PROPAGATION OF RADIOWAVE FOR LMDS SYSTEMS

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Abstract

The design, planning and deployment of LMDS (Local Multipoint Distribution Service) systems require a good understanding of radio wave propagation. After a presentation of the different propagation mechanisms , we present the propagation channel characteristics: attenuation, variability and frequency selectivity due to multi-path; the selectivity being defined from wideband parameters such as delay spread, delay window, coherence bandwidth ...To each environment correspond particular typical models (theoretical, statistic or semi-empirical). Different models for narrow bandwidth prediction in different environments found in the literature will be summarised; effects of vegetation and rain will be taken into account. In broadband some frequency selectivity characteristics will be given from France Telecom measurements and experimental data found in the literature.

1 - Introduction

The design, planning and deployment of LMDS (Local Multipoint Distribution Service) systems require a good understanding of radio wave propagation. The wave propagation behaviour knowledge in the terrestrial environment permits us to determine emitting power, polarisation and to choose antennas, modulation, transmission protocol, etc.

After a presentation of the different propagation mechanisms (line of sight, transmission, reflection, diffraction, scattering, guided waves) we present the propagation channel characteristics: attenuation (free space, gaseous, vegetation, rain, etc), variability, and frequency selectivity due to multi-path.

To each environment correspond particular typical models (theoretical, statistic or semi-empirical). Theoretical models are based on adequate approximations of physical fundamental laws. Empirical models are based on statistical analysis of an important numerous of experimental measurements carried out in function of different parameters such as frequency, distance, effective high of emitting and receiving antenna, etc. The semi-empirical models combine an analytical formulation of physical phenomena (reflection, transmission, diffusion, diffraction) with and a variable fitting with experimental measurements. Different models in narrow bandwidth in different environments (urban, suburban, rural) found in the literature will be summarised; effect of vegetation and rain will be taken into account. In broadband some selectivity characteristics (mean delay, delay spread, delay interval, delay window, coherence bandwidth) will be given from France Telecom measurements and experimental data found in the literature.

2 - Propagation mechanisms

To define the propagation environment we must consider different boundaries media such as air, ground, buildings, walls, vegetation, etc. These different boundaries give rise to change in amplitude, phase and direction of propagating wave between transmitter (Tx) and receiver (Rx). We discern direct, reflected, transmitted, scattered and guided waves.

2.1 – Direct wave

A wave is direct if it is located inside the first Fresnel ellipsoid that determines the radio electrical visibility between Tx and Rx. It characterises the space region where the major energy part is transmitted. The following relation gives the ellipsoid maximum radius: $r_{max} = \left(\lambda d / 2\right)^{1/2}$, where d is the Tx-Rx distance.

2.2 – Reflected wave

Reflection mechanism arise when the wave meets a surface whose dimensions are large comparatively to the wavelength (ground, building, wall,vegetation, etc). Reflection characteristics of any surface depend of several factors: surface material (smooth, rough), length and angle of the incident wave. A smooth surface reflects incident wave in only one direction like a mirror (specular reflection) while a rough surface reflects it on all directions (scattered reflection).

2.2.1 – Specular reflected wave

Specular reflection, common phenomena to all frequencies, is due to a perfect smooth surface. Propagation attenuation which results from such reflections can be evaluated by Fresnel relations and depends on dielectrical characteristics of the reflecting surface (conductivity σ, permittivity ε).

2.2.2 – Scattered reflected wave

Such wave results from the roughness of the obstacles surface. The reflected waves are spread over all directions. The Rayleigh criteria is used to discriminate the specular from the scattered reflection. The minimum depth of the surface irregularity h is given by :

$$h > \lambda/(8\sin(\theta)) \tag{1}$$

where λ and θ are the wavelength and the incident angle respectively.

Two models are usually used to represent scattered reflection : LAMBERT and PHONG models.

- LAMBERT model considers a reflection in all directions independently of the incident wave. It is described by the following relation:

$$R(\theta_0) = \rho R_i \frac{1}{\pi}\cos(\theta_0) \tag{2}$$

where :

- ρ is the surface reflection coefficient,
- R_i represent the incident power,
- θ_0 is the observation angle.

- PHONG model considers the reflecting diagram as the sum of two components: specular and diffuse component. It is described by the following relation:

$$R(\theta_i,\theta_0) = \rho\frac{R_i}{\pi}\left[r_d\cos(\theta_0) + (1-r_d)\cos^m(\theta_0-\theta_i)\right] \tag{3}$$

where :

- ρ is the surface reflection coefficient,
- R_i represent the incident power,
- r_d is the percentage of the ray which is reflected on scatter form (value included between 0 and 1),
- m is a parameter which control directivity of the specular reflection component directivity,
- θ_i and θ_0 are respectively incident and observation angles.

2.3 – Transmitted wave

Transmission phenomenon is the mechanism, which permits to waves to go through an obstacle (building, wall, vegetation, etc). The amplitude of the transmitted wave is given relative to the incident wave amplitude by the Fresnel transmission coefficients, which depend on the impedance of the media and on the incident angle.

2.4 – Diffracted wave

Diffraction phenomena arise when waves meet obstacles or apertures that dimensions are large comparatively to the wavelength. It constitutes one of the most important factors in radio wave propagation. It gives rise to perturbations in wave propagation: presence of energy in shadow region, radio beam divergence from aperture.

2.5 – Guided wave

Some environments such as canyon streets, corridors, tunnels, act as real wave-guide consecutively to multi successively reflections on the different walls.

3 - Propagation Channel characteristics

The previous phenomena give rise to important variations in radio wave amplitude due to multi-path interference. We distinguish three categories: large, medium and small scale variations.

- Large-scale variations are dependant from distance between transmitter and receiver. They determine the global attenuation

- Medium scale variations are called slow fading or shadowing. They result from the obstacles close to the radio link. The scale of such variations is this of obstacles size. Attenuation can reach about several ten dB.

- Small scale variations or fast fading result from the multi-paths channel on the received field strength.

Attenuation models permit to predict large and medium scale variations. Small scales variations have a random character: they can be taken into account statistically (variability and selectivity)

3.1 – Attenuation

Different attenuation model are defined in the literature [1]. We distinguish, between others the free space attenuation and the excess attenuation relatively to the previous one (gas, rain, vegetation, wall, diffraction, etc). The free space attenuation A in dB is given by the following relation:

$$A = 32.4 + 20\log_{10}(f) + 20\log_{10}(d) \quad (4)$$

where f is the frequency in MHz and d the distance between Tx and Rx in km.

3.2 - Variability

The environment is variable: mobile vehicle, pedestrian, wind in trees, etc. The receiver intercepts many direct, reflected and diffracted waves with several directions of arrival involving a multiple interfering field and variations of the instantaneous received power. The statistical laws attached to the fast fading follow Rayleigh, Rice and Nakagami distributions [2]. The fade duration and the amplitude level of the fast fading are usually mitigated with diversity solutions, combined interleaving and error correcting coding processing.

3.3-Frequency selectivity

When multi-path time delay differences are important relatively to the symbol duration, the channel transfer function amplitude varies significantly across the signal bandwidth. The channel is frequency selective and must be regarded as wideband. A wideband modelling is then necessary to evaluate a transmission chain, to design new systems and to ensure a good quality of service on numerical transmissions. Different wideband parameters deduced from the power delay profile help to characterize this selectivity. These parameters are intended to predict radio impairments, equaliser size ...

4 - LMDS propagation modelling

4.1 - Narrow band analysis

4.1.1 - Rain attenuation

The rain attenuation results from the rain drop-size compared to the wavelength and depends on the rain fall rates, the polarisation and the frequency. The ITU-R model [3] is the most known model. The Perlow model [4], deduced from ITU-R model is expressed as follows:

$$A_{rain} = a(f,p)\,R^{b(f,p)}\,\frac{90d}{90+4d} \quad (5)$$

where :

- a and b are the ITU-R coefficients and depend on frequency f and polarisation p,
- d is the Tx-Rx distance

The following table give rain values attenuation at 28 and 40 GHz over a distance of 1 km for different values of rainfall rates (12, 22 et 35 mm/h).

Rain rate (mm/h)	Attenuation at 28 Ghz	Attenuation at 40 GHz
12	2.04	3.61
22	3.82	6.30
35	6.19	9.65

Table 1. Rain values attenuation at 28 and 40 GHz on a 1 km distance.

In [5] the reader can find a review of the different rain attenuation models for Earth –satellite links.

4.1.2 - Vegetation attenuation

Propagation measurements in urban and suburban area for 55 GHz [6] and 28 GHz [7], [8] [9] frequency band were realised and all indicated that it would be difficult to cover a given area with only one base station above the roof top, even in case of very high building., due to shadowing by other buildings or vegetation. In non line of sight (NLOS) it is not always possible to receive indirect signal by reflections or diffractions on man made structures [7]. Attenuation due to vegetation is growing with frequency [11], [12] so that it must be taken into account for the total propagation loss when only trees or foliage obstruct the direct link between Tx and Rx. An attenuation model has been proposed by UIT-R [13] expressed as follows :

$$A_{vegetation} = \alpha f_{MHz}^{\beta} d^{\gamma} \quad (6)$$

where :

f is the frequency in MHz,
d is the distance through vegetation,
α, β and γ are the model coefficients.

These coefficients have been improved by [11] using measurements through vegetation carrying back the rms errors between prediction and measurements from 22 to 11 dB. It is reduced to 8 dB if we take into account the lighting common zone by both transmitter and receiver antenna [11].

Experimental and theoretical studies based on energy radiative transfer theory were performed for 9.6, 28.8 and 57.6 GHz frequency [12]. They showed that attenuation due to vegetation in dB grows quickly with frequency linearly in function of distance *d* through vegetation for *d* less than 30 m from 1.3 to dB per meter, presents a transition zone and after that it continues to grow linearly at 0,05dB per meter depending of vegetation type.

Some results around 28 GHz have also been presented by US WEST [14]. Attenuation due to vegetation can reach about several tens of dB. A mean value of 4 dB/km is advanced with a rms error of 10 dB at 28 GHz in a sub urban area. The polarisation state of a wave passing through vegetation is altered (a purely vertical polarised wave may emerge with some horizontal components or vice versa; we have a depolarisation). The more important is the attenuation and the more important is the depolarisation. For an initial cross polar isolation value in free space of 24 dB, US WEST experimentally found a decrease of 1dB in cross polar isolation when attenuation due to vegetation increases of 3 dB. Vegetation depolarisation seems more important than rain depolarisation.

France Telecom R&D carried out propagation measurements around 28 and 40 GHz. Micro-cells (antennas below roof top level) were chosen for these measurements in order to consider obstructions due to vegetation and also to road traffic. Antennas were typical LMDS linearly polarized antennas. Firstly, the distance dependent path loss is obtained by an analysis of the temporal mean of the measured received powers in direct line of sight of the Tx. We find a 25.5log10(d) dependency (Fig.1), somewhat greater than for free space, but we think that the difference is mainly due to slight errors of the Rx antenna pointing. When the direct path passes through some trees, the propagation loss becomes much larger as we get a distance dependency of 50.5log10(d) in the range $100<d<200$m. The presence of vegetation causes an additional path loss of 25 dB for our worst cases around 40 GHz. We recall that trees were out of leaves at the measurement season, and we expect a much larger propagation loss in case of trees with all their foliage. Similar results were obtained around 28 GHz.

4.1.3 - Variability

Besides an additional path loss to the free space path loss, vegetation can also creates temporal variations of signals characterised by fast fading laws and Doppler spectra depending on the wind conditions. Temporal fading on fixed outdoor links can also be caused by the movement of cars causing changes in multi-path conditions surrounding a radio link and by intermittent path obstructions. From our measurements, we conclude that the presence of cars may have a significant influence on the received power, particularly for a low Rx antenna height of 3 m above the street level. Variations of received powers can be as much as 25 dB depending on the measurement conditions. Fig. 2 gives an example of average Doppler spectrum evaluated on short windows (0.5s) where the fast fading seems quasi stationary. The shape of this Doppler spectrum is typical of those encountered for fixed links with motion around [15], as the major contribution is near the null Doppler frequency. It is totally different from the Doppler spectra usually mentioned for normalised channel models, for which Jakes Doppler, flat or Gaussian Doppler is usually recommended.

4.2 – Wideband analysis

Very little publications deal with wideband channel modelling in millimetre frequency for LMDS system. The existing results mention low values of delayed path comparatively to direct path with an excess attenuation loss from 15 to 20 dB. Some tapped delay line wideband models based on measurements with a 500 MHz bandwidth have been published [10]. Such measurements include both line (LOS) and non line of sight (NLOS) cases (building, houses or vegetation shadowing). The characteristics of such models (invariant in time) are called to mind in table 2. The used antennas have typical beam width for LMDS applications. Recently others multi-path models have been proposed and adopted by ETSI/BRAN workshops.

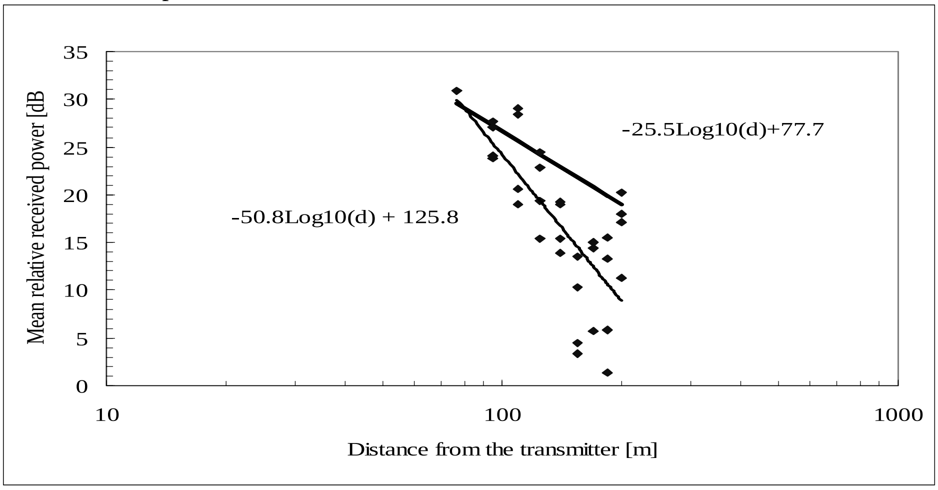

Fig. 1. Mean power variations versus distance from transmitter in case of shadowing by trees.

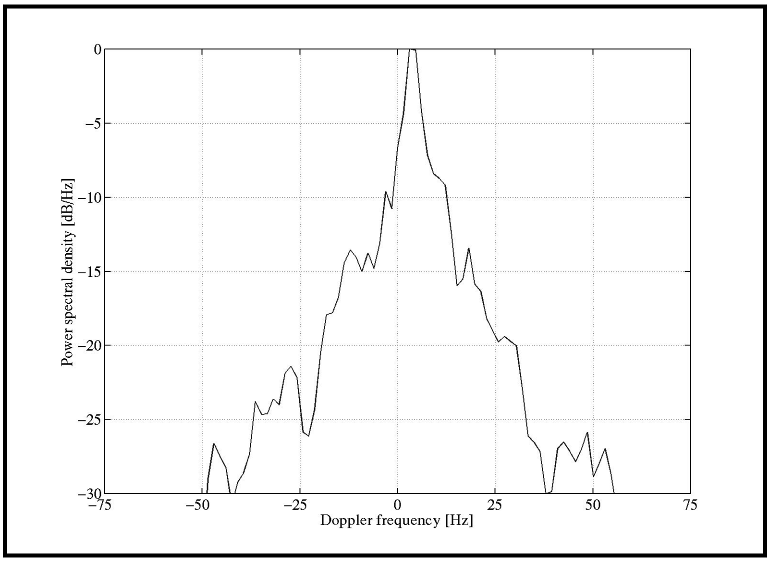

Fig. 2. Average Doppler spectrum corresponding to fast fading due to traffic road

Model type	# tap	Power β [dBm]	Delay τ [ns]
A: Low selectivity (Sd = 1.26 ns)	1	0	0
B: Moderate selectivity (Sd = 1.60 ns)	1	0	0
	2	-13.7	5.3
C : Important selectivity (Sd=2.95 ns)	1	0	0
	2	-2.8	3.6
	3	-16.2	15.3

Table 2. Wideband model parameters [10] where Sd is the Delay spread

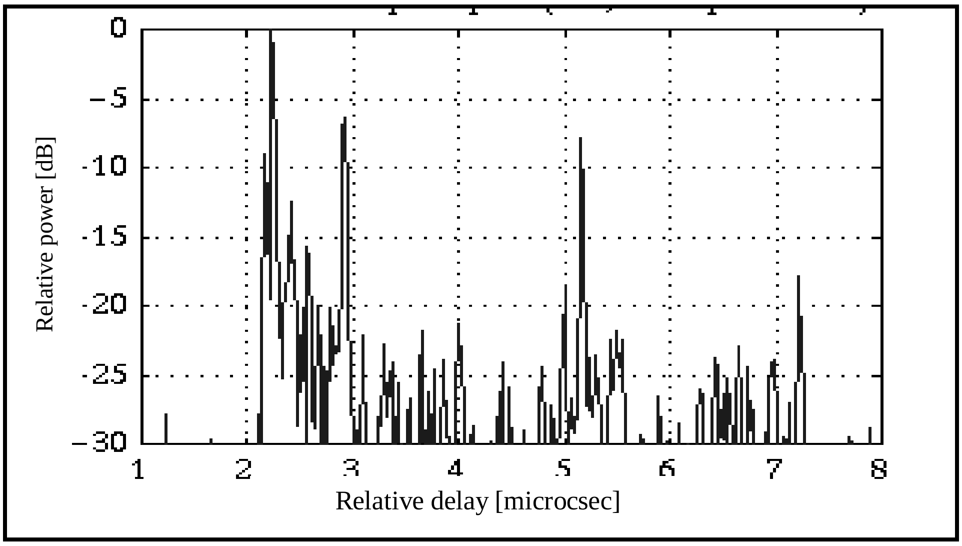

Fig.3. Example of a very selective channel measured in non line of sight (NLOS) at 28 GHz.

	Sd [ns]	DW75[ns]	DW90 [ns]	DI6 [ns]	DI15 [ns]	BC50[MHz]
Micro_cell (40 GHz)	*12,9*	*34,5*	*49,3*	*48,8*	*75,6*	*13,6*
Small_cell (28 GHz)	*12*	*27,5*	*40*	*41,5*	*64*	*15,8*

Table 3 : Wideband parameters of the measured channel on a 50 MHz bandwidth with a Hanning spectral window (mean value)

Usual wideband parameters defined by COST 207 and ITU-R were evaluated: the delay spread (Sd), the delay interval (DIx) for a level of 6, and 15 dB below the principal path of the impulse response (IR), the delay window (Wx) containing x=75% and 90 % of the received power, and the correlation bandwidth Bc for a 0.5 correlation. Tab. 3 gives statistical results evaluated over all the measured IRs around 40 GHz in micro-cells (Tx and Rx in the same street) and 28 GHz in small cells (antennas above roof top level). The main result is that the channel frequency selectivity is very low over a 50 MHz bandwidth in micro cells and in LOS for small cells: the wideband parameters are very close to the limit values of a 50 MHz non frequency selective channel thanks to the directivity of the Rx antenna. It does not necessary mean that there is a unique path: other paths may have a delay difference too small with the direct path to influence the frequency selectivity over a 50 MHz band. For NLOS situations (building shadowing) for some measurements we noticed severe multi-paths (Fig. 3) in a typical urban small cell.

5 – Conclusion

After a presentation of the different propagation mechanisms (line of sight, transmission, reflection, diffraction, diffusion, guided waves) the propagation channel characteristics have been presented: attenuation (free space, gaseous, vegetation, rain, …), variability and frequency selectivity.

Different models in narrow bandwidth in different environments (urban, suburban, rural) noticed in the literature have been summarised. Effects of rain and vegetation have been particularly taken into account. Rain attenuation is a function of rainfall rate and frequency : attenuation from 5 to 10 dB/km are typical values. The presence of vegetation causes variability and an additional path loss of 25dB depending on the vegetation depth, species and frequency.

In broadband some selectivity characteristics (delay spread, delay interval, delay window, coherence bandwidth) have been given from experimental data and from simulation found in the literature.

A better understanding of radio wave propagation in that frequency band must contribute to design, planning and deployment of LMDS (Local Multipoint Distribution Systems). This domain covers a wide range of application from telephony in rural areas or in developing countries to broadband access in developed countries.

6 - References

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