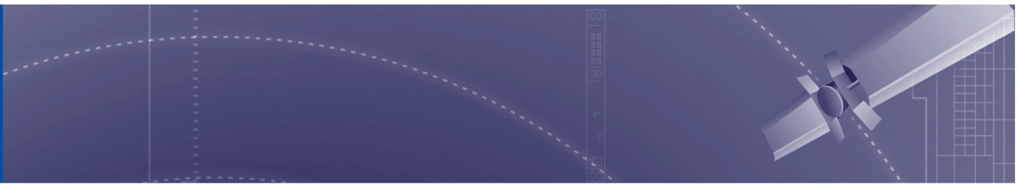
HUGHES
NETWORK SYSTEMS

Mitigating Propagation Impairments at Millimeter Wave Frequencies In Point-to-Multipoint Broadband Wireless Systems

HUGHES
NETWORK SYSTEMS



A White Paper for Telecommunications Service Providers Using the AIReach® Broadband 9000 System

This AIReach Broadband White Paper discusses issues associated with radio wave propagation at millimeter wave frequencies. It examines the impact of rain and discusses steps that a radio system can take to mitigate this impact. The intended audience of this paper is the technical staff of telecommunications service providers who are taking advantage of AIReach 9000 systems for broadband wireless access (BWA) or cellular backhaul networks.

1.0 Background

As the cost of high-frequency components has fallen, millimeter wave bands have become attractive for the transmission of broadband data and voice. These transmissions include 24, 26, 28, 31, and 38 GHz bands. Millimeter bands offer higher capacity than traditional, lower frequency bands as well as high gain/directivity antennas. Since they are line-of-sight systems, they offer better frequency utilization efficiency due to the superior frequency reuse schemes rendered by high gain antennas.

Many factors contribute to the use of point-to-multipoint (PMP) systems in millimeter wave bands. These factors include the efficient use of spectrum, the ability to deliver true broadband services at symmetrical rates up to 45 Mbps, and the ability to address the issue of the high, recurring rooftop costs for placing antennas on desirable buildings. With the AIReach system, a single radio at the PMP hub can deliver and manage 45 Mbps of full duplex user traffic, spread over a large number of remote sites, using only 25 MHz of spectrum. By contrast, depending upon the traffic profile per site, it could take a large number of point-to-point transceiver radios and antennas at the hub to serve the same requirement.

“PMP systems … deliver true broadband services at symmetrical rates up to 45 Mbps…”

In using PMP systems, the absorption of radio frequency (RF) energy by rain in the millimeter wave bands is a consideration. This absorption, known as rain fade, limits the effective range during precipitation and must be considered in system design. In computing PMP link performance, the rain fade margin becomes a major contributor. Therefore, to achieve the desired system availability, system performance is set by rain conditions. The rain fade margin can range from 5 dB to 30 dB depending on system availability goals, link range, frequency band, and rain zone. Per ITU Recommendations 837-1 and 838, the Earth has been partitioned into different rain zones where, based upon long-term climactic data, each zone presents a probability of different yearly rain rates. The rain-fade margin is a function of the rain rate (mm/hour). Therefore, for a particular system availability goal and rain zone, the rain-fade margin is computed, and the system’s range is established.

“to achieve a desired system availability, the system performance is set by the rain condition”

Figure 1-1 illustrates the link range model, depicting the downlink, which is the link in the direction from the PMP hub to the remote site. The hub is broadcasting with EIRP of P dBm. (EIRP is the product of transmit power and transmit antenna gain, expressed in dBW or dBm.) The signal experiences propagation loss, L, and loss due to rain fade, F. The receiver sensitivity is R dBm. In dB, the total path loss equals P – R, which also equates to L+F. Improving receiver sensitivity increases the allowable path loss, therefore increasing the range.

The fade component is a function of the attenuation per kilometer for a given rain rate and distance. The total path loss is given by Equation 1:

Equation 1. Path loss = L + Fade Rate x Range (in km)

For the line-of-sight system, the path loss increases with the distance (Equation 2). The first order approximation of the range equation for a 24 GHz system is

Equation 2. $$\text{Range} = 10^{(\text{pathloss}-120.33)/20} = 10^{(L + \text{Fade Rate x Range}-120.33)/20}$$

Iteration is required to solve the above transcendental equation for range.

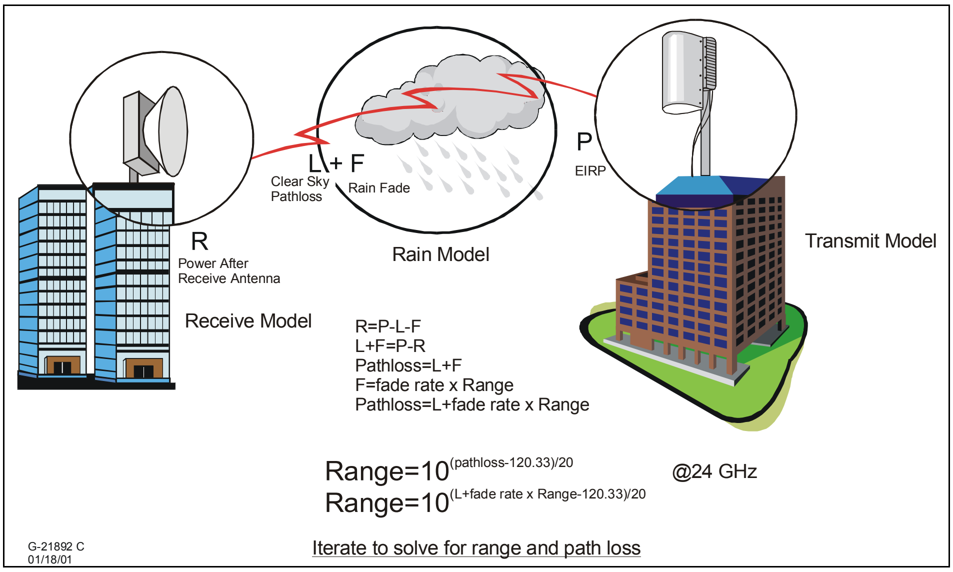


Figure 1-1. Link Analysis Illustration

2.0 Effects of Modulation

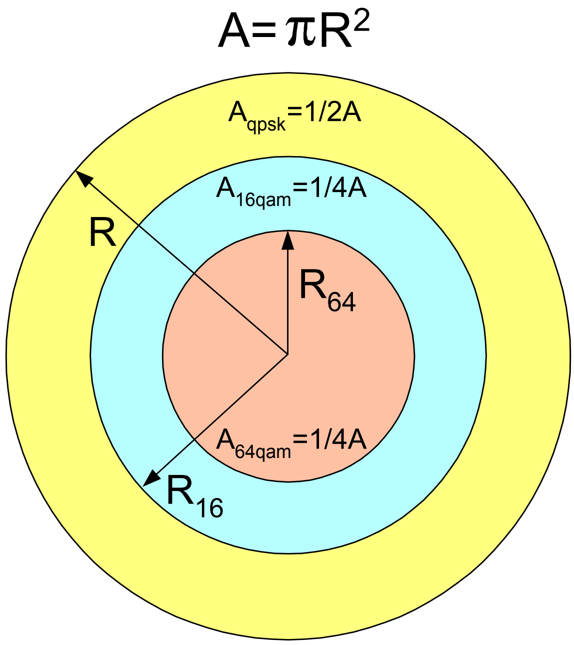
Modulations employed in PMP systems are QPSK, 16-QAM, and 64-QAM. The 64-QAM modulation has 3 times the bits per symbol of QPSK. The higher order constellation modulations can be utilized since these systems are predominantly line-of-sight, and there is a minimal amount of multipath fading.

The drawback to the higher order modulations is the larger C/I ratio and receiver sensitivity required for demodulation. The typical difference in required receiver sensitivity between QPSK and 64-QAM is approximately 14 dB, and between QPSK and 16-QAM, this difference is some 7 dB. From Equation 2, this translates into reduced ranges. For the three modulations, typical E_b/N_0, C/I, and receiver sensitivities to achieve the specified BERs are shown in **Table 2-1**.

Table 2-1. Demodulation Requirements for Various Modulations

Modulation	**Bit Error Rate**					
	1E-13	**1E-12**	**1E-10**	**1E-09**	**1E-08**	**1E-06**
QPSK	8.3	8.1	7.7	7.5	7.3	6.9
16-QAM	12.0	11.8	11.5	11.2	11.0	10.6
64-QAM	16.3	16.1	15.8	15.5	15.3	14.9
	Theoretical E_b/N_0 (dB)					
	1E-13	**1E-12**	**1E-10**	**1E-09**	**1E-08**	**1E-06**
QPSK	13.3	12.6	12.2	11.5	10.8	10.4
16-QAM	20.5	19.8	19.5	18.7	18.0	17.6
64-QAM	27.1	26.4	26.1	25.3	24.6	24.2
	C/I (dB)					
	1E-13	**1E-12**	**1E-10**	**1E-09**	**1E-08**	**1E-06**
QPSK	-86.2	-86.9	-87.3	-88.0	-88.7	-89.1
16-QAM	-79.0	-79.7	-80.0	-80.8	-81.5	-81.9
64-QAM	-72.4	-73.1	-73.4	-74.2	-74.9	-75.3
	Receive Signal Level (dBm)					

Table 2-1 shows that, as the modulation order increases, larger values of E_b/N_0, C/I, and receiver power are needed to sustain a given BER. Therefore QPSK will always have a greater range and larger coverage area than other modulations. Similarly, the coverage area of 16-QAM will always be larger than that of 64-QAM. This tradeoff between coverage and capacity is depicted in **Figure 2-1**, which superimposes the ranges and coverage areas of the three modulations used in PMP systems to approximate scale.



G-21893 V
1/09/01

Figure 2-1. Tradeoff Between Coverage and Capacity

In **Figure 2-1**, A represents the total coverage area, established by the range of QPSK coverage. The innermost circle, the area covered by high-data rate, 64-QAM, represents approximately 25% of the total system coverage area. The inner ring represents the area serviceable by 16-QAM (or QPSK) but not 64-QAM. This area also represents about 25% of the system coverage area. The outer ring represents the area serviceable only by QPSK. It represents the remaining 50% of the system coverage area. Of course, when PMP systems are implemented, the 360° coverage area depicted in the figure is derived from perhaps four or more operating sectors using two or more carrier frequencies.

Under the assumption of a uniformly distributed subscriber population, the achieved capacity of the PMP hub coverage area is given by Equation 3.

$$Achieved\ Capacity = \frac{Max\ Radio\ Capacity}{3\left[\frac{A_{QPSK}}{A}\right]+\frac{3}{2}\left[\frac{A_{16QAM}}{A}\right]+\left[\frac{A_{64QAM}}{A}\right]}$$

Equation 3. Uniformly Distributed Subscribers

In this equation, Max Radio Capacity is the maximum capacity supportable by the carriers operating in the coverage area. For example, in the AIReach 9000, a single 12.5 MHz carrier operating with 64-QAM, can support 45 Mbps. In this case, the maximum radio capacity would equal 45 Mbps times the number of carriers used.

A uniformly distributed subscriber base using the area ratios from **Figure 2-1** in Equation 3 yields:

Equation 4. Achieved Capacity = 8/17 Max Radio Capacity = 0.47 Max Radio Capacity

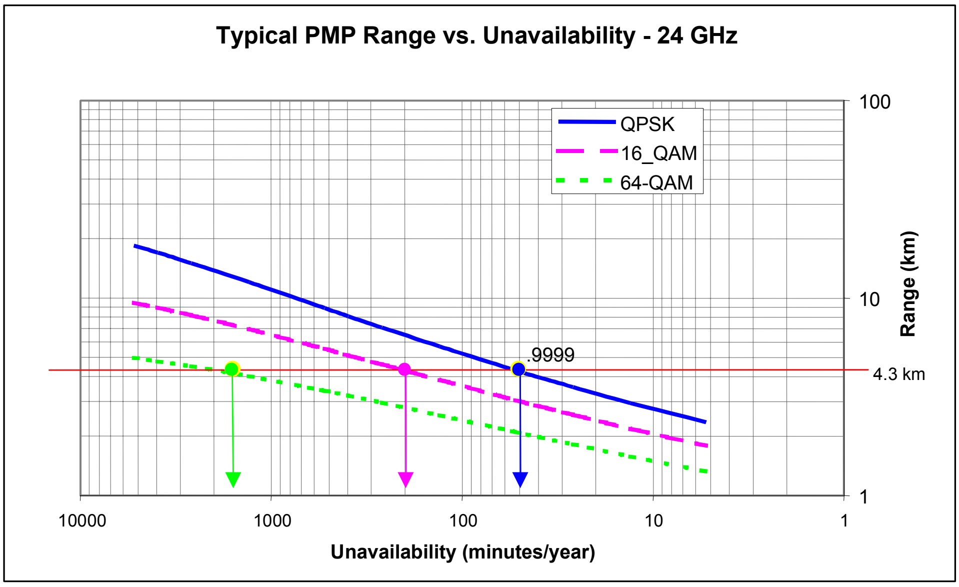
Therefore, if the PMP hub time-shares between each of the modulations in proportion to its subscriber population, only 47% of the maximum capacity is utilized. In practice, office space tends to cluster, so subscribers do not fall into uniform distributions. Therefore, the actual maximum capacity utilized will vary from this number. Nevertheless, if 64-QAM could be utilized for the entire area, then the maximum hub capacity would be achieved.

3.0 Recovering Rain Margin and System Capacity

If the rain margin could be utilized during clear sky conditions, then it would be possible to extend the range of the 64-QAM radius to that of the (rain margin-included) QPSK radius. For example, referring to **Figure 2-1**, if 64-QAM were utilizing its rain margin, its range or coverage area would extend to the outer circle. As a result, the maximum hub capacity would be achieved, and the entire subscriber population would benefit from the full 64-QAM data rate performance.

During a significant rain event, it would be optimal for the system to detect the need for the additional rain margin and, depending upon the intensity of the rain rate, to throttle the modulations specified by the modulation ranges in the figure. This approach – which is the one followed by AIReach Broadband – would allow for the maximum hub range, provide high data rates virtually all of the time, and still guarantee minimum data rates. To compute the amount of time subscribers in the outer operating ranges would be served by QPSK, 16-QAM, or 64-QAM modulations, the range as a function of availability must be derived. **Figure 3-1** assumes a wide (90°) PMP sector and shows typical range versus unavailability performance for the three modulations in the 24 GHz band for ITU Model Rain Zone K. Rain Zone K or a less-rainy zone covers almost all of the U.S.A. and Canada, southern South America, Europe, western and northern Asia, and Japan.

For an availability of 0.9999, or a total of only 50 minutes of outage during a year, **Figure 3-1** shows that the expected QPSK range is 4.3 km. The corresponding 16-QAM range is 3 km and 64-QAM range is about 2 km. If a smaller sector (e.g., 45°) were used, the ranges would increase because of the increase in EIRP.



G-21984 P 01/16/01

Figure 3-1. Typical PMP Ranges Versus Unavailability at 24 GHz. Ranges Assume a 90° PMP Sector

Figure 3-1 shows that by increasing the 64-QAM range to 4.3 km, 64-QAM annual unavailability increases to approximately 1800 minutes or roughly 30 hours. For the higher order modulations, this is not total unavailability, just the unavailability of one modulation and the downshifting to one of a lower order. Therefore, by varying the modulation, a subscriber site at the worst-case edge of the QPSK range will be in 64-QAM mode 364 days a year, will fall back to 16-QAM about 27 hours over the year, and will fall back to QPSK mode only 150 minutes during the year. As the subscriber site range decreases, the amount of time spent at lower modulations also decreases.

The data is shown in a different format in **Figure 3-2**. There we clearly see the availability of 64-QAM as a function of range and that, even at the worst case range, at least one of the higher order modulations is nearly always available.

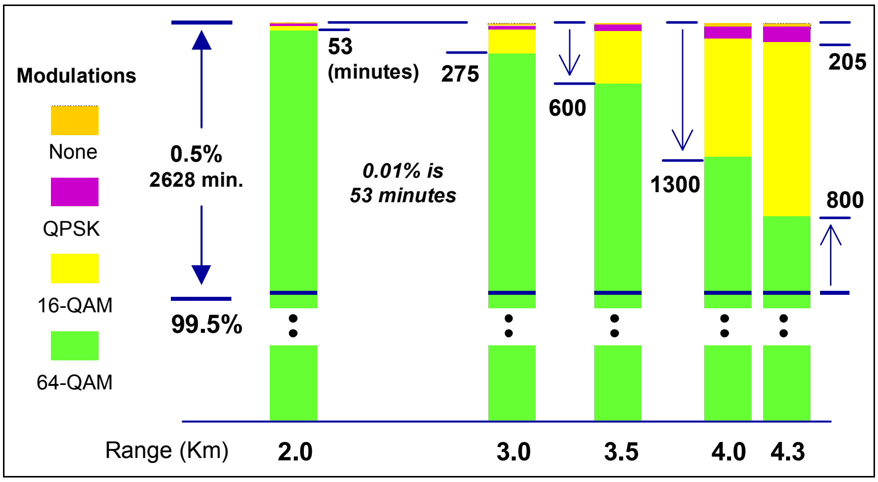
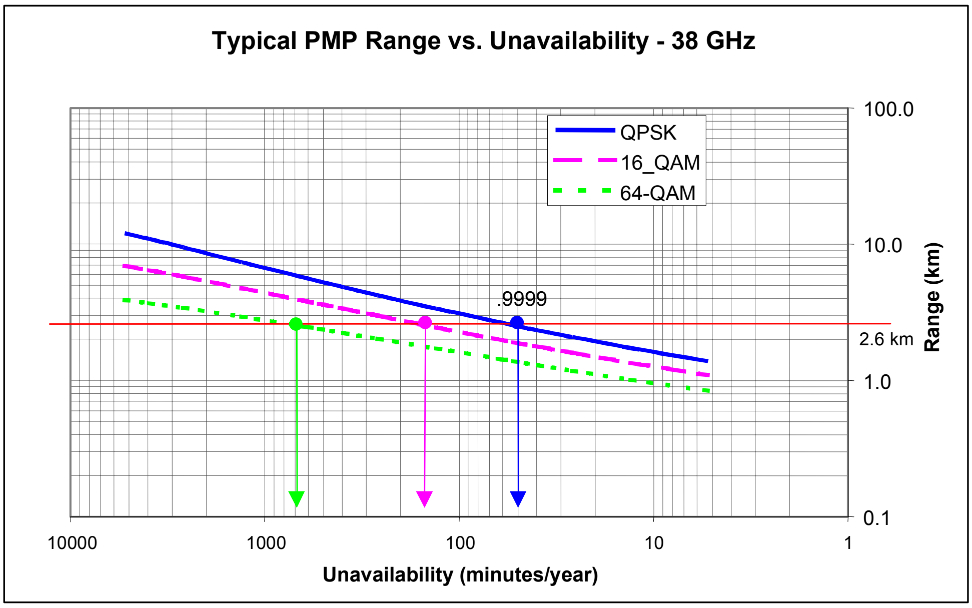


Figure 4. Alternate Formatting of Figure 3 Showing Availability of Various Modulations

Figure 3-2. Alternate Formatting of Figure 3-1 Showing Availability of Various Modulation

For the 38 GHz band shown in **Figure 3-3**, a subscriber site at the worst-case edge of QPSK coverage would operate in 64-QAM mode 365 days minus 700 minutes per year, in 16-QAM 580 (700 - 120) minutes per year, and in QPSK mode 120 minutes per year. Stated another way, this worst-case subscriber site would still operate with one of the higher order modulations for all except 170 minutes per year.



G-21985 P 01/16/01

Figure 3-3. ***Typical PMP Ranges Versus Outages at 38 GHz. Ranges Assume a 90° PMP Sector***

4.0 Maximizing System Capacity with AIRmatch™ Dynamic Modulation Matching

A PMP system with static modulation is one in which the modulation serving a given site is either fixed, changes in lock-step with other sites served by the same carrier, and/or must be changed by operator intervention. As noted in Equation 4, a static modulation system would waste about 50% of the hub capacity, practically speaking.

AIReach 9000 uses a dynamic technique called *AIRmatch*™ Dynamic Modulation Matching to take advantage of clear sky conditions and achieve the availability of the higher order modulations. With the AIRmatch technique, the system continually monitors the link with each site to see what modulation can be supported at that time. Sites that can support 64-QAM are served by this higher order modulation. Should conditions change and 64-QAM not be sustainable, the modulation for that site will drop to 16-QAM (or even to QPSK). Therefore, even within a TDMA frame, sites are served by the highest order modulation that they can support, and capacity is optimized to match local environmental conditions dynamically. The significance of the *AIRmatch* technique is that what otherwise would be bandwidth lost to rain margin is converted into revenue-generating capacity. This statement is particularly true for data services where uncommitted bandwidths are the norm.

“The significance of *AIRmatch* is that what otherwise would be bandwidth lost to rain margin is converted into revenue-generating capacity.”

5.0 Summary

Impacts of rain and rain margins must be considered in the design and operation of a PMP system. *AIRmatch* Dynamic Modulation Matching provides an easy means to take advantage of the rain margin under clear sky conditions, thereby reclaiming system capacity that would otherwise be lost.

AIReach®, AIRmatch™ Dynamic Modulation Matching, and AIRange™ Coverage Extension technologies are registered trademarks or trademarks of Hughes Electronics Corporation (HUGHES).