Simulations of Channel Capacity and Frequency Reuse in Multipoint LMDS Systems

Harry R. Anderson, Ph.D., P.E.
EDX Engineering, Inc.
P.O. Box 1547
Eugene, Oregon 97440-1547
Tel: (541) 345-0019 Fax: (541) 345-8145 e-mail: hra@edx.com

***Abstract*- The results of several studies of microwave LMDS system capacity are presented. Assuming standard multi-sector hub site configuration with four sectors with alternating polarizations, and cross-polarization uplinks and downlinks, the cumulative distribution of link availability in the system is calculated as a function of system loading, cross polarization rejection, and required C/I+N) performance. Using standard methodology, fade and rain outages are also considered on every link. The results show that increasing antenna gain and cross polarization rejection increase system capacity. With an idealized system layout, and a C/(I+N) ratio of 15 dB, a system loading of greater than 90% of channels per sector is possible (a frequency reuse factor of nearly 4). For 64QAM with a C/(I+N) ratio of 25 dB, this hub frequency reuse factor reduces to about 2.**

1. Introduction

Of several recent wireless spectrum allocations, one of the more valuable is the LMDS (Local Multipoint Distribution Service) spectrum that is planned for operation in frequency bands above 20 GHz. LMDS systems are intended as fixed systems where the system distribution hubs and user (customer) terminals are at fixed rather than mobile locations[1].

In recent years a vast amount of research has been done on the capacity and frequency reuse capabilities of PCS and cellular systems operating below 2 GHz. However, because LMDS systems operate at much higher frequencies and use fixed links, the capacity and reuse models developed for cellular and PCS are not generally applicable. In particular, fixed systems can employ directional antennas at the customer terminals which, depending on the directivity, can provide enormous processing gain (undesired signal rejection) in the system, just as the processing gain due to spreading in spread spectrum systems provides interference rejection. Unlike spread spectrum systems, in fixed systems this processing gain does not come at the expense of occupied bandwidth. The drawback of antenna processing gain is that it is inflexible – the antenna is pointed in a single fixed direction. Adaptive antennas, though currently cost-prohibitive for customer terminals, can partly overcome this limitation.

Unlike mobile systems, fixed systems can also take advantage of polarization discrimination to increase system capacity. The degree of polarization rejection that can be realized as a practical matter depends on the antenna design and, more importantly, the propagation environment.

This paper explores the impact of customer terminal (CT) antenna gain, polarization discrimination, and channel loading on the service availability of several thousand hub-to-CT links. These issues are explored using a hypothetical system on flat terrain configured as a grid of 4x4 hub sites, spaced at approximately 5 km intervals, each with four sectors with alternating polarizations. A regular grid of CT's are distributed on a grid inside the square service boundary and assigned to the best serving hub sector.

Using a state-of-the-art LMDS system design tool and this system scenario, analyses were done of service availability percentages on the forward and reverse links as a function of polarization discrimination, channel loading, and CT antenna gain.

2. Study System Layout

The system layout used for the studies is shown in Figure 1. In this map, approximately 3,200 CT's are distributed on a regular grid 20 km x 20 km in size.

To increase system loading, the hub configuration was held constant while the density of CT's was increased. Using a channel plan with 200 uplink and downlink channels (2.5 MHz channels in 1000 MHz – roughly the useable spectrum in 28 GHz LMDS A block). With this arrangement, the average channel re-use is shown in Table 1.

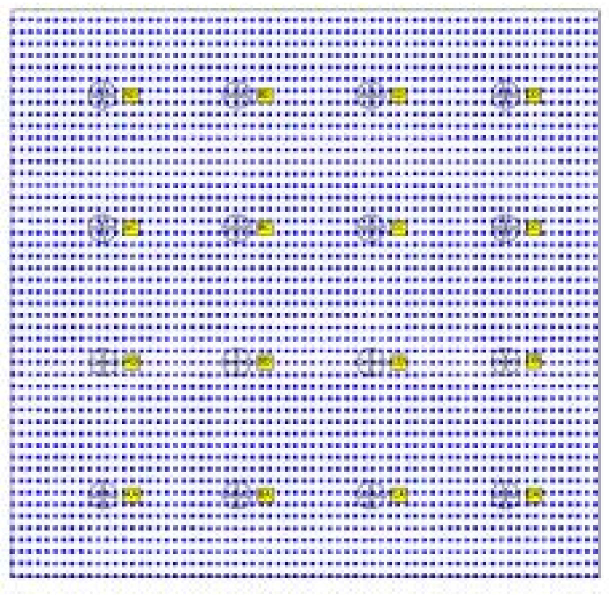

Figure 1. Test system layout. 16 hub sites, each with four 90 degree H-V-H-V sectors.

For the reuse=4 case, the total number of CT's in the service area is 12,800, or about 32 per square km. This is a reasonable fraction of commercial buildings in many cities.

3. Channel Assignments

In order to get a realistic channel loading on the sectors in each hub, a frequency-planning algorithm was employed which roughly mimics an incremental manual assignment process.

This algorithm first randomized the order of the CT's in the grid and adds them one at a time to the system map.

As each CT is added, the most likely server (MLS) sector is determined as the one providing the strongest signal. Once found, the polarization of that sector is assigned to the CT and the CT's directional antenna is pointed toward that sector. The downlink channel assigned to this CT is drawn from one of the 200 downlink channels in the channel plan. As additional CT's are added, if the MLS is at the same hub site, the list of channels already assigned to the hub site are considered and an unassigned channel used for the new CT. This process is continued until all the downlink channels are assigned at a hub site. The process then continues by using channels from hub sites which are not the optimum server (if channels are available). Thus the channel re-use is demand-driven and varies from hub to hub. The average required channel re-use therefore depends on how many CT's demand service.
Since the assumed channel plan is symmetrical, a similar process is used for uplink channel assignments.

4. Study Assumptions

The basic study approach is to essentially perform a propagation path analysis and on every hub-CT link, calculate the flat fade margin (against noise), the interference fade margin, and the fade and rain outage, and produce a calculation of service availability percentage for the link from each CT to its MLS.

Several assumptions were made for these studies:

Channel bandwidth	2.5 MHz
Adj. channel rejection:	40 dB
> adj. channel rejection	80 dB
Noise Figure:	6 dB
Required static C/(I+N):	15 dB
Hub sector ERPi	0 dBmW
CT transmitter power:	-10 dBmW
CT antenna gain:	36 dBi
CT system losses	3 dB
Propagation:	Free space (flat earth)
Rain region:	Crane Region C

Independent variables:

Cross-polarization rejection:	0, 5, 10, 15, 20 dB
Channel loading	Per Table 1

Table 1

Total number of system sectors	Number of customer terminals served	Ave. channels needed per sector	Average system channel reuse
64 (90° beamwidth)	3,200	50	1
64 (90° beamwidth)	6,400	100	2
64 (90° beamwidth)	9,600	150	3
64 (90° beamwidth)	12,800	200	4

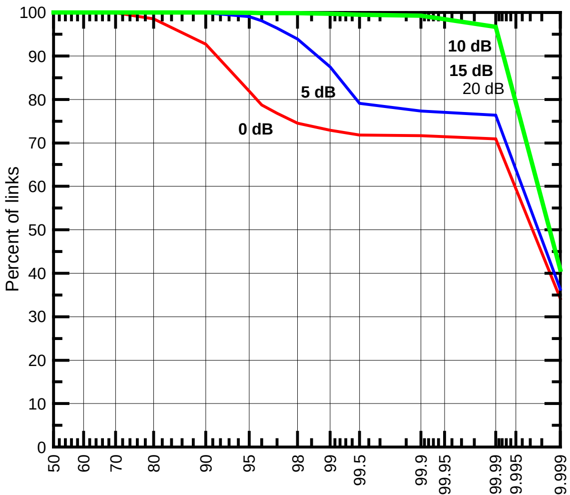

Figure 2. Frequency reuse = 1. Link availability versus cross-polarization rejection dB.

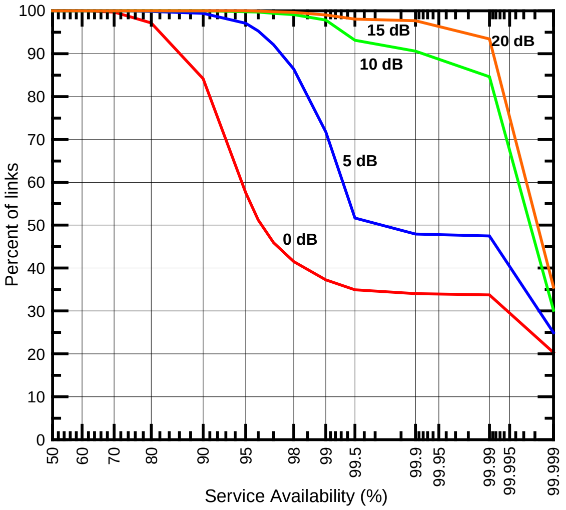

Figure 3. Frequency reuse = 2. Link availability versus cross-polarization rejection dB.

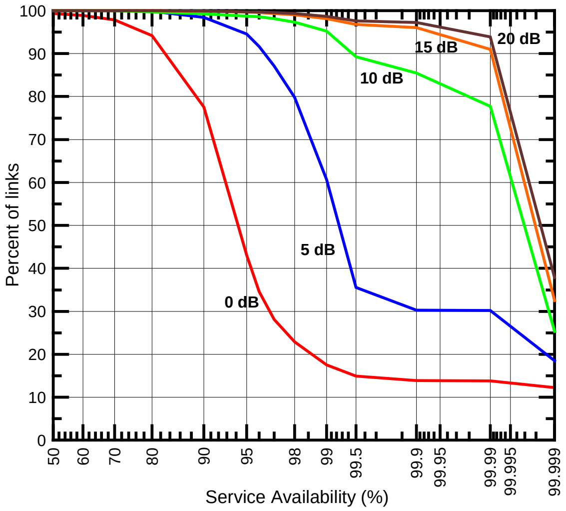

Figure 4. Frequency reuse = 3. Link availability versus cross-polarization rejection dB.

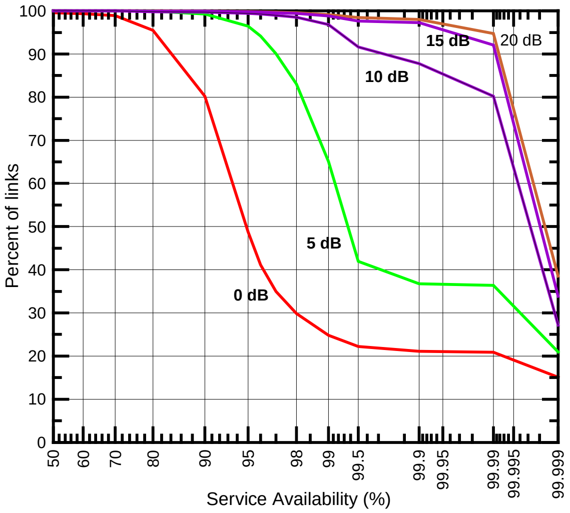

Figure 5. Frequency reuse = 4. Link availability versus cross-polarization rejection dB.

The downlink and uplink service availability percentages are based on nominal mean received desired power versus receiver noise plus composite co-channel and adjacent channel system interference, as well as fade and rain outage statistics using standard methodology.

5. Study Results

Figures 2 through 5 show the cumulative distribution of the study link availability percentages on the downlink as a function of cross-polarization rejection for an average channel re-use of 1, 2, 3 and 4. As expected, as the rejection increases, the rejection of interference from neighboring cross-polarized hubs (even same hub sectors) increase and service improves. A recent published paper[2] contains measurements which suggest that 15 dB might an appropriate average number in typical urban and suburban residential environments. For CT antennas on top of office or commercial buildings, some greater degree of isolation and clearance from surrounding depolarizing scatter sources (poles, overhead wires, trees, etc.) might make 17 of 18 dB a viable value for system planning purposes.

The rapid decrease in the number of high performing links is due to CT's noise-limited performance on the fringe of the service area.

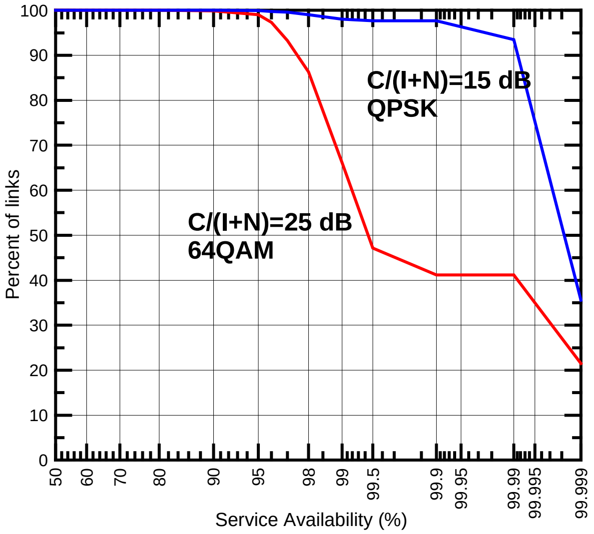

Figure 6. Link performance versus channel C/(I+N) ratio. Cross polarization rejection=15 dB.

The relationship from one Figure to the next in this series demonstrates how average system link performance degrades as system loading is increased. Considering a link availability percentage of 99.9% as a minimum acceptable, increasing loading from a reuse factor of 1 to a factor 4 reduces the percentage of 99.9% links from 99% to 92%. For a transmission scheme which requires a 15 dB C/(I+N) ratio, these results show that a re-use factor if 4 is possible for more than 90% of the links in this hypothetical study area. The net number of successful (99.99%) links ranges from 3095 for a reuse=1 to 11,648 for a reuse=4.

6. Customer Antenna Gain

As mentioned in the introduction, the directional antenna used at the customer terminal is a primary method for increasing system capacity. The antenna gain was increased by 6 dB to 42 dB and several of the studies redone. The results showed the service availability increased a few percent for the 99.99% service standard for a reuse factor of 4 with a 42 dBi gain antenna.

7. 64QAM Modulation

A commonly used modulation technique for increased system capacity is 64QAM, which offers about 4 times the data throughput of QPSK (depending on error coding and other overhead) but requires a C/(I+N) ratio about 10 dB higher, or 25 dB instead of 15 dB. The higher required C/(I+N) results in fewer links being successful, but those that are carry more data. When analyzed through the simulations as used for QPSK here, it was found that the number of successful links decreased from 93% for QPSK to 41% for 64QAM as shown in Figure 6. (CT antenna gain=36 dBi, cross polarization rejection =15 dB, 99.99% availability).

In general, system capacity can be considered as the number of links that provide a given C/(I+N) ratio with a given reliability, and where those links are available. How that C/(I+N) is utilized, both in terms of modulation and user services (voice/data, exclusive/shared) is more appropriately a commercial utilization issue rather than a radio capacity issue.

8. Conclusions

If system capacity is considered to be the number of links the system can support with a given data throughput and reliability, preliminary simulation results show that polarization discrimination is an effective mechanism to increase system capacity. For systems requiring a C/(I+N) ratio of 15 dB, a frequency reuse factor of nearly 4 at a hub site is possible in ideal system deployment circumstances. Because this is a hypothetical system with ideal hub and CT locations, this figure should be viewed as an upper limit. Real system deployments will likely realize lower reuse figures.

Similarly, increasing CT antenna gain increases system capacity but again there is a practical limit. With narrow beamwidth antennas, accurate, stable pointing angles become increasingly critical as gain increases. For casual home or small business installations, the required degree of accuracy and mechanical stability may not be easy to achieve, especially with windy conditions. Future research with this simulation will investigate this effect and others by introducing a random CT antenna pointing angle error to assess the wind's effect on system capacity.

9. References

[1] D.G Gray, "A broadband wireless access system at 28 GHz", *Proceedings of the Wireless Communications Conference*, 1997, pp. 1–7. (IEEE catalog number 97TH8315).

[2] P.B. Papazian and G.A. Hufford, "Time variability and depolarization of the local multipoint distribution service radio channel", *Proceedings of the Wireless Communications Conference*, 1997, pp. 8–11. (IEEE catalog number 97TH8315).