# LANCOM™ Techpaper
# 802.11n Indoor Performance

The standard 802.11n draft 2.0 features a number of new mechanisms which significantly increase available bandwidths. The former wireless LAN standards based on 802.11a/g enable physical gross data rates of up to 54 Mbps, or approximately 24 Mbps net. Networks based on 802.11n currently achieve a gross data throughput of up to 300 Mbps (depending on protocol up to 160 Mbps net) – theoretically the standard defines up to 600 Mbps with four data streams, which should be implemented in future with the appropriate hardware.
The performance available from a WLAN in any given situation depends upon a number of factors, such as the protocol employed, the packet size, the distance between the client and access point, and the actual application itself.
Note: Any reference to "802.11n" in this document implies the current draft 2.0, which has become established as an interim solution on the way to an officially adopted IEEE standard.

## Advantages of 802.11n

The new technology includes the following advantages:

- Higher effective data throughput
- Improved and more reliable wireless coverage
- Greater range

This tech-paper deals with throughput performance of 11n systems for indoor applications.

The following technical approaches are used by 802.11n to improve data throughput:

- 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 (current chip sets only have two parallel data streams implemented).
- Improved OFDM modulation
- 40 MHz channels, i.e. channel bundling of two 20 MHz channels similar to LANCOM's proprietary 108 Mbps Turbo Mode, which is not compatible to the 40 MHz channels.
- Short pauses between signals. A WLAN system pauses briefly between consecutive signals, to avoid interference at the receiver. With IEEE 802.11a/g the pause is 0.8 µs – 802.11n reduces the pause to the so-called "short guard interval" of just 0.4 µs.

By combining the transmission of data in shorter intervals with improved OFDM modulation, two parallel data streams, and transmission at 40 MHz, maximum data throughput increases to 300 Mbps. In addition to significantly increased data transfer rates, the MIMO technology introduced with 802.11n offers greatly improved signal coverage. More about this later.

## Data throughput: Gross vs. net

Data rates for wireless LANs are usually expressed as gross values. These are the result of the signal quality and the WLAN standard used or its method of modulation. Elaborate security methods and collision avoidance mean that the overhead is significantly higher than in cabled networks. A gross to 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 existing signal quality, WLAN systems may reduce 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.

## Performance measurement

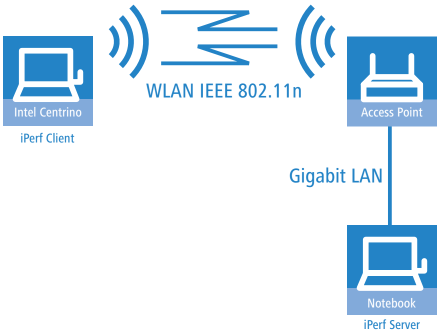
What are the actual throughput rates that can be achieved with 802.11n? This tech-paper describes the practical measurement of WLAN transmissions with access points from LANCOM Systems.

Data transmission between a server and a client each 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.

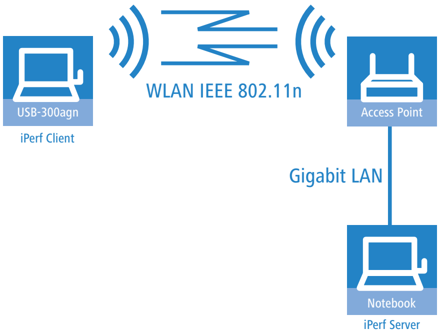
## The measuring system

To measure the actual throughput between two LANCOM access points, an experimental system is set up that allows three different scenarios for measuring the results of different applications with the iPerf client. The distance between the two access points is about 2 m:

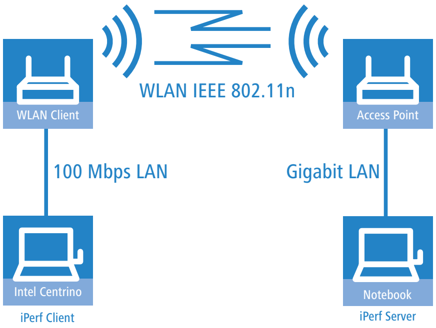
- Notebook with integrated Intel Centrino WLAN adapter



- AirLancer USB-300agn in the same notebook as an alternative to the integrated WLAN adapter



- LANCOM L-310agn Wireless in client mode, connected to the notebook



Further details on the equipment used:

- iPerf server:
    - INTEL Pentium DualCore E2160, 1.8 GHz
    - 1GB RAM
    - Realtek RTL8169/8110 Gigabit Ethernet NIC
    - Microsoft Windows XP SP2 and/or Linux, Ubuntu - Kernel 2.6.24-19
    - iPerf 1.7.0
    - iPerf TCP: -s -w 256k
    - iPerf UDP: -s-w 256k -u -l 1470
- iPerf client WLAN adapter 1:
    - Intel Centrino 4965agn with driver 12.2.3
- iPerf client WLAN adapter 2:
    - AirLancer USB-300agn with Atheros 9170, driver version 3.0.0.131
- iPerf client WLAN adapter 3:
    - LANCOM L-310agn Wireless (LCOS 7.60.0160)
    - Client mode
- iPerf client settings on the notebook:
    - 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 L-310agn Wireless (LCOS 7.60.0160)
    - Access point mode
    - Antenna configuration 1+2+3
    - 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

# LANCOM™ Techpaper
# 802.11n Indoor Performance

- 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 operating system configuration for the computer with the iPerf client. The TCP window size can be set with free tools such as improveTCP.

## Results of TCP measurements

The measurement of TCP transmissions provides information on the potential data throughput for TCP-based, connection-oriented data services such as FTP.

iPerf measures a data flow in a fixed direction between client and server. In order to take measurements in the transmit and the receive directions, client and server have to swap roles.

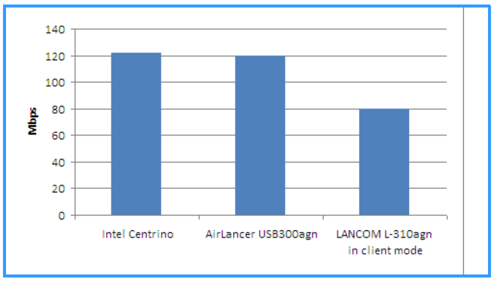
The results presented in the following are meaned values for a series of measurements, each with five individual measurements. Deviations between individual measurements were observed as +/-15% from the mean value.

| TCP | Transmit | Receive |
|---|---|---|
| **Intel Centrino** | 122 | 101 |
| **AirLancer USB300agn** | 120 | 80 |
| **LANCOM L-310agn in client mode** | 80 | 95 |

## Comparison of TCP measurements

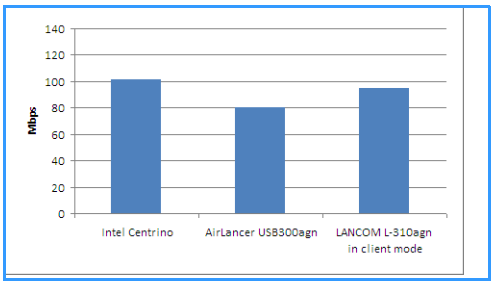
- **TCP performance in the transmit direction**

Data is transmitted from the notebook with WLAN adapter to the access point.



- **TCP performance in the receive direction**

Data is received by the notebook with WLAN adapter from the access point.



## Results of UDP measurements

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 slow down the dialog – 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 kB was used (which thus corresponds to full Ethernet frames). To determine the maximum throughput for a given packet size, the data throughput was increased until a packet-loss threshold was reached (<0.1%).

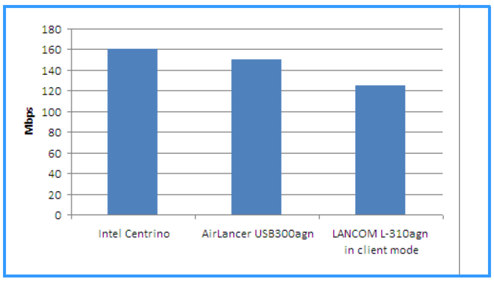
# LANCOM™ Techpaper
# 802.11n Indoor Performance

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

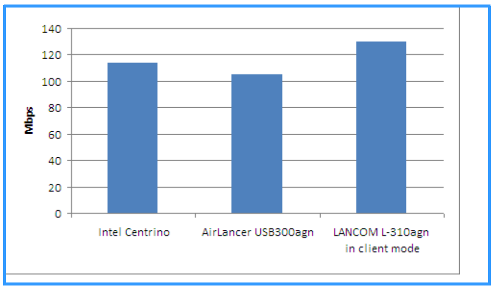
| UDP | Transmit | Receive |
|---|---|---|
| **Intel Centrino** | 160 | 114 |
| **AirLancer USB300agn** | 150 | 105 |
| **LANCOM L-310agn in client mode** | 125 | 130 |

## Comparison of UDP measurements

- **UDP performance in the transmit direction**



- **UDP performance in the receive direction**



## Signal coverage in comparison

The new 802.11n technologies do not just increase date throughput but bring about improvements in the range and reduce the wireless dead spots in existing a/b/g installations.

This results in better signal coverage and improved stability for significantly better utilization of wireless networks, in particular for users in professional environments.

In order to compare the different WLAN standards with regard to signal coverage, there following aspects are to be taken into account:

- With 2.4 GHz and 5 GHz, different frequency bands can be used for WLAN networks, according to the respective standard.
- The use of the 5 GHz band for 802.11n is advisable, as the 2.4 GHz range only offers three channels without overlap, which thus effectively rules out the use of channel bundling (40 MHz channels) in all installations with multiple access points.
- IEEE 802.11n makes use of "multiple input multiple output" (MIMO) with several transmitters and receivers: Signal reflections which cause disturbance in other WLAN standards are exploited so as to improve signal coverage.

Using the LANCOM Systems offices as an example, the following measurements show the significantly better signal coverage with 802.11n access points, compared to the previous access point generation (802.11a/g). It is also clear that 802.11n access points improve the signal coverage for conventional WLAN clients with 54 Mbps WLAN technology based on 802.11g or 802.11a.

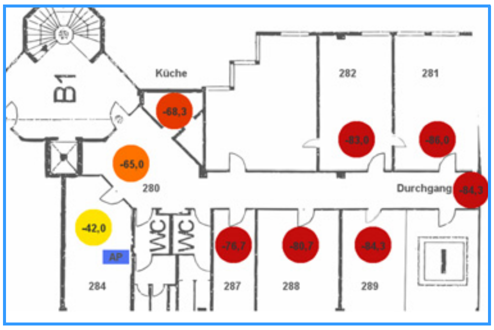
### 802.11g vs. 802.11n in the 2.4-GHz band

For the first measurement test, a LANCOM L-54ag with two antennas was set up as an access point operating with 802.11g (2.4 GHz), and it was positioned at one end of the building. A notebook with an AirLancer USB-54pro was used as the WLAN client.

In the immediate vicinity of the access point, the WLAN client measured a signal strength of -56.0 dB. As the distance from the access point increased, a decrease in signal quality was observed, until the minimum value of -91.3 dB was reached in the last room at the opposite end of the building.

For comparison, a LANCOM L-310agn with three antennas was positioned as an access point and set to use 802.11g. With measurements at the same reference locations, the signal quality in this case reached -42.0 dB in the immediate vicinity of the access point and -86.0 dB in the furthest room.

# LANCOM™ Techpaper
# 802.11n Indoor Performance



The measurements at the individual locations yielded the following values [in dB]:

| L-310, 2.4 GHz | L-54, 2.4 GHz | Advantage of 802.11n |
|---|---|---|
| -68.3 | -79 | 10.7 |
| -65 | -69 | 4 |
| -42 | -56 | 14 |
| -76.7 | -83 | 6.3 |
| -80.7 | -89.3 | 8.6 |
| -83 | -90.3 | 7.3 |
| -84.3 | -90 | 5.7 |
| -86 | -91.3 | 5.3 |
| -84.3 | -82.7 | -1.6 |
| | **Average** | **6.7** |

The results show a 6.7-dB improvement in the signal when using an access point based on 802.11n with WLAN clients working with 802.11g. At some points the SNR improved by up to 14 dB. Evidently, existing WLAN clients also benefit from the connection to an access point based on 802.11n. This is made possible by more powerful WLAN modules and the use of MIMO, for instance.

## 802.11a vs. 802.11n in the 5 GHz band

For the second measurement test, the LANCOM L-54ag with two antennas was set to 802.11a (5 GHz) – the WLAN client was again an AirLancer USB-54pro. With measurements at the reference locations, the signal quality now reached -40.3 dB in the immediate vicinity of the access point and -80.7 dB in the furthest room.

The comparison with the LANCOM L-310agn again shows significant advantages from IEEE 802.11n. The measurements range from -40.3 dB in the immediate vicinity of the access point to -74.7 dB in the furthest room.

The measurements at the individual locations yielded the following values [in dB]:

| L-310, 5 GHz | L-54, 5 GHz | Advantage of 802.11n |
|---|---|---|
| -55.7 | -57.7 | 2 |
| -48.3 | -55 | 6.7 |
| -40.3 | -40.3 | 0 |
| -57.3 | -61.3 | 4 |
| -62 | -65.3 | 3.3 |
| -70 | -76.3 | 6.3 |
| -71.3 | -75.7 | 4.4 |
| -74.7 | -80.7 | 6 |
| -73.3 | -74.3 | 1 |
| | **Average** | **3.7** |

The results show a 3.7-dB improvement in the signal when an 802.11n access point works with 802.11a-based WLAN clients. At some locations the SNR improved by up to 6.7 dB.