Deployment Considerations for 5 GHz WLAN Technology

Greater total bandwidth and higher data rates make 5 GHz attractive for high-speed WLAN.

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The success of WLAN technology was firmly established by Wi-Fi (IEEE 802.11b) products operating in the 2.4 GHz band. Wi-Fi delivers reliable service at data rates up to 11 Mbps. Over the next 12 months, 5 GHz systems will begin entering the market. Greater total bandwidth and higher data rates make the 5 GHz band very attractive for high-speed wireless LAN applications. This article takes a look at the relative strengths of 2.4 GHz and 5 GHz WLAN technologies.

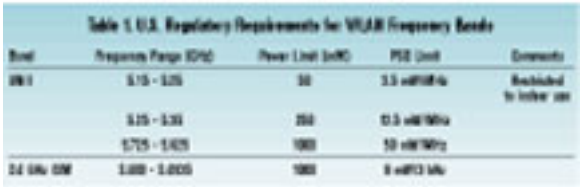
An explanation of terminology is required. &quotWi-Fi&quot is the trade name developed by the Wireless Ethernet Compatibility Alliance (WECA) to denote IEEE 802.11b systems that have passed rigorous interoperability testing. WECA will also be providing interoperability testing for IEEE 802.11a systems in the very near future, though the new logo has yet to be defined.

The IEEE 802.11a standard provides data rates up to 54 Mbps in the 5 GHz band. In order to fully appreciate the benefits of this emerging technology, it's helpful to use existing Wi-Fi systems operating in the 2.4 GHz band as a benchmark. A number of factors such as carrier frequency, data rates, multipath, number of channels, and modulation scheme affect operation. Once these factors are understood, market adoption for major segments can be more readily discussed.

Radio Propagation

Propagation loss at 2.4 vs. 5 GHz, as well as the means by which 802.11a and Wi-Fi systems deal with multipath, are essential to understanding the respective strengths of the two technologies. Wi-Fi systems operate in the 2.4 GHz Industrial, Scientific and Medical equipment (ISM) band, while IEEE 802.11a systems operate in the 5 GHz bands. In the U.S., the 5 GHz bands are collectively known as the Unlicensed National Information Infrastructure (UNII) bands.

There is a lot more bandwidth available at 5 GHz, but there is a large gap from 5.35 GHz to 5.725 GHz. As a result, most radios will only cover the lowest 200 MHz of spectrum (5.15 GHz to 5.35 GHz). Even so, IEEE 802.11a devices will have at least 8 channels, as compared to only 3 for Wi-Fi systems.



Propagation Loss

For any given range, the signal strength at the receiver is reduced as the carrier

frequency (*f*) increases due to an effect called propagation loss (L_p). This can be calculated as:

$L_p = X \log_{10} [4p\ D\ f]$ (1) / C
Where:
X = loss coefficient
D = distance (meters)
f = frequency (Hz)
c = speed of light (meters/sec)

From Equation (1), losses are greater at higher frequencies. Indoors, signals may be further attenuated by walls and furniture. The loss coefficient (X) is 20 in free space. Indoors it can vary greatly, and typically varies from 30 to 40. Systems in the 2.4 GHz frequency will offer greater range, but just how much more depends largely on assumptions regarding propagating conditions. More about this later.

Combating Noise and Multipath

Multipath distortion occurs when the transmitted signal arrives at the receiver antenna by more than one path, as shown in Figure 1.

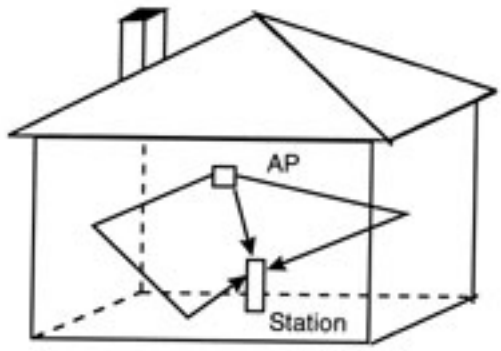
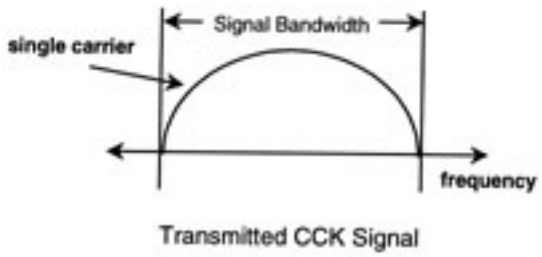


Figure 1. Multipath is Caused by Signal Reflections from Objects in the Local Environment

Note that the different paths have different physical lengths. As a result, multiple copies of the transmitted signal arrive at the receiver antenna slightly staggered in time. The resulting composite received signal can be seriously distorted, as shown in Figure 2.



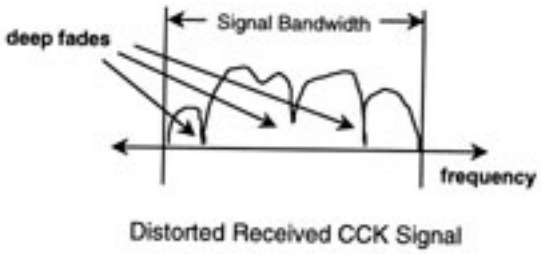


Figure 2. Multipath Can Result in Severe Distortion of the Received Signal

Wi-Fi radios which operate in the 2.4 GHz band use sophisticated adaptive signal processing techniques, such as RAKE receivers and linear channel equalization to combat multipath. The protocol uses a known preamble on each packet that enables receivers to correct the distorted signal for each and every packet. Thus, the radio is constantly adapting to the changing local environment. In addition, Wi-Fi systems employ Complimentary Code Keying (CCK). The robust CCK code improves system reliability in the presence of noise and interference and simplifies channel equalizer design.

In contrast, IEEE 802.11a systems operating in the 5 GHz bands utilize Orthogonal Frequency Division Multiplexing (OFDM). OFDM is a very powerful method for combating multipath distortion. OFDM systems distribute encoded data over many closely spaced *sub-carriers*, as shown in Figure 3. The sub-carrier frequency separation and the data transmission rate are carefully selected to ensure that there is no interference between adjacent sub-carriers.

As seen in Figure 3, multipath distortion can result in different levels of attenuation for each sub-carrier. OFDM systems can often correct distorted sub-carriers. In addition, the data is distributed over several sub-carriers. Complete loss of one or even several sub-carriers will not disrupt operation.

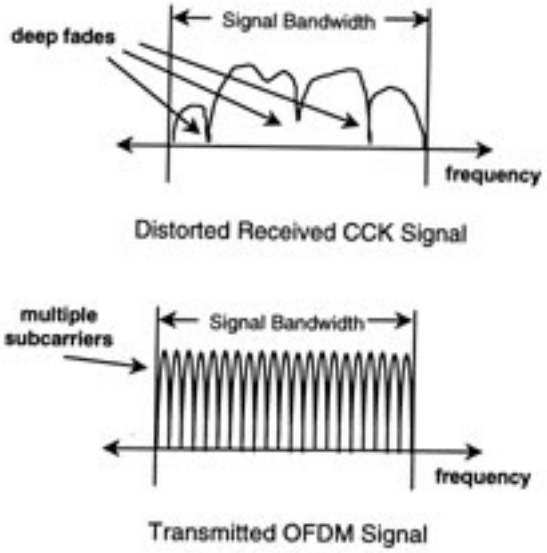


Figure 3. OFDM Distributes Data Among Multiple Sub-carriers to Combat Multipath

Antenna diversity is another important feature that can help combat multipath. Although both Wi-Fi and IEEE 802.11a receivers can make use of diversity, the Wi-Fi protocol was designed specifically to permit diversity reception on a *packet-by-packet basis*. During reception of the Wi-Fi packet preamble the receiver checks the

signal quality on two antennas.

How Can ODFM Systems Deliver Such High Data Rates?

IEEE 802.11a systems have channel widths that are actually slightly smaller than Wi-Fi systems. In general, transmission of higher data rates requires wider channel widths (more bandwidth). This raises a question: *How can 802.11a systems deliver data at rates up to five times faster than Wi-Fi systems in spite of having slightly narrower bandwidths?* The answer lies in the use of more complex modulation schemes.

Wi-Fi systems employ Binary Phase Shift Keying (BPSK) or Quadrature Shift Keying (QPSK), depending on the data rate transmitted. BPSK employs two phases (0 and 180 degrees) to transmit information. Each phase (or symbol) corresponds to one bit of information (0 or 1). With QPSK, four phases are used (0, 90, 180, and 270 degrees). Each symbol represents two bits of information (00, 01, 10, or 11), thus doubling the data rate while maintaining the same channel width.

IEEE 802.11a systems also use BPSK and QPSK modulation at data rates up to 18 Mbps. For higher rates (18 - 54 Mbps), a more complex form of modulation called Quadrature Amplitude Modulation (QAM) is used. QAM varies both amplitude and phase to encode more bits on each symbol. With 16 QAM, sixteen different combinations of amplitude and phase (symbols) are possible. Each symbol represents *four* bits of data. By extension, with 64 QAM each symbol representing *six* bits of data. Assuming the same symbol transmission rate is the same, a system using 64 QAM can transmit six times more data than a system using BPSK modulation within the same channel width. Of course, there's a catch. More complex modulation schemes require more signal power for reliable operation.

What about Range?

As it turns out, the price to be paid for higher data rates is reduced receiver sensitivity. Figures 4 illustrates why this occurs. At low signal-to-noise (SNR) levels, it's obviously easier to pick from 2 possible symbols (BPSK) than from 64 (64 QAM). Wi-Fi receivers generally deliver better receiver sensitivity. This is due mainly to transmission of lower data rates and less complex modulation methods (BPSK and QPSK). Even at similar data rates (5.5 vs. 6, or 11 vs. 12), 802.11b radios have a slight sensitivity advantage.

Figure 4. Signal Constellations for PSK and QAM Modulation

Carrier frequency also affects range, as described above. In general, a lower carrier frequency is more desirable. Again, IEEE 802.11b systems enjoy an advantage of approximately 7 to 10 dB because of the use of a lower carrier frequency. It is not possible to state absolute ranges due to the large variation in propagation conditions in homes and offices. However, it is illustrative to show estimated ranges of IEEE 802.11a and Wi-Fi systems operating at various data rates under stated conditions.

A commonly used model for indoor propagation models signal loss as a function of range (r). The model assumes line-of-sight propagation for the first meter (range squared, or r^2), and somewhat higher loss as a function of range beyond one meter

($r^{3.5}$). The loss exponent can vary considerably, but is typically in the range of 3.0 to 4.0 for indoor applications. Assuming the same transmit power (15 dBm) with omni directional antennas (0 dB gain), the estimated ranges of IEEE 802.11a and Wi-Fi systems are shown in Figure 5.

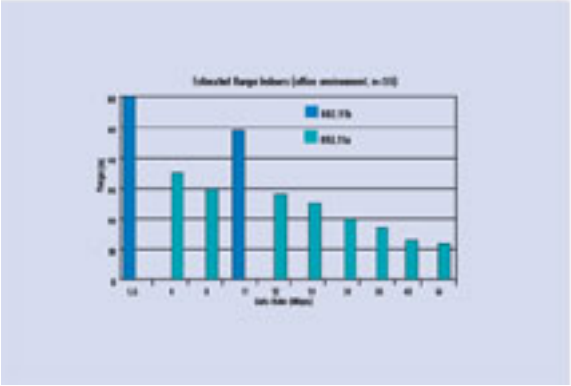


Figure 5. Relative Range of IEEE 802.11a and 8802.11b WLAN Systems

Market Adoption of 5 GHz Technology

5 GHz WLANs have a distinct advantage over 2.4 GHz WLANs in terms of data rate and the number of channels. On the other hand, Wi-Fi systems have an advantage in terms of range, particularly when compared to 5 GHz systems operating at data rates of 24 Mbps and higher. These factors will have an impact on market adoption in the various market segments.

Outdoor Bridges

WLAN technology is commonly used in bridging applications (point-to-point) as a replacement for expensive leased high rate transmission lines. To a large degree, the range limitations described above can be overcome in fixed applications with highly directional antennas. At 5 GHz, a 10 dB reflector has a diameter of about 1 foot. For fixed point-to-point or point-to-multipoint applications, directional antennas can compensate for the lower power limits and higher path loss encountered in the 5 GHz bands. In addition, properly sited antennas can sometimes eliminate the multipath problem. 802.11a systems will experience rapid adoption in this segment.

Enterprise Use

There is no question that higher data rates are more attractive in the enterprise market. Range limitations may be offset in the enterprise via the installation of additional access points. This is practical because there will be at least 8 channels available to site planners. The use of additional access points will also increase overall system capacity.

At the same time, it is doubtful that 54 Mbps coverage could become ubiquitously available in an enterprise setting. If higher data rates are sought, access points will have to be placed closer together. However, at higher data rates, adjacent channel interference (ACI) immunity is drastically reduced. In addition, 5 GHz systems will initially cost more, and will very likely consume significantly higher power than 2.4 GHz systems. Both issues will be resolved over time as smaller lithography CMOS processes become available and production volumes ramp. These issues may delay, but will not prevent, adoption of 802.11a in the enterprise.

5 GHz in the Home

In many ways, the home represents the most challenging market space for adoption of 5 GHz technology. Consumers will likely have a single access point, which may be co-located with (or be a part of) a set-top box such as a cable or DSL modem.

Applications will likely be driven by multimedia content. Reliable multimedia delivery throughout the home will require an extremely reliable high rate wireless link.

As described above, 5GHz WLANs generally have less range than their 2.4 GHz counterparts. Installation of multiple access points is not a practical option in the home. However, consumer applications are extremely asymmetric. For multimedia applications, downstream traffic will far exceed upstream traffic. Transmit power at the gateway could be increased since this end of the link is fixed and powered from AC. Improved antenna technology could also offer significant advantage.

Conclusions

802.11a WLANs can deliver higher data rates and have more channels than current 802.11b systems. Range limitations can be overcome via the use of directional antennas in the bridging/fixed wireless market. However, range restrictions may limit the usefulness of 5 GHz WLAN technology in consumer applications.

Range issues can be compensated for to some degree in the enterprise via the installation of a higher density of access points. Cost and power consumption issues may slow, but will not prevent, adoption in the enterprise.

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