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Title	**Recommendation on Time Varying Radio Propagation Channel Models and Study of System Performance for LMDS**
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Re:	This contribution is submitted in response to call for contributions from the IEEE 802.16 chair for submissions of PHY proposals for BWA, Session #7.
Abstract	We recommend novel flexible propagation channel models for urban, suburban and rural environments developed based on measurements conducted in Singapore applicable to Local Multipoint Distribution Service (LMDS). The following assumptions were made in the modeling: (1) Line of sight (LOS) condition exists between transmitter hub and receiver antenna mounted on rooftop; (2) Complete blockage of receiver and heavy rain conditions were not considered; (3) multipath components below –30dB compared to direct LOS signal were excluded. A generalised tapped delay line model was developed to represent the time varying two-sided complex channel impulse response. The system performance was studied in terms of various first-order and second-order statistical characteristics such as cumulative distribution function, level crossing rate, average fade duration, mean delay, rms delay spread and correlation bandwidth of the wide-band channel. Finally the channel multipath-fading behavior was modeled by Rician K-factor.
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 Time Varying Radio Propagation Channel Models and Study of System Performance for LMDS

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Abstract - *Local Multipoint Distribution Service (LMDS) has been recognised as an effective last mile solution to provide broadband wireless access to fixed networks providing services ranging from one-way video distribution and telephony to fully interactive switched broadband multimedia applications for residential and business customers. In this paper, we recommend the realistic and accurate LMDS channel models based on the measurements conducted in urban, suburban and rural environments of Singapore at 27.4 GHz. A generalised tapped delay line model was developed to represent the time varying complex channel impulse response. The propagation characteristics obtained include received signal short-term fluctuations and delay characteristics. Also the system performance was studied using various first-order and second-order statistical characteristics such as cumulative distribution function, level crossing rate and average fade duration of the fading signal. These characteristics provide valuable information on the coverage limitations, choice of suitable data rates, word lengths and modulation and coding schemes in an operational LMDS system.*

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 propagation channel is the main contributor for many problems that beset the performance of any digital radio system. The LMDS system performance is limited by the fast signal attenuation in this frequency range and excess loss due to rain. 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 [1]. Papazian *et al* reported about area coverage, signal depolarisation issue, delay spread values and K-factors of Rician distribution [2]. In another study Zhang *et al* reported about channel classification and impulse response parameters [3]. But to the knowledge of the author there is no attempt to obtain LMDS channel impulse response models similar to the existing GSM standard channel models. In our earlier paper [4], we have reported propagation measurements conducted in Singapore, excess pathloss, delay characteristics and the preliminary time varying LMDS channel impulse response models. This paper summarises the measurement methodology and reports about a novel generalised tapped delay line model to represent the time varying two-sided complex channel impulse response for urban, suburban and rural environments. Simulation was carried out to obtain the total received signal and the fast fading behavior was studied using various first-order and second-order statistical characteristics. Also the wide-band dispersive channel behavior was studied using delay characteristics.

II. Site Description and Measurements

The transmitter was fixed on the rooftop of a building located on a hill so as 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.

The measurement system is based on Swept Time Delay Cross-Correlation (STDCC) technique to measure the channel impulse response. The transmitter modulates an IF carrier at 2 GHz using BPSK with a 511 bit m-sequence at the chip rate of 50 Mb/s and then up converted to 27.4GHz. The modulator output was amplified to +30dBm and transmitted through a vertically polarized omnidirectional antenna with 11dB gain. The receiver is a flat panel antenna with a gain of 31dB and a 3dB beamwidth of 4^o in both azimuth and elevation planes. The received signal was first down converted to 2 GHz IF and despreaded in a sliding correlator, whose clock frequency was slightly offset from the transmitted code rate. The I and Q signals were digitized using an A/D converter in a PCMCIA acquisition card and stored in a Laptop computer for further processing.

III. Channel Impulse Response Modeling

The impulse response of the radio channel is very important in the design, development and planning of radio systems as it completely describes the radio propagation channel [5]. The total received signal at any instant of time can be obtained as follows,

$$r(t) = s(t) \otimes h(t,t) + n(t) \qquad (1)$$

where *s(t)* is any transmitted signal, *h(t,t)* is the time varying two-sided complex channel impulse response and *n(t)* is the AWGN noise signal as given in [6]. The channel impulse response at any observation time t_k can be represented by tapped delay line model, which is given by,

$$h(t_k, t) = c_k \sum_{n=0}^{N-1} m(t_n) d(t_k - t_n) e^{-j(w_c t_n + f)} \qquad (2)$$

where *n* is the tap index, *N* is the maximum number of taps, w_c is the carrier angular frequency, t_n is the excess delay of each multipath component and *F* is the random phase in the range [0,2π). The factor c_k models the time varying nature of channel impulse response and $m(t_n)$ represents a particular multipath cluster, which provides the distribution of the tap gains of various multipath components. The channel impulse response may contain one to five multipath clusters with different peak times depending on the type of channel environment.

There are two major advantages with our channel modelling compared to others [2,3]. The first one is that the time variations as well as distance variations of the channel impulse response within the same type of environment were considered. Second advantage is that the longer delayed two-sided multipath clusters were included in the model as they can cause larger delay spread values even though they are weak. Fig.1 to Fig.4 shows the normalised averaged power delay profiles obtained from the measurements in various channel conditions, approximated with the developed mathematical equations. The main differences are the maximum excess delay time and the presence of various multipath clusters for various channels.

Fig.1 shows the derived power delay profiles for the worst case and best case of the urban environment. The presence of longer delayed multipath clusters, mainly due the surrounding high rise buildings, can cause high delay spread and hence inter-symbol interference. However it can be noticed that the longer delayed multipath clusters are 25dB weak compared to the direct LOS signal. Fig.2 shows the power delay profiles measured in typical urban environment. It can be observed from the Fig.2 that the delay profile varies slightly for different measurement locations, which was also taken into consideration in the development of the channel models. Fig.3 shows the power delay profiles obtained in the suburban environment, where the receiver is surrounded by residential blocks of same height. It can be seen that there are no significant longer delayed multipath clusters present. Fig.4 shows the measured power delay profiles in rural environment, where the receiver was located nearer to the transmitter and no buildings present in between them. It can be seen from the plot that there were no secondary multipath clusters present in this case.

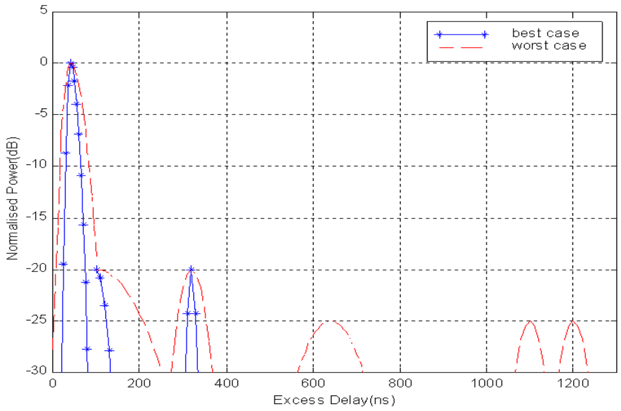

Fig.1. Power delay profiles for dense urban channel with clear LOS.

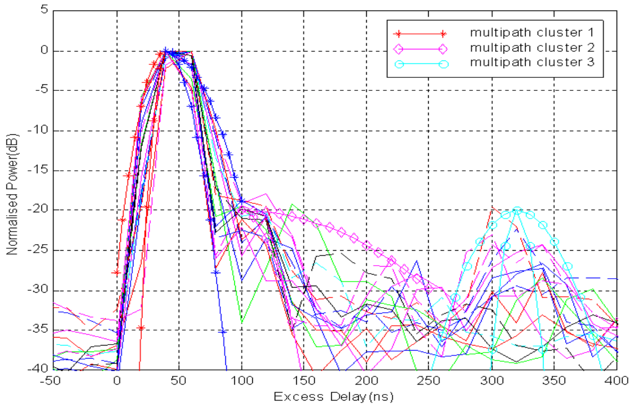

Fig.2. Power delay profiles for typical urban channel with clear LOS.

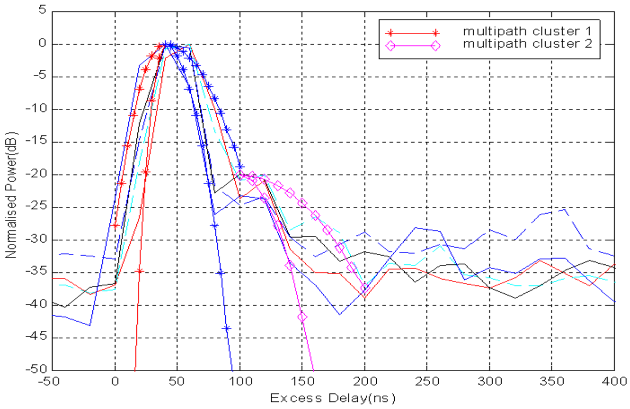

Fig.3. Power delay profiles for suburban areas with clear LOS.

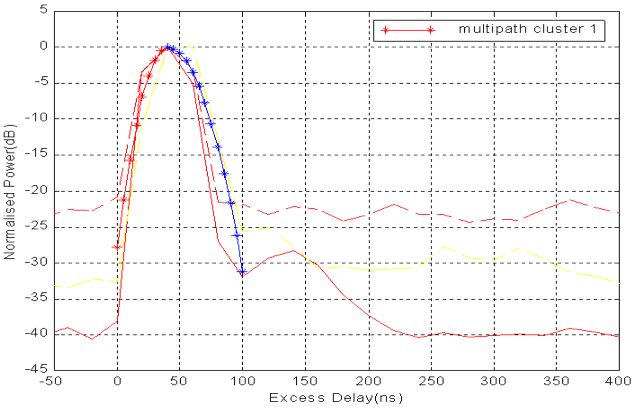

Fig.4. Power delay profiles for nearby rural areas with clear LOS.

Among the measurement locations in Singapore, it was observed that 80 percent of them were fall in urban area, 15 percent fall in suburban area and the remaining 5 percent belongs to rural environment. The general equation used to fit a particular multipath cluster is of the form:

$$m(t_n) = a \exp\left\{-b\left(\frac{t_n - t_p}{100}\right)^2\right\} \qquad (3)$$

where b controls the rate of decay of tap gains, a is the peak amplitude and t_p is the peak time of a particular multipath cluster. The values of these channel impulse response parameters are summarized in Table 1. The decay factor b and c_k are random variables, whose values are given in Table 2 based on measurements for various channel types such as dense urban, typical urban, suburban and rural environments.

Table 1. Summary of channel model parameters

Case (i)	**Peak time, τ_p (ns)**	**Attenuation factor, α_i**	**Decay factor, β_i**	**Excess delay *t* (ns)**
1	40 ns 40 ns	1.0 1.0	β_1 β_2	0 – 40 40 – 100
2	100 ns	0.1	β_3	100 – 250
3	320 ns	0.1	β_4	250 – 400
4	640 ns 1100 ns 1200 ns	0.056 0.056 0.056	1 5 5	560 – 720 1060 – 1140 1160 – 1240

Table 2. Classification of propagation channel

Parameter	**Urban1**	**Urban2**	**Suburban**	**Rural**
c_k (dB)	-10 – 6	-10 – 6	-5 – 3	-5 – 3
β_1	20 – 100	20 – 100	50 – 120	50 – 120
β_2	6 – 20	6 – 20	10 – 25	10 – 25
β_3	0.5 – 10	0.5 – 10	1 – 10	0
β_4	5 – 50	5 – 50	0	0
t_{max} (ns)	1240	400	250	100

IV. Propagation Channel Characterisation

The total received signal was obtained by convoluting the channel impulse response with an unmodulated unit step transmitted signal in the presence of additive white Gaussian noise as given by Eqn.(1). Fig.5 shows the complementary cumulative distribution *(ccdf)* curves of the received signal for various channel conditions. It can be observed that only 65 percent of the time the signal level lies above local mean. This suggests the provision of extra link margin of 10dB for the reliable operation of the receiver over 95 percent of the time.

Level crossing rate *(lcr)* at any threshold level is defined as the expected rate at which the signal envelope crosses that level in positive (or negative) going direction [6]. Fig.6 shows the variation of normalised *lcr* as a function of threshold level, which is found to be 18 at the local mean. Assuming a relative speed of 15m/s between the receiver and propagation channel, the signal crosses the local mean for each 40.5µs of observation time, which is four times the sampling interval. Provision of 10dB extra margin increases this to 243.3µs, which clarifies the favourable slow fading behaviour of LMDS channel. The received signal experience periods insufficient signal strength or "fading interval" during which the bit error rate is close to one half and the receiver may not function reliably. The characteristic average fade duration (*afd)* determines how long the signal lies below a given threshold level on average. Thus helps to determine the most likely number of signaling bits that may be lost during a fade [6]. At the local mean normalised *afd* was found to be 0.025, which corresponds to 18.5µs for each second of observation period. However it reduces to 7.3µs with the provision of 10dB fade-margin. These two characteristics named *lcr* and *afd* are called second-order statistics since they depend on both observation time and distance. These are useful in predicting the burst of errors without doing the end-to-end system simulation and in the design of the error control codes, interleaver and diversity schemes [6].

The wideband dispersive nature of the LMDS channel can be characterized using average excess delay, rms delay spread, correlation bandwidth. These are useful in the choice of suitable data rates and codec to avoid intersymbol interference. The average delay *(T_D)* is the power weighted average of the excess delays given by the first moment of the impulse response. The rms delay spread *(S)* is the power weighted standard deviation of the excess delays given by the second moment of the impulse response and provides a measure of the variability of mean delay. For a sampled version of the power delay profile average delay and rms delay spread can be calculated as follows [5]:

$$T_D = \frac{\sum_{n=0}^{N-1} t_n m(t_n)}{P_m} \qquad (4)$$

$$S = \sqrt{\frac{\sum_{n=0}^{N-1} (t_n - T_D)^2 m(t_n)}{P_m}} \qquad (5)$$

where, P_m is the total energy given by,

$$P_m = \sum_{n=0}^{N-1} m(t_n) \qquad (6)$$

Fig.7 shows the *ccdf* curves of the excess delay for various channel types. It can be noticed that over 95 percent of time mean delay lies below 47ns, 50ns and 55ns for rural, suburban and typical urban areas respectively. But in high dense urban area it exceeds 65ns over 95 percent of the time. This characteristic is useful in the design of equiliser taps. The minimum number taps can be evaluated using the following simple relation,

$$N = \left[\frac{t_{\max}}{T_s}\right] + 1 \qquad (7)$$

where, T_s is the symbol duration.

Fig.8 shows the *ccdf* curves of rms delay spread for various channel environments. It can be noticed that over 95 percent of time delay spread lies below 10ns, 20ns and 40ns for rural, suburban and typical urban areas respectively. Where as delay spread exceeds 120ns over 95 percent of time in high dense urban area. This is mainly due to the presence of longer delayed multipath clusters.

V. Conclusion

In this paper, we summerised the propagation measurement campaign conducted at 27.4GHZ in Singapore and reported the new tapped delay line LMDS channel impulse response models for urban, suburban and rural multipath propagation environments. The variations of channel impulse response w.r.t both observation time and distance within a particular channel type were also considered. The LMDS system performance was studied using various first-order and second-order statistical characteristics such as *ccdf*, *lcr* and *afd* as well as delay characteristics. The results show that the excess path loss due to blockage conditions and rms delay spread are the most serious propagation impairments for LMDS system. Rician K-factor values were found to be in the range of 10-15dB for various environments. The summary of these characteristics is listed in Table 3.

Table 3. Summary of propagation characteristics

Characteristic	Urban1	Urban2	Suburban	Rural
lcr_{-10dB}	3.22	2.1	3.78	3.36
afd_{-10dB}	0.015	0.014	0.015	0.015
Mean Delay (ns)	70.41	48.08	46.41	45.41
Delay Spread (ns)	134.57	30.32	12.75	9.05
CorrBW (MHz)	5.0	9.46	14.0	14.91
K-Factor (dB)	10.13	10.38	14.28	14.86

VI. Acknowledgements

The authors would like to thank the 3Com Corporation, USA for sponsoring the measurement campaign through a co-operative research and development work. Also the authors are grateful to National Science and Technology Board, Singapore for their continuous support. The contributions of K V Ravi, R.N.S. Ruwan, T.B. Chuan, C.L. Chia and W. Myint to the success of measurement campaign are highly appreciated.

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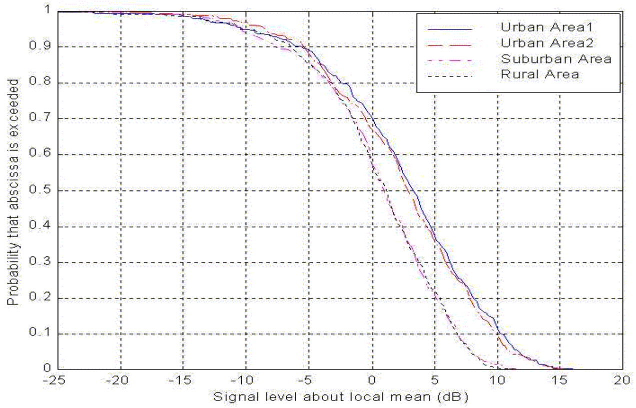

Fig.5. Comparison of signal *ccdf* curves for various environments.

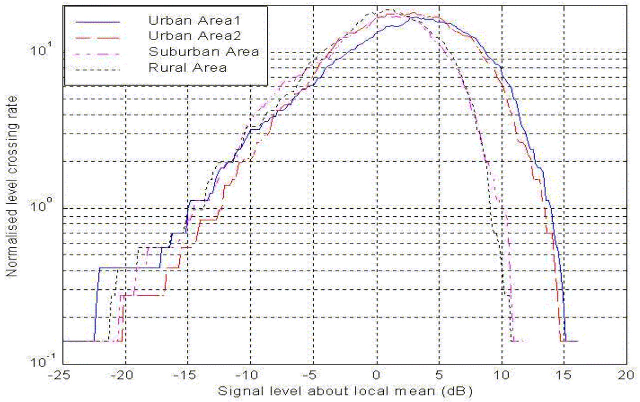

Fig.6. Comparison of normalised *lcr* curves for various environments.

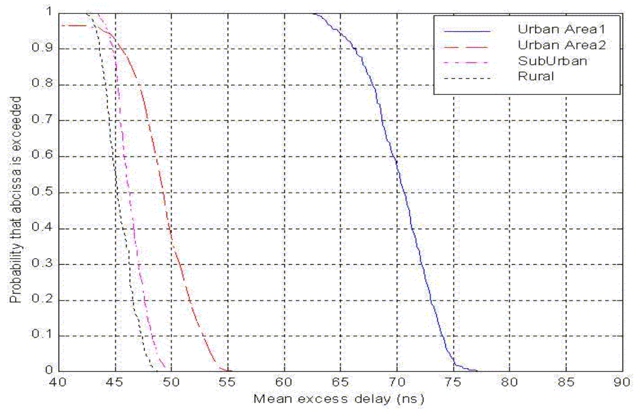

Fig.7. Comparison of mean delay *ccdf* curves for various environments.

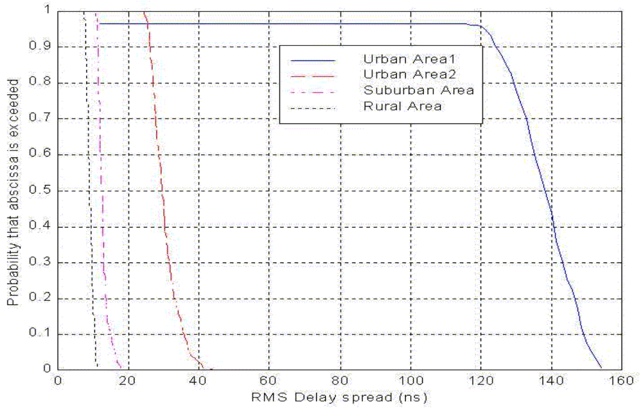

Fig.8. Comparison of delay spread *ccdf* curves for various environments.