IEEE 802.11n – Leading edge wireless connectivity

Industrial Ethernet has become the standard method of communication and control for automation, and rightly so. Reliability of communication, throughput and data integrity is an ongoing challenge when managing an industrial network.

Wireless Ethernet has been criticised for being both unsecure and unreliable, with limited distance, bandwidth and throughput. In the last 10 years, wireless LANs have evolved from a consumer technology to a media that can be taken seriously; and during the past 5 years it has become the default media for edge connectivity. As WLAN evolves, with the use of 802.11n, it is only a matter of time before it makes an impact with industrial WLANs.

There are two main reasons why wireless LAN can be considered as a viable alternative to the wired network and as a comparison with IEEE 802.11a/b/g:

1. A six-fold increase in throughput
2. Increased reliability

Organisations would need to consider their own reasons and agenda for implementing IEEE 802.11n; however a couple of main issues need to be understood.

1. What are the practical and operational differences between IEEE 802.11n and existing WLAN standards?
2. Is IEEE 802.11n backwardly compatible with an existing network design?

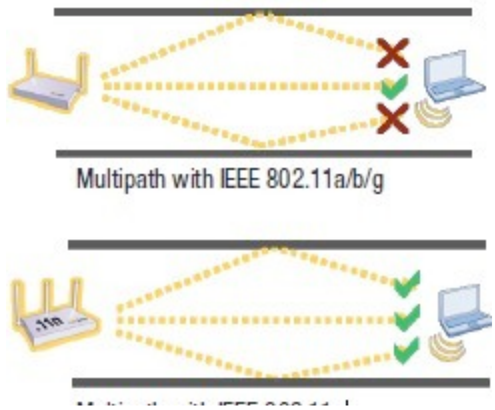
IEEE 802.11n uses complex radio/broadcast technologies; therefore it can be a more challenging concept for IT managers to implement. Our focus will be on the major methods that IEEE 802.11n uses to deliver on its claim of large increases in throughput and reliability.

The interaction of two key technologies ensures backward compatibility, increased reliability and higher performance: MIMO and Channel Bonding.

1. Multiple In, Multiple Out (MIMO)

Consider how a single sound produced in a valley can result in an echo, sounding as though it is produced many times over and out of sync (phase). This echo effect makes it difficult to decipher from the original message. Signals received in different phases can combine or even completely cancel each other out. Similarly, when you use a single transmitter and receiver, you are subject to multipath interference. The waveform will interact with anything it encounters on its way to the receiver. Metal will reflect signals; microwaves will interfere, whilst moisture, plants or even people will absorb it.

One way to overcome this is to provide a diverse set of antennas, as seen with the AWK-3121/4121/6222/5222. This is not MIMO, but a way in which the WLAN is able to select the antenna set with the best signal to noise ratio. When using MIMO and its multiple receiving antennae, the echo like effects become additive; multiple messages can be received by multiple antennae and combined.



With MIMO technology, the message can be easily reorganised, and actually use multipath reflections to gain signal strength and thus improve reliability. This leads to a greater coverage area for a given data rate, or higher data rates for a given coverage area and more bandwidth.

MIMO allows between 2 and 4 transmitter and receiver antennae to operate simultaneously. Using signal processing at both ends, MIMO transmitters can multiplex a message over separate antennas. The receiver processes the signal digitally, to identify separate bit streams (spatial streams) and reassemble them; this multiplexing increases the effective bandwidth. The 2 biggest improvements MIMO brings are:-

a) The ability to decipher multiple echoes, which increases reliability and bandwidth per user
b) The ability to multiplex different data streams across multiple transmitters which increases bandwidth

The IEEE 802.11n standard allows for several different configurations of the transmitter and receiver. MIMO systems are described by quoting the number of transmitters and receivers. Thus a 2x2 MIMO has 2 transmitters and 2 receivers.

Legacy Clients

Traditional IEEE 802.11a/b/g hardware deals with multipath interference by scaling back the data rate. In an ideal environment you may be able to get 54Mbps; however, only achieve 36Mbps at a short distance from the access point in real life situations. This means that MIMO technology can still operate reliably with legacy IEEE 802.a/b/g clients, achieved by scaling back the data rate to accommodate the slower/legacy devices on the network.

2. Channel Bonding

With IEEE802.11 systems multiple channels are available for use in order to co-exist with each other without interference. With 802.1a/b/g each channel is 20MHz wide. Typically a 20 Mhz channel does not use the 2 edges of the band in order to avoid overlap of channels.

Channel bonding allows the use of 2 x 20Mhz channels and the gap between them, resulting in slightly more than double the bandwidth.

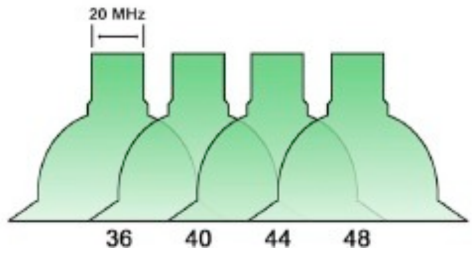
The highest data rate on 802.11a or g is 54Mbps for a single transmitter and on a 20MHz channel. The number of subcarriers in this configuration is 48, this equates to 1.125Mbps per subcarrier. For 802.11n, and when using a 20Mhz channel, the number of subcarriers increases to 52. So using this method, the highest data rate on 802.11n is 58.5Mbps for a single transmitter.

In addition to increasing the amount of sub-carriers, the digital processing or coding rate on 802.11n is 5/6 compared to 3/4 for 802.11g, thereby giving rise to an increased data rate of 65Mbps.

Reduced guard interval

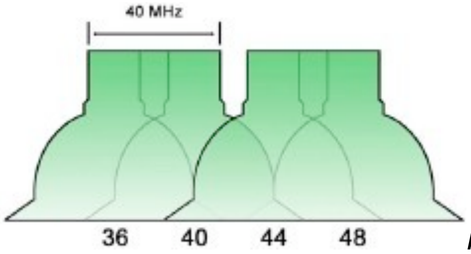
The throughput can be further increased by reducing the guard interval. A Guard Interval is a set amount of time between transmissions, such that individual transmissions do not interfere with each other. Its job is to increase immunity to propagation delays, echoes and reflections. The shorter the guard interval, the more efficient channel usage and hence its suitability where objects are close and are received quicker. A shorter G.I. was added as an option in 802.11n to allow for higher data rates where a longer G.I. is not required; reducing the G.I. from 800ns to 400ns, increases throughput of a 20MHz, single transmitter to 72.2Mbps, and for 4 transmitters it would increase to 288.9Mbps, (4x4 MIMO).

By combining all of the fore mentioned methods to increase the data rate, transmission speeds of up to 150Mbps can be achieved for a single transmitter/spatial stream:



Four 5GHz 20MHz channels

By effectively joining two 20MHz channels together, a 40MHz wide channel can be created. A 40MHz bonded channel on a single transmitter has 108 subcarriers so 121.5Mbps. Increased coding rate gives 135Mbps.



Four 5GHz 20MHz channels bonded to form two 40MHz channels

Reducing the Guard Interval from 800ns to 400ns gives a throughput of 150Mbps for a 40MHz single transmitter. Therefore by using 2 transmitters/spatial streams (2x2 MIMO) the data rate can be doubled to 300Mbps, and with a 4x4 MIMO, we would get 600Mbps.

	1 Spatial Stream	2 Spatial Streams	3 Spatial Streams	4 Spatial Streams
20 MHz Channel	65 Mbps	130 Mbps	195 Mbps	260 Mbps
40 MHz Channel	135 Mbps	270 Mbps	405 Mbps	540 Mbps

Long (800ns) Guard Interval

	1 Spatial Stream	2 Spatial Streams	3 Spatial Streams	4 Spatial Streams
20 MHz Channel	72 Mbps	144 Mbps	217 Mbps	289 Mbps
40 MHz Channel	150 Mbps	300 Mbps	450 Mbps	600 Mbps

Short (400ns) Guard Interval

The effects of channel bonding and Guard Interval set against the maximum attainable data rate using IEEE 802.11n

802.11n Compatibility

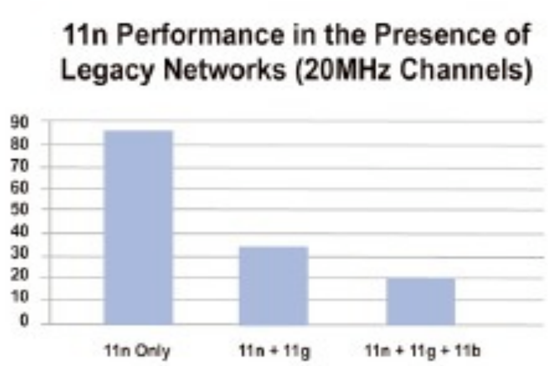
An 802.11n access point can be configured to operate in 3 different modes:

1. **Legacy Mode:-**

   The access point is configured just like an 802.11a/g device. No MIMO or channel bonding benefits.

2. **Mixed mode:-**

   This is the most popular deployment. The access point is set to behave in 802.11n, whilst also communicating with 802.11a/b/g devices. This will reduce overall bandwidth capacity due to the lower data rates on a/g clients.



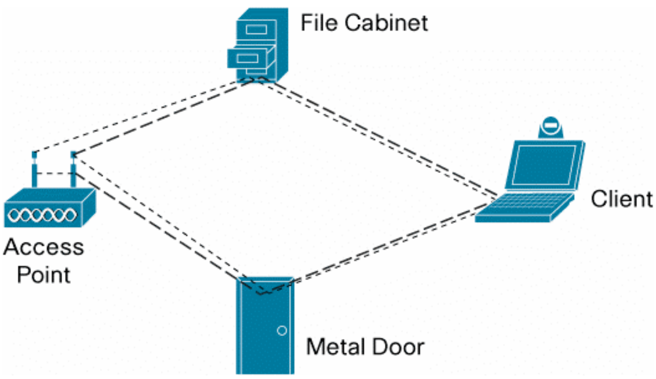
This drops by almost 50% if an 802.11g station is causing congestion in the network. The performance is cut by almost 75% if there is an 802.11b station causing congestion

3. **Greenfield Mode:-**

   This mode assumes that only 802.11n devices operate. Manufacturers reduce cost of 802.11n chipsets by not including this mode, but this will be more prevalent in the near future.

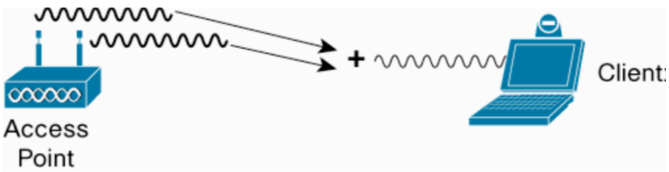
What's Different about 802.11n?

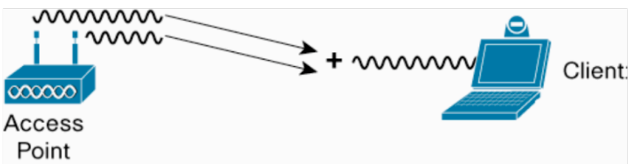
1. **Spatial Division Multiplexing**



The technique of transmitting data via parallel channels over multiple antennas to create different data paths is called space division multiplexing.

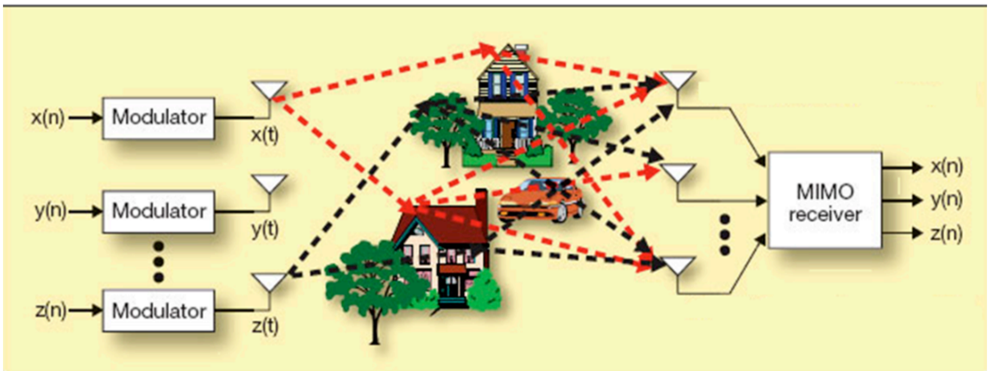
2. **Beam-Forming**





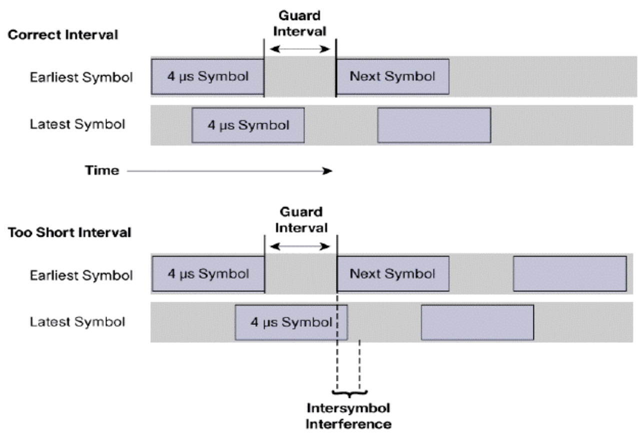
Beam forming can improve the throughput when further away form the AP, but cannot increase the coverage area

3. Diversity



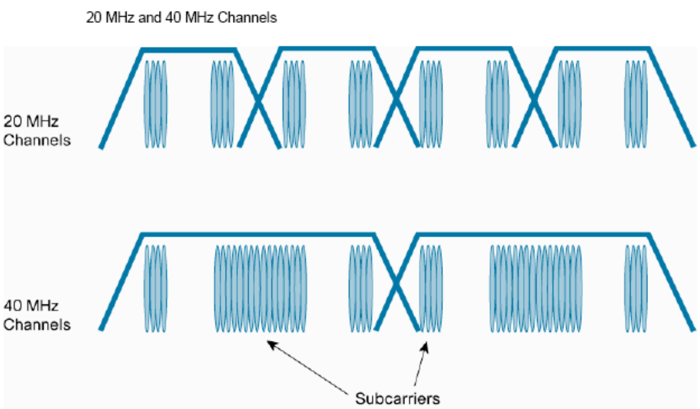
Use multiple antennas to improve coverage area and reliability

4. Short Guard Interval



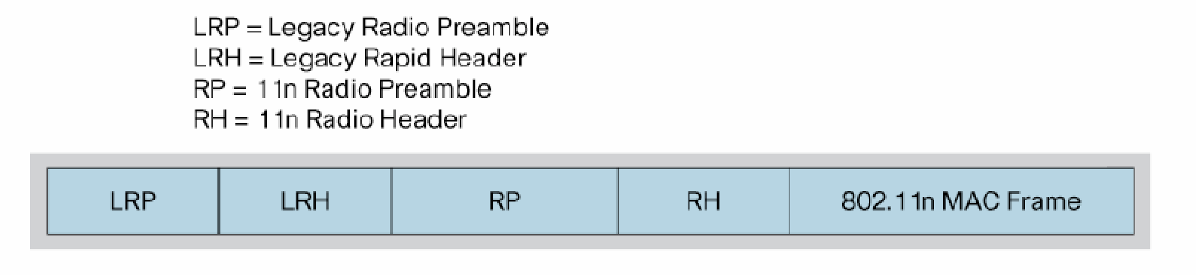
Shortening the guard interval can improve throughput, but intersymbol interference will degrade the SNR

5. 40MHz Channel Bandwidth



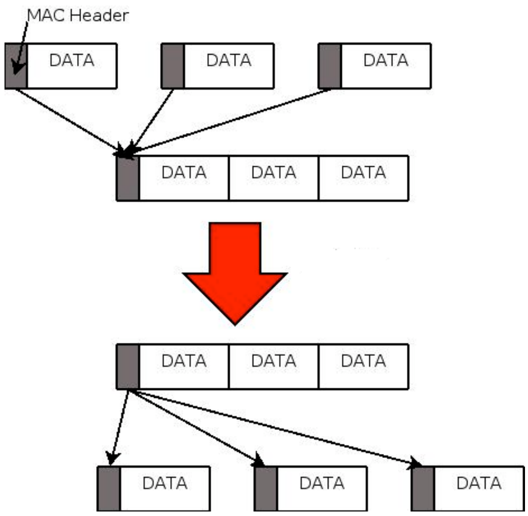
An increase of bandwidth from 20MHz to 40MHz can double the data rate but will reduce the available channels for other devices.

6. Greenfield and Mixed Mode



Greenfield is for all 802.11n compatible devices. Mixed mode is when 802.11a/b/g devices are also present.

7. Frame aggregation



Data can be combined into larger frames to save header overhead.

Advantages:-

Factory Automation

The cost of installing wire conduits at the factory site can be prohibitive, especially if end points are mobile such as automated guided vehicles and workstations. The use of slip rings is one solution, however, compared with WLAN, the costs of implementing them in high. Once installed, slips rings and other wired solutions are inflexible.

Furthermore, with an indoor environment, there are many obstacles in the way, making the possibility of traditional WLAN installations unreliable. IEEE 802.11n, allows diversity, increased coverage area and hence reliable.

Benefits:

- Wireless networks can be installed quickly, and help reduce the cost of cabling and maintenance
- Enhance the overall efficiency of your production facilities and warehouse operation
- Factory workers are able to transport products from the warehouse to the loading area much more quickly
- Use of IEEE 802.11n, enables installation of access points and clients easier due to backward compatibility to IEEE 802.11a/b/g
- Increased number of channels available with 5GHz

Security Automation

The introduction of IP video technology has made the digital encoding and transfer of video faster and easier. Modern video surveillance technology is not only capable of transferring data over wired, but increasingly wireless networks as well. IEEE 802.11n allows positioning of access points in covert locations easier, due to its multipath advantages and more flexible. Traditional WLAN standards limited each spatial stream to no more than 10 cameras (assuming 1-2Mbps per camera being the norm). The 'n' standard allows many more cameras per access point, reducing cost furthermore

Benefits:

- IEEE 802.11n support with the 5GHz band, allowing higher throughput
- QoS support
- Multipath technology

Transport

Providing immediate status updates and control to avoid accidents, due to power losses and breakdowns, Communication Based Train Control systems are being deployed in all modern metro systems around the world. A well designed CBTC system should include access points no ore than 200m apart along the track. For redundancy, 2 access points are placed in the same location. Two access points are also positions onboard the train. Access points should be able to communicate when trains are travelling up to 100km/h and roaming must be within 50ms. Total latency should be no more than 2 seconds from the train to the control centre. At these speeds and coverage, drop outs and data drop outs can be poor. Using IEEE 802.11n alleviates these by lending a wider coverage and multipath technology.

Benefits:

- Multipath technology
- Wider coverage
- Less data drop outs due to encoding
- 100km/h operating speed

Onboard Wi-Fi for Trains

More and more people use trains to commute to work or to go on business trips. Because people are spending more time on trains, onboard Internet services have become more and more important to help business travellers maximize their efficiency. These travellers demand high bandwidth so WiFi is the best solution for this kind of mobile communication. It is not very difficult to implement a local WiFi network on a train. However, connecting to the Internet can be problematic because WiFi is not designed for high speed vehicles travelling at speeds over 80 km/h, such as a high speed train. Therefore, satellite and cellular communication is used to connect high speed trains to the Internet. Besides an Internet service, railway companies can also use wireless technology to provide multimedia entertainment services.

Benefits:

- IEEE802.11n can provide up to 600 Mbps bandwidth hence throughput
- IEEE802.11n with 5 GHz band for inter-coach communication and IEEE802.11b/g with 2.4 GHz band for intra-coach service. This set up reduces interference by virtue of using different frequency bands and a choice of many more channels.

	802.11b	802.11a	802.11g	802.11n
Amendment Approved	July 1999	July 1999	June 2003	Draft 2.0 February 2007
Maximum Data Rate	11 Mbps	54 Mbps	54 Mbps	300 - 600 Mbps
Supported Modulation	HR/DSSS	OFDM	HR/DSSS & OFDM	HR/DSSS & OFDM
RF Band	2.4 GHz	5 GHz	2.4 GHz	2.4 / 5 GHz
Number of Spatial Streams	1	1	1	1 - 4
Channel Width	22 MHz	20 MHz	20 MHz	20 / 40 MHz

Table outlining basic differences between IEEE802.11a/b/g/n

Conclusion

The increase in performance, throughput and reliability of 802.11n allows the Wireless LAN to become a viable alternative or co-inhabitant to the wired network for high bandwidth and robust applications. MIMO takes the challenge of multipath interference and uses it to increase performance and reliability of the network and existing legacy clients. Some clever digital processing helps to increase throughput through channel bonding. These all allow immediate advantages to be seen when migrating to an 802.11n wireless network, even with legacy wireless clients.