IEEE 802.11n delivers maximum video performance in wireless entertainment applications

A new breed of wireless entertainment network must provide higher bit rates to support the distribution of multiple-quality video and HDTV streams from a central location, along with total home coverage. These video applications cannot tolerate bandwidth fluctuations. Therefore, guaranteed bandwidth and quality of service (QoS) are essential requirements in order to provide wire-like performance regardless of changing environmental conditions.

By Gil Epshtein

These challenges in the new digital home entertainment environment cannot be met with existing IEEE 802.11 a/b/g-based wireless products. Products attempting to use wireless local area network (WLAN) technology for video distribution have fallen well short of consumer expectations for link range and picture quality. Their biggest deficiency has been inadequate effective throughput (Figure 1). Although not a panacea for all video-handling challenges, higher throughput improves immunity to interference while delivering a means to handle degraded link conditions. Additionally, any excess bandwidth can be traded for extended reach and lower power consumption. To achieve this higher effective throughput, several new techniques have been developed including multiple-input, multiple-output (MIMO) technology, channel bonding and more efficient media access controller (MAC). To support the required quality of service, the 5 GHz low-interference band along with enhanced quality of service (QoS) mechanisms are used. Together, this set of technologies enables more robust and reliable video delivery over WLANs in the home.

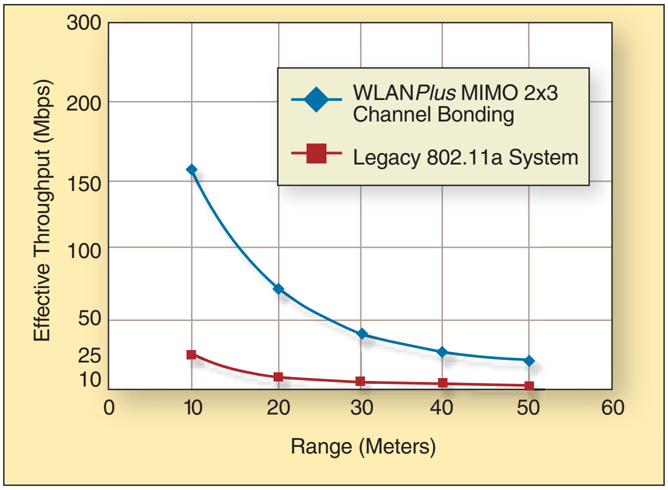

Figure 1. IEEE 802.11a achieves 25 Mbps effective throughput at less than 10 meters, which barely covers the living room of a typical home. Solutions like Metalink's WLANPlus, on the other hand, reach 60 Mbps at 20 meters using the same 5 GHz band, which enables full coverage.

MIMO and channel bonding deliver record performance

MIMO is the key underlying technology in the IEEE 802.11n draft specification that was approved in January, and its performance-enhancing benefits can be further extended through channel bonding in the 5 GHz band. The main advantages of MIMO include higher data transmission rate by a factor equal to the number of transmit streams, and the ability to establish a wireless connection in multipath environments.

A multidimensional signal processing and smart antenna technology, MIMO sends an independent data stream through each antenna. This increases the wireless spectrum use by a factor equivalent to the number of transmit streams (also known as the MIMO rank). To accomplish this, MIMO uses spatial multiplexing (multiple antennas) on top of orthogonal frequency-division multiplexing (OFDM). It codes the information across the spatial and spectral domains by using multiple transmit and receive antennas. This, combined with OFDM modulation on each antenna, increases the diversity and, hence, the robustness. This enables MIMO to withstand channel impairments such as inter-symbol interference (ISI) and other interferences.

On the transmission side, MIMO encodes a single high-rate data stream by splitting it and transmitting it across spatially separated antennas. Having two streams instead of one enables one of two options. System designers can either choose to deliver twice the throughput by keeping the same rate for each of the streams or they can extend the reach of the original stream since each of the lower-rate streams can use lower constellations and recover a correspondingly lower signal-to-noise ratio (SNR). On the receive side, the MIMO receiver uses mathematical algorithms to recover the transmitted signals and combine them into a single stream.

MIMO also takes advantage of the reflected multipath signals that arrive at the receiver some time after the original—or line-of-sight—signal is received. While multipath has traditionally been perceived as a system impairment that degrades a wireless receiver's ability to recover the transmitted information, MIMO-based networks actually rely on it for their operation (Figure 2).

MIMO's benefits are enhanced through the use of channel bonding in the 5 GHz band. Channel bonding takes advantage of Shannon's capacity law, which stipulates that the theoretical capacity limit increases linearly with bandwidth. According to this law, the simplest solution to increasing the rate of any given system is to expand its operating bandwidth, otherwise known as channel bonding. With channel bonding, extended bandwidth is achieved by bonding

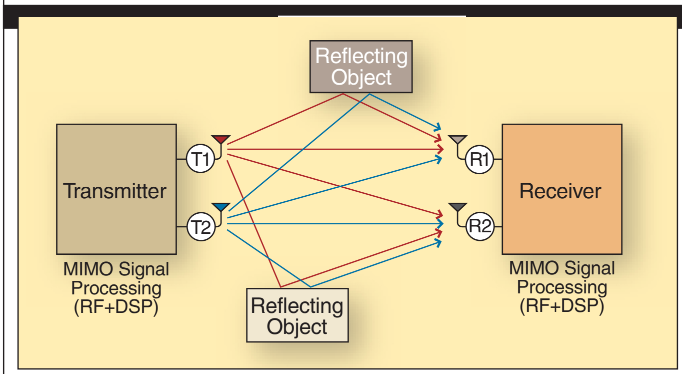

Figure 2. MIMO-based networks are capable of establishing a wireless connection in multipath environments, and actually rely on multipath for their operation.

two adjacent 20 MHz channels into a single 40 MHz channel. The bandwidth increase is actually more than double since the guard band between the two bonded channels can also be removed (Figure 3).

Since only three non-overlapping 20 MHz channels are available in the 2.4 GHz (2.4 GHz to 2.4835 GHz) spectrum band used by the IEEE 802.11b and IEEE 802.11g WLAN communication standards, channel bonding is not a feasible option. It imposes hard limitations on the number of users that can be served and the number of adjacent networks that can operate without interference. Adding to the challenge is the interference resulting from home microwaves, Bluetooth devices and cordless phones, which all operate on the same band. Given these channel-bonding and interference issues, the 2.4 GHz becomes irrelevant for quality home video distribution.

The 5 GHz band (5.15 GHz to 5.85 GHz) currently used by the IEEE 802.11a standard offers more than twenty 20 MHz channels in most parts of the world, which allows the support of much higher numbers of users, much higher bandwidth per user, and higher immunity from interference. It also supports channel bonding, which is an essential tool for meeting the performance rate and reach targets for video delivery.

Better MACs reduce overhead

More efficient MACs enable WLAN systems to optimize the performance-enhancing benefits of MIMO technology coupled with channel bonding in the 5 GHz spectrum band. The 802.11 MAC/PHY has fixed overhead irrespective of packet size. Reducing the overhead has been one of the main concerns in enhancing the current 802.11 WLAN standards.

MAC efficiency of IEEE 802.11a/b/g is typically about 50% at the best conditions. Aggregate exchange sequences are made possible with a protocol that acknowledges aggregated MAC protocol data unit (A-MPDU) with a single block acknowledgment (block ACK) instead of multiple ACK signals. This protocol effectively eliminates the need to initiate a new transfer for every MPDU.

The common overhead associated with each multiple MAC protocol data unit (MPDU) transmission of IEEE 802.11a/b/g, is now associated with a large number of MPDUs. This proportionally increases the efficient throughput.

Figure 4 demonstrates the MAC efficiency difference between a system that doesn't use aggregation (MPDU per aggregate =1) and a Metalink WLANPlus-based system that does. It is seen that a system that doesn't use aggregation is blocked at 35 Mbps effective throughput (MPDU per aggregate is equal to 1).

Enhanced QoS: Jitter cancellation and clock recovery

There are several methods to enhance QoS to the minimum levels required by wireless video delivery, including jitter cancellation and clock recovery, and support for the IEEE 802.11e QoS standard.

Jitter is a critical phenomenon impacting a system's ability to interpret MPEG video presentation and timing information.

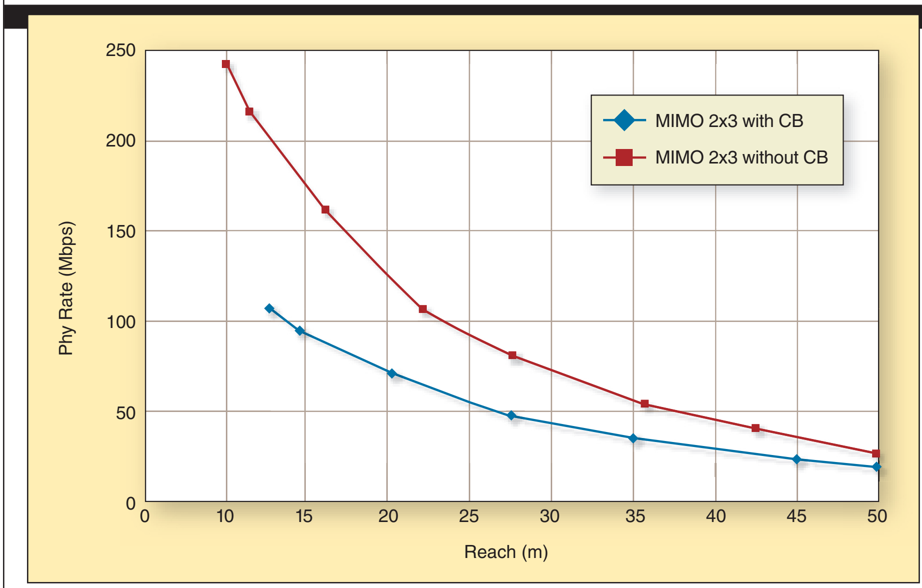

Figure 3. Channel bonding vs. non-channel bonding. By using channel bonding, system designers can achieve a 60 Mbps effective throughput that is more than double the maximum effective throughput that can be achieved without channel bonding in IEEE 802.11a/g standards.

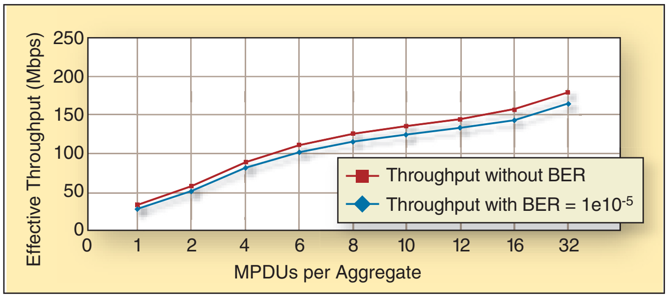

Figure 4. Effective throughput per number of aggregated MPDUs. In this example, a WLANplus system using a maximum PHY rate of 216 Mbps, a 1,000-byte packet length and 32-MPDU aggregation can reach an effective throughput of 178 Mbps without bit error rate (BER) and 164 Mbps with BER of 1e10^{-5}.

Most video broadcasts use the MPEG2 transport standard. In order to correctly interpret the MPEG presentation and timing information, the decoder clock must be locked on the encoder clock. Otherwise, overflow and underflow might occur at the decoder buffer, which risks creating packet loss.

There are several mechanisms to cancel jitter, and all share the same requirement for a common clock at both the sender and receiver. Since the traffic is variable bit rate (VBR), a jitter buffer at the receiver edge of the asynchronous network can be used in conjunction with a time stamp signature at the sender edge of the asynchronous network. These time stamp signatures will inform the jitter buffer mechanism exactly when to play out the next packet.

However, interpreting the time stamps at the receiver in exactly the form originated by the sender requires clock synchronization between the sender time stamp mechanism and the receiver jitter buffer time stamp mechanism. Otherwise, the jitter buffer can overflow or underflow along the time, and packets will be lost.

There are many algorithms that facilitate clock recovery between network ends in the presence of jitter. These algorithms evaluate the network jitter and isolate it from the clock difference. This is required in order to be able to correct the sent time stamps so the difference between them reflects only the clock difference and not the network jitter. This capability requires sophisticated mechanisms for measuring the network jitter with very fast response time.

Once jitter cancellation and clock recovery mechanisms have been put into place, designers must turn their attention to QoS support. The existing 802.11 protocols primarily use the distributed coordination function (DCF) access method to the wireless medium. The DCF provides an equal chance to each device to access the wireless medium. When dealing with video, gaming and other applications that are intolerant to bandwidth fluctuations, the fairness access provided by DCF is inadequate.

The IEEE 802.11e standard is targeted at addressing these issues and contains two main sections. The first is enhanced distributed channel access (EDCA), which defines four priority levels or four access categories (ACs) for different types of packets. It doesn't, however, guarantee bandwidth, jitter or latency. The second is hybrid coordination function (HCF) controlled channel access (HCCA), which guarantees reserved bandwidth for packets classified based on EDCA by using a central arbiter for the bandwidth usage.

While in the DCF all stations try to access the wireless medium with the same priority, in EDCA there are four levels of priority or ACs. The mechanism of listening to the medium and using a back-off mechanism to determine the allowed transmission time is similar to that defined by DCF.

However, unlike DCF, the maximum back-off times are different for the different ACs, meaning that higher-priority ACs have a shorter maximum back-off time than lower-priority ACs. The shorter maximum back-off time allows the higher-priority AC to win access to the wireless medium more frequently than the lower-priority AC. Applications or packets that share the same AC also have the same maximum back-off time and, hence, the same chance to gain access to the wireless medium. EDCA is fairly simple to implement, but cannot guarantee latency, jitter or bandwidth.

HCCA uses another approach to guarantee QoS. Instead of waiting for an idle time for transmission and using a back-off mechanism, HCCA relies on centralized control by the access point that can guarantee time and duration of transmission for each of the connected stations. Every station that would like to join the network must request permission from the central access point. This request includes a traffic specification that details the QoS required by the station. The access point then determines if it can support the requested QoS specifications and admits or denies station. The access point maintains a centralized schedule that is based on the QoS requirements of all of its registered stations. Then, the access point notifies each of the stations about the time it will have access to the wireless medium. Since this process is managed from a central location, it is guaranteed that the access will be contention-free.

Because everything is predetermined upon registration, HCCA is able to guarantee bandwidth, jitter and latency, which is otherwise a difficult challenge in a mixed data and multimedia environment.

A combined approach is based on EDCA with the addition of admission control, which is mandatory for HCCA and optional for EDCA. EDCA admission control is mandatory at the AP, and optional at the station. The AP may indicate that it requires stations to support admission control and explicitly request access rights if they wish to use an access category.

As in HCCA a station specifies its traffic flow requirements (data rate, delay bounds, packet size, and others) and requests the AP to approve. The AP calculates the existing load based on the current set of issued requests. Based on the current conditions, the AP may accept or deny the new request. If the request is denied, the high priority access category inside the station is not permitted to use the high priority access parameters, but it must use lower priority parameters instead.

EDCA plus admission control allow taking advantage of the fairly simple implementation of EDCA while enjoying the admission control benefits of HCCA.

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Summary

The broadband revolution continues to drive the convergence of consumer electronics, telecommunications and networking while creating demand for seamless connectivity between a growing array of multimedia and entertainment platforms. The draft IEEE 802.11n standard provides a powerful solution for meeting these connectivity challenges by leveraging MIMO technology and its ability to deliver significantly higher data transmission rates and whole-house coverage with no line of sight. System designers can further improve wireless video performance through such techniques as channel bonding in the 5 GHz spectrum band, better MAC efficiency, and improved QoS. Each of these techniques offers its own individual advantages, but it is not until they are implemented collectively that the full extent of their benefits can be realized for next-generation wireless video networking. RFD

ABOUT THE AUTHOR

Gil Epshtein is a senior product manager at Metalink, responsible for its WLANPlus product line. He holds a B.Sc. in Electronic Engineering from the Israel Institute of Technology (Technion) and has 15 years of experience in the telecommunications industry. Prior to joining Metalink in 2001, Epshtein worked for Teledata Communications and ECI Networks. He can be reached at GilE@metalinkBB.com.