White Paper

Orthogon Systems

True Non-Line-of-Sight Wireless Networks

Space Time Coding:

The key to successful deployment in a dynamically varying non-line-of-sight environment

Orthogon Systems

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CONTENTS

1 SCOPE OF DOCUMENT

This white paper highlights the main issues confronting point-to-point wireless network installations where there is a need to operate in a dynamically varying non-line-of-sight environment with high data throughput and link availability of 99.99% or better. It is shown that a combination of the latest techniques, including the use of space time coding, can deliver the best chance of achieving a reliable, secure, high-availability broadband connection.

2 MARKET NEED

The need for data connections offering high bandwidth combined with high reliability applies not only to building-to-building connections between local area networks (LANs) but also to wide area connections and carrier services such as subscriber connections (local loop) and backhaul services.

Many of these applications have traditionally been “best efforts” relying on higher-level network protocols to manage the end-to-end link. However, modern data networks are carrying more and more delay-sensitive traffic such as synchronization data for secure applications such as VPNs and thin clients, as well as real-time applications such as voice-over IP and video conferencing. All of this leads to a requirement for high throughput and high availability in all parts of the network. Achieving both of these business-critical criteria can be a major challenge when implementing radio-based point-to-point solutions, especially where there is no line of sight between the communicating stations.

3 WIRELESS FUNDAMENTALS

Radio waves behave very much like light waves. On striking the surface of an object they are partially reflected, partially absorbed and partially transmitted through the object. The relative extent to which the radio waves are reflected, absorbed or transmitted depends on many factors, including the wavelength, the angle of incidence and the material of the object. Also, like light waves in high-school physics experiments, radio waves are diffracted as they pass obstacles and refracted as they pass through materials of varying density.

When a radio wave is transmitted, these basic physical laws cause the signal to take a multitude of different paths towards the receiving station. Some of these paths lead to the receiver with sufficient signal strength to be detectable and demodulated into a meaningful data stream.

4 THE NON-LINE-OF-SIGHT CHALLENGE

The nature of a non-line-of-sight link is that there are obstacles such as buildings, vehicles, trees and hills between the transmitting station and the receiving station, completely obscuring the line of sight. Even in such environments, multiple paths do exist between transmitter and receiver via a combination of reflection, diffraction and penetration. These “multi-paths” are of different lengths and have different characteristics. Hence, the signals arrive with varying amplitudes and dispersed over time, causing self-interference.

To make things worse, as the environment changes due to movement of obstacles such as trees or vehicles, or even to changes in air pressure or ambient temperature, the nature of each path dynamically changes. This fading effect causes the received signal quality to vary unpredictably. Fading can reduce a signal's strength by a factor of up to 10,000 (-40 dB) for periods of seconds, minutes or even days in some cases. The remainder of this paper looks at the techniques and technologies available to overcome this significant obstacle.

5 TWO WAYS TO FADE

Fading occurs in two different ways: flat fading and frequency-selective fading. Flat fading occurs when the received signal spectrum remains a close replica of the transmitted signal spectrum except for a change in amplitude. This amplitude change of the signal spectrum varies over space because of the interference of the combined electromagnetic waves. This interference can be constructive or destructive and as a result the fades (changes in the received signal magnitude) due to flat fading can be very significant, 30 dB or more.

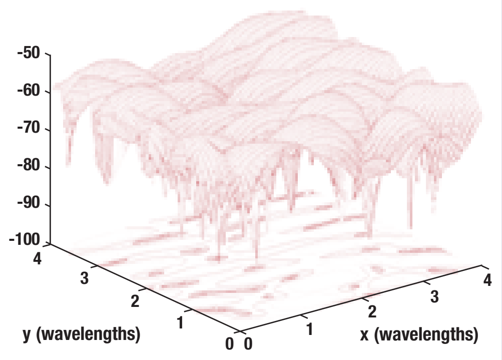

Figure 1: Fading due to space variation

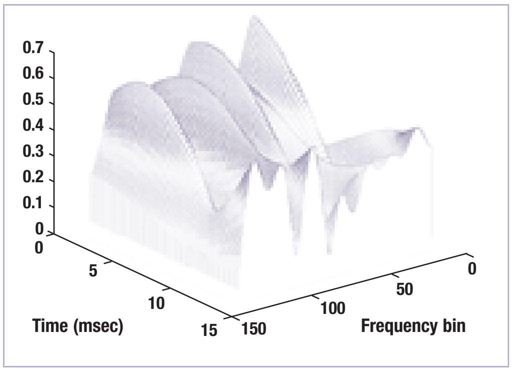

Figure 2: Fading due to time variation

The amount of fading varies according to the exact path characteristics at any point in space and time. *Figure 2* shows how a signal may fade with respect to the location of the receiving antenna. Flat fading occurs when the Root Mean Square (RMS) delay spread of the channel is much smaller than the symbol period of the transmitted signal.

Frequency-selective fading occurs when the RMS delay spread of the channel is more than about 10% of the symbol period, thereby causing the wireless channel to alter the received signal spectrum. In the time domain, the received symbols can no longer be identified individually. They interfere with each other since they are dispersed in time and overlap one another. This is known as Inter-Symbol Interference (ISI). In the frequency domain, the channel response can no longer be considered "flat," its amplitude has significant variation and its phase is not linear with frequency.

As illustrated in *Figure 1,* if the objects in the medium are not moving, the standing wave pattern will be static in space. Thus, for a fixed point in space, the wireless channel will be time-invariant. If, however, there is motion in the environment (although neither the transmitter nor the receiver may be moving), it alters each standing wave pattern and consequently the wireless channel is also time-varying. *Figure 2* illustrates the effect of time-varying fading.

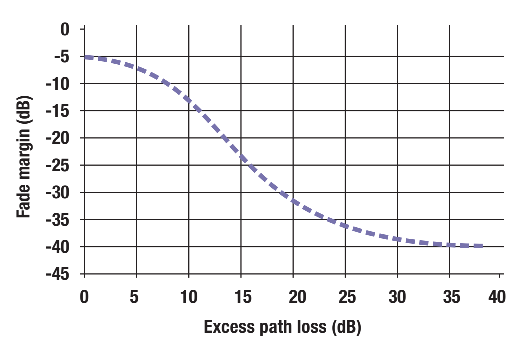

Figure 3: Calculating fade margin in a single-carrier system

6 CALCULATING FADE MARGIN

In a single carrier system, it is essential to calculate the system power budget to include an allowance for fading. This is known as the fade margin. Experience has shown that in non-line-of-sight environments, the amount of fade margin is related to the excess path loss caused by the obstructions in the line of sight. *Figure 3* shows how to calculate fade margin based on excess path loss.

7 COMBATING FADING

The most commonly used solution to multi-path fading is careful site selection to provide a single, unobstructed line-of-sight path between the transmitter and receiver either directly or via relay stations. Where this is not feasible, flat fading can be compensated for by a sufficient fade margin as in *Figure 4* at the cost of limiting range and coverage.

Mitigation of narrowband interference is typically achieved by spreading the signal over the frequency band using spread-spectrum techniques such as Frequency Hopping or Direct Sequence Spread Spectrum. Using OFDM (Orthogonal Frequency Division Modulation) and coding across the frequency band can also mitigate narrowband interference. Indeed, coding and OFDM exhibit a spreading gain similar to spread-spectrum techniques.

To combat frequency-selective fading, a wireless system should use a signal processing technique to remove ISI. ISI occurs where the channel is dispersive so that the received waveform suffers delay spread, causing transmitted symbols to overlap one another.

Techniques to overcome ISI are, in general, known as channel equalization techniques. Equalization algorithms with varying degrees of speed of convergence, computational complexity and stability are well understood. However, the time-varying nature of wireless channels makes the problem of channel equalization much more difficult compared to wire line systems such as voice band or subscriber loop modems.

In addition, space diversity by means of multiple antennas can help solve the fading problem. With adequate antenna separation, when the signal received by one antenna fades, there is a good probability that the signal strength at the other antenna is still sufficiently large. This is one part of the space time coding solution described below.

8 MITIGATION TECHNOLOGIES

A special blend of advanced techniques and technologies is required to overcome fading and other interference problems in non-line-of-sight wireless connections.

Elements of a non-line-of-sight solution should include:

- High system gain
- Fading mitigation
- Dispersion mitigation
- Multi-path compensation

These can be achieved using technologies such as:

- Space Time Coding
- Orthogonal Frequency Division Modulation
- Adaptive Modulation
- Dynamic Frequency Selection

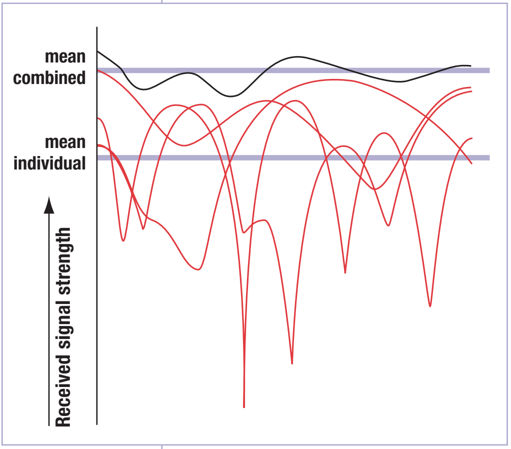

Figure 4: Improved signal strength through space time coding.

Space Time Coding Space time coding (STC) is a method of transmitting multiple data beams on multiple transmitters to multiple receivers. The advantage of STC is that the odds of receiving the data are massively increased. Basically, if any one path is faded, there is a high probability that the other paths are not, so the signal still gets through.

A simple analogy is if a single coin is tossed, there is a 0.5 chance of a head. If there are four coins, there is a 15/16 chance of getting at least one head.

For STC to be effective, the paths need to be de-correlated (i.e, the signals travelling on those paths need to behave differently from each other). This can be done using techniques such as spatial separation of the antennas or separation of the transmitted waveforms via time separation, data sequence separation, polarization separation, frequency separation or modulation separation. The OS-Gemini Wireless Ethernet Bridge deploys a unique combination of techniques that generate a pseudo-circular polarization, optimized for both zero ground bounce nulls for line-of-sight deployments and maximum de-correlation in non-line-of-sight deployments.

Figure 4 shows the relative strength of the received signal in a space time coding system with multiple individual de-correlated signals. It is this effective gain in received signal strength that allows for resistance to fading.

Figure 5 highlights the benefits of STC in combating fading. This figure shows how the use of STC reduces the amount of fade margin required by up to a factor of 1000 (30dB), allowing for an equivalent increase in coverage and probability of establishing a link.

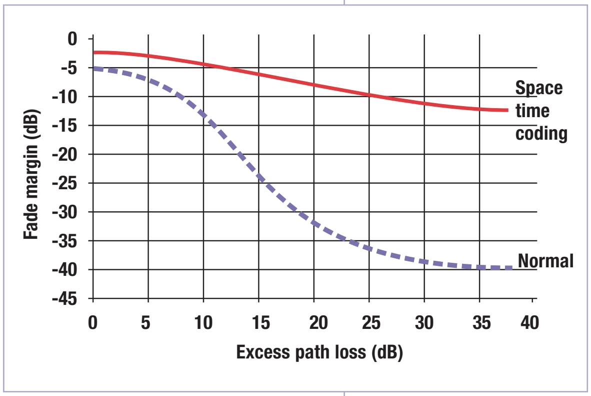

Figure 5: Fade margin using space time coding.

Orthogonal Frequency Division Modulation Orthogonal Frequency Division Modulation (OFDM) involves the transmission of data on multiple frequencies for the duration of a symbol (typically around 100 microseconds). By using multiple carriers, communication is maintained should one or more carriers be affected by either narrowband or multi-path interference. A key aspect of OFDM is that the individual carriers overlap to improve spectral efficiency. Normally, overlapping signals would interfere with each other. However, through special signal processing, the carriers in an OFDM waveform are spaced in such a manner that they effectively do not see each other, i.e, they are orthogonal to each other so that there is no cross-interference and hence no signal loss.

The key benefits of OFDM include higher spectral efficiency (throughput/MHz of channel bandwidth) and high resistance to multi-path interference and frequency-selective fading.

Orthogon Systems uses an enhanced version of OFDM called Intelligent-OFDM, which offers improved recovery from fading, by the use of multiple pilot tones. These tones provide advanced channel equalization feedback to allow instant recovery from even the deepest of fading situations.

Adaptive Modulation (AMod) In this technique the radio phase and amplitude modulation are dynamically modified according to the signal level received. Since the channel may vary in intensity on a sub-second basis, adaptive modulation allows the system to transmit the maximum amount of data possible by rapidly optimizing itself to the channel conditions. The effect is to increase the data rate capability and the reliability of the system.

Dynamic Frequency Selection Dynamic Frequency Selection (DFS) also allows the radio system to optimize the data throughput and the availability of the link. In this technique, each available radio channel is monitored for sources of interference such that the radio dynamically moves to the clearest channel available.

9 CONCLUSION

Without line-of-sight, traditional point-to-point data connectivity solutions are rendered useless. As demonstrated in the OS-Gemini Bridge, a special blend of advanced techniques and technologies are required to overcome fading and the other problems of non-line-of-sight wireless connections. These techniques include OFDM, STC, AMod and DFS.

Reference: [1] VOFDM Broadband Wireless Transmission and Its Advantages over Single-Carrier Modulation, Broadband Wireless Internet Forum, Document Number WP-1_TG-1, December 2000.

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