How Non-Line-of-Sight Backhaul Really Works

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Ever wondered how non-line-of-sight (NLOS) backhaul really works? And how NLOS backhaul is different from Line-of-Sight (LOS) backhaul? I will explain the difference here and highlight some key issues that make a very big difference in the performance of NLOS systems.

A fundamental practice in designing wireless systems is to understand the characteristics of the propagation channel and to design a system that takes advantage of such characteristics while mitigating for different impairments. This is because the wireless propagation channel exhibits different characteristics in different deployment scenarios. For example, an outdoor channel is different than an indoor one. Furthermore, the channel behaves differently in different antenna deployment scenarios.

So we start by outlining some of the main impairments of the wireless propagation channel to illustrate how NLOS systems are designed and how they differentiate from LOS and between each other.

Overview of Wireless Channel Characteristics

In non-line-of-sight propagation conditions, signals arrive at the receiver through different paths as they reflect and diffract off obstacles between the transmitter and receiver. The arriving signals will have different delay, amplitude and phase characteristics. When the arriving signals combine out of phase at the receiver (i.e. destructively), the result is a low-quality signal which can effectively wipe out all communication. This is phenomenon is called ‘multipath fading.’

Multipath fading results in the spreading of signals in the time, frequency and spatial domains. For our purposes, we will focus on the time domain which has the most pronounced impact on the wireless channel for a small cell backhaul link.

In the time-domain, multipath fading will result in several replicas of the transmitted signal arriving at the receiver. This dispersion (commonly referred to as delay spread) indicates the spreading of the signals in the time domain. Excessively delayed replicas of a transmitted symbol result in inter-symbol interference (ISI) when they overlap with the following symbol.

The time domain dispersion provides a measure of the variability of the propagation channel to different frequencies. When viewed in the frequency domain, multipath fading is similar to a ‘notch’ that affects the signal. How wide and deep the notch is depends on the environment and the propagation channel. If the signal bandwidth is smaller than the notch, then the channel is termed ‘flat’ because it impacts the entire bandwidth of the signal in a similar manner. However, if the signal bandwidth is larger than the notch, the channel is called ‘frequency selective.’ A frequency selective channel leads to inter-symbol interference. The measure of the channel bandwidth that results in the same effects on the transmitted signal is termed ‘coherence bandwidth.’ The coherence bandwidth is inversely proportional to the delay spread.

Mitigating Wireless Channel Impairments

To counter multipath fading and other wireless channel impairments, wireless communication systems feature a physical layer optimized for different deployment scenarios.

In line-of-sight systems, the physical layer consists of a single frequency carrier with a bandwidth that ranges between 7 and 56 MHz. The operation of these systems mandates clearance of obstacles to minimize the impact of fading to a level that does not impact system performance or to a level where techniques such as equalization can be used to compensate for channel impairments cost effectively. This is because as the channel bandwidth increases, the computational complexity of equalization techniques increases correspondingly.

Non-line-of-sight systems on the other hand use a multi-carrier physical layer. The channel bandwidth is divided into several sub-carriers that have a narrow frequency bandwidth. The sub-carriers are aligned such that the peak of a sub-carrier coincides with the nulls of the other sub-carriers as shown in Figure 1. Arranging the sub-carriers in such a manner eliminates interference between them. This physical layer is called OFDM (Orthogonal Frequency Division Multiplex). Although OFDM is not a new invention (it dates back to the 1960’s), its implementation in commercial silicon only became possible in the late 1990’s beginning with 802.11a and then became widely available in the 2000’s (802.16/WiMAX and LTE).

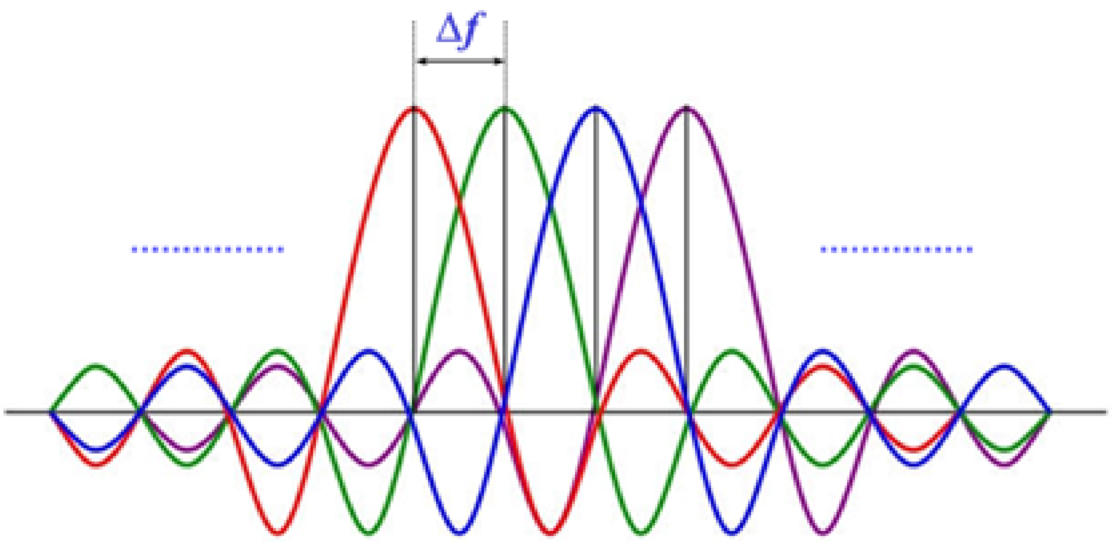

Figure 1 OFDM signal consists of several narrow sub-carriers.

In OFDM, data symbols are mapped onto different sub-carriers which modulate the data symbols for transmission over the air in what we call an OFDM symbol. When the bandwidth of the individual sub-carrier is smaller than the coherence bandwidth of the propagation channel, multipath fading notches a variable number of sub-carriers causing errors in communication that are corrected for using error correction codes (e.g. convolutional turbo codes).

How NLOS Systems Stack Against Each Other

When viewed in the time domain, the OFDM symbol that is transmitted over the air has a duration that is inversely proportional to the subcarrier spacing (Δf). Hence, the narrower the sub-carrier the longer the OFDM symbol, as shown in Figure 2. To mitigate against inter-symbol interference from delayed replicas of transmitted symbols, the OFDM symbol leads with a guard band commonly known as the cyclic prefix as shown in Figure 3. The cyclic prefix should be long enough such that delayed replicas arrive within it. However, the delay spread varies according to the surrounding environment. For example, the delay in indoor areas is generally small, on the order of sub 1 micro second. In urban areas, the delay is longer, on the order of 4-5 micro seconds, while in rural and open areas, as long as 20 micro seconds or more can be encountered. Note that the cyclic prefix is an overhead which reduces the capacity of the channel. Therefore, it’s important to have just enough guard time to mitigate ISI, but not so long that it reduces the throughput rate of the system.

The design of the symbol ought to take account of the deployment scenario to mitigate against wireless channel impairments. For a given channel bandwidth we have the option of using a small number of relatively wide sub-carriers or a large number of relatively narrow sub-carriers. The former results in short symbol duration while the latter in long symbol duration. For outdoor environments, it is desirable to use a larger number of sub-carriers which allows for a longer cyclic prefix while maintaining sufficiently low overhead to achieve a high data rate.

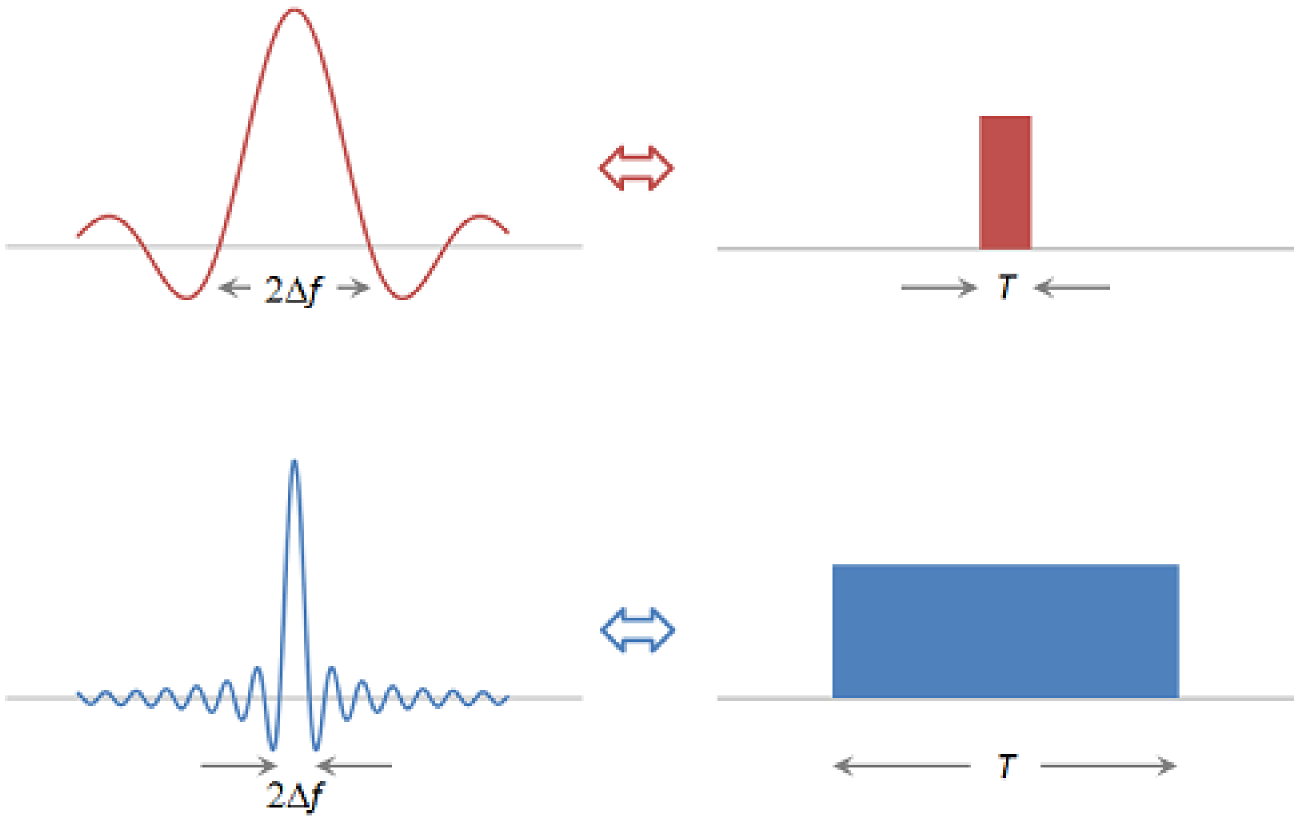

Figure 2 Relationship between OFDM frequency domain sub-carrier width and time-domain symbol width.

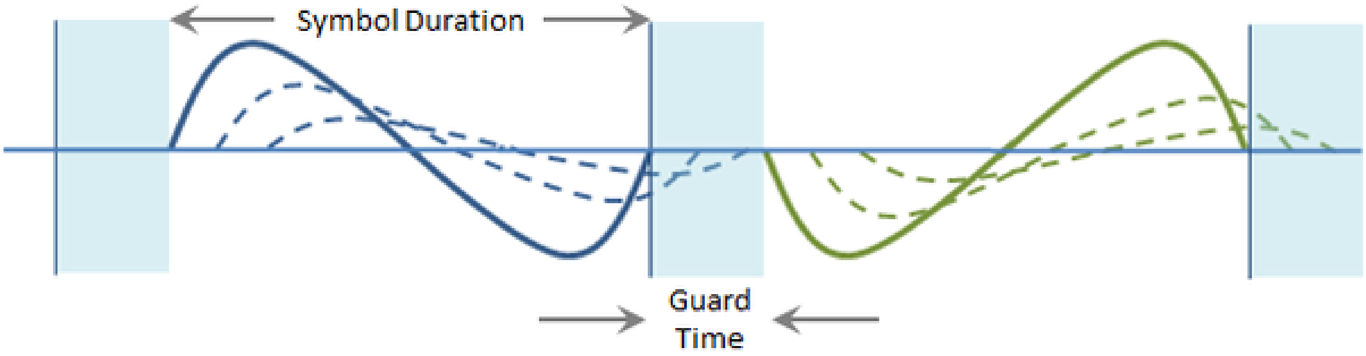

Figure 3 Guard band added at the beginning of the OFDM symbol to mitigate inter-symbol interference.

As an example of how this is implemented in practice, Table 1 shows a comparison between WiFi and LTE: both operate over a 20 MHz channel, but while WiFi uses 64 sub-carriers, LTE uses 2048 sub-carriers. WiFi and LTE have different deployment scenarios: WiFi is designed for local area networks and extensively used indoors, while LTE is an access technology designed to operate outdoors to provide service to large areas. While WiFi and other systems based on wide sub-carrier OFDM can be used outdoors, they would not be able to cope in true non-line-of-sight conditions where the delay spread exceed the cyclic prefix of 800 nano-seconds. For this reason, many such systems are deployed in near line-of-sight where there is a clear optical path, but no clear RF path (i.e. obstacles within the first Fresnel zone).

Table 1 Example of relationship between sub-carrier spacing and symbol duration.

Frequency (MHz)	20	
Technology	WiFi	LTE
No. Sub-Carriers	64	2048
Sub-Carrier Spacing (kHz)	312.5	15
Symbol Length (μsec)	3.2	66.7
Cyclic Prefix (μsec)	0.8	4.7
% Overhead	20%	6.6%

The design of the physical layer is one differentiator between LOS and NLOS systems. It is also a differentiator within the family of NLOS solutions. Because the characteristics of the wireless propagation channel are determined to a large extent by the deployment scenario, not all NLOS systems are the same. The performance can vary widely between different systems claiming to operate in NLOS conditions. This opens the door for differentiation between solutions each of which can stress a certain deployment scenario. This is the case for NLOS wireless backhaul as well which features a unique deployment scenario that is different from either wide area mobile networks or local area networks.

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