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Interference Considerations at LMDS/LMCS License Boundaries[1]

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1 Introduction

Point-to-multipoint (P-MP) communications systems[2] in the 25 to 32 GHz are being licensed throughout the world. These systems are variously referred to as local multipoint communications systems (LMCS) or local multipoint distribution service (LMDS). Administrations generally issue operating licenses on a region or country basis and over a block bandwidth of several hundred MHz. Operators select bandplans (RF channel arrangements) to match their market need and may adjust the bandplans without notifying administrations.

Equipment for LMDS/LMCS is designed for deployment in a cellular structure. Hub stations generally cover an area from 1 to 5 kilometers around the cell site. Some systems separate the coverage area into sectors (typically 90º). Subscriber stations[3] generally use high-gain directional antennas pointed directly at the hub stations.

Self-interference management is an important consideration for designing these systems. Systems within an operating area are coordinated so that inter-cell interference is low enough to permit system operations. Operators may choose to deploy equipment from different vendors or equipment with different bandplans, which will create the equivalent of coordination boundaries within an operator's area.

Transmissions from systems can cause interference to other systems. Systems near regional boundaries are likely to have signal levels strong enough to cause interference to other systems and will need to be coordinated to mitigate the effects of interference between the systems.

This paper presents a discussion of the interference mechanisms, derives quantitative relationships for modeling interference, and proposes a recommendation for coordination triggers (Appendix A).

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[2] These systems are referred to as Local Multipoint Communication Systems (LMCS) and Local Multipoint Distribution Services (LMDS).

[3] A subscriber station is also known as a remote terminal (RT) or customer premises equipment (CPE)

2 Authorized Operating Levels

In the United States, LMDS/LMCS equipment hubs can operate at up to +30 dB(Wi/MHz)[4] and subscriber stations can operate at up to +42 dB(Wi/MHz) EIRP [FCC, 101]. In Canada, LMDS hubs can operate at up to -52 dB(Wi/Hz) which we interpret as +8 dB(Wi/MHz) [IC, RS191].

For sharing between fixed services (FS) and inter-satellite services (ISS), the protection limit for fixed services is -115 dB(W/m^2) in any 1 MHz bandwidth for elevation angles from 0º to 5º [ITU-R RR S21].

Spurious emissions may also produce interference signals. For digitally modulated signals around 28 GHz, the emission rules in terms of attenuation of emissions into the antenna are as follows:

- In any 4 kHz band, the center of which is removed from the assigned frequency by more than 250% of the authorized bandwidth: at least 43 + 10 $\log_{10}$(mean power output in Watts) or 80 dB, whichever is the least attenuation [Freeman, & ITU-R CPM97].
- For transmitters operating at less than +37 dBW, the emission rule becomes an absolute power of -43 dBW.
- In the United States, a 1 MHz bandwidth is used [FCC-101].

3 Equipment Characteristics

System characteristics for LMDS systems are beginning to be published [ITU-R F.758mod]. The tables for LMDS for the draft modification to ITU-R F.758 are reprinted in Appendix B of this document. These tables reflect the implementation of Bosch Telecom, Inc. Other equipment vendors may have different characteristics for their LMDS systems. The input document for the draft modification is on the ITU-R web server [ITU-R 9B/37-E, 9D/35-E and JRG7D-9D/11-E], which has details about link margin calculations and antenna patterns.

Table B-1 in Appendix B denotes a system operating at +8 dB(Wi/MHz) hub EIRP spectral density and table B-2 denotes a system operating at +30 dB(Wi/MHz) hub station EIRP spectral density. Footnote 8 describes the clear-air link margin produced by the system. Footnote 7 denotes operational plans to operate the hub transmit power set-point over a [20] dB range depending on deployment considerations such as rain zone, link availability requirements, and interference to other receivers. The upstream path operates like a point-to-point (P-P) link in that the remote terminal (RT) transmitter uses a narrow beamwidth antenna. The downstream path operates like a broadcast station in that the hub station transmits energy over a wide-coverage area.

As implied in the tables, automatic power control (APC) is used for the upstream path (remote terminal to hub) but not the downstream path (hub-to-remote terminal). Power control for the upstream path is also referred to as remote terminal power control (RTPC).

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[4] Conventionally, the unit is dB(W/MHz) for EIRP spectral density. For clarification purposes, the authors prefer to use dB(Wi/MHz) to signify deciBels referenced to Watts in a 1 MegaHertz bandwidth relative to an isotropic antenna.

Upstream power control is necessary and feasible in point-to-multipoint systems with adjacent sector and adjacent cell frequency reuse capability. Footnote 3 denotes that an interference detection algorithm is necessary to prevent escalation of remote terminal EIRP based on interference. The algorithm is necessary for system stability (i.e., to prevent remote terminal from escalating to full power in an interference-rich band or from intermodulation products caused by overloading the hub receiver). The narrow beamwidth of the remote terminal assures that high EIRP signals are directed toward the hub. With APC, the remote terminal transmits with high EIRP only to overcome excess pathloss between the hub and the remote terminal. The remote terminal transmits with enough power to maintain a constant single-to-noise ratio (SNR) at the hub receiver.

While downstream power control is desirable, there are several technical implementation difficulties for providing more than a few dB of power control range. The difficulties arise from trying to isolate between sectors and re-using the frequency between sectors. The hub antennas illuminate a broad coverage area (typically 90° or 360°). An attempt to raise power to overcome fades in one direction is much more likely to cause high-EIRP interference to adjacent systems with hub APC rather than remote terminal APC.

LMDS/LMCS systems can operate with over 100 remote terminals transmitting simultaneously (on different frequencies) within a sector. The upstream power control algorithm adjusts the remote terminal power to balance the signal strength received at the hub to within a few dB. If an interference signal is present on a particular channel, the power control algorithm will increase the remote terminal transmit power to maintain a constant E_b/N_0 (at the hub). Interference has the effect of imbalancing the signals seen at the hub receiver. The dynamic range of the hub receiver must be sufficient for anywhere from one to many carriers, as well as any carrier imbalance due to interference. Interference therefore adds to the dynamic range requirements of the hub receiver. If the dynamic range of the hub receiver is exceeded, then higher-order intermodulation products can be created which will be received by the hub demodulators and cause APC algorithms to react wildly.

4 Typical Operating Levels

The system described in Table B-1 of Appendix B is often operated at -5 dB(Wi/MHz) hub EIRP by provisioning the operating point of the hub transmitters.

5 Interference Scenarios

One system's signal is another system's interference. Figure 1 shows some scenarios. Transmitter T_1 sends the desired signal S_{12} to desired receiver R_2. Receiver R_2 also receives interference I_{32} (as well as other interferers such as I_{52} and I_{72} which are not shown in the figure). Transmitter T_3 sends signal S_{34} to receiver R_4. Other combinations are possible.

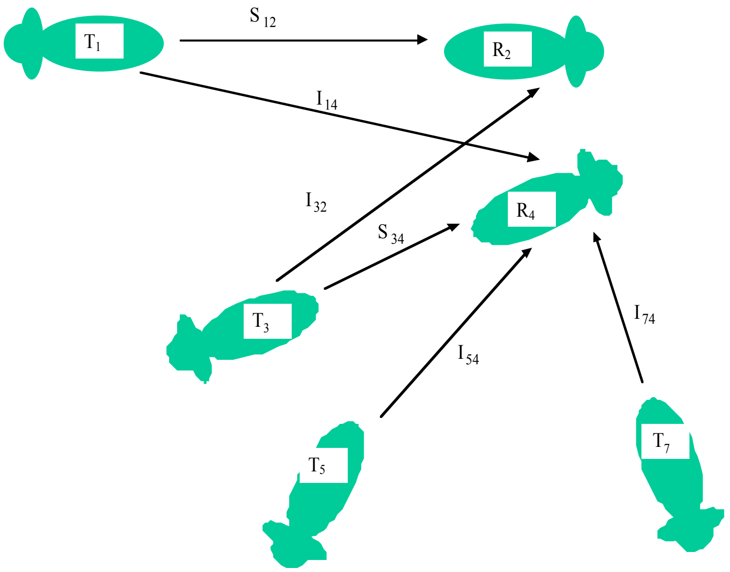

Figure 1 - Scenario Showing Possible Interactions between Various Transmitters and Receivers.

With automatic power control, transmit power is increased to compensate for path loss. If the signal fades, then its transmit power is increased to offset the fade. The additional transmit power available to offset fades is the power control dynamic range. It should be noted that if a transmitter increases power then interference also increases to other systems (e.g., I_{14}). A positive feedback situation can occur if there is interference coupling between the systems. If transmitter T_4 increases power to compensate for interference I_{14}, then the interference to receiver I_2 could increase (I_{32}). The instability potential is especially important if interference I_{32} causes intermodulation products that are sensed by the power control algorithm. Intermodulation products increase at twice the rate of interference or signal increases.

In addition, the signals and interference may vary with time. The transmitter may be turned on an off at various duty cycles. The transmitter may also change frequencies.

6 Signals, Noise, and Interference Relationships

Each path in Figure 1 is characterized by a received signal power which is a function of transmit power, antenna gains, and other factors as described in most radio engineering texts. Pettit gives an especially good treatment when considering the effects of interference [Pettit].

6.1 Link Equation

The power received at the antenna port of a receiver can be written as:

$$P_r = \frac{P_t \, G_{tr} \, G_{rt} \, \lambda^2}{(4\pi)^2 \, R_{tr}^2 \, L_{tr}} \qquad (1)$$

where

P_r = Received power spectral density, W/MHz

P_t = Transmit power spectral density, W/MHz

G_{tr} = Gain of transmit antenna in the direction of the receiver

G_{rt} = Gain of the receive antenna in the direction of the transmitter

L_{tr} = Attenuation in excess of free space due to atmospheric loss, rain fades, and other phenomenon along the path between the transmitter and receiver. At 28 GHz and for line-of-sight (LOS) orientation, the mean value of L_{tr} is approximately 0.15 dB/km [ITU-R P.530]. Scintillation can cause attenuation and path enhancement. Path enhancements (i.e., up-fades) of a few dB can occur occasionally [Marin]. Rain fades are the predominant mechanism for fades greater than 20 dB for paths less than 5 km.

λ = Wavelength of transmission

π = 3.14159

R_{tr} = Distance between the transmitter and receiver, meters

6.2 Power Flux Density and Effective Antenna Area

For frequency sharing studies, it is useful to separate the terms in equation (1) and define a power flux density and an effective receiver antenna area. Equation (1) can then be written as:

$$P_r = PFD_{tr} \cdot A_e = \left(\frac{P_t \, G_{tr}}{4\pi \, R_{tr}^2 \, L_{tr}} \right) \cdot \left(\frac{\lambda^2}{4\pi} \right) \cdot G_{rt} \tag{2}$$

where

PFD_{tr} = Power flux density, W/MHz-m^2

A_e = Effective receiver antenna area, m^2

The effective isotropically radiated power spectral density transmitted in the direction of the receiver is defined as:

$$EIRP_{tr} = P_t \cdot G_{tr} \tag{3}$$

where

$EIRP_{tr}$ = Effective isotropically radiated power spectral density in the direction of the receiver, W/MHz

The first term in equation (2) is the power flux density at the receiver due to the transmitter as given by:

$$PFD_{tr} = \frac{EIRP_{tr}}{4\pi \, R_{tr}^2 \, L_{tr}} \tag{4}$$

The second term in equation (2) is the effective area of the receive antenna as given by:

$$A_e = \left(\frac{\lambda^2}{4\pi}\right) G_{rt} \qquad (5)$$

The power flux density required at a receiver to produce a given received power at the output of the antenna is given by:

$$PFD_{Req} = \frac{P_r}{A_e} = \left(\frac{P_r}{G_{rt}}\right)\left(\frac{4\pi\, f^2}{c^2}\right) \qquad (6)$$

where

PFD_{Req} = Required power flux density at the receive antenna output, W/MHz-m^2

c = 3×10^8 = Speed of light, m/sec

λ = c/f = Wavelength of transmission, meters

f = Operating frequency, Hz

6.3 Signal to Noise

The signal-to-noise ratio can be defined as:

$$SNR = \frac{S}{N} \qquad (7)$$

where

SNR = Signal-to-noise ratio

S = Desired signal power, Watts

N = Noise power, Watts

The noise can be defined as:

$$N = k\, T_{sys}\, B \qquad (8)$$

where

k = 1.38×10^{-23} = Boltzmann's constant, J/K

T_{sys} = System temperature, K

B = Noise bandwidth, Hz

In terms of system noise figure, equation (8) can be rewritten as:

$$N = k\, T_0\, B\, F \qquad (9)$$

where

F = System noise figure

T_0 = 290 = System temperature, K

For digital links, the demodulator performance is often described by the term E_b/N_0. The relationship between E_b/N_0 and SNR is:

$$SNR_{Thr} = \left(\frac{E_b}{N_{0,Thr}} \right) \cdot \left(\frac{R_b}{B_N} \right) \tag{10}$$

where

SNR_{Thr} = Signal-to-noise threshold for proper circuit operation, which is often defined at a bit error rate (BER) less than 10^{-6}

E_b = Energy per bit, Joules/bit or Watt-sec/bit

N_0 = Noise energy, Joules, or equivalent noise power spectral density, Watt/Hz or Watt-sec

R_b = Payload bit rate without forward error correction, bits/sec

B_N = Nyquist bandwidth, Hz or 1/sec, which is often defined as the inverse of the symbol period ($1/T_s$) or the over-the-air symbol rate (R_S)

Assuming that forward error correction (FEC) is used, the relationship between over-the-air symbol rate and payload rate is:

$$R_b = m\, R_S\, r_C = log_2(M) \cdot (R_S\, r_C) \tag{11}$$

where

m = Number of information bits per RF symbol for a particular digital modulation method, bits/Symbol

M = Number of levels (or states) for an M-ary (or multilevel) transmission system; e.g., M = 4 levels and m = 2 bits/Symbol for QPSK

R_S = Over-the-air symbol rate, Symbols/sec

r_C = Code rate factor (i.e., ratio of payload bits to over-the-air bits)

Combining equations (10) and (11) yields:

$$SNR_{Thr} = \left(\frac{E_b}{N_{0,Thr}} \right) m\, R_C \tag{12}$$

For proper link operation,

$$SNR_{Rcvd} > SNR_{Thr} \tag{13}$$

That is, the received signal-to-noise ratio, SNR_{Rcvd}, must be large enough to produce a signal-to-noise ratio greater than the signal-to-noise threshold, SNR_{Thr}. (The received signal-to-noise ratio is measured at the demodulator output.)

When interference is present, a signal-to-noise-plus-interference ratio is defined as:

$$SNIR = \frac{S}{N+I} \tag{14a}$$

Alternatively, equation (14a) can be re-written as:

$$SNIR = \left(\frac{S}{N}\right) \frac{1}{1+(I/N)} \tag{14b}$$

where

I/N = Interference-to-noise ratio

The first term in equation (14b) is the signal-to-noise ratio. The second term is the SNIR degradation. The SNIR degradation results from the presence of interference power on the signal-to-noise ratio.

For proper ratio link operation, the received signal must be larger than the noise and interference according to:

$$SNIR_{Rcvd} > SNIR_{Thr} \tag{15}$$

where

$SNIR_{Rcvd}$ = Received signal-to-noise ratio

$SNIR_{Thr}$ = Signal-to-noise-plus-interference threshold for proper circuit operation, which is often defined at a bit error rate (BER) less than 10^{-6}

6.4 SNIR with Propagated Interference

Referring back to Figure 1, the desired signal at receiver R_2 from transmitter T_1 is:

$$S_{12} = \frac{P_1\, G_{12}\, G_{21}\, \lambda^2}{(4\pi)^2\, R_{12}^2\, L_{12}} \tag{16a}$$

The interference from transmitter T_3 into receiver R_2 is:

$$I_{32} = \frac{P_3\, G_{32}\, G_{23}\, \lambda^2}{(4\pi)^2\, R_{32}^2\, L_{32}} \tag{16b}$$

The signal-to-noise-plus-interference ratio at receiver 2 is:

$$SNIR_2 = \left(\frac{S_{12}}{N}\right) \frac{1}{1+(I_{32}/N)} = \left(\frac{S_{12}}{k\, T_{sys}\, B}\right) \frac{1}{1+(I_{32}/k\, T_{sys}\, B)} \tag{16c}$$

Substituting equations (16a) and (16b) into equation (14b) yields:

$$SNIR_2 = \frac{P_1\, G_{12}\, G_{21}\, \lambda^2}{(4\pi)^2\, R_{12}^2\, L_{12}\, (k\, T_2\, B_2)} \;?\; \frac{1}{1 + \dfrac{P_3\, G_{23}\, G_{32}\, \lambda^2}{(4\pi)^2\, R_{32}^2\, L_{32}\, (k\, T_2\, B_2)}} \quad (16d)$$

Equations (16c) and (16d) provide insight into several conditions. For systems without APC, the link design parameters (P_1, G_{12}, G_{21}, T_2, R_{12}, B_2) are set to provide a specific clear-air link margin. Clear-air link margins of 20 to 60 dB are necessary depending on the range and geographic location. The margin is the limit of how much the path L_{12} can increase without loss of service.

For systems with APC, P_1 increases to compensate for increases in L_{12}. The second term in (16c) is written in terms of an interference-to-noise ratio. An increase in P_3 causes a decrease in signal-to-noise-plus-interference ratio.

For equation (16d), Table 1 shows the SNIR degradation as a function of the interference-to-noise ratio. A typical system might have a fade margin of 20 dB, (i.e., a clear-air signal-to-noise requirement of 20 dB). Table 1 shows that the signal-to-noise-plus-interference ratio is reduced as the interference-to-noise ratio is increased. Reducing the signal-to-noise-plus-interference ratio decreases the link margin. An interference-to-noise ratio as little as -10 dB reduces link margin by 0.41 dB.

Table 1 - SNIR Degradation as a Function of I/N.

I/N, dB	SNIR Degradation, dB
-30	-0.0043
-20	-0.0432
-10	-0.4139
0	-3.0103
10	-10.4139

Equations 16c and 16d are written in terms of a single interference, but can be extended to incorporate additional interference sources.

7 Transmitted Power Flux Density

What is the transmitted power flux density for various values of EIRP spectral density as a function of distance from a transmitter? From equation (4) and for free-space conditions (i.e., L_{tr} = 0 dB),

$$PFD_t = 10\,log\left(\frac{10^{EIRP/10}}{4\pi\, R_{tr}^2}\right) \quad (17)$$

A transmitter operating at a power spectral density of -5 dB(Wi/MHz) will produce a line-of-sight power flux density of -116 dB(W/MHz-m^2) at a distance of 100 km.

To meet a power flux density limit of -115 dB(W/MHz-m^2) and assuming line-of-sight orientation, the transmitter 100 km from that receiver can radiate at no more than -4 dB(Wi/MHz) in the direction of the receiver.

Using equation (17), Table 2 shows the effects of distance and EIRP spectral density on power flux density.

Table 2 - Power Flux Density, dB(W/MHz-m^2), as a Function of Distance for a Given EIRP Spectral Density.

EIRP Spectral Density, dB(Wi/MHz)	Power Flux Density, dB(W/MHz-m^2), from a Transmitter					
	Distance, km					
	1	5	10	20	50	100
-50	-121	-135	-141	-147	-155	-161
-30	-101	-115	-121	-127	-135	-141
-10	-81	-95	-101	-107	-115	-121
-5	-76	-90	-96	-102	-110	-116
8	-63	-77	-83	-89	-97	-103
30	-41	-55	-61	-67	-75	-81
42	-29	-43	-49	-55	-63	-69

What is the potential effect of spurious emissions? Spurious emissions at -43 dB(W/4 kHz) are equivalent to -19 dB(W/MHz) for broadband signals. A spurious emission at -19 dB(W/MHz) processed by a 15 dBi gain antenna produces -4 dB(Wi/MHz). Therefore, spurious emissions can be comparable to desired signal levels.

What is the allowed *EIRP* to meet a power flux density limit? Rewriting equation (4) in terms of *EIRP* for a given transmitted power flux density yields:

$$EIRP = 10\log\left(\frac{L_a \cdot 10^{PFD_t/10}}{4\pi R_{tr}^2}\right) \tag{18}$$

For equation (18), Table 3 shows the effects of distance and power flux density on EIRP spectral density.

Table 3 - EIRP Spectral Density, dB(Wi/MHz), as a Function of Distance for a Given Power Flux Density.

Power Flux Density, dB(W/MHz-m^2)	EIRP Spectral Density, dB(Wi/MHz)					
	Distance, km					
	1	5	10	20	50	100
-115	-44	-30	-24	-18	-10	-4
-110	-39	-25	-19	-13	-5	1
-105	-34	-20	-14	-8	0	6
-100	-29	-15	-9	-3	5	11
-90	-19	-5	1	7	15	21
-80	-9	5	11	17	25	31
-70	1	15	21	27	35	41
-60	11	25	31	37	45	51

Flux density decreases as the distance increases from a transmitter. For a given EIRP spectral density and a specified flux density, Figure 2 shows the allowed distance for selected PFD values. A hub operating with an EIRP spectral density in the direction of a victim system at -5 dB(Wi/MHz) needs to be over 90 km away to meet a PFD limit of say -115 dB(W/MHz-m^2).

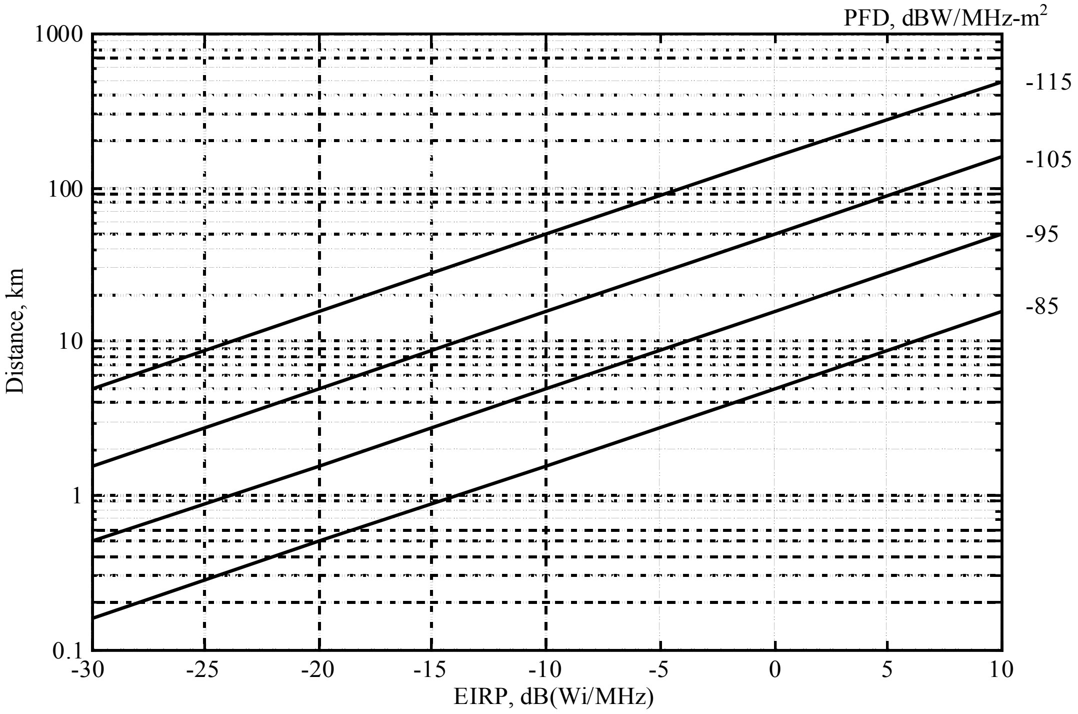

Figure 2 - Distance versus Transmitter EIRP Spectral Density for a Specified Flux Density at a Receiver.

To meet a coordination boundary requirement of say -115 dB(W/MHz-m^2) while at the same time operating at -5 dB(Wi/MHz) EIRP spectral density to some subscribers, a hub antenna would have to discriminate by either cross-polarization or by sidelobes and backlobe. If 20 dB of isolation can be obtained, then the hub could be just over 10 km from the victim system.

Why choose -115 dB(W/MHz-m^2)? This value was picked as a compromise. It is good enough for hubs that look over a broad azimuth; however, it is not good enough for subscriber terminals. However, the narrow beam width of subscriber terminal antennas reduces the probability that interference will effect communications with the subscriber terminal. The PFD value of -115 dB(W/MHz-m^2) also matches the satellite interference protection limit for low elevation angles [ITU-R RR S21].

Note that a coordination distance of 20 km is insufficient to assure only slight interference between systems.

8 Power Flux Density Required for Communications

From the parameters of Appendix B, an interference signal received at -146 dB(Wi/MHz) will cause 0.5 dB of degradation for downstream and 0.5 dB of transmit power increase for upstream. Table 4 converts the received signal level (RSL) spectral density into a power flux density required for service.

Table 4 - Power Flux Density, dB(W/MHz-m^2), at 27.5 GHz as a Function of Receive Signal Spectral Density for a Given Receive Antenna Gain.

Receive Antenna Gain, dBi	Power Flux Density, dB(W/MHz-m^2), at 27.5 GHz				
	Receive Signal Level Spectral Density, dBW/MHz				
	-150	-130	-110	-90	-70
0	-100	-80	-60	-40	-20
10	-110	-90	-70	-50	-30
20	-120	-100	-80	-60	-40
30	-130	-110	-90	-70	-50
40	-140	-120	-100	-80	-60
50	-150	-130	-110	-90	-70

The receive signal threshold is -127 dBW/MHz. The noise floor is at -136 dB(W/MHz) and the maximum interference power for an I/N of -10 dB is -146 dB(W/MHz). Upstream and downstream signal power levels are within a few dB of each other due to slight differences in noise figure and the effect of automatic power control. The power flux density for various antenna gains is shown in Table 5. From Table 5, a remote terminal will sense interference in the presence of external interferers.

Table 5 - Power Flux Density, dB(W/MHz-m^2), at 27.5 GHz as a Function of Receive Antenna Gain for a Given Receive Signal Level Spectral Density.

RSL Spectral Density, dB(W/MHz)	Comments	Power Flux Density, dB(W/MHz-m^2), at 27.5 GHz					
		Antenna Gain, dBi					
		36	16	6	0	-4	-14
-93	RSL @ 5km & +8 dB(Wi/MHz) EIRP	-79	-59	-49	-43	-39	-29
-106	RSL @ 5km & -5 dB(Wi/MHz) EIRP	-92	-72	-62	-56	-52	-42
-127	RSL threshold, BER = 10^{-6}	-113	-93	-83	-77	-73	-63
-136	Noise floor	-122	-102	-92	-86	-82	-72
-146	Max interference for I/N < -10 dB	-132	-112	-102	-96	-92	-82

Figure 3 shows that the minimum signal PFD required is -93 and -112 dB(W/MHz-m^2) at the hub and remote terminal, respectively. The maximum interference PFD in the main-beam of the receive antenna is -112 and -132 dB(W/MHz-m^2) for the hub and remote terminal, respectively. Minimum signal levels occur when the links are faded by the link margin of the radio link. These limits apply when the links are at the maximum fade margin in the signal path. Assuming 0 dBi sidelobe and -10 dBi backlobe receive antenna gain in the direction of the interference, the interference PFD can be up to -96 and -86 dB(W/MHz-m^2), respectively. A cross-polarity coupling of 0 dBi is also a good approximation for cross-polarized interference in the main-beam direction.

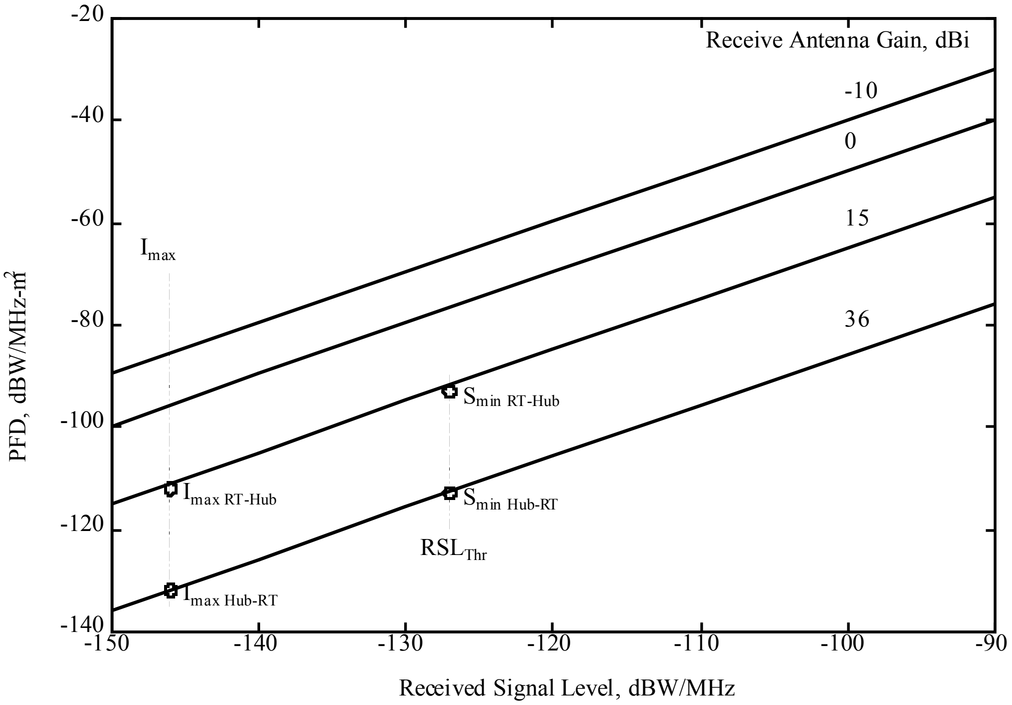

Figure 3 - PFD Required During Maximum Fade Conditions for a Given Signal or Interference Level and for a Specified Receive Antenna Gain.

Figure 4 shows an example scenario of interference into adjacent LMDS/LMCS cells from a remote terminal near a sector boundary. This is a function of several factors: hub spacing, alignment, visibility (line-of-sight), frequency, and polarization.

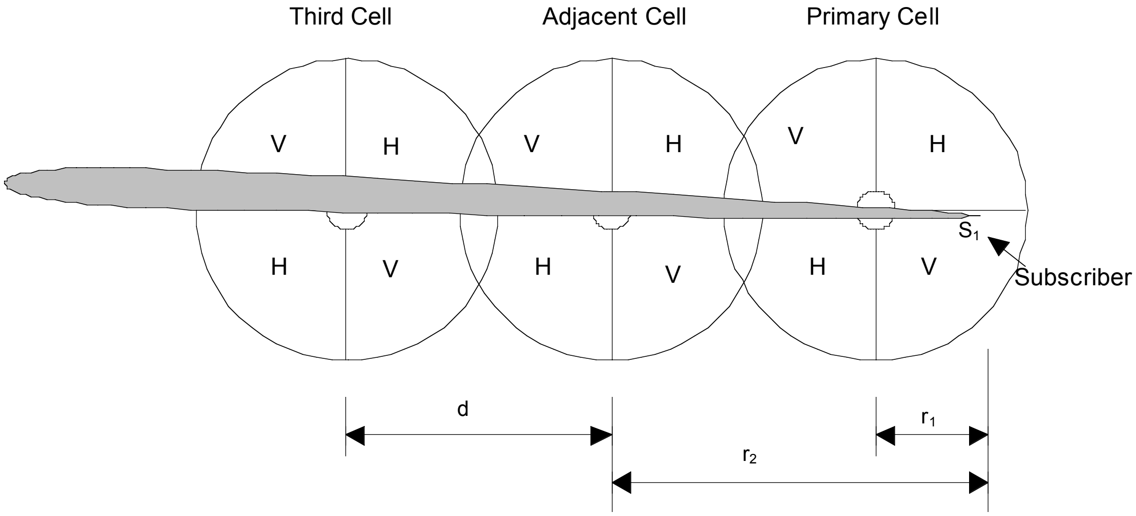

Figure 4 - Subscriber Interference Alignment.

What is the separation distance required for various antenna orientations using the system parameters of Appendix B? Figure 5 shows four possible antenna orientations. (1) back-to-back, (2) back-to-front, (3) front-to-front, and (4) front-to-back. The curved line in the center of the figure represents a coordination boundary.

Table 6 provides the distance required to meet the PFDtol. Back-to-back hubs can be closely located, nominally 300 meters. The approximate probability column is the probability of the stated orientation as one terminal is moved in azimuth around the other terminal and assumes a 180 degree beam width for hubs and 2 degree beam width for RTs. Front-to-back separation requires 3 km. Back-to-back coupling is used to allow closely space hubs. Back-to-back and back-to-front are likely scenarios at coordination boundaries. Note that front-to-front coupling between hubs requires 63 km. The front-to-front coupling of hubs that are second-removed from the boundary would need coordination.

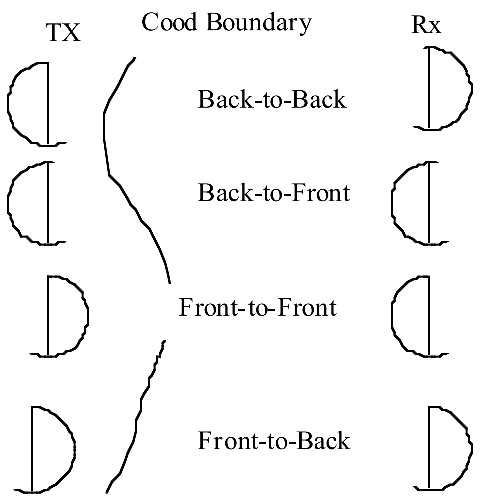

Figure 5 - Hub and RT Antenna Orientation Relative to Interference.

The biggest interference problem occurs for hub-to-hub coupling because the field of view is large which results in a high probability of occurrence. If the hubs are cross-polarized and the antennas have 20 dB discrimination, the separation distance becomes 6.3 km.

Table 6 - Range Required to Mean I$_{max}$ for a Given EIRP.

(antenna: hub front 15 dBi, hub back –10 dbi, RT front 36 dBi, RT back –10 dBi)

Path	Orientation	EIRP, dB(W/MHz)	PFD$_{tol}$, dB(W/MHz-m^2)	Range, km	Approx. Probability	Comments
Hub-to-Hub	Back-to-Back	-25	-86	0.3	0.5	
	Back-to-Front	-25	-112	6.3	0.5	
	Front-to-Back	-5	-86	3.2	0.5	
	Front-to-Front	-5	-112	63.1	0.5	Problem
RT-to-Hub	Back-to-Back	-25	-86	0.3	0.5	
	Back-to-Front	-25	-112	6.3	0.5	
	Front-to-Back	-5.3	-86	3.1	0.006	
	Front-to-Front	-5.3	-112	61.0	0.006	Low probability, APC
Hub-to-RT	Back-to-Back	-25	-86	0.3	0.5	
	Back-to-Front	-25	-132	63.1	0.006	Low probability
	Front-to-Back	-5	-86	3.2	0.5	Reduces fade magin
	Front-to-Front	-5	-132	631.0	0.003	Low probability
RT-to-RT	Back-to-Back	-51	-86	0.0	0.5	
	Back-to-Front	-51	-132	3.2	0.006	
	Front-to-Back	-5.3	-86	3.1	0.006	
	Front-to-Front	-5.3	-132	609.5	0.003	Low probability

Again, coordination boundaries of 20 km are not sufficient for hub-to-hub coupling.

9 Automatic Power Control

While power control helps reduce interference to other systems, the potential to interfere with other systems during faded conditions still exists. Debate has raged for years on an appropriate method to estimate interference between systems that employ APC.

Some of the debate is captured in the following [ITU-R F.758, Annex 3]:

"APC has been implemented to facilitate intra-service sharing and coordination based on lower transmit power. During fade conditions the power level is increased for a short duration to overcome the effect of the fade condition. There are two problems associated with the use of APC to overcome interference. First, it does not appear likely that the potential total interference time from non-GSO networks would be considered a short-term event. Therefore, any intra-service coordination based upon lower power levels would be inappropriate. The higher power levels that would need to be used for coordination purposes between FS systems may impact sharing with other services. Additionally, the higher transmit power of the FS would make other inter-service sharing issues, including interference into non-GSO network uplinks, more difficult. The second and perhaps more significant problem is that there is currently no practical method for sensing interference that would cause APC to activate. An increase in link margin beyond current engineering practices is not considered an appropriate method to improve resistance to interference and may make other inter-service sharing issues more difficult."

While the above quote was written specifically for an inter-service sharing issue at 1-3 GHz, many of the points apply to LMDS/LMCS when considering sharing across boundaries and sharing between cells in an array of cells. A suggested write of the above for LMDS/LMCS is as follows:

"LMDS/LMCS systems may implement APC in both upstream and downstream directions to facilitate sharing, reduce system cost, and improve system performance. During fade conditions, the transmit power may increase to overcome the effect of a fade condition. However when transmit powers are increased, not only is the desired signal increased, but potential interference from the main-beam, sidelobes, in-band, out-of-band, and spurious signals also may increase. Depending on the transmit antenna characteristics and the direction of the interfered-with system some, but probably not all, of the potential interference signal may be attenuated by the fade event that caused the increase in power. These interference signals can in turn cause APC algorithms on interfered-with systems to increase transmit power, causing an escalation of transmit powers by all affected systems and system instability.

There are two problems associated with the use of APC to overcome interference. First, it does not appear likely that interference time would be considered a short-term event or would come and go before APC algorithms on interfered-with systems would adjust to the interference. Therefore, coordination based on the power levels during non-fade conditions is inappropriate for coordination purposes. The higher power levels (of both desired and spurious signals) used during a fade event should be used when calculating interference caused by the systems that are affected by the fade event. (It should be noted that the probability of deep fades is less likely over areas covering a few kilometers.)

The second problem is that interference can decrease link margin and increase dynamic range requirements. Increasing link margin, increasing dynamic range, or sensing interference that would cause APC to activate adds significantly to the cost of LMDS/LMCS systems. But assuming interference *could be sensed, then the interfered-with system could move stations to another frequency resulting in less than full use of the authorized band."*

With APC enabled, the signal and interference limits calculated during a fade condition are the same as during clear sky conditions.

Without APC and during clear-sky conditions, the received signal increases above RSL threshold by the link margin. The link can therefore tolerate more interference than when faded to threshold. If the interference path loss is 100% correlated with the signal path loss, the interference can increase to a value that meets the receiver SNIR threshold. But 100% correlation is unlikely, so allowing that much interference is not good design practice. If the interference path loss in 100% uncorrelated with the signal path loss, the interference level must remain at less than the maximum interference, I_{max}, allowed during a maximum fade event. Because of the narrow beam width of the remote terminal antenna, interference into the remote terminal main-beam is expected to be highly correlated with path loss. Because of the broad sector coverage of the hub antenna, interference into the hub main-beam is expected to range from slightly to heavily correlated with signal path loss. Interference into the sidelobes and backlobes of either hub or remote terminal is expected to be slightly correlated with signal path loss.

For the upstream path, the remote terminal antennas are able to limit transmitted interference into other receivers for the following reasons: narrow beamwidth, high gain, and low sidelobe/backlobe levels. Obstruction of the desired signal is more likely to be the controlling mechanism for remote terminal APC. Remote terminal power control normalizes the received signal level at the input of hub receiver, thus allowing a few to a large number of carriers to be supported without adjusting the hub receiver. If subscriber signals vary more than a few dB at the hub receiver, additional dynamic range in hub receiver is required.

For the downstream path, transmissions from hubs are radiated over an area rather in a narrow beam. Downstream APC algorithms can either (1) increase power on an individual carrier basis or (2) sense coverage reductions over all subscribers in an area. If a carrier supports only one subscriber, then a power increase is based on a single remote terminal received signal strength. If a carrier supports several subscribers (downstream TDM), then an algorithm is needed to sense that the aggregate group of subscribers needs more power. Increasing any downstream carrier relative to signal levels in adjacent sectors has the effect of reducing isolation between the sectors. With current antenna technology, isolation of more than 20 dB between sectors is not practical. For frequency re-use between sectors, analysis shows that a carrier imbalance of approximately 6 dB is feasible. This would limit the downstream APC to 6 dB of dynamic range. It should be noted that hub antenna sidelobe and backlobe levels are typically not reduced nearly as much as those for the remote terminal antenna. Therefore for an obstruction causing a serious fade condition, an increase in hub transmit power is more likely to cause higher EIRP in all directions than a remote terminal power increase.

10 Conclusions

Point-to-multipoint LMDS/LMCS systems are being developed and deployed in bands around 28 GHz. Several interference considerations have been discussed. Observations are as follows:

1. Increasing power to overcome interference during clear-air conditions can cause interference into other systems. Coordination thresholds should be set such the interference has only a minor degradation (<0.5 dB) in system performance.
2. The use of power control reduces the probability of interference during clear sky conditions, but during fade events and in interference rich areas, power control can cause substantial interference.
3. Potential interference should be calculated based on the maximum transmit power capability during a fade event with proper consideration for the path loss and antenna gain between the transmitter and the victim system or "coordination" boundary.
4. Desensitization and inter-modulation distortion of the hub (node) receiver can occur if carrier imbalance (between the remote terminal signals) is greater than a few dB. Distortion events can cause power control algorithms to react wildly and coordination thresholds should be low enough to avoid causing distortion events to victim system.
5. High levels of interference degrade the signal-to-noise-plus-interference ratio (and hence the signal-to-noise ratio). Fade events may or may not attenuate interference along with the desired signal. A remote terminal with a high gain, narrow beamwidth antenna is a good discriminator against interference.
6. Coordination options include the following techniques: frequency, distance, antenna characteristics (low sidelobes and cross-polarization), and transmit power (including automatic power control).
7. A coordination boundary of 20 km is sufficient for many interference scenarios, but is not sufficient for scenarios with main-beam coupling such as for hub-to-hub or RT-to-RT. A coordination threshold should be based on a PFD limit rather than a coordination distance.
8. A suggested rule is to coordinate whenever [systems are less than 20 km from a "coordination" boundary or] the PFD exceeds a threshold of -115 dB(W/MHz-m^2). At such a level, a slight (0.5 dB) degradation in the signal-to-noise ratio might be experienced for some orientations of RT coupling.

REFERENCES

[FCC 101] US Federal Communications Commission, CFR-Title 47, Part 101, Fixed Microwave Services.

[FCC 2] US Federal Communications Commissions, CFR Title 47, Chapter 1, Part 2 Frequency Allocations and Radio Treaty Matters; General Rules and Regulations.

[Freeman] Roger L. Freeman, *Radio Systems Design for Telecommunications (1-100 GHz)*, John Wiley & Sons, New York, 1987.

[IC RSS191] Industry Canada, RSS191, Issue 1 (Draft), "Multipoint Communications Systems at 23 GHz, Local Multipoint Communications Systems at 28 GHz, and Point-to-Point Systems at 38 GHz," June 1997.

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[ITU-R 9B/temp/17-E] ITU-R 9B/TEMP/17-E, "Preliminary Draft Revision of Recommendation F.755-1, Point-to-Multipoint Systems in the Fixed Service."

[ITU-R F.1108] ITU-R F.1108-1, "Determination of the Criteria to Protect Fixed Service Receivers from the Emissions of Space Stations Operating in Non-Geostationary Orbits in Shared Frequency Bands," 1994-1995.

[ITU-R F.1191] ITU-R F.1191, "Bandwidths and Unwanted Emissions of Digital Radio-Relay Systems," 1995.

[ITU-R F.758mod] ITU-R/TEMP/9-e, "Preliminary Draft Revision to Recommendation ITU-R F.758-1 Considerations in the Development of Criteria for Sharing between the Terrestrial Fixed Service and Other Services," 6 Mar 1998.

[ITU-R F-758] ITU-R F.758-1 "Considerations in the Development of Criteria for Sharing between the Terrestrial Fixed Service and Other Services."

[ITU-R LMDS] ITU-R 9B/37-E and 9D/35-E, "Typical Technical and Operational Characteristics and Potential Interference Considerations of High Density Point-to-Multipoint Systems in the Frequency Band 25-32 GHz."

[ITU-R P.530] ITU-R P.530 "Propagation Data and Prediction Methods Required for Design of Terrestrial Line-of-Sight Systems," 1995.

[ITU-R RR S21] ITU-R Radio Regulations, Article S21, "Terrestrial and Space Services Sharing Frequency Bands Above 1 GHz."

[Marin] Scott Marin, William Myers, and Donnie Burt, "Medium Range Terrestrial Propagation Study at 28 GHz," Wireless Technologies and Systems: Millimeter-Wave and Optics Conference Proceeding, SPIE, Nov. 1997.

[Pettit] Ray H. Pettit, *ECM and ECCM Techniques for Digital Communications Systems*, Lifetime Learning Publications, 1982.

Appendix A - Preliminary Draft Recommendation

Coordination at Boundaries between LMDS/LMCS License Holders

The [administrations],

Considering,

a) that it is necessary to establish criteria for coordination between operators of Local Multipoint Communication Systems (LMCS) and Local Multipoint Distribution Service (LMDS) systems at boundaries.

b) that sharing may be managed by determining allowable values of performance and availability degradation's caused by interference between systems operating in LMDS/LMCS service.

c) that LMDS/LMCS systems will experience interference from systems in other services and bands.

d) that power control algorithms typically sense S/(N+I) ratio and will increase power to overcome interference and that increasing power to overcome interference can cause escalation of transmit power and system instability.

Recommends,

1) that a protection limit of [-115] dB(W/m^2) measured in a 1 MHz bandwidth be used as a criteria for coordination between operators on each side of a boundary. Table A-1 provides guidance on determining a coordination distance based on the power flux density limit.

2) that emissions no more than [5] dB above the protection limit in recommends 1) are allowed no more than [0.1%] of the time without coordination between operators.

Table A-1 - EIRP Spectral Density, dB(Wi/MHz), as a Function of Distance for a Given Power Flux Density.

Power Flux Density, dB(W/MHz-m^2)	EIRP Spectral Density, dB(Wi/MHz), Allowed for a Given PFD Limit				
	Distance, km				
	5	10	20	50	100
-115	-30	-24	-18	-10	-4
-110	-25	-19	-13	-5	1
-105	-20	-14	-8	0	6
-100	-15	-9	-3	5	11

Appendix B - Preliminary Draft Recommendation

LMDS/LMCS System Parameters for FS Frequency Sharing above 10 GHz

A paper[1] presenting the technical characteristics and operating factors for Local Multipoint Communication Systems (LMCS) and Local Multipoint Distribution Service (LMDS) systems in the frequency band 25 - 32 GHz was submitted by Bosch Telecom, Inc. via the U.S. delegation at the March 1998 WP9 meeting in Geneva. Tables B-1 and B-2 were included in a preliminary draft modification to ITU-R F758-1. [2]

LMDS/LMCS systems are proposed by various administrations in bands from 25 to 32 GHz. Some of these bands are shared with satellite services. Tables B-1 and B-2 contain the technical characteristics of high density point-to-multipoint systems providing video, T1, and data services. Other services can be provided with similar channelization and modulation formats. The tables summarize the LMCS/LMDS characteristics in Recommendation ITU-R F.758-1[3] format. It should be noted that the maximum hub station transmit power may be adjusted on a geographic basis to meet grade of service goals.

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[1] *Typical Technical and Operational Characteristics and Potential Interference Considerations of High Density Point-to-Multipoint Systems in the Frequency Band 25 - 32 GHz*, Document USWP-9B/2 (Rev 2).

[2] ITU-R/TEMP/9-e, “Preliminary Draft Revision to Recommendation ITU-R F.758-1 Considerations in the Development of Criteria for Sharing between the Terrestrial Fixed Service and Other Services,” 6 March 1998.

[3] Recommendation ITU-R F.758-1, “Considerations in the Development of Criteria for Sharing between the Terrestrial Fixed Service and Other Services,” 1997.

Table B-1 - Typical High Density Point-to-Multipoint Fixed Service System Parameters for FS Frequency Sharing above 10 GHz (Operation at +8 dB(Wi/MHz) Hub EIRP Spectral Density)

Frequency band (GHz)	Notes	25.25-27.5, 27.5-28.35, 29.1-29.25, 31.0-31.3 (8) (9)						
Service Type		1-way Broadcast	2-way Symmetric			2-way Asymmetric – TDMA		
Modulation		QPSK FDM/TDM	QPSK FDM/TDM	QPSK FDM/TDM	QPSK FDM/TDM	QPSK FDM/TDM	QPSK FDM/TDMA	QPSK FDM/TDMA
Capacity		1 Ch / 40 MHz BW	20 Ch / 30 MHz BW	20 Ch / 30 MHz BW	20 Ch / 30 MHz BW	1 Ch / 50 MHz BW	20 Ch / 50 MHz BW	20 Ch / 50 MHz BW
Channel Spacing (code rate _) (MHz)		40	1.36	1.36	1.36	50	2.5	2.5
		Hub - RT	Hub - RT	RT - Hub	RT - Hub	Hub - RT	RT - Hub	RT - Hub
Condition		Clear - Air	Clear - Air	Clear - Air	Rain - Faded	Clear - Air	Clear - Air	Rain - Faded
Antenna Gain (Max.) (dBi)		15	15	36	36	15	36	36
Feeder/Multiplexer Loss (Min.) (dB)		0	0	0	0	0	0	0
Antenna Type (EL x AZ)		15° x 90° Horn	15° x 90° Horn	2° x 2° Dish	2° x 2° Dish	15° x 90° Horn	2° x 2° Dish	2° x 2° Dish
Max. Tx Output Power (dBW)		9.0 (7)	-5.7 (7)	-40.0	-4.2 (7)	10.0 (7)	-32.7	4.0 (7)
Max. Tx Power Spectral Dens. (dBW/MHz)		-7.0 (7)	-7.0 (7)	-41.3	-5.5 (7)	-7.0 (7)	-36.7	0.0 (7)
EIRP (Max.) (dBW)		24.0 (7)	9.3 (7)	-4.0	31.8 (7)	25.0 (7)	3.3	40.0 (7)
Receiver IF Bandwidth (MHz)	(6)	40.0	1.36	1.36	1.36	50.0	2.5	2.5
Receiver Noise Figure (Typ.) (dB)		7.0	7.0	7.5	7.5	7.0	7.5	7.5
Receiver Thermal Noise (dBW)	(5)	-121.0	-135.6	-135.1	-135.1	-120.0	-132.6	-132.6
Rx Input Level for 10^{-3} BER (dBW)								
Nominal Rx Input Level for 10^{-6} BER @ 5 km (dBW)		-77.0	-91.7	-126.0	-125.9	-76.0	-118.7	-118.6
Rx E_b/N_0 for 10^{-6} BER (dB)		7.2	7.6	8.6	8.6	7.2	14.0	14.0
Nominal Short-Term Interference (dBW) (% time)								
Nominal Long-Term Interference (dBW)	(1) (2)	-130.1	-144.8	-144.3	-144.3	-129.1	-141.6	-141.6
Equivalent Power (dBW/4 kHz)		-170	-170	-170	-170	-170	-170	-170
Spectral Density (dBW/MHz)		-146	-146	-146	-146	-146	-146	-146
Refer to Notes			(4)	(3) (4)	(3) (4)		(3)	(3)

Hub: Hub Station   RT: Remote Terminal (Subscriber Station)   TDM: Time-Division Multiplexed (Continuous Transmission When in Service)
N/A: Not Applicable   FDM: Frequency-Division Multiplexed   TDMA: Time-Division Multiple Access (Burst Transmission)

(1) Specified interference will reduce system *C/N* by 0.5 dB.
(2) The specified interference level is total power within the receiver bandwidth.
(3) Remote terminal power control (RTPC) is used to transmit the minimum power necessary to meet the hub receiver threshold (E_b/N_0). In order to limit system self-interference to less than 10 dB, an interference mitigation algorithm detects interference and restricts transmit EIRP escalation.
(4) Code rates typically range from rate _ to rate 7/8.
(5) Receiver thermal noise is based on Nyquist bandwidth of detection process.
(6) Total occupied bandwidth per carrier.
(7) Operating points are typically set to meet fade margin requirements while minimizing self-interference. Systems with these values will typically be operated in locations where fade margins at 5 km are from 20 to 40 dB. Interference studies should take into account fade margin requirements and related operating points for a given location and hub-to-RT separation.
(8) Typical parameters for a point-to-multipoint system operating at +8 dB(Wi/MHz) hub EIRP spectral density and requiring 37 dB of fade margin at 5 km hub-to-RT separation.
(9) JRG 7D-9D is considering sharing in the band 25.25 to 27.5 GHz.

Table B-2 - Typical High Density Point-to-Multipoint Fixed Service System Parameters for FS Frequency Sharing above 10 GHz (Operation at +30 dB(Wi/MHz) Hub EIRP Spectral Density)

Frequency band (GHz)	Notes	27.5-28.35, 29.1-29.25, 31.0-31.3 (8)						
Service Type		1-way Broadcast	2-way Symmetric			2-way Asymmetric – TDMA		
Modulation		QPSK FDM/TDM	QPSK FDM/TDM	QPSK FDM/TDM	QPSK FDM/TDM	QPSK FDM/TDM	QPSK FDM/TDMA	QPSK FDM/TDMA
Capacity		1 Ch / 40 MHz BW	20 Ch / 30 MHz BW	20 Ch / 30 MHz BW	20 Ch / 30 MHz BW	1 Ch / 50 MHz BW	20 Ch / 50 MHz BW	20 Ch / 50 MHz BW
Channel Spacing (code rate _) (MHz)		40	1.36	1.36	1.36	50	2.5	2.5
		Hub - RT	Hub - RT	RT - Hub	RT - Hub	Hub - RT	RT - Hub	RT - Hub
Condition		Clear - Air	Clear - Air	Clear - Air	Rain - Faded	Clear - Air	Clear - Air	Rain - Faded
Antenna Gain (Max.) (dBi)		24	24	36	36	24	36	36
Feeder/Multiplexer Loss (Min.) (dB)		0	0	0	0	0	0	0
Antenna Type (EL x AZ)		3° x 45° Horn	3° x 45° Horn	2° x 2° Dish	2° x 2° Dish	3° x 45° Horn	2° x 2° Dish	2° x 2° Dish
Max. Tx Output Power (dBW)		22.0 (7)	7.3 (7)	-49.0	7.3 (7)	23.0 (7)	-41.7	10.0 (7)
Max. Tx Power Spectral Dens. (dBW/MHz)		6.0 (7)	6.0 (7)	-50.3	6.0 (7)	6.0 (7)	-45.7	60.0 (7)
EIRP (Max.) (dBW)		46.0 (7)	31.3 (7)	-13.0	43.3 (7)	47.0 (7)	-5.7	46.0 (7)
Receiver IF Bandwidth (MHz)	(6)	40.0	1.36	1.36	1.36	50.0	2.5	2.5
Receiver Noise Figure (Typ.) (dB)		7.0	7.0	7.5	7.5	7.0	7.5	7.5
Receiver Thermal Noise (dBW)	(5)	-121.0	-135.6	-135.1	-135.1	-120.0	-132.5	-132.5
Rx Input Level for 10^{-3} BER (dBW)								
Nominal Rx Input Level for 10^{-6} BER @ 5 km (dBW)		-55.0	-69.7	-126.0	-125.9	-54.0	-118.7	-118.6
Rx E_b/N_0 for 10^{-6} BER (dB)		7.2	7.6	8.6	8.6	7.2	14.0	14.0
Nominal Short-Term Interference (dBW) (% time)								
Nominal Long-Term Interference (dBW)	(1) (2)	-130.1	-144.8	-144.3	-144.3	-129.1	-141.6	-141.6
Equivalent Power (dBW/4 kHz)		-170	-170	-170	-170	-170	-170	-170
Spectral Density (dBW/MHz)		-146	-146	-146	-146	-146	-146	-146
Refer to Notes			(4)	(3) (4)	(3) (4)		(3)	(3)

Hub:	Hub Station	RT:	Remote Terminal (Subscriber Station)	TDM:	Time-Division Multiplexed (Continuous Transmission When in Service)
N/A:	Not Applicable	FDM:	Frequency-Division Multiplexed	TDMA:	Time-Division Multiple Access (Burst Transmission)

(1) Specified interference will reduce system *C/N* by 0.5 dB.

(2) The specified interference level is total power within the receiver bandwidth.

(3) Remote terminal power control (RTPC) is used to transmit the minimum power necessary to meet the hub receiver threshold (E_b/N_0). In order to limit system self-interference to less than 10 dB, an interference mitigation algorithm detects interference and restricts transmit EIRP escalation.

(4) Code rates typically range from rate _ to rate 7/8.

(5) Receiver thermal noise is based on Nyquist bandwidth of detection process.

(6) Total occupied bandwidth per carrier.

(7) Operating points are typically set to meet fade margin requirements while minimizing self-interference. Systems with these values will typically be operated in locations where fade margins at 5 km are from 40 to 60 dB. Interference studies should take into account fade margin requirements and related operating points for a given location and hub-to-RT separation.

(8) Typical parameters for a point-to-multipoint system operating at +30 dB(Wi/MHz) hub EIRP spectral density, up to +42 dB(Wi/MHz) RT EIRP spectral density, and requiring 57 dB of fade margin at 5 km hub-to-RT separation.