Estimating 28 GHz LMDS Channel Dispersion in Urban Areas Using a Ray-Tracing Propagation Model

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Abstract- **Broadband wireless systems such as LMDS operating in the millimeter wave band offer the potential for a highly flexible, high-speed, two-way information distribution network to serve local and metropolitan areas. To date, relatively little research has been done to characterize such wireless channels in order to determine the degree of sophistication required in the transmission hardware. This paper uses a ray-tracing propagation model to investigate the dispersive nature of the transmission channel in a typical urban environment. The results of this work show that highly directional antennas can effectively reduce channel dispersion so that high-speed digital transmission should be possible without requiring equalizers in the receivers. This research also suggests that intelligent use of stable reflection paths could provide an effective means of providing LMDS service to non line-of-sight locations.**

1. Introduction

Of several recent wireless spectrum allocations, one of the more valuable is LMDS (Local Multipoint Distribution Service) spectrum that is planned for operation in frequency bands above 20 GHz. LMDS systems are intended to be fixed systems in that the system distribution hubs and user terminals will be at fixed rather than mobile locations.

In recent years a vast amount of research has been done to characterize mobile radio channels, primarily to support the design and deployment of cellular and PCS systems operating below 2 GHz. However, because LMDS systems operate at much higher frequencies and use fixed links, the wireless channel models develop for mobile systems are not directly applicable. New channel modeling research effort is needed to devise channel models for LMDS that will properly account for such factors as foliage attenuation, building attenuation, and rain and fade outage statistics. Currently employed rain and fade outage statistical models are almost entirely based on measured results at frequencies below 13 GHz using relative long path lengths and consequently are probably not well-suited to short-range LMDS system design.

Because LMDS is planned to carry high-speed digital signaling or digital video, one channel characteristic that is particularly important is channel dispersion due to multipath propagation, also referred to as frequency-selective fading. In currently-deployed point-to-point microwave links carrying high-speed digital traffic, channel dispersion is sufficiently important that considerable effort and expense is devoted to dealing with it, either through the use of antenna diversity, or more commonly, by using equalizers in the receivers. From a commercial standpoint, inexpensive terminals are important to the success of an LMDS service. If equalizers or other special techniques are needed to deal with channel dispersion, it could have a dramatic impact on terminal cost. Therefore, understanding channel dispersion in LMDS systems is critical to designing systems that can be cost-effective.

To estimate channel dispersion for LMDS systems in urban areas, the research described in this paper employs a ray-tracing propagation model with a typical downtown building scene. Ray-tracing is a high-frequency technique that is well-suited to this application because it inherently provides time delay information of signals arriving at a receiver (as a function of ray trajectory length) and angle of arrival and departure information. Angle of arrival and departure information is essential to study the effect of different directional (or adaptive) antenna strategies.

In this paper the characterization of LMDS channel dispersion in urban areas has been done in terms of channel RMS delay spread and coherence bandwidth.

The results show that the degree of channel dispersion varies widely (by more than an order of magnitude) from one location to another, and that antenna directionality and pointing angle have an important impact on channel dispersion. Depending on transmission data rate and modulation type, high-speed transmission in an LMDS system should be possible without equalizers at the customer terminals, even if the terminal is not line-of-sight to the transmitter.

2. Dispersive Channel Response Model Using Ray-Tracing

A general model for the low-pass frequency response for a radio channel is:

$$h(t) = \sum_{n=1}^{N} A_n \delta(t-\tau_n)\exp(-j(\theta_n - \Delta\theta_n)) \qquad (1)$$

in which the impulse response $h(t)$ is the sum of N impulses arriving at delay times τ_n with amplitudes A_n, phases θ_n, and phase displacements $\Delta\theta_n$. The phase displacements result from the motion of the receiver (not applicable in the fixed system case), or from the motion of the receiver *relative* to the rest of the propagation environment (reflections from moving cars, buses, etc.)

To use this model, it is necessary to identify the amplitudes, time delays, and absolute phase shifts of the N components of $h(t)$. The received components may consist of the line-of-sight signal from the transmitter and a variety of signals reaching the receive antenna via specular surface reflection, edge diffraction, transmission through objects, diffuse scattering, or a combination of all of these mechanisms. When using ray-tracing techniques, the energy emitted from the source transmitter antenna is geometrically traced to determine those surfaces and edges (corners) which are illuminated. For the ray-tracing model used here, each illuminated surface is replaced by an image transmitter or scattering source such that the radiation from the image represents (in amplitude, phase and radiating directions) the energy reflected from the source. Similarly, an illuminated edge is replaced by an equivalent wedge diffraction source. With the first set (generation) of images and illuminated edges determined, each of them is then considered in turn by ray-tracing to find the surfaces and edges they illuminate. This process is repeated for as many iterations as may be relevant to the problem at hand, or which are practical from a computational point of view. The computation time is a function of the number of iterations and the number of elements (walls and edges) that describe the propagation environment. A more detailed description of the theoretical ray-tracing model used here can be found in [1].

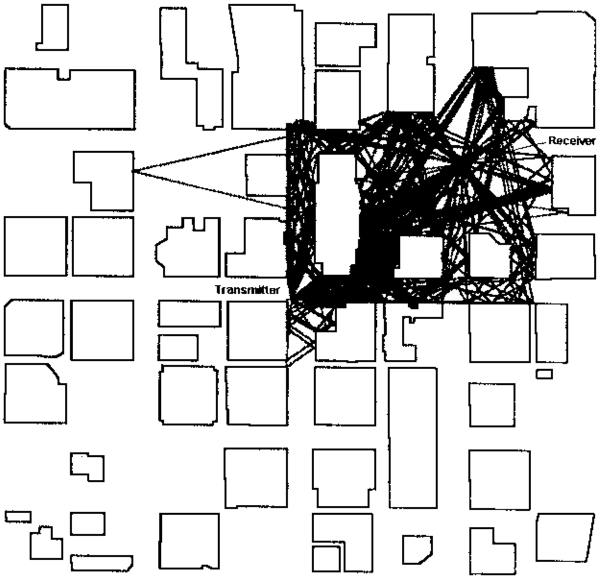

Fig. 1. Rays showing multipath signal trajectories in an urban environment

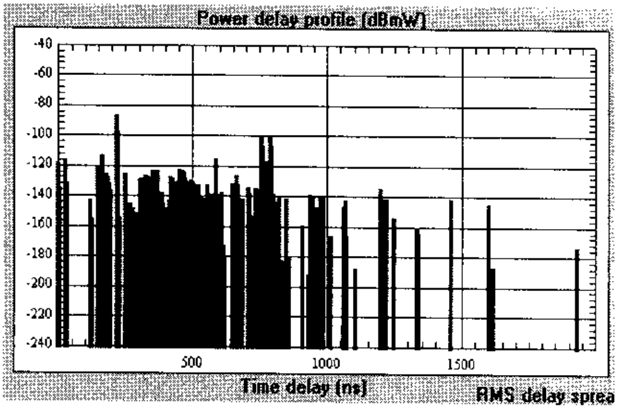

Fig. 2 – Power delay profile for analysis point in Fig. 1.

The ray interactions with the propagation environment are tracked for both horizontal and vertical polarizations (HP and VP) by taking into account the conductivity and permittivity of the walls and edges, and the angle of incidence for the interaction at each wall and edge. A typical ray-tracing study for a transmitter in an urban building environment is shown in Figure 1. The "power delay profile" which shows the amplitude and arrival times of rays at this location is shown in Figure 2. An example of 3D ray-tracing using a simpler building environment is shown in Figure 3.

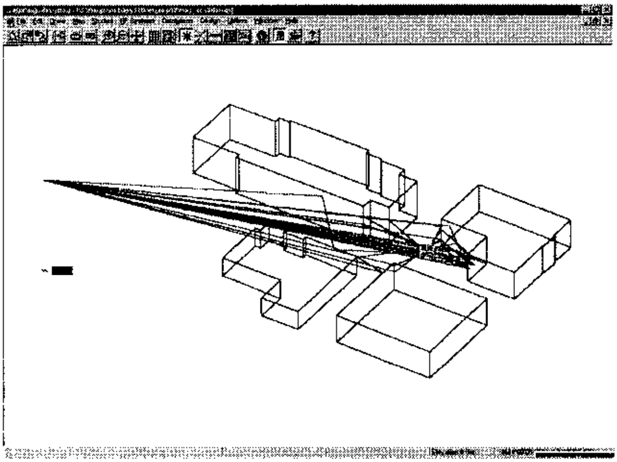

Fig. 3. 3D radio wave propagation over buildings in an urban environment.

As shown in [1], the magnitude and phase of the reflection coefficient will be a strong function of the angle of incidence of the reflecting ray. The edge diffraction coefficient is also a strong function of its material constants and the angle of incidence.

A ray-tracing propagation model only provides the ray amplitudes and phases to a single precise point in space. At this point it may happen that the vector sum of the rays results in the null (fade) or peak in the resultant envelope voltage. However, in general the geometry of the environment is not known with sufficient accuracy to predict the absolute phase delay of the ray voltage. In a typical urban building database, the building wall locations may only be known with perhaps one meter accuracy relative to one another – far too crude to predict phase delay at 28 GHz. Because absolute phase can't be known, it is necessary to determine the channel response over a range of positions around the precise location where the ray-tracing analysis is performed. This can be done by considering a number of *time signatures* representing channel response over a range of wavelength displacements around the ray-tracing point (Figure 4).

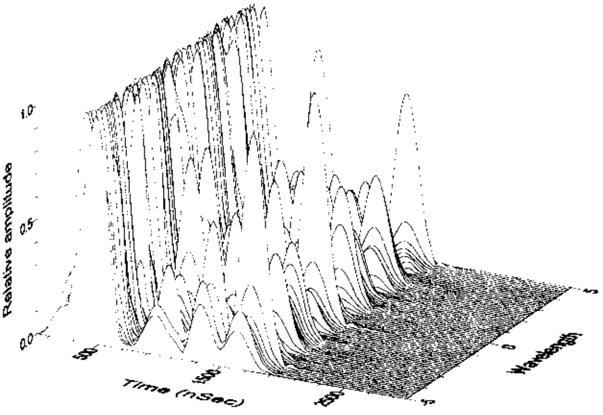

Fig. 4. Time signatures of channel response in a over ± 5 wavelength displacement.

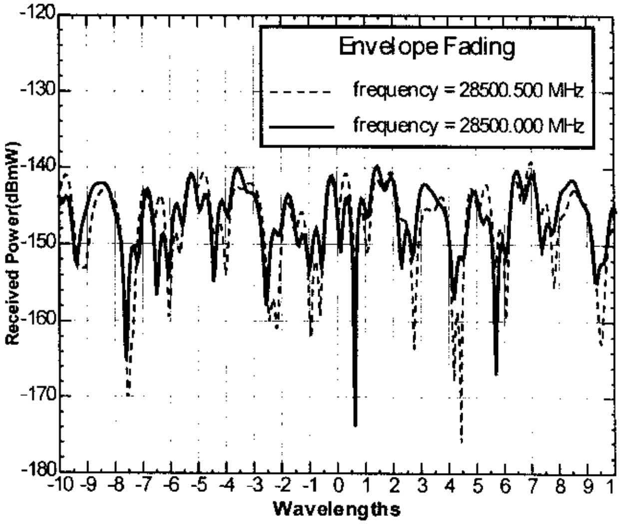

Fig 5. Fading envelopes at different frequencies.

Using the same concept of wavelength displacement, it is possible to calculate the fading envelopes, which are simply the vector sum of the rays at each displacement location. For a typical analysis, the fading voltage envelope is calculated at points spaced every $1/16\,\lambda$ over a range of $\pm 10\lambda$ in four crossing directions around the ray-tracing analysis point. This uniform pattern of four fade paths was used to reduce any anomalies that might result due to the location of the point relative to the physical environment and the particular arrival angles of the rays. With four fade paths and 320 samples per path, a total of 1280 envelope samples per ray-tracing study point were used to investigate the channel response.

Following the approach in [2], the fading envelopes can be created for any set of frequencies and the correlation of the envelopes at any two frequencies found by comparing the envelopes. Figure 5 shows two typical fading envelopes for frequencies separated by 0.5 MHz at a nominal carrier frequency of 28.5 GHz. The absence of direct coincidence of many deep nulls is clear from the fading envelope examples in Figure 5.

3. Dispersive Channel Response

The degree of time dispersion in the response of a wireless communication channel is usually characterized by one of two parameters – the RMS delay spread (σ_τ), or the coherence or correlation bandwidth. The RMS delay spread is a simple statistical moment that indicates how spread out in time the received energy is. It can be directly calculated from the components of the power delay profile (Figure 2) as:

$$\sigma_\tau = \left[\sum_{n=1}^{N} (\tau_n - \bar{\tau})^2 \, p(\tau_n) \right]^{1/2} \tag{2}$$

where the mean value of the power delay profile is

$$\bar{\tau} = \sum_{n=1}^{N} (\tau_n) p(\tau_n) \tag{3}$$

and

$$p(\tau_n) = \frac{A_n^2}{\sum_{n=1}^{N} A_n^2} \tag{4}$$

The parameter RMS delay spread itself is only a very general indicator of the time dispersion in the channel which does not carry with it any information about the phase and arrival angle of the rays, nor the relative distribution of received energy as a function of time. To analyze the performance of wideband digital communication systems, a more detailed representation of the dynamic channel is needed.

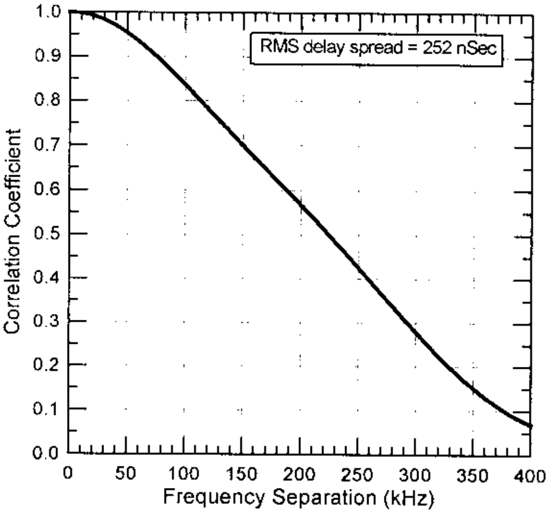

Fig. 6. Correlation coefficient vs. frequency separation for a ray-tracing study point

Coherence bandwidth is more difficult to calculate directly for a site-specific channel response. However, by applying the ray-tracing model incrementally over a range of frequencies, and finding the correlation coefficient ρ of the fading envelopes (Figure 5) for pairs of frequencies, the decrease in ρ as a function of frequency separation can be found. The frequency separation at which ρ decreases to 0.9 or 0.5 is usually taken as the coherence bandwidth. In this research, coherence bandwidth is defined as the frequency separation where ρ decreases to 0.9. The linear correlation coefficient is given by:

$$\rho_f = \frac{\sum_n (f_1 - \bar{f}_1)(f_2 - \bar{f}_2)}{N\sqrt{\sigma_{f_1}^2 \, \sigma_{f_2}^2}} \tag{5}$$

where $\bar{f}_1$ and $\bar{f}_2$ are the mean values of the voltage envelopes at frequencies f_1 and f_2, respectively, and $\sigma_{f_1}^2$ and $\sigma_{f_2}^2$ are the corresponding variances of the envelope waveforms, both taken across N waveform samples as described in Section 2. An example of correlation coefficient as a function of frequency separation is shown in Figure 6.

4. LMDS Channel Response Study in an Urban Environment

We have now described a ray-tracing propagation model that will provide the basic ingredients to determine channel dispersion, and two ways of characterizing channel dispersion. These techniques were employed to find the degree of channel dispersion in the urban environment of downtown Eugene, Oregon (Figure 7). Buildings in the four square block section used here range up to 13 stories in height. While this is much less intense urbanization than places such as Manhattan, it is representative of many communities, and of commercial centers in spread out metropolitan areas.

To investigate the general character of the channel dispersion at a wide variety of points, both line-of-sight (LOS) and obstructed (NLOS), a study route was devised along one street in this environment. A 28.5 GHz transmitter was positioned at the center of the buildings, and a ray-tracing study carried out at points spaced every 5 meters along the study route. An omni-directional transmit antenna was set at 30 meters above ground. The receiving antenna was set at 4 meters above ground. Two types of directional antennas were used at the receiver, one with a 16 degree beamwidth (about 20 dBi gain) and

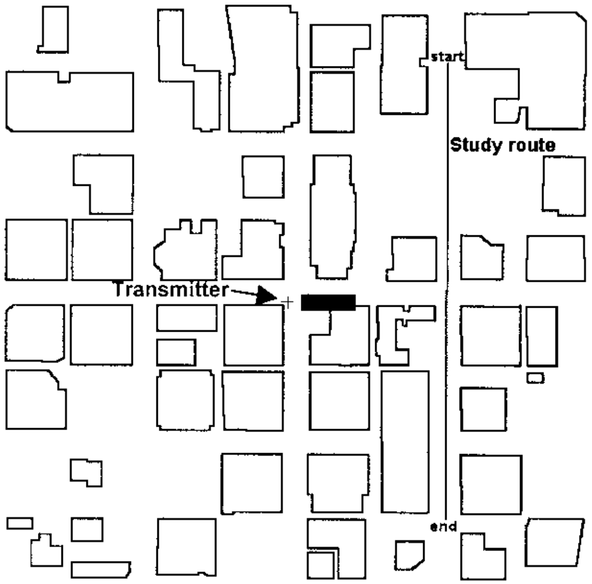

Fig. 7. Study route through urban area.

the other with a 2 degree beamwidth (about 35 dBi gain). The latter is more typical of the antennas that will be employed in the LMDS service. For this analysis the receive antenna was automatically oriented in the direction of the maximum amplitude ray, with the off-axis gain pattern of the antenna used to discriminate against rays arriving from other directions.

Figure 8 shows the RMS delay spread as a function of distance for the 74 points along the study route for the two types of receive antennas. It is apparent that the gain of the receive antenna has a pronounced effect on the channel dispersion. The higher gain antenna does a better job of discriminating against the rays arriving from other directions which cause the multipath channel dispersion.

Figure 9 shows the coherence bandwidth as a function of distance along the study route. As described in Section 3, at each ray-tracing point the fading envelopes and correlation coefficient were calculated every 0.2 MHz for 10 MHz. As with the RMS delay spread case, the coherence bandwidth increases with the higher gain antenna due to the greater off-axis rejection of multipath signals.

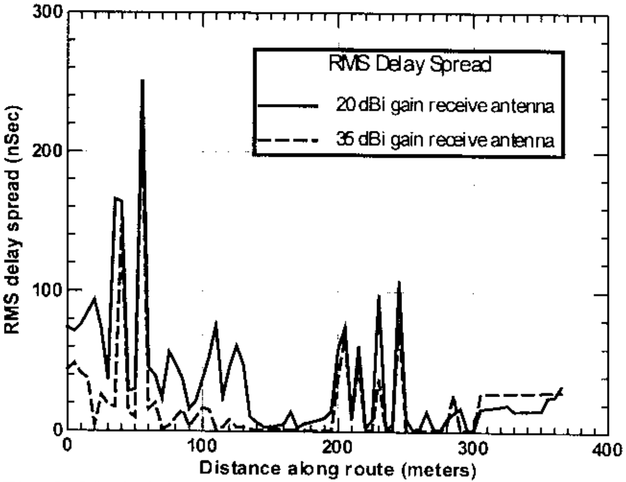

Fig. 8. RMS delay spread along study route.

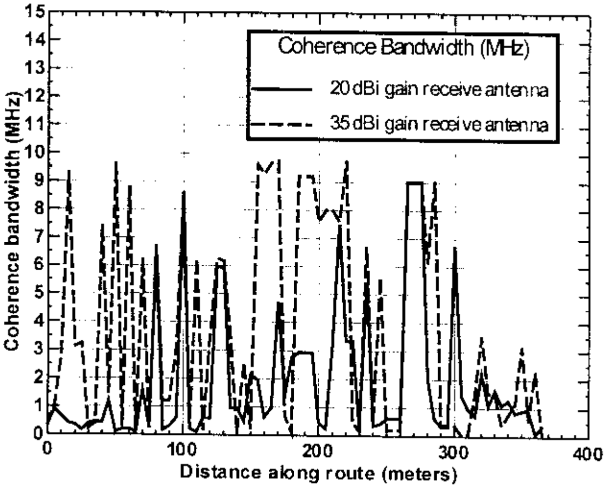

Fig. 9. Coherence bandwidth along study route.

4.1 Discussion of Results

It is clear from Figures 8 and 9 that the higher gain antenna results in lower RMS delay spread and higher coherence bandwidth. However, in a few cases the RMS delay spread is actually slightly higher with the high gain antenna. This is a result of the very narrow beamwidth which may actually reject significant rays of low delay time while accepting low amplitude rays of high delay. With reduced energy around the maximum amplitude ray, the RMS delay spread will be more biased by the outlying rays, and consequently increase the RMS delay spread.

As noted above, these studies were all done with the receive antenna automatically pointed toward the direction (azimuth and elevation) of the maximum amplitude ray – a strategy which would probably be employed in the field. A interesting supplemental study was done in which the receive antenna was not pointed in the direction of the maximum ray but rather in the direction of which resulted in the minimum RMS delay spread (not an easy thing to do in the field). The results show that far lower RMS delay spread values can be achieve in this way, although with a sacrifice in total receive power (and hence, fade margin). In dealing with some challenging service locations in an LMDS system, pointing the antenna to achieve minimum multipath rather than maximum signal could be an effective approach

Supplemental coherence bandwidth studies were also run with different starting frequencies. This did have a small impact on the correlation bandwidth, but the results of these studies were consistent with the general trend indicated by Figure 9.

For both the RMS delay spread and coherence bandwidth cases, it is interesting to note that low dispersion can be achieved even in locations which are totally obstructed from transmitter. A common approximation suggests that if the normalized RMS delay spread (symbol time T divided by σ_τ) is less that 0.1 to 0.2, then sufficiently low error rates can be achieved for most digital transmission applications. From this, the RMS delay spread figures imply successful transmission at 5 to 10 Mbits with BPSK. As demonstrated in [3], the RMS delay spread is only a highly approximate indicator of error rate performance in a given channel. Moreover, typical LMDS systems with used more efficient modulation techniques such as 16, 64 or 128QAM. The performance of these modulation techniques in the dispersive LMDS channel environment dealt with here is the subject of on-going research.

The results also suggest that successful transmission may be possible to NLOS locations if the ray trajectory path is stable (i.e. reflection from a building wall) - similar to passive repeater (billboard reflector) techniques that have been successfully used for many years in traditional point-to-point microwave link design. If this proves to be true, it could provide a useful set of alternate system deployment strategies in urban areas where system designs are currently seeking only LOS paths to provide service. A ray-tracing propagation model such as the one used here is a excellent tool for graphically identifying candidate locations where a existing “passive reflector” building wall can be exploited to provide service.

5. Conclusions

A ray-tracing propagation model has been described that can efficiently characterize the channel response of 28 GHz LMDS wireless communications systems in urban areas. Of particular interest is the time dispersion of the channel that can have a profound effect on the error rate performance of high speed digital transmission schemes.

The channel dispersion was characterized using two parameters – the RMS delay spread and the coherence bandwidth. These parameters where calculated over a range of locations in an urban environment with two types of receive antennas that might be employed in an LMDS system. The results show that greater antenna directionality can substantially reduce the channel dispersion experienced at the receiver. Supplemental studies showed that orienting the antenna to achieve maximum signal may not be the best orientation to achieve minimum channel dispersion.

The results presented here also suggest LMDS system designers may be able to exploit the stable reflective properties of existing structures in urban areas to provide service to locations which are not line-of-sight to the LMDS transmitter.

6. References

[1] H.R. Anderson, "A ray-tracing propagation model for digital broadcast systems in urban areas," *IEEE Trans. on Broadcasting*, Vol. 39, no. 3, Sept. 1993, pp. 309-317.

[1] H.R. Anderson and J.P. McGeehan, "Direct calculation of coherence bandwidth in urban microcells using a ray-tracing propagation model," *Proceedings of the Fifth Annual Symposium in Personal, Indoor, and Mobile Communications*, The Hague, Sept. 1994, pp. 20-24.

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