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A.	R.B. Perlow; “Microwave video distribution: 28- and 42-GHz”, published in Proceedings of ICC/SUPERCOMM '96 - International Conference on Communications, date of conference June 23-27, 1996.
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11. R.B. Perlow; "Microwave video distribution: 28- and 42-GHz", published in Proceedings of ICC/SUPERCOMM '96 - International Conference on Communications, date of conference June 23-27, 1996. Copies of the conference proceedings were made available no later than the last day of the conference. The article is currently available for public download from the IEEE digital library, IEEE Xplore.

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EXHIBIT A

Microwave Video Distribution: 28- and 42-GHz

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Introduction

Activity over the last several years, both within the United States and abroad, has focused on the investigation, licensing, and deployment of local wireless video distribution systems operating at frequencies near 28- and 42-GHz. In Europe, the 40.5-42.5-GHz band has been proposed for multipoint video distribution, while activity within the U.S. has been focused on operation within the 27.5-29.5-GHz band originally allocated for use by fixed satellite service (FSS) providers. Opening of the 40.5-42.0 GHz band has also been proposed for microwave video delivery in the United States. This paper provides an overview the system-level architecture currently employed for multipoint video distribution systems at 28- and 42-GHz and compares performance at these frequencies. It is shown that higher propagation losses at 42-GHz result in significant reductions in cell coverage and link availability.

Local Multipoint Distribution Service (LMDS)

In the United States, microwave video distribution at 28-GHz has been referred to as local multipoint distribution service (LMDS)¹. In Europe, the multipoint video distribution systems (MVDS) study group has proposed recommendations for a similar system operating in the 40.5-42.5-GHz band [2,3]. Both of these video delivery systems are designed to provide service direct to the home, and would

compete with current cable operators and direct broadcast satellite (DBS) service providers.

LMDS (and equivalently MVDS) offer advantages similar to DBS. Because the service is wireless, LMDS² systems can be easily made available to regions not currently served by wireline cable providers. However, in contrast to DBS systems which offer the same programming throughout a global coverage area, LMDS systems provide local coverage. An LMDS system is therefore capable of offering local television programming within its coverage area.

A disadvantage of LMDS is that the quality of service is not uniform throughout the coverage area. As in all terrestrial wireless systems, subscribers located near the transmitter generally obtain a higher quality transmission than those further away. Furthermore, at 28- and 42-GHz, reception depends on an unobstructed line-of-sight between the transmitter and receiver, or a strong reflection from a building or other object. Obstacles such as trees and buildings located in the path provide significant attenuation of the signal, and can prevent the reception of LMDS service in some regions of the coverage area.

Another disadvantage of LMDS systems is their sensitivity to precipitation. At 28 GHz, the corresponding wavelength is 11 mm. For 42 GHz, the wavelength is only 7 mm. These wavelengths are the order of precipitation, and scattering can produce significant levels of attenuation. Rain fading therefore limits the coverage area of a broadcasting headend.

Proposals to improve quality of service in difficult areas include the deployment of higher gain antennas at the fringe of the coverage area, and the use of

¹ An LMDS video delivery system has been developed in the United States by CellularVision Technology and Telecommunications, Inc. (CT&T) of New York. In 1992, the FCC granted a license and pioneer's preference to CellularVision for the deployment of their 28-GHz LMDS system in the Brighton Beach section of Brooklyn[1].

² For the remainder of the paper, the term LMDS will be used to describe both LMDS and MVDS unless otherwise stated.

repeaters and passive reflectors to extend coverage to shadowed areas. High power margins are required to counter the effects of rain fading in LMDS systems.

System Architecture

This section provides a brief overview of the characteristic features of an LMDS system. Some of these features will be examined in more detail with regard to system performance in the following sections. The characteristic features of LMDS systems include

- A cellular architecture with a local broadcasting headend
- Wideband FM channels
- Small, highly directive subscriber antennas
- Efficient frequency reuse
- Link availability exceeding 99.7%

These features are discussed below.

LMDS systems are planned to be deployed in a cellular configuration with a local broadcasting headend in each cell. Each headend is expected to serve a cell ranging from 1-5-km. Cell size is ultimately determined by a number of factors which include effective radiated power at the headend, the gain of the subscriber antennas, sensitivity of the receiver, and the designed link availability. The transmitter power and receiver sensitivity are primarily bounded by economic constraints. The gain of the subscriber antenna is limited by both economic and sociological constraints since customers are generally adverse to placing large antennas at their residence. In the next section, it will be shown that the primary tradeoff in LMDS systems is between cell size and link availability.

Because of the difficulty in achieving high transmitter power at these frequencies, wideband FM channels with frequency division multiplexing (FDM) have been proposed³. FM modulation is more robust to noise than standard NTSC AM modulation and can therefore achieve the same picture quality at significantly reduced carrier-to-noise ratios. In the future it is likely that digital modulation schemes and digital compression will be employed for more

efficient use of the available bandwidth. Currently, however, FM offers high picture quality with low cost subscriber equipment.

Subscribers residing within the cell of coverage receive the hub transmission using a high-gain directional antenna and a set-top converter. The set-top converter tunes and demodulates the received signal. The converter may also contain a decoder or descrambler for secure transmission. Because of the very high frequency of the hub transmission, the required antenna at the subscriber site can be very small and still achieve high gain. For example, a 18.3-cm (7.25-inch) diameter parabolic antenna with 55% efficiency provides a gain of 32 dBi at 28-GHz.

The beamwidth of this antenna at 28-GHz is only 4.5°. The use of highly directive subscriber antennas is a characteristic feature of an LMDS system which greatly reduces the effects of multipath and interference from adjacent cells. To further reduce the effects of inter-cell interference, adjacent cells would use reverse polarized antennas and offset carrier frequencies. These factors allow efficient frequency reuse in nearby cells.⁴

Because LMDS systems are to be competitive with other wireless services such as DBS, the number of outages due to weather-related effects must be kept to a minimum. The standard used by DBS is 99.7% availability which correspond to 99% availability for the worst month [2]. The availability of LMDS systems must be at least this level to remain competitive.

Issues for LMDS Deployment at 28- and 42-GHz

Currently two frequency bands have been proposed for LMDS allocation in the United States: 27.5-29.5-GHz and 40.5-42.0-GHz. The 28 GHz band has also been proposed for use by emerging satellite technologies. Initial competition for frequency allocation sparked an examination of the technical issues regarding deployment of LMDS in both the 28- and 42-GHz bands. Although satellite and LMDS service providers are currently negotiating a plan for sharing the 28-GHz band, these studies are still

³ CellularVision has proposed the use of 49 20-MHz FM channels in each cell. The MVDS study group has proposed 32 26-MHz FM channels.

⁴ CellularVision proposes the same frequency band be reused in every cell.

relevant to potential use of 42-GHz for LMDS both in Europe and the United States.

Using identical system parameters at both frequencies (i.e. transmit power, antenna gain, receiver sensitivity, etc.), system performance can be compared by examining the effective cell size or predicted link availability at each frequency. Differences in system performance at 28- and 42-GHz are attributable to a difference in propagation characteristics at each frequency.

With line-of-sight transmission over short distances (1-5-km) to a 3°-beamwidth antenna, multipath fades are not expected to be significant at either frequency. The substantial differences in propagation result from increased path loss and rain attenuation at the higher frequency. These differences are examined below. The one-way path loss is derived from the radar range equation and is given in dB as

$$L = 20 \log(4000\pi D) - 20 \log(\lambda) \quad (1)$$

where D is the path distance in kilometers and λ is the wavelength of the carrier in meters. At 42-GHz, a smaller wavelength results in a path loss that is 3.5 dB than at 28 GHz for the same gain antenna⁴. This increased path loss hinders performance at 42-GHz.

Rain attenuation is also larger at 42-GHz. To compute rainfall attenuation, we use the CCIR prediction model for terrestrial paths[4]. Using this model, the rain fade (in dB) that is exceeded 0.01% of the year is given by

$$A(0.01\%) = \alpha R_{0.01}^{\beta} \frac{90D}{90 + 4D} \quad (2a)$$

where α and β are frequency dependent constants:

$$28\text{-GHz: } \alpha = 0.162$$

$$\beta = 1.037$$

$$42\text{-GHz: } \alpha = 0.387$$

$$\beta = 0.917$$

D is the path distance in km, and $R_{0.01}$ is the rainfall rate in mm/hr that is exceeded 0.01% of the year. The rain fade for percentages other than 0.01% is then predicted by

$$A(p) = A(0.01\%) \left[0.12 p^{-(0.546 + 0.043 \log p)} \right] \quad (2b)$$

when $0.001\% < p < 1\%$. Comparison of the rain fade in (2b) at 28- and 42-GHz varies depending on the rainfall rate, the distance, and the level of link unavailability p . In the next section, results are obtained using (2b) for various parameters.

Link Comparisons: 28- and 42-GHz

In this section we compare link performance for an LMDS system at 28- and 42-GHz using the same system link parameters at both frequencies^{5,6}. The only difference in the calculation at each frequency is due to the difference in propagation. Two comparisons are made. In the first, cell size is computed at each frequency for a specified link availability. In the second, link availability is determined for a specified cell size.

As a baseline, we use a LMDS system proposed to provide 99.9% link availability in New York City ($R_{0.01} = 52.4$ mm/hr). The system broadcasts 50 18-MHz FM channels; for impulse-free FM reception, the required carrier-to-noise ratio (CNR) is selected at 13.4-dB⁷. The baseline transmitter uses a 100-Watt TWT amplifier backed off by 7 dB for linearity. A 1 dB line loss is assumed at the transmitter. Other link parameters are given in Table 1. As the table shows, a margin of 149 dB exists for the combined propagation path loss and rain fade.

Comparison 1: Cell Size

In this first comparison, we compute the maximum cell size at 28- and 42-GHz for 99.9% link

⁵ For this study, antenna gain, rather than antenna size, is held constant to provide the same antenna coverage at each frequency.

⁶ This comparison is based strictly on technical considerations. In practice, some parameters like transmit power will be more difficult to obtain at the higher frequency without significant increase in cost. These factors are discussed further at the end of the paper.

⁷ For an FM deviation of approximately 7 MHz, this CNR results in a signal-to-noise ratio of 46 dB and yields good protection from white noise interference. However, this deviation exceeds Carson's rule for an 18 MHz bandwidth, and filtering may produce a small tolerable amount of visible picture distortion. If necessary, a larger required CNR could be specified to provide the same SNR with a lower FM deviation.

TABLE 1. BASELINE LMDS SYSTEM

TWT Transmit Power	20	dBW
Linearity Backoff	7	dB
Transmit Antenna Gain	10	dBi
Line Losses	1	dB
Channel Factor (10 log 1/50)	-17	dB
ERP/Channel	5	dBW
Thermal Noise @ 300K (18-MHz bandwidth)	-131.4	dBW
Receiver Noise Figure	6	dB
Receiver Noise	-125.4	dBW
Receive Antenna Gain	32	dBi
Required CNR	13.4	dB
Propagation Loss Margin	149	dB

availability. This can be determined from Eqs. (1) and (2) and the propagation margin given in Table 1:

$$L + A(0.1\%) = 149 \quad (3)$$

Expanding Eq. (3) we can obtain an expression in terms of distance:

$$20 \log(4000\pi D) + \alpha(52.4)^\beta \frac{90D}{90 + 4D} (0.382) = 149 + 20 \log(\lambda) \quad (4)$$

where D is the path length in kilometers and λ is the wavelength in meters. Solving (4) using the values for α and β given in the previous section, one obtains $D = 4.60$ -km (2.86-miles) for a 28-GHz system, and $D = 2.97$ -km (1.84-miles) for a 42-GHz system.

The ratio of the cell radii at the two frequencies is 0.646. The ratio of the effective areas of coverage is therefore $(0.646)^2 = 0.417$. From these results, we conclude that deployment of the baseline LMDS system at 42-GHz would require 2.4 times as many headends to cover a large area with the same quality of service.

Comparison 2: Availability

A second comparison is the link availability for a specified cell size. It was determined above that at 28-GHz, the baseline LMDS system obtains 99.9% availability for a cell radius of 4.60-km. At 42-GHz, the increased path loss and rain attenuation limits the performance of the baseline system. For the same 4.60-km cell radius, this decrease in performance is exhibited as a lower level of link availability.

For this comparison, we determine the availability level ($100\% - p$) which satisfies the propagation loss margin:

$$L + A(p) = 149 \quad (5)$$

Expanding Eq. (5) above, and substituting $D = 4.60$ -km, we obtain the expression

$$20 \log(18400\pi) + \alpha(52.4)^\beta (3.82) \times [0.12 p^{-(0.546+0.043 \log p)}] = 149 + 20 \log(\lambda) \quad (6)$$

Solving for Eq. (6) at 42-GHz, we obtain $p = 0.40\%$. Therefore, the availability at the edge of a 4.60-km cell is 99.6%.

For a 365-day year, a link availability of 99.9% implies that subscribers at the edge of a cell will experience unacceptable picture quality⁸, on average, 8.76 hours per year. Reduction of link availability to 99.6% means that service outages due to propagation effects occur four times as often, 35.0 hours per year.

Conclusions

We have described the features of proposed local microwave delivery systems at frequencies near 28- and 42-GHz. The primary difference is the increased propagation losses at the higher frequency. For 99.9% availability at a distance of 4.60-km in New York City ($R_{0.01} = 52.4$ mm/hr), the difference in rainfall attenuation at 28- and 42-GHz is approximately 7.3 dB. The added path loss at 42-GHz brings the total difference in propagation loss to 10.8 dB. Therefore, an LMDS system deployed at 42-GHz requires a loss margin that is 10.8 dB larger to provide the same coverage and quality of service as at 28-GHz. An improved margin can be brought about through the use of larger transmitter power, larger antenna gain, or fewer channels. However, these changes all translate to higher system cost.

⁸ Unacceptable picture is defined by reception of a signal with the carrier-to-noise ratio below the specified minimum requirement.

Comparisons of a baseline LMDS system at each of these frequencies shows that deployment at 42-GHz results in a tradeoff of:

- A 58% reduction in effective coverage area, or
- Four times the number of weather-caused system outages

The comparisons described in this paper use equal system operating parameters at both frequencies and ignore differences in equipment cost at the two frequencies.

As a final comment, it is noted that because of the increased difficulty of generating power at higher frequencies, it is anticipated that economic constraints will further limit system performance at 42-GHz. A 3 dB loss in transmitter power at 42-GHz, would result in an effective cell radius of 2.57-km at 99.9% availability (a reduction in effective coverage area of 69%), and an availability of 99.25% (7.5 times the number of system outages) at a radius of 4.60-km.

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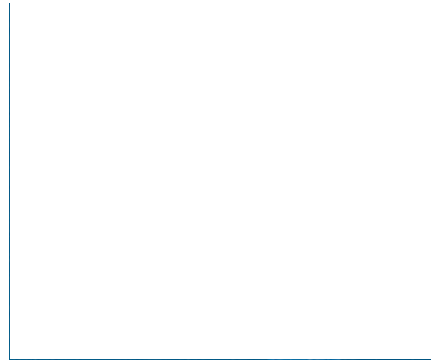
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