Wireless Handheld Devices -- The 802.11n Advantage

Here's how the full benefits of 11n in an enterprise scenario may be compromised by the presence of legacy 11b/g devices, and why a single-stream 11n solution is the best fit for upcoming handheld devices.

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Introduction

The benefits of upcoming 802.11n standard are well-known. The methods defined in this standard are so beneficial and the standard itself so crucial to the growth of wireless LAN that the Wi-Fi Alliance® has created a certification program based on the draft standard itself. And the certification programs based on the legacy 802.11a/b/g standards have been so successful that the term ‘Wi-Fi’ is widely used interchangeably with ‘WLAN’.

The growth in the adoption of Wi-Fi has been tremendous – and has met or exceeded most projections over the past few years. Starting with widespread integration into laptop or notebook computers, Wi-Fi is becoming the choice of connectivity in a wide variety of mobile as well as fixed devices – including mobile phones, PDAs, music players, handheld gadgets, industrial equipment, display devices, and many others. For the WLAN industry, significant attention is, of course, on mobile phones – those devices that are becoming so inseparable from individuals that they promise to be soon an extension of one’s persona. A significant proportion of the growth beyond voice calls is enabled by the availability of some form of data connectivity – a function handily addressed by wireless LAN given the increasing availability of WLAN connectivity in the enterprise, home, and public environments.

There are key issues to be considered while integrating WLAN connectivity into a mobile phone – a primary consideration being power consumption. These have been addressed by various WLAN device providers – but most of these solutions have focused on the legacy 802.11b/g standard. Now on the one hand, we have an explosive growth in the adoption of Wi-Fi in all environments with a strong trend of 802.11n becoming the standard of choice in high traffic scenarios, and on the other hand a fast increasing number of WLAN connected hand-held devices that might use legacy 802.11b/g connectivity. In this article, we see how the full benefits of 11n in an enterprise scenario may be compromised by the presence of legacy 11b/g devices, and why a single-stream 11n solution would be the best fit for emerging hand-held devices.

802.11n Enhancements

The most prominent of enhancements brought in by 802.11n is of course MIMO, or Spatial Multiplexing. This technique, which, for a two-stream implementation, enables the doubling of throughput over a channel, requires multiple transmitters, multiple receivers, and distinct uncorrelated paths for each stream through the medium. Distinct multipath signals can be achieved by antennas that are spatially separated, or are pointed in different directions, or are polarized differently. Other techniques at the physical layer specified by 802.11n are the use of 40 MHz (double bandwidth) channels, range extension methods that make use of multiple antennas like space-time block codes (STBC) and beam-forming, higher coding rates to increase available data rates, the use of a larger percentage of available subcarriers for data transmission, and a short guard interval option.

Table 1 summarizes the on-air data rates made available by the use of 802.11n PHY enhancements, comparing them with legacy data rates.

Mode	Channel	Streams	Peak Data Rate (Mbps)
802.11b			11
802.11a,g			54
802.11n (800 ns GI)	20 MHz	One	65
	20 MHz	Two	130
	40 MHz	One	135
	40 MHz	Two	270
802.11n with short GI (400 ns)	20 MHz	One	72.2
	20 MHz	Two	144.4
	40 MHz	One	150
	40 MHz	Two	300

Table 1: 802.11n Data Rates

The primary objective of 802.11n being the provision of increased throughput to the user, there were several improvements made at the MAC layer. The fixed overhead in each frame, and including the interframe spaces, is considerable and at the higher physical layer rates afforded by the new standard, this overhead can often be longer than the data portion of the frame. And every attempt at transmission has a finite probability of ending in failure due to a collision. The 802.11n standard has defined packet aggregation methods to help mitigate these issues and to increase overall throughput. Aggregation is the concatenation of several frames into one large frame, with a sharing of overhead. Useful data payload form a greater percentage of aggregated frames than they do in normal frames. Aggregation can be carried out on the Ethernet frames or on 802.11 format frames – in the latter case the individual frames of the aggregated superframe are acknowledged together through a block-ack.

MAC layer enhancements can contribute over a 50% increase in user throughput.

Legacy Interoperability

The WLAN protocol defines mechanisms by which individual nodes in a network can help avoid excessive collisions. One of the primary rules here is the 'listen before you talk', or CSMA/CA, principle, where each node looks for valid WLAN packets on the air before attempting transmission. When a valid WLAN packet is detected, a node also sets its Network Allocation Vector (NAV) value from information in the header of the frame on air regarding the duration of the frame and the ACK or other follow-up frames that may succeed it. During the definition of the 802.11g standard, it was realized that, since legacy 802.11b devices would not be able to decode the newer 802.11g frames, there ought to be a separate mechanism to help legacy devices set their NAV correctly and therefore to reduce the percentage of collisions on air. The 11g standard made use of existing 'protection mechanisms' – RTS and CTS – to help legacy stations set their NAV.

A similar situation arose during the definition of the 802.11n standard. Legacy 802.11a/b/g devices would not be able to decode the 802.11n headers – and therefore a protection mechanism becomes necessary. One of these is the transmission of legacy preamble and header that enable the 802.11a/g/ device to detect the 802.11n packet and to decode the information in its signal field, from which the correct packet duration can be determined.

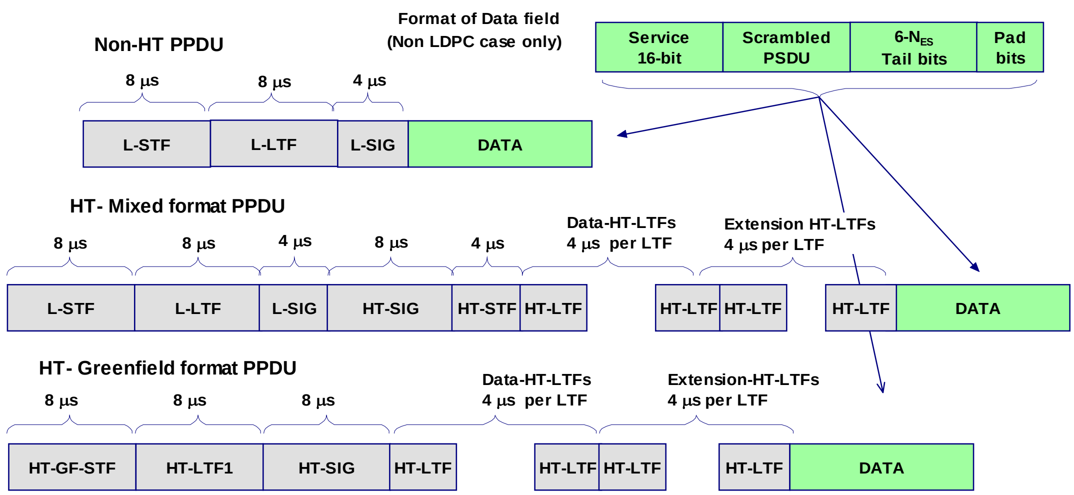

Figure 1: PLCP Frame Structure in 802.11n

The HT-mixed mode, in theory, is sufficient as a protection mechanism in cases where an 802.11a/g device is part of an otherwise 802.11n network. This mixed mode does involve additional overhead compared with the all-11n 'greenfield' network – where the devices in the network can use the Greenfield preamble format to save on the additional and otherwise unnecessary HT-mixed overhead.

However, there are circumstances where this proves insufficient and calls for a reversion to RTS/CTS based protection mechanism. Beamforming and MIMO modes in a communication between a 11n AP and 11n station can result in changes in power when the data portion of a frame begins. These changes in power can cause a listening legacy station to abandon its current state and attempt a re-synchronization – in which case, the previously conveyed NAV is lost.

Most 802.11n APs therefore use RTS/CTS protection for 11n transmissions when a legacy 802.11a/b/g station is associated with the BSS, or if they detect legacy nodes in other BSS's in the same channel and vicinity.

Performance in a mixed network

When an 802.11n Access Point sees only 802.11n capable clients connected to its BSS, it is free to use all the 11n features it and the clients support. The 802.11n clients are guaranteed to support the decoding of frame length information from the PLCP header of each transmitted frame. The AP and clients therefore use 11n data rates and, if supported, Greenfield preambles and short GI options. The overall throughputs between the clients and the AP are therefore maximized. Figure 2 shows the configuration of a test setup to observe the behavior of pure 11n and mixed networks, and to obtain quantitative information on the throughput comparison between the two cases.

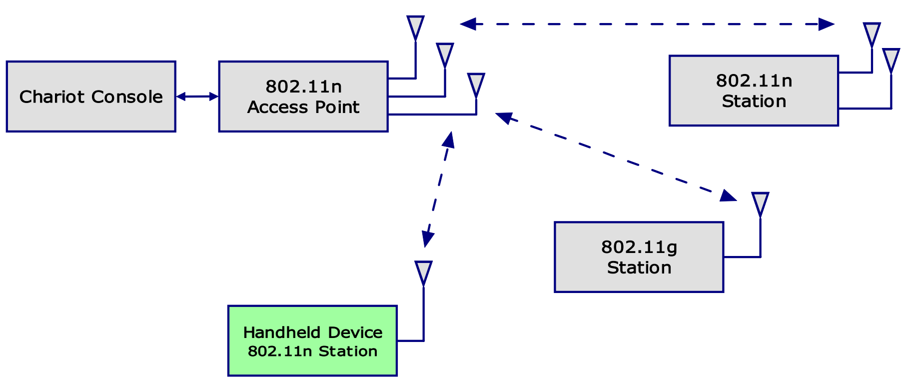

Figure 2: Test Setup

Figure 3 shows a snapshot of frame exchanges between an AP and the two-stream 11n client without the introduction of the 802.11g station or the single-stream 802.11n handheld device. Note that 11n rates are freely used.

9	100%	-42	58.0	98	0.677004	PING Req
9	100%	-36	24.0	14	0.000009	802.11 Ack
9	100%	-41	144.5	98	0.000378	PING Reply
9	100%	-38	24.0	14	0.000028	802.11 Ack
9	100%	-45	54.0	122	0.322195	PING Req
9	100%	-36	24.0	14	0.000008	802.11 Ack
9	100%	-42	65.0	122	0.000417	PING Reply
9	100%	-43	36.0	14	0.000007	802.11 Ack
9	100%	-44	58.0	98	0.676948	PING Req
9	100%	-39	24.0	14	0.000009	802.11 Ack
9	100%	-46	144.5	98	0.000365	PING Reply
9	100%	-40	24.0	14	0.000038	802.11 Ack

Figure 3: Data exchange in an all-11n network

The result of a free use of 11n rates without the invocation of protection mechanisms is the achievement of the maximum possible throughput permitted by the wireless channel conditions. Figure 4 shows the result of a throughput test using Chariot. The test used commercially available 802.11n Draft 2.0 Wi-Fi compliant devices. For the record, the test shows an average throughput of

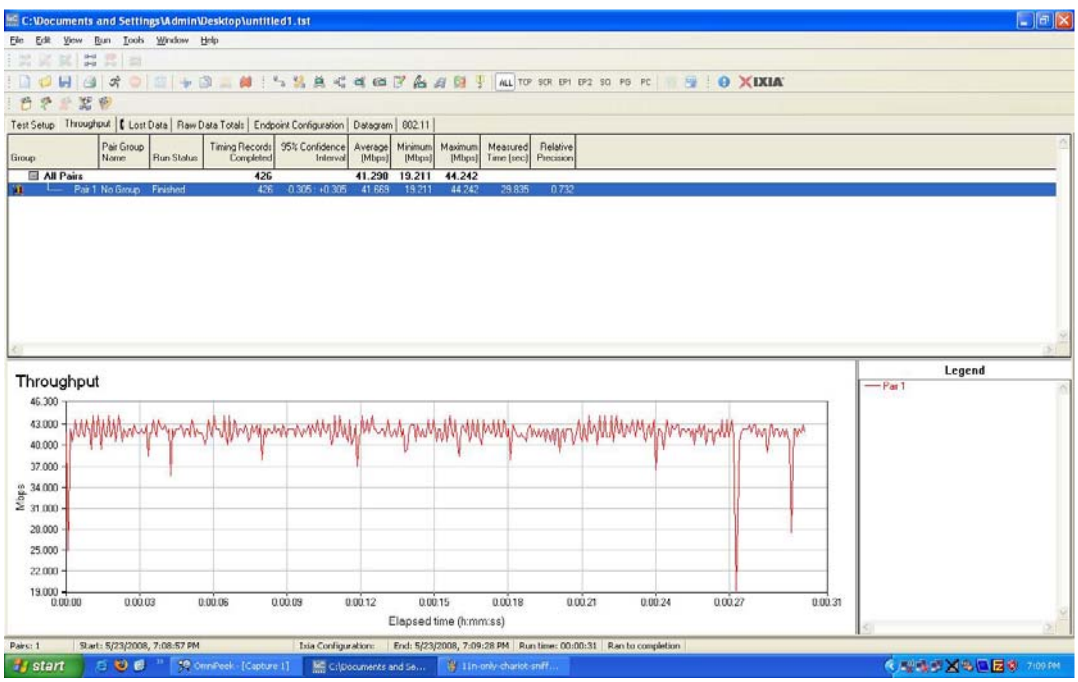

Figure 4: Throughput in an all-11n network

The test now brings on the 11g station to create the mixed 11n-11g environment. The 11g client merely connects to the BSS – no active data transfer takes place. When the throughput test is repeated between the AP and the two-stream 11n client, we see protection mechanisms kick in. Figure 5 shows a snapshot of packet exchange during the throughput test. Note the CTS frames that are transmitted, taking up air time.

9	100%	-36	6.0	20	0.000443	802.11 RTS
9	100%	-36	6.0	14	0.000012	802.11 CTS
9	100%	-43	144.5	1535	0.000003	UDP
9	100%	-36	24.0	14	0.000005	802.11 Ack
9	100%	-36	6.0	20	0.000407	802.11 RTS
9	100%	-35	6.0	14	0.000005	802.11 CTS
9	100%	-42	144.5	1535	0.000003	UDP
9	100%	-36	24.0	14	0.000004	802.11 Ack
9	100%	-36	6.0	20	0.000003	802.11 RTS
9	100%	-35	6.0	14	0.000331	802.11 CTS
9	100%	-41	144.5	1535	0.000004	UDP
9	100%	-38	24.0	14	0.000004	802.11 Ack
9	100%	-36	6.0	20	0.000386	802.11 RTS
9	100%	-37	6.0	14	0.000004	802.11 CTS
9	100%	-40	144.5	1535	0.000002	UDP
9	100%	-36	24.0	14	0.000005	802.11 Ack
9	100%	-36	6.0	20	0.000386	802.11 RTS
9	100%	-37	6.0	14	0.000004	802.11 CTS
9	100%	-44	144.5	1535	0.000003	UDP
9	100%	-36	24.0	14	0.000003	802.11 Ack
9	100%	-37	6.0	20	0.000414	802.11 RTS
9	100%	-38	6.0	14	0.000005	802.11 CTS
9	100%	-43	144.5	1535	0.000003	UDP

Figure 5: Packet exchange in a mixed 11n-11g network

The result of this is a reduced overall throughput, as captured in Figure 6. The average throughput is less than 28 Mbps – a drop of over 30%. The percentage loss would be higher when higher data rates were used, based on the environmental conditions. This is the significant price paid for having a 11g station in an 11n network.

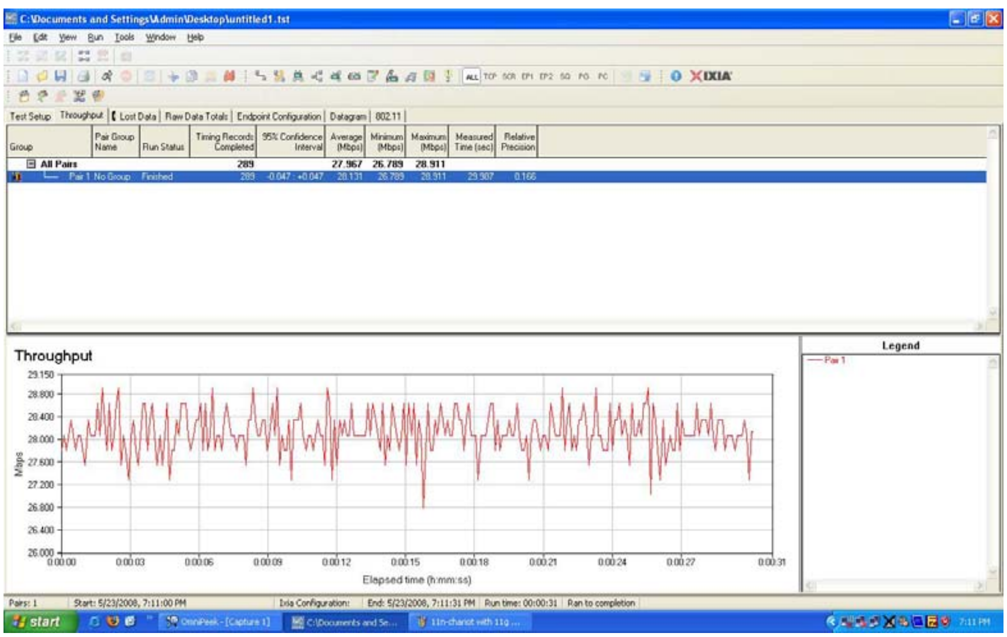

Figure 6: Throughput in a mixed 11n-11g network

We now look at another scenario – the introduction of a single-stream 802.11n handheld device into the 11n network populated thus far by a two-stream AP and a two-stream station. When the throughput test is repeated we see that data transfer between the AP and the two-stream 11n client proceeds without the use of protection mechanisms – shown in Figure 7.

9	100%	-39	144.5	1535	0.000189	UDP
9	100%	-35	24.0	14	0.000039	802.11 Ack
9	100%	-39	144.5	1535	0.000223	UDP
9	100%	-37	24.0	14	0.000039	802.11 Ack
9	100%	-39	144.5	1535	0.000309	UDP
9	100%	-36	24.0	14	0.000006	802.11 Ack
9	100%	-40	144.5	1535	0.000300	UDP
9	100%	-35	24.0	14	0.000006	802.11 Ack
9	100%	-37	144.5	1535	0.000313	UDP
9	100%	-37	24.0	14	0.000006	802.11 Ack
9	100%	-40	144.5	1535	0.000180	UDP
9	100%	-36	24.0	14	0.000044	802.11 Ack
9	100%	-37	144.5	1535	0.000254	UDP
9	100%	-34	24.0	14	0.000057	802.11 Ack
9	100%	-40	144.5	1535	0.000217	UDP

Figure 7: Packet transfer in an all 11n network with a single stream 11n handheld

The absence of the employment of protection mechanisms – i.e. data transfer without RTS and CTS frames. The result is the complete preservation of throughput, as seen in Figure 8.

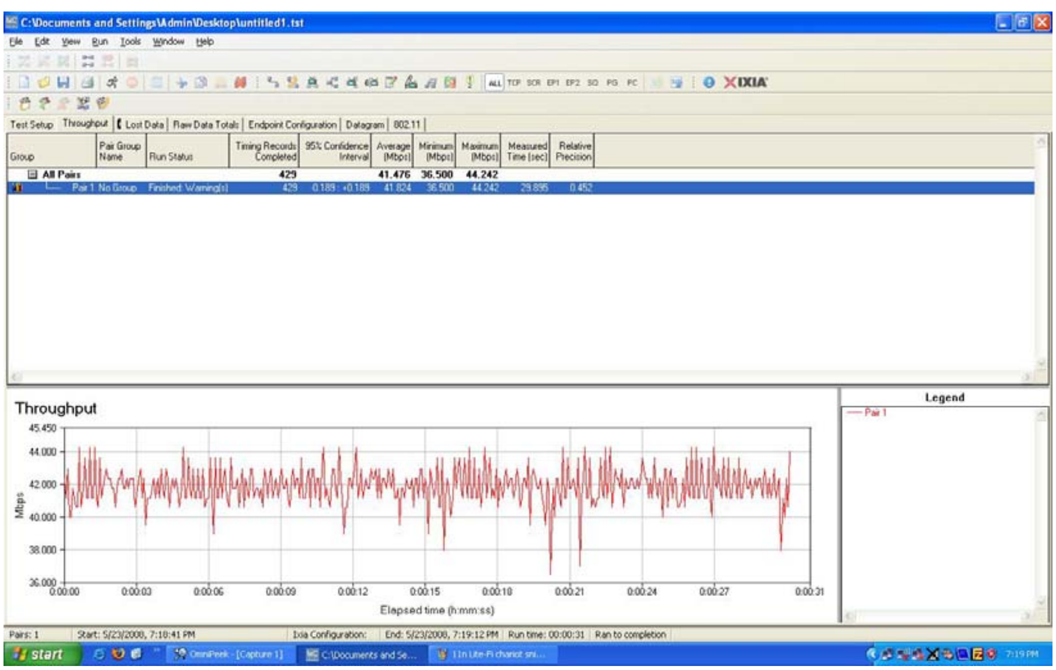

Figure 8: Throughput in a 11n network in the presence of single stream 1n handheld

We see that network throughput is perfectly preserved – average throughput continues to remain about 41 Mbps.

Different environmental conditions may result in varying throughputs enjoyed by devices in a wireless network, but the fact remains that the overall throughput advantages of 802.11n are best preserved by ensuring that low-cost and low-power handheld devices use single-stream 802.11n rather than the legacy 802.11g connectivity.

The Handheld Certification

The Wi-Fi Alliance announced the availability of a program to certify products based on the 802.11n draft 2.0 standard in June, 2007. The program defined a set of features that would be necessary and tested for, and a level of interoperability with a set of vendor equipment supporting those features. While the certification mandates the availability of two antennas, or actually the two-stream MIMO mode in a certified device, it also provides for an exception to be made in the case of handheld devices. The rationale behind this is that these devices stand to gain from the benefits of 802.11n. Their typical applications include voice services, file transfer, and media streaming; and they require higher throughputs and increased range in order to conserve battery life. At the same time, these devices typically use a single antenna configuration due to constraints of size and battery supplied power. Even with a single antenna, the 11n device gains from the 11n capabilities of aggregation, STBC, beam-forming at the AP, and other features providing better efficiency of data transfer and better quality of service. The price paid by single stream 802.11n WLAN solutions over legacy 802.11b/g solutions may be that of additional complexity of implementation, with its attendant cost, size and power penalty. However, state of the art solutions today, including Redpine Signals' Lite-Fi™, over these with well designed implementations and provide all the benefits of 802.11n – both to the handheld device as well as to the overall network – at a cost and size similar to that of legacy solutions. These solutions would truly enable the universal adoption of 802.11n technology in all scenarios.