

Exhibit 1027

WIREVOLUTION.COM

Voice on the Internet

2007-09-07 BY MICHAEL

How does 802.11n get to 600Mbps?

802.11n incorporates all earlier amendments to 802.11, including the MAC enhancements in 802.11e for QoS and power savings.

The design goal of the 802.11n amendment is “HT” for High Throughput. The throughput it claims is high indeed: up to 600 Mbps in raw bit-rate. Let’s start with the maximum throughput of 802.11g (54 Mbps), and see what techniques 802.11n applies to boost it to 600 Mbps:

1. More subcarriers: 802.11g has 48 OFDM data subcarriers. 802.11n increases this number to 52, thereby boosting throughput from 54Mbps to 58.5 Mbps.

2. FEC: 802.11g has a maximum FEC (Forward Error Correction) coding rate of 3/4. 802.11n squeezes some redundancy out of this with a 5/6 coding rate, boosting the link rate from 58.5 Mbps to 65 Mbps.

3. Guard Interval: 802.11a has Guard Interval between transmissions of 800ns. 802.11n has an option to reduce this to 400ns, which boosts the throughput from 65 Mbps to 72.2 Mbps.

4. MIMO: thanks to the magical effect of spatial multiplexing, provided there are sufficient multi-path reflections, the throughput of a system goes up linearly with each extra antenna at both ends. Two antennas at each end double the throughput, three antennas at each end triple it, and four quadruple it. The maximum number of antennas

in the receive and transmit arrays specified by 802.11n is four. This allows four simultaneous 72.2 Mbps streams, yielding a total throughput of 288.9 Mbps.

5. 40 MHz channels: all previous versions of 802.11 have a channel bandwidth of 20MHz. 802.11n has an optional mode (controversial and not usable in many circumstances) where the channel bandwidth is 40 MHz. While the channel bandwidth is doubled, the number of data subcarriers is slightly more than doubled, going from 52 to 108. This yields a total channel throughput of 150 Mbps. So again combining four channels with MIMO, we get 600 Mbps.

Lower MAC overhead

But raw throughput is not a very informative number.

The 11a/g link rate is 54 Mbps, but the higher layer throughput is only 26 Mbps; the MAC overhead is over 50%! In 11n when the link rate is 65 Mbps, the higher layer throughput is about 50 Mbps; the MAC overhead is down to 25%.

Bear mind that these numbers are the absolute top speed you can get out of the system. 802.11n has numerous modulation schemes to fall back to when the conditions are less than perfect, which is most of the time.

But to minimize these fall-backs, 11n contains additional improvements to make the effective throughput as high as possible under all circumstances. These improvements are described in the following paragraphs.

Fast MCS feedback – rate selection.

Existing equipment finds it hard to track rapid changes in the channel. Say you walk through the shadow of a pole in the building. The rate may go from 50 to 6 to 50 mbps in one step. It's hard for conventional systems to track this, because they adapt based on transmit errors. With delay sensitive data like voice you have to be very conservative, so adapting up is much slower than down. 11n adds explicit per-packet feedback, recommending the transmission speed for the next packet. This is called Fast MCS (Modulation and Coding Scheme) Feedback.

LDPC (Low Density Parity Check) coding

LDPC is a super duper Forward Error Correction mechanism. Although it is almost 50 years old, it is the most effective error correcting code developed to date; it nears the theoretical limit of efficiency. It was little used until recently because of its high compute requirement. An interesting by-product of its antiquity is that it is relatively free of patent issues.

Transmit beam-forming

The term beam-forming conjures up images of a laser-like beam of radio waves pointing exactly at the client device, but it doesn't really work like that. If you look at a fine-resolution map of signal intensity in a room covered by a Wi-Fi access point, it looks like the surface of a pond disturbed by a gust of wind – it is a patchwork of bumps and dips in signal intensity, some as small as a few cubic inches in volume. Transmit beam-forming adjusts the phase and transmit power at the various antennas to move one of the maxima of signal intensity to where the client device is.

STBC

In a phone the chances are that there will only be one Wi-Fi antenna, so there will be only one spatial channel. Even so, the MIMO technique of STBC (Space-Time Block Coding) enables the handset to take advantage of the multiple antennas on the Access Point to improve range, both rate-at-range and limiting range.

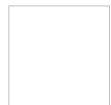
Incidentally, to receive 802.11n certification by the Wi-Fi Alliance, all devices must have two or more antennas except handsets which can optionally have a single antenna. Several considerations went into allowing this concession to handsets, mainly size and power constraints. STBC is particularly useful to handsets. It yields the robustness of MIMO without a second radio, which saves all the power the second radio would burn. This power saving is compounded with another: because of the greater rate-at-range the radio is on for less time while transmitting a given quantity of data. STBC is optional in 802.11n, though it should always be implemented for systems that support 802.11n handsets.

Hardware assistance

Many of these features impose a considerable compute load. LDPC and STBC fall into this category. This is an issue for handsets, since computation costs battery life. Fortunately these features are amenable to hardware implementation. With dedicated hardware the computation happens rapidly and with little cost in power.

 DUAL-MODE, PHONES, UNCATEGORIZED, VOIP, WI-FI

25 Replies to “How does 802.11n get to 600Mbps?”



Marvin

2008-01-20 AT 13:01

So is every thing finalized at this point, and when can we expect to have access to hardware with these speed capabilities?



Pavan Kulkarni

2008-01-28 AT 08:58

Cant wait to get there!.. cant wait to see my office absolutely cableless!



Svi poslovi

2008-05-13 AT 05:15

What about the range? I don't need 600 Mb/s but I need to connect two computers which are not in the same buliding. On the other hand, there's less then 70m between those computers... What makes me think my attempt to connect them without wires would be a failure is a lot of concrete.

**Michael****2008-05-13 AT 08:23**

Great question. 70 meters and a lot of concrete sounds very challenging. You can do it, of course, depending on your motivation and budget.

It is possible that the MIMO feature of 802.11n could help, though your range is on the edge of what is doable without special measures. There is an interesting presentation [here](#) that shows that multi-path can sometimes find a way through. Take a look at slide 10. Of course this presentation is about 60 GHz, but similar considerations may apply at 2.4 and at 5 GHz. Slide 4 shows that concrete is somewhat penetrable below 3 GHz.

In your shoes, I would start with some experimenting. Consider getting two 802.11n access points (make sure the specifications mention MIMO and beam forming or beam steering) and plugging each into a computer (so two computers.) Set them to bridging mode in the same room and establish communication between them. Then move one of them to the other location and see if they can reach each other. This probably won't work. If you can put the access points near windows in each building, that would be the next step, then mounting antennas on external walls. Google for Wi-Fi, MIMO, concrete and similar keywords to see other peoples' experiences with this kind of issue.

**Svi Poslovi****2008-05-30 AT 02:38**

Thanks for a brief explanation and these advices, Michael. I've noticed further developments of N by IEEE are going to be minimized. Maybe I'll wait for the final 802.11n to be caught up by hardware industry.

After all, slides you provided here were more than descriptive. I have to pass more than 50" of concrete walls and I wasn't even thinking about not being able to "shoot" perpendicularly... Was I optimistic or what? 😊

I'll let you know if I dare to try in spite of reason.

Pingback: Bend in the Weather



John

2009-04-09 AT 11:57

A company called Quantenna claims they can do 600Mbps and even 1Gbps using 4x4 MIMO. I just read about it on their website.



Matt

2009-04-18 AT 05:23

IEEE is estimated to have 802.11n finalized and approved sometime in January of 2010. As for when the masses can expect all of that... it depends heavily on how quickly the ISP's can upgrade their infrastructures to handle that much data. I'm currently seeing commercials for "blazing fast speeds up to 50 mbps" from one company. Average is about 10mbps or lower, unless you've got a T1/T3 or better...

600mbps is pretty sweet, but as someone who works in WiFi, I can tell you that you're not going to get a 600mb file in one second over 11n. Actual data transfer rates to the end user depend on A) transfer protocol; B) hardware capabilities, both on the user's device and the networking devices; C) environmental conditions; D) ISP bandwidth capacity. If the internet line the router is plugged in to can only support 20mbps, you're not going to get 600.

So... AT&T, Comcast, Hughes, SBC, and all the other ISP's out there... you've got under twelve months to produce lines capable of transferring 60 times the current market standard. Good luck.

Pingback: DS2 Blog



Jorge

2009-07-18 AT 01:30

Quoting Matt: “..I can tell you that you’re not going to get a 600mb file in one second over 11n..”

Remember that the unit Mbps. DOES NOT stand for MegaBytes per second but for MegaBits per second. It has nothing to do with file sizes.

1 byte=8-bits, Mb=MegaBits, and MB=MegaBytes.

If it was truly a 600Mbps. connection, the actual speed translated to MB/s would be around 73MB/s.



TBerry

2009-09-27 AT 10:22

Regarding the problem with the “concrete walls”, my suggestion is to use a directional antenna between APs.



key

2009-10-10 AT 12:45

Good overview of 11n improvements...

Can anybody clarify number of non overlapping channels with 11n in 5.4 GHZ spectrum with Channel Bonding (40Mhz)

I am confused as a Gartner document says there are only 3 non overlapping channels with 40 MHZ

**Michael****2009-12-02 AT 16:51**

The available spectrum varies from country to country. The Gartner comment probably referred to 2.4 GHz spectrum in the USA, which is usually too crowded to be usable for 40 MHz channels anyway. Here is a diagram of the 5 GHz spectrum in the USA that shows that you can get 23 non-overlapping 20 MHz channels, which equates to 11 non-overlapping 40 MHz channels:

**Daniel****2009-12-03 AT 22:28**

Very good review. Quick, to the point, yet quite technical and clever.
Thank you

**Wei****2009-12-10 AT 09:04**

Is there a reason for not including Hybrid ARQ in 802.11n ? New standards such as WiMax has included it already, why not 802.11n?

**Michael****2009-12-10 AT 10:33**

802.11n doesn't include HARQ because:
1. It's too expensive.

2. And it wouldn't work anyway

HARQ works by retaining your record of a packet that was received with error and combining it with a retry packet in such a way as to reduce errors. You can only do this if you retain a sample-by-sample record of the packet.

802.11 PHYs are stateless in the sense that they don't care who spoke to them previously, using what rate or PHY mode; each packet is fully independent.

The cost arises in HARQ because the PHY has to keep a copy of previous packets.

It doesn't work in 802.11 because it breaks the stateless nature of the PHY, i.e. the processing of the next packet depends on the previous one. In an unlicensed band you don't have full control of this. Furthermore it breaks the layering because now the PHY needs to know which packets came from which STAs before attempting HARQ recombination.

So HARQ can work in systems like WiMax because:

1. It's a licensed band – the FCC can shut down anybody who doesn't follow the rules.
2. The base-station controls exactly who talks and when
3. The cost / complexity is loaded into the base-station to improve uplink (where signal is weak), not downlink (where you don't need it due to high tx power).



Ron

2010-01-13 AT 09:53

I just finished reading "Next Generation Wireless LANs" a Cambridge book. This article was extremely good and helped summarize what I just finished reading. In the book it discussed that the use of RIFs in place of SIFs added significant data throughput (I think Greenfield only). Can someone comment on this?



Michael

2010-01-24 AT 08:28

Here's a discussion of interframe spaces that might help:
http://www.cwnp.com/pdf/802.11_arbitration.pdf.



DS Nagi

2010-05-27 AT 01:47

Great overview of 11n improvements



Michael

2010-08-31 AT 09:56

Here's a good article on the same topic: <http://www.eetimes.com/design/communications-design/4206045/How-throughput-enhancements-dramatically-boost-802-11n-MAC-efficiency>



Dmitry

2010-11-15 AT 04:55

600Mbit/s – “half duplex”, “unidirection” ?

if you have 4x4 MIMO, is this 2 TX 2 RX antenna on the first side and 2TX 2 RX on the second side or 4 TX 4 RX on both sides?

if 2, then 300 “full duplex” (minus overhead – 200 and in real life you never have 64QAM 5/6). As result you can garanted to customers 30-50 Mbit/s without QOS (if you use QOS, equipment have low cost processors and “voila” 10-20 Mbit/s).



Michael

2010-11-15 AT 08:39

4x4 is 4 antennas on the transmit side and 4 antennas on the receive side. So there are 4 antennas on each device, since the same antennas are used for both transmit and receive on a particular device. Each antenna does both TX and RX. The TX and RX take turns.

**Bill Tiso****2012-03-20 AT 17:30**

Good reading – still as informative in 2012 as it was back in 2007

**Chris****2012-04-18 AT 12:01**

Nice, but the section on MIMO isn't quite right.

This section would more correctly be labeled as SM or Spatial Multiplexing.

MIMO is good for improving the signal on the received end...not increasing the data rate.

SM is what is transmitting multiple unique 'streams' over different antennas, and THIS is what ends up doubling, tripling, or quadrupling the throughput.

Pingback: Wi-Fi real max speed / bandwidth / throughput / bitrate