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Title	**Recommendation on LMDS Radio Propagation Channel Models**
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Re:	This contribution is submitted in response to the IEEE 802.16 PHY Task Group request for simplified channel models during the presentation of our earlier paper (IEEE 802.16.1pp-00/24) in Session #8, July 10-14, 2000, La Jolla, San Diego.
Abstract	This paper recommends static as well as time varying radio channel impulse response models based on the measurements conducted in Singapore for LMDS. Also blockage classification based on the excess loss and a relationship between delay spread and excess loss were reported. The assumptions made in the modeling include: (1) Line of sight condition exists between transmitter hub and receiver antenna; (2) Complete blockage of receiver and heavy rain conditions were not considered; (3) multipath components below –25dB compared to direct LOS signal were excluded.
Purpose	To provide an input to the physical layer task group specific criterion called "robustness to channel impairments – multipath fading"
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Recommendation on LMDS Radio Propagation Channel Models

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Abstract **-** *This paper recommends the static as well as the time variant LMDS channel models based on the measurements conducted in urban, suburban and rural environments of Singapore at 27.4 GHz. The static channel models were classified into good, moderate and bad channel types based on the signal reception quality. A generalised tapped delay line model was reported to represent the time varying complex channel impulse response. Also excess path loss models and the relationship between delay spread and excess loss were reported.*

I. Introduction

Local multipoint distribution service (LMDS) has been widely recognized as an effective last mile solution to provide broadband wireless access to fixed networks via millimeter wave radio transmission at 27 GHz. It uses cellular-like network architecture to deliver services ranging from one-way video distribution and telephony to fully interactive switched broadband multimedia applications such as interactive video, video-on-demand, video conferencing real-time multimedia file transfer with high speed internet access to residential and business customers. Large bandwidth, lower installation cost and ease of deployment coupled with recent advancements in MMICs make LMDS an attractive solution for broadband service delivery. The LMDS system performance is limited by the fast signal attenuation in this frequency range. In addition, the frequency selective fading behaviour becomes significant at these higher data rates. However due to the static nature of propagation scenario, the channel conditions can be expected to be more favourable. Thus it is necessary and important to have thorough understanding and accurate channel models for optimum system design.

In the literature, Scott Siedal *et al* reported propagation experiments at 28 GHz and path loss models with different types of blockage conditions [1]. Papazian *et al* reported about area coverage, signal depolarisation issue, delay spread values and K-factors of Rician distribution [2]. In our earlier papers[1] [3,4,5], we have reported the propagation measurement methodology and data processing in detail. We have also reported the excess path loss, delay characteristics and the preliminary time varying LMDS channel impulse response models. This paper attempts to fulfill the comments received during the presentation of [4] in IEEE 802.16 session #8. In this paper, simplified static channel models with less number of variable parameters were recommended. Also the refined time variant channel models with less number of multipath components and random variable parameters was reported to take into consideration of as many situations as possible. Blockage classification and the corresponding relationship between delay spread and excess loss were discussed in detail.

II. Excess Path Loss Models

The transmitter was fixed on the rooftop of a building located on a hill such that it can be seen by most of the receiver locations ranging from 500m-5km. Measurements were carried out on the rooftops of various 13-25 storied residential blocks located in urban, sub-urban and rural areas. The receiver sites were usually surrounded by several residential blocks, business centres, foliaged sport grounds and by a hilly terrain. Factors that affect the service quality include attenuation by vegetation, blockage by adjacent buildings. The signal reception was considered under various conditions such as clear LOS availability, partial blockage and complete blockage by two or more buildings. One of the major areas of interest in RF network planning is the classification of the blockage characteristics and the corresponding excess path loss models. It is necessary to mitigate the blockage loss by providing an extra link margin for better signal reception. The total received power at a particular distance is computed as follows,

$$P_r = P_t + G_t + G_r - 32.44 - 20\log(f_{GHz} d_m) - L_{ex} \qquad (1)$$

where, P_t is the transmitted power in dBm, f_{GHz} is the operating frequency in GHz, d_m is the distance of separation in meters, G_t and G_r are the gains of transmitter and receiver respectively in dB. Finally L_{ex} represents the excess path loss in dB due to the blockage by buildings and vegetation, rainy climate and multipath fading environment, which is given by,

$$L_{ex} = P_t + G_t + G_r - 32.44 - 20\log(f_{GHz}) + L_{env} \qquad (2)$$

where, the parameter L_{env} represents the environment loss. Fig.1 shows the scatter plot of the received power for various measurement locations at different distances. The solid lines indicate the received power calculated using our model given by eqn. (1) for various values of the environment loss factor. It was observed that the L_{env} varies from 4 to 40dB for various locations. Fig.2 shows the variation of L_{env} with the distance of separation, where the solid line represents the developed approximate model. The model is optimized for a mean error of 0.0047, excluding the four highly deviating points, which is given by,

$$L_{env}(dB) = 20\log(2.25 / d_{km}) \qquad (3)$$

Also it was observed from Fig.2 that most of the points fall into the moderate and bad groups with environment loss over 15dB correspond to the shorter receiver separations. Fig.3 shows the combined scattered plot of mean delay (T_D) and delay spread (S) obtained from measurements as a function of the receiver separation distance. For most of the locations, mean delay is less than 60ns and delay spread is less than 40ns. However it can be noticed that for some of the neighboring locations, the presence of significant longer delayed multipath clusters due to the surrounding high-rise buildings, causes high delay spread values. Fig.4 shows the relationship between rms delay spread and environment loss.

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[1] Part of the results in this paper are reproduced from [5] to be presented in RAWCON'00, Sep10-13, 2000, Colorado.

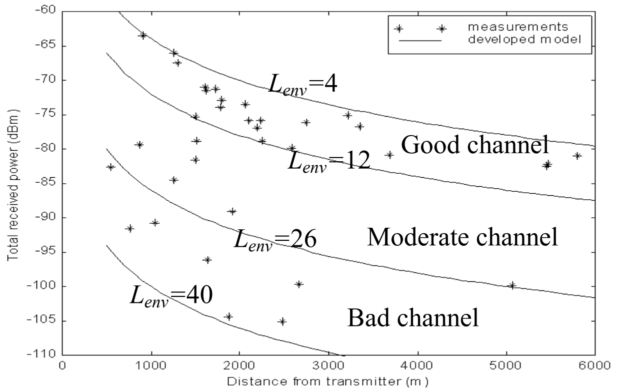

Fig.1 Scatter plot of total received power with distance of separation

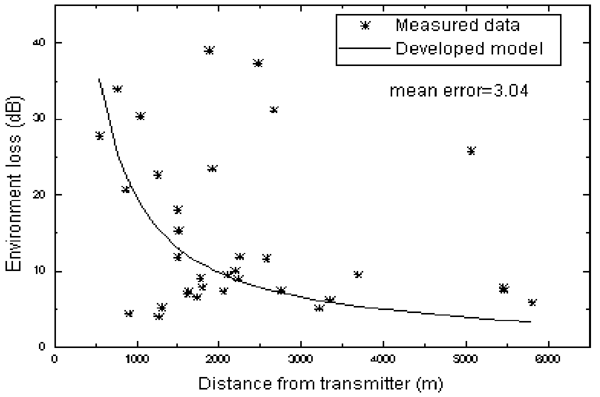

Fig.2 Scatter plot of environment loss with distance of separation

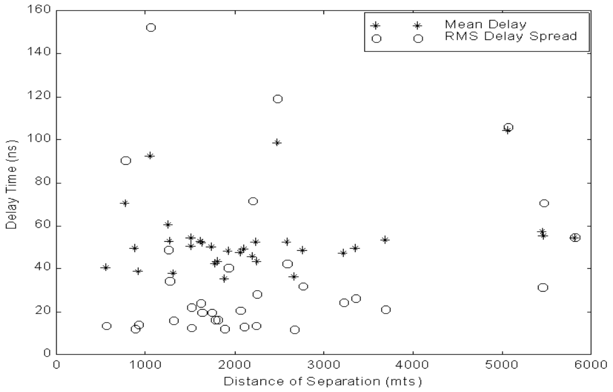

Fig.3 Scatter plot of delay characteristics with distance.

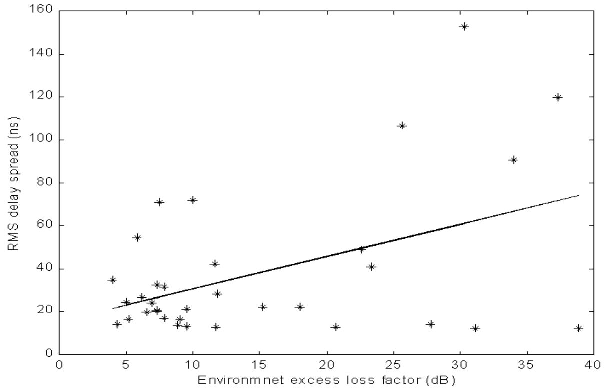

Fig.4 Linear relation ship between delay spread and environment loss.

The locations with high loss and large delay spread values correspond to the nearby full blockage channel conditions. It was observed that delay spread increases linearly with the environment loss and the derived relationship is given by,

$$S(ns) = 15.75 + 1.5L_{env}(dB) \qquad (4)$$

III. Static Channel Models

As shown in Fig.1, the LMDS channel was classified mainly into good, moderate and bad types based on the environment loss factor. These groups are independent of the receiver separation distance and the channel impulse response may vary within the each group depending on the environment surrounding the receiver. For example strong multipath contribution may present at shorter distances than the farther locations. This fact leads to the further classification based on the delay spread values and the shape of the impulse response with in each group. The static channel models were obtained by taking the average of several impulse responses in a particular group. The excess path loss and delay characteristics of the static channel models are summarized in Table 5.

a) Good Channel

The good channel models primarily represent the locations with strong signal reception having environment loss in the range of 4 – 12dB. It was also observed that the longer delayed multipath components are very weak compared to the direct LOS component. The static channel models for various cases are listed in Table1 and Table 2. The channel models listed in Table 1 have less number of multipath components compared to the moderate multipath contribution of the channel models listed in Table 2. The rms delay spread values for this group varies from 10 to 70ns as observed from measured data shown in Fig.4. However the static model predict much lower values ranging from 12 to 18ns as shown in Table 5.

Table 1. Good multipath models for good reception

Excess Delay (ns)	Tap gain (Model 1)		Tap gain (Model 2)	
	Numeric	dB	Numeric	dB
0	0.74	-2.65	0.48	-6.31
20	1	0	1	0
40	0.40	-8.05	0.66	-3.67

Table 2. Moderate multipath models for good reception

Excess Delay (ns)	Tap gain (Model 3)		Tap gain (Model 4)	
	Numeric	dB	Numeric	dB
0	0.12	-18.18	0.29	-10.86
20	0.92	-0.69	1	0
40	1	0	0.79	-2.00
60	0.21	-13.45	0.08	-21.86
80	0.06	-24.54	0.10	-19.68
100	0.10	-20.00	0.09	-20.79

b) Moderate Channel

The moderate channel models represent the locations with moderate signal reception having environment loss in the range of 12 – 26dB and the delay spread varies from 20ns to 100ns. There were two models for less and more multipath conditions as shown in Table 3.

Table 3. Channel models for moderate signal reception

Excess Delay (ns)	Tap gain (Model 1) Numeric	dB	Tap gain (Model 2) Numeric	dB
0	0.24	-12.36	0.48	-6.37
20	1	0	1	0
40	0.94	-0.50	0.58	-4.70
60	0.17	-15.56	0.12	-18.16
80			0.10	-20.00
200			0.10	-19.91
280			0.12	-18.71
300			0.15	-16.74
340			0.12	-18.68
360			0.13	-17.65

c) Bad Channel

Finally, those locations under heavy blockage conditions with environment loss factor varying from 26 to 40dB were grouped into bad channel type. The two channel models are listed in Table 4. Model 7 represent a long distance (5km) LOS case where the received signal to noise ratio (SNR) is only 8dB. It indicates that when the main signal is weak due to the longer separation distance or rainy climate, there exists no more multipath contribution. Model 8 represent a nearby (1.5km) measured location where the SNR value is 15 dB. The significant multipath components cause the high delay spread value for this case. Moreover there exist the null service regions with excess loss as high as 35dB and maximum excess delay of 1240ns in this group.

Table 4. Channel models for poor signal reception

Excess Delay (ns)	Tap gain (Model 1) Numeric	dB	Tap gain (Model 2) Numeric	dB
0	0.70	-3.05	0.70	-3.12
20	1.0	0.0	1.00	0
40	0.62	-4.10	0.52	-5.68
60			0.24	-12.31
80			0.35	-9.24
100			0.37	-8.64
120			0.24	-12.34
140			0.21	-13.43
200			0.23	-12.7
220			0.20	-14.1
260			0.27	-11.32
280			0.43	-7.27
300			0.42	-7.44
320			0.27	-11.3

Table 5. Summary of the static channel models

Channel Type		Mean Delay (ns)	Delay Spread (ns)	Excess Loss (dB)
Good	Model1	15.46	11.96	0 – 12
	Model2	22.46	14.61	
	Model3	31.72	18.16	
	Model4	27.10	16.65	
Mode-rate	Model1	28.97	16.67	12 – 26
	Model2	35.27	50.89	
Bad	Model1	18.87	13.69	26 – 40
	Model2	85.35	75.84	

IV. Time Variant Channel Models

Due to the complexity of the propagation channel, the static channel model with few variable parameters is not applicable for all the possible situations. A more realistic approach is to represent the channel with as many random variables as possible to account for the time as well distance and environmental variations. These models can be easily modified for an operational LMDS system at various data rates. The complex channel impulse response at any observation time t_k can be represented by the tapped delay line model as follows,

$$h(t_k, \tau) = c_k \sum_{n=0}^{N-1} m(\tau_n)\delta(t_k - \tau_n)e^{-j(\omega_c \tau_n + \phi)} \qquad (5)$$

where, n is the tap index, N is the maximum number of taps, ω_c is the carrier angular frequency, τ_n is the excess delay of each multipath component and Φ is the random phase in the range $[0,2\pi)$. The factor c_k models the time varying nature of channel impulse response and $m(\tau_n)$ represents the distribution of the tap gains of various multipath components. The general equation used to fit a particular multipath cluster is of the form,

$$m(\tau_n) = \alpha \exp\left\{-\beta\left(\frac{\tau_n - \tau_p}{100}\right)^2\right\} \qquad (6)$$

where, β controls the rate of decay of tap gains, α is the peak amplitude and τ_p is the peak time of a particular multipath cluster. The values of the factors α and β varies randomly in a given range with the distance for various locations. Thus the model considers the time variations as well as distance variations of the channel impulse response within the same environment type. Also the longer delayed two-sided multipath clusters were included as they can cause high delay spread values. The values of various channel impulse response parameters are summarized in Table 6. The models given in [4] are refined in Table 6 so that the weak multipath components with excess delay more than 400ns were excluded. The decay factor β and c_k are random variables, whose values are given in Table 7 based on the measurements for various channel types. The time variant channel models are found to be well in agreement with the measurements than the static channel models.

Table 6. Summary of time variant model parameters

Case (i)	Peak time, τ_p (ns)	Attenuation factor, α_i	Decay factor, β_i	Excess delay τ(ns)
1	40	1.0	β_1	0 – 40
	40	1.0	β_2	40 – 100
2	100	0.1	β_3	100 – 250
3	320	0.1	β_4	250 – 400

Table 7. Classification of time variant channel

Parameter	Urban	Suburban	Rural
c_k (dB)	-10 – 6	-5 – 3	-5 – 3
β_1	20 – 100	50 – 120	50 – 120
β_2	6 – 20	10 – 25	10 – 25
β_3	0.5 – 10	1 – 10	0
β_4	5 – 50	0	0
τ_{max} (ns)	400	250	100

V. Conclusion

This paper recommended the static as well as time variant LMDS channel impulse response models for urban, suburban and rural multipath propagation environments. Based on the received signal strength the channel was classified into good, moderate and bad types. The static channel models for each channel type were further classified into various sub categories having different impulse response shapes and the corresponding delay spread values. The static models could not be applicable to all possible situations of the propagation channel. The channel impulse response variations w.r.t the observation time as well the separation distance were modeled by a generalised tapped delay line model. Also the prediction models for the excess path loss as a function of the environmental blockage conditions as well as the distance were reported. Excess path loss was found to be the most serious propagation impairment for an operational LMDS system. There exist some cases with high excess loss and high delay spread values, which probably correspond to a block hole, where service can not be provided. Proper precautions have to be taken in the installation of the receiver antenna to ensure sufficient signal strength in this case. A linear relationship between delay spread and environment loss was reported. This relationship suggests that the delay spread vary from 21.75ns to 75.75ns.

Acknowledgements

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