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802.11n in overview

The new wireless LAN standard 802.11n features a number of technical developments that promise up to six-times the performance in wireless LANs. The changes have not yet been officially approved by the IEEE, but the foreseeable technological leap is so enticing that the industry is already bringing updated WLAN devices to market before the standards have been adopted. Current discussions are embodied by what is known as "draft 2.0", which is the basis for devices currently available on the market.
Any reference to "802.11n" in this document always implies the current draft 2.0, which is not a standard adopted by the IEEE.

Advantages of 802.11n

The new technology offers the following advantages:

- **Higher effective data throughput**

  802.11n draft 2.0 includes a number of new mechanisms to significantly increase available bandwidth. Current wireless LAN standards based on 802.11a/g enable physical data rates (gross data rates) of up to 54 Mbps, which turn out to be approx. 22 Mbps net. Networks based on 802.11n **currently** achieve a gross data throughput of up to 300 Mbps (in reality approx. 120 to 130 Mbps net) – theoretically the standard defines up to 600 Mbps with four data streams. For the first time speeds can actually exceed the 100 Mbps of cable-based Fast Ethernet networks, which are currently standard in most workplaces.

- **Improved and more reliable wireless coverage**

  The new 802.11n technologies not only increase data throughput, but they also reduce areas without reception at the same time. This results in better signal coverage and improved stability for significantly better utilization of wireless networks, in particular for users in professional environments.

- **Greater range**

  Data throughput generally decreases when the distance between receiver and transmitter increases. The overall improved data throughput allows wireless LANs based on 802.11n to achieve greater ranges, as a significantly stronger wireless signal is received by the Access Point over a given distance than in 802.11a/b/g networks.

Compatibility with other standards

The 802.11n standard is backwardly compatible to previous standards (IEEE 802.11a/b/g). However, some of the advantages of the new technology are only available when the WLAN clients support 802.11n technologies as well as the access points.

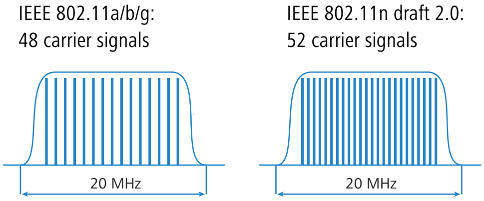
In order to allow the co-existence of wireless LAN clients based on 802.11a/b/g (called "legacy clients") 802.11n access points offer special modes for mixed operation, where performance increases over 802.11a/b/g are not as high. Only in all-802.11n environments is the "greenfield mode" used, which can exploit all the advantages of the new technology.

Technical aspects of 802.11n

Improved OFDM modulation

Like 802.11a/g, 802.11n uses the OFDM scheme (Orthogonal Frequency Division Multiplex) as its method of modulation. This modulates the data signal not on just one carrier signal but in parallel over several. The data throughput that can be achieved with OFDM modulation depends on the following parameters, among other things:

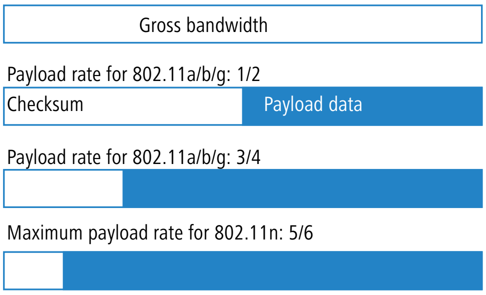
- Number of carrier signals: Whereas 802.11a/g uses 48 carrier signals, 802.11n can use a maximum of 52.



IEEE 802.11a/b/g:
48 carrier signals

IEEE 802.11n draft 2.0:
52 carrier signals

- Payload data rate: Airborne data transmission is fundamentally unreliable. Even small glitches in the WLAN system can result in errors in data transmission. Check sums are used to compensate for these errors, but these take up a part of the available bandwidth. The payload data rate indicates the ratio between theoretically available bandwidth and actual payload. 802.11a/g can operate at payload rates of 1/2 or 3/4 while 802.11n can use up to 5/6 of the theoretically available bandwidth for payload data.



These two features increase the maximum useable bandwidth of 54 Mbps for 802.11a/g to 65 Mbps for 802.11n. This increase is not exactly spectacular, but it can be further improved by using the following features:

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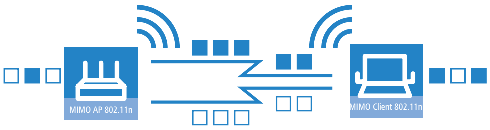
MIMO technology

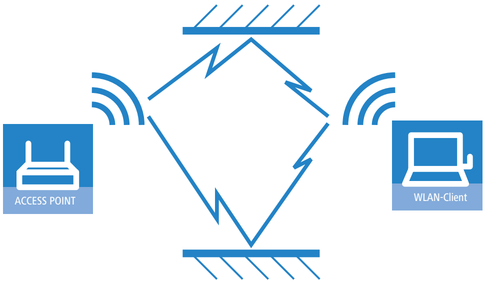
MIMO (multiple input multiple output) is the most important new technology contained in 802.11n. MIMO uses several transmitters and several receivers to transmit up to four parallel data streams on the same transmission channel (currently only two parallel data streams have been implemented). The result is an increase in data throughput and improved wireless coverage.



For example, the Access Point splits the data into two groups which are then sent simultaneously via separate antennas to the WLAN client. Data throughput can therefore be doubled using two transmitting and receiving antennas.

But how can several signals be transmitted on a single channel simultaneously? This was considered impossible with previous WLAN applications.

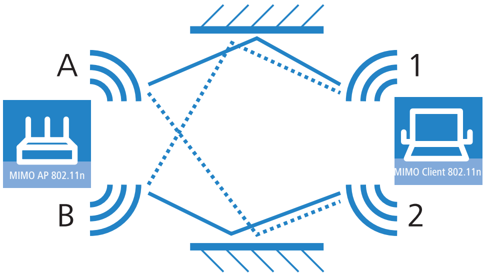
Let us consider how data is transmitted in "normal" wireless LAN networks: Depending on antenna type, an Access Point's antenna broadcasts data in several directions simultaneously. These electromagnetic waves are reflected by the surrounding surfaces causing a broadcast signal to reach the WLAN client's antenna over many different paths; this is also referred to as "multipath propagation". Each of these paths has a different length meaning that individual signals reach the client with a different time delay.



These time-delayed signals interfere with each other at the WLAN client and significantly weaken the original signal. For this reason, conventional WLAN networks should always have a direct line of sight (LOS) between transmitter and receiver in order to reduce the influence of reflections.

MIMO technology transforms this weakness in WLAN transmission into a strength that allows an enormous increase in data throughput. As mentioned above, it is virtually impossible to transmit different signals on the same channel simultaneously as the receiver cannot distinguish between them. MIMO uses the reflection of electromagnetic waves and the associated spatial aspect to obtain a third criterion for identifying the signals.

A signal sent by transmitter A and received by receiver 1 follows a different path than a signal from transmitter B to receiver 2. Due to the different reflections and changes in polarization that both signals experience along their paths, each of these paths takes on its own characteristics. When data transmission starts, a training phases records the characteristics of the path by transmitting standardized data. Subsequently, the data received here is used to calculate which data stream the signals belong to. The receiver decides for itself which of the incoming signals is to be processed, thus avoiding loss from interference.



MIMO thus allows the simultaneous transmission of several signals over one shared medium, such as the air. Individual transmitters and receivers must be positioned a minimum distance apart from one another, although this is just a few centimeters. This separation results in differing reflections and signal paths that can be used to separate the signals.

Generally speaking, MIMO can provide up to four parallel data streams, which are also called "spatial streams". However, the current generation of chips can only implement two parallel data streams as the separation of data streams based on characteristic path information demands high levels of computing power, which consumes both time and electricity. The latter tends to be undesirable particularly for WLAN systems, where attempts are often made to achieve independence from power sockets by using PoE as an electricity supply.

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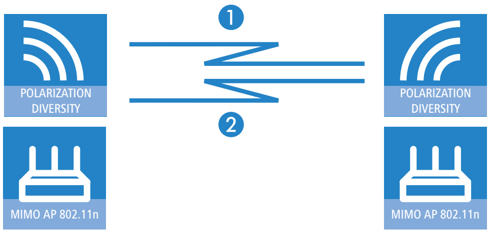
Even if the aim of four spatial streams has not yet been achieved, the use of two separate data connections results in a doubling of data throughput, which represents a true technological leap in the area of WLAN systems. Combined with the improvements in OFDM modulation, the data throughput that can be attained increases to 130 Mbps.

The short description "transmitter x receiver" expresses the actual number of transmitting and receiving antennas. 3x3 MIMO describes three transmitting and three receiving antennas. However, the number of antennas does not equate with the number of data streams: the antennas available only limit the maximum number of spatial streams. The reason for using more antennas than strictly necessary for data stream transmission relates to the method of allocating the signals according to their characteristic path: A third signal is used to transmit additional spatial information. If the data from the first two signals cannot be uniquely identified, their computation can still be performed with the aid of the third signal. The use of additional antennas does not contribute to an increase in data throughput, but it does result in a more even, stronger coverage for clients.

MIMO in outdoor use

Outdoor 802.11n applications cannot use natural reflections since signal transmission usually takes place over the direct path between directional antennas. In order to transmit two data streams in parallel, special antennas are employed that use polarization channels turned through 90° to each other. These so-called "dual-slant" antennas are really two antennas in one housing. Since a third signal does not offer additional reliability, outdoor applications generally use as many antennas (or polarization channels) as there are data streams for transmission.

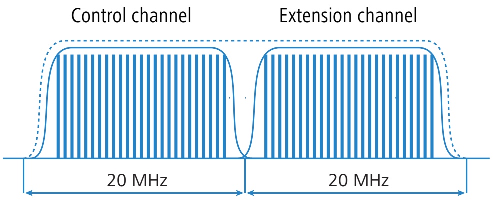


40 MHz channels

As the above explanation of OFDM modulation states, data throughput rises with an increasing number of carrier signals because this allows several signals to be transmitted simultaneously. If a channel with a bandwidth of 20 MHz supports no more than 48 (802.11a/g) or 52 (802.11n) carrier signals, the obvious choice would be to use a second channel with additional carrier signals.

This method was used in the past by a number of manufacturers (including LANCOM Systems) and was referred to as "turbo mode", allowing data rates of up to 108 Mbps. Turbo mode does not form part of the official IEEE standard but is frequently employed on point-to-point connections, for example, because compatibility to other manufacturers tends to play a secondary role.

However, the success of the underlying technology has lead to its incorporation into 802.11n. IEEE draft 2.0 uses the second transmission channel in a way that maintains compatibility to IEEE 802.11a/g devices. 802.11n transmits data over two contiguous channels. One of these assumes the task of a control channel that, among other things, handles the administration of data transmission. Concentrating these basic tasks into the control channel means that devices supporting a transmission at 20 MHz only can also be connected. The second channel is an extension that only comes into effect if the remote client also supports data transmission at 40 MHz. The use of the second channel remains optional throughout, with transmitter and receiver deciding dynamically whether one or two channels should be employed.

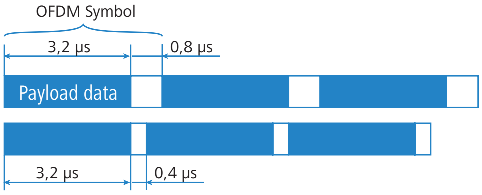


As the implementation of 40 MHz with separate control and extension channels is more efficient in the 802.11n draft than in the conventional turbo mode, more than double the amount of carrier signals can be obtained (108 in total). The maximum data throughput when using improved OFDM modulation and two parallel data streams thus rises to 270 Mbps.

Short guard interval

The final improvement of the 802.11n draft is the improvement in the chronological sequence of data transmission. A signal that is to be transmitted in a WLAN system is not broadcast at a distinct point in time but is "held up" for a certain, constant transmission period. In order to prevent interference at the receiving end, a short break is made following the transmission period before the transmission of the next signal commences. The entire duration of transmission period and break are referred to in WLAN terminology as "symbol length" and the break itself is known as the "guard interval".

IEEE 802.11a/g uses a symbol length of 4 µs: the information transmitted on the carrier signal changes following transmission of 3.2 µs and a break of 0.8 µs. 802.11n reduces the break between transmissions to the so-called "short guard interval" of only 0.4 µs.



Transmitting data in shorter intervals thus increases the maximum data throughput when using improved OFDM modulation, two parallel data streams and transmission at 40 MHz to 300 Mbps.

Optimizing net data throughput

The methods described so far are intended to improve the maximum physically possible data throughput. The methods described below are used in 802.11n networks to optimize net data throughput, i.e. the throughput of actual payload data.

Frame aggregation

In addition to the actual payload data, each data packet includes management information, which is important for the smooth exchange of data. Frame aggregation is used to combine several data packets (frames) into one large packet. As a consequence, management information only needs to be specified once for the complete data packet, and the proportion of payload data to the total data volume increases.

Block acknowledgement

Each data packet is acknowledged on receipt. In this way, the transmitter is informed that the packet was received correctly and does not need to be repeated. This principle also applies to aggregated frames in 802.11n.

However, some packets in an aggregated frame may be delivered successfully while others are not. In order to avoid having to retransmit an entire aggregated frame from which perhaps just one data packet was **not** delivered, a separate acknowledgement is generated for every single WLAN packet in the aggregated frame. These acknowledgements are again combined to form a block and relayed back to the sender as a group (block acknowledgement). The sender receives information about the receipt status of every single WLAN packet and can, if necessary, resend only those specific packets that were not successful.

Resulting data throughput

The overall data throughput in a 802.11n network is determined by applying the methods described above. A specific combination of modulation method, payload data rate and number of spatial streams is referred to as modulation coding scheme (MCS). Data throughput also depends on whether the short guard interval and channel bundling to 40 MHz are used.

802.11n uses the term "data throughput" instead of the term "data rate" used in older WLAN standards, because data rate is no longer an adequate description. The following table shows the maximum data throughput when using the short guard interval with 40 MHz channels.

The net data throughput, i.e. the actual number of IP packets transferred, can be up to 90 Mbps for one 802.11n data stream and, accordingly, for two spatial streams up to 180 Mbps. The net data throughput currently (early 2008) observed in practice is usually between 80 and 130 Mbps, depending on how mature the hardware and software are and also on how well the different manufacturers' chip sets work together.

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Data streams	Modulation	Payload data rate	Data throughput (GI=0.4 µs, 40 MHz)
1	BPSK	1/2	15
1	QPSK	1/2	30
1	QPSK	3/4	45
1	16QAM	1/2	60
1	16QAM	3/4	90
1	64QAM	1/2	120
1	64QAM	3/4	135
1	64QAM	5/6	150
2	BPSK	1/2	30
2	QPSK	1/2	60
2	QPSK	3/4	90
2	16QAM	1/2	120
2	16QAM	3/4	180
2	64QAM	1/2	240
2	64QAM	3/4	270
2	64QAM	5/6	300