Performance Enhancement of MIMO WLAN – A Critical Analysis

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Abstract

There are three basic parameters that completely describe the quality and usefulness of any wireless link: speed, range and reliability. Prior to the development of MIMOOFDM, the three parameters were interrelated according to strict rules. Speed could be increased only by sacrificing range and reliability. Range could be extended at the expense of speed and reliability. And reliability could be improved by reducing speed and range. MIMO OFDM has redefined the tradeoffs, clearly demonstrating that it can boost all three parameters simultaneously. While MIMO will ultimately benefit every major wireless industry including mobile telephone, the wireless LAN industry is leading the way in exploiting MIMO innovations.

Keywords: MIMO WLAN, optimal selection.

1.Introduction

The market for wireless LANs, particularly in the consumer and small business segments, has skyrocketed. By all accounts, annual growth in wireless LAN device shipments has increased from threefold to fivefold since 2001 [1-3]. With huge opportunities for wireless LANs looming in home entertainment, Voice over IP (VoIP), and public access, the biggest market growth may yet lie ahead. Existing wireless LAN standards also lack the throughput levels required by emerging and potentially huge applications such as home entertainment. For example, a single High Definition TV (HDTV) stream requires at least 20-24 Mbps of sustained throughput throughout the home. A wireless LAN's advertised data speed is usually the "raw" link rate—a significant fraction of which is reserved for protocol overhead (commands, status messages, and error control mechanisms). Plus, the capacity of a wireless LAN may be shared between multiple users and applications. Though today's wireless LAN standards promise speeds up to 54 Mbps, actual user throughput often drops into the single digits near the edge of the home coverage area—if a connection can even be maintained—making "wired quality" streaming video impractical using wireless LAN devices based on existing standards. Fortunately, these limitations are surmounted using a combination of MIMO and OFDM technologies. That is why MIMO-OFDM is the foundation of all proposals for the IEEE 802.11n standard.

2. MIMO Technology

Multipath propagation is a feature of all wireless communication environments. There is usually a primary (most direct) path from a transmitter at point "A" to a receiver at point "B." Inevitably, some of the transmitted signal takes other paths to the receiver, bouncing off objects, the ground, or layers of the atmosphere. Signals traversing less direct paths arrive at the receiver later and are often attenuated. A common strategy for dealing with weaker multipath signals is to simply ignore them—in which case the energy they contain is wasted. The strongest multipath signals may be too strong to ignore, however, and can degrade the performance of wireless LAN equipment based on existing standards. Radio signals can be depicted on a graph with the vertical axis indicating amplitude and the horizontal axis indicating time as sine waves. Figure 1a. When a multipath signal arrives slightly later than the primary signal, its peaks and troughs are not quite aligned with those of the primary signal, and the (combined) signal seen by the receiver is somewhat blurred. Figure 1b. If the delay is sufficient to cause the multipath signal's peaks to line up with the primary signal's troughs, the multipath signal will partially or totally cancel out the main signal. Figure 1c. Traditional radio systems either do nothing to combat multipath interference, relying on the primary signal to out-muscle interfering copies, or they employ multipath mitigation techniques. One mitigation technique uses multiple antennas to capture.

Figure 1: How multipath propagation affects radio signals. The strongest signal at each moment in time. Another technique adds different delays to received signals to force the peaks and troughs back into alignment. Whatever the mitigation technique, all assume multipath signals are wasteful and/or harmful and strive to limit the damage.

MIMO, in contrast, takes advantage of multipath propagation to increase throughput, range/coverage, and reliability. Rather than combating multipath signals, MIMO puts multipath signals to work carrying more information. This is accomplished by sending and receiving more than one data signal in the same radio channel at the same time. The use of multiple waveforms constitutes a new type of radio communication—communication using multi-dimensional signals—which is the only way known to improve all three basic link performance parameters (range, speed and reliability). Because MIMO transmits multiple signals across the communications channel (rather than the conventional system's single signal), MIMO has the ability to multiply capacity (which is another word for "speed"). A common measure of wireless Capacity is spectral efficiency—the number of units of information per unit of time per unit of bandwidth—usually denoted in bits per second per Hertz, or b/s/Hz. Using conventional radio technology, engineers struggle to increase spectral efficiency incrementally (i.e. one b/s/Hz at a time). By transmitting multiple signals containing different information streams over the same frequency channel, MIMO provides a means of doubling or tripling spectral efficiency. MIMO can also be thought of as a multi-dimensional wireless communications system. Conventional radio systems try to squeeze as much information as possible through a one-dimensional pipe. In order to do that, engineers must adapt their designs to the noise and other limitations of a one-dimensional channel. MIMO empowers engineers to work in multiple dimensions, creating opportunities to work around the limitations of a one-dimensional channel. Greater spectral efficiency translates into higher data rates, greater range, an increased number of users, enhanced reliability, or any combination of the preceding factors. By multiplying spectral efficiency, MIMO opens the door to a variety of new applications and enables more cost-effective implementation for existing applications.

3. MIMO-OFDM

MIMO can be used with any modulation or access technique. Today, most digital radio systems use Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), or Orthogonal Frequency Division Multiplexing (OFDM). Time division systems transmit bits over a narrowband channel, using time slots to segregate bits for different users or purposes. Code division systems transmit bits over a wideband (spread spectrum) channel, using codes to segregate bits for different users or purposes. OFDM is also a wideband system, but unlike CDMA which spreads the signal continuously over the entire channel, OFDM employs multiple, discrete, lower data rate sub channels. MIMO can be used with any modulation or access technique. However, research shows that implementation is much simpler—particularly at high data rates—for MIMO-OFDM. Specifically, MIMO-OFDM signals can be processed using relatively straightforward matrix algebra.

4. MIMO-OFDM Enables New Wireless LAN Applications and Markets

Wireless LANs scored their first major success in vertical industrial applications—primarily warehouse and retail floor inventory management. The market exploded as wireless LANs were embraced for PC networking and sharing broadband access in small businesses and homes.

This success has positioned wireless LANs to drive the development of three new markets with huge growth potential: home entertainment networking, cordless Voice over IP (VoIP), and a variety of machine-to-machine (M2M) applications. Currently, tens of millions of wireless LAN nodes are shipped annually. Home entertainment applications present the opportunity to sell hundreds of millions of nodes per year—one for every television, stereo system, DVD player, remote screen, remote speaker, and portable record/playback device shipped. Cordless VoIP represents an even greater prospect. Assuming a significant fraction of private and public wireless LANs are modified to handle VoIP traffic, a market for integrating Wi-Fi with mobile phones will emerge. There are currently 1.5 billion mobile phone subscribers, with more than 500 million handsets sold annually. And there is more to cordless VoIP than first meets the eye; for example, cordless VoIP could enable strategic alliances between mobile phone and cable network operators. Major cable operators are entering local phone markets, creating opportunities for mobile carriers to offer handsets that serve as cordless phones in the home—a single phone for all of users' telephone service needs. The potential number of wireless LAN nodes needed for machine-to-machine applications is mind boggling. For example, the average home security system could easily use a dozen nodes for door and window sensors, motion detectors, and video cams. Other major wireless M2M applications include telemetric, asset monitoring, mobile commerce, healthcare, real-time enterprise communications, and homeland security [4]

5.Antenna Selection in MIMO Wireless LAN System

Wireless local area network (WLAN) is a deriving application which uses MIMO antennal selection in MIMO OFDM System. MIMO antenna selection is attractive for performance of WLAN. Diversity and spatial multiplexing gain or recognized to be the main benefits of MIMO Communication system while diversity reduces the outage on random fading channels, thereby increasing reliably achievable rate, spatial multiplexing achieve a similar goal by expanding channel dimensions. The importance of diversity versus multiplexing gain depends on the desired link reliability, channel condition and rate requirements. As both diversity and multiplexing gain come from the spatial dimension of the MIMO channel, there exist inherent trend of between these two benefits.

Considering a family of MIMO transmission (coding) scheme that can sustain rate R(ρ) with probability (1-P_{out}(ρ)), subject to signal to noise ratio (ρ). Where Pout (ρ) is the outage probability. The multiplexing gain are and diversity gain (d) are defined as follow:

$$r = \lim_{\to\infty} \frac{R(\rho)}{Log_2 \rho} \text{ ---(1)}$$

$$d = -\lim_{\to\infty} \frac{LogP_{out}(\rho)}{Log\ \rho} \text{ ----(2)}$$

In other words, r defines scaling of the achievable data rate R(ρ) w.r.t $\log_2$(ρ), whereas d defines the exponent of corresponding outage rate :

$$R(\rho) \dot{=} r \log_2 \rho \text{ -----(3)}$$

$$P_{out}(\rho) \dot{=} \rho^{-d} \text{ ------(4)}$$

where (=) means asymptotic equality as ρ tends to infinity. The figure 2 shows the Optimum mode of scalability for antenna selection in MIMO systems. The maximum achievable data rate is given by the capacity as given below

$$X[k] = \sqrt{\rho} Hs[k] + n[k] \text{ ------(5)}$$

where X[k] is M_R 1 vector corresponding to signal received at M_R receivers and sampled at the symbol rate s[k] correspondence to M_T*1 symbol vector transmitted by the M_T transmit antenna. ρ is average signal energy per receive antenna and per channel use. N[k] is additive Gaussian Noise with variance ½ per real dimension, H is the M_R * M_T channel matrix. M_T represent transmit and M_R represent receiver.

The maximum achievable diversity gain $d_*(r)$ subject to a fixed multiplexing gain satisfy

$$d_*(m) = -l\ \underset{\rho\to\infty}{im} \frac{\log P\{C(H,\rho) < r\log_2(\rho)\}}{\log \rho}$$

-----(6)

The block diagram a typical MIMO OFDM system considered for WLAN is shown in fig 3. Such transreceiver performs spatial multiplexing and N_T transmit antennas in order to increase the data rate by a factor of N_T compared to the standard IEEE 802.11a/g system at the receiver, the original data stream is reconstructed from N_R received signal. When antenna subset selection is used, these N_T transmit (N_R receive) antennas of selected from the total available antennas. Antenna selection algorithm are applied to the main tap of the frequency selective M_R*M_T MIMO channel. This approach is applicable in typical WLAN environments since the RMS delay spread is often less than 10ns, for the total signal bandwidth of 20 MHz. Work is under progress to simulate the system with optimal combined transmit receive antenna selection as given in Eqn (6) as well as suboptimal selection using standard algorithm for decoupled transmit / receiver selection for the estimation of the packed error rate with variation of average (SNR) per receive antenna for different value of M_T and M_R

Conclusion:

MIMO-OFDM technology is more than the latest technical improvement for wireless LANs. MIMO-OFDM is a major technology upgrade enabling demanding new applications with huge market potential and facilitating significant growth in existing applications. Though the

IEEE 802.11n task group is developing a standard for MIMO-OFDM wireless LAN devices around which the entire industry should rally, the delivery of pre-standard MIMO enhanced Wi-Fi devices today can only boost development of a robust market for MIMO-OFDM wireless LAN devices. Although MIMO technology improve reliability and transmission rate achievable in wireless system, the improvement comes at the expense of higher hardware cost. Indeed, every extra transmit/ receive antenna requires its own hardware chain (power amplifier, low noise amplifier, A to D converter etc) Therefore, cost effective implementation of MIMO technology remain in major challenge. Antenna subset selection, where transmission /reception is perform through a subset of available antenna elements which reduces the implementation cost while retaining most of the benefits of MIMO technology. The MIMO WLAN Communication system has been presented using antenna selection for substantial gains

References

[1] Gartner, Wireless LAN Semiconductors: Worldwide 2002-2007 (1/30/04);

[2] IDC, Worldwide WLAN Semiconductor Forecast and Analysis 2004-2008 (July 2004); and

[3] The Linley Group, A Guide to Wireless LAN Chipsets (June 2004)

[4] Wireless Machine-to-Machine: an In-depth Study of Applications and Vertical Markets," published July 16, 2004 Datacomm Research Report.

[5] Spatio-Temporal Coding for Wireless Communications, Raleigh, G.G.; Cioffi, J.M.Global Telecommunications Conference, 1996: vol. 3, 18-22 Nov. 1996, pp. 1809-1814

[6] MIMO Technology is Today's Most Significant Advance in Wireless Communications--but not all MIMO Claims are Accurate, Datacomm Research Company, Research Alert, February 8, 2005

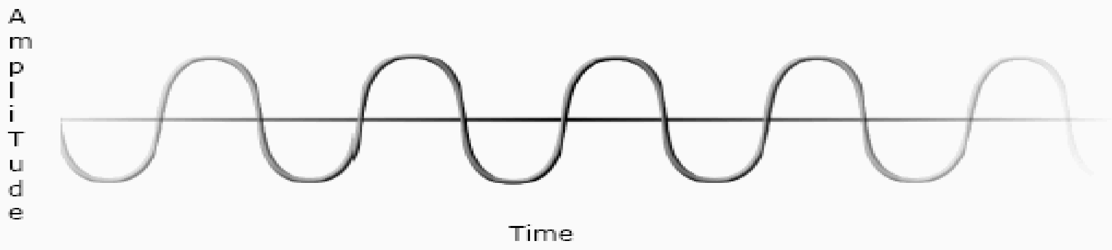
[7] MIMO products boost 802.11g nets, Craig Mathias, Network World, 03/21/05

[8] Zheng and D Tse, "Diversity and Multiplexing : A fundamental tradeoff in multiple antenna channels, " IEEE Trans. Inf.Theory, Vol. 49. No5 PP1073-1096, May 2003.

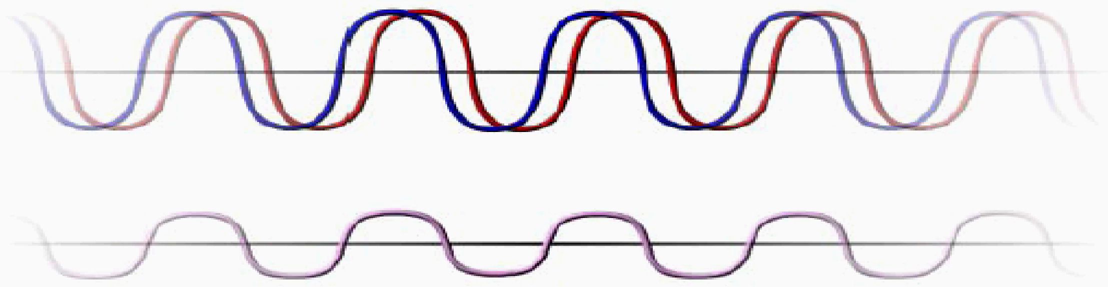
[9] A Ghrayeb and T. Duman, "Performance analysis of MIMO system with antenna selection over quassi-static fading channels," IEEE Trans. Veh. Tech.,Vol.52, No. 3, PP 281-288, Mar 2003.

[10] AGorokhov, "Antenna selection algorithms for MEA transmission systems, " in Proc. IEEE ICASSP, Vol. 3 Orlando, FL, May 2002, PP2857-2860.

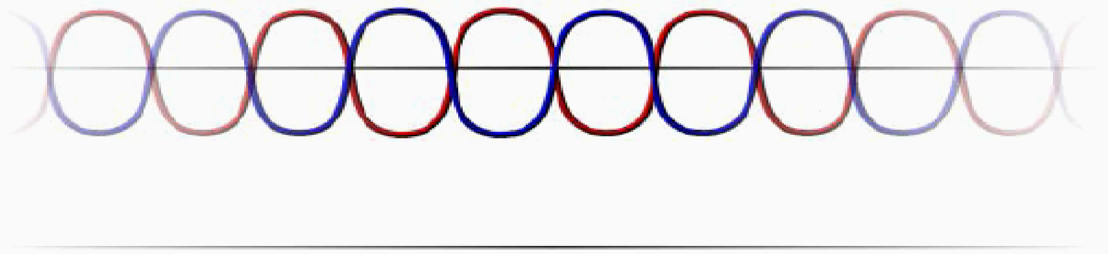
Figure 1: How multipath propagation affects radio signals



a. A radio signal may be represented as a sine wave



b. Multipath signals arriving slightly out-of-phase combine at the receiver to create a somewhat weaker and less distinct signal



c. In the extreme case, multipath signals arriving 180° out-of-phase will cancel each other out

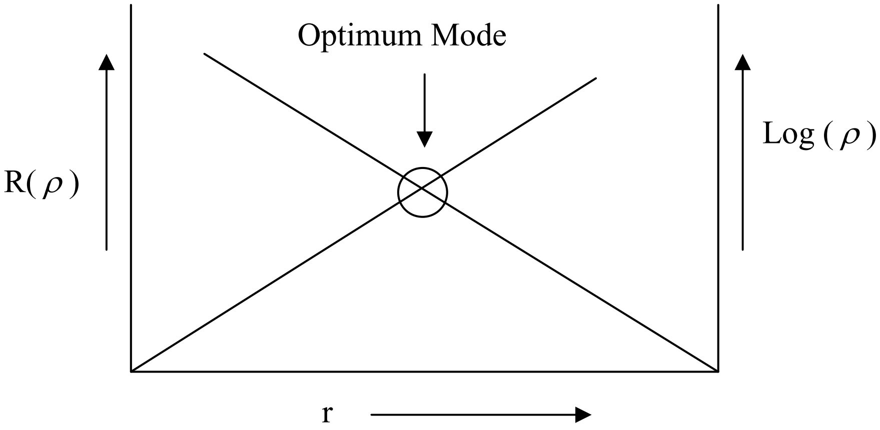


Figure 3 Scalability for Optimum Selection

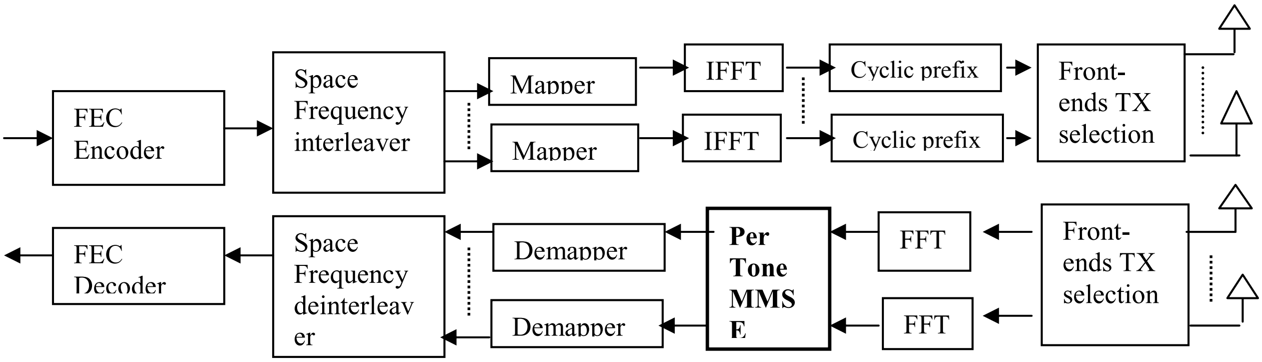


Figure 3 MIMO-OFDM transceiver