Wireless and Home Networking:
A Foundation for Service Provider Applications

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Abstract

The explosion in the variety of Consumer Electronic (CE) devices and applications that deliver video and internet experiences has produced the need for simple and integrated home networking solutions. The cable TV community has analyzed, tested and debated the viability of offering home networking solutions for many years but competitive pressures and technology advancements has finally prompted near term action.

Although the home networking environmental conditions are reaching an inflection point, the standards, consortiums and technologies are very fragmented and the network operator economics justifying a service offering can be marginal.

This paper focuses on various wireless home networking technologies and solutions. The drivers for home networking are considered and a variety of wireless home networking configurations are discussed.

Preliminary test results from both a performance and economic basis are evaluated. Of particular importance will be to assess the user and operator experience from a set-up and maintenance perspective.

The conclusion section will contrast the technical and economic characteristics and benefits of the various wireless home networking solutions. A recommendation will be proposed that identifies areas of opportunities for wireless home networking solutions for Multiple System Operators (MSO's).

EVALUATING THE DRIVERS FOR SERVICE PROVIDER SUPPORTED HOME NETWORKING

In this section of the paper we explore the technology drivers for adoption of home networking. We consider the following drivers:

- Proliferation of wireless networked devices.
- Rise of Wireless Home Networking Standards and Ease of Use.
- Rise of Personal Web Applications, Place-shifting, and Social Networking
- Rise of Personal Digital Media and Low Cost Home Storage, and the decline of Digital Rights Management (DRM).
- Access Competition, Product Relevance and Substitution.
- Wireless Home Networking is happening today !

Proliferation of Wireless Networked Devices

Today"s digital home includes many networking capable devices, with the range of multi-media networked devices continuing to increase. End users require home networking in order to support many of these new devices.

Multi-media Devices: Manufacturers are starting to include network connections or Wi-Fi technology in common devices like digital still cameras and MP3 players and printers. Examples include Apples Wi-Fi enabled iPod touch, or iPhone; Eye-Fi"s Wi-Fi SD memory card; Archos personal media player; and the Hitachi Wooo camcorder or

Kodak Zx1camcorder that can stream live video using Wi-Fi to the HDTV set.

Media Extenders & Streamers: A range of IP connected media extender and streamer devices have entered the market in recent years. Examples include Apple TV, Netgear"s recently announced ITV2000 Internet TV player.[1] In addition we see emerging streamers such as the Netflix Roku device, and networked gaming consoles such as the X-Box 360 which recently included the Netflix service. It is no surprise that today"s TV require many HDMI ports !

Multi-room Audio: Multi-room audio solutions that leverage home networking capabilities are emerging. Examples include Sonos, Linksys by Cisco Wireless Home Audio system [2], and Apple"s Airport-based wireless audio streaming; in addition to audio streamers such as the Logitech"s Squeezebox, and Internet radio devices such as Tangent"s Quattro Internet radio.

Networked TVs: TV sets with built in networking are beginning to emerge. At CES 2009 for example Sony, Samsung, LG and Toshiba were all introducing TVs with Ethernet and/or Wireless connections [3] which could be used to display Yahoo! widgets.

<u>Rise of Wireless Home Networking Standards and Ease of Use</u>

(a) Standards

Standards are critical in evaluating the drivers for service provider supported home networking. Support for forwards and backwards compatibility with today"s networked devices determines the quality of experience subscribers experience and helps resolve end user issues. The key to achieving this support is the extent wireless home networking technology can be embedded in CPE devices, application layer standards for device discovery, and service provider.

(b) Ease of use

Manufacturers such as Linksys (with its LELA – Linksys EasyLink Advisor - software) have significantly improved the installation, configuration, and maintenance software for wireless networking devices.

However it is still quite complex for most mainstream consumers and causes additional call volume to ISP customer care centers.

Service providers can drive home networking further toward mass market by building a proper integrated support ecosystem. Installers and service providers could incorporate available tools to allow easy maintenance and upgrades.

<u>Rise of Place-shifting, Media multi-tasking, Personal Web Applications and Social Networking</u>

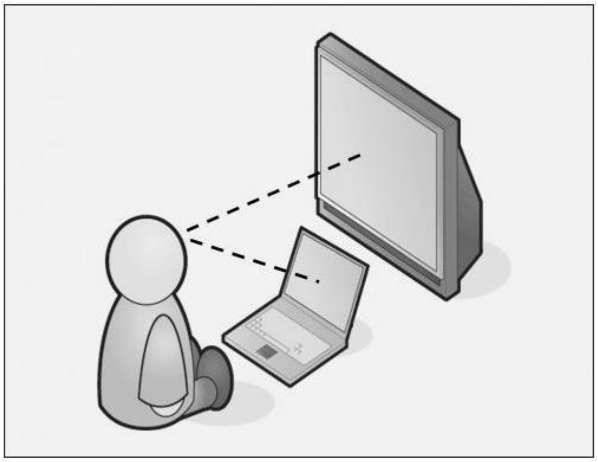
(a) Place-shifting and multi-tasking

Place shifting devices such as the Slingbox have emerged to enable services to be used in any room. Place shifting devices and services require a home network ideally based on a solution that supports location flexibility or portability.

Emerging home server solutions such as Microsoft Windows Home Server, and Linksys by Cisco Media Hub[4] are emerging that support multi-user and remote access to user generated digital content, requiring a home network.

With the proliferation of devices there is anecdotal evidence that multi-tasking is taking place in the living room, combining for example, the TV viewing experience with laptop browsing. Wireless networking is an enabler of multi-tasking.

Figure 1: Living-room Multi-tasking



(b) Personal Web Applications & Social Networking

The personalization of the web is evident in the explosion of web-based email platforms such as Gmail, Yahoo Mail and Windows Live Mail.

With the emergence of social networking applications such as MySpace and Facebook, combined with micro-blogging platforms Twitter and Friendfeed; web-based applications reinforce the personalized nature of networked communication.

The speed at which web-based personal applications have been developed for wireless networked devices, such as the Apple iPhone and Google"s Android platform emphasizes the importance of operator-supported wireless home networking.

Rise of Personal Digital Media and Low Cost Home Storage, and the decline of DRM

(a) Personal Digital Media

With today"s explosion of multi-media digital devices such as Camera"s, Handycam"s, and Multi-media Handheld device, users are generating more personal digital content than ever before.

As highlighted in Table 1 below, it is estimated that the typical U.S. broadband household will have almost 1 terabyte of personal digital media in the home by 2012.

Table 1: U.S. Household Digital Media Growth [5]

	2008 (GB/hh)	2010 (GB/hh)	2012 (GB/hh)
Music	11	17	24
Photos	14	47	151
Video	201	347	723

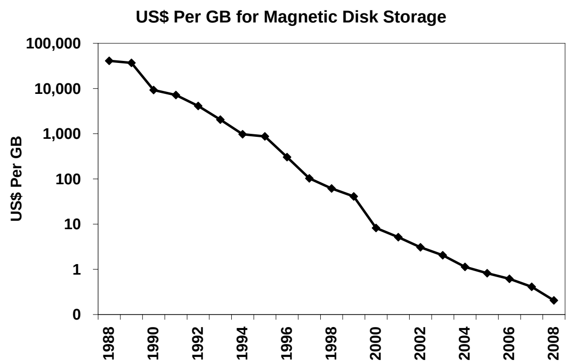
With an expanding library of personal digital content including music, photos and movies; the home network starts to play a pivotal role in allowing a user"s multiple devices to synchronize or access personal content between rooms and across devices.

Furthermore, applications are emerging to support multi-device synchronization of personal digital media such as Microsoft Live Mesh, driving the need for home networking.

(b) Low Cost Home Storage

In 1988 1 GB of storage in the home would cost about US$40,000, so storing an 11GB music library would cost US$440,000! That cost has dramatically declined so that in 2008 1 GB of storage cost of approximately US$0.20 meaning that 11GB music library could be stored for US$2.20. This dramatic shift in the economics of storage has enabled households to store large libraries of multi-media content for consumption around the home.

Figure 2: Consumer Price Per GB Declines [6]



Additionally, small form factor storage, such as SD cards, and smaller Mini and Micro SD cards are supporting multi-media from a range of new home wireless networked devices such as Apple"s iPhone and Google"s G1 Android handset. Such devices are able to both access and contribute to the personal digital media library.

(c) The demise of Digital Rights Management (DRM)

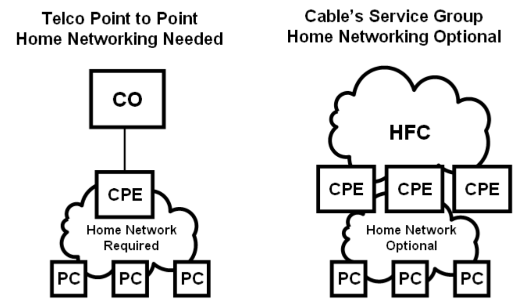
Recently Apple announced it was abandoning DRM protection for iTunes song downloads in favour of a non-DRM model[7]. The fall of DRM means that a barrier to multi-room audio has fallen and this facilitates a wider device ecology for the consumption of multi-room around the home. The key question is whether this trend will extend to the video world? In particular, the ability to move MPEG4/H.264 HD content to various devices within the home at its much lower bandwidth requirements could be a key enabler for whole home wireless networking of video, data and voice.

Access Competition, Product Relevance and Substitution

(a) Access Competition Driving Wireless Home Networking

Telco access architectures have been a driver of home networking. The Telco point to point architecture requires an in home solution to enable multiple devices to connect to the same service. This can be compared to Cable"s service group which can support multiple devices with a dedicated CPE if required.

Figure 3: Telco Access Architectures Depend on Home Networking



As a result Telco"s have deployed advanced residential gateways for several years by necessity.

(b) Product Relevance and Substitution Driving Service Provider Wireless Home Networking

The traditional RBOC or Incumbent Telco, has typically placed an emphasis on the residential gateway CPE device with the latest features as a way to attract subscribers, reporting the residential gateway CPE as a subscriber acquisition expense. This has provided a head start for Telco"s in residential gateway adoption and wireless home networking penetration.

A subset of Telco residential gateway deployments can be seen below in Table 2:

Table 2: Telco Residential Gateways [8]

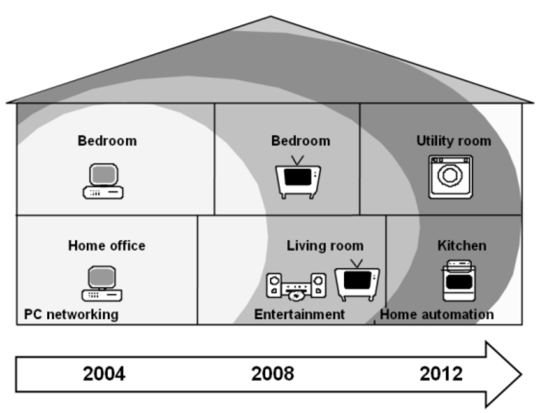
Telco	Gateway Product	Sales/Units Deployed
British Telecom	Hub (integrated Wi-Fi and DECT)	3.5m HUB boxes, about 100k per month
France Telecom	Livebox (Integrated Wi-Fi, USB DECT dongle)	7.5m sold, selling 300k per month
Deutsche Telekom	Speedport (Integrated Wi-Fi and DECT)	Selling 200k to 250k per month

Substitution challenges can also be a driver for service providers. Wireless home networking could be a unique selling point to counter wireless mobile broadband offerings in the market place.

Wirelesss home networking is happening today !!

Wireless home networking is happening today and solutions are emerging to support not only basic connectivity but also other devices such as gaming consoles, multi-media extenders and entertainment devices as outlined in the networked home in Figure 4.

Figure 4: The Networked Home [9]



Wireless is playing a larger role in home networking. As seen in the table below, outlining the shift in European online consumer home networking, there is a trend toward wireless becoming the default method of home networking.

Table 3: European Online Consumer Use of Home Networking [10]

	Q4 2006	Q4 2008
Yes – Wired	12%	8%
Yes - Wireless	13%	20%
Yes – Mixed /not sure	7%	12%
No	68%	60%

Summary of Wireless Home Networking Drivers

Proliferation in networked devices, ever-expanding user generated content libraries, the desire for „anywhere‟ place-shifted content access, the rise of the dynamic multi-media web, the rise of real-time social networking, and new viewing behaviors are all driving the end user adoption of wireless home networking.

Competitive access products from Telco‟s already include wireless home networking, and the threat of mobile broadband substitution creates additional urgency for fixed line service providers.

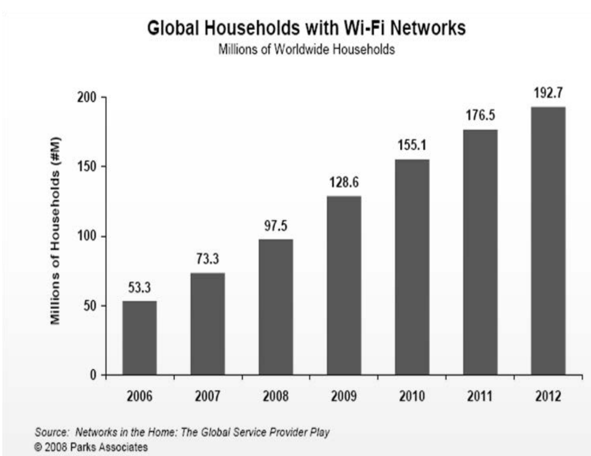
The message for the service provider: wireless home networking is happening today, service providers can either choose to participate and add service provider supported features and value for the subscriber, or watch from the sidelines at the risk of market share loss, mobile broadband substitution, and loss of relevance in the home multi-media experience.

THE POSSIBILITIES OF WIRELESS HOME NETWORKING

If a service provider, like a Cable TV Company, could utilize in home wireless technology to help solve its home networking needs then many complexities of whole house distribution could be solved. Wireless is inherently a simple, flexible, low cost and convenient medium for both the subscriber and network operator. Wireless is a particularly attractive option for the author"s family of international companies because, unlike the United States, most homes in Western Europe, Eastern Europe, Asia and South America are smaller size, multi-dwelling units and not pre-wired with coaxial cable.

Wireless technologies (Wi-Fi, cordless and DECT phones) are currently the solution of choice for in-home data communications and phone services as illustrated by the chart below.

Figure 5: Global Households with Wi-Fi Networks[10]



The progress in viable technologies (e.g.- DLNA, UpNP, MPEG4 video compression) and applications (e.g.- Internet TV, Apple TV, Hulu, multi-room DVR…) that move video around the home has accelerated the need for a reliable in home transport medium and further raises the bar for wireless as a total home networking solution. As a total home networking tool the bandwidth, performance and quality issues of video over wireless have limited in-home wireless technology and could hamper its evolution beyond basic data and voice applications.

In this paper we will look at transmitting HD video throughout the home, replacing HDMI video cables within a room via "wireless HDMI" and traditional data/voice home networking.

Regulatory, technological and standardization advances in the wireless sector over the past few years has placed wireless home networking in a position where it could possibly meet the home networking challenge just described.

Regulatory

For instance, on the regulatory front, higher power transmission of signals has been allowed in the 5 GHz Wi-Fi spectrum in Europe. The spectrum available in Europe and the U.S. are becoming more aligned for 5 GHz Wi-Fi, UWB (6-10 GHz) and even 60 GHz. Finally, larger blocks of contiguous spectrum are being made available (~ 600 MHz at 5 GHz, 1.7 GHz at UWB, 7 GHz at 60 GHz).

Technology

Overall, wireless technology advances have made huge leaps. Orthogonal Frequency Division Multiplexing (OFDM) modulation, Multiple Input Multiple Output (MIMO) antenna schemes, large channel bandwidths (e.g.- 40 MHz channels), chip integration that puts baseband and RF functions on a single chip and high quality video compression techniques provide economical and bandwidth efficient solutions. The combination of these technological advances gives operators the appearance that wireless whole home networking is feasible even when entertainment applications are assumed.

Standards

Finally, the standards bodies, and in particular the IEEE, have made tremendous strides at continually updating and improving their wireless specifications. The 802.11 working groups have created new amendments and standards in many areas (e.g. - high throughput/802.11n, Quality of Service/ WMM, Security/WPA2, Power Save/APSD) that help improve service levels and capabilities. Although these specifications take longer than desired to become standards the progress made in the difficult political environment of the standardization process is impressive.

THE REALITY OF WIRELESS HOME NETWORKING

All the positive indicators just mentioned must be tempered with the reality of the wireless medium. The wireless channel is unstable and unpredictable in an outdoor environment but becomes extremely variable indoors as floor plan layouts, furniture, walls and living quarter sizes vary widely. The characteristics of the Radio Frequency (RF) channel can change rapidly over a time period due to fading and interference. Consequently, the capacity of the channel and signal strength (signal to noise ratio or SNR) seen by the receiver fluctuates constantly.

The evaluation of wireless whole home networking solutions must be looked at along five critical success criteria.

- High volume components & chips to meet consumer electronic (CE) device economics
- Sufficient and uniform spectrum at the right frequencies
- Transmit power levels versus interference trade-off‟s
- Quality of service capability for video applications
- Compression versus latency versus bandwidth tradeoff‟s for video applications

The interplay and relationships between the success criteria results in complex systems architectures.

Consumer Electronics (CE) Device Volumes

A large ecosystem of wireless home networking chipsets and devices are required to reach the proper economics in the C.E. world. But success in obtaining the proper device scale in the unlicensed, unregulated spectrum realm of the home network means too many wireless devices operating in the same spectrum which causes interference, quality and capacity issues. It has taken about 5 years for the 60 MHz of Wi-Fi 2.4 GHz spectrum (three 20 MHz channels) to become too congested using just voice and data applications. In some ways, the great success of Wi-Fi has bred failure for wireless as a home networking solution.

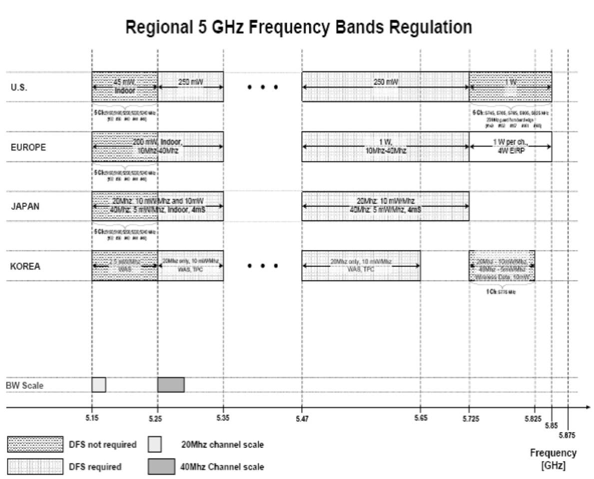
Spectrum Availability

As a positive consideration, the 5 GHz Wi-Fi frequency is relatively greenfield, contains ~500 MHz of contiguous spectrum (twenty-four 20 MHz channels) and is available almost uniformly across both the U.S. and Europe. The future success of 802.11n devices combined with the higher bandwidth requirements of video applications means a similar 2.4 GHz congestion problem could eventually occur. The capacity and quality limits at 5 GHz would occur first in the denser urban areas of apartments and multi dwelling units and in areas where public Wi-Fi networks are operating in the same frequencies. Anticipating this eventuality, standards bodies and start-up companies are venturing into the higher frequencies of UWB (6-10 GHz) and 60 GHz spectrum where much larger blocks of spectrum are available. Unfortunately, higher frequencies have the well known disadvantages of severely limiting the range the signal can go and requiring higher power and costs. For this reason UWB and 60 GHz solutions have been currently relegated to in room solutions only.

Transmit Power Levels

In general, transmit power limits in wireless devices have similar economic, cost and interference trade-off‟s. The EU has recently increased the allowable transmit power limits across most of the 5 GHz Wi-Fi frequencies to 1 Watt.[11] Although this certainly helps in getting whole home networking solutions to work in houses and apartments that are larger and made of stronger materials the RF energy from adjacent networks will raise the noise floor and interference levels. Higher power levels in devices also translates into additional costs. Transmit power levels above a certain point (~100 mW) limits the ability to integrate a power amplifier (PA) into a chip as non-linearity and peak to average power ratios cause problems in chip designs. Outboard PA‟s typically translates into higher costs.

Figure 6: Wi-Fi 802.11n 5 GHz Frequencies and Transmit Power[12]



Quality of Service (QoS)

Whole home wireless solutions that accommodate delay sensitive applications such as video and voice must at a minimum be able to prioritize various traffic types. The 802.11 standard that specifies QoS is called WMM (Wireless Multi-Media) and has the potential to ensure quality video transmissions within the home. Unfortunately, wireless home networks have not reached the point where they will guarantee and reserve bandwidth by offering parameterized QoS as is done within the cable TV and DOCSIS network of a cable operator.

Compression, Latency and Bandwidth

In the wireless home networking arena a debate rages over the effects of transporting uncompressed (e.g.- HDMI) versus a compressed video signal (e.g.- MPEG2 or MPEG4/H.264). No wireless technology transports true uncompressed HDMI as a baseband video signal. Other than the large spectrum range of the 60 GHz frequencies, all other in-home wireless technologies use some sort of real time compression. Compression (e.g.- H.264) will be needed to send video over wireless especially as video scales up with higher frame rates, deeper colors and higher resolutions.[13] Some vendors introduce the concept of lossless versus lossy compression to further differentiate their products. Traditionally the industry has regarded any compression above 4X compression ratios as lossy compression. Compression at lower compression ratios allow it to be categorized as lossless compression.[14]

Linked in with this discussion is the latency issues associated with transcoding from one codec to another when dealing with compressed video, the ability to move a compressed signal across devices while still complying with all DRM considerations and the ability to add the graphic overlay for an

EPG (Electronic Program Guide) over the compressed signal. Obviously a compressed signal has substantial advantages in moving video content around the home as the bandwidth requirements of MPEG2 HD are 15 to 20 Mb/s (7 to 10 Mb/s for MPEG4/H.264) while uncompressed HD requires > 3 Gb/s of capacity.

WHOLE HOME NETWORKING REQUIREMENTS

The CableLabs OpenCable Home Networking study group has spent a considerable amount of time defining the various use cases for moving video, data and voice applications throughout the home. As a result of this effort the minimal bandwidth, performance requirements and architectures of a home network have been proposed.

A typical deployment scenario of one Set Top Box (STB) with storage capability and two STB"s without storage depicts a requirement for four times the maximum bandwidth for a single HD stream of MPEG2 video content being transported between network elements in the home. Assuming a 20 Mb/s per HD stream requirement (MPEG2) a consistent and reliable 80 Mb/s wireless network is needed within the home that offers full Quality of Service (QoS) and prioritization (or better yet reserved capacity) of video media content. CableLabs assumes another 20 Mb/s for best efforts based data traffic and prioritized voice traffic. Therefore the MAC throughput data rate of at least 100 Mb/s is required to support all types of in home networking video, data and voice streams.[15]

OVERVIEW OF TECHNOLOGY OPTIONS FOR WIRELESS HOME NETWORKING

There is a range of wireless technology options, associated frequencies, existing or emerging standards and industry associations that could possibly meet the demanding home networking requirements of video, data and voice applications. The major alternatives investigated in this paper include:

- DECT (Digital Enhanced Cordless Telecommunications)
- High Throughput Wi-Fi (802.11n)
- Variations To High Throughput Wi-Fi (802.11n) Specification
- Optimized Video At 5 Ghz Or Proprietary Wireless HDMI.
- Ultra Wide Band (UWB) and (IEEE 802.15.3c or 802.11ad) technology

Each of these four alternatives have a number of start-up and established companies pushing their particular technology and specification. Many have established consortiums of companies and industry associations and consortiums of companies with the intent of bringing their specification to a standardization body for approval. The table below summarizes the major technology options. In all cases the standardization process is ongoing and in many cases at an early stage. Only the Wi-Fi 802.11n standard is very near completion and has a large ecosystem of chipsets and consumer electronic devices currently being built.

Table 4: Wireless In-Home Alternatives[16]

Name	Association	Spectrum	Standard Body	Major Chip Suppliers	Data Rate Claims	Indoor Range
DECT	DECT Forum	1.88–1.9GHz in Europe, 1.92–1.93GHz in the US	ETSI	DSP Group and SiTel	64Kb/s, 300Kb/s (CAT-iq)	~50m
High Throughput Wi-Fi	Wi-Fi ™Alliance [17]	2.4 GHz and 5 GHz	IEEE 802.11n	Intel, Broadcom Marvell …	300-600 Mb/s	~100m
Optimized Video at 5GHz (Proprietary Wireless HDMI)	Wireless Home Digital Interface (WHDI ™) [18]	5 GHz	IEEE 802.11a a, ac	Amimon	1 Gb/s	~50m
Ultra Wide Band (UWB)	WiMedia ™ [19]	6 to 10 GHz	Formally IEEE 802.15.3	TZero Radiospir	480 Mb/s	<10m

			a now ECMA-368	Sigma Designs, PulseLink…		
Very High Throughput 60 GHz (Proprietary Wireless HDMI)	Wireless HD ™ (WiHD) [20]	60 GHz	IEEE 802.13.3c and 802.11ad formally 802.11vht	SiBeam	3 Gb/s	<10m

DECT Digital Enhanced Cordless Telephone

DECT was developed by ETSI but has since been adopted by many countries all over the world. The original DECT frequency band (1880 MHz–1900 MHz) is used in all countries in Europe. Outside Europe, it is used in most of Asia, Australia and South America, making it well suited to the author‟s international systems.

In the United States, the Federal Communications Commission in 2005 changed channelization and licensing costs in a nearby band (1920 MHz–1930 MHz, or 1.9 GHz), known as Unlicensed Personal Communications Services (UPCS), allowing DECT devices to be sold in the U.S.

Although the DECT data rate makes it unsuitable for high speed data or video, many voice service providers consider that "DECT is the go to platform for voice calling in the home"[21]. Further, as a home wireless technology for voice, DECT has the advantage of a well established ecology of handset device manufacturers. Additionally many subscribers are familiar with DECT, the technology does not require additional subscriber education.

High Throughput Wi-Fi (802.11n)

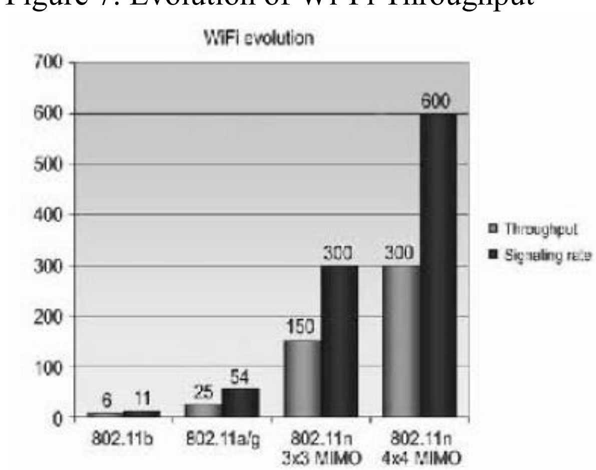
Wi-Fi is the wireless LAN technology brand developed by the Wi-Fi Alliance to certify IEEE 802.11 devices. In a little over a decade Wi-Fi has evolved from an innovative idea into an indispensible technology for consumers. The original standard has been continually updated and enhanced, which has led to the tremendous growth in the industry. The chart below outlines some of the key milestones in the 802.11 committee‟s progress.

Table 5: Key IEEE 802.11 Standards[22]

Standard	Date	Description
802.11a	1999	First 5 GHz standard. Incorporates OFDM technology with speeds up to 54 Mb/s
802.11b	1999	First standard to gain wide adoption. Operates in the 2.4 GHz using DSS CDMA technology and 11 Mb/s speeds
802.11g	2003	Operates at 2.4 GHz but employs OFDM technology at speeds of 54 Mb/s and is backwards compatible with 802.11b
802.11n	2008 for Draft 2.0	Next generation standard that uses 2.4 & 5GHz and leverages MIMO, beamforming to produce 600 MB/s speeds
802.11e	2005	Provides support for Multimedia Applications with Quality of Service, called WMM
802.11i	2007	Adds security features to improve on WEP using Advanced Encryption Standard (AES)

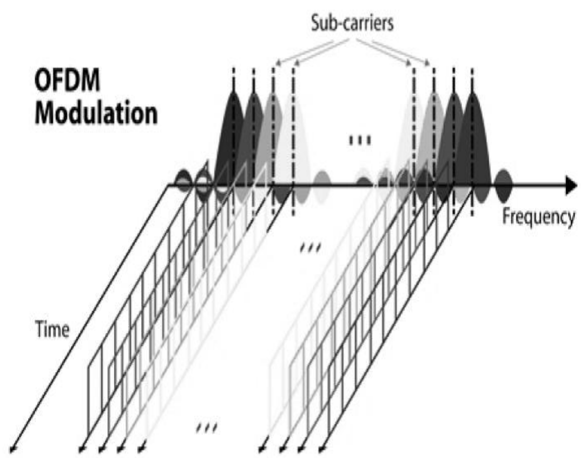
The innovative technologies employed in the 802.11n specification results in greater throughput and reliability over previous Wi-Fi solutions. Data rates as high as 600 Mb/s, 10 times greater than 802.11 a/g previous standard, are possible with 802.11n. Figure 7 illustrates the dramatic boost in network capacity and ultimately the speeds possible for in-home wireless networking applications using 802.11n technology. Contrasting this development with today‟s 802.11a/g speeds of 54 Mb/s and typical wired Ethernet 100 Mb/s throughputs begins to put this advancement in perspective.

Figure 7: Evolution of Wi-Fi Throughput [23]



The 802.11n specification is built on the cornerstones of OFDM and 802.11a and 802.11g standards. In this technique the usable bandwidth is divided into a large number of smaller bandwidths or subcarriers. These subcarriers are mathematically orthogonal or unique and can be tightly packed next to each other to gain maximum spectral efficiency. The high speed information to be transported is then divided into multiple lower speed signals and transmitted simultaneously on different frequencies (subcarriers) in parallel.[24] Both 802.11a/g and .11n specifications utilize 52 subcarriers spread across a 20 MHz channel bandwidth. Figure 8 illustrates the various subcarriers and how the data to be transported is distributed across the subcarriers in both frequency and time.

Figure 8: OFDM Technology [25]



A major advantage of OFDM and 802.11n is its ability to tolerate multipath fading by carrying small amounts of information on individual subcarriers or frequencies. If one or two frequencies/subcarriers are lost due to a fade then only a small amount of information is lost which can be compensated for via error correction coding and retransmissions.

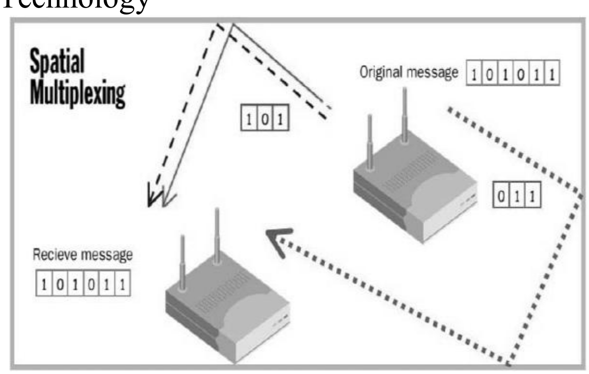
The primary innovations that allowed the 802.11n standard to make such a large leap in performance and throughput from its predecessors are:

- Multiple Input Multiple Output (MIMO) technology
- Enhancements in modulation and coding schemes
- Packet overhead improvements called packet or frame aggregation.
- Channel bonding (40 MHz channels)

(a) MIMO Technology

MIMO uses multiple radios and antennas to allow different data to be simultaneously transmitted across multiple transmit antennas. On the receive side of the wireless data link the separate unique data streams go across free space on different paths and are received by the separate receive antennas. Because of the spatial diversity of the multiple paths through the air, MIMO systems are able to transmit two unique data streams. This results in data transmissions at twice the data rate of single antenna and radio systems. This concept is called MIMO Spatial Multiplexing (SM) and is illustrated in Figure 9. In Figure 9 the original data stream or message (101011) is sent simultaneously as two different messages (101 and 011) across two different radios, antennas and spatial stream paths to the receiving device antennas. The 802.11n standard can support four spatial streams across four transmit and receive antennas.

Figure 9: MIMO Spatial Multiplexing Technology[26]



(b) Enhancements in Modulation and Coding Schemes

802.11a/g Wi-Fi networks use a single stream and eight possible modulation and coding schemes resulting in eight possible data rates. 802.11n MIMO technology can implement a concept called rate adaptation and variable modulation and coding schemes. If the RF conditions are good and the signal strength of the receiver is strong a higher modulation level (e.g. 64QAM) and weaker error correction code can employed at that instant for the data stream. This results in a higher data rate for that particular data stream. As an example of the power and complexity of the 802.11n specification there are 77 different modulation and coding schemes (MCS) possible where 8 MCS schemes are mandatory.[27] The end result of the multiple spatial streams, coding and modulation options, are the possibility for much higher data rates.

(c) Packet and Frame Aggregation

Reducing the packet overhead required for data transmission is critical for reliable high speed delivery of data operating in the 802.11n mode. In conventional wireless transmission systems the amount of overhead is fixed regardless of the size of the data packet. As the data rate increases the overhead remains the same. The 802.11n specification has fixed this problem by aggregating multiple packets of overhead into a single transmission frame.[28]

Unfortunately, aggregating multiple overhead packets can cause an increase in system latency as the radio must hang onto packets at the transmitter until it creates a transmission frame of the desired size. For that reason some real time applications (e.g.-voice) do not utilize the benefits of packet aggregation.

(d) Channel Bonding

802.11n networks gain an immediate capacity increase by implementing the concept of channel bonding. Combining two 20 MHz channels into a 40 MHz channel is a very straightforward way of increasing the bandwidth and capacity of the system. This technique is utilized more effectively in the 5 GHz range as there are twenty-four 20 MHz channels to work with versus the three 20 MHz channels in the 2.4 GHz frequency.[29]

The combination of a 40 MHz channel, two spatial streams and the packet aggregation gains of frame aggregation will provide a 300 Mb/s maximum data rate. If four spatial streams are used this peak data rate can increase to 600 Mb/s.

(e) Implementation Issues

To ensure a seamless transition to the newer 802.11n technology the specification was designed for backwards compatibility. Legacy clients (802.11a/b/g) will operate without problems in an 802.11n network. For instance, 11a clients operate in the 5 GHz spectrum and will continue to do so in a 5 GHz 802.11n network.[30]

The downside to this configuration is a reduction in performance when older devices operate in a 802.11n system. Legacy clients in an 11n network will reduce the overall throughput of the 11n system. The peak performance of an 11g client is ¼ that of 11n. So if an 11g client is operating at 10 Mb/s then the 11n capacity will only be at 40 Mb/s (1/4 the 11n system).[31]

As previously mentioned transmit power is important and can be a key implementation issue for 802.11n systems. Additional power is required for each additional MIMO antenna and to operate in the wider 40 MHz channel mode. Each MIMO antenna will require a separate PA and RF chain so power consumption and resulting cost is increased.[32] Likewise, to keep an equivalent range shown in a 40 MHz system for a 20 MHz implementation will take much more transmit power.

Unfortunately the gain of a MIMO Spatial Multiplexing (SM) system assumes the existence of multipath and uncorrelated signals for each of the spatial streams being transmitted. Radio signals need to reflect off of walls and furniture to cause the receiver to see multiple representations of the same signal arriving at different times and amplitudes. In typical residential homes this phenomena occurs but situations could arise where the intended multipath effect is not present thereby decreasing the benefit of MIMO and increases in system capacity.

In 802.11n systems it is important for all traffic to be classified as priority, best efforts or background type traffic. Implementing the Quality of Service traffic classifications called Wireless Multi-Media (WMM) will be a difficult but important process. The correct tagging and classification will be critical to properly manage the traffic in a wireless home network. Not all consumers will be up to this task and could cause performance issues that will reflect poorly on the technology.

A final implementation and design consideration in the 802.11n specification are the use of two interference control mechanisms called Dynamic Frequency Selection (DFS) and Transmit power Control (TPC). DFS is a feature that checks for the presence of military radar operating in the 5 GHz frequencies and if detected requires the 802.11n device to utilize other available frequencies. TPC requires 802.11n devices to reduce their transmit power if they are operating very close to each other.[33] Although these interference controls are a burden to the 802.11n system developer they are not hugely disruptive issues but must be taken into account when Wi-Fi systems are being implemented.

Variations To High Throughput Wi-Fi (802.11n) Specification

Because the 802.11n specification has provisions for many optional features there exists the ability of a chip designer and access point developers to offer a variety of standards compliant 802.11n implementations. The major suppliers of 802.11a,b,g chipsets and start-up companies have begun to optimize video transport within the home over the 5 GHz spectrum associated with 802.11n.

The ability to use the additional 20 and 40 MHz channel bandwidths, aggregate baseband and RF functions onto a single System on a Chip (SoC), utilize MPEG4/H.264 compression and take advantage of MIMO technologies have led to many advancements in video distribution within the home.

Some new and innovative chip design shops have creatively utilized the various core technologies listed below to great advantage while still complying with the standard.

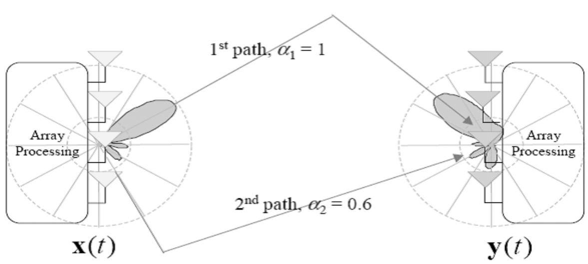
- Beamforming MIMO (simultaneous transmission of the same data streams over multiple antennas)
- Adaptive channel modulation and coding options
- Enhanced QoS (prioritizing video, data and voice services)
- Radio resource techniques (utilizing feedback information from the client devices while transmitting)
- Linking compressed video (H.264) chip and MIMO RF technologies
- Integration of advanced Power Amplifier (PA) and antenna designs

As these many variations of the 802.11n standard enter the market it will be very important for the Wi-Fi Alliance and network operators offering wireless home solutions to properly certify interoperability across access points and client devices. The beamforming variants discussed here add the most gains and consequentially the greatest complexity and interoperability issues.

(a) 802.11n Standards Compliant Implementations: Beamforming MIMO

MIMO technology has the two major design choices of either Spatial Multiplexing (SM) or beamforming. By choosing the beamforming approach the video transport can be optimized for high performance and distance. Beamforming MIMO allows for the control of the RF signal and actually steers the signal from the access point to where the client device is located. These RF pattern adjustments are made very quickly from moment to moment if either the client device moves, multiple clients are in the range of the Access Point (AP) or the RF conditions vary naturally. By choosing the beamforming MIMO option over SM MIMO the 802.11n chip or system designer typically foregoes the bandwidth gains of SM MIMO. In many cases multiple unique data streams are no longer being transmitted from each antenna simultaneously.

Figure 10: 802.11n Beamforming MIMO Architecture[34]

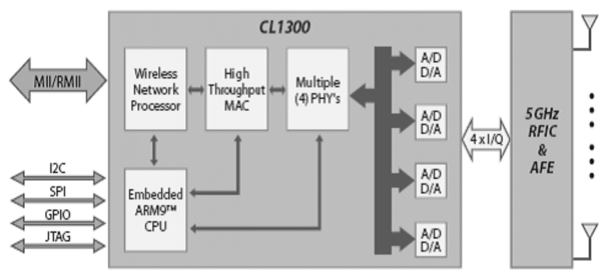


In the 802.11n specification there are chip level and system level implementations of beamforming. Chip level designs typically use mathematical and DSP based processing power to manipulate the phase of the baseband RF signal. As shown in Figure 10, these phase shifted signals are transmitted out over integrated MIMO antennas to accomplish the beam forming or optimized RF patterns.[35]

(b) Chip Level MIMO Beamforming Designs

There are many creative companies developing chip level MIMO beamforming designs. Because of the inherent bandwidth restrictions on beamforming MIMO, most chip level MIMO beamforming designs utilize an H.264 codec chip along with the baseband and RF chipset to ensure guaranteed video quality and wireless transmission of multiple HD video content.

Figure 11: 802.11n Chip Level MIMO Beamforming Architecture[36]



In one such design a 20 MHz channel carries three MPEG4/H.264 streams (1080p, 60fps) at between 8 to 10 Mb/s each. Vendor testing claims of a consistent 30 Mb/s (UDP transmission) of capacity across 25 meters and through multiple walls in a suburban home are one of many published 802.11n results.[37]

Another key beamforming MIMO chip design option involves either having the beamforming performed at one end (AP side) or both ends (AP & client). In one particular implementation the semiconductor vendor focused on delivering optimized MPEG4/H.264 HD video content where its chip is located at the transmit end of the video stream only. Therefore, it is placed in a central distribution point (access point, home gateways, multi-room DVR‟s) of HD content and interworks with standard off the shelf 802.11n chips (and MPEG4 codecs) in the client device such as a remote STB or HD TV display.[38] The reliability and distance benefit of beamforming MIMO combined with a low total cost for a whole home implementation (because of the ability to interoperate with low end 802.11n chipsets) is a very advantageous design. A second major chip vendor decided to implement their beamforming MIMO design by using their chip is used at both ends of the link. The result is probably a higher performance design but at a greater cost.

The decision to use either 20 MHz or 40 MHz (two bonded channels) channel bandwidths is likewise important. If the 802.11n implementation utilizes a single 20 MHz channel in the 5 GHz frequency to transport MPEG4 HD content then the transmit power and antenna gains can be more focused and contribute to a better range result. An implementation using two bonded 20 MHz channels (40 MHz) will need higher transmit power to get the same distance and throughputs (all things being equal). The second start-up vendors beamforming chip design utilizes 4 transmit and 4 receive antennas in their chip with a 40 MHz channel. This chip design is an excellent way to get both high capacities (40 MHz channel) and also reliable and long range performance (4x4 Beamforming MIMO).

Additionally, the transmit power and number of power amplifiers decision is crucial as it is a major contributor of cost and ability to integrate on a chip and circuit board level for vendors. Transmit power level of up to 100 mW are known to provide the best linear characteristics of the highly modulated signals (e.g.- 64QAM) of the 802.11n specification. Likewise, the number of RF chains and quantity of MIMO antennas to choose from are critical performance and cost decisions. In one illustrative beamforming design the entire video stream (comprised of 3 MPEG4 streams) is sent simultaneously over the 2 RF chains using 2 PA‟s where 4 antenna choices are possible.[39] Another chip level beamforming vendor chose to utilize 4 RF chains, four PA‟s and 4 antennas.[40] This design probably has more power and more beamforming patterns possible but probably at a higher cost.

The beamforming software in a particular vendors design is the "secret sauce" for their MIMO implementation. Software that chooses the best antennas and in effect creates an optimum transmit antenna pattern can make all the difference in performance. The ability to have many beamforming pattern options and continually (and quickly) adjust the pattern due to the varying conditions of the RF environment within the home cannot be underestimated. The 802.11n standard allows for information from the client side of the link to be sent back to the transmitters so that these software decisions can be made.

Unfortunately, there are multiple options and much complexity written into the standard for this critical feedback information. For instance, the implicit feedback option means the 11n client provides very limited information and the chip vendors implementation calculates how it should change its beamforming from moment to moment. The explicit feedback option in the standard spells out the continuous feedback of information the client must send. To date, no chip manufacturers of client end only chips have implemented this portion of the standard. Start-up chip vendors that have their MIMO beamforming solution on one end only are utilizing implicit feedback while those with chips on both ends use some form of explicit feedback to adjust the beam.[41]

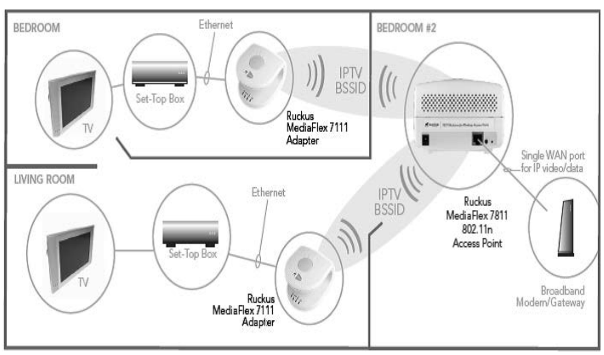
Because of the many options and complexity the interoperability testing and certification of the beamforming portion of the 802.11 standard is very much in its infancy and will be an extremely difficult area to enforce.

Suffice it to say, when beamforming is used between different vendors equipment the performance will most likely fall off considerably and firmware or even hardware changes will be require for interoperability.

(c) System Level MIMO Beamforming Designs

Companies that utilize off the shelf 802.11n chips and add their own hardware and software implementations of beamforming MIMO technologies are known as system level MIMO beamforming designs. Their area of expertise is in the design of enhanced multi antenna systems and beamforming software algorithms that continually create and direct new RF patterns.

Figure 12: 802.11n System Level MIMO Beamforming Architecture[42]



Key enablers for system level MIMO beamforming designs is the ability to create many different patterns using multiple antenna choices, directional antennas, sophisticated software that continuously adjusts and changes patterns, and efficient power amplifiers.

One such vendor‟s implementation is able to get high capacity, performance and range by utilizing directional antennas (6 in 1 of their 5 GHz implementations), beamforming technology and the higher transmit power possible with outboard power amplifiers (250mW). A standard 3x3 MIMO baseband chipset from a traditional 802.11 chip vendor is combined with 3 PA‟s and RF chains to 6 directional antennas. At any point in time an optimized beamforming pattern is sent out over the best 3 antennas using knowledge obtained from the RF channel and the far end wireless adapter. At any point in time hundreds of different antenna patterns are possible that can add gain to the system performance or even reject interference.[43]

As in many of the other creative implementations of the 802.11n standard the system level MIMO beamforming designs are only able to get the improved range and bandwidth performance claimed when their MIMO beamforming units are used at both ends of the video or data stream. Optional software programmable configurations are possible to allow the main access point to communicate with industry standard, off the shelf 802.11n adapters and extenders in laptops and other devices, but the performance will be reduced.

A nice advantage of the system based solution is that it is not optimized for video at the chip level and therefore offers a true bidirectional home networking solution where both video and data services can be transported over the data stream. QoS (802.11 WMM) is implemented so prioritized video and best efforts data transmission share the 300 Mb/s of capacity.

A key challenge for the network operators incorporating higher end implementations of the 802.11n standard in their home networking solutions is the ultimate performance these devices obtain when deployed in a mixed operating mode. The in home network performance may match claims in a perfect end to end single vendor environment but degrade severely when a variety of vendors and chipsets are used in a home network. In addition, because the beamforming implementation at their access point is a unique implementation of MIMO beamforming it may not be compatible with standard 802.11n client device implementations (such as explicit chip level feedback designs).

Optimized Video At 5 Ghz or Proprietary Wireless HDMI technology.

Targeting the large, unused, contiguous spectrum available to Wi-Fi technology in the 802.11n 5 GHz frequencies some vendors have chosen to create a unique specification targeted for video transmission and wireless HDMI applications.

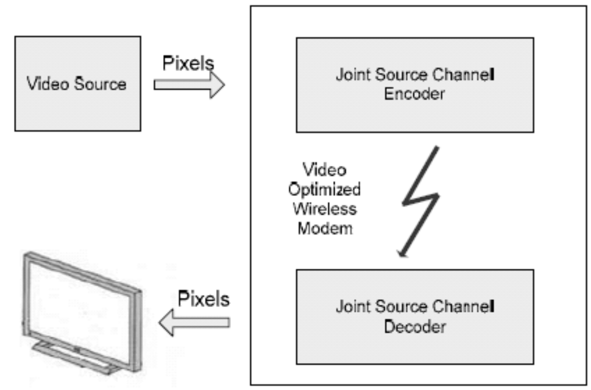
Amimon is one such start-up silicon vendor that has designed a very effective chip design optimized for video transmission at 250 to 800 Mb/s. They have created a consortium of vendors (called WHDI), that includes CE manufacturers, to create a specification and standard for wireless HDMI.[44]

Their technology also takes advantage of the multi antenna gains possible with MIMO technology (4x5 MIMO) and 40 MHz wide channel bandwidths.[25] As a result, large capacity video streams are possible with their implementation.

In addition, they claim their transmission does not use compressed video. Amimon appears to perform some form of compression but at lower compression ratios (< 4X) that allow it to be categorized as lossless compression, or for their definition, uncompressed.

The key to their uncompressed video is their ability to combine real time video processing of the video source with channel coding and modulation function present in traditional wireless transmission systems. The Amimon chip prioritizes the source video components according to their importance and only keeps the most significant bits. By tightly linking an understanding of the varying RF channel with the actual encoding and processing of the video source allows the Amimon reference design shown in Figure 13 to optimize the wireless connection for video applications.[45]

Figure 13: Optimized Video Proprietary Architecture[46]



As in all proprietary designs the key for this technology will be to obtain standards approval for the reference design in the 802.11 study groups and then build an ecosystem of supportive CE vendors.

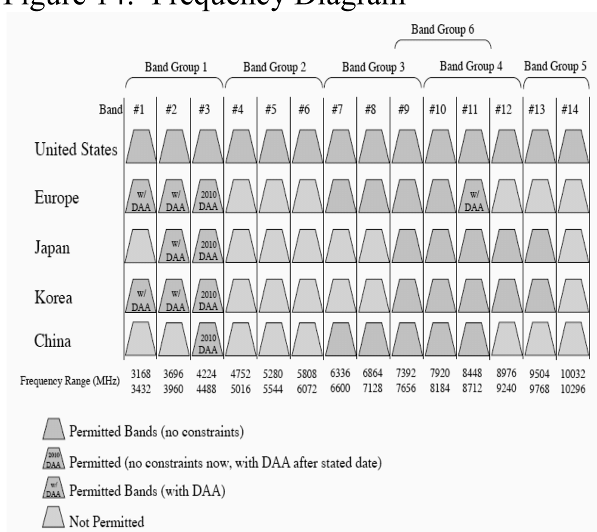
Ultra Wide Band (UWB) Technology (ECMA-368)

Ultra-Wide Band is a radio technology that uses a 528 MHz channel bandwidth (compared to the 20 or 40 MHz channels of 802.11n) within various frequencies from 3.1 to 10.3 GHz. The technology is heavily promoted by the WiMedia™ Alliance and utilizes the well known OFDM technology and is being used to transport compressed video (1080p at 30 fps) within a single room only.

WiMedia UWB can support data rates of up to 480 Mb/s and transmits at very low power levels. The FCC has placed transmit power levels (.1 mW) on these frequencies as a majority of the bands compete with other users operating in these bands. As a result of a .1 mW peak transmit power limit spread across 528 MHz the Power Spectral Density (PSD) is quite low for UWB technologies whch results in operation across very short distances (< 10 meters). Because UWB technology operates across such a wide channel bandwidth it is very resistant to frequency fading. By utilizing 128 OFDM 4 MHz subcarriers across the full 528 MHz wide channel it is able to guarantee quite high quality HD video with its built in frequency diversity.

Additionally, there is over 7 GHz of spectrum available in the various band groups from 3.1 GHz to 10.3 GHz. Only the U.S. has access to the full allocation as Europe is allowed to use only 3.250 GHz of spectrum. Also in many of the bands (e.g.- 3.5 GHz) UWB operation is required to Detect And Avoid (DAA) outside operation from WiMAX, radar operators and others before transmitting in those frequencies.

Figure 14: Frequency Diagram[47]



Although the UWB specification originally started out originally with much promise but has had much difficulty gaining traction in the marketplace and standards bodies over the years. Seven major vendors such as T-Zero, WiQuest, Radiospire, Pulselink, Focus Semiconductor, Artemi and Intel were recently forced to either shut down or merge their UWB operations leaving just two or three vendors left in the WiMedia space.[48] Most remaining vendors appear to begin offering UWB technology over coax as the WiMedia group seems to be retrenching slightly from the pure wireless applications.

One of the biggest disappointments for the UWB technology and the WiMedia Association has been their inability to obtain IEEE 802.15.3a Personal Area Networks (PAN‟s) standards approval as the specification languished for three years. Eventually the committee was disbanded and the WiMedia Association was forced to gain approval from the ECMA international standards organization[49].

It appears that the biggest issue associated with the UWB technology is that the very low power limits imposed by the FCC have limited its applications to in-room compressed HD video. This limited application is being outstripped by in-room uncompressed video at 60 GHz or whole home compressed HD video possible with the many 802.11n technologies and their variants at 5 GHz. At this writing the UWB technology appears to have become a shelved technology that has never lived up to its original hype.

<u>Very High Throughput 60 GHz Technology (Proprietary Wireless HDMI)</u>

The millimeter wave spectrum is very advantageous for the high bandwidth requirements of transporting HD video signals because of the large amount (7 GHz of spectrum between 57 and 64 GHz) of unused spectrum available in the 60 GHz frequencies. This technology certainly comes closest to pure wireless HDMI as full HD quality video at 1080p and 60 fps is possible over a 4 Gb/s stream including the A/V control signaling associated with HDMI. The well known benefits of transporting uncompressed video are therefore its major attraction. Additional benefits of 60 Ghz include the uniformity of this spectrum availability across the U.S., Europe, Japan, China and other major markets. The combination of large spectrum bands and wireless technology advances of MIMO makes multi gigabit rates possible.

Unfortunately, the well known downside of 60 GHz transmission is the short distance limits due to signal strength losses through free space. Although the antennas possible at these high frequencies can be made very small and compact the maximum transmit power requirements for even very short distances are quite large. SiBeam is the major chipset vendor in this area and is the leader in promoting their specification for standardization. They require a 7 Watt power amplifier to transmit one video stream 10 meters in a Non Line Of Site (NLOS) mode or 25 meters with Line Of Site (LOS).[50] Further integrated circuit advancements may reduce the power to 4 Watts and eventually 2 Watts but the large power requirements and resulting high total system costs continue to make this technology very much a niche offering.

The ability to reduce power, costs and obtain standardization will be very important for 60 GHz technology adoption. At this writing the SiBeam specifications are well positioned for being pushed through the 802.11ad Very High Throughput (formally 802.11vht) task group.[51] The WirelessHD™ (WiHD) consortium has also been effective at promoting this specification within the standards bodies. As is sometimes the case, this specification is also being promoted in the IEEE 802.15c working group which is part of the Personal Area Networks (PAN) study groups.

Because this technology and the frequency it operates in will most likely always be an in-room solution only, its applications and uses will most likely are limited and therefore be a primarily a niche technology for home networking solutions.

TEST RESULTS OF VARIOUS WIRELESS HOME NETWORKING SOLUTIONS

Preliminary Findings

Preliminary test results of unmodified 802.11n draft technology, based on a sample of standalone gateway devices that utilize 2.4GHz and Gigabit Ethernet LAN and WAN ports provided an insight into the potential challenges associated with delivering triple play services over today‟s wireless home network solutions.

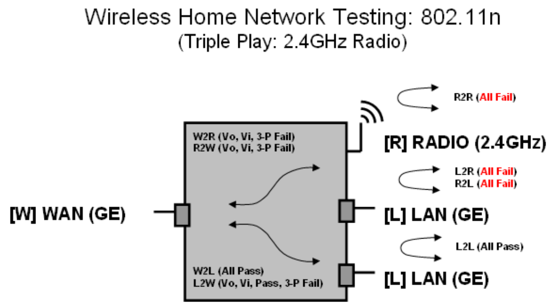
The test configuration included multiple services (Video, Voice and Data) over each wireless home networking device in specific directions as outline in Table 6.

Table 6: Triple Play Test Traffic Direction

Abbreviation	Description
L2L	LAN to LAN
W2L	WAN to LAN
L2W	LAN to WAN
W2R	WAN to Radio
R2W	Radio to WAN
L2R	LAN to Radio
R2L	Radio to LAN
R2R	Radio to Radio

Key findings indicate that when the home wireless devices were loaded with service provider traffic that Gigabit Ethernet ports including LAN to LAN performance and LAN to WAN performance met performance thresholds, where as most test that required use of the Radio (i.e. Radio to Radio and L:AN to Radio did no meet requirements.

Figure 15: 802.11n Wireless Test Flows



More detailed results are summarized in the table below in Table 7, with results in bold indicating they fell outside the threshold requirement.

Table 7: 802.11n Triple Play Performance

802.11n, 2.4GHz			
Service	Data	1-Way 12 Mbps Video	Voice G.711
Throughput (Mbps) Required > 100	L2L: 390.1 W2L: 117.6 **L2W: 41.3** **W2R: 8.9** **R2W: 15.1** **L2R: 8.6** **R2L: 7.5** **R2R: 3.2**	L2L: 11.9 W2L: 11.9 L2W: 11.9 W2R: 11.9 R2W: 11.8 L2R: 11.7 R2L: 11.8 **R2R: 10.9**	Not tested
% Bytes Lost Required: < 0.1	Not tested	L2L: 0.0 W2L: 0.0 L2W: 0.0 **W2R: 0.6** **R2W: 1.0** **L2R: 1.8** **R2L: 1.4** **R2R: 8.5**	L2L: 0.0 W2L: 0.0 L2W: 0.0 **W2R: 0.2** **R2W: 0.4** **L2R: 0.1** **R2L: 0.2** **R2R: 3.0**
Jitter (ms) Required: < 2	Not tested	Not tested	L2L: 0.0 W2L: 0.5 **L2W: 2.3** **W2R: 2.4** **R2W: 4.0** **L2R: 2.8** **R2L: 3.0** **R2R: 8.5**
1-way delay (ms) Required: <120	Not tested	Not tested	L2L: 0.8 W2L: 1.3 L2W: 3.5 W2R: 4.7 R2W: 8.0 L2R: 7.0 R2L: 6.5 R2R: 28.2
MOS Required: > 3.5	Not tested	Not tested	L2L: 4.4 W2L: 4.4 L2W: 4.3 W2R: 4.2 R2W: 4.0 L2R: 4.0 R2L: 4.1 R2R: 4.0
Key Finding	Radio speeds to not support 100 Mbps data product speeds	Radio, esp. Radio to Radio does not support <0.1 bytes lost for video.	Radio, esp. Radio to Radio does not support < 2ms jitter, or < 0.1 bytes lost for voice.

Testing in 5GHz bands indicates some significant improvement over 2.4GHz and as more devices become available in the 5GHz band this will be the subject of additional testing.

Further testing with a wider range of wireless home networking devices during 2009 will be the subject of a future paper.

Future evaluation and testing 802.11n Solutions for Home Networking

The key criteria in evaluating implementations will be:

- Capacity of multi-play capabilities, for example to determine whether the entire channel is dedicated for video transmission or other services are possible on the bandwidth simultaneously.
- Consistent and reliable performance such as voice/video quality (latency, jitter and packet loss) over range and network load.
- Effective throughput and capacity over path loss.
- Receiver sensitivity and spectral efficiency.
- Service specific quality matrix such as video startup and zapping latency.

THE SERVICE PROVIDER SUPPORTED WIRELESS HOME NETWORKING BUSINESS MODEL

What is the cost of adding wireless home networking for the service provider? Are the costs different between the various wireless technologies? We explore the economics across multiple wireless home networking solutions.

Developing the wireless home network "Pain Threshold"

We assume that the average revenue from wireless home networking is $10 per month per subscriber. Of this $10 per month we assume that 80%, or $8 is required for sales and marketing, customer care, billing and G&A per subscriber per month. This leaves $2 per month per subscriber to cover all wireless home network related technology costs.

Considering the technology costs we initially reviewed the incremental costs of wireless home networking technology we considered bit the A-end or Access Point incremental cost to add wireless and the B-end, in the case that a specialized B-end device is needed to complete the link.

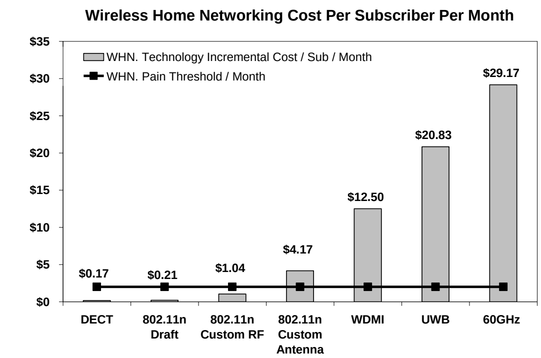
Table 8: CAPEX Cost of Adding Wireless

	Access Point Incremental Cost ($US)	Client Cost ($US)	Total Service Provider Cost
DECT	$4	Any DECT Handset	$4
Wi-Fi 802.11n (Baseline)	$5	Any Wi-Fi	$5
Wi-Fi 802.11n (Celeno) *	$25	Any Wi-Fi	$25
Wi-Fi 802.11n (Ruckus) **	$50	$50	$100
WDMI (Amimon) ***	$150	$150	$300
UWB (Tzero) ***	$250	$250	$500
60GHz (Sibeam) ***	$350	$350	$700

* Note: Celeno are targeting a chip-based solution for embedding in CPE/RG devices so no additional cost is needed for casing, packaging, cabling.
** Note: Ruckus had no plans for a CPE/RG integrated device and would only consider on a business case basis so the cost is based on an add-on access point MediaFlex 7000 at the estimated cost to the Telco rather than the list price.
*** Note: WDMI, UWB, and 60GHz solutions are primarily targeting cable replacement in 1st generation of products so the cost is including casing, packaging, cabling, power for each end of the link.

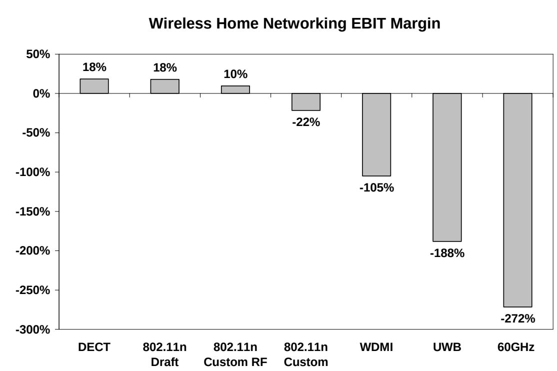
How does the pain threshold described above compare to the cost of the wireless home networking technologies? To make this comparison we assume a 24 month life span for wireless CPE accommodating the shorter life cycle associated with emerging wireless home networking technologies. The resulting cost per sub per month can be compared to the $2 pain threshold in Figure 16 below.

Figure 16: Wireless Home Networking "Pain Threshold" and Technology Costs



The analysis of EBIT margin, highlighted in Figure 17 below, indicates that unmodified 802.11n and 802.11n with minimal customizations do not add substantially to the CPE cost or require a custom or proprietary chip at both ends of the link, support a business case for wireless home networking.

Figure 17: Wireless Home Networking EBIT Margin



This clearly demonstrates the economic advantage of leveraging established device and certification ecosystems; in addition to scale and forwards and backwards compatibility in selecting a suitable wireless home networking solution.

We can summarize that 802.11n, or a variant of 802.11n, that supports a large established ecosystem of devices and also provides robustness for video, in conjunction with DECT for telephony; can potentially provide a wireless home networking foundation that is economically viable for service providers.

CONCLUSION

This paper highlights that there is not a "one-size fits all" approach for wireless home networking in support of service provider applications.

Testing of 802.11n devices against service provider triple play services indicates that it is technically challenging to utilize only a single 20 MHz radio channel for all services and service provider product requirements.

The wireless home networking technologies that are most suited to integration into the service provider CPE are those that (a) have a significant established ecosystem, (b) have volumes that support economies of scale, (c) are low cost, (d) support backwards interoperability, (e) have the flexibility to support multi-regional variations, and (f) are able to operate in well penetrated radio-congested environments.

Preliminary findings indicate that 802.11n, or a variant of 802.11n that is backwards compatible with the standards, for data and video and DECT for voice both have well established ecosystems and compelling economics and are strong candidates for service provider CPE integration.

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