

# 802.11n: The next generation in wireless LAN technology

**W**ireless data networking, frequently referred to as Wi-Fi, started its life in the small-office/home-office environment where performance takes second place to cost. But this wireless local area networking (WLAN) technology is about to turn the corner into the lucrative enterprise and wireless video-distribution markets with the emergence of a high-speed physical-layer technology now being standardized by the Institute of Electrical and Electronics Engineers (IEEE) 802.11n task group.

The IEEE 802.11n specification, due to be released in October 2008, raises the throughput of WLAN by a factor of four or higher and guarantees at least 100 Mbits/sec of real data throughput, with data rates reaching 600 Mbits/sec. Already, pre-standard chipsets from such companies as Intel, Broadcom, Qualcomm, Atheros, and Marvell claim measured throughput in the 300-Mbits/sec range or higher. With this level of throughput on the airlink, wireless access points (WAPs) will need to step up to 1000Base-T Gigabit Ethernet-level connections to the infrastructure in order to keep up.

## Finding MIMO

IEEE 802.11n owes its high-throughput performance to the latest wireless transmission advancement—multiple-input multiple-output (MIMO). The 802.11n wireless transmission technology is based on MIMO signaling.

MIMO is a significant innovation in the area of wireless data transmission. It turns the long-time nemesis of WLANs—multipath—into a friend. Multipath is common indoors, where the wireless signal reflects from walls, floors, ceilings, furniture, and people. Reflections add together in the air, presenting a challenge to the receiver that has to separate the original transmitted signal from the reflections. While today's 802.11a/b/g radios struggle to separate the signal from this muddle, 802.11n MIMO radios actually take advantage of multipath to send mul-

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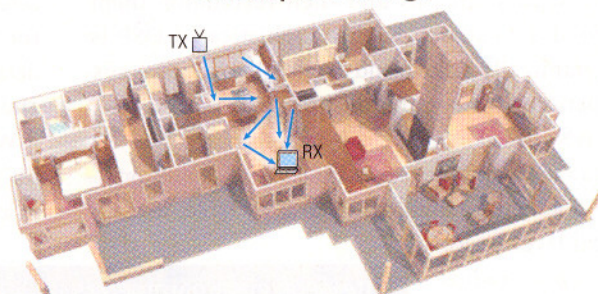
Multiple-input multiple-output transmission is the key for high-throughput wireless networking.

iple data streams via the available spatial paths.

MIMO radios use multipath to achieve gains in operating range and throughput. Two techniques employed in MIMO are *spatial multiplexing* and *beamforming*:

- When the MIMO radio uses *spatial multiplexing*, it sends more than one data stream simultaneously to increase throughput.
- When it employs *beamforming*, it sends multiple ver-

### The multipath challenge



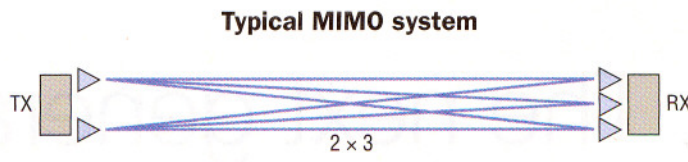
Multipath creates multiple versions of the signal by virtue of reflections from walls, floors, ceiling, furniture, and people. The reflections accumulate in the air, making it challenging for the receiver to recover the original signal.

sions of a single data stream via multiple antennas to improve reception and minimize packet error rate.

Beamforming works in conjunction with maximum ratio combining (MRC), which is a digital signal processing (DSP) technique that adjusts amplitudes and phases of received data signals, and adds them in such a way as to optimize the bit error rate (BER) performance.

Spatial multiplexing can yield higher throughput than beamforming by virtue of sending multiple distinct data streams, but it may not work in some environments where line-of-sight transmission paths dominate and multiple paths may not be available. ➤

A MIMO  $N \times M$  system typically refers to radios with  $N$  transmitters and  $M$  receivers. The signal from each transmitter is received by each receiver through the wireless channel. The possible number of paths through the channel are  $N \times M$ , so a  $2 \times 3$  MIMO channel has six paths.



This is an example of a  $2 \times 3$  MIMO system with two transmitters and three receivers, totaling six paths.

The communicating radios automatically determine the best possible signaling scheme based on the channel conditions. For channels where direct line-of-sight path dominates, beamforming is used to send the same data stream from each transmitter so that multiple versions of the same signal can be received by the receivers and either combined using MRC or selected based on signal integrity.

When multipath creates multiple spatial paths, the data stream can be divided and sent in parallel by multiple transmitters through each of the available paths, thereby multiplying data throughput. The receivers each can select one of the unique spatial streams and then recombine them into the original data signal. Highly sophisticated DSP is needed to dynamically adjust and negotiate the transmission scheme between the communicating radios.

Legacy WLANs based on 802.11a, b, or g specifications use automatic data rate adaptation based on channel conditions—the better the channel, the higher the rate. (See table, “Legacy 802.11 physical layer operation.”) These legacy radios transmit a single data stream using either Direct Sequence Spread Spectrum (DSSS) or Orthogonal Frequency Division Multiplexing (OFDM) modulation.

In 802.11n MIMO networks, signaling selection is considerably more complex than in legacy networks, which has driven the 802.11n task group to introduce the concept of modulation coding scheme (MCS). The variables in MCS selection include such factors as number of spatial streams, and modulation and data rate on each

stream. Radios establishing or maintaining a link must automatically negotiate the optimum MCS based on channel conditions and then continuously adjust the selection of MCS based on motion of devices or changing channel conditions caused by fading and other real-time events.

There are 77 different MCSs specified in IEEE P802.11n/D1.10—the current draft of the 802.11 standard as of January—with eight of those MCSs being mandatory for 802.11n-compliant devices to implement. The table “Rate-dependent parameters” is an example of how MCSs are specified.

The highest data rate of 600 Mbits/sec is achievable with MCS #31 using 64-quadrature amplitude modulation (QAM) in a

Legacy 802.11 physical layer operation		
	Supported data rates (Mbits/sec)	Supported frequency band (GHz)
802.11b (DSSS)	1, 2, 5.5, 11	2.4
802.11a (OFDM)	6, 9, 12, 18, 24, 36, 48, 54	5.8
802.11g (11b and 11a)	1, 2, 6, 9, 12, 18, 24, 36, 48, 54	2.4

40-MHz channel and operating with a short guard interval (GI) of 400 nanoseconds. GI is the time delay the receiver uses when recovering data. It is optimized for data sampling in the presence of propagation delays, echoes, and reflections in a multipath channel.

With 77 MCSs from which to choose, the complexity of MCS adaptation decisions becomes considerably higher than in legacy networks. This level of complexity likely makes in-

Rate-dependent parameters (For mandatory 20 MHz, NSS=1, MCSs, NES=1)									
MCS index	Modulation	R	N <sub>BPSCS</sub> (iss)	N <sub>SD</sub>	N <sub>SP</sub>	N <sub>CBPS</sub>	N <sub>DBPS</sub>	Data rate (Mbits/sec)	
								800 ns GI	400 ns GI
0	BPSK	0.5	1	108	6	108	54	13.5	15
1	QPSK	0.5	2	108	6	216	108	27	30
2	QPSK	0.75	2	108	6	216	162	40.5	45
3	16-QAM	0.5	4	108	6	432	216	54	60
4	16-QAM	0.75	4	108	6	432	324	81	90
5	64-QAM	0.66	6	108	6	648	432	108	120
6	64-QAM	0.75	6	108	6	648	486	121.5	135
7	64-QAM	0.83	6	108	6	648	540	135	150

GI = Guard Interval, or the time delay used by the receiver in recovering data  
 NSS = Number of spatial streams  
 R = Code rate  
 N<sub>BPSCS</sub> = Number of coded bits per single carrier  
 N<sub>BPSCS</sub> (iss) = Number of coded bits per single carrier for each spatial stream, iss

N<sub>SD</sub> = Number of data subcarriers  
 N<sub>SP</sub> = Number of pilot subcarriers  
 N<sub>CBPS</sub> = Number of coded bits per symbol  
 N<sub>DBPS</sub> = Number of data bits per symbol

teroperability between devices from different vendors challenging.

IEEE 802.11n networks use existing unlicensed bands at 2.4 GHz and 5 GHz, matching the frequency plan of legacy networks. But while legacy networks occupy a single 20-MHz channel, 802.11n networks can use 20- or 40-MHz channels. A 40-MHz channel consists of two 20-MHz channels—a primary and a secondary. The primary 20-MHz channel boundaries and regulations are the same as for the legacy

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802.11a, b, and g networks. The secondary channel is the adjacent 20-MHz channel, either above or below the primary channel. This secondary channel may be shared among different basic service sets. A basic service set is analogous to a cell in a cellular network, and consists of the WAP and its associated stations.

802.11n will also operate in the 3.65- to 3.70-GHz contention-based band being standardized by the IEEE 802.11y task group. MIMO devices can operate in three modes: Legacy (802.11a/b/g), mixed mode (802.11n and 802.11a/b/g), or greenfield (802.11n only). The highest throughput is achieved in greenfield mode, when only the 802.11n devices are present on the network. The mode of operation impacts network throughput.

At this phase of the 802.11n technological progress, it is important to compare the throughput performance of legacy, mixed, and greenfield modes. A single legacy station on an 802.11n network can significantly decrease total network throughput.

Greenfield 802.11n networks are made up entirely of MIMO devices and can achieve the highest throughput, which makes them suitable for video transmission.

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### New cabling opportunities

The emerging 802.11n standard creates two types of opportunities for the cabling and network installer community:

First, it is enterprise-ready because of its high throughput, maturity, improved security, and manageability. Enterprise networks may require upgrades to cabling and telecommunications-room equipment to support the new Gigabit Ethernet and Power over Ethernet-capable MIMO WAPs.

In addition, 802.11n is poised to jumpstart the huge wireless video distribution market, which has the potential of significantly increasing the demand for video-grade cabled networks in the homes to interconnect MIMO WAPs.

The wireless multimedia communications era is just beginning. ☒

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