Maximizing Wireless LAN Range by Exploiting Two Types of Antenna Diversity

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Abstract: Contained herein is a simple explanation of how antenna diversity maximizes the range of a Wireless LAN. Furthermore, Oberon’s technique for simultaneously exploiting spatial and polarization antenna diversity to minimize antenna signal fading correlation is explained. Finally, simulation results for Evaluate and Switch diversity combining is given over various levels of channel fading correlation. The simulation shows that two-branch Evaluate and Switch combining leads to ~11 dB of diversity gain and improves the coverage area by 260% over a single antenna in uncorrelated Rayleigh fading channels. More measurements and simulations are required to realistically quantify the spatial and polarization diversity gain achievable in a typical in-building radio environment.

Introduction

Indoor Wireless LANs (WLANs) operate in harsh radio conditions that can severely reduce their effective coverage areas. The reduction in coverage is due to the destructive interference caused by multiple copies received at any point inside a building.

Radio environments exhibit three types of signal fading: exponential path loss over the radio transmitter-receiver separation distance known as the area mean, a local mean due to large obstacles in the path of the Line-of-Sight (LOS) radio ray, and a multipath fading component due to multiple reflections of the signal arriving at the receiver out of phase. These fading types are physically superimposed upon each other in most indoor WLAN environments as shown in Figure 1.

- Path Loss: Exponential loss of signal power over distance. The free-space assumption of the inverse square law does not usually hold inside a building. Typical values range from 1.5 to 6, depending on building material and floor layout.

- Large Scale Fading: Random signal fading that possesses a lognormal probability distribution as averaged over 20 wavelengths (several feet at 2.4 GHz). This type of signal fading is caused by obstructions that greatly attenuate radio signals such as people, desks, and cabinets. It is often referred to as Shadow fading because large surfaces obstruct the primary radio path similar to blocking an optic ray.

- Small Scale Fading: Random signal fading that possesses a Rayleigh or Rician probability distribution over a couple wavelengths. This type of fading is the most detrimental because deep signal nulls cause the desired signal to almost completely disappear. Fortunately, if the signals arrive from many angles, there is often a location of good reception only a fraction of a wavelength away. Rayleigh distributed fading occurs when multiple copies of the transmitted signal arrive out of phase with each other at the receiver and there is no dominant reflected or Line-of-Sight (LOS) component. The addition of multiple copies of the same signal with different phases results in mostly destructive interference. A Rician fading channel has a
greater average power and lower statistical variation than a Rayleigh fading channel because there is a dominant ray.

**Benefits of Antenna Diversity**

Similar to investing in several unrelated corporate stocks in order to minimize one’s losses when a single stock dips in value, antenna diversity increases the probability that a transmitted signal arrives intact at the receiving radio. It is a property of diversification that this probability increases exponentially with each additional antenna added to the receiver. In the case of a WLAN radio with two receive antennas; the probability that a signal is received above the minimum required level for successful reception is the square of the probability that a single antenna capturing enough energy.

It is possible to *increase* the total coverage area or conversely *reduce* the required transmit power by relying on antenna diversity techniques. Oberon’s dual diversity technique incorporates spatial and polarization diversity to minimize the correlation of signal fading at each receive antenna.

**Principle of Spatial Diversity:**

The gain of spatial diversity arises when a transmitted signal experiences unique, or uncorrelated, signal fading for both antennas in a rich scattering environment. If the relative phases of the multiple reflections are uniformly distributed (from 0 to $2\pi$) as often is case for an indoor WLAN radio channel received with omni-directional dipole antennas, then only a half wavelength antenna separation distance is required to obtain uncorrelated fading channels [1]. It appears that this is the assumption held by most WLAN Access Point (AP) manufacturers for setting the standard WLAN antenna separation distance.

However, it is important to note spatial correlation over antenna separation distance is not always reciprocal at the WLAN AP and the client. Many ceiling or wall mounted APs are located at a height where both antennas receive signal from a limited range of angles and therefore experience highly correlated fading. The WLAN client, however, is located down in the “clutter” where it receives signal reflections from a large range of angles and experiences less correlation between its antennas [2]. Spatial diversity is not effective when there is a dominant LOS component because that causes highly correlated signal fading between antennas.

Although there is currently little published data to show correlation of WLAN antennas inside a building, Figure 2 contains the two-antenna spatial correlation function for a cellular Mobile and Base Station. While the Mobile Station can typically use just under a half wavelength antenna separation, the Base Station requires 12 or more wavelengths, depending on the antenna beam width [1].

**Principle of Polarization Diversity:**

It is possible to gain from polarization diversity because an indoor radio environment depolarizes a transmitted signal each time it is reflected. Therefore, if typical WLAN receive antennas are oriented for only one of the two linear polarizations (horizontal and vertical), the other polarization may be underutilized. Unlike the spatial diversity approach, diversity gain is possible with polarization diversity when there is a dominant LOS component because of the random and unknown orientation of the WLAN client’s antenna to the cross-polarized AP antennas.

Oberon is currently characterizing the nature of depolarization in typical office environments through controlled field strength measurements.

**WLAN’s Combining Technique**

It is well known that IEEE 802.11 WLAN compliant radios rely on two-branch antenna diversity to improve performance inside a building [3]. Once the beginning of the WLAN packet is received, the radio demodulates the synchronization portion of the packet with first one antenna branch and then the other. Based on that observation, it decides which antenna branch has the greatest signal strength or SNR and uses that one antenna for receiving the remainder of the packet.
Conversely, the radio will transmit with the same antenna from which it last successfully received a packet for a given device [3]. This is an optimal choice of antenna as long as the radio environment has not changed due to client mobility or the relative movement of reflecting objects within the building. This assumption is usually met because the indoor wireless channel for fixed users changes slowly compared to the duration of a WLAN packet and the total inter-packet delay [4].

It should be noted that commercial WLANs do not yet possess transmit diversity as pioneered in recent Multi-Input-Multi-Output (MIMO) radios. Although research shows that richly scattered indoor radio channels can support spatial multiplexing, the current IEEE 802.11 flavors do not. Therefore, in order to maintain backwards compatibility with the IEEE 802.11 standard, Oberon advises the use of receive-side diversity techniques exclusively.

Figure 3 is a plot of time samples of two uncorrelated fading channels superimposed with the results of the WLAN Selection Combining technique, referred to by the more descriptive name of Evaluate and Switch Combining (ESC).

![Instantaneous Path Loss for two Rayleigh channels and Evaluate and Switch Combining](image)

*Fig. 3: WLAN's combining technique exploits uncorrelated signal fading at each antenna*

It is clear from Figure 3 that Rayleigh fading can result in deep signal fades (maximum fade is 25 dB over this small sample, but are theoretically infinite). Fortunately, the ESC algorithm can select the other antenna when this deep fading occurs and a large comparative advantage is statistically likely. Figure 4 shows that in an average sense, ESC improves the received SNR mean by 3 dB and decreases the standard deviation of the signal variation by 1 dB for uncorrelated (\(\rho=0\)) channels. This figure also shows that as the channels become more correlated, the benefits of ECS decay exponentially.

![Antenna fading correlation Vs. Mean and Std Dev of channel Path Loss](image)

*Fig. 4: WLAN diversity combining increases the average received power for uncorrelated antenna*

**Oberon’s Recommended Dual Diversity Antenna Advantage**

The commercial WLAN market offers many external Access Point WLAN antennas, but few choices give the user much control over spatial or polarization antenna diversity. Typical antennas are directional, linearly polarized patch panel antennas that do not integrate a second antenna, or omni-directional “rubber duck” dipoles that are low gain.

The story is similar for the antennas on the WLAN client side. The vertical and horizontal polarized antenna patterns for the standard PCMCIA client card integrated antenna are shown in Figure 5 [5]. This horizontally oriented antenna is naturally horizontally polarized, but there are still deep nulls in the pattern over many angles of arrival. The vertical polarized antenna pattern is, of course, much worse in the azimuth plane. Fortunately, that is the pattern most users rely upon when receiving from vertically polarized AP antennas. Since the orientation of the client’s integrated antenna is unknown, although presumed to be horizontal during normal usage, rotating one of the AP antennas to the horizontal position would be beneficial. Also, since the vertical and horizontal
patterns appear to be negatively correlated (where the horizontal pattern has a null, the vertical has acceptable gain) a cross-polarized antenna would cover both scenarios.

![Figure 5. Horizontally and Vertically polarized antenna patterns for an integrated PCMCIA WLAN client card in the azimuth plane](image)

**Combining Simulation Results**

The previously mentioned Evaluate and Switch Combining (ECS) algorithm is simulated for various levels of antenna correlation to demonstrate the importance of effective antenna diversity techniques. This combining algorithm is applied on a per packet basis for IEEE 802.11b standard Complementary Code Keyed (CCK) modulated WLAN packets of 1024 bytes length, at an 11 Mbps data rate. The objective of the simulation is to prove that a combining technique will produce effective diversity gain only if each diversity antenna experiences unique signal fading and that this gain decreases exponentially as the correlation increases.

Figure 6 shows the complete range of Packet Error Rate (PER) performance for the ESC technique for selected antenna correlation values. This figure emphasizes that it is the role of antenna diversity to reduce the PER from worst-case Rayleigh fading to approach the best-case Additive White Gaussian Noise (AWGN) PER curve (not shown). In fact, it is possible to asymptotically approach the AWGN PER curve if a WLAN receiver could be built that effectively combined all the signals from an infinite number of antennas.

![Figure 6: Packet Error Rate simulation results for WLAN’s Evaluate and Switch combining technique for various diversity branch correlation values](image)

Figure 7 shows that since the diversity gain rolls off quickly as the signal fading at each antenna approaches full correlation, even a small amount of antenna diversity produces respectable diversity gain and greatly increases WLAN coverage area and range.

![Figure 7: Simulated ESC diversity gain and percent improvement for coverage area and range (40 dB path loss per decade) for 8% Packet Error Rate](image)
An important metric for a radio link is the predicted availability of the radio link at any time. The probability of outage plot shown in Figure 8 shows that for totally uncorrelated fading of two antennas, there is an order of magnitude increase in link availability for the SNR required (6.25 dB) to maintain a PER of 8% for IEEE 802.11b CCK modulation at 11 Mbps with packets of length 1024 bytes.

![Fig. 8: Probability of Outage for Bit Error Rate of 10⁻³ over various antenna correlation values](image)

Oberon is currently revising these physical layer simulations so that they incorporate our previously mentioned experimental field strength measurements.

**Conclusion**

Wireless LAN must operate in the harsh radio environments found inside most buildings. Antenna diversity is an excellent way to mitigate the deleterious effects of signal fading and is currently built into most WLAN radios. However, it is important to take the unintentional correlation of the received signals at each antenna into consideration when selecting diversity antennas for WLAN. For example, the WLAN Access Point and client may experience very different radio environments and should use different antenna separation distances. This white paper demonstrates that spatial and polarization diversity are *complementary* in certain radio environments and can maximize diversity gain where either one alone would fail.

**References**


