

NON-LINE OF SIGHT: TECHNOLOGY & IMPLEMENTATION

Introduction

To many industry insiders, the promise of broadband wireless access (BWA) is clear. Delivery of last mile, enterprise infrastructure and MAN traffic at lower cost than incumbent technologies – ADSL, cable modem, T1/E1, etc – is the goal. The reality can be best characterized as hit or miss. The current generation technology is sufficient to meet the business needs of datacom customers in some niche markets. For example, BWA growth in domestic rural and some lesser developed countries has been strong. But this growth has not been seen in the majority of urban and suburban centers due to the strong presence of competing technologies. In other words, BWA has grabbed hold only in markets where other technologies are absent. What has relegated BWA to remain a niche technology? Two reasons: non line of sight (NLOS) coverage and cost.

Both issues boil down to technology. Advancing beyond traditional line of sight (LOS) deployment means developing technologies that can handle the added impairments of NLOS operation. Doing this inexpensively requires smart architecture choices and high levels of integration to drive hardware costs down. Delivering both in a single, reliable radio is today's challenge.

NLOS, The Holy Grail

Typical single carrier and spread spectrum radios are designed to be operated in an LOS configuration. This has its advantages. The design of the radio and link can follow well-proven methodologies refined over many decades of use. Without considering the challenges of NLOS impairments, the radio remains relatively simple. The link design is straightforward with ranges that can be estimated by using the free space path loss equation based on the Friis equation:

$$PL(d) = PL(d_o) + 10n \log \left(\frac{d}{d_o} \right), \text{ where } n=2 \text{ for free space.}$$

Equation 1: Path Loss Equation

Because radio energy travels as a wave, LOS clearance also requires that a link remain obstruction-free not only along its visual line of sight, but for an expanded distance called the Fresnel Zone. As seen in Figure 1, the Fresnel zones appear as ellipsoidal shaped contours centered around the visual LOS. A link is typically considered LOS when 60% of the first Fresnel Zone remains unobstructed.

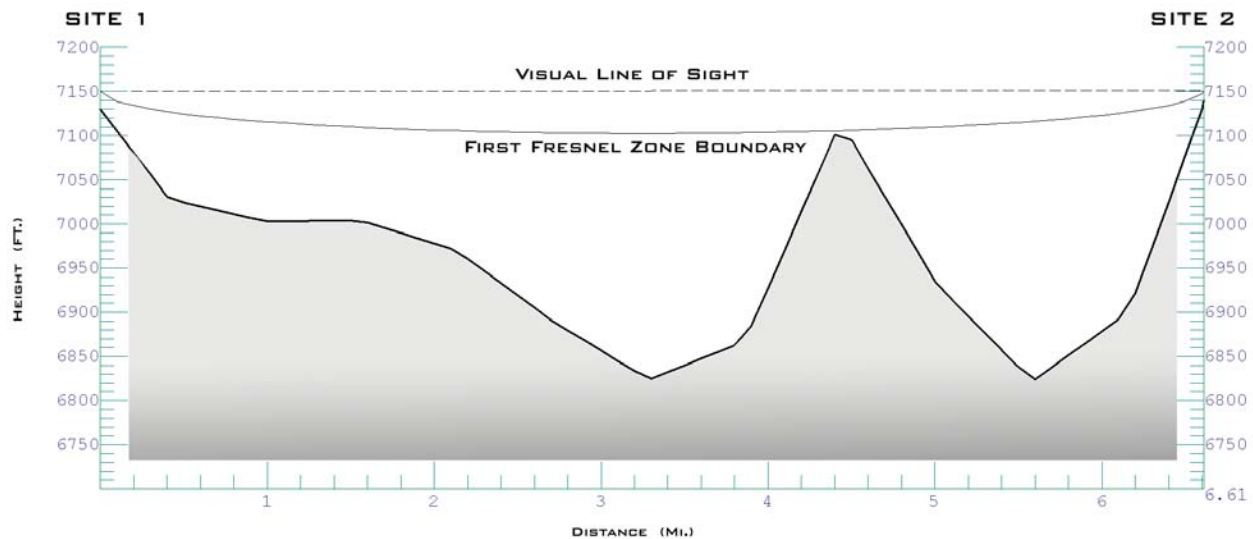


Figure 1: Fresnel Zone

In practice, achieving these LOS conditions is difficult, often requiring careful site selection, erecting towers and, in many cases, needing to reject sites entirely. This 'simple' technology is too restrictive to meet the needs of a large majority of customers and thus BWA has been relegated to niche applications.

Enter NLOS operation. Sometimes referred to as 'Near LOS' or 'Non LOS', its meaning refers to a capability spanning a continuum of impairments.

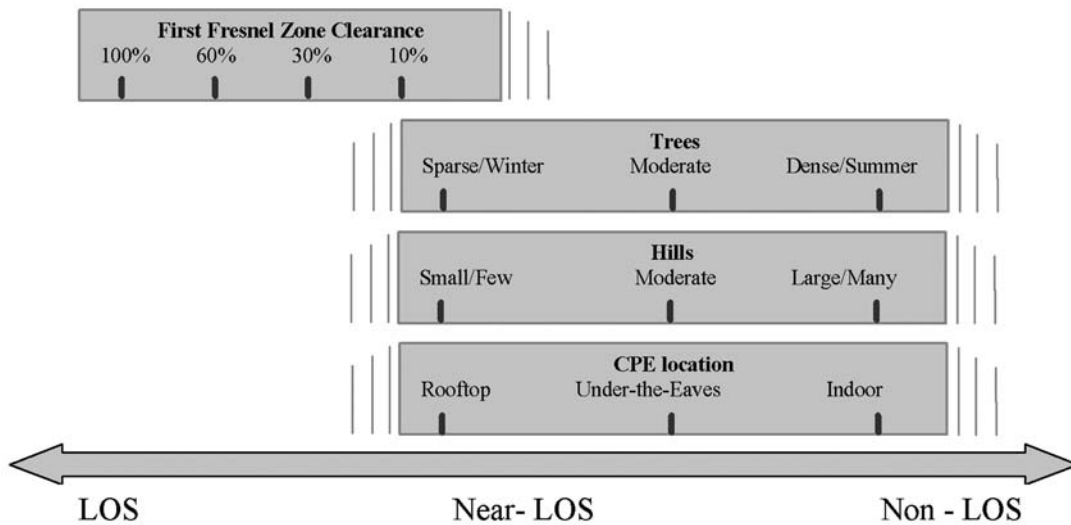


Figure 2: Line of Sight Continuum

At one end of the spectrum, NLOS can refer to the capability of a link operate predictably and reliably even with less than 60% of Fresnel Zone clearance. At the other end of the spectrum, NLOS also refers to the industry's holy grail of indoor, customer installed radios covering 90% or more of possible CPE sites. Between these two points, there are many additional opportunity targets for deployment including tree penetration, partial roof/building obscuration, and hill/horizon barriers.

NLOS Impairments

Operating in an NLOS environment subjects a radio to a number of severe impairments that must be managed properly for a link to remain reliable.

NLOS obstructions create higher link attenuation than what is predicted by the free space path loss equation. Transmission models normally address this by increasing 'n' in equation to values above two, implying a faster rate of RF level attenuator as distance is increased (see Figure 3). In addition, a fixed shadowing term is added to address single instance obstructions such as a rooftop or walls.

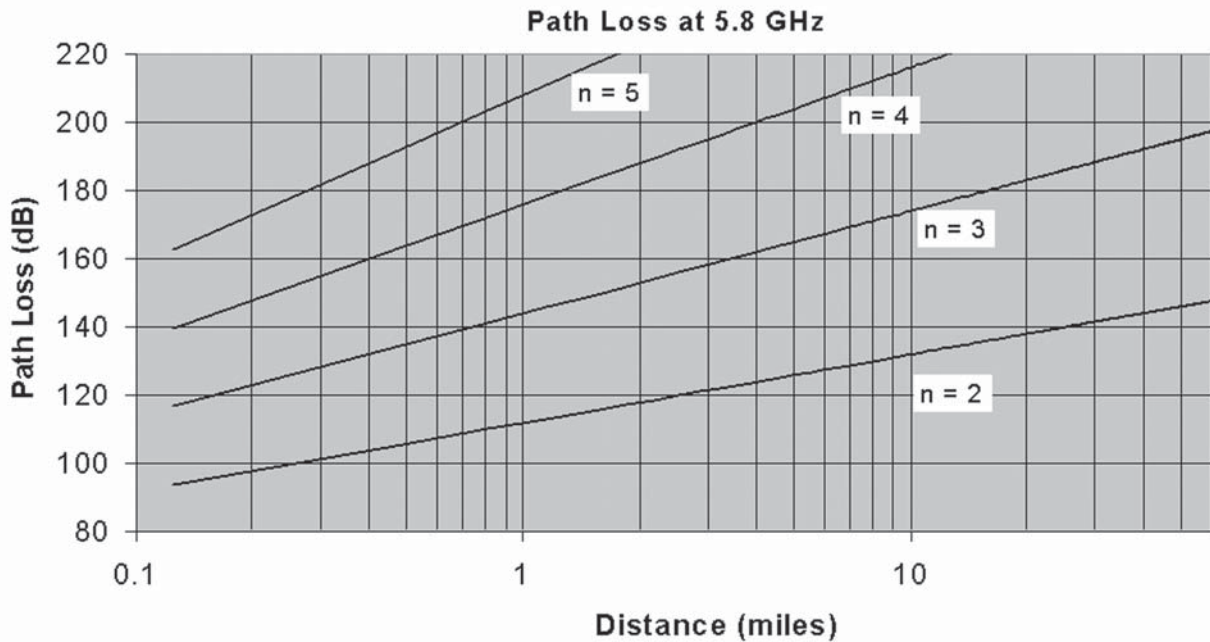


Figure 3: NLOS Path Loss

The more drastic effect of NLOS transmission is the increased severity of multipath and its effects. Multipath can be likened to an acoustic echo – RF reflections received by the radio from multiple, indirect paths. The echoes, though attenuated from the main path (if there is one), are delayed in time. The distribution of echoes over time, or delay spread, create inter-symbol interference (ISI), a condition where the delayed energy from one transmitted data symbol begins to corrupt the symbol next arriving along a faster RF path.

Another consequence of multipath is fading. As waves of the same frequency, the radio is sensitized to peaks and valleys of power that are created by the overlapping waves. The effects can be severe – narrowband fades on the order of 20 dB and more are possible when the receiver is repositioned by only inches. Moreover, since the multipath is often created by moving objects – trees, cars and to a lesser extent, buildings, the distribution varies as a function of time as well as position.

A final consequence of multipath involves the motion of reflecting objects. Any wave that hits a moving object, for example a car, will experience a slight frequency shift. This Doppler Effect creates echoes that are not only distributed in time but also in frequency.

In all, reliable NLOS links require a radio system able to tolerate increased path loss and a number of distorted echoes of the original signal. How can this be accomplished?

Technology

For the past 15 years and more, most BWA equipment consisted of low power, single carrier and DSSS radios. Suitable for LOS applications, their utility in NLOS links decreases dramatically. Their low power and average receive sensitivity does not allow them to operate in the presence of increased path loss, shadowing and multipath fades. LOS link distances to 10 miles and more quickly deteriorate to under a mile, due to power loss. In addition, these older systems are not designed to easily survive the ISI and other distortions created by delay spread and Doppler effects.

OFDM (orthogonal frequency division multiplexing) modulation has been growing in usage due to its ability to overcome the shortcomings of earlier commercial technology. Technology sectors such as 802.11a/g WLAN, DVB/DAB broadcast and upcoming 802.16 WMAN products are all looking to OFDM to address NLOS challenges. For outdoor use, OFDM is a powerful asset.

The OFDM concept is to create a wideband signal comprised of a number of independent or 'orthogonal' subcarriers, each carrying a low bit rate data stream. The low data rate bit stream allows for a sizeable guard band at the beginning of each symbol, effectively isolating the symbols from each other and neutralizing the effect of delay spread. In addition, the subchannelized operation in conjunction with the proper error correction system proves to be very tolerant of narrowband multipath fades. In most cases, only a limited number of subcarriers may be affected by a fade, causing the loss of symbols. With the remainder of the wideband signal unaffected, the error correction system takes over and is able to reconstruct the small percentage of missing data bytes.

OFDM is a key element of the NLOS solution, though, additional tricks are required to begin approaching the 'holy grail' of indoor deployment. The sheer magnitude of the link loss between a base station and a NLOS client, due to obstructions and multipath fading, mandate additional measures be taken to increase link gain.

The most obvious is to increase the link gain of the system by increasing the output power of the transmitting radio or receive sensitivity of the receiver. Due to strict linearity requirements for an OFDM system, a high power OFDM radio requires more care design and construction than previous generations of design.

Recent developments to combat link attenuation involve using sophisticated methods of spatial and time diversity. Space-time coding and Multi-input / Multi-output (MIMO) radio systems are able to assess the real time channel conditions and adjust how data is sent to multiple transmit antennas and how best to extract symbols from multiple receive antennas. Progress in this area is rapid, but the complexity of multi radio designs prevents such an approach from being cost effective today.

Implementation Example

The approach employed by Solectek Corporation to address NLOS operation is to adhere to the KISS principle – 'Keep It Simple Stupid'. Development of the SkyWay 5000 series has demonstrated that a high power OFDM radio is able to open many more potential client sites as compared to older technology with little to no cost penalty.

The wideband OFDM engine provides all of the benefits described previously, including tolerance of multipath fades, elimination of delay spread and Doppler effects. A 400 mW RF stage creates the link gain to work through many instances of shadowing effects and absorption through obstructions.

Test Results

To test the capability of its new OFDM system, a variety of field tests were conducted at Solectek headquarters in San Diego, CA. The effects of trees, rooflines and hillsides were all put to the test by comparing TCP/IP throughput results against LOS performance at the same distance. As seen in Figure 4, three locations were used for the testing, each with a number of possible impairments to be evaluated.

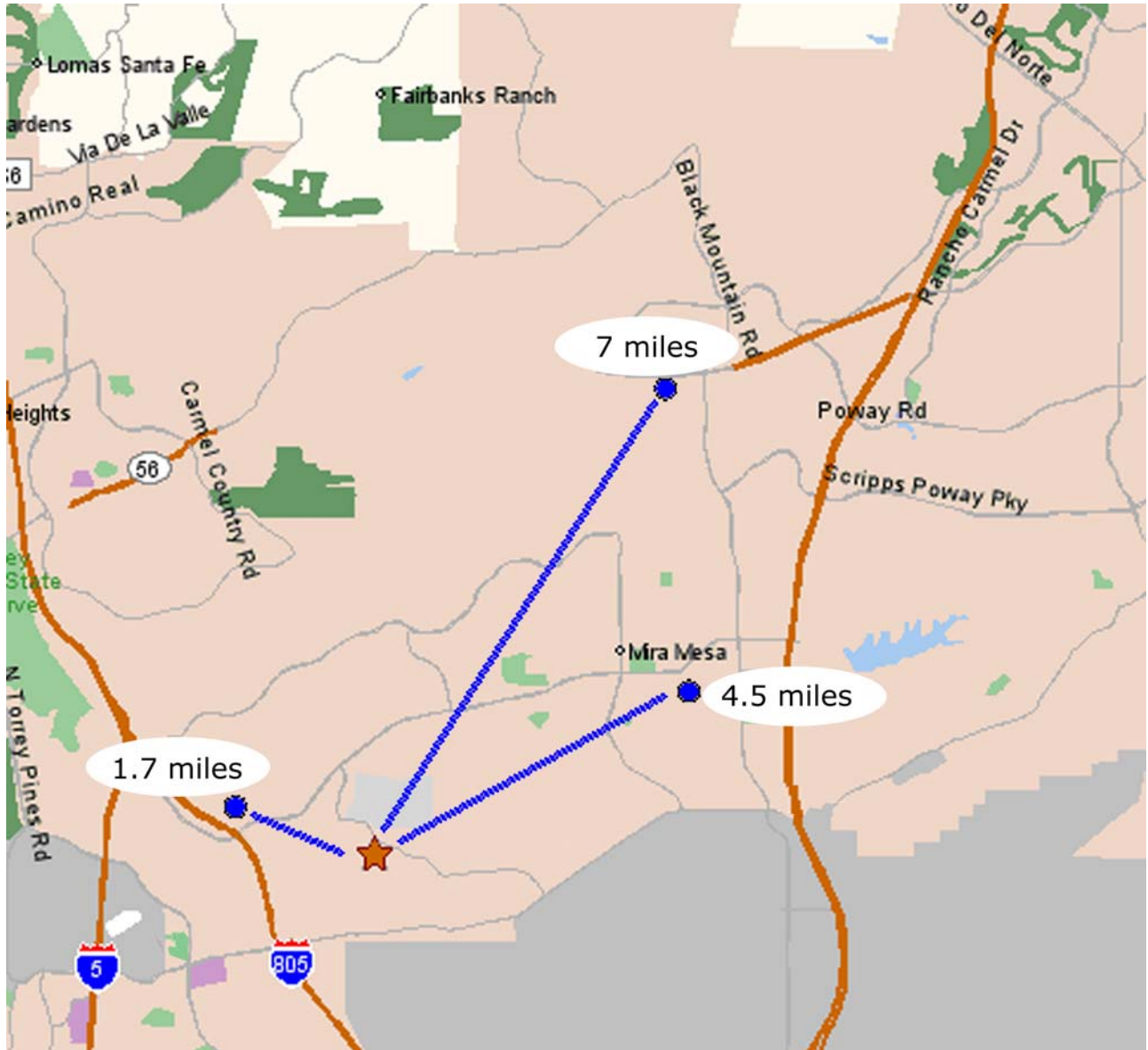


Figure 4: Test Locations in San Diego, CA

A SkyWay 5600 base station with a built-in 90 degree sectoral antenna was tower mounted on the roof of Solectek's 2 story headquarters building. Total height above ground level is approximately 40 feet. The SkyWay 5300 subscriber unit with an integrated one-foot 23dBi antenna was mounted to the rear of a Jeep. At each of the three general locations, the Jeep was driven to both LOS and near- or non-LOS points.

Throughput was measured using Ixia's Qcheck software, configured to measure TCP/IP throughput between PCs at each end of the radio link

Location 1: 1.7 miles / Business Park / 36 Mbps data rate setting

The general location is in a business park where LOS conditions can be established on a hilltop. From this position, a TCP throughput of 15-16 Mbps was achieved.

In the area, two NLOS test sites were identified. See Figures 5, 6.



Figure 5

The first NLOS location was on the same hilltop but with two impairments. The subscriber unit was located behind a large tree, and an office building approximately 0.5 mile away obscured a majority of the 1st Fresnel zone. In this position, a TCP throughput of 15-16 Mbps was measured.

The second NLOS position required a move rearward approximately 300 feet behind and below a 10 foot embankment topped with small trees and bushes. In this position, there was no visual line of sight between the base and CPE. A TCP throughput of 12 Mbps was achieved.



Figure 6



Figure 7

Location 2: 4.5 miles / Condominium complex / 36 Mbps data rate setting

The next location is within a housing community with a road meandering between townhomes. With LOS conditions, TCP throughput was 13-14 Mbps.

Three NLOS conditions were established. First, a location behind a number of large thick trees was tested, as seen in Figure 7. From this point, throughput was 13 Mbps. Next, a hillside location was tested visual LOS was obscured by a townhome rooftop (Figure 8). From this vantage, TCP throughput was 11-12 Mbps. Finally, a location was established

behind a small opening between two buildings with a large tree in the middle (Figure 9). TCP throughput was 10 Mbps.

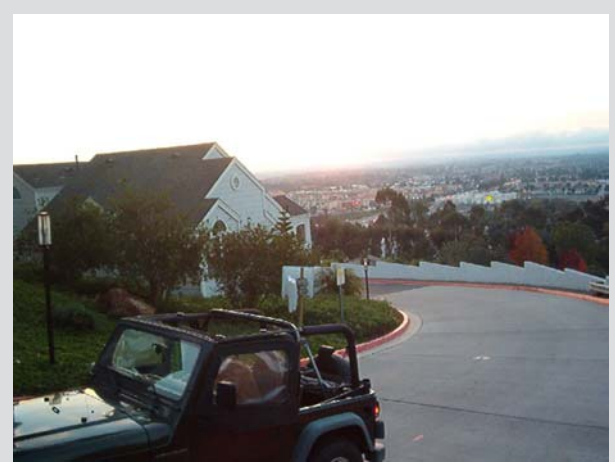


Figure 8



Figure 9

Location 3: 7 miles / Community Park / 72 Mbps & 18 Mbps data rate setting

This park is on a mesa overlooking the valley where the base station is located. At the edge of the park, clear LOS can be established with the base station. When set to 72 Mbps data rate, a TCP throughput of 20 Mbps was measured.

Two NLOS locations were tested. First, a location approximately 300 feet behind and slightly below the LOS test area was used. See Figure 10. With no visual LOS to the base station, a TCP throughput of 19-20 Mbps was achieved.

Moving further away from the mesa edge further obscured visual LOS and added several trees, bushes and a parked car in the visual LOS between subscriber and base station. See Figure 11. For this test, the data rate setting was reduced to 18 Mbps. At this setting, a TCP throughput 6 Mbps was achieved.



Figure 10



Figure 11

Conclusion

Until recently, the development of a cost effective NLOS radio was virtual impossible. But increasing levels of system and chip integration has provided the means to create a high power OFDM system that can operate in near, and in some cases, non line of sight situations at long distance and with high data throughput. While not suitable for mass indoor deployment, Solectek's SkyWay 5000 is an example of the industry's latest technology, now even better able to achieve the objectives of WISP, enterprise and government broadband wireless customers.