

LANCOM™ Techpaper

IEEE 802.11n Outdoor Performance

Introduction

The MIMO (multiple input, multiple output) technology described in the IEEE 802.11n standard transforms the disadvantages of multipath propagation in wireless LAN transmissions into an advantage that enables an enormous increase in data rates. MIMO works with the multipath propagation of electromagnetic waves. Multiple transmit/receive paths in combination with signal processing to superimpose the signals produce a significant improvement in reception quality.

The WLAN chipsets of the current 300-Mbps generation each feature two or three independent send/receive paths. For example, a 3x3 MIMO system is equipped with three transmitters and three receivers. However, the actual internal signal processing only works with two spatial streams. This arrangement is used in particular for outdoor WLAN installations, where MIMO is used to improve performance even over radio links which are completely free of reflections.

802.11n for outdoor applications

There are special considerations to be made when operating 802.11n outdoors. MIMO makes use of the spatial characteristics mainly caused by reflections to differentiate between the data streams. However, with outdoor point-to-point connections there is a direct line of sight (LOS) between transmitter and receiver; also, the Fresnel zone has to be free of obstructions. Consequently, there are no reflections that can be used to differentiate between spatial streams.

For this reason, outdoor applications with 802.11n use a combination of the established polarization diversity method and MIMO technology: MIMO generates multiple parallel data streams and uses polarization to differentiate between the data streams. This combination is implemented with what are known as dual-slant antennas. These are antennas with two

separate ports combining two polarization antennas turned through 90° to each other in a single housing:

- The two ports allow the access point to transmit/receive separate data streams.
- The different polarizations allow the data streams to be transmitted in parallel through the medium of "air".

This approach opens up completely new dimensions of data throughput and range for outdoor P2P links. Even after taking all available performance functions (such as turbo-mode, bursting, compression) into consideration, previous methods achieved a maximum net data throughput of approx. 40 to 50 Mbps. P2P connections with 802.11n achieve up to 80 Mbps net using ordinary antennas and **one** data stream. Dual-slant antennas transmit **two** separate data streams and therefore offer up to 160 Mbps net in practice. Depending on the protocol used, the overhead and the packet size, the actual data throughput is generally lower than these maximum values.

This tech-paper deals with throughput performance of 802.11n systems for outdoor applications.

Data throughput: Gross vs. net

Data rates for wireless LANs are usually expressed as gross values. These result from the signal quality, the WLAN standard used, and the method of modulation. Elaborate security methods and collision avoidance mean that the overhead is significantly higher than in cabled networks. A gross:net ratio of just under 2:1 can normally be expected. 802.11g/a WLANs with a gross data rate of 54 Mbps achieve a maximum net data rate of 24 Mbps. WLANs using the current 802.11n standard with 300 Mbps gross achieve a maximum net value of approximately 160 Mbps, depending on the protocol in use. In correlation with the existing signal quality, WLAN systems may reduce

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their throughput performance step by step in order to counteract impairments in radio signals. Packet retransmissions are necessary, leading to a reduction in net throughput when there is radio interference. Over distances of several kilometers, time delays also have to be considered which require greater tolerances when accessing the radio medium.

Frequency ranges and transmission power requirements

Wireless LAN is generally approved for use in two frequency ranges: 2.4 GHz and 5 GHz. The differences between the two lie primarily in the effects of interference, the number of non-overlapping channels, and the legally permitted transmission power. The following frequencies are available for outdoor operation in Europe. The actual conditions for approval and permitted frequencies vary from country to country.

Overview of regulations for various frequency ranges

Frequency GHz	Non-overlapping channels*	Transmission power (EIRP)	Special features*	Interference from other users
2,400 – 2,483	3 (13 in total)	100 mW	–	High
5,470 – 5,725	14	1000 mW	DFS/TPC	Low, co-existence with radar
5,775 – 5,875*	4	4000 mW	BFWA, DFS/TPC, commercial distribution systems, permissions required	Very low, co-existence with radar

* The number of channels approved for use and other specifications may vary from country to country.

2.4 GHz or 5 GHz?

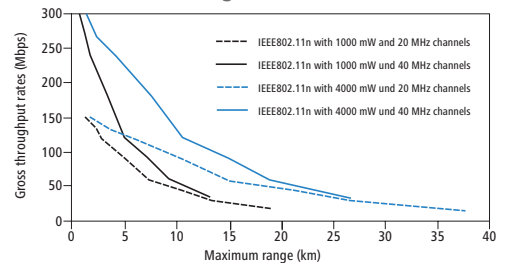
In principle, both frequency ranges are suitable for outdoor operation. The 2.4 GHz band is best suited for shorter ranges and low levels of interference.

The 5 GHz band uses higher signal levels to bridge greater distances and provide lower susceptibility to interference. A significantly higher number of non-overlapping channels allows channel bundling to increase throughput rates. However, to achieve these

higher performance levels, technical requirements such as TPC and DFS must be implemented.

The information below relates to the 5 GHz band, which is mainly employed for outdoor applications. The diagram below compares the maximum ranges and throughput performance of 802.11a and 802.11n systems, each operating with 20 MHz or 40 MHz channel widths.

Maximum gross data throughput of 5 GHz WLAN directional radio bridges



Maximum available ranges are limited by the internal timing of the WLAN modules. Depending on the operating mode, ranges may be up to 30 km.

Performance measurement tests

What actual throughput rates can be achieved with 802.11n? This tech-paper describes the practical measurement of WLAN transmissions with access points from LANCOM Systems.

Data transmission between a server and a client connected via an 802.11n bridge is measured with the tool iPerf. iPerf is a free tool that measures the TCP and UDP throughput between two network components. iPerf is the standard tool for benchmark testing network devices used by a number of renowned IT magazines. It runs under Windows, Linux and Mac OS X, meaning that comparisons can be made between operating systems.

The measuring system

To measure the actual throughput between two LANCOM access points in point-to-point mode, an ex-

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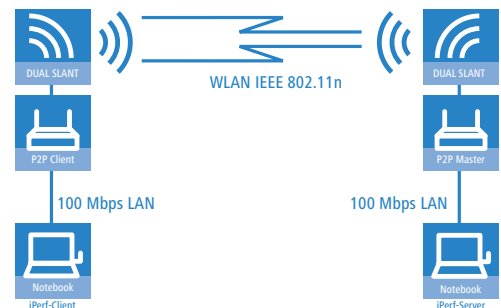
perimental system is set up that allows comparison of results for different applications over three different ranges.

Overview of the measurement system:

- The iPerf server is installed on a notebook, which is connected to the P2P master via a Fast-Ethernet LAN connection.
- A LANCOM OAP-310agn with an AirLancer O-D9a antenna is used as the P2P master.
- A P2P client is connected to this master via a P2P link based on IEEE 802.11n. Here too, a LANCOM OAP-310agn with an AirLancer O-D9a antenna is used.
- A notebook with the iPerf client is connected to the P2P slave via a 100 Mbps LAN connection.

Further details on the equipment used:

- iPerf server:
 - Linux
 - iPerf 1.7.0
 - iPerf TCP: -s -w 256k
 - iPerf UDP: -s-w 256k -u-l 1470
- iPerf client:
 - iPerf 2.0.2
 - iPerf TCP: -c [Server-IP] -w 256k -i 2 -t 60
 - iPerf UDP: -c [server IP] -w 256k -i 2 -t 60 -u -l 1470 -b [bandwidth]
- Access point:
 - LANCOM OAP-310agn Wireless
 - (LCOS 7.60.0160)
 - P2P mode
 - Antenna configuration 1+2
 - Short guard interval
 - 2 spatial streams
 - 40 MHz channels activated in the 5 GHz band



Making measurements properly

Measurements of throughput rates are only valid under the proper conditions. The following aspects are important when measuring the performance values over a WLAN bridge:

- The WLAN bridge must be the “slowest” portion of the connection being measured. If the WLAN bridge is replaced by a cable connection, data throughput must be significantly higher than the values measured over the WLAN bridge. This ensures, for example, that the results are not distorted by a poorly configured network card.
- The TCP window size on the computers must be set to a value that matches the iPerf parameters. The TCP window size is the buffer for received data packets. When this buffer is full, the sender has to await confirmation from the receiver before sending further packets. If TCP window size is not set properly on the computers, maximum throughput rates will not be achieved over the connection. The standard maximum for the TCP window size in Windows XP and Windows Server 2003 is 65,535 bytes, a value which is actually insufficient in most cases. Many applications demand a larger TCP window size. iPerf works with a maximum of 65,535 bytes as standard, which causes major differences to the values measured for other applications. To attain a realistic result, measurements were taken with a maximum TCP windows size of 256 kB as set in the iPerf clients’

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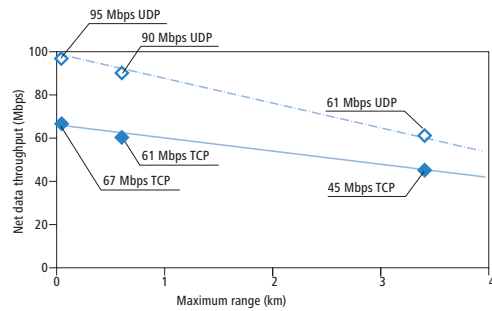
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system configuration. The TCP window size can be set with free tools such as improveTCP.

Results of measurements

In order to determine the maximum possible values for P2P transmission, a reference measurement was taken first, at a distance of approximately 7 m. Over this short distance, the TCP transmission measurement was 67 Mbps and the UDP transmission measurement was 95 Mbps, with 0% loss.

P2P net data rates at 1000 mW EIRP and 40 MHz channel width (LANCOM OAP-310agn Wireless with AirLancer Extender O-D9a)



The UDP value of 95 Mbps is subject to the limitations from the 100 Mbps LAN interface on the LANCOM OAP-310agn Wireless.

Of the two P2P links used for outdoor measurement tests, the first was carried out between the LANCOM Systems office building and a nearby airfield. Over this distance of 3.4 km, the TCP transmission measurement was 45 Mbps and the UDP transmission measurement was 60 Mbps, with 0% loss.

The second measurement was made over a shorter distance, between the airfield's tower and a hall. Over this distance of 400 m, the TCP transmission measurement was 61 Mbps and the UDP transmission measurement was 94 Mbps, with 0% loss.

Meaning of TCP and UDP measurements

The measurement of TCP transmissions provides information on the potential data throughput for TCP-based, connection-oriented data services such as FTP. With data connections which use TCP as the transport protocol, packets which are lost in transmission get repeated. However, with real-time applications, such as Voice over IP (VoIP), the repeated packet requests would interrupt the conversation – for this reason, these applications often use connectionless UDP which, unlike TCP, does not include a control mechanism.

Depending on the data transfer requirements, different applications use different packet sizes in UDP: For instance, voice applications use very small data frames so as to keep the latencies low, whereas video is transmitted with significantly larger frames so as to make it possible to achieve a higher throughput. Similarly, other applications are adapted to suit the purpose at hand.

For the test setup, a packet size of 1470 bytes was used. To determine the maximum throughput for a given packet size, the data throughput was increased until a packet-loss threshold was reached (<0.1%).

i The data throughput via UDP is generally higher than the TCP throughput, as there is no protocol overhead for connection control.

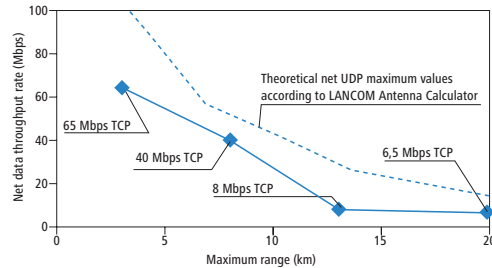
Performance in real applications

The previously indicated results were obtained in two different test scenarios. The following values, measured by LANCOM Systems customers in practical WLAN applications, provide a good comparison to "real" applications. In all examples, access points of type LANCOM L-310agn or LANCOM OAP-310agn were used. The gross/net ratio was assumed to be 2:1. The observed values for TCP applications were a little under the theoretical limit, as is to be expected.

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LANCOM customers' measurements of TCP net data rates with 1000 mW EIRP



Troubleshooting

If, in a particular application, the data rates are significantly lower than the expected values, the first step should be to check the following framework conditions of the installation:

- Distance settings

For longer-range wireless links to function properly, the range between the two antennas has to be specified (rounded up to the nearest kilometer). This allows the system's internal timing values to be adjusted accordingly.

- Encryption

Ideally, in order to achieve maximum security for the transmitted data, set the WLANs' encryption to WPA2. In so doing, use only "AES" as the session encryption type. The alternative type "TKIP" is not supported by IEEE 802.11n at full speed, which prevents the high data rates of 802.11n from being attained in TKIP-encrypted WLANs.

- Connection of antennas and configuration

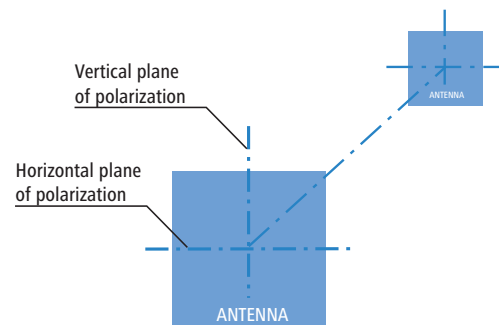
Current LANCOM access points based on IEEE 802.11n are generally equipped with three antenna ports. The antennas for P2P transmission have two ports, so as to be able to transmit two separate data streams (spatial streams).

Note which antenna ports are activated in the configuration of the access point (for dual-slant antennas either 1+2 or 1+3). In order to connect the antenna,

select the appropriate antenna ports at the access point – e.g. the two on the upper side of the housing (1+2) for the LANCOM OAP-310agn.

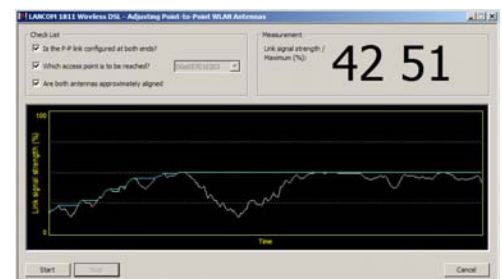
- Antenna alignment for P2P operations

Some antennas for WLAN transmission operate with polarization, i.e. they rely on the orientation of the electromagnetic waves. For point-to-point links, the direction of polarization of the antennas at each end of the connection must be precisely aligned in the same direction (either exactly parallel or exactly vertical). Here, there must be a direct line of sight between the two antennas.



The polarization layers of the send and receive units must not be aligned out of parallel to one another. For this reason the correct alignment – both in direction and polarity – must be checked in the interests of optimal data throughput when installing outdoor WLAN systems.

The current signal quality over a P2P connection can be displayed on the device's LEDs or in LANmonitor in order to optimize the antenna alignment.



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■ Background scanning

Background scanning should generally be deactivated on P2P links. Rogue APs are not to be expected on a direct link and the “passive scan” necessary in the 5 GHz band requires off-channel times of 0.5s per scanned channel. Short scan intervals in particular lead to a noticeable deterioration of performance.

■ Influence of frame aggregation with IEEE 802.11n

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 (16 kB). 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. With frame aggregation, 802.11n networks optimize the net throughput, i.e. the throughput of actual payload data.

With a P2P connection, packets which are not confirmed by the receiver are retransmitted – up to 10 times as standard (default value for “hard retries”). The WLAN’s data-link layer is responsible for this procedure, in that confirmation is expected for unicast packets, regardless of the protocol used. In the worst-case scenario, the transmission speed of 802.11n connections is 6.5 Mbps. Thus, in highly unfavorable situations, the use of frame aggregation may lead to transmission delays (jitter) of 200 ms (16kB x 10 retries x 1024 x 8 / 6,500,000 bps). This worst-case value very rarely occurs in practice.

The relevance of this jitter depends on the application: For FTP transmissions, the transmission delay is generally insignificant, but for VoIP applications, even short delays have unpleasant side effects. In order to improve the transmission behavior in such cases, the number of retries can be reduced, for instance in WE-Bconfig via the following path:

LCOS menu tree > Setup > Interfaces > WLAN > Transmission > Hard retries

■ Antenna cables

To optimize performance, ensure that you use a minimum length of antenna cable with the lowest possible attenuation values.

■ DFS channel selection

Check whether free WLAN channels are identified by the access point:

LCOS menu tree > Status > WLAN > Channel scan results

■ 40 MHz mode

To optimize performance of 802.11n access points, a neighboring channel must be available for channel bundling. The LCOS menu tree informs you whether an “extension channel” is available under “Status > WLAN > Radios”.

■ General diagnosis

Packet transmission statistics can be found under “Status > WLAN > Packets” and “Status > WLAN > Errors”. It is normal for WLANs to produce a certain proportion of transmission errors.

However, high values may well indicate an environment with strong interference.

Check the following values for an indication of the signal/noise ratio and for detecting rogue APs:

Status > WLAN > Channel scan results

Status > WLAN > WLAN parameters

Status > WLAN > Competing networks.

If error rates are 100%, the most probable cause is a value for distance that is too low (see section above).

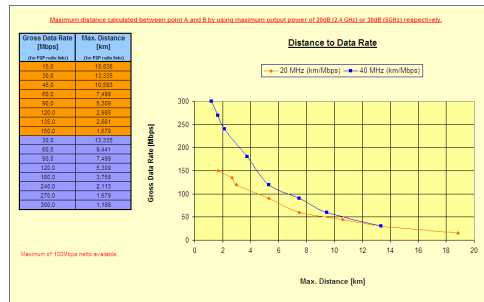
■ The LANCOM Antenna Calculator

After selection of the components used (access points, antennas, lightning protection and cables), the LANCOM Antenna Calculator (download from www.lancom.eu) calculates the data rates which can be achieved at certain distances. The LANCOM Antenna

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Calculator also computes the necessary mast heights for obstruction-free Fresnel zones.



Summary

An additional application of the MIMO technique is for 802.11n outdoor radio bridges which employ antennas with different angels of polarization. This can yield net data rates of 100 Mbps and higher.

When combined with high transmission powers of 1000 mW (or even 4000 mW under certain circumstances), ranges in excess of 20 km can be achieved.

This makes economical WLAN infrastructures viable for new areas of application, which were formerly the exclusive reserve of complex and expensive directional radio systems.

i Before using 4000 mW transmission power, please observe the national regulations of your country!