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# A Survey of Broadband Broadcasting Technologies: *MMDS, LMCS, LMDS, and MVDS*

**Bernard Caron, Pierre Bouchard,  
Michèle Guillet**

Television Systems and Transmission  
Broadcast Technologies Research

CRC TN No. CRC TN-99-002  
Ottawa, July 1999

**CRC** Communications  
Research Centre  
Centre de recherches  
sur les communications

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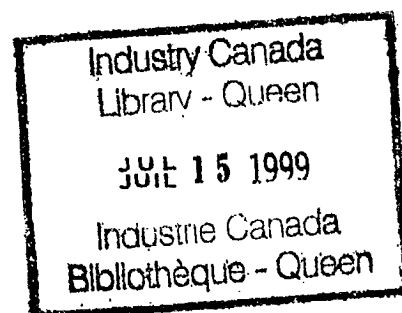
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## Abstract

For many years, multichannel broadcasting of video, audio, and data, has been done using coaxial cable. It is only recently that terrestrial microwave transmitters, operating at frequencies ranging from 2 to 45 GHz, have become available for multichannel broadcasting at a reasonable cost.

This Technical Note presents a survey of the latest developments in microwave broadband broadcasting (point-to-multipoint) systems around the world. The survey includes Multichannel Multipoint Distribution Systems (MMDS), Local Multipoint Communications Systems (LMCS), Local Multipoint Distribution Services (LMDS), and Multipoint Video Distribution Systems (MVDS).

While every effort has been made to present up-to-date information, it is important to note that many of these technologies are still in their experimental phase so technical details presented in this survey are subject to change. Moreover, proposed and existing systems are reviewed in as much detail as was available at the time of writing.

## Résumé

Durant plusieurs années, la diffusion multi-canaux d'images, d'audio et de données s'est faite par câble coaxial. L'utilisation de transmetteurs micro-ondes terrestres opérant entre 2 et 45 GHz pour ces applications n'est devenue courante que très récemment.

Cette note technique présente un survol des derniers développements dans le domaine des systèmes de diffusion à large bande de type point à multipoint à travers le monde. De manière plus spécifique, ce document traite des systèmes suivants:

- systèmes de télécommunications multipoint (STM) ainsi que les systèmes de distribution multipoint (SDM-TV);
- systèmes de télécommunications multipoint locaux (STML), de même que leurs équivalents ailleurs en Amérique, les LMDS ("Local Multipoint Distribution Services");
- les systèmes européens de distribution vidéo multipoint appelés MVDS ("Multipoint Video Distribution Systems").

Il est important de noter qu'un grand nombre de ces systèmes sont encore des prototypes plus ou moins testés dans des conditions réelles d'utilisation; par conséquent, leurs spécifications peuvent changer sans préavis. Enfin, ce document décrit ces systèmes avec plus ou moins de détails, suivant la bonne volonté de leurs concepteurs à fournir de l'information technique.

## 1. Introduction

For many years, coaxial cable has been used for multichannel broadcasting. Satellite or local television signals are collected at a head-end where they are frequency division multiplexed and then distributed via fibre/coaxial cable systems. Amplifiers along the coaxial cable maintain the signal at an appropriate level. The signals are received by a cable-ready television set or by a set-top converter. Analog cable distribution systems have been in service for many years. Transition to digital systems has begun because it provides, using video compression, a means to significantly increase the number of programs that can be transmitted in a given bandwidth.

Multichannel broadcasting is now also available using terrestrial microwave transmitters operating between 2 and 45 GHz which is more or less within the Super High Frequency (SHF) or microwave band (3-30 GHz) and at the bottom of the Extremely High Frequency (EHF) or millimetric band which extends from 30 to 300 GHz. These broadband wireless systems are known as MMDS, LMDS, LMCS, and MVDS.

These wireless systems typically operate over a wide bandwidth, from a few hundred megahertz up to more than one gigahertz. A target reception area is typically covered with many transmitters, often in a cellular configuration. The size of individual cells will mostly depend on the frequency of operation. This configuration reduces transmission power requirements and makes it possible to provide two-way communications. The receiving installation is fixed and typically consists of a rooftop directional antenna connected to a conventional satellite or cable receiver with a suitable downconverter.

In addition to wide bandwidths, the use of higher carrier frequencies can also bring several other implementation advantages, including [1]:

- hardware with reduced size and weight;
- smaller antennas with narrower beamwidths, leading to increased immunity to interference;
- ease of installation and reconfiguration.

These broadband wireless systems can either be complementary or competitive to established wired services such as telephone and cable television. In North America, for example, they will compete with existing services already widely available. In countries where telephone or cable television services are not widespread, wireless broadband systems could be used to quickly make them available to a large population.



## 2. Broadband Wireless Services

So far, the main service provided by broadband wireless broadcasting has been video programs. Transition from analog transmission to digital has begun making it possible to increase the number of programs available. Digital transmission also provides an easier way to offer services such as pay-per-view or even video-on-demand due to the relative ease with which encryption and conditional access can be provided with digital technologies. Table 1 presents typical compressed data rates required for different video qualities.

Video Quality	Data Rate (Mb/s)
Studio	200
Perfect domestic reception	8
High quality domestic reception	5
Acceptable for movies	2

**Table 1** Data rate for various video qualities (Standard Resolution).

Given its cellular and local nature, broadband wireless systems can be designed to enable two-way communications. Services like Internet access, telephony or tele-games<sup>1</sup> are possible. Typically, the data rate will be different for the transmission from the hub to the subscriber and reverse, 5 Mb/s vs. 10-20 kb/s. Broadband wireless systems can be seen as a wireless extension to wireline protocols such as Asynchronous Transfer Mode (ATM)<sup>2</sup> networks which can carry voice, data, and video. They can also be used as the backbone transmission system for Personal Communications Systems (PCS). Real-time video services can also be used to support specialized applications such as telemedicine or video teleconference. A return video channel can also be useful for security or traffic monitoring for Intelligent Transportation Systems (ITS)<sup>3</sup>. Packet data could be delivered using a wireless extension of ATM with a new control layer protocol.

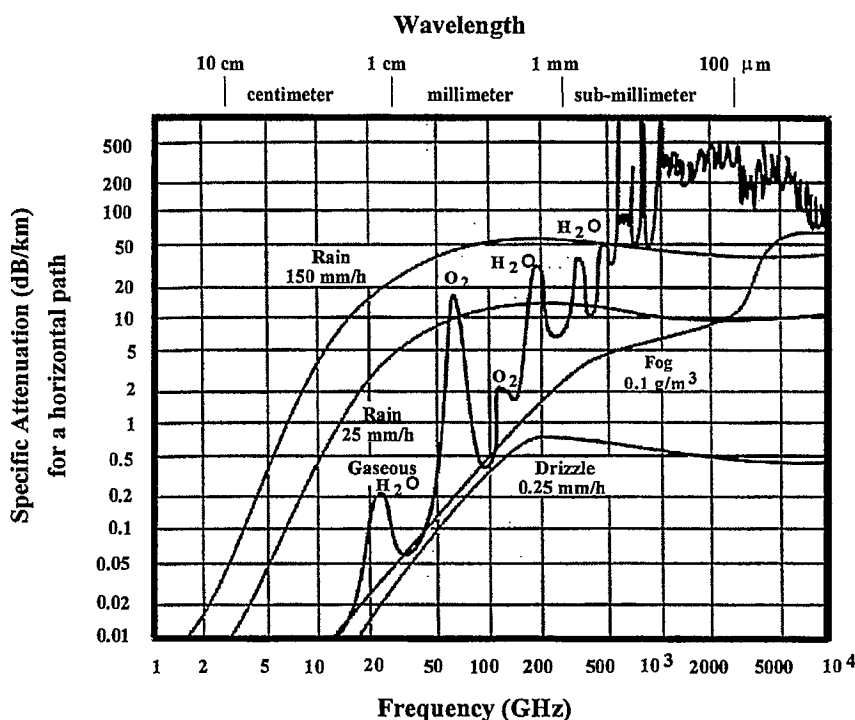
<sup>1</sup> A game being played over a network or downloaded to a game station from the network.

<sup>2</sup> A packet-oriented communication protocol that uses 53-byte fixed size cells to transfer information in the network. ATM provides efficient service for bursty data and for mixed traffic (data, image, audio, voice, and video) [2].

<sup>3</sup> On a larger perspective, planned ITS include vehicular radar, in-vehicle computer-based navigation systems, electronic road signs, real-time information about highway traffic and road conditions, automatic vehicle location, recovery of stolen vehicle, electronic toll collection and traffic signals that can sense and adapt to changes in traffic conditions [1].

### 3. Some Considerations on Microwave and Millimeter Wave Propagation

The ever-present free-space losses affect microwaves and millimeter waves like any other frequency bands, but beginning at about 10 GHz, absorption, scattering and refraction by atmospheric gases and hydrometeors<sup>4</sup> become very important limiting factors for wave propagation. Figure 1<sup>5</sup> shows the specific attenuation in dB/km as a function of frequency for atmospheric gases and liquid hydrometeors. From this figure, it is clear that attenuation for moderate (25 mm/h) to heavy (150 mm/h) rain is stronger than for a clear atmosphere over most of the millimeter range [1]. Therefore, the use of millimeter waves for very long terrestrial paths where other propagation effects – like multipath – can come into play, appears unlikely, except perhaps for a region having a very dry climate.



Temperature: 20°C, Pressure: sea level: 1 atm, Water Vapour: 7.5 g/m<sup>3</sup>

**Figure 1** Attenuation due to atmospheric gases and hydrometeors for transmissions through the atmosphere (from CCIR reports 719-3 and 664-1).

#### 3.1 Gaseous Attenuation

Gaseous attenuation is caused by the gaseous constituents of the atmosphere that are present in the transmission path. Only oxygen and water vapor have observable resonance frequencies in the radio wave bands used for communications (see again Figure 1). Oxygen has

<sup>4</sup> The various forms of precipitated water vapor such as rain, fog, sleet, and snow.

<sup>5</sup> Courtesy of Luc M. Boucher (CRC) [1].

a series of very close absorption lines near 60 GHz and an isolated absorption line at 118.74 GHz. Water vapor has lines at 22.3, 183.3, and 323.8 GHz. Oxygen absorption involves magnetic dipole changes, whereas water vapor absorption consists of electric dipole transitions between rotational states [2]. At those specific frequencies (shown as peaks in Figure 1) terrestrial re-use distance will be reduced, and satellite-to-satellite links will be relatively free of interference from co-channel terrestrial stations [1].

### 3.2 Rain Attenuation and Time Availability

Hydrometeor attenuation is caused by both scattering and absorptive processes. Rain is the most significant attenuator and it can be very severe at frequencies greater than 10 GHz, at elevation angles below 10 degrees, or for links requiring high availability [1]. Much research on the statistics and effects of rain has been conducted, and many propagation models have been developed [2]. For example, Table 2 presents rainfall attenuation at 28 GHz for major Canadian and American cities [3].

Experience with current commercial point-to-point terrestrial systems has shown that for 99.99 % time availability, typical useable distances are in the order of 8 to 15 km at the lower millimeter wave frequencies (e.g. 30-40 GHz). On the other hand, that range decreases to 1-3 km at higher frequencies and at frequencies experiencing high molecular absorption (e.g. 55 to 65 GHz) [1].

To improve the time availability in rain conditions, classical solutions include path diversity, variation of the power margin and closer repeater spacing for terrestrial links. These and other techniques can also be used to combat multipath effects and to compensate for the severe effect of blockage caused by foliage.

### 3.3 Attenuation Caused by Snow and Fog

Wet snowfalls can cause attenuation that is higher than rain for comparable values of equivalent rain rate. At frequencies below 100 GHz, attenuation by dry snowfalls appears to be about the same as for rain for comparable values of equivalent rain rate. Since the equivalent rain rate of dry snow does not usually exceed 10 mm/hr (a moderate rainfall), the effect of snow is less severe than rain in many cases [1]. The degradation of the antenna characteristics due to accumulations of snow and ice may be of greater importance than snow along the path. Tests in Switzerland (see Section 8.2) showed that signal quality remained high even during heavy snowfalls.

Fog results from the condensation of atmospheric water vapor into droplets that remains suspended in the air. There are two types of fog, advection and radiation. Advection fog forms in coastal areas where when warm, moist air moves over colder water. Radiation fog forms at night, usually in valleys, low areas and along rivers [2]. Typical fog layers are only 50-100 m in

height. Nevertheless, attenuation caused by fog can be significant at frequencies near 100 GHz and above [1]. The liquid water content of fog is typically  $0.05 \text{ g/m}^3$  for fog of medium density (visibility of about 300 m) and  $0.5 \text{ g/m}^3$  for dense fog (visibility of about 50 m). The corresponding specific attenuation would be, for example, 0.4 dB/km and 4 dB/km, respectively, at 140 GHz. Other factors may influence the actual figures [1].

Rain Region and cities	F Los Angeles And San Diego, CA Phoenix, AZ Salt Lake City, UT	B Denver, CO Portland, ME Spokane, WA Calgary, Alb	C San Francisco and Sacramento, CA Seattle, WA Portland, OR Vancouver, BC	D1 Ottawa, On Montréal, Qc Toronto, On Dallas, TX Minneapolis, Minnesota	D2 New York, NY Philadelphia, PA Boston, MA Chicago, IL Washington, DC Cleveland, OH Austin, TX	D3 Memphis, TN Atlanta, GA	E Houston, TX New Orleans, Louisiana Miami, FL
Rainfall Attenuation for 99.9 % Availability (dB/km)	1.24	1.55	1.62	2.45	3.26	4.69	7.18
Rainfall Attenuation for 99.99 % Availability (dB/km)	7.85	6.65	9.40	12.15	15.70	19.70	29.25

**Table 2** Rainfall attenuation at 28 GHz for major Canadian and American cities. Adapted from [3]. A time availability of 99.99 % represents a cumulative outage of 52.56 minutes per year; on the other hand, a time availability of 99.9 % represents a cumulative outage of 8.76 hours per year.

### 3.4 Multipath

For terrestrial broadband services using paths of a few kilometers, atmospheric attenuation may become of secondary importance compared to the effects of buildings, vegetation, and other scattering objects on the received signal [1]. The transmitted signal will be dispersed in time, due to the various scatterers in the vicinity of the transmitter and receiver. Moreover, energy will arrive at the receiver via a number of propagation paths of different lengths, possibly causing Inter-Symbol Interference (ISI).

Most of the time, microwave signals can be received reliably only if the transmitter is in Line Of Sight (LOS) with the receiver. Reflections from the ground or buildings usually suffer too much attenuation to provide a satisfactory reception. Hewlett-Packard [4] reported however that "a relatively high percentage of households,..., can be covered even if they are not truly in

line-of-sight if excess link margins can be maintained at 20 dB or more.” However, the cost of maintaining such a high excess link margin to cover the path losses caused by obstacles, diffraction, time-varying fades, etc. can be prohibitive in regions with high rainfall conditions where a 99.99 % time availability is expected, as can be seen in Table 2.

Multipath measured in Canada at 28 GHz (see Section 7.3.4.2) was very weak – less than 15 dB – and had a short delay, less than 10 ns. In Europe, the multipath signal was typically –40 dB below the direct signal with a few reflections as high as –20 dB (see Section 8.4.2).

### **3.5 Shadowing Caused by Vegetation**

At millimeter wave frequencies, the effect of blockage caused by vegetation can be quite severe. Average attenuation in the order of 4 dB/m of vegetation has been reported [1]. During tests in Canada at 28 GHz (see Sections 7.3.4.2 and 7.3.4.3) foliage attenuated the signal by more than 10 dB. Tests in Europe around 42 GHz (see Section 8.4.2) showed that trees caused an attenuation of 4-5 to up to 10 dB per meter of vegetation. Therefore, one must avoid the foliage by some means. Possible solutions include raising the antennas above the foliage, using a repeater to go around the foliage, increasing the transmitted power or removing the foliage, if possible [1].

### **3.6 Attenuation through Building Materials**

The effect of different building materials on signal propagation is another important consideration. It appears that "hard" building materials, such as concrete and steel, give a high attenuation, while "soft" materials like Sheetrock, glass, and gypsum give a much lower attenuation. For example, at 35 GHz, the attenuation of gypsum is 5 dB, while the attenuation of concrete is approximately 45 dB. In general, the attenuation increases with frequency [1].

### **3.7 Depolarization**

Depolarization involves a change in the polarization characteristics of a radio wave caused by hydrometeors, (primarily rain or ice particles), multipath propagation, or vegetation. A depolarized radio wave will have its polarization state altered such that power is transferred from the desired polarization state to an undesired orthogonally polarized state, resulting in interference or crosstalk between the two orthogonally polarized channels [2].

Propagation tests done at 28 GHz [4] indicated that in most environment some depolarization between vertical and horizontal transmission occurs and that using alternating polarity could provide isolation only in relatively benign propagation environment.

Experiments conducted at the Institute for Telecommunications Sciences (ITS) have characterized millimeter wave depolarization caused by scattering from vegetation in both coniferous and deciduous trees [66]. The most serious impairments were consistently seen in conifer trees where the average Cross-Polarization Discrimination (XPD)<sup>6</sup> at 28.8 GHz was 12 dB for foliage depths of 20 m and decreased to about 9 dB after 60 m [66]. However, it is hard to apply these results to cells proposed for LMDS applications because the foliage depth and tree species for any particular subscriber are random and unknown.

### 3.8 Channel Characterization

Not much information is available about the channel characteristics for wideband point-to-multipoint terrestrial transmission. A study from the Institute for Telecommunication Sciences [5] provides some results at 30.3 GHz for 20 MHz wide channels. The tests were done with transmitting antenna heights of 16 and 40 m and with the receiving antenna raised 1 m above the roof of one to three story home in front of which the measurement was done. The proposed cell was 5 km. The excess path loss was due to building and vegetation as there was no terrain obstruction in this Boulder, Colorado suburb. It was between 10 and 35 dB for 80 % of the sites. It was less than 6 dB for 11% of them and 10 dB or less for 20 %. The cumulative distribution of excess path loss for the 16 and 40 meter height antenna was close with a median of 15 dB for the 40 m and 18 dB for the 16 m. These tests also showed that over ten bands of 20 MHz each, the median values were within 1 dB, indicating independence of frequency over that bandwidth. Delay spread varied between 0.8 and 10 ns with a median of less than 1 ns. Multipath was limited because of the receiving antenna narrow beamwidth.

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<sup>6</sup> That parameter was defined as  $XPD = 10 \log_{10} (P_{\text{co-pol}} / P_{\text{cross-pol}})$  where  $P_{\text{co-pol}}$  is the co-polarized received power and  $P_{\text{cross-pol}}$  is the cross-polarized received power. For these measurements, a vertically polarized signal was transmitted and both vertically and horizontally polarized signals were received [66].

## 4. Propagation Models

Work has been done to develop millimeter wave propagation prediction models. For example, such a model, called Millimeter Wave Propagation Prediction Model (MMWPROP), developed by R. Meidenbauer [6], predicts signal attenuation and phase dispersion in the 0.1 to 300 GHz range, for both terrestrial transmission links and earth-space links. MMWPROP carries several computational tasks: the confirmation of a line-of-sight path for a smooth spherical earth or optionally with Digital Terrain Elevation Data (DTED) topographic files created by Worldwide Topographic Loader (WOTL), the calculation of the free-space spreading attenuation, the computation of molecular absorption by oxygen and water vapor as well as molecular phase dispersion. It also computes the rain attenuation or the ionospheric scintillation not likely to be exceeded for a given percentage of time. However, this model is limited to radio line-of-sight cases and has no provision for predicting the effect of vegetation or man-made structures like buildings.

A simple model was proposed in [7] for MMDS. It is based on some measurements made from a television tower<sup>7</sup> in and around the city of Denver, Colorado (USA) [8]. It was suggested to use the Wide Sense Stationary Uncorrelated Scatterers (WSSUS) model (a direct ray followed by an exponentially decaying tail of delayed rays) with a delay spread ( $T$ )<sup>8</sup> of 1  $\mu$ s and a tail strength ( $R$ ) of -10 dB for a typical case and 2  $\mu$ s and -14 dB for a directional antenna. The intersymbol interference (ISI) obtained in the end, without equalization and in a noiseless channel, is close to the value of the multipath tail strength  $R$ . Simulations using this model showed that a Trellis coded 64 QAM (code rate of 5/6) provides a satisfactory operation ( $BER < 10^{-3}$  before Reed-Solomon coding) for a SNR of 24 dB. A large area of Denver can be served with an EIRP of 100 watts per carrier and a receiver with a 6-dB noise figure and a gain of 18 dB. The transmitter is located on Lookout Mt., several hundred meters above the city.

Some work has also been done by J.-P. DeCruyenaere at Carleton University (Ottawa) on a propagation model for LMCS system design. The simulator was written for predicting coverage in suburban environments [9]-[10].

Coverage prediction models were also studied by the CRABS Project for MVDS (see Section 8.4.2).

<sup>7</sup> The authors of [7] state that these measurements at about 600 MHz [8] represent "the best approximation to the MMDS situation".

<sup>8</sup> After a time equal to  $T$ , the expected power of the received signal will have dropped by a factor  $1/e$  (37 %).

## 5. Multiprogram Multipoint Distribution Systems (MMDS)<sup>9</sup>

MMDS, the most widely used broadband wireless system, is more commonly known by the oxymoron “wireless cable”. It is a radio alternative to cable TV distribution. MMDS may be particularly important in rural areas because it can be used to distribute a large number of analog or digital TV channels in some situations where there is neither local broadcasting nor sufficient customer density to support a regular cable system. In this context, it is primarily an alternative to satellite TV, with the additional advantage that MMDS can supply local programming.

### 5.1 Origins of MMDS

The primary precursor of MMDS was Instructional Television Fixed Services (ITFS) in operation in Canada and the USA since the early 1960's [12]. Such services evolved mainly from the demand for further ancillary services to education and consequently proved very popular as a complementary facility for college students. Broadcasts consisted of various forms of instructional programming obtained from a video library. Quite often, the service function would change during the course of the week: lecture material during the school hours and entertainment material after hours and on weekends. For areas surrounding the city, ITFS would normally be used to relay educational programs to local schools.

With the passing of time the service took on a more commercial aspect. Recognizing this trend, the Federal Communications Commission (FCC) in the USA decided to allocate a portion of the spectrum for broadcasting using this new technology. The 6 MHz channel located at 2.150-2.156 GHz was popular for TV and later another one between 2.156 and 2.162 GHz was set aside. TV operators could then provide their customers with either a single or two-channel subscription system, known as Multipoint Distribution Systems (MDS). The service continued to grow well into the 1970's alongside the ITFS services operating on similar, adjacent frequencies.

The development of cable TV considerably limited the growth of MDS during the mid 1970's and today still proves to be the main alternative or competing technology. Cable could provide viewers with a greater diversity of programs for comparable costs once the infrastructure was in place. The lack of strong demand for ITFS in the early 1980's prompted the allocation of more bandwidth to MDS on a *shared* basis with ITFS. As a result, the entire 2.5-2.686 GHz band was made available, so viewers could now obtain a number of channels comparable to cable users. The new service was called Multichannel Multipoint Distribution Service (MMDS).

From 1984 on, the technology spread to other countries of the world and became known under various other names such as Microwave Multipoint Distribution Service, Microwave

---

<sup>9</sup> Also known as Multichannel Multipoint Distribution Service in the USA. In Ireland, Canada, Australia, and Hong Kong, these systems are sometimes called Multipoint Distribution Systems (MDS). MDS in Canada provide one-way or two-way video and data services (e.g. instructional TV, video conferencing, multi-media applications) [11].



Multichannel Distribution Service, Microwave Low-power Distribution Service, Multipoint Video Distribution Service, and wireless cable, as mentioned earlier.

These implementations used analog transmission methods such as Amplitude Vestigial Modulation (AM-VSB), to transmit video programs. Transition to digital transmission is now taking place, mostly using some kind of Quadrature Amplitude Modulation (QAM).

## 5.2 MMDS in Canada and in the USA

As mentioned earlier, MMDS operate around 2.5 GHz. In North America, for example, MMDS frequency allocations are between 2.596 to 2.686 GHz (and also between 2.150 to 2.162 GHz in the United States) and can support up to 31 (33 in the USA) 6 MHz analog TV channels. However, digital modulation schemes (e.g. 64 QAM at about 1 Gb/s in approximately 200 MHz of bandwidth) and MPEG-2 compression techniques may lead to a number of channels in the 100 range [3]. Multiple Dwelling Units (MDUs) and hotels offer a good market potential for MMDS since it can provide TV and data services for specific target audiences at a lower cost than the local cable company<sup>10</sup>.

At these frequencies, the cell size can be quite large, up to 16-64 km (10-40 miles) in radius. The maximum power allowed is 100 watt per channel. Typical waveguide losses are 3 dB and the transmit antenna gain is 12-15 dB. Parabolic reflectors with diameters between 0.3 m to 0.8 m are used as receiving antennas, providing gain from 15 to 24 dB. The downconverter has a 4 to 8 dB noise figure, and converts the signal to TV frequencies (cable or UHF). Sometimes, the band is shared with ITFS which is allocated between 2.5 and 2.596 GHz and between 2.644 and 2.686 GHz [13]. The band between 2.684 and 2.690 GHz is used in the US by subscribers to transmit information back to the system operator<sup>11</sup>. The list of the 31 channels allotted in Canada in the 2.5 GHz range is shown in Table 3.

After public consultation, Industry Canada released a Notice in June 1999 entitled "Multipoint Communications Systems in the 2500 MHz range: Policy and Licensing Procedures" (available on the World Wide Web at <http://strategis.ic.gc.ca/SSG/sf01858e.html>). Industry Canada has concluded that there is a need for out-of-band return spectrum for new MCS (2500-2596 MHz) and MDS (2596-2686 MHz) systems. This will allow MCS systems to provide a certain level of two-way interactive service and MDS operators the ability to provide interaction with programming and non-programming services. As a result, the Department is designating the band 2150-2160 MHz to provide return capability to both the MCS band and the MDS band. MCS systems will have exclusive access to 2150-2156 MHz, and MDS systems will have access to 2156-2160 MHz. This additional spectrum provides a closer alignment with the spectrum usage in the United States and may result in economies of scale for equipment procurement. In addition to this, spectrum in the band 2686-2690 MHz will also be designated

<sup>10</sup> In urban areas, cable TV offers more than 35 channels, compared to a maximum of 31 for analog MMDS.

<sup>11</sup> It contains 31 "response channels", each having a 125 kHz bandwidth. These channels were originally intended to transmit voice from a classroom to a remote instructor [13].

on an equitable and proportional basis for MCS and MDS systems in Canada. For the purpose of facilitating the division of spectrum between MCS and MDS licensees as well as coordination, spectrum is divided into 31 narrowband channels of 125 kHz. The lower portion of the band, 2686-2688 MHz, will be designated for MCS and the upper portion of the band, 2688-2690 MHz, will be available for MDS.

Channel Designator	Frequency (GHz)
A-1	2.500-2.506
B-1	2.506-2.512
A-2	2.512-2.518
B-2	2.518-2.524
A-3	2.524-2.530
B-3	2.530-2.536
A-4	2.536-2.542
B-4	2.542-2.548
C-1	2.548-2.554
D-1	2.554-2.560
C-2	2.560-2.566
D-2	2.566-2.572
C-3	2.572-2.578
D-3	2.578-2.584
C-4	2.584-2.590
D-4	2.590-2.596
E-1	2.596-2.602
F-1	2.602-2.608
E-2	2.608-2.614
F-2	2.614-2.620
E-3	2.620-2.626
F-3	2.626-2.632
E-4	2.632-2.638
F-4	2.638-2.644
G-1	2.644-2.650
H-1	2.650-2.656
G-2	2.656-2.662
H-2	2.662-2.668
G-3	2.668-2.674
H-3	2.674-2.680
G-4	2.680-2.686

**Table 3** Frequency allocations in Canada in the 2.5 GHz range. Since 1985, the 2.500-2.596 GHz band (Channels A-1 to D-4) is allocated to Multipoint Communications Systems (MCS) [11]. The 2.596-2.686 GHz band (Channels E-1 to G-4) is allocated to Multipoint Distribution Television Broadcasting Undertakings (MDS-TV) [15], [16].

Moreover, on June 9, 1999, John Manley, Minister of Industry, launched the selection process for MCS licensing across Canada. One MCS license will be awarded in each of the 13 service areas across the country. Licenses will be distributed to applicants who successfully demonstrate a capacity to establish a commercially and technically sound service while supporting learning advancement. For more information, the reader is invited to visit Industry Canada's Web page: <http://strategis.ic.gc.ca/spectrum>.

Here are a few examples of MMDS implementations in the U.S. and in Canada:

Heartland Wireless Communications, based in Dallas, Texas, is the largest wireless cable TV operator in the United States, with more than 166,000 multichannel video subscribers in 57 markets [14]. In 1998, Heartland introduced high-speed Internet services in Sherman, Texas. The suite of services, offered under the brand name HeartNet, provides downstream speeds of about 768 kb/s. Data is received at the subscriber's site via cable modem/router and distributed across a Local Area Network (LAN).

In the same vein, Wireless One Inc., based in Mississippi, has more than 106,000 subscribers. The company offers wireless video, data, and voice services using its MMDS and Wireless Communications Spectrum (WCS) licenses. In 1998, Wireless One refocused its operation on data transmission services and Multiple Dwelling Unit (MDU) video services [14]. The company launched its two-way, high-speed Internet access service, Warp One, in Jackson, Mississippi. The service, which uses MMDS downstream and WCS upstream, was later expanded to include commercial customers in Baton Rouge, Louisiana. For MDU subscribers, Wireless One offers a 28-channel package giving property managers the freedom to customize lineups based on resident demographics. Subscribers also have the option of ordering DirecTV direct broadcast satellite programming.

In Canada, SkyCable [17] uses a dozen MMDS transmitters to cover much of the province of Manitoba. Digital Video Compression (MPEG-2) and QAM are used to provide up to 150 video programs. The system covers an area of 36,000 square miles, using 13 broadcasting sites. There are more than 300,000 line-of-sight homes in the service area with more than 50,000, mostly in rural areas, which do not have any current cable service available. The installation fee is around \$200 and the monthly fee for the basic package<sup>12</sup> is about \$25. A two-way Internet service is also under development. The consumer set tops are fully addressable and are controlled from the SkyCable customer service facility in Brandon, Manitoba, through instructions transmitted via the MMDS network. Customers can call in and request any event up to five minutes prior to the air time of the event and as far as one month in advance. The system uses smart-card technology and software downloaded from the headend for security. The billing center can turn individual customers' set tops on and off on demand and also authorize pay-per-view events for specific time periods.

Image Wireless (see <http://www.imagecable.com/wireless/>), a digital MMDS provider, covers Saskatchewan using 13 transmitters. The trunking between the sites is in-band. Up to 300,000 line-of-sight homes now have access to 50 television programs. This number could be increased to 150. More than 80% of the homes within a 60-km radius of the transmitter are expected to be able to receive the signal. There are also plans to offer Internet access. Both

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<sup>12</sup> The package consists of 40 channels with an additional 20 pay-per-view movies and specialty events available on a per-subscriber basis [17].

SkyCable and Image Wireless use equipment from Broadband Networks Inc (BNI), now part of Nortel Networks<sup>13</sup>.

Other types of MMDS are also being implemented in Southern Ontario and Québec by LookTV, a Teleglobe subsidiary. Look Communications Inc. obtained their license from the Canadian Radio-television and Telecommunications Commission (CRTC) for Southern Ontario in August 1997 and for Eastern Ontario and Québec in February 1998. The company launched its operations in the Greater Toronto area in August 1998, and in Montréal in January 1999. The service is currently available to 5 million households in the vast Southern Ontario market as well as covering the Metropolitan Montréal region, thus serving the two most densely populated centres in Ontario and Québec. LookTV plans to launch in the Québec City and Ottawa markets in the summer of 1999. LookTV's digital television signals are broadcast from the CN Tower and other towers in its coverage area in the Greater Toronto, Hamilton-Niagara and London-Kitchener/Waterloo-Guelph corridor. It offers more than 110 digital audio and television channels as well as high-speed Internet access. On May 17, 1999, Look Communications and I.D. Internet Direct, Canada's largest independent Internet service provider, announced they had signed a term sheet to amalgamate the two companies (for more details, see <http://www.newswire.ca/releases/June1999/14/c3893.html>). Look Communications expects to have an 8 % market share by the time its licence expires in 2003 [18].

The 1989 agreement between United States and Canada on the coordination of the 2500-2686 MHz band within 80 kilometers of the border specified that Canadian transmitters can use only vertical polarization, while U.S. facilities are restricted to horizontal polarization [19]<sup>14</sup>. To reduce the co-channel interference to analog television signals, the transmitters must demonstrate a  $\pm 500$  Hz frequency tolerance for non-precision offset at S-band. Moreover, the U.S. assignments will operate on the nominal channel frequencies, while the Canadian assignments will use the nominal channel frequencies with an offset of  $\pm 10$  kHz. The use of frequency offset at the relatively tight  $\pm 500$  Hz tolerance results in a 17-dB reduction in co-channel interference in the MMDS band, according to reference [19]. In addition, the Power Flux Density (PFD) cannot be greater than  $-70$  dBW/m<sup>2</sup> across the border for *analog* systems. The FCC and Industry Canada agreed in December 1997 [15] to establish a PFD of  $-80$  dBW/m<sup>2</sup> at the border as the coordination threshold for *digital* systems. These requirements limit the strengths of signals from each country going into the other, further mitigating the potential for co-channel interference. Meeting these requirements may require using higher performance receiving antennas with excellent front-to-back (28 dB) and front-to-side ratios and narrow beamwidths (12 degrees) [15].

The use of MMDS technologies in other parts of the world is discussed below.

<sup>13</sup> On January 9, 1998, Nortel Networks acquired Broadband Networks Inc. (BNI), a Manitoba-based start-up company and a leader in the design and manufacture of fixed broadband wireless communications networks.

<sup>14</sup> This principle is still valid in the 1997 agreement between the two countries [15].

## 5.3 MMDS in Other Parts of the World

### 5.3.1 Mexico

Like most Latin American countries, Mexico does not have an extensive cable infrastructure and thus MMDS is a good way to provide TV services to a large percentage of the population within a reasonably short period of time. Mexico's MMDS systems operate in the 2.5 – 2.7 GHz range and typically use equipment from US sources [12]. Coverage to date is concentrated in the capital city where there is a large potential for growth. The system is PAL or NTSC compatible and does not use de-scramblers or set-top boxes. Instead, the system is addressable. Each individual subscriber is identified by a unique address and his status may be altered at the headend, further reducing the cost of the receiving equipment and allowing the operator greater flexibility in choosing and modifying his markets. In 1997, Mexico City had the largest number of subscribers for a single system in the world [20].

### 5.3.2 Europe

As a point-to-multipoint TV delivery medium, the status of MMDS in Europe varies substantially from nation to nation [12]. Existing technology is analog, with commercial use largely confined to two frequency bands. Two analog standards are currently in use: PAL and SECAM, with PAL System I<sup>15</sup> the dominant format in all but France and some parts of Germany. The emphasis is generally on the regional distribution of local services with limited coverage area. The Republic of Ireland is an exception, since it has established a national plan for MMDS coverage of the entire country. MMDS in Europe will be primarily an extension of the existing cable networks, providing multichannel television to non-cabled areas [12].

Ireland has probably the most established analog MMDS service system in Western Europe, with a national plan currently dividing the country into 29 cells. It grew from the demand for multichannel television in parts of the country where only one TV service was available (The National Broadcaster, RTE) and – not surprisingly – where it was not commercially viable to lay cable due to the sparse rural population base. In 1997, there were approximately 410,000 cable subscribers and 75,000 MMDS subscribers for a market of more than one million TV households [21]. Some parts of Ireland along the east coast and along the Northern Ireland border are able to pick up seven off-air channels due to a mixture of the Irish National State Broadcaster's service and international spillover from various UK terrestrial broadcasters. This has undoubtedly hindered the take-up of MMDS services in these areas [21]. In other parts of the country, the growth of illegal deflector systems, fueled by the demand for UK terrestrial TV channels<sup>16</sup> and lack of anti-deflector enforcement by successive governments, has had the same effect. These illegal operators have grown from serving neighboring households to generating large revenues streams by extending their customer base to large rural

<sup>15</sup> With 625 lines per frame, an 8 MHz channel and a 5.5 MHz video bandwidth.

<sup>16</sup> There are basically four channels: BBC1, BBC2, ITV and Channel 4.

communities. They charge \$32 to \$80 US per year, which is significantly less than the average annual MMDS subscription fee [21].

The Irish Regulatory Authority has allocated the 2.5-2.676 GHz band for MMDS. This 176 MHz of bandwidth is divided into 22 channels with 8 MHz spacing, subdivided into two groups of 11 channels. In order to avoid co-channel interference between cells and adjacent channel interference within one cell, the following scheme was used. Each of the two groups, called A for *odd* channel numbers and B for *even* channel numbers<sup>17</sup>, can be used with or without a frequency offset of both the visual and aural carriers, that is, 0 kHz or 7.8125 kHz, the latter being designated by a "+". All four combinations can be polarized either horizontally or vertically, yielding eight different possibilities [22]:

AH	BH	AV	BV
AH+	BH+	AV+	BV+

Each cell can therefore transmit up to 11 PAL System I channels. This is comparable to the service offered by existing cable companies in the country. The cells' assigned radii are typically between 16 and 48 km (10 and 30 miles).

Moreover, tests at 2.672 GHz were conducted in Ireland to study the possibility of transmitting four digital television programs in an 8 MHz channel using QPSK, 16-QAM, 32-QAM and 64-QAM with respective bit rates of 12.6, 25.3, 31.6 and 38 Mb/s<sup>18</sup>. The threshold value of C/N was respectively 16, 23, 27, and 30 dB. The cell used in this experimental setup had a 24.1-km (15-mile) assigned radius. The transmitter antenna was a standard 10-meter vertically polarized cardioid with a 16-dBi gain mounted at the top of a 67-meter tower located 238 meters above sea level. The directional receiving antenna was mounted on a van equipped with a 15 meter mast and had a gain of 24 dBi. The MMDS downconverter had a nominal gain of 30 dB and a noise figure of less than 2 dB. An external local oscillator at 2.005 GHz with low phase noise was used. Heavy rain was found to cause less than 1 dB degradation. Some short term fading was observed for long sea paths at low elevation angles [23].

Again in Ireland, some tests were also done to demonstrate interactive services<sup>19</sup> over MMDS. The upstream channel was located at 2.732-2.740 GHz and the downstream channel at 2.684-2.692 GHz to insure a good isolation between the two and to operate outside the 2.5-2.676 GHz band allocated for MMDS. The same plate antenna with a beamwidth of 80° was used for both transmission and reception. Operation was limited to a short distance (1-2 km) because the gain of the transmit antenna was only 17 dBi instead of the planned 40 dBi. There were also

<sup>17</sup> Within one cell, the 8 MHz "guard band" between channels limits adjacent channel interference. However, it is rare to find a single broadcast site per cell [22]. In general, the cells have to use gap fillers to reach areas not covered by the headend, creating a potential for interference. In order to alleviate this problem, Ireland used a combination of the eight configurations outlined above.

<sup>18</sup> The effective bit rate was reduced to 32 Mb/s when Forward Error Correction (FEC) was used [23].

<sup>19</sup> A multi-player video game in that case.

some problems related to the filtering of spurious signals in the return path chain, degrading the BER performance [24].

Hungary is an example of an Eastern European nation turning to MMDS as a viable means of introducing multichannel television services quickly and inexpensively. Analog MMDS has been in operation in Budapest since 1984, covering a region with a potential of 3 million subscribers using three transmitters [12]. Antenna Hungaria's MMDS uses the SECAM system and is called *AM-micro*. It operates in the 12.3015 to 12.5035 GHz range, providing 26 channels of 8 MHz. Further expansion in this frequency band is not possible due to interference with existing satellite broadcasts so an additional band at 10 GHz has been allocated<sup>20</sup>. Although Hungary has developed a national plan for countrywide coverage, it appears that only the capital has an established infrastructure to date [12]. As a free service, the system has no need for set-top boxes containing decoding and de-scrambling circuits: all 26 channels are available to anyone with an appropriate receiver and downconverter.

In 1998, Antenna Hungaria launched AntenNet, a line of high-speed Internet access and Intranet services. Subscribers use New Media's Cyberstream MMDS receiver cards, easily installed in a PC, to receive data at up to 52 Mb/s via outdoor antennas [14]. Antenna Hungaria also provides data broadcasting and Internet Protocol (IP) multicasting push capabilities, to allow business customers to distribute data, software applications, and other business-related content to their employees.

MMDS can also be used as a point-to-point link for a variety of applications. For example, Sweden operates a system in the 17 GHz band where MMDS is used to connect headend transmissions to a small number of servers. Other applications include its use by the military, which accounts for 30 % of the frequency allocations in the United Kingdom [12].

As a country with a typically flat terrain, the Netherlands would be an ideal candidate for MMDS. Its topography would thus allow line-of-sight operation between the headend and the domestic end user in most locations. However, the Netherlands has an extensive and well-established cable network [12]. The 40.5-42.5 GHz band has nevertheless been allocated for MVDS in this country and there have been investigations on possible uses of this band as well as others.

### 5.3.3 Africa

For many years, television broadcasting in Africa has remained a state monopoly. The state-owned broadcasting institutions continue to be a burden to the governments requiring large subsidies and expensive bureaucracies. Nevertheless, for political reasons, African governments are not willing to leave the control of broadcasting to private companies. As a result, there were 2.3 television sets per 100 inhabitants in Africa in 1997 [25]. However, this figure may change

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<sup>20</sup> Romania also operates services at 10 and 12 GHz.

in the near future, due to the prevailing climate of liberalization, activity in the private sector and the introduction of new technologies in terrestrial and satellite broadcasting.

In many African countries, entrepreneurs are asking permission to set up their own TV stations. As a result, a number of countries are in the process of deregulating their broadcasting industries. Among them, we note: Nigeria, Kenya, South Africa, Uganda, Namibia, Tanzania, Mozambique, Tunisia, Senegal, Cote d'Ivoire, and Gabon [25].

On the other hand, satellite operators such as Intelsat and PanAmSat have made it possible to receive many channels anywhere on the continent. In this context, MMDS now offers the possibility of inexpensive, local broadcasting by operating outside the highly regulated VHF and UHF bands, at a lower cost than possible with DTH satellite transmission.

The first MMDS pay-TV African broadcaster was ABG Communications in Nigeria. This broadcaster started transmitting in 1991, well in advance of official government allocations for that type of service. MMDS is also used in the following French-speaking countries: Togo, Senegal, Cameroon, Gabon, Burkina Faso, Cote D'Ivoire, and Mali [25].

In Tanzania, private television broadcasting started in 1994, as a result of the prevailing climate of liberalization. The terrestrial stations are operating mainly in the capital, Dar es Salaam [26]. The majority of cable TV operators in East Africa can be found in Tanzania, with over 10 operators scattered throughout the country. Just like in any other developing country, cable TV faces the problem of extending their network in sparsely populated areas.

For this reason, two companies are currently installing MMDS networks in Tanzania [26]. The Tanzania Communications Commission (TCC) has assigned sixteen 8 MHz channels for MMDS using the PAL I standard, between 2.524 GHz and 2.652 GHz, a band that has been traditionally used by telephone networks in this country. Both companies are interested in offering service in Dar el Salaam, planning for seven encoded channels. The equipment will include a 50 W ITS transmitter, an eight-bay omnidirectional antenna, together with video addressing and scrambling subsystems. Two Scientific-Atlanta 4.5-meter antennas will receive the desired satellite programs [26].

#### 5.3.4 Asia

Wireless cable is a growing technology in Asia Pacific, where cable penetration rate is relatively slow in many countries like China and Malaysia. A lower capital investment for the MMDS operator is an important contributing factor to the fast growth.

Although Cable TV and C-band satellite TV exist in China, the majority of households can only receive a handful of channels – mostly controlled by the government. With the recent economic growth, viewing multichannel programs is now considered a necessity rather than a luxury; MMDS satisfies that need for China. In 1997, the country had around eight million wireless cable TV subscribers [27]. There are over 400 MMDS systems across the country, most



of them operating in the 2.5 GHz to 2.686 GHz band, delivering 10 to 20 channels, mostly in rural areas [28]. Nevertheless, MMDS is also popular in major cities like Beijing, Xian, Chengdu, Kwangchow, and Chengchow. The Beijing hybrid MMDS/cable system, now serving more than 1.1 million households, is a case in point [14]-[28]. It is widely considered the world's largest wireless cable system [14]. Operating with 23 channels in Waveband S (2.5-2.7 GHz), the Beijing Cable Television Network transmits 50 W per channel. The antenna height is around 180 m and the coverage radius is about 60 km. With a transmitter manufactured by Comwave and antennas provided by Andrew Co., the system was able to withstand several environmental tests, ranging from hurricanes, rainstorms, snowstorms, and hail.

A unique feature of MMDS in China is the possibility to share one antenna and one downconverter among approximately 50 households [27]. The signal is split and distributed to each house by coaxial cable. The cost of the receiving equipment is shared by these subscribers, thereby reducing the market size for the manufacturers of these types of equipment.

The majority of MMDS transmitters used in China are made in the US. Most of the receiving antennas are manufactured locally to reduce the costs. Downconverters made by Telelynx and California Amplifier are widely used in this country [27].

In Malaysia, Cableview Services Sdn Bhd (Mega TV) is the first and, apparently, the only subscription TV network [27]. It offers eight scrambled channels (CNN International, Discovery Channel, ESPN, HBO, TNT, Variety Channel, AXN and Cartoon Network) 24 hours a day, seven days a week and plans to offer more channels in the near future [14].

Again in Malaysia, Mega TV operates a MMDS network in the 2.5 GHz-2.686 GHz band, using EMCEE and Cable AML transmitters. In 1997, it served approximately 120,000 subscribers [27]. According to Gordon Chen, Mega TV has a potential to reach over 300,000 subscribers in the next few years if operations can be improved and more channels, including local programs in Malay and Chinese, can be delivered [27].

Microwave distribution in Hong Kong actually exists in both the 2.5 GHz and the 12 GHz bands. The 12 GHz band has been the most successful, primarily due to its compatibility with satellite services. The system uses FM, delivering PAL TV signals to densely packed subscribers in apartment complexes [12]. Audio signals are digital NICAM normally located 5.85 MHz above the visual carrier. Wharf Cable is slowly abandoning its 20-channel MMDS network (2.5 and 12 GHz) in favor of fiber optic cable.

In Korea, the Ministry of Information and Communications (MIC) announced in March 1997 that wireless cable TV will be commercially available to the public. The MIC has allocated a 120 MHz block between 2.535 and 2.655 GHz for MMDS and an 800 MHz block for LMDS [29]. For MMDS, the 120 MHz block can be used for standard 6 MHz analog channels or digital services. In mid-1997, there were 29 program providers and four off-air broadcasters. They have to offer at least 33 channels to operate. If the applicant chooses to offer digital television, he may use the 120 MHz block to provide 100 channels. Regardless of the technology used,

whether analog or digital, wireless cable TV services will be a reality in Korea in the near future [29].

#### 5.4 Low-power MMDS (LMMDS)

In Canada, Low-power MMDS (LMMDS) typically uses 1 W per channel, covering a radius of about 12 km [30]. It operates in the same band (see Table 3) as the regular power MMDS (up to 100 W/channel). This technology is practical to use in rural communities, where most households have access to only a handful of TV channels of more or less acceptable quality: typically CBC, a local independent and perhaps an educational station. LMMDS can also be used to extend the coverage for existing cable systems.

The low-power approach is practical and cost-effective for groups of eight channels because it is the number of channels a typical transmitter can combine. If 16 channels are needed, one expensive but reliable approach is to use a separate interfacility link and antenna system per group of eight channels [30].

A typical LMMDS was set up and began transmission April 18, 1991 to serve a rural area located northeast of Timmins, Ontario. A total of 16 scrambled NTSC channels have been offered to the communities of Val Gagné, Monteich, Shillington, and surrounding areas. The area was ideal for LMMDS because of its flat terrain. The transmitting tower, located east of Monteich at more than 300 m above sea level, was 45-meter high. The system uses two transmitters and two antennas with 0.97 W/channel. In November, 1998, there were 175 subscribers [31]. Over 95 % of the household antennas were in LOS with the transmitter. Providing cable TV to 100 % of the 325 households in these rural communities would have taken 150 km of cable products for approximately 1.6 million dollars (CDN in 1990), or about \$5000 (CDN in 1990) per potential household, excluding maintenance costs [30]. Thus LMMDS technology was by far the most cost-effective system for providing 16 new TV services in these rural communities.

## 5.5 Equipment Manufacturers for MMDS

The following is a short list of some equipment manufacturers.

- Incospec is a Canadian systems integrator serving several segments of the broadcasting and cable television industries both with analogue and digital transmission. Incospec specializes in the engineering, supply, integration and commissioning of MMDS, cable TV, fiber optic systems, low power TV LPTV, FM and data broadcast equipment, satellite communications systems and all associated equipment. *Web site:* <http://www.incospec.com>.
- Nortel Reunion Broadband Wireless Access is a “last mile” solution that delivers full voice, data, Internet, and video services at frequencies from 2 GHz to 42 GHz. Reunion allows telecommunications and multimedia network operators to quickly and cost effectively provide high-capacity, point-to-multipoint communications services to new and existing business and residential customers. The Reunion portfolio includes base station equipment with multiple interfaces to the wireless backbone, wireless transmission and reception equipment (transmitters, receivers, transceivers, repeaters), customer premises equipment and integrated network management. *Web site:* <http://www1.nortelnetworks.com/wireless/bwa>.
- ADC Telecommunications Microwave Systems Division has installed thousands of MMDS transmitters for operators in many parts of the world. Their new series of broadband transmitters and boosters offers an effective way to extend coverage. *Web site:* <http://www.adc.com>.
- Andrew Corporation offers a good selection of antennas, transmission lines, and elliptical waveguides suitable for MMDS. *Web site:* <http://www.andrew.com>.
- California Amplifier has a good selection of planar array and reflector antennas, integrated antennas/downconverters stand-alone downconverters, and accessories for MMDS. *Web site:* <http://www2.calamp.com>.
- Comwave manufactures a range of MMDS transmitters from 1 W to 200 W per channel for both analog PAL, NTSC or digital services, as well as on-frequency repeaters, control and monitoring and agile standby transmitters. *Web site:* <http://www.comsyst.com.au/cwave.htm>.
- EMCEE manufactures transmitters for VHF, UHF, LP, and MMDS television. EMCEE is the equipment supplier to the largest MMDS and educational (ITFS) systems in the U.S. and abroad. *Web site:* <http://www.emceebd.com>.

## 6. Local Multipoint Distribution Service (LMDS)

### 6.1 Introduction

LMDS is being proposed in the United States to provide broadband two-way communications including video distribution, teleconferencing, and data services using a cellular system design. It can offer small, medium and large size businesses access to data rates from 6 to more than 50 Mb/s.

The typical system (Figure 2) will entail a Central Office/Head End connected with an optical fiber backbone to many hub base stations. The central office contains all the service access modes such as satellite, local content, Internet and telephone networks links, as well as housing the operational management systems. Each hub covers an individual cell access area, between 2 to 30 km<sup>2</sup>, with broadband data links to thousands of households, schools, and businesses.

Since the access is fully wireless – just like MMDS – the subscriber deployment proceeds fast and at relatively low cost per subscriber, with no under-the-street or on-the-pole cable or optical fiber necessary. It also avoids right-of-way problems, and in the case of cables, the need to “pass” every home.

With the variety of broadband distribution technologies competing for business and consumer communications budgets, it is not obvious which of the potential wireless applications will be implemented first. Some observers feel that services might be offered in this sequence [3]:

#### *Data:*

- Medium businesses, with data needs up to 6 Mb/s;
- Small businesses requiring a low cost data access of fractional T1 capacity<sup>21</sup>;
- Work at home, a rapidly growing market, needing low-cost access to corporate Local Area Networks (LANs) and data rates to 10 Mb/s;
- High-speed Internet, a massive market, waiting for high-speed access to release powerful new applications.

#### *Telephony:*

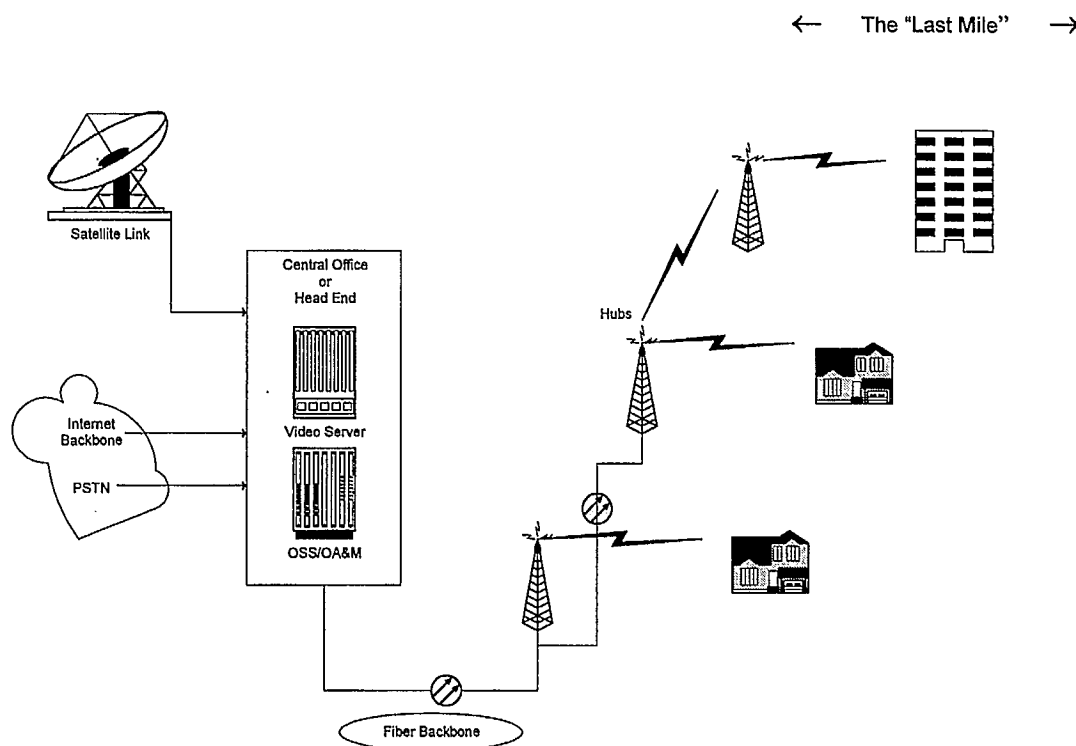
- Business and then residential, integrated voice communications.

#### *Video:*

- Broadcast and narrowcast, conferencing and other interactive video services.

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<sup>21</sup> T1 capacity is 1.544 Mb/s (24 voice channels @ 64 kb/s).



Notes:

*PSTN*: Public Switched Telephone Network;

*OSS*: Operations Support System. A network management system supporting a specific management function, such as alarm surveillance and provisioning, in a carrier network. Many OSSs are large centralized systems running on mainframes or minicomputers.

*OA&M* (also sometimes listed as OAM or OAM cell or OAM&P): Operation, Administration, and Maintenance cell. ATM Forum specification for cells used to monitor virtual circuits. OAM cells provide a virtual circuit-level loopback in which a router responds to the cells, demonstrating that the circuit is up, and the router is operational. OAM&P is Operations Administration Maintenance and Provisioning.

**Figure 2** An overview of LMDS. Adapted from [3]. Drawing by P. Corriveau.

Since LMDS is not linked to any one of the above technologies, it serves more as a very wideband "data pipe" and can be likened to "optical fiber in the sky". It is reasonable to predict that high-data rate links for business will be the particular service that will predominate early on.

## 6.2 Frequency Allocation for LMDS in the USA

### 6.2.1 LMDS Bands in the USA

These systems are to operate two-way between 27.5 and 28.35 GHz, and hub-to-subscriber transmission only between 29.1 and 29.25 GHz (see Table 4). A band between 31.0 and 31.3 GHz has also been designated for LMDS. Incumbent licensees (such as Sierra Digital

31 GHz point-to-point systems used for traffic light control, internal business communications and other similar applications), other than Local Television Transmission Service (LTTS) are protected from harmful interference at 31.0-31.075 and 31.225-31.3 GHz.

The segments beginning at 27.5 and 31.0 GHz have a sole primary allocation and liberal restrictions on radiated power: 30 dBW/MHz for hubs and 42 dBW/MHz for subscribers. There are no restrictions on transmission direction between hub and subscriber stations [32].

On the other hand, since the 29 GHz spectrum is shared with nongeostationary mobile satellite (NGSO-MSS) uplinks (also called feeder links), it is restricted in use to downstream or hub to hub transmissions only. This is to prevent potential interference to these low earth orbiting satellites that might occur if a significant number of subscribers were transmitting simultaneously in the general direction of the satellites. Other restrictions include: 1) LMDS hub antennas are restricted as to upper elevation gain; 2) the aggregate radiated power per square kilometer is restricted, and 3) in some cases coordination is required with MSS earth stations. These restrictions limit the distance between hub and subscriber transmitters and increase system design and administration cost [32].

Block	Bands (GHz)	Bandwidth (MHz)	Applications
A (1150 MHz)	27.50-28.35	850	H-S, S-H and H-H
	29.10-29.25	150	H-S and H-H
	31.075-31.225	150	H-S, S-H and H-H
B (150 MHz)	31.000-31.075	75	Shared with Incumbents
	31.225-31.300	75	

Notes:

H-S: Hub to Subscriber (downstream)

S-H: Subscriber to Hub (upstream)

H-H: Hub to Hub (backbone)

A hub is a centrally located transmitter.

Intervening bands are allocated for the following purposes:

- 28.35-28.60 GHz: Geostationary Orbit (GSO) Fixed Satellite Service (FSS);
- 28.60-29.10 GHz: non-GSO FSS;
- 29.10-29.25 GHz: MSS feeder links;
- 29.25-29.50 GHz: MSS feeder links and GSO FSS;
- 29.5-30.00 GHz: GSO FSS;
- 30.00-31.0 GHz: not used.

**Table 4** LMDS bands in the USA as per the FCC.

In all bands, coordination is required when transmitters are within 20 km of a Basic Trading Area (BTA)<sup>22</sup> boundary. Within 20 km of such a boundary, signals from one system are likely to be detected as interference by receivers on the other side of the boundary. If the interference is strong enough, the system being interfered with may not be able to use a given desired frequency. Rules for coordination between licensees across borders such as U.S./Canada and U.S./Mexico are still under development [32].

### 6.2.2 LMDS Auctions in the USA

On February 18, 1998, 986 LMDS licenses covering 1150 MHz (Block A of Table 4) and 150 MHz (Block B of Table 4) were issued by auction in 493 BTAs in the United States. Each BTA is composed of two above-mentioned blocks, for a total of 1300 MHz [35]-[36]. The auction's multiple-round bidding process ended on March 25 1998, after 26 days of bidding and 128 auction rounds with \$578 million US in revenue [37]. The largest winning bidder was WNP Communications, a well-financed group of venture capitalists, technology companies, and others with an interest in turning LMDS into a profitable venture. WNP purchased 39 A-Block licenses and one B-Block license for over \$186 million US. The licenses cover BTAs around the country, and include Los Angeles, New York, Baltimore/Washington, Atlanta, and Boston<sup>23</sup>. The top three bidders (WNP, NEXTBAND, and WinStar) together pledged more than 60% of the total auction revenue. Virginia Tech was successful at becoming the first public university to win spectrum at an FCC auction. The school obtained A-Block licenses in four southwestern Virginia and eastern Tennessee BTAs. Virginia Tech plans to create a "wireless village" using LMDS service in and around the Blacksburg campus [39].

In an effort to encourage new entrants and small companies, the FCC had not only granted bidding credit, but had also barred phone and cable companies from holding licenses in their local BTAs for three years [36]. The FCC's broad definition of LMDS permits a wide range of traditional and alternative uses. "We are largely leaving it up to the winning bidders to use these opportunities to serve their markets as consumer demand dictates," said FCC Chairman William Kennard in early 1998 [36]. Industry insiders said this is what makes the spectrum so valuable.

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<sup>22</sup> A geographic area, based on the Rand McNally 1992 Commercial Atlas & Marketing Guide, used by the FCC to define the coverage of spectrum licenses for certain services. Each BTA theoretically represents a somewhat homogeneous geographic market. The Trading Area boundaries are on a *county-line basis* because most statistics relevant to marketing are compiled in terms of whole counties. The boundaries were determined after intensive study of such factors as physiography (physical geography), population distribution, newspaper circulation, economic activities, highway facilities, railroad service, suburban transportation and field reports of experienced analysts [33]. The United States is divided into 487 BTAs. The FCC has further defined 6 other BTA-like areas: American Samoa; Guam; Northern Mariana Islands; San Juan, Puerto Rico; Mayaguez/Aguadilla-Ponce, Puerto Rico; and the United States Virgin Islands, for a total of 493 BTAs [34]. The size of the BTA was somewhat arbitrarily set to place each major U.S. metropolitan area into a different BTA [32].

<sup>23</sup> In March 1999, Nextlink Communications, a company founded in 1994 by cellular magnate Craig McCaw, was hoping to purchase the LMDS holdings of WNP for \$695 million US, including \$152.9 million US in FCC fees [38].

On November 6, 1998, Public Notice DA98-2266 announced reauction of 168 LMDS licenses set to begin on April 27, 1999, and sought comment on procedural issues relating to the LMDS reauction. These licenses either received no bids in the original LMDS auction that closed on March 25, 1998 or were defaulted licenses made available for reauction [37].

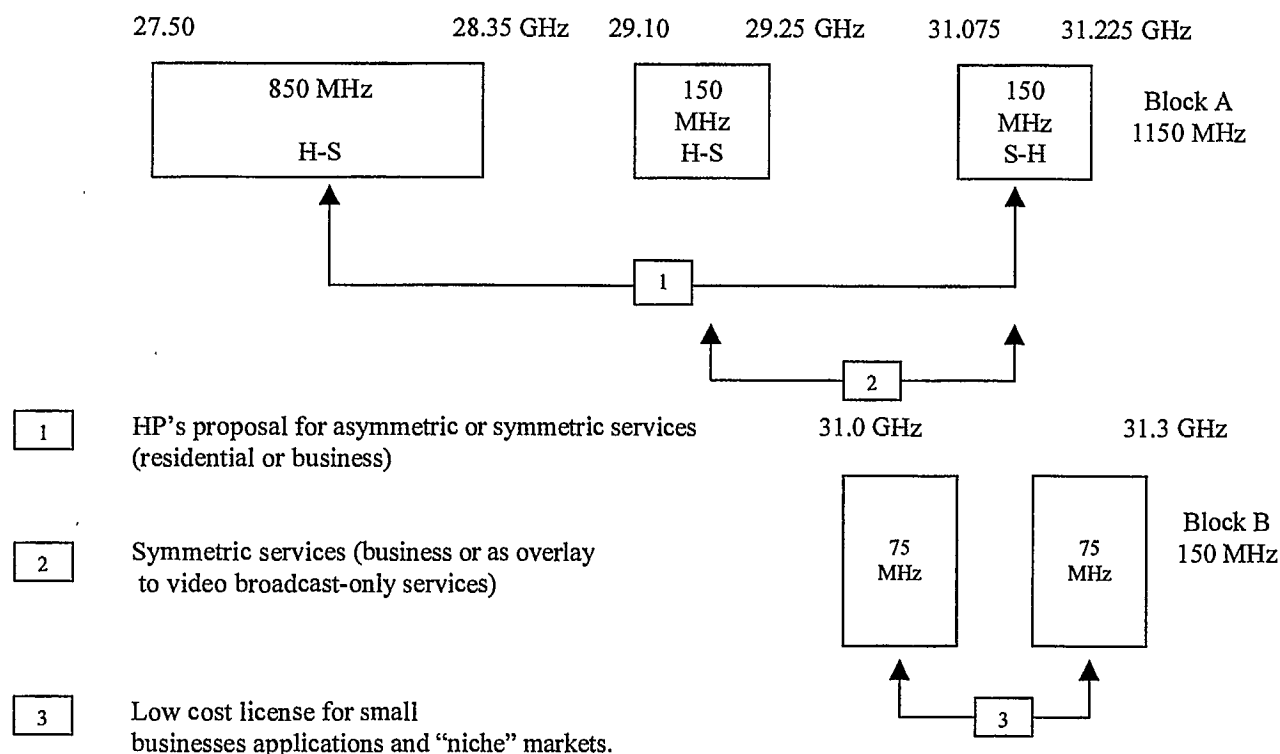
Reauction began April 27, 1999, and ended May 12, 1999 [40]. Public Notice DA99-742, released on April 16, 1999, removed seven licenses from the original list of 168 licenses issued in Public Notice DA98-2266. Thus a total of 161 LMDS licenses were awarded in the reauction of this spectrum; one license in each of 121 Block A BTAs and 40 Block B BTAs. Licenses will be issued for a ten-year term from the initial license grant date. At the end of the 10-year period, licensees will be required to submit an acceptable showing to the Commission demonstrating that they are providing "substantial service" to their service area. Licensees failing to demonstrate that they are providing substantial service will be subject to forfeiture of their licenses.

### 6.2.3 An Example of LMDS Spectrum Utilization

The spectrum shown in Table 4 can be utilized in many ways. In this respect, it is instructive to consider the LMDS system originally designed by Hewlett-Packard<sup>24</sup> (see Figure 3) [3]-[42]. The company wanted to offer broadcast and interactive services. The non-contiguous spectrum provided sufficient separation between the transmit and receive signals to enable isolation between the transmitter and the receiver to be achieved with relatively low cost filtering. This is especially important in order to provide a low cost design for the residential Consumer Premises Equipment (CPE). In a typical deployment calling for multiple services, a portion of the 28 GHz band can be used to deliver broadcast types of services (video and/or data) and the remainder of the spectrum can provide interactive services, such as telephony, data, and video on demand. For example, with QPSK modulation, 60 MPEG-2 compressed video channels can be provided in approximately 200 MHz of bandwidth, thus leaving 650 MHz for interactive data, video, and voice traffic. The asymmetry between downstream and upstream is quite consistent with the normal data flow, particularly for residential applications. The spectrum can also be used to provide symmetric traffic that would typically be required for business applications. In this case, a portion of the 28 GHz band can be paired with the 31 GHz band or, alternatively, the 29 GHz band can be used for downstream traffic and paired with the 31 GHz band for upstream traffic. The spectrum defined by Block B can also be used for business applications or combined with the 31 GHz spectrum of Block A if both licenses are acquired by the same service provider [42].

<sup>24</sup> Lucent Technologies recently acquired the Wireless Broadband Network Division from Hewlett-Packard [36]. Lucent Technologies' LMDS system is called OnDemand. On May 12, 1999, Lucent announced that it is deploying its wireless broadband systems for Techtel of Argentina, a company owned by Techint Group [41].





**Figure 3** LMDS spectrum utilization proposed by Hewlett-Packard in 1997. Adapted from [3].

### 6.3 Standards for LMDS: Two Points of View

#### 6.3.1 The Point of View of The National Wireless Electronic Systems Testbed (N-WEST)

The next paragraphs present the point of view of The National Wireless Electronic Systems Testbed (N-WEST) on the adoption of a standard for broadband wireless systems. These are excerpts from a white paper by Dr. Roger B. Marks, Director of N-WEST and Chair of the IEEE 802.16 Working Group on broadband wireless access standards. The full paper is available on the Word Wide Web at <http://nwest.nist.gov/> [43].

*"(...) The radio spectrum is the key to the wireless information explosion. In a dramatic policy shift, the U.S. government, represented by the Federal Communications Commission, began in 1994 to move spectrum into private hands in a series of auctions. An accompanying shift in regulation policy, from restrictive regulatory oversight to almost complete deregulation, resulted in a virtual "wild West" frontier environment. The FCC's spectrum auction income goes directly to the U.S. Treasury. None of it is held in reserve for supporting the development of the infrastructure in that spectrum. Although personnel at the FCC feel the Commission has a stake in the development of the new spectrum, they have no authority to regulate it and have not yet identified a mechanism to help encourage the development in a positive direction for U.S. industry or consumers. No other federal agency has assumed this responsibility."*

*"What can happen in the open frontier of unregulated spectrum ? In a 1996 address, FCC Chairman Reed Hundt contrasted the advantages of the U.S.'s market approach regarding personal communications systems (PCS) technology to Europe's government-mandated standards. He strongly argued that the U.S. approach would bring the latest technology to market faster and more efficiently. While the U.S. approach did indeed yield a strong showing for American-born CDMA technology, this market approach did not live up to its technological promise, primarily because licensing debt forced licensees to rush into readily available systems. The auction process also left a fractured marketplace with many standards. The result is added cost for component suppliers and system operators and an inconvenient patchwork of incompatible systems faced by travelers who carry their portable telephones out of their home region (...)"*

*"Although the LMDS auction is complete, the launch of LMDS on a wide scale is not imminent. The problem is that many systems remain at the prototype level. The system integrators have not yet answered many of the key technical questions that influence basic system design choices. When they have answered such questions, the solutions have generally been proprietary."*

*"In order to make well-founded technical decisions, system designers need good performance data or, failing that, the combination of reliable system simulation tools and reliable component level measurements. At present, none of these tools is widely available."*

*"The National Wireless Electronic Systems Testbed (N-WEST) is intended as an experiment in how federal agencies within the U.S. Department of Commerce can coordinate with commercial enterprises to accelerate the development and standardization of superior wireless technology. The experiment will focus on the spectrum for Local Multipoint Distribution Service (LMDS), auctioned in February and March of 1998."*

*"N-WEST will seek as partners the LMDS license holders, systems manufacturers, and component suppliers. The technical thrust of the testbed is to evaluate the performance of prototype systems and the dependence of that performance on modulation, coding, propagation, interference, components, and other critical factors. By exposing key industry players to the same sets of data, N-WEST intends to provide the industry with a sound technical basis for consensus operational standards. At the same time, correlating system performance to component-level characterization carried out in federal laboratories will provide the data needed to establish realistic component specifications that ensure functionality without building in excess costs due to overspecification."*

*"The National Wireless Electronic System Testbed (N-WEST) seeks a middle ground between outright regulation and outright chaos by forging industry consensus standards in wireless communications. Such consensus will be driven by technical considerations illuminated by measurements."*

### 6.3.2 The Point of View of Bosch Telecom, Inc.

The next paragraphs present the point of view of Bosch Telecom, Inc. on the adoption of a common high-level band plan for LMDS in the U.S. These are excerpts from a paper entitled "Recommended LMDS band plan for systems in the United States," by S. Marin, D. Weiner, and J. McCoy presented at the 1999 IEEE Emerging Technologies Symposium, Richardson, Texas on April 12 [32].

*"(...)The licensing methods and policies for LMDS systems differ from those for conventional point-to-point systems which normally use channelized band plans and are authorized on a link-by-link basis".*

*"The advantage of these open, flexible plans is that licensees are free to select the channel plan that best suits their local market, equipment capability, and business plan. Further, in a block-allocation scheme, licensees may ongoingly adjust channel plans to meet changing market conditions. A licensee may use equipment from a single supplier throughout a license area to minimize logistics cost and assure tight control on intra-system self-interference. Alternatively, equipment from different suppliers may be used in portions of the band to optimize delivery of specific services. Subscribers, licensees, and administrations all benefit from block spectrum and geographic area licensing of point-to-multipoint systems. Regulatory agencies have less administrative burden, licensees have more freedom to provide what is needed in their area, and last but not least, subscribers have access to appropriate state-of-the-art services."*

*"The frequency of each transmitter within the LMDS system is chosen using algorithms that optimize delivery of desired services. The chosen frequency must also maintain low levels of interference to receivers in other cells. Intra-system self-interference is a key constraint in the design and operation of these systems (...)."*

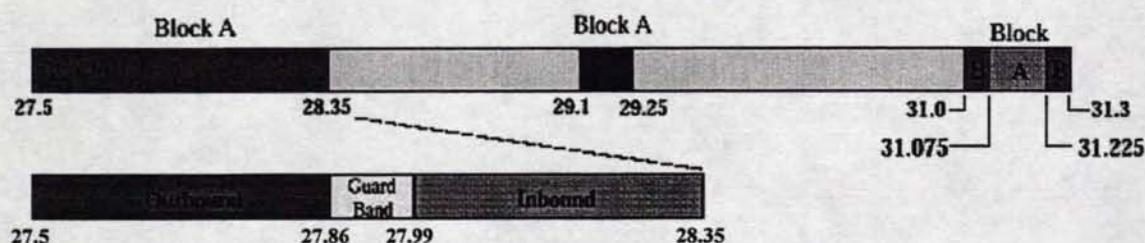
*"Band planning can be done at various levels. At the highest level, it can be simple agreement on which half of the band is used for hub or subscriber transmissions and where transmit-to-receive transition bands are placed. At a more detailed level, upstream and downstream segments may be independently partitioned into channels, and the resolution for minimum channel spacing may be set. At a very detailed level, conventional channel arrangements can be stated that define channel bandwidth, bandwidth multiples, duplex spacing, and sometimes antenna polarization. Any plan must be designed carefully to avoid leaving spectrum unusable. Licensees must be allowed to deviate from a defined plan to address special markets".*

*"(...) Interference may change dynamically as station transmissions and circuits within the links turn on or off and bandwidth assignment adapts to new calls. At times, a system may need to avoid certain frequencies because of excessive interference. Robust algorithms for dynamic frequency assignment that consider interference mitigation and algorithms for interference detection are likely to be deployed only after experience is gained operating point-to-multipoint systems in a high-interference environment. Rather than constrain these algorithms to conventional channel plans which could result in more unusable channels, it seems better to remain flexible and allow development of optimum algorithms that maximize spectrum use."*

*"(...) In a large license area requiring several hubs for complete coverage, the licensee is self-motivated to reuse the spectrum in order to maximize the services delivered to customers. As long as the frequency block allocated is approximately 1 GHz, point-to-multipoint systems provide competition to high-bandwidth wired alternatives that use coax or fiber. The flexibility to use a large block of spectrum in a way that matches local market demand results in the lowest possible cost to deliver services and the highest potential revenue from those services."*

*"If there is a sudden change in the business mix within a particular area, a provider must be able to move quickly. Block band plans greatly facilitate the process. Perhaps a large customer moves out of or into the area. The provider must be able to readily supply the greatest array of services priced competitively with other options available to the customer. This scenario is ideal for point-to-multipoint LMDS systems. Block band plans also allow great flexibility in the case of a market shift from symmetric services to asymmetric or one-way services. In such a case, a conventional symmetric band plan may cause channels to go unused."*

Based on these considerations, Bosch Telecom proposes the following band plan (see Figure 4 and also Table 4) that can support many LMDS market situations:



**Figure 4** LMDS bandplan suggested by Bosch Telecom for systems in the U.S. All frequencies are in GHz. Adapted from [32].

*"(...) For the large Block A segment beginning at 27.5 GHz, the lower portion of the band is used for hub-to-sub transmissions, and the upper portion of the band is used for sub-to-hub transmissions. The choice of upper versus lower (hub versus sub) frequencies is now fairly arbitrary, but it has its legacy in preliminary band plans issued by the FCC during the LMDS rule-making process. The original band plans were designed to avoid hub transmissions in certain portions of the band. As a result of band segmentation and negotiated rule-making, the arguments about subscribers or hub transmission placement are now moot points, but altering equipment to reverse the transmission sub-band requires substantial time and investment."*

*"A transmit-to-receive transition band of nominally 130 MHz is necessary. Analysis has shown, however, that a transition band of only 120 MHz may be feasible with moderate risk of receiver desensitization."*

*"(...) The 29.1 and 31.75 GHz segments are ideally suited for access links and point-to-point backhaul links to node sites."*



*"For Block B, symmetric utilization pairing the lower and upper portions of the band is suggested. The lower portion is recommended for hub-to-sub transmissions and the upper portion for sub-to-hub transmissions. The Block B segment is ideal for point-to-point links and could support point-to-multipoint systems in a low-capacity deployment. The outstanding issue here is widespread international adoption of this plan. Such adoption would raise market demand and rationalize development of a unique product."*

*"The above band plan is a high-level framework that can aid in frequency coordination. It can also allow systems between adjacent license boundaries to be more closely located or operate at higher power near the boundary. Some cost reduction may also occur through economies of scale since more equipment will be manufactured for a common plan than for multiple plans. At the intermediate level of a plan (sic), planning parameters such as carrier center frequencies, if done on a fairly fine resolution such as 1 MHz, may aid development of synthesizers. But channel bandwidth and the pairing of upstream versus downstream channels needs to remain dynamically adjustable by the radio equipment to prevent wasting spectrum. At the detailed band planning level, spectrum would be wasted if rigid duplex spacing and only symmetric channel arrangement were invoked."*

*"As another argument against detailed channel plans, note that adaptive frequency assignment algorithms are likely to evolve especially in the upstream path. (...) Frequencies may be assigned on a per link, per call, per packet or per cell basis. Some frequencies may contain excessive interference (permanent or temporary) and might need to be tagged as unusable or usable only by certain subscriber stations that can overcome the interference without imbalancing the interference budgets elsewhere in the system."*

## **6.4 Challenges and Advantages at 28 GHz**

Clearly, there are significant challenges associated with deploying multipoint systems at 28 GHz. Section 3 of this survey addressed, among other things, the issues of free-space path losses increasing with the square of the frequency and rainfall attenuation. Moreover, virtually everything represents an obstacle at these frequencies so coverage becomes an issue. Deployment of point-to-point radios at 38 GHz has proven that reliable links can be achieved at millimeter wave frequencies. However, there are significant differences associated with a multipoint local access system. Point-to-point installations have the obvious advantage of being able to choose the location of both ends of the link. This enables the planner to assure a clear line of sight is achieved. In a multipoint system, only the hub location can be strategically selected. The subscribers are in fixed locations and the CPE antennas would be mounted at or near the roofline as opposed to being mounted on towers.

On the other hand, there are some advantages in working at these frequencies. Most importantly, of course, is the availability of the spectrum. It is inconceivable to imagine that it would be possible to free up over 1 GHz of spectrum at lower frequencies. Another advantage is that high gain antennas are relatively small. It is possible to design a 35-dBi antenna having a

beamwidth of less than 3 degrees with a diameter smaller than 30 cm [42]. The high path losses and rainfall attenuation dictates smaller cell sizes, this translates to lower hub antenna heights to clear the first Fresnel zone and, with fewer subscribers per cell, a higher data rate per subscriber. Higher data rates means more services can be provided over the network and this, in turn, generates more revenues for the service provider.

## 6.5 LMDS Network Architecture

Just as there are numerous ways to utilize the spectrum allocated for LMDS, one can use many different approaches for the LMDS network architecture. For illustrative purposes, we will examine once again Hewlett-Packard's original system design [3], [42].

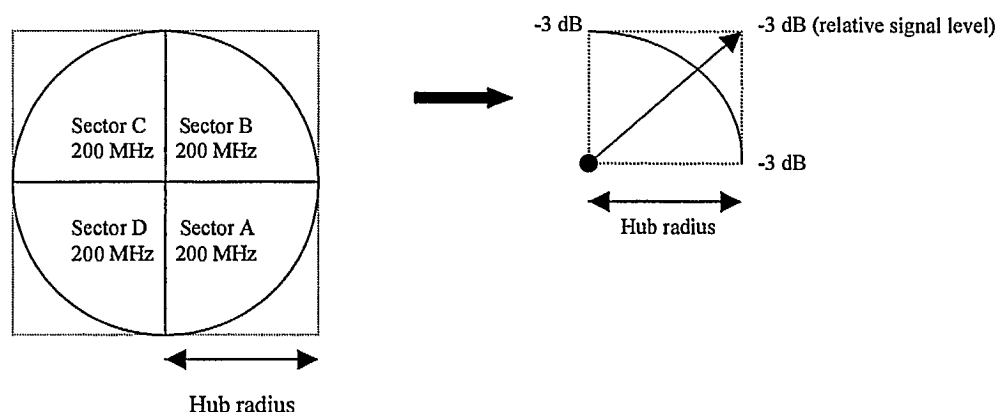
The most likely LMDS system will be a microcellular configuration, with hub spacing ranging, on the average, from 2 to 6 km. In any given environment, the cell size will be dependent on a number of variables. One of the most important one is the power level that can be realized in the CPE at an affordable cost. This power level determines the upstream link margin. Other considerations include:

- Terrain: hilly or flat;
  - Number and types of obstacles: foliage or buildings;
  - Right-of-way: availability will determine where the hubs can be placed and where the backbone may be located. These placements may not be optimal;
  - Ease of access to right-of-way: the cost might be significant;
  - Household densities will vary greatly between urban, suburban, and rural. Different deployment strategies will apply to each;
  - Infrastructure sharing: major savings are possible when facilities and right-of-way are shared;
- Local regulations: most service providers are familiar with the pluses and minuses of working with municipalities.

### 6.5.1 Hub

For the base station (hub), the leading alternative for network architecture is a 90-degree (azimuth), 5 to 7 degree (elevation) sectorized antenna pattern. This represents a good compromise between the cost of the hub's electronics, the link margin, frequency reuse and cell-to-cell interference. The hub receivers are integrated with the transmitters, but use a separate 90-degree (azimuth) antenna. It is also possible to increase the number of sectors to achieve higher frequency reuse and higher data capacity. Increasing the number of sectors adds capacity but of course increase costs, since the transceivers have to be replicated in each sector. It is also possible to use a higher number of sectors for the receiving side only to increase the upstream capacity. The resulting higher gain receiving antennas will relax the requirements in the CPE transmitter power.

For any one sector, the antenna patterns can be designed to provide a near-square pattern, as shown in Figure 5, since the locus of points of equal signal strength do indeed come closer to approximating a square than they do a circle [4].



**Figure 5** Hub frequency plan originally proposed by Hewlett-Packard. Adapted from [3].

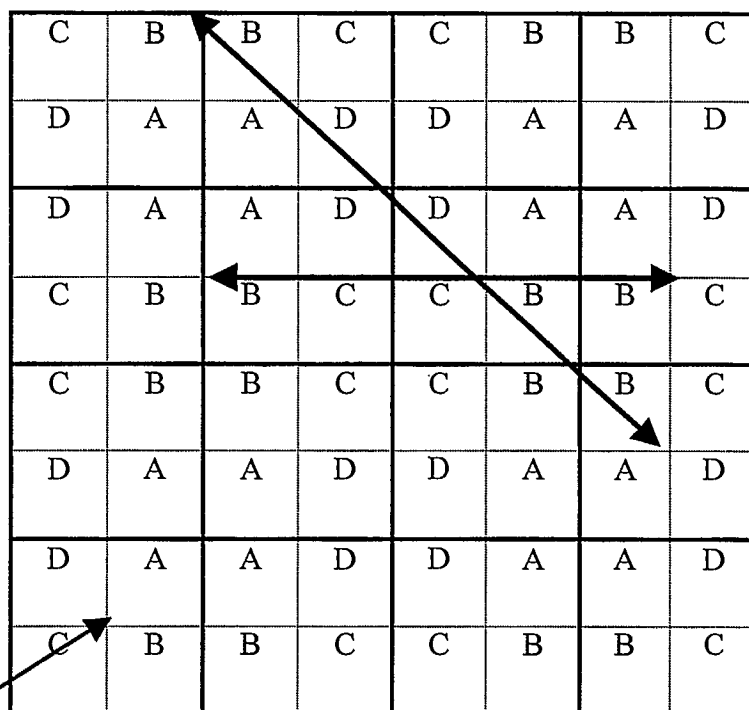
Each of the four sectors is assigned a different frequency, A to D, or, as explained later, a different polarization. The hub antennas are designed for a gain of approximately 15 dBi, providing an EIRP of  $-9$  dBW/MHz.

The hub antenna height can be relatively low, typically in the order of 15 to 25 meters, since in most cases hubs will be spaced at intervals ranging from 2 to 6 km. Clearly, to achieve high coverage, “the higher the hub antenna the better.” However, one will have to contend with local zoning restrictions and adverse public opinion regarding the impact these hubs will have on the neighborhood. A height of 15 to 25 meters was considered reasonable by Hewlett-Packard since it is quite consistent with the heights of street lights and telephone poles already in place [42]. It is interesting to note that hub spacings for LMDS are quite similar to antenna spacings for Personal Communications Systems (PCS) installations. This provides an opportunity to share some of these sites to minimize adverse neighborhood impact as well as reduce infrastructure costs.

The alternating frequency assignment shown in Figure 5 results in the overall layout of Figure 6. In this way, the multiple cells and their repeating patterns assure that potential interference of adjacent cells is minimized and that potential interferers are separated by five cell radii: a frequency reuse of one is thus achieved. On the other hand, a frequency reuse of two can be achieved by using polarization discrimination: the spectrum is used twice in each hub<sup>25</sup>. This can be accomplished by assigning half the spectrum to each sector [42]. In most environments, some depolarization will occur, so the more conservative approach is to depend on frequency diversity rather than polarization diversity between sectors [3]. For example, frequency re-use

<sup>25</sup> Referring to Figure 5, instead of having e.g. CBAD (clockwise) for the upper left hub, one would use AH, BV, AV, and BH.

between sectors may be precluded for QAM, as the achievable cross-polarization isolation may not be sufficient.



*The hub is located at the center of each square*

**Figure 6** Alternating frequency plan originally proposed by Hewlett-Packard for adjacent hubs provided five radii separation. Adapted from [3].

### 6.5.2 Customer Premises Equipment (CPE)

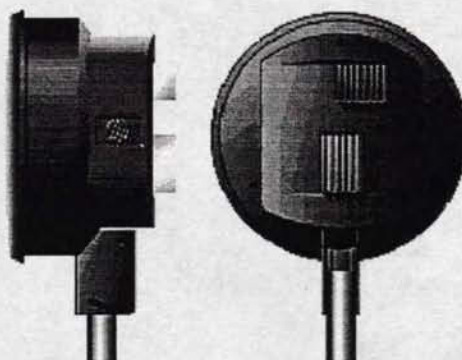
Subscriber unit antennas can be designed with beamwidths less than 3 degrees and a gain of 35 dBi, and be nevertheless relatively small and low cost. Considering that these highly directional antennas are pointed straight at their dedicated hub antenna, and that the adjacent cell subscriber antenna on the same frequency is pointed 90 or 180 degrees in the opposite direction, the next available interference-causing cell is about 5 cell radii away, and even there, probably aimed off boresight more than enough to be outside the CPE antenna pattern.

It is desirable to mount the CPE antenna unit as high as possible to maximize LOS, but it is equally important to consider homeowners' acceptance. Hewlett-Packard assumed that the CPE antenna unit would be mounted no higher than the roofline<sup>26</sup> and given the small size of the

<sup>26</sup> From measurements made at 28 GHz by Hewlett-Packard [47], the difference between the path losses for the receiving antenna at roof-line and above roof-line is small when the distance is less than 1 km but becomes significant (more than 10 dB) for paths longer than 1 km.



equipment, it is quite inconspicuous at that height [42]. CPE antenna heights are usually less of an issue for businesses and MDUs. Figure 7 shows a typical 30-cm CPE building-mount antenna.

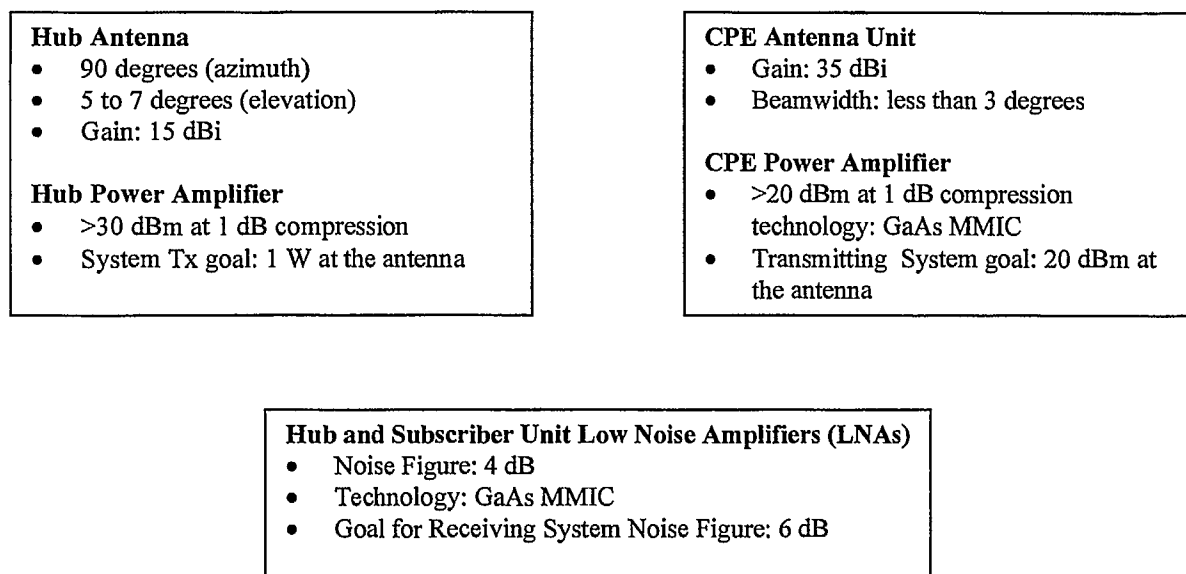


**Figure 7** CPE antenna with a compact profile, as originally proposed by Hewlett-Packard. From [3].

The CPE antenna unit contained all of the microwave hardware and was connected to the indoor unit via a single  $75\ \Omega$  coaxial cable which carries the downstream IF, upstream IF and DC to power the antenna unit. It operated over the full downstream and upstream spectrum. Its transmitter used a 100 mW GaAs MMIC amplifier [42].

The CPE also included an indoor unit (a modem) designed to process a single 40 MHz channel downstream, with a capacity of about 52 Mb/s, and a 2 MHz channel upstream with a capacity of about 3 Mb/s. This indoor unit provided the interface to the computer, telephone, or television. A separate MPEG-II decoder would have been required at each TV set. Modem performance and cost were related to the data rate requirements, whether large or small business or residence.

The key microwave component requirements for Hewlett-Packard's original LMDS design are summarized in Figure 8.



**Figure 8** Key component requirements for Hewlett-Packard's original LMDS design. Adapted from [3].

## 6.6 Digital Modulation Schemes Suitable for LMDS

In order to maximize the system channel capacity, Hewlett-Packard's designers considered digital modulation schemes with high spectrum efficiency, such as 16 QAM or 64 QAM [3]. However, since the more common applications will most likely require the highest data integrity, it was determined that in the interest of link robustness, the initial systems would have used the QPSK format. Moving to more spectrally efficient schemes like 16 QAM in the future – as the market matures and the need for higher capacity shows itself in selected areas – was considered an easy migration as higher performance microwave components come on line. The CPE was pre-designed to demodulate various digital modulation formats, like 16 QAM, the electronics needing only a minor re-programming. The lower initial costs supported the smaller initial capacity.

Table 5 compares spectrum efficiencies for various modulation schemes. It is important to note that those higher-order modulation formats also require additional back-off of the transmitter power amplifier to account for higher peak-to-average ratios. Moreover, QAM components must be designed with better phase noise performance, since it plays a more significant role in signal integrity. Power back-off decreases the excess link margin, while signal sources with better phase noise performance mean higher costs [3]. As can be seen from Table 5, QPSK is more robust to phase noise than higher order schemes such as QAM but requires more spectrum to transmit the same amount of information.

Modulation Scheme	Spectrum Efficiency (b/s/Hz)	Relative Power Requirements (dB)	Linearity Requirements (Peak-to-average ratios) (dB)	Phase Noise (Relative) (dBc)
QPSK	1.2-2	0 (Ref.)	5	0 (Ref.)
8 PSK	2-3	5	9	-6
16 QAM	2.5-3.5	7	13	-10
64 QAM	4.5-5	13.5	20	-15
256 QAM	5-7	20	27	-25

**Table 5** Comparison between various digital modulation schemes suitable for LMDS [44].

Modulation Scheme	Channel Coding	C/N for BER = $1 \times 10^{-6}$ (dB)	Spectrum Efficiency (b/s/Hz)	Standard or Manufacturer	Comments
QPSK	1/2	7.2	1.00	EF Data, Radyne, ComStream, etc.	Satellite modem. For various speed LMDS data service
	3/4	10.6	1.50		
	7/8	12.3	1.75		
	1/2 + R-S	6.2	0.92	DVB-S, DigiCipher; SA, GI, TeeCom, TVCom, etc.	For Digital Television broadcasting on LMDS
	3/4 + R-S	9.5	1.38		
	7/8 + R-S	11.0	1.61		
8 PSK	2/3 + R-S	9.3	1.84	EF Data	Satellite modem. For high-speed data, high spectrum efficiency on LMDS.
16 QAM	5/6 + R-S	12.5	2.30		
	3/4 + R-S	13.1	2.76		
	7/8 + R-S	15.4	3.23	DVB-T, OFDM-6 DVB-C, DAVIC-C DVB-T, OFDM-6 DVB-C, DAVIC-C	Possible Point-to-Point LMDS service
	1/2 + R-S	9.8	1.84		
64 QAM	R-S	19.2	3.69		
	2/3 + R-S	17.5	3.69		
	R-S	25.5	5.53		
256 QAM	R-S	31.8	7.37		
8 VSB	2/3 + R-S	17.5	3.69	ATSC A/53	For high-speed data or point-to-point LMDS service

**Table 6** Summary of different modulation schemes with FEC for LMDS Adapted from [45].

For completeness, Table 6 presents a summary of different coding and modulation schemes with their estimated C/N for a BER of  $1 \times 10^{-6}$ , their spectrum efficiencies, related manufacturers or standards, as well as comments on their suitability for LMDS/LMCS service [45]. Soft-decision decoding is assumed throughout for convolutional or Trellis Coded Modulation (TCM) decoding. A Reed-Solomon code (R-S (204, 188)) is also assumed throughout, except for the 8 VSB system where an R-S (207, 187) code is implemented. A

margin of about 1.5 dB was added to the C/N values to account for signal fading and scintillation<sup>27</sup>.

From Table 6, it appears that concatenated channel coding with convolutional (or TCM code as the inner code and R-S as the outer code) is the most suitable coding scheme for LMCS implementation. QPSK, 8 PSK and 16 QAM are the most suitable modulation techniques. Some tests have also been carried out at CRC with Coded Orthogonal Frequency Division Multiplexing (COFDM), a multicarrier modulation scheme (See Section 7.4 of this survey).

## 6.7 Some Aspects of LMDS Economics

According to Hewlett-Packard [3], LMDS is particularly attractive at low take rates, since the hub infrastructure is economical at installation time and the CPE costs are incurred only as the subscriber signups increase.

In order to arrive at an optimal hub layout for an LMDS network, two variables are of considerable interest [47]:

- *Coverage*: It may be the percentage of households or businesses covered, depending on the market segment being targeted. In general, one would want a hub deployment that maximizes coverage;
- *Infrastructure costs*: Costs needed to get one into business of providing broadband wireless services to a particular set of customers. Obviously, a service provider is interested in minimizing these costs for a desired coverage. Infrastructure costs can be segmented into three areas:
  - 1) *The head-end costs*, including the cost of the central office, the cost of the FCC license, the cost of the head-end equipment, modems, etc., and the cost of engineering and network planning;
  - 2) *Backbone costs* include the optical fiber (see Figure 2), which may be above or below ground and/or in some cases, wireless point-to-point links. The cost of the optical transducers have to be included as part of the fiber backbone;
  - 3) *Hub costs* include LMDS transceivers, the antenna and the mast, installation costs and, when appropriate, the cost of site acquisition. If the site is leased, it would show up as an operational cost, rather than a capital infrastructure cost.

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<sup>27</sup> *Scintillation fading* occurs when an air mass (e.g. warm air, dried land breeze, and supercooled clouds) whose refractivity index differs from that of the surrounding air passes transversally across a radio path. The received signal then fluctuates around its mean value. These variations can be several dBs in amplitude and are more rapid with higher radio frequencies. This is caused by abnormal refraction on a portion of the radio path [46].

Hewlett-Packard conducted an analysis of the above infrastructure costs vs. hub spacing [3]. The results are intuitive: a closer hub spacing results in higher infrastructure costs, but at the same time results in more households covered, which reduces the per-household costs. As the hub radius increases, costs come down until the coverage gets poorer due to signal falloff, then per subscriber costs start increasing. For example, let us consider the following conditions: a household density of 1000 households per square km, a service area of 16 by 16 km, an underground optical fiber backbone, rainfall of Region C<sup>28</sup> with 99.9 % availability, excess losses<sup>29</sup> varying as  $1/r^4$  with hub radius  $r$  and a hub antenna height that varies with hub spacing from 15 to 30 meters. Using these parameters, Hewlett-Packard determined that the optimal hub spacing for maximum return on investment was about 4 km [3]. In that case, hub spacing for *maximum coverage* would be 1-2 km, while for minimum infrastructure costs, hub spacing would have to be more than 6 km. LMDS systems intended for regions with *high* rainfall conditions, like Miami, Florida – which are less than 10 % of the geographical area of the U.S. – would require configurations with smaller cell sizes. More attention should also be given to geographical features of the region.

## 6.8 Other LMDS Systems

### 6.8.1 CellularVision

In 1991, *CellularVision*<sup>30</sup> (See <http://www.cellularvision.com>) got a commercial license for a limited LMDS deployment at Brighton Beach, New York [48]. In December 1995, the FCC approved CellularVision's plan to build 34 additional transmitter sites to provide broadcast video and high-speed Internet access to the 3.2 million households in the New York Primary Metropolitan Statistical Area (PMSA)<sup>31</sup>. There were approximately 528,000 households in the area covered by the company's two operational transmitters. The company claimed 12,500 subscribers by mid-1997 [33], [49]. This frequency modulated (FM) analog system supported forty-nine 20 MHz wide video channels. The 49-channel transmitter was built in 1992 by Dudley Lab (See <http://www.dudleylab.com>). Two-way communications to businesses, under experimentation in the downtown Manhattan area [49], was done using signals of orthogonal

<sup>28</sup> Region C includes cities like San Francisco, Sacramento (California), Portland (Oregon), Seattle (Washington) and Vancouver (British Columbia). Rainfall losses are typically 1.62 dB/km for 99.9 % availability and 9.4 dB/km for 99.99 % availability (see Table 2).

<sup>29</sup> Excess losses are losses over and above what would be predicted by the  $1/r^2$  free-space propagation model and by rainfall attenuation. These excess losses can be caused by diffraction, ground reflections and path obstructions [47].

<sup>30</sup> CellularVision is also the designation of the patented technology for LMCS/LMDS, developed by American inventor Bernard Bossard. Bossard, who had worked with microwaves for the military, believed he could make point-to-multipoint video work in the 28 GHz band. He wasn't interested in sending high powered, low frequency signals over long distances. Instead, he focused on sending low powered, high frequency signals over a short distance. In 1986, Bossard received funding from Shant Hovnanian and his father Vahak, the northeast seaboard real-estate moguls. Together, they formed CellularVision. CellularVision then spun off the technical rights to their techniques for LMDS into a separate subsidiary, CT&T, which would license CellularVision technologies [33].

<sup>31</sup> A geographic area defined by the Office of Management and Budget and modified by the FCC. There are 306 MSAs in the US, including New England County Metropolitan Areas and the Gulf of Mexico Service Area (water area of the Gulf of Mexico, border is the coastline) [34].

polarization. Each cell covered a 5 to 8 km radius area. Interference between cells was avoided by using cross-polarized signals. CellularVision's data service was delivered over a 5 Mb/s channel, divided into ten 500 kb/s shared frequency slots, using telephone links for the return channel at 28.8 kb/s.

Video programming was downlinked from geosynchronous satellites to the CellularVision head-end facility, where local broadcast transmissions were also received. At the company's master control room, the programming signals were then amplified, sequenced, scrambled and upconverted to 28 GHz. The CellularVision transmitters and repeaters then broadcasted a polarized FM signal in the 28 GHz spectrum over a radius of up to 5 km (three miles) to subscribers and to adjacent cells for transmission. A 6 5/8 inch square, highly directional, flat plate, window, roof, or wall-mounted antenna received the scrambled signal and delivered it to the CellularVision addressable set-top converter, which decodes the signal. The subscriber received 49 channels of high quality video and audio programming, including pay-per-view and premium channels.

During the summer of 1998, CellularVision disaggregated 850 MHz of its New York City LMDS license and sold the spectrum to WinStar Communications, a major developer of broadband millimeter wave point-to-point and point-to-multipoint systems [49]. The sale followed CellularVision's reported decision to investigate ways of moving away from its business, presumably as a result of the company's limited success at marketing LMDS [50]. WinStar paid CellularVision \$ 32.5 million for the New York spectrum, and will lend an additional \$ 5.5 million to the company. Proposed reasons [50] for the low subscriber count include competition from more established services such as cable television and the LOS requirements between the subscriber's terminal and the LMDS base station. Moreover, some analysts believe that LMDS is best suited for broadband data distribution to business users, rather than video program distribution to residential areas. Critics have also pointed out that digital transmission techniques should be employed, rather than analog [50].

### **6.8.2 LMDS in Venezuela**

In 1992, Dudley Lab also built the first 28 GHz system to provide LMDS television, in Caracas, Venezuela. This system, set up by CellularVision, called Viva-Vision, has 36 channels of television programming. Later that same year, Dudley Lab built TV-Cellular in Valencia, Venezuela, with 48 channels of television operating at 29 GHz. Both of these systems are analog FM and are providing continuous service to more than 5,000 subscribers each.

### **6.8.3 MultiPoint**

Texas Instruments (TI) [44], [51] developed MultiPoint, a LMDS architecture supporting two-way digital services including telephony, data and video for business and residential subscribers. The MultiPoint system provided connectivity to other networks including the Public Switched Telephone Network (PSTN), ATM packet switched network, video networks,



private networks, the Internet, etc. These interfaces were part of the hardware and the software designated as *base equipment* [51]. The base equipment also included modems, multiplexers, demultiplexers, upconverters, downconverters, and optical modems. It was connected to the *node equipment* via optical fiber cable to provide two-way transmission capability between the two elements at distances up to 40 km.

The base equipment consisted of optical modems, upconverters, millimeter wave transmitter, receivers, and antennas. The node was usually located on top of either a tower or a building and provided multipoint communications with subscribers via a two-way 28-GHz link [51].

The CPE consisted of three major pieces of equipment: the Roof Unit (RU), the Network Interface Unit (NIU), and the Set-Top Box (STB). The RU provided the 28-GHz receiver/downconverter and the upconverter/transmitter as well as the 30-cm diameter antenna for the MultiPoint link. The RU was connected to the NIU via coaxial cable at an L-band IF frequency. The NIU provided the demodulation, demultiplexing, and interface functions for the downstream telephony and data service as well as multiplexing and modulation for the upstream telephony and data service. The STB was connected to the RU or NIU at IF and provided the video demodulation and video decompression. In addition to these basic functions, the system also provided network management functions such as provisioning, alarm monitoring and reporting, network control, etc [51].

Each cell was divided into sectors (four, for example) to make two-way communications available to up to 16,000 subscribers per cell. The system architecture provided for interface to the North American digital hierarchy (DS-0, DS-1, etc.), ITU-T standards (E1, E3, etc.), video standards (MPEG-2, NTSC, PAL, etc.) and SONET (OC-1 @ 51.84 Mb/s and OC-3 @ 155.52 Mb/s). MultiPoint implemented a combination of Frequency Division Multiplexing (FDM), Time Division Multiplexing (TDM) and Frequency Division Multiple Access/Time Division Multiple Access (FDMA/TDMA) techniques [51].

Using QPSK, TI claimed that the system was able to deliver twelve MPEG-2 TV channels or 464/480 DS-0 circuits @ 64 kb/s each, or 16 E1, or 576 DS-0, 24 DS-1/T1 circuits @ 1.544 Mb/s each in a 40 MHz bandwidth. Upstream MultiPoint offered 24 DS-0, one DS-1 in a 2.5 MHz bandwidth. Texas Instruments claimed that 100 video channels (3.2 Mb/s) and 2300 DS-0 could be provided in each sector with 1 GHz bandwidth. One thousand voice channels, 56 video programs, and 200 video-on-demand channels could be made available in each sector of a cell. Downstream channels were 30 or 40 MHz wide. Upstream could be, for example, 2.5-MHz wide and there could be 192 carriers available in one sector [51]. There were about 10 times more narrow upstream channels than wide (30-40 MHz) downstream ones, but they shared about one half of the total bandwidth.

Tests in Dallas in 1994 demonstrated the possibility of a coverage as high as 98% (transmitter power: 20 dBm; transmitting antenna: horn with a gain of 23 dBi; receiving antenna: a 35-dBi dish for a range 0.4 to 4.8 km (0.25 to 3 miles)). Texas Instruments claimed that 1 W per RF channel allowed a 5-km range with QPSK.

Since that time, that division of Texas Instruments has been bought by Bosch Telecom [52], who is now offering the SpectraPoint system discussed in the next section.

#### 6.8.4 SpectraPoint

Bosch Telecom's LMDS product, SpectraPoint [52], formerly called MultiPoint, is a fully integrated network that supports the numerous service offerings targeted for the LMDS market, including telephony, high-speed data and multimedia applications. The SpectraPoint family includes both point-to-point and point-to-multipoint wireless access products, which offer the service provider flexibility in the use of both dedicated and shared access solutions. The product is managed by Bosch Telecom's Open NSU, a highly flexible network management system that provides seamless integration with management of other systems and network elements. SpectraPoint service offerings span business modeling, market analysis development, installation and network design, and integration.

Control of the system is typically accomplished through interfaces at the point of presence. The Network Management Software within a Network Operations Center is used to monitor the LMDS equipment. This software receives alarms and allows for the commanding and provisioning of the LMDS equipment. In addition, the LMDS equipment is locally accessible via Craft Interface Devices (CID) through which Service Controller software manages and operates the equipment.

The base equipment is configured in a modular fashion allowing deployment for virtually any number of circuits per sector.

Each sector of the node consists of a Sector Radio Interface Unit, receiver module, and transmitter modules. Each sector has a 90°-azimuth field of view with a range of 0.2 km to 5 km. In the initial configuration, the sector could be deployed with two transmitters, (Pilot Tone and Content) and one receiver. Additional capacity upgrades to the Sector can be performed easily by adding additional transmitters or spares as required.

The node equipment is modular by design and can be deployed in a minimum configuration with capacity added as required by the service provider. The transmitter modules can be added individually as capacity needs dictate.

The system utilizes four 90-degree sectors per node by exploiting polarization diversity to achieve complete frequency reuse within a node. Each sector is independent and uses the same frequency plan as the other three sectors. This frequency reuse provides a 4:1 advantage over non-frequency reuse systems. The NIU at the CPE provides a standardized interface to common premises equipment, such as channel banks, Private Business Exchanges<sup>32</sup> (PBX's) and Integrated Access Multiplexers.

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<sup>32</sup> Privately owned telephone switching computers used to interconnect phones in a building and provide access to outside lines provided by common carriers. PBXs offering both telephone and data services are now available [2].



LMDS offers always-on high-speed data rates, which enable fast Internet access and seamless PC-to-PC connectivity across the public Wide Area Network (WAN). With no need for cables, rapid, targeted, and scalable deployment is assured. Other applications like commercial data services, interactive games, and electronic commerce can be added as needed.

## 6.9 LMDS Showcases, Field Trials, and Experimental Systems

Please note that some European field tests are also described in Section 8 of this survey.

### 6.9.1 The LMDS Multimedia Dallas Showcase

Bosch Telecom, Inc. created and is managing, in collaboration with Frazier/King Media<sup>33</sup> and nine industry leaders<sup>34</sup>, an advanced broadband showcase called the LMDS Multimedia Dallas Showcase (see <http://www.lmds-showcase.com/>). The Showcase uses Bosch Telecom's SpectraPoint LMDS technology and offers voice, data and video services. Now located in Richardson, Texas (north of Dallas) in Bosch Telecom corporate headquarters, it began operating April 2, 1998 in the Frazier/King Media facility in Irving, Texas [53]. The LMDS Showcase highlights advanced broadband services, incorporating Competitive Local Exchange Carrier (CLEC)<sup>35</sup> telephone service, high-speed data (e-mail, Internet, Intranet, etc.) and multichannel video services. It allows consumers, service providers, regulators, and investors to experience a real-world, fully functional LMDS first-hand and see the operational and financial benefits of integrating an LMDS system into existing networks.

Over a single infrastructure, all those services are being provided to 60-80 real-world users in 18 business and apartment buildings. Two transmission sites are delivering service over a distance up to 5 km. In addition to the actual users in the community, six different environments are simulated, including a Small Office/Home Office (SOHO), a doctor's office, a financial center, a classroom, a sports bar, and a home living room. A sampling of the broad range of applications includes teleshopping, telemedicine (x-rays, interactive diagnosis, etc.), distance learning and high speed Internet access.

### 6.9.2 LMDS Trial in Denver, Colorado

FORMUS Communications, headquartered in Englewood, Colorado, developed a proof-of-concept LMDS system in the Denver area in 1998 [53]. The company received an experimental license from the FCC which will allow the development and testing of a broadband

<sup>33</sup> A Dallas-based telecommunications service provider via terrestrial and satellite networks.

<sup>34</sup> Newbridge Networks, Hewlett-Packard, Stonehouse Technologies, SBA Communications Corporation, TDI Inc., Virtual Information Systems, General Instruments, WorldCom, and Learnstar Inc.

<sup>35</sup> A bypass of the local telephone company.

data network connecting buildings in Denver. FORMUS is part of WNP Communications, the largest bidder in the 1998 LMDS auction (see Section 6.2.2).

FORMUS' test system will allow downstream connectivity at speeds up to 36.5 Mb/s, and upstream connectivity at speeds up to 1.6 Mb/s [53]. At the downstream rate, the contents of an entire CD-ROM could be transmitted in approximately 2.5 minutes.

### 6.9.3 SmartWave

Based in Vienna, Virginia, Teligent (<http://www.teligent.com/>) offers local, long distance, high-speed data and Internet access services with its digital SmartWave™ technology at 24 GHz [54]. Teligent gives smaller businesses the higher network speed and capacity – up to 45 Mb/s – they need to compete. Unlike many other new communications companies that have emerged in recent years, Teligent is building its own local networks – not simply reselling services – over the local phone networks.

Teligent service is currently available in over 27 markets across the U.S., including: New York, Los Angeles, Houston, Dallas-Fort Worth, Washington DC, and Boston. Together, those 27 markets comprise more than 434 cities and towns with a combined population of more than 80 million. By the end of 1999, Teligent expects to offer service in 40 markets across the country.

Teligent's digital SmartWave technology uses various QAM schemes – between 4 QAM and 64 QAM. Teligent's network features a Class 5 central-office switch similar to a traditional landline or cellular network. The company installs a 12-inch dish on top of a customer building, and all of the customer's traffic, whether it be voice, data or video, is routed to this antenna. The traffic is converted into ATM format and transmitted via ATM to Teligent's base station where it's taken off the air and routed back to the central-office switch. At the switching center, Teligent uses ATM switches and data routers along with Nortel DMS switches to hand off the traffic to other networks – the public circuit-switched voice network, the packet-switched Internet, and private data networks.

### 6.9.4 The WinStar Wireless Fiber Network at 38 GHz

WinStar (<http://www.winstar.com/>) Wireless Fiber Network offers the same capability as fiber optic cables without all the overhead costs. It uses instead one to two-foot diameter antennas aimed at each other atop roofs or in windows. These devices are then linked through a "hub-and-spoke" network to WinStar's own local switching center or to an existing fiber optic network already in the ground.

WinStar's network uses wireless transmissions in the 38 GHz frequency band. With licenses in more than 160 major markets, including all of the top 50 cities in the U.S., WinStar's network will cover more than 60% of America's small to medium-sized businesses. Currently,

over 8,000 buildings without access to broadband telecommunications services have been targeted.

In markets where it did not have any or enough bandwidth at 38 GHz, WinStar bid for LMDS licenses at 28 GHz to fill in coverage gaps. From a customer's point of view, it makes no difference whether the company is using 28 or 38 GHz, according to WinStar [54]: "It only affects the first mile." After that, traffic moves through the same switches and hubs and over the same backhaul microwave and fibre links.

## 7. Local Multipoint Communications Systems (LMCS) in Canada

### 7.1 LMCS Frequency Bands in Canada

Local Multipoint Communications Systems are also called Local Microwave Communications Systems or Last Mile Connection Systems. LMCS is known in the USA as LMDS.

Through public consultation in October 1996, it was decided to have six blocks available for LMCS in Canada (see Table 7). Blocks A and B were made available via a comparative process in the first licensing round. For this licensing round, eligibility to apply was limited to companies that were not telephone companies, cable companies, or an affiliate<sup>36</sup>. This was intended to ensure that consumers have choice in the provision of broadband telecommunications facilities. Also in October 1996, Canada licensed LMCS to three different organizations selected among 13 proponents. Western International Communications Ltd (WIC) ConneXus<sup>37</sup> (formerly called CellularVision Canada) and MaxLink will each serve 33 urban markets of at least 10,000 households. The third organization, Regional Vision, will cover 127 small communities across Canada<sup>38</sup>. Each organization has been allocated the band between 27.35 and 28.35 GHz – a whole 1 GHz piece of spectrum – because they felt a 500 MHz block simply was not enough bandwidth.

However, LMCS markets worldwide are being developed at a slower pace than the experts predicted. Many factors contribute to that: the lack of equipment at a reasonable cost, the ongoing evolution of technology, as well as delays of similar licensing initiatives in the US and other countries.

For this reason, on June 1, 1998, Industry Canada Minister John Manley announced that there will be a postponement in the licensing of further spectrum in the 28 GHz band for LMCS for at least 18 months due to licensing delays in the U.S. market. This complements the decision to make new similar spectrum available in other bands (24 GHz and 38 GHz) and will ensure the orderly development of leading edge wireless broadband infrastructure in Canada. The Minister also announced a one-year extension on the service roll-out requirements of the existing LMCS licensees, and indicated that applications to merge existing licensees, or to transfer ownership to eligible purchasers will be considered as part of building innovative and globally competitive wireless services.

<sup>36</sup> In Canada, LMCS will be in competition with cable, telephone, and satellite systems.

<sup>37</sup> WIC acquired the CellularVision technology rights in Canada in 1993 and began field trials in 1994 (see Section 7.2 of this survey).

<sup>38</sup> On June 17, 1999, WIC Ltd. announced that it has entered into an agreement to sell its wholly-owned division, WIC ConneXus to MaxLink. WIC President and CEO, Peter R. Classon, also announced that the sale included WIC's 49% interest in LMCS provider, Regional Vision Inc. and the sale by Canadian Satellite Communications Inc. of its 51% interest in Regional Vision Inc. The transaction is to close by July 7, 1999. For more details, see <http://www.newswire.ca/releases/June1999/17/c5046.html>.

Band	Frequency Range (GHz)	Bandwidth (MHz)
A	27.85-28.35	500
B	27.35-27.85	500
C	26.85-27.35	500
D	26.35-26.85	500
E	25.85-26.35	500
F	25.35-25.85	500

**Table 7** LMCS bands in Canada.

Because of the large overlap between the Canadian and the American band plans (compare Table 4 and Table 7), systems manufactured for the U.S. market are also expected to be usable in Canada after appropriate certification. Radio system manufacturers consider commonality with Canadian band plans necessary to reduce cost and expand the market for a specific system.

Moreover, Industry Canada has recently reviewed and analyzed responses to its consultation paper published in August 1998 on the use and restructuring of the 24 and 38 GHz bands [55]. The department released a document entitled "Policy and Licensing Procedures for the Auction of the 24 and 38 GHz Frequency Bands" on May 29, 1999 (available at <http://strategis.ic.gc.ca/SSG/sf01820e.html>). This paper defines the final policy framework for these bands and outlines the rules and procedures of the licensing process for them. The new spectrum will be auctioned in early October 1999. There will be 800 MHz of spectrum available in the 38 GHz band and 400 MHz available in the 24 GHz band. The 24 GHz band will be offered as one 400 MHz licence. The 38 GHz band will be packaged as follows: one 400 MHz licence and four 100 MHz licences. For example, the 24.25-24.45 and 25.05-25.25 GHz bands will be licensed for fixed services, either point-to-point or point-to-multipoint. This allocation is aligned with the use of similar frequencies in the U.S. for the Digital Electronic Message Service (DEMS), which was relocated out of the 18 GHz band [55].

The above-mentioned auctioned licenses will have a ten-year term with a high expectation of renewal. The intention is to renew auctioned licences for subsequent ten-year terms unless a breach of licence condition occurs, a fundamental reallocation of spectrum to a new service is required (e.g., a reallocation by the International Telecommunication Union), or an overriding policy need arises (e.g., a spectrum reallocation to address a national security issue). For more details, see <http://strategis.ic.gc.ca/SSG/sf01822e.html>.

## 7.2 Experimental LMCS System in Calgary, Alberta

Between 1994 and 1996, an experimental CellularVision<sup>39</sup> system was set up in Calgary to demonstrate the technology and to perform some tests. This demonstration site provided for the distribution of analog and digital channels over two cells with 10-km diameters with overlapping signals. One cell was located in a suburban area, the other in the centre of the downtown core. The two cell centers were separated by about 5.6 km, which resulted in an overlapping area of 24 km<sup>2</sup>. Both cells had reverse polarization: horizontal for the main cell and vertical for the secondary one. The trial was intended to show the multi-cell operation of the technology and determine its ability to reliably receive signals in a typical downtown "concrete canyon". The purpose of the overlapped area was to test polarization diversity. The system demonstration was carried out under an Industry Canada experimental license for the use of the spectrum between 27.5 and 29.5 GHz. Within each cell, a frequency band of 1 GHz was proposed for multichannel video programming distribution and two-way services such as interactive television, video teleconferencing, data and voice transmission. The second 1 GHz band could have been activated in the same cell if needed. Each 1 GHz block was divided into fifty 20 MHz channels allowing for the distribution of 49 TV channels each occupying a maximum bandwidth of 18 MHz. An unoccupied 2 MHz remained between each TV channel, providing a total of 118 MHz of bandwidth to carry other services (allowing a 2 MHz guard band at the top and bottom of the band). The adjacent cell was offset by 10 MHz and used the orthogonal polarization, as mentioned earlier [56].

Unfortunately, at the time of the system assessment by The Canadian Broadcasting Corporation (CBC) in 1995 [57], only one cell was in operation and there were no bi-directional distribution capability. A typical cell could have a radius of 5 km with a transmitter of less than 30 W<sup>40</sup>. A city could be covered with 10 cells, alternatively switching between frequencies and polarizations. It was claimed that reception was excellent even with reflected signals, for more than 95 % of locations. The parameters included: -4 dBW per channel, a TX antenna gain of 10 dBi, a cell radius of 5 km, free-space loss of 135.1 dB, a receiving antenna gain of 32 dBi and rain attenuation of 15 dB. The predicted analog video SNR at the receiver was 42 dB or better [56]. This analog implementation has now been replaced by a new digital one.

## 7.3 LMCS Field Tests in Canada

### 7.3.1 Introduction

The Communications Research Centre (CRC) conducted field tests in a major urban centre on a pilot Local Multipoint Communications System (LMCS) in September of 1997.

<sup>39</sup> See Section 6.8.1 of this survey.

<sup>40</sup> For example, using a 120-W Traveling Wave Tube (TWT) transmitter with a 7 dB output back-off.



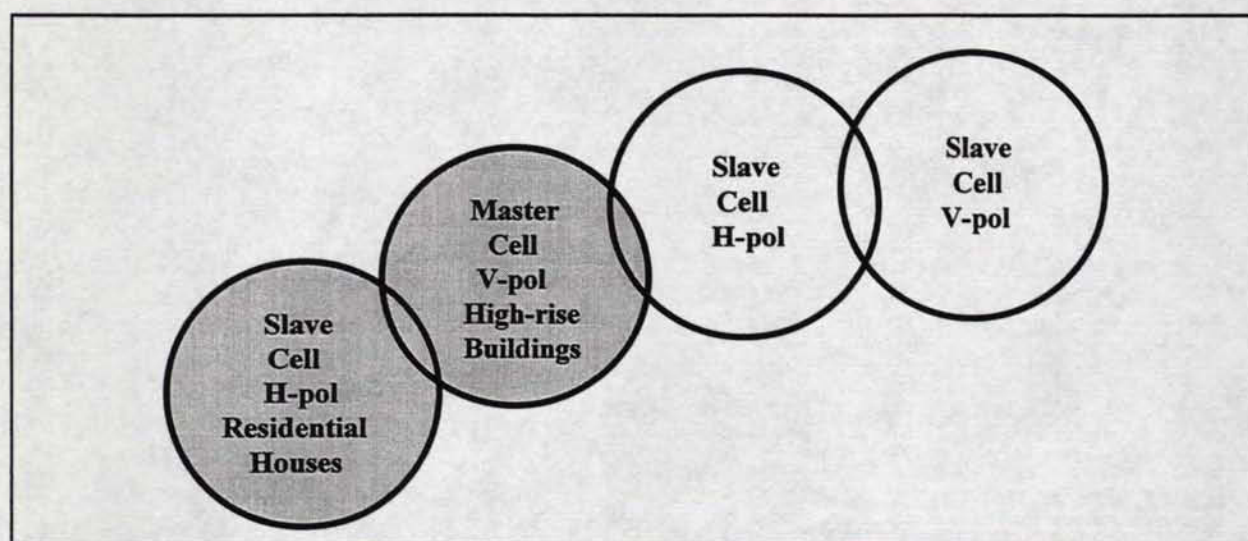
About 400 test sites were visited. The coverage of two of the four operational cells was studied: the master cell and a slave cell.

The field tests were conducted when the leaves on the trees were still green, a seasonal period that is considered to represent the worst operating conditions.

### 7.3.2 Characteristics of the Pilot LMCS Project

Four cells were operational in the Pilot LMCS Project (see Figure 9). This system was originally configured to broadcast video and audio programs originating from a satellite signal.

Compressed digital video Single Channel Per Carrier (SCPC) satellite signals were used to test the broadcast service. The symbol rate of the satellite signal was 6.145 MS/s and the carrier spacing was about 10 MHz. In the field, the Threshold Of Visibility (TOV), where impairments become visible in the video, was observed at a Carrier-to-Noise ratio (C/N) of about 11 dB. The spectrum plot of the signal as received at a calibration site is shown in Figure 10.

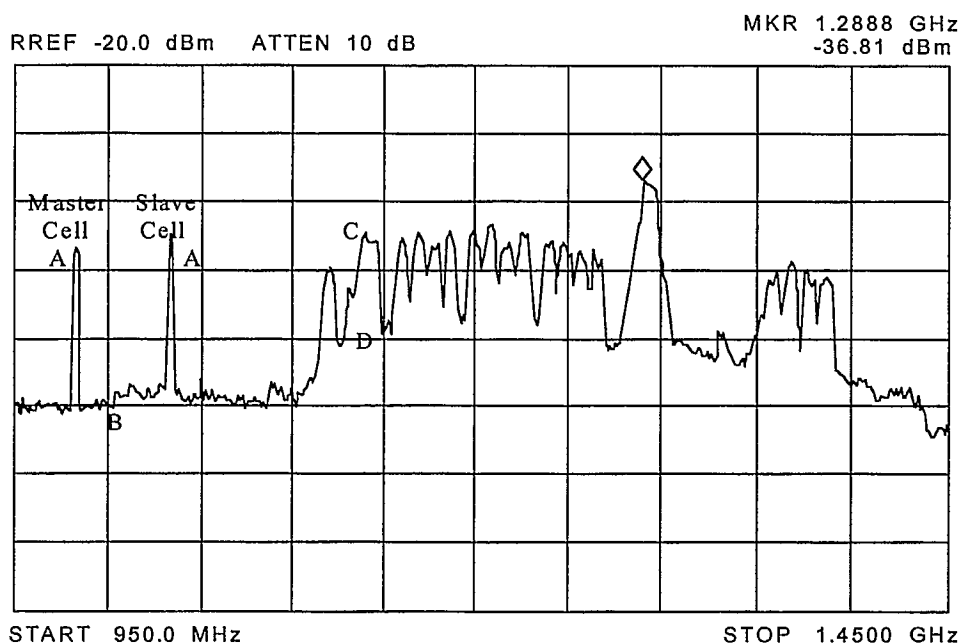


**Figure 9** Pilot LMCS project. The various polarizations used are indicated in each cell. The gray areas represent the cells that were visited during the field tests. Note the presence of overlapping areas between cells.

#### 7.3.2.1 Transmission Facilities

The height of the transmitting antenna of the master cell was about 130 m above ground level. The broadcast service signal was transmitted from a vertically polarized (V-pol.) omnidirectional antenna with a 10-dBi gain, using a 120-W (20.8 dBW) Traveling-Wave Tube (TWT) power amplifier. The total output back-off was 10.8 dB. The same signal was also

transmitted toward one of the slave cells, by a directional 24-inch parabolic antenna (42 dBi) using horizontal polarization (H-pol.). This Inter-Cell Link (ICL) used a one-watt Solid State Power Amplifier (SSPA) with a 10-dB output back-off. The ICL link was 8.25 km long. A second similar ICL operated toward a building complex located 10.6 km away from the master site.



**Figure 10** Spectrum plot at a calibration site (resolution bandwidth: 300 kHz).

*Point A:* Continuous-Wave (CW) tone from the master cell and the slave cell;

*Point B:* Noise floor;

*Point C:* Transponder signal;

*Point D:* Noise floor + intermodulation products + adjacent channel interference.

During the field tests, a Continuous-Wave (CW) and a QPSK signal were added to the signal originating from the master cell and one of the slave cells. These signals were used to characterize the LMCS transmission alone. Using the satellite feed, it was impossible to differentiate between the degradation created by the satellite transmission and the one caused by the LMCS transmission.

### 7.3.2.2 Receiving Equipment

In the test van, the signal was received by an antenna combined with a down-converter and a Low Noise Amplifier (LNA). The receiver antenna gain was about 31 dBi. The maximum beamwidth of this antenna was 6 degrees. The receiver LNA gain was about 26 dB. The download loss, combiner, and other insertion losses were estimated to be around 8 dB.



The output of the antenna-downconverter was fed to a spectrum analyzer or to a satellite receiver, as described in the next section.

### 7.3.3 Description of the Tests and Measurements

Sites were located on radials and arcs selected to either present a variety of conditions or to be located in areas of particular interest. Tests were repeated daily at two calibration sites over the period of the field tests to determine time availability of the service and to confirm proper operation of the test equipment.

In all cases, the receiving antenna was first oriented toward the desired hub for maximum signal power, using a remote-controlled pan-and-tilt device, which was critical to the success of the field tests. Without this mechanism, it would have been impossible to properly orient the antenna vertically as its beamwidth was less than six degrees. A video camera with a telephoto lens aligned with the antenna boresight was used to determine the Line-Of-Sight (LOS) direction and the clearance of rooftop and tree blockage. The tests were repeated, whenever possible, to receive the signal from another hub on the other polarization. The antenna was then directed to the other hub and the tests repeated for both polarizations. To assist the measurements, two receiving antennas were used, one for each polarization.

At all sites, the following general information was recorded:

- Weather conditions (wind, temperature, humidity, etc.);
- Pictures of the test site;
- Global Positioning System (GPS) readings;
- Compass readings and heading of the receiving antenna.

A CW tone was inserted at each cell transmitter and mixed with the other signals, as shown in Figure 10. The CW tone was selected to be far from the other signals to avoid intermodulation products. The CW tone from the master cell was re-transmitted by the other slave cells.

The feed from a satellite service was converted to the LMCS frequency and transmitted from the central cell hub. This method of signal acquisition is a worst-case model, as it involves block conversion of the entire L-band feed of a satellite system. The signals thus inherit all of the satellite system's degradation in the form of intermodulation distortion, cross-polarization and C/N degradation.

At the receiving site, the antenna fed an L-band satellite receiver, and the resulting video was displayed on a video monitor for observation. The signal and noise power in a portion of the QPSK satellite signal was also measured at Point C, Figure 10.

In order to verify the receiving signal level and to estimate the video margin, the signal was attenuated until the decoded video pictures started to lock up. Moreover, a noise generator was used to inject white noise to establish a precise video margin, which is noted at the point where the decoded video sequence started to freeze.

### 7.3.4 Tests Results and Analysis

#### 7.3.4.1 Location Availability

During Phase I and II, measurements were taken at 395 sites within a 5-km radius to evaluate the location availability of the system.

Availability of sites in the master cell was higher than that of the slave's. Here are some possible explanations:

- The slave cell was located in an old residential area where high trees blocked the LOS path;
- The height of the transmitter antenna at the slave cell was only half that of the master cell site (However, an antenna that is too high can result in more inter-cell interference);
- The south side of the slave cell was close to a lakeshore, where the terrain elevation was low, resulting in terrain blockage.

The location availability is highly dependent on terrain, path clearance, and transmitter/receiver antenna height. Another noteworthy point is that, for both cells, there were sites available outside the desired 5-km radius. This indicates that the LOS path is crucial for reliable reception of broadcast service: a longer LOS path might be more favorable than a shorter non-LOS path. However, the locations outside the 5-km radius might not have enough rain margin. In other words, the time availability for those sites might be low if the current transmitted power level were maintained. As there were no rainfall during the test period, this hypothesis could not be confirmed. However, if we use data from Table 2, for Region D1, a 12.25-dB rain margin is needed for a time availability of 99.9% at 5 km; but the estimated C/N margin under clear sky conditions was 7.4 dB for QPSK, which would be insufficient for 99.9 % availability.

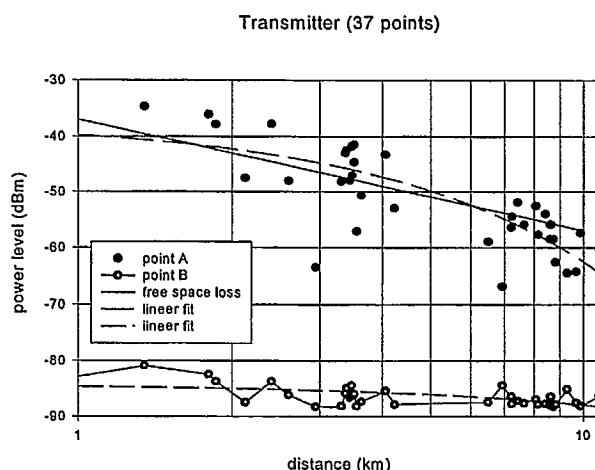
The field tests results on location availability might represent a worst-case scenario. For example, a roof-mounted receiving antenna may be less obstructed by trees than the antenna of the test van, which was parked on the curbside. For multiple dwelling units with a master antenna system, the household access availability would also be significantly improved. Gap fillers, active or passive, would also improve the location availability.

### 7.3.4.2 Measured Signal Power After Downconversion (SPAD)

Figure 11 shows the measured SPAD (point A, unmodulated tone, in Figure 10) and noise floor (point B in Figure 10) for the master cell test sites. Only those sites that could reliably receive the video signals, including partial blockage cases, are presented. The solid line represents the calculated SPAD assuming free-space propagation; the dashed line, the average of the measured SPAD. It can be seen that the two lines fit well.

The following observations can be made:

- The signal power of those sites that can receive reliable video signals were very close to the calculated value assuming free-space propagation. This further confirmed the argument that a LOS path is required for reliable LMCS service;
- The difference between the received signal power and values predicted by free-space propagation increased with receiving distance. Possible causes include atmospheric absorption, partial path blockage, depolarization, etc;
- The required SPAD for reliable reception of a video signal is around -70 dBm, not including a rain margin. (Note: there is a LNA with a gain of about +18 dB, including downlead and combiner losses);
- Foliage and diffraction caused by buildings can easily attenuate the SPAD by more than 10 dB;
- The measured noise floor at a 5 km distance is about -87 dBm for the master cell and -84 dBm for the slave cell;
- For a given test site, if the received signal strength is high, the noise floor is also high. This could be caused by the limited dynamic range of the antenna-LNA-downconverter system.



**Figure 11** Measured Signal Power After Downconversion (SPAD) (upper curve) and noise floor (lower curve) vs. distance at sites in the master cell (only those sites that could reliably receive broadcast service video signals are presented). The solid line represents the calculated SPAD assuming free-space propagation; the dashed line, the average of the measured SPAD.

Figures 12(a) and 12(b) present SPAD and noise floor variations within clusters. For reference, the free-space propagation SPAD curves are also presented. A cluster consists of three-by-three test sites, spaced at a distance equal to one residential house, to simulate an actual LMCS implementation case. The purpose of this test was to confirm that there exist no large variations of signal power within a small area, where there is no major LOS blockage.

Two clusters were selected: Cluster 1 in the master cell and Cluster 2 in the master/slave overlapping area, where signals from both transmitters could be received. From Figure 12, it can be noted that the SPAD variation was only a few dBs within a cluster. Meanwhile, all measured SPADs matched closely with the free-space SPAD curves.

During the tests, some weak multipath reflections were observed. However, the level of the multipath was quite low, less than 15 dB. The delay spread was also quite small, less than 10 nanoseconds. This would not cause receiving errors in these tests, since the satellite receiver could withstand multipath of up to 6.4 dB within 1  $\mu$ s. The corresponding loss of noise threshold was also negligible.

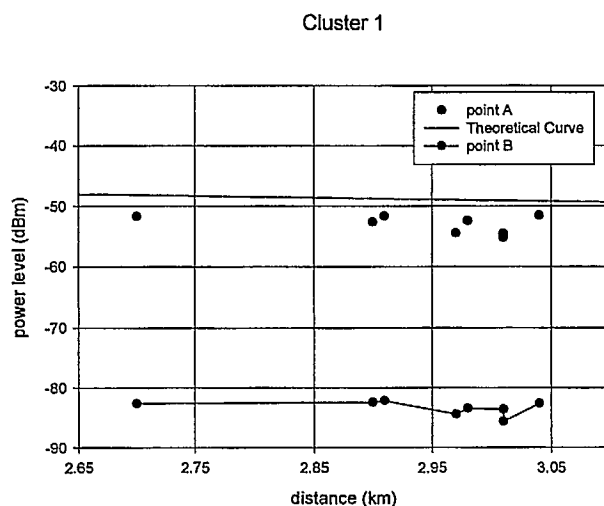
### 7.3.4.3 Foliage

All the above measurements were made when the leaves were still on the trees. Some were repeated at fourteen selected sites in the master cell in November 1997, after the leaves had fallen from the trees.

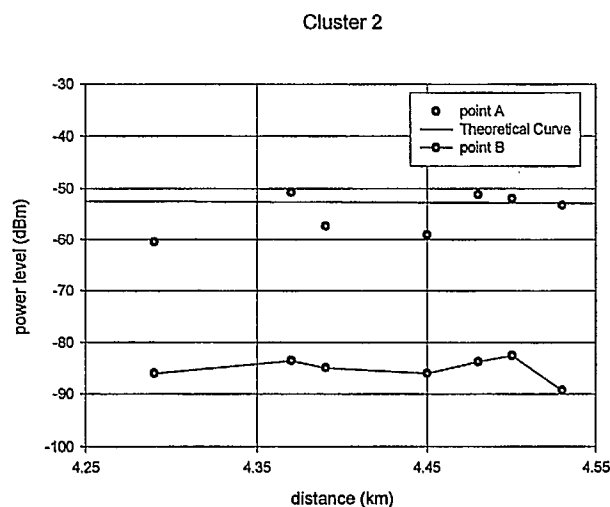
There were no signal for eight of the sites visited when the foliage was still on the trees. Reception was possible at four of these sites after the foliage was gone.

For example, the foliage caused an attenuation of more than 20 dB at one of the sites. On rainy or snowy days, there would be additional signal strength losses. A clear LOS path is therefore essential to maintain LMCS service quality. Clearly, LMCS operators will have to do some planning to take into account the future growth of foliage when setting up a system in a residential area.

The tests done without foliage showed that for many of the sites where no signal was received before, good reception was possible after the autumn defoliation. This result is not statistically valid as the number of sites is too low and sites were not randomly selected. However, it provides an indication about how much coverage could be lost once the trees have grown in a newly developed area where there were no reception problems before. Further tests may be required for confirmation.



**Figure 12(a)** Slave cell transmitter: measured Signal Power After Downconversion (SPAD) (upper curve) and noise floor (lower curve) vs. distance inside Cluster 1.



**Figure 12(b)** Overlapping area, slave cell transmitter: measured Signal Power After Downconversion (SPAD) (upper curve) and noise floor (lower curve) vs. distance inside Cluster 2.

### 7.3.5 LMCS Field Trial Conclusions and Recommendations

The results of field trials in a major urban centre showed that:

- A LOS path is required to provide reliable LMCS service;
- Vegetation attenuation and building diffraction can easily result in a signal attenuation of more than 10 dB;
- If a LOS path is available, the received Signal Power After Downconversion (SPAD) is quite close to the value obtained under free-space conditions;
- The average location availability for the LMCS service is better for the new business/residential area surrounding the master cell than the mature residential area in the slave cell. The major problems for the sites located in the slave cell were vegetation attenuation and terrain blockage near the lakeshore area, where gap fillers may be required;
- The broadcast service can be provided reliably within a 5-km cell, when a LOS path is available.

Future work has to be done to establish the long-term time availability of the service, especially under varying weather conditions.

Cell overlapping will improve the location coverage availability by increasing the number of possible LOS paths. Such measures will also reduce the distance between hubs and, therefore, may improve the performance of the Inter-cell Links.

A higher transmission tower could improve the availability of LOS paths. It may also reduce the terrestrial noise picked up by the receiving antenna. On the other hand, it may result in higher interference to other cells.

Limited multipath distortion was observed during the field tests. More studies are required to characterize the delay spread, amplitude, and stability under different operating environment, weather, and seasonal conditions.

CRC has also tested COFDM for LMCS (see next section) and is now planning to conduct additional field tests at 29 GHz during the course of 1999 to evaluate the performance of other modulation schemes like 16 QAM and COFDM.

## 7.4 COFDM for LMCS Applications

### 7.4.1 What Is COFDM

COFDM was selected in Europe and in Japan for DTV terrestrial transmission. It has been implemented in the European Digital Video Broadcasting system for Terrestrial broadcasting (DVB-T) and in the Japanese Band Segmented Transmission using OFDM (BST-OFDM) system. One of the reasons behind this choice is the robustness of COFDM against multipath.

The distorting effect (the intersymbol interference or ISI) produced by a given combination of multipath depends not only on the total power and relative delay of the echoes but also on the ratio of the temporal spread of the echoes to the symbol length of the signal. In VHF and UHF terrestrial transmission, most echoes occur within about 20  $\mu$ s of the main signal. This does not cause much trouble with AM or FM audio broadcasting, with a symbol length of about 25  $\mu$ s, but it produces heavy impairment in television, with a symbol length of about 100 ns. Obviously, one way to reduce – but not eliminate – the distortion is to divide the signal into a large number of components, each of which has a much longer symbol length, and to transmit these components as narrowband modulated carriers within the original channel. The ISI can be completely eliminated by inserting after each symbol a *guard interval* during which a portion of the symbol waveform is replicated. This permits integrating each symbol over its symbol duration without unintentionally including energy from symbols just before or after the symbol being demodulated. The guard interval itself must be longer than the multipath delay. Since the guard interval reduces the efficiency of the transmission, it is advisable to make the symbol long as compared with the guard interval, with a correspondingly large number of carriers<sup>41</sup>.

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<sup>41</sup> However, increasing the number of carriers increases the receiver complexity and the sensitivity to phase noise.

Frequency-division multiplex, as discussed above, has been improved by two developments: orthogonalization of the modulated carriers so that no bandwidth need be wasted by using guard bands, and implementation by means of the Discrete Fourier Transform (DFT). The resulting system is called Orthogonal Frequency Division Multiplexing (OFDM) [63].

An important property of OFDM is that out-of-band spillover is much less than in single carrier modulation (SCM). This is because orthogonality, as produced by the DFT, makes the spectrum of each modulated carrier have the shape  $(\sin(\omega)/\omega)$  centered on the carrier frequency with the zeroes placed at the locations of the neighboring carriers. With thousands of carriers, the spectrum thus decays extremely rapidly at the edge of the channel, even without filters.

One of the advantages of the OFDM system is that each subcarrier can be turned off to create spectrum notches to accommodate tone interference. The power level of each subcarrier can also be adjusted to adapt to interference that has a non-flat spectrum or to channels having non-flat responses. Another advantage of OFDM is that it can withstand strong multipath distortion if proper channel coding is implemented. The OFDM with channel coding is called Coded Orthogonal Frequency Division Multiplexing (COFDM). Usually, concatenated channel coding is used with TCM as inner code and R-S code as the outer code.

The COFDM proposed in Europe for DVB allows for the use of either 1705 carriers (usually known as "2k mode"), or 6817 carriers ("8k mode"). The "2k mode" is suitable for single transmitter operation and for relatively small single frequency networks with limited transmitted power. The "8k mode" can be used both for single transmitter operation and for large area single frequency networks. The guard interval is selectable and the "8k" system is backward compatible with the "2k" system.

#### 7.4.2 Tests on COFDM

Tests were carried out at the Communications Research Centre (CRC) to evaluate the performance of COFDM for LMCS. These tests were conducted using a prototype 6 MHz COFDM-6 modem that was developed in Scandinavia by HD-Divine and Sintef Delab for Digital Television transmission in North America. The modem was built for the COFDM Evaluation Project, a consortium of American, Canadian, and Brazilian broadcasters.

In 1995, CRC tested the COFDM modem in its transmission laboratory and conducted field tests at VHF [64]. In 1996, CRC also conducted laboratory and field tests in the Ka-band with a prototype Local Multipoint Communication Systems (LMCS) transmitter-receiver built in-house [65].

Following preliminary studies conducted at CRC, the prototype COFDM-6 modem used in these tests was programmed with five different sets of parameters (System I to V) for LMCS applications. The selected parameters of the COFDM-6 modem are presented in Table 8.



System I was used for VHF-UHF Digital Television terrestrial transmission laboratory evaluation. Systems II to V were selected for possible LMCS applications.

Systems II and IV used 64 QAM and 16 QAM, respectively, as the modulation scheme. The advantage of System II is that the data throughput is twice that of System IV. On the other hand, the advantage of System IV over System II is its greater robustness to Gaussian noise ( $\Delta=6.9$  dB), phase noise ( $\Delta=6.5$  dB @ 20 kHz), and multipath.

Systems I, II, and IV can withstand very strong ghosts (even up to 0 dB) at the cost of a degradation to the system's robustness to Gaussian noise.

Systems III and V used QPSK and 8PSK respectively as modulation schemes. These two systems did not use Trellis Coded Modulation (TCM) and they were not able to deal with strong ghosts as well as the other systems.

PARAMETERS	SYSTEM I	SYSTEM II	SYSTEM III	SYSTEM IV	SYSTEM V
Channel useful bandwidth	5.557 MHz	5.508 MHz	5.508 MHz	5.508 MHz	5.440 MHz
Carrier separation	0.9078 kHz	6.7449 kHz	6.7449 kHz	6.7449 kHz	10.0 kHz
Useful symbol duration	1101.607 $\mu$ s	148.15 $\mu$ s	148.15 $\mu$ s	148.15 $\mu$ s	100.0 $\mu$ s
Guard interval duration	64.0094 $\mu$ s	8.1 $\mu$ s	8.1 $\mu$ s	8.1 $\mu$ s	8.001 $\mu$ s
Total no. of carriers	6120	816	816	816	544
Number of ref. Pilots	0	0	0	0	0
Number of data carriers	6120	816	816	816	544
FFT size required	8 k	1k	1k	1k	1k
FFT size used	16.384 k	1.024 k	1.024 k	1.024 k	1.024 k
Modulation scheme	64 QAM	64 QAM	QPSK	16 QAM	8 PSK
TCM coding rate	2/3	2/3	none	1/2	none
Reed-Solomon code	(255,239)	(204,188)	(204,188)	(204,188)	(204,188)
No. of ref. symbols/frame	3	3	3	3	3
No. of total symbols/frame	105	105	105	105	105
No. of data symbols/frame	102	102	102	102	102
Frame duration	122.390 ms	16.406 ms	16.406 ms	16.406 ms	11.340 ms
Total payload throughput	19.12 Mb/s	18.70 Mb/s	9.35 Mb/s	9.35 Mb/s	13.52 Mb/s
C/N @ VHF-11	16.1 dB	15.7 dB	10.3 dB	9.1 dB	15.1 dB

**Table 8** Parameters for the COFDM-6 Modem.

### 7.4.3 Tests in the Ka-Band with COFDM

The COFDM-6 modem was tested in the Ka-Band with three different sets of parameters (Systems I, II, and IV). A prototype LMCS transmitter-receiver built at CRC, was used to upconvert the signal from 70 MHz to 28.072 GHz and downconvert it from 28.072 GHz to 70 MHz. The process of up and down frequency conversion involved many oscillators and mixers, which increased the phase noise. Thus the performance of each COFDM-6 system against Gaussian noise was degraded by about 1 dB in comparison with operation at VHF or UHF.

System I had a bit error rate of  $3 \times 10^{-6}$ , when the carrier-to-noise ratio (C/N) was 17.1 dB in the Ka-Band. Robustness to Gaussian noise was 16.6 dB for System II and 9.7 dB for System IV.

The C/N requirement at a BER of  $3 \times 10^{-6}$  in the Ka-band in the presence of a -5 dB ghost was 18 dB for System II. Under the same conditions, the requirement was only 10.6 dB for System IV but 20.5 dB for System I.

Robustness against phase noise at 10 kHz for a bit error rate of  $3 \times 10^{-6}$  was -80, -74 and -67.5 dBc/Hz for Systems I, II and IV, respectively. It was -69.83, -62.83, and -56.67 dBc/Hz at 1 kHz.

#### 7.4.4 LMCS Field Tests with COFDM

For field-testing, the COFDM-6 modulator was installed on the top of a three-story building at CRC. The COFDM-6 modulator was fed by its internal pseudo-random data source, same as for the laboratory evaluation. The RF output at 28.072 GHz, after passing through a 100-mW solid state power amplifier, was fed to a standard gain horn antenna. Horn antennas with gains of 23 dBi (with a 10-degree beamwidth) and 13 dBi (with a 30-degree beamwidth) were used during the field test.

Because of time limitations, only Systems II and IV were tested. Although only one site was visited during the test, it provided interesting results.

For each system, the transmitting and the receiving antennas were physically peaked to have the maximum power at the receiver input. Calibration was conducted with a 70 MHz reference oscillator connected at the input of the frequency converter at the transmitter site.

The receiver was in LOS with the transmitter and was located 2.3 km away. The first set-up was with System IV using the 23-dBi horn at the transmitter, and the 13-dBi horn at the receiver. The C/N ratio for a BER of  $3 \times 10^{-6}$  was around 9.8 dB, which is about the same as the laboratory result of 9.7 dB. The system was also tested in nonlinear conditions (saturation) and performed very well. However working in saturation created some sidelobes in the spectrum as well as interference in adjacent channels.

A comparison of results obtained with and without R-S coding showed the effects of phase noise in the LMCS environment. Theoretically, a BER of  $1 \times 10^{-4}$  without R-S coding is equivalent to a BER of  $3 \times 10^{-6}$  with R-S coding in a Gaussian channel. In the field, however, for a (C+N)/N of 9.4 dB, a BER of  $2 \times 10^{-4}$  without R/S coding was found equivalent to a BER varying between  $3 \times 10^{-4}$  and  $7 \times 10^{-7}$  with R-S coding. The variation is due to bursts of errors created by phase noise. Based on this result, it will be appropriate to add a 1-dB margin to the C/N required for reliable operation in a LMCS channel. For example, the C/N required for LMCS service in the 28 GHz band with System IV should be 10.8 dB instead of 9.8 dB to account for the phase noise impairment.

Due to the use of directional antennas and the short distance between the transmitter and the receiver, no multipath was observed during the field test. From laboratory results, the C/N degradation due to typical multipath ( $< 10$ -dB ghost) will, however, be less than 0.5 dB for Systems II and IV.

The second set-up was for System II with the 23-dBi horn at the transmitter and the 13-dBi horn at the receiver. The system was in saturation for a C/N higher than 16.2 dB. It was impossible to operate the system with a BER better than  $4 \times 10^{-5}$  in saturation or better than  $5 \times 10^{-3}$  without saturation.

The third set-up was for System II with the 23-dBi horn at the receiver instead of the 13 dBi one. The C/N ratio for a BER of  $3 \times 10^{-6}$  was around 16.7 dB and was comparable to the laboratory result of 16.6 dB. The same explanation about the effect of phase noise for System II set-up applies also to System IV.

Calculations done after the field tests show that the antennas may not have been peaked for maximum received power as believed. The calculations for System IV show that the measured C/N ratio of 9.8 dB should have been 8.3 dB. This is 1.5 dB more margin at the receiver than measured.

#### **7.4.5 Conclusion on COFDM**

The results of laboratory and field tests show that COFDM can be used for LMCS applications. The laboratory results show that the main advantage of using COFDM is the ability to deal with strong ghosts. This may not be a sufficient advantage for using COFDM for LMCS systems as they typically used high gain directional and LOS reception sites, both factors tending to decrease the strength of reflected signals. In LMCS applications, the need to deal with strong multipath is mostly due to signals coming from other cells. In certain cases, polarization diversity may not cure all of these problems.

### **7.5 LMCS Network Showcase in the Ottawa-Hull Region**

On Sept. 22, 1998, MaxLink Communications Inc. (<http://www.maxlink.ca/>) opened its LMCS network showcase in the Ottawa-Hull region to the public. The showcase, the result of two years of testing and development, unveiled MaxLink's suite of advanced telecommunications services on a fully operational network. MaxLink's broadband wireless network offers high-speed Internet access, local and long-distance telephone services, high capacity private data transmission, enhanced multimedia communications and broadcast video.

The showcase consists of three coverage areas in the Ottawa region [58]. One base station, located across the Ottawa River in Hull, Québec, provides coverage of the commercial downtown Ottawa core and the city of Hull. The second base station covers both downtown and

the central-west end of Ottawa. The third cell services the east end of Ottawa. MaxLink has set up a customer premise site located in downtown Ottawa to serve as a public showcase for the network.

Two hundred or more customers will be added to the network during the next phase that will allow MaxLink to shape service offerings according to customers' needs. Commercial service will roll out throughout the course of 1999.

## **7.6 The CRC Terrestrial Wireless Testbed: WISELAB**

In 1998, CRC established a terrestrial wireless testbed called WISELAB (see <http://www.crc.ca/wiselab>). By providing a versatile experimentation environment, the WISELAB can support advanced development and evaluation of terrestrial wireless technologies for industries, governments, and universities, and can assist in the orderly deployment of new wireless systems.

WISELAB offers a large array of resources, expertise, equipment, and collaboration opportunities with CRC's research groups in many communications technology areas such as:

- 3G mobile systems;
- propagation, modulation and coding;
- channel characterization;
- advanced antenna systems;
- voice, video and audio coding;
- wireless broadband communications and
- wireless network protocols.

The CRC terrestrial wireless testbed can support many developmental activities, for example:

- test new wireless concepts, prototypes, and products (complete systems or individual modules);
- demonstrate leading-edge communication systems;
- test interconnection of wireless and wireline networks, including access to the information highway;
- evaluate competing technologies;
- evaluate the performance and interference effects of wireless systems operating under various conditions;
- experiment with new technologies and frequency bands to support the development of policy, regulations and standards, and to facilitate frequency coordination.

A versatile infrastructure is in place to support the activities of the wireless testbed, including:

- high-speed interfaces with ATM and Ethernet networks;

- connections to a high data rate video-on-demand server and to other wireline multimedia data streams;
- a 3-Mb/s wireless LAN with seamless roaming capability between access points deployed at 2.4 GHz;
- a 29-GHz LMCS experimental link;
- a 5-GHz communications link;
- a protocol conversion software to support point-to-multipoint connections and seamless interface with TCP/IP networks;
- a 90-foot tower for radio equipment installation, located on campus about 2 km from CRC's main buildings.

This infrastructure will expand as needed to support the requirements of any joint activities.

## **8. Multipoint (or Microwave) Video Distribution Systems (MVDS) and Digital Multipoint Distribution Systems (DMDS)**

In Europe, broadband microwave broadcasting is called MVDS (Microwave Video Distribution Systems) or Digital Multipoint Distribution System (DMDS). These systems have the capability to distribute at least 20 television channels, providing a service equivalent to cable.

### **8.1 European Standards**

For digital MVDS, two European telecommunications standards, DVB-MC and DVB-MS, have been published.

The European Telecommunication Standard EN 300 749 (see <http://www.etsi.org/>) or DVB-MC proposed that Digital Multipoint Distribution Systems operating below 10 GHz should use the DVB-C standard for coaxial cable (EN 300 429), based on 64 QAM.

For systems operating at 10 GHz and above, the DVB-MS standard [EN 300 748] is based on the standard for satellite distribution at 11/12 GHz [EN 300 421]. It allows the same consumer Integrated Receiver Decoder (IRD) to be used for either service, when used with a Low Noise Block downconverter (LNB) for the appropriate frequency band. The system uses QPSK modulation and concatenated error protection strategy based on a convolutional code and shortened Reed-Solomon (R-S) code. The standard is suitable for single carrier or multicarrier systems. The band between 40.5 to 42.5 GHz has been harmonized within the European Conference of Post and Telecommunications Administrations (CEPT) under recommendation T/R 52-01 for MVDS, as there is no spectrum available below that in most European countries. This band had also been allocated by the ITU for satellite broadcasting. Service in that band is not expected before 2010 at least, but development and experiments are on-going, as described below.

### **8.2 MVDS Pilot Project in Switzerland**

A 50-household pilot project began during the fall of 1996 in the valley of Val d'Hérens, near Sion, in southwestern Switzerland using Philips MVDS technology operating at 42 GHz [59]. The region is sparsely populated, with villages scattered throughout the mountains, beyond the reach of cable. The MVDS system grew out of the desire of local residents for access to more TV channels [60].

Twenty-four analog FM TV signals were transmitted from a main transmitter and two line-of-sight microcells covering two hidden pockets 500 meters farther. Acceptable signal quality was observed 99.7% of the time over a 6-month period. Signal quality remained excellent even during heavy snowfall. Heavy rain (raindrops 4-5 millimeters in diameter) with strong winds produced some signal degradation however but this kind of storm are quite rare in

Europe. Moreover, mountain dwellers tend to unplug their television sets during such storms because of the danger of lightning, according to J. -P. Panchard, project manager at Swisscom [59].

The short range of MVDS – 5 to 10 km – was not a problem in the steep mountain valleys of Val d'Hérens. The challenge was to choose a proper site for the transmitter to extend the elevation angle of the beam to 25 degrees so that villages at 1100 meters above sea level and ski resorts at 2200 meters could equally receive the service [59].

### 8.3 Field Trials in Sweden

Some field trials have been done in Sweden by Telia, one of the largest telecommunications company in Scandinavia (see <http://www.telia.se/>). Telia's LMDS trial project began in February 1997 with tests and demonstration at 40 GHz. The company followed this up with a 28-GHz technical trial using ATM technology in May 1997 [61].

In January 1998, Telia launched a 28-GHz lab trial using ATM, followed by a field trial in March. These steps prepared the company for large-scale commercial introduction during the first two quarters of 1999.

Telia's systems featured a cell radius of less than 5 km. A small village with 200 households would need five base stations to reach 75% building coverage. The CPE for residential and SOHO services included 10BaseT (@10 Mb/s), MPEG-2 Transport Stream, and Internet Protocol (IP) telephony.

The first system used in the technical trial at 28 GHz (hereafter system I) consisted of one base station and two CPE receivers [67]. The second system used (hereafter system II) had two base station sectors and more than 15 CPE receivers. The radio frequency for the downlink was 28 GHz for both systems and the uplink the frequency was 29 GHz and 31 GHz for system I and II, respectively. Both systems used QPSK at 27 Mb/s in the downlink with a roll-off  $\alpha = 0.35$ . A Reed-Solomon R-S (204, 188, 8) FEC was applied to reach the ATM channel requirements. A convolutional outer code with rate 7/8 was also used in system II to reduce the C/(N+I) threshold from 13.5 to 11.0 dB for a BER =  $10^{-10}$ . The transmission rate for the uplink was 4 Mb/s and DQPSK modulation with a roll-off  $\alpha = 0.5$  (system I) and  $\alpha = 0.3$  (system II) was used. No channel coding was used in the uplink in system I, while system II used a R-S (63, 53, 5), which reduced the BER= $10^{-6}$  threshold from 19.1 to 17.1 dB. Table 9 presents a link budget and the various parameters used.

Measurements of the first part of the trial (system I) have been made in Malmö, Sweden [67]. The base station was installed on top of a building; the antennas were placed on the roof, approximately 85 m above ground level. Both CPE receivers were installed 1.4 km away from the base station. One CPE receiver was installed on the roof of a building, approximately 20 m above ground level. From this CPE location there was clear LOS to the base station. The other

CPE receiver was installed on the outside of the same building, but on different windows, approximately 7 m above ground level. The paths between the base station and the two window locations were classified as obstructed line-of-sight (OLOS), due to trees and rooftops obstructing part of the path [67].

Tests with system II consisted of one base station with two Outdoor Units (ODU's), for coverage of two 90° sectors (pointing north and south). The base station was put on a tower approximately 75 m above ground at Telia's premises in Farsta. Measurements were made at eight CPE locations with a van up to the coverage range of approximately 5 km [67].

The system measurements led to the following conclusions [61]:

- The link quality can be assured under clear LOS conditions, including attenuation caused by rain, for up to 5 km (probably longer);
- At a few locations with obstructed LOS or non-LOS, multipath caused a high downlink BER. The use of equalizers should be considered;
- Round-trip delay was low, within ATM requirements.

	System I Downlink	System I Uplink	System II Downlink	System II Uplink
Frequency	28 GHz	29 GHz	28 GHz	31 GHz
Tx Power per Carrier	20 dBm	17 dBm	22.5 dBm	20 dBm
EIRP	25.4 dBm	42.0 dBm	33.9 dBm	47.0 dBm
Rx Power @ 2 km	-77.0 dBm	-80.0 dBm	-66.5 dBm	-69.3 dBm
C/N @ 2 km	18.2 dB	23.9 dB	28.6 dB	34.8 dB
C/N BER Threshold	13.5 dB	19.1 dB	11.0 dB	17.1 dB
Link Margin	4.7 dB	4.8 dB	17.6 dB	17.7 dB
System Margin (Including Rain)	1.9 dB	2.0 dB	14.8 dB	14.7 dB
Antennas	Omni; 6 dBi	4° Sector; 28 dBi	90° Sector; 12 dBi	4° Sector; 30 dBi
Modulation Scheme	QPSK	DQPSK	QPSK	DQPSK
Channel Coding	R-S (204, 188, 8)	None	R-S + 7/8 CC	R-S (63, 53, 5)

**Table 9** Link budget and typical system parameters used for the field trials in Sweden [67].

#### 8.4 The Cellular Radio Access for Broadband Services (CRABS) Project

The main objective of CRABS [62] is to develop and demonstrate a cellular radio system to provide broadband interactive digital television and multi-media services through several user and service trials in various areas in Europe. The project involves detailed studies of the systems architecture necessary for implementation and the development of standards vital for future



commercial products. Frequency planning and spectrum engineering play an important role in this process. Mechanisms to exploit the technology commercially will be established.

The project is concerned with cellular radio access to interactive television and broadband services. Based on the definition of user, service, and technical requirements, it involves extensive user and service trials in two phases. The project features a detailed study of the systems architecture required for the successful commercial deployment of interactive TV and other broadband services such as fast Internet. Compatibility with MPEG-2 and DVB is paramount. The protocols, modulation, and coding schemes, which provide optimum solutions in terms of error rate, quality of service and response time, are investigated through simulations and technical trials. Investigations of millimeter-wave propagation issues will be conducted. The current ACTS projects on radio access, multi-media and ATM technology will also provide relevant and valuable inputs for this project.

#### 8.4.1 General Description

The system was developed in the frequency band of 40.5 - 42.5 GHz selected by CEPT. The services offered by CRABS included television broadcasting, Interactive network (Internet access), teleconference and Electronic News Gathering (ENG). The downlink was using either QPSK or 16 QAM while the up link was using GMSK, QPSK, or DQPSK. COFDM was under consideration but the absence of strong multipath (against which COFDM is very robust) and the relative weakness of COFDM to phase noise make it an unlikely candidate (see Section 7.4 of this survey for more information on COFDM). Table 10 presents the various parameters used.

Cell size (Radius)	2 to 5 km	
Base Station Antenna Height	20 to 40 m	
Access Scheme Downlink	FDM/TDM	
Access Scheme Uplink	TDM/MF-TDMA	
Downlink		
RF Power at the Transmitter	20 to 27 dBm	
Bandwidth of the Amplifier	500 MHz to 1.5 GHz	
Channel Coding	2/3 or ¾ rate Viterbi with concatenated R-S	
Modulation Scheme	QPSK or 16 QAM	
Rx Noise Figure for the LNA	6 to 7 dB	
Transmission Data Rate (MPEG-2)	34 Mb/s	
ATM Traffic Data Rate	25 Mb/s	
Channel Spacing	39 MHz	
Uplink	Current	Future Upgrade
RF Power	14 dBm	20 dBm
Transmission Rate	8.5 Mb/s	34 Mb/s
Actual Data Rate	6 Mb/s	25 Mb/s
Modulation Scheme	GMSK or DQPSK	QPSK
Channel Coding	Reed-Solomon (R-S)	
Noise Figure at the Base Station Rx	5 dB	4 dB

**Table 10** Typical parameters for the CRABS MVDS project.

One of the prototype systems was used to re-broadcast satellite programs. A simple frequency conversion was used to convert the signal from satellite frequency to LMDS but added a loss. Demodulation from the satellite and re-modulation to LMCS would provide better performance. The transmission was done by dividing an area in 90-degree sectors and by alternatively using two different frequency bands and two polarizations (vertical and horizontal). New antennas using dual reflector provide an almost square coverage pattern. A contention channel was used to control two-way traffic in high-density areas. The return path used FSK because of its simplicity and availability. GMSK (more power-efficient) and DQPSK (more capacity) will be used in the future.

A standard for the MVDS interaction channel [EN 301 199] has been proposed to the ITU. It is based on the DVB standard on Return Channel for Cable & LMDS (RCCL). The downlink is using DVB-S and the up-link is providing a 3 and a 6 Mb/s ATM. Three access modes are offered. Future versions of this standard should include a higher upstream data rate. This standard was submitted to ITU-R-3 Working Party 3K (Document 3-47). (See <http://www.itu.int/itudoc/itu-r/sg3/docs/wp3k/1998-99/contrib/index.html>).

#### 8.4.2 Coverage

A typical cell has a 2 (in urban areas) to 5-km radius (in rural areas). Within a 2-km cell and using a 30-m transmitter antenna, the location availability is estimated to be between 40 and 60 %. A 99.99 % availability will require a 15-dB rain margin for most of Europe. The margin requirements will be too high to make a 99.997 % availability practical. Some space diversity at the base station could be required.

Coverage is improved when an area can receive from more than one transmitter: from 44 % with one transmitter to 80 % for two. The improvement becomes smaller when there is more than three transmitters available. This availability was also increased by 1-2% for each meter of additional height at the transmitter antenna and by 3-4% for each meter added to the user antenna height. Tree blockage affected about 20% of the area in the UK, with attenuation of 4-5 to up to 10 dB per meter of vegetation. Dynamic attenuation of up to 20 dB was observed when the wind moved the trees. The attenuation is proportional to the wind speed and can last from 10 ms to 1 second. Wet snow on the antenna will also create a very significant attenuation. Typical multipath amplitude is -40 dB with a few reflections as high as -20 dB. Coverage prediction of the Oxford area was also completed using a precise (1-meter) three-dimensional building database, which included buildings and vegetation. Statistical prediction models were also developed. The prediction is based on the ratio between land and built-up area and the building height distribution. The prediction model also takes into consideration the spatial distribution of rain.

### 8.4.3 Implementation

Business plans were developed (See <http://www.eurescom.de/public/newpub.htm>). Various demonstrations and tests were done in Russia, Italy, Norway, and Greece to determine user requirements, and to try to establish pricing. The trials were performed by cable operators, broadcasters, telecom operators, and research organizations. They included digital broadcasting, fast Internet, educational aspects, and telecom services requiring broadband access. These trials, which comprised two phases, provided several channels of digital broadcasting at 42-GHz with an interactive return path, initially at low data rates. This utilized either existing radio-based systems (DECT or GSM), or twisted pairs. In the second phase, broadband interactive channels were implemented at data rates up to several Mb/s where ATM technology was used. The return path transmissions were accomplished through millimeter-wave systems. From the third phase, the project extension MAPT (Microcellular Access Platform for Telecommunications) has been included in CRABS. Its main objective was to establish a platform for provision of TV and Telephony in particular, but also Internet and other services, in areas with poor telecommunications infrastructure.

Some limitations of the experimental system (not enough TV channels, only Italian TV channels available in Greece, not enough participants, etc.) did not make the study very conclusive. Philips predicts 1.8 millions users at 28 GHz and 0.5 million at 42 GHz in the year 2001. In 2002 these numbers could be 2.3 millions and 3.0 millions. The MMIC technology is favored for implementation over a hybrid technology. The production is pending the definitive channel planning. More work is required to:

- design low-cost equipment;
- establish regulation on interference between two neighboring operators;
- establish commonality between satellite and MVDS;
- determine the best implementation for the return channel;
- confirm that MPEG-2 is better than ATM encapsulation on the forward channel.

The main competition to MVDS seems to be coming from the latest generation of cellular communication, the UMTS, which can provide links of up to 2 Mb/s.

## 9. Conclusion

More tests are required in order to characterize the channel for different frequency bands and to determine what is the best digital modulation scheme for each broadband wireless transmission system. There is also a need to develop appropriate coverage prediction software – especially for various tree densities and built-up areas – that can be used to find the most appropriate design for network configuration. In particular, there is a lack of information on the effectiveness of passive reflectors and active on-frequency repeaters. Finally, demonstrations and market studies are necessary to assure consumer's acceptance.

We hope that the information presented in this survey will be helpful in reaching these objectives.

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