowledge about propagation characteristics at 5 GHz by a literature survey. It is pointed out that the knowledge of some critical parameters is poor for some type of environments. For these environments extensive measurements are strongly recommended. The use of ray tracing techniques, as an alternative, is not advisable since they usually involve large uncertainties due to poor knowledge about electromagnetic material parameters in the corresponding environments. Furthermore, the difficulty to accurately reproduce the effect of diffuse scattering using these techniques is well known.

Simple type of models, which agree statistically well with measurements, are suggested for both channel simulations and path loss prediction.

2 Channel characteristics

2.1 Modeling

For simulation purpose a simple type of channel model described by a few measurable parameters is adequate. Still, a sufficient level of complexity must be kept allowing a realistic modeling of relevant channel characteristics. A model based on a tapped delay line is suggested [1] (essentially the same as the ComNets HIPERLAN/2 model [2]). The impulse response h is modeled as

$$h(\tau, t) = \sum_{k=1}^{N} a_k(t)\delta[\tau - (k-1)\Delta\tau], \qquad (2.1)$$

where t is time, τ delay, a_k are complex amplitudes, $\Delta\tau$ is the tap spacing with respect to time. For a given bandwidth, W, the channel is unambiguously determined if $\Delta t < 1/W$ i.e. if Nyquist's sampling theorem is fulfilled. For e.g. W=25 MHz $\Delta\tau$ should be less than 40 ns. N is given by the maximum excess delay and $\Delta\tau$. For e.g. a maximum excess delay of 350 ns $N \geq 10$. The fading of each tap is assumed to follow a Rayleigh probability distribution where different taps are uncorrelated. The average power per tap $\bar{a}_k$ is assumed to decline exponentially with time i.e.

$$\bar{a}_k = A\exp\left[-\frac{(k-1)\Delta\tau}{2\Gamma}\right], \qquad (2.2)$$

where Γ is the expected rms delay spread and A is a normalization constant. Some measurements indicate that also secondary clusters of taps, with exponential decline, might have to be taken into consideration. The variation of impulse response with respect to time (due to $a_k(t)$) is given by the corresponding Doppler spectrum. A uniform distribution of angles of arrival is assumed for the received signals. The corresponding Doppler spectrum for a moving receiver with an omnidirectional antenna is given by

$$D(f) = \frac{1}{2\pi f_{max}}\left[1 - \left(\frac{f}{f_{max}}\right)^2\right]^{-1/2} \tag{2.3}$$

where f is the Doppler frequency, and $f_{max} = v/\lambda$ where v is the receiver velocity and λ is the carrier wavelength. For directive antennas the shape of the Doppler spectrum can be calculated using the corresponding antenna diagrams. In order to allow modeling of Ricean channels a contribution that is constant in amplitude and Doppler frequency may be added to the LOS tap.

The Rayleigh probability distribution of tap amplitudes can be realized by e.g. a complex Gaussian random process where the time variation is given by Doppler filtering. This means that a sequence of impulse responses, that are equidistant in time, is generated. The distribution is transformed to the Doppler frequency domain, by a DFT of the time sequence of each tap, and then filtered in accordance with the desired Doppler spectrum. Finally the distribution is transformed back to time domain by an inverse DFT.

In Fig. 1 is shown the comparison of a modeled and a measured power delay profile from a typical indoor environment. The measurement was performed in the frequency domain (201 frequencies between 1700 and 1900 MHz) and then transformed to time domain by an inverse DFT using a Hanning window. The modeled channel is pure Rayleigh with Γ set to 45 ns (Γ=expected rms delay spread) and with a Gaussian noise contribution. The agreement between the model and the measurement is very good for this particular case.

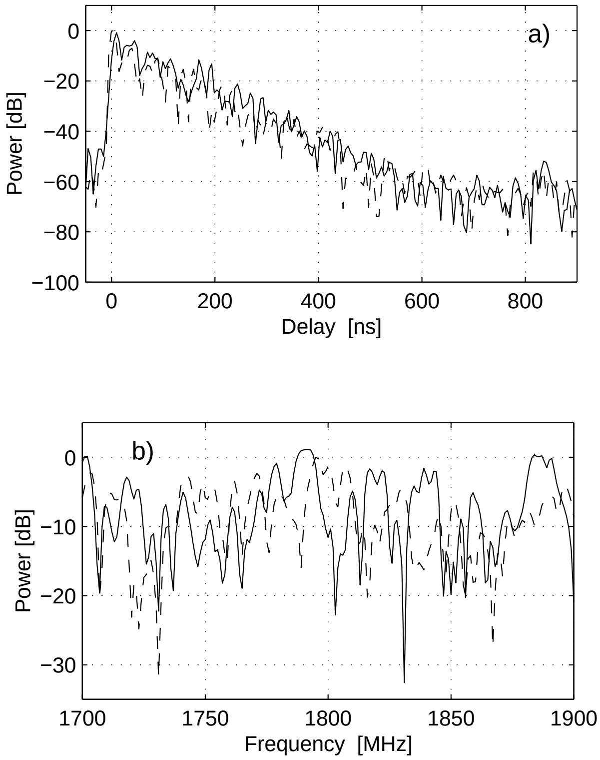

Figure 1. Power delay profile, a), and frequency spectrum, b), measured (solid line) with omnidirectional antennas in a typical semi-large open space indoor environment, and modeled (dashed line).

2.2 Measurements

An increasing number propagation measurements at 5 GHz have been reported in the recent years. The focus has been on wideband characteristics for office type of environments. Reported measurements are rare for outdoor and large open-space indoor environments. In order to establish the propagation characteristics for these type environments further measurements are needed.

For office type of environments different measurements seem to agree well (See Table 1). The upper limit of rms delay spread is about 50-60 ns for distances up to 30 m while the typical value is 10-20 ns. Moreover, the assumption that the power has an exponential decline agree very well with the measurements.

Table 1 rms delay spread (ns) measured in office type of environments.

Ref.	LOS				NLOS			
	d < 10m		10m < d < 30m		d < 10m		10m < d < 30m	
	ave	max	ave	max	ave	max	ave	max
Pla93 [3]								40[1]
Nob93 [4]	15				22			59
Dev90a [5]							50[2]	130[2]
Jan92 [6]			24					
Air96 [7]	16							
Str95 [8]		11						
Gue97 [9]	36				49			
Haf97 [10]	25 10[3]	40 11[3]	12 8[3]	30 11[3]			40	
Kiv97 [11]							25	50-60

1. Delay at 20 dB below main peak was measured. The rms value was obtained assuming exponential decay.
2. Measured in a 100x50 m office environment i.e. d < 100 m.
3. Receiver 20 dB horn with 3 dB beamwidth of 15°.

For large open space indoor environments, like airport terminals, larger delay spreads are expected. One measurement in a 130x100 m car-manufacturing assembly-hall reports a 20 dB delay interval of 460 ns which corresponds to a rms delay spread of 100 ns [3]. It is however unclear if this is a typical value since no other similar measurements have been found in literature.

3 Path loss prediction

The predictive power of empirical models is essentially as good as that of present physical models. For the case where the transmitter and the receiver are located at the same floor the Keenan-Motley approach has been proven to give accurate predictions. Expressed in dB the path loss L is given by

$$L(d) = L_{FS}(d) + n_w L_w \tag{3.1}$$

where L_{FS} is the free space loss, i.e. for isotropic antennas

$$L_{FS}(d_m) = 32.4 + 20\log_{10} f_{GHz} + 20\log_{10} d_m, \qquad (3.2)$$

and n_w the number of walls that are penetrated. Reported rms prediction errors are typically about 5 dB [12]. This approach can be further simplified by assuming that the loss due to walls is a linear function (dB) of distance [5], i.e.

$$L(d) = L_{FS}(d) + \alpha d \qquad (3.3)$$

where α is a constant typically in the range 0.2 to 1 dB/m. For two explicit buildings α was measured to be 0.47 and 0.23 dB/m where the standard deviation of the measured path loss was 8.5 dB. A dependence of the standard deviation, σ, on distance have been shown in [5]. It is given by

$$\sigma(d) = \beta[P_{dB}(d) - P_{dB}(0.3m)] \qquad (3.4)$$

where β is a constant and P_{dB} is the received power in dB as predicted by the model. For the two buildings mentioned above, β was determined to be 0.15 and 0.19 respectively. This linear loss modeling is suggested for office type of environments. However, the fact that only a few measurements have been found in literature seems to necessitate additional measurements.

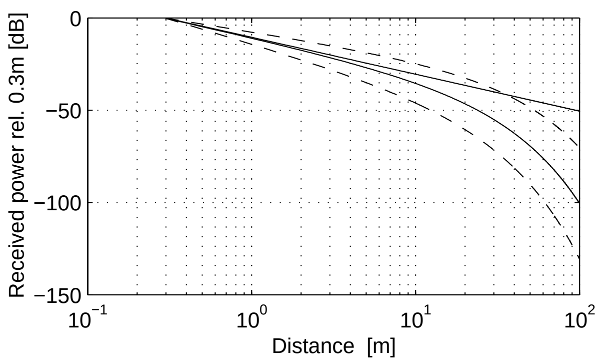

Figure 2. Received power in dB versus distance in meters. The straight solid line corresponds to free space loss. The curved solid line corresponds to the linear loss model with α=0.5. Dashed lines indicate bounds corresponding to two standard deviations for β=0.15.

If the receiver and transmitter are separated by one or more floors the path loss behavior is different. Support for a model of the type

$$L(d) = L_{FS}(1m) + 10n\log_{10} d + FAF, \qquad (3.5)$$

where the floor attenuation factor FAF depends on the number of penetrated floors, has been found for frequencies around 900 MHz [12]. It seems as if *n* has only weak dependence on the number penetrated floors and therefore can be fixed. The increase of FAF per floor decreases as the number of penetrated floors increases. Typical values are $n = 3$ and for penetration of floor FAF = 13-16 dB, and for penetration of three floors FAF = 30 dB. In order to establish realistic parameter values for this type of modeling at 5 GHz, measurements are needed.

4 Summary and conclusions

It has been shown that a realistic description of propagation at 5 GHz, for representative indoor environments, can be achieved by simple models. The range of parameter values of the suggested channel model is well established by literature for office type of environments. A type of path loss model (supported by [5]) for office environments with transmitter and receiver at the same floor have been suggested.

It remains to determine the representative range of channel model parameters for outdoor and large open-space indoor environments. This is important since significantly larger delay spreads are expected for these type of environments (supported by [3]). Directive antennas are of particular interest since they might allow a reduction of delay spread to the same level as for office environments (supported by [10]). A literature search indicates that measurements are needed.

Concerning path loss, the suggested modeling is probably adequate. The uncertainty about the range of values for model parameters is, however, very large since only a few measurements at 5 GHz have been found in literature. Hence, an extensive measurement campaign seems to be required.

5 References

[1] K. Pahlavan, A. H. Levesque, ‘‘Wireless Information Networks’’, John Wiley & Sons, 1995.

[2] ETSI EP BRAN Temporary document WG3TD73, ‘‘A simple/accurate Propagation Model for the 5.2 GHz Indoor Radio Channel’’, S. Mangold et al.

[3] Plattner-A; Prediger-N; Herzig-W, ‘‘Indoor and outdoor propagation measurements at 5 and 60 GHz for radio LAN application’’, 1993 IEEE MTT-S International Microwave Symposium Digest (Cat. No.93CH3277-1), Atlanta, GA, USA, 14-18 June 1993, p.853-6 vol.2.

[4] P. Nobles et al., ‘‘Propagation Measurments in an Indoor Radio Environment at 2,5 and 17 GHz’’, IEE Colloquium on ‘High Bit Rate UHF/SHF Channel Sounders - Technology and Measurement’ (Digest No.1993/233), London, UK, 3 Dec. 1993. Sponsors: IEE. In: p.4/1-6, 1993.

[5] D.M.J. Devasirvatham, C. Banerjee, M.J. Krain & D.A. Rappaport, ‘‘Multi-Frequency Radiowave Propagation Measurements in the Portable Radio Environment’’, in Proc. Second IEEE Int. Symp. Personal, Indoor and Mobile Radio Commun., London, England, Sept. 1991, pp. 98-103., COST 231 TD(90)14

[6] G.J.M. Janssen and R. Prasad, ‘‘Propagation Measurements in an indoor Radio Environment at 2.4GHz, 4.75GHz and 11.5GHz’’, in Proceedings of the 42nd IEEE Vehicular Tech. conf., Denver, Colorado,May 11-13 1992.

[7] J. Airs, ‘‘Comparative Indoor RF Channel Soundings at 2, 5 & 17 GHz’’, Wireless Personal Communications 3: 353-363, 1996.

[8] Street-A-M; Moss-J-G-O; Edwards-D-J; Mehler-M-J, ‘‘Indoor propagation measurements at 5 GHz’’, IEE Colloquium on 'Propagation in Buildings' (Digest No.1995/134), London, UK, 14 June 1995. Sponsors: IEE. In: p.2/1-6, 1995.

[9] Guerin-S; Guo-Y-J; Barton-S-K, ‘‘Indoor propagation measurements at 5 GHz for HIPERLAN’’, Tenth International Conference on Antennas and Propagation (Conf. Publ. No.436), vol.2, Edinburgh, UK, 14-17 April 1997. Sponsors: IEE. In: p.306-10 vol.2, 1997.

[10] P. Hafezi, D. Wedge, M.A. Beach, M. Lawton, ‘‘Propagation Measurements at 5.2 GHz in Commercial and Domestic Environments’’, in Proc. of Int. Symp. on Pers., Indoor and Mob. Radio Comm., PIMRC'97, Helsinki, Finland, 1997, pp. 509-513.

[11]J. Kivinen, P. Vainikainen, ‘‘Wideband Indoor Propagation Measurements at 5.3 GHz’’, COST 259 TD(97)54.

[12]Seidel, S. Y. and Rappoport, T. S., ‘‘914 MHz Path Loss Prediction Models for Indoor Wireless Communications in Multifloor Buildings,’’ IEEE Transactions on Antennas and Propagation, Vol. 40, No. 2, February, 1992, pps. 207 - 217.