Motorola PTP 400 Series Bridges Non-Line-of-Sight Operation

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Introduction

Typically only 14% of properties that are 1,500 feet (500 meters) apart have an optical line-of-sight (LoS) path between their roofs. At higher ranges and in low-rise rural environments, this percentage is even lower. These factors lead to an increasing demand for non-line-of-sight (NLoS) wireless Ethernet bridges. The cost and delay of non-wireless methods of connection are very high, and there is increasing interest in unlicensed bands where the speed of deployment can be measured in hours rather than months.

In the 2.4 and 5.8 GHz frequency bands, many products have been coming into the market that claim NLoS operation when, in fact, only one or perhaps two of the required features have been included. The actual requirement is for a comprehensive range of features to deliver full NLoS performance.

This paper describes issues affecting NLoS application performance and the features required to fully address them. The radio applications that are enabled by this performance are described in the section titled, *Application Data*. The network applications are described in the *Network Applications* section. Some of the performance figures in this paper apply only to the FCC-regulated equipment for which the maximum power output is allowed.

Why Point-to-Point 5.8 GHz Is A Preferred Technology

There are various methods of connecting buildings together, including:

- Leased line
- Trenching or overhanging wires
- Licensed Point-to-Point (PTP)
- Unlicensed PTP
- Optical PTP

Of these, the lowest overall cost is usually the unlicensed point-to-point link because the cost of equipment is normally lower and non-line-of-sight operation is allowed. If, however, the equipment does not have sufficient ability to connect directly between the two buildings, then the link must go via an intermediate point. In this case, there will be additional equipment, rental and maintenance costs. There will also be reduced reliability and security, and increased into-service time.

It is highly desirable to have a direct link in an unlicensed band, removing the need for spectrum license fees. 5.8 GHz is the lowest frequency that fulfills the requirements of bandwidth availability and yet is not overused by other services. 5.8 GHz regulations also allow sufficient link budget to diffract around large obstacles.

Table 1 (next page) shows the losses associated with certain obstacles in various environments. As shown here, these losses are much greater for infrared and W-band radios than they are for 5.8 GHz radios. The cost of generating power at the higher frequencies is also greater, so the way in which they have been made to work over long ranges is to restrict the beam-width of the radiators. This narrowing of the width brings problems in the stability of the mounting point. Laser devices often need to be self-adjusting for the movement of tall buildings in the wind.

Table 1: Typical signal losses depend on the environment

OBSTACLE	INFRARED LIGHT (765NM)	W-BAND RADIO (60 GHZ)	5.8 GHZ RADIO
Clear, still air	-1 dB/km	-15 dB/km	-0.1 dB/km
Scintillation	0 to -3 dB/km	0 dB/km	0 dB/km
Birds or foliage	Impenetrable	0 to -20 dB/km	0 to -2 dB/km
Window (double-glazed)	-3 dB/km	-1 dB/km	-0.5 dB/km
Light mist (visibility 400m)	-25 dB/km	-1 dB/km	0 dB/km
Medium fog (visibility 100m)	-120 dB/km	-1 dB/km	0 dB/km
Light rain (25mm/hour)	-10 dB/km	-10 dB/km	0 dB/km
Heavy rain (150mm/hour)	-25 dB/km	-40 dB/km	-1 dB/km

NLoS Radio Propagation Requirements

There are a number of requirements for a radio system that is intended to operate in a non-line-of-sight manner. These are:

- Sufficient power budget
- Demodulator with sufficient dispersion mitigation
- Fading mitigation
- Adaptive link characteristics

Power Budget. In Motorola's case, creating sufficient power budget involves transmitting as much power as the regulations in any particular country allow. Of course there is also Transmit Power control to ensure that unnecessary power is not transmitted. On the receive side, the budget is optimized by large antenna gain, low noise figure and low system loss (relative to Shannon).

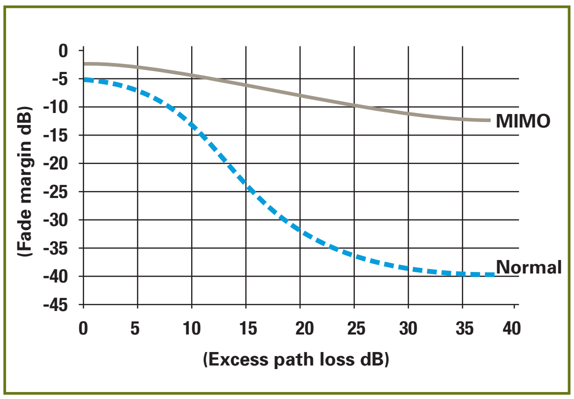

Figure 1: Conventional systems require a 40 dB fade margin to operate successfully in paths that require only 10 dB fade margin for Multiple-Input Multiple-Output (MIMO).

Dispersion. In the type of NLoS channels that are being used, dispersion can be as much as 2 μS. Equalizing a 10 MHz bandwidth channel with this much dispersion can be a challenge for single-carrier systems. The Motorola PTP 400 Series point-to-point wireless Ethernet bridges use a variety of Orthogonal Frequency Division Multiplexing (OFDM), which has sufficient equalization pilots to give the exact dispersion characteristics. This, in conjunction with forward error correction in the frequency domain, ensures perfect demodulation in any channel.

Fading. In NLoS paths, multipath fading is significantly accentuated. Extensive testing has shown that the graph in *Figure 1* applies. Using Multiple-Input Multiple-Output (MIMO), the Motorola PTP 400 Series 5.8 GHz point-to-point solutions address this problem. *Figure 1* shows that, for 99.99% link availability, a conventional system requires 40 dB fade margin for NLoS paths. With MIMO, this requirement is reduced to just 15 dB, giving a performance benefit of 25 dB. Another way of viewing this is that, given that only 15 dB is available for fade margin, a conventional system-deployed NLoS solution would achieve only 93% link availability while the Motorola MIMO system would achieve 99.99% link availability.

Fade rates are variable by path, and depend upon the movement of objects in and around the path. Trees are often the dominant source of fast fading. When the wind is high, the fade rate bandwidth can be up to 4 Hz. In still conditions, the path loss through trees becomes stationary at any random point in the fade cycle. Urban paths above tree level often exhibit very slow fading, and it becomes very difficult to determine the effective mean signal level – and thus the fade margin required – for the site being installed at the time of installation.

Adaptive Modulation. Adaptive modulation, often used to increase the capacity of point-to-multipoint systems, is also applicable to point-to-point systems. In this technique, the radio modulation and bandwidth can be modified according to the signal level received. Since the channel often varies in intensity on a sub-second basis, transmitting the maximum amount of data possible means that such a system must rapidly optimize itself to the channel conditions. The effect is to increase the data rate capability and to improve the reliability of the system.

Application Data

The result of applying this design method is that Motorola is able to increase – by a very large percentage – the probability of being able to install and operate a point-to-point link. To give some concrete examples, Motorola has used the ATDI ICS Telecom tool to survey Paris and generate average probabilities of connecting two typical buildings in an urban environment. For illustration, the coverage around some common obstacles is also presented: propagation around a building, propagation over a hill and propagation through trees. All of the following results have been confirmed by trials of the equipment apart from the statistical nature of the heights of equipment in the Paris model.

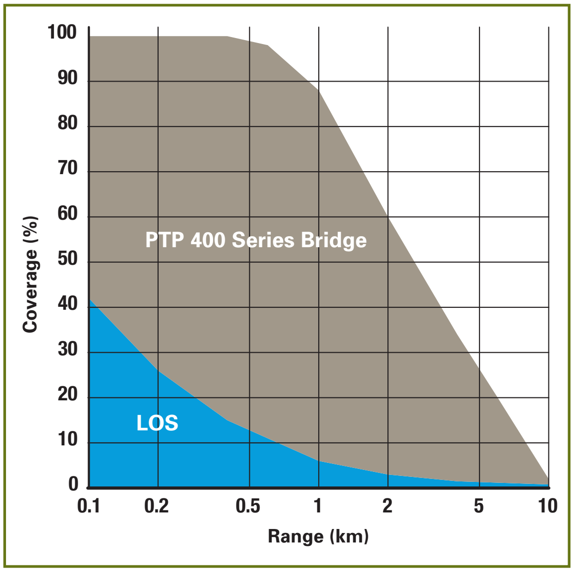

Figure 2:
Over a range of up to 10 km (6 miles) in an urban setting (Paris), the Motorola PTP 400 Series bridge greatly increases the probability of signal coverage

Detailed Survey of Paris. In the detailed survey of the center of Paris, a Digital Elevation Model (DEM) with 4-meter (13-foot) resolution was used to position 9,000 PTP links. The propagation was taken from the highest point in a 10-meter (32-foot) radius around the property entrance. The probability of LoS or NLoS coverage was then computed, as shown in *Figure 2*.

This figure shows that the probability of connecting a device that is capable of reliable NLoS operation is substantially more than a device that has only LoS capability. The ATDI tool for this analysis used P.526-7 for the detailed propagation model.

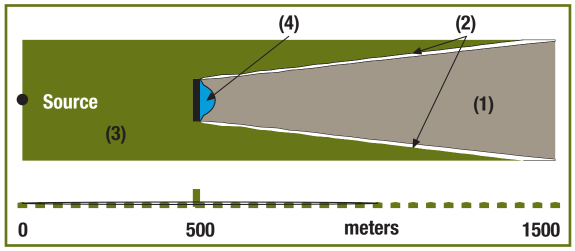

Figure 3:
The Motorola PTP 400 bridge greatly increases the coverage area behind a large building.

Propagation Around a Building. *Figure 3* shows the coverage behind a substantial building. The deployment is in a flat area with the normal two-story building height of 8 meters (26 feet) upon which the normal installations must take place. There is an "office block" standing 37 meters (121 feet) high and 120 meters (394 feet) wide. The office block represents a 12-story building in this case. In the lower part of the figure, this stands well above the Fresnel zone. The PTP links are installed on the two 2-story buildings, two meters (7 feet) above the roof.

Coverage in the shadow of the building is displayed with the gray area (1) showing where the normal data rate is typically at maximum with occasional deviations down to the lowest data rate in moments of extreme fading. The white area (2) is where a PTP 400 Series bridge always works at the maximum data rate. The green area (3) is where a LoS system can be deployed.

The area of blue (4) where the PTP 400 Series system cannot be installed (without mounting a relay station) is very small and is in the immediate shadow of the building.

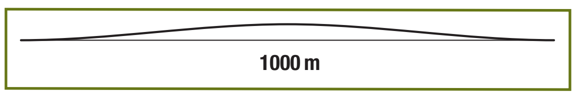

Figure 4:
In the worst-case scenario, a hill only 18 meters (59 feet) high can block successful signal propagation – shown here between two points 1,000 meters (3,280 feet) apart.

Propagation Over a Hill. In the case of hills, the propagation depends very much upon the shape of the hill being traversed. Reference [1] (on the last page) shows that the hill drawn in *Figure 4* can be only 18 meters (59 feet) high. In practice this is a worst case because any roughness in the path improves the propagation. Buildings that can be seen by both parties improve the propagation further.

System performance in this area will mostly be at the full data rate with occasional fades into the lower data rate. This is similar to the performance in the gray area of *Figure 3*.

Figure 5:
A combination of height and size determines an object's impact on propagation success.

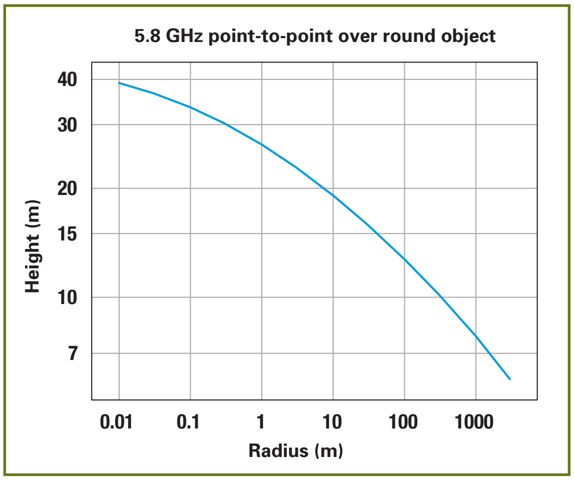

Figure 5 shows the maximum height of a smooth hill with a given radius above the optical line-of-sight path of 1 km (0.6 mile). Rough hills should normally give better propagation.

Propagation Through Trees. There is a high degree of variability in the loss associated with trees. The loss varies with the size, thickness, type and wetness, and there is an annual component with the cycling of the leaves. Trees are also a very common obstruction in provincial and rural settings. In the case of a single tree, which can be traversed at a loss of about 25 dB, this means that the range is restricted to 8 km (5 miles) if a single tree is the multipoint obstruction.

PTP Link Estimator. Clearly the issues above are difficult to quantify. Therefore, Motorola provides at no cost to customers a PTP Link Estimator tool which enables point-to-point links to be designed and performance to be predicted before installation. The estimator provides data rate and reliability expectations for correctly modeled and installed links. The estimator can also be used to enable a clearer understanding of non-line-of-sight and long range line-of-sight issues.

Network Applications

None of the foregoing radio performance would be any use without providing for network applications. The Motorola PTP 400 Series solutions provide up to 43 Mbps aggregate data rate as an Ethernet bridge. Under particularly stressful radio conditions, this may drop to 4.4 Mbps. Typically this will be used to connect together two Ethernet LANs. The device is so inexpensive that it can be efficiently used as a backup for leased line or optical links. If very high reliability is required, one can use two links in parallel with the additional advantage of 85 Mbps aggregate data rate. Further applications include:

- Upgrades to existing analog or slower digital links
- Very long distance wireless links via staging points giving 25 miles (40 km) or more range
- Backhaul for mobile cellular networks

The Motorola Point-to-Point Wireless Ethernet Bridges – PTP 400 Series – are part of Motorola's MOTOwi4 portfolio of innovative wireless broadband solutions that create, complement and complete IP networks. Delivering IP coverage to virtually all spaces, the MOTOwi4 portfolio includes Fixed Broadband, WiMAX, Mesh and Broadband-over-Powerline solutions for private and public networks.

Reference: [1] (2002). RECOMMENDATION ITU-R P.526-7 – Propagation by diffraction. Recommendation P.526, International Telecommunications Union.

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