

Introduction and comparison of competing in-home technologies

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Abstract

This paper introduces comprehensive new technologies for home networking comprising *home-plug*, *802.11-family members*, *MIMO*, *Zigbee*, *Wibree* and *Bluetooth*, then compares them from various reasonable aspects in order to analyze their advantages and disadvantages, which is followed by adapting these technologies into next generation services. Finally, a rough RI experiment is carried out to analyse wireless performance under different RI sources environment. According to this paper, people are able to select the most suitable technology to establish home networking with respect to their designing purposes, such as home network, home entertainment, and home automation. This paper is based on a survey of the literature research and the evaluation of comparison would be concentrated on the most significant parameters: such as throughput, range, interference, interoperability, security, applications and companies support.

KEYWORDS: comparison, home-networking, high bandwidth, low bandwidth

1 Introduction

Until recently, the major obstruction to the "next generation networked house" was the convergence of those new technology criteria. For years, more than 10 candidate technologies or technical standard specifications for building home networking have been proposed or even implemented already. Unfortunately, there is still little agreement on which technology is the best since all of them have crucial shortcomings in certain fields and therefore have been unable to dominate the entire market.

[1] Although home networking has been paid continuous attention, it improves so quickly that a number of candidates are already out of date. The objective of this paper is to compare those which have potentially bright future as a whole in detail.

The rest of the article is organized as follows: Firstly, we will take a look at currently the most widely accepted or advanced home-networking technologies which could ensure the readers being familiar with these new terms. Secondly, we analyze and compare them relatively by two groups: high bandwidth group and low bandwidth group. Subsequently, all these technologies are adapted into next generation home network, which comprises the most likely new applications at home in near future. Finally, we draw conclusions for these technologies.

IEEE WLAN Standard	OTA Estimates	MAC SAP Estimates
802.11b	11 Mbps	5 Mbps
802.11g	54 Mbps	25 Mbps
802.11a	54 Mbps	25 Mbps
802.11n	200+ Mbps	100 Mbps

Table 1: Comparison of different 802.11 transfer rates. Source: Intel Labs

2 Introduction of technologies

802.11 (Wi-Fi) [2] 802.11-family consists of a group of specifications developed by IEEE and utilized in wireless local area networks (WLANs). It is also called Wi-Fi and is the most popular wireless technology nowadays. Up to tens of millions of Wi-Fi devices have been sold in 2006, and many more will be bought in 2007. The most popular 802.11 family members presently are those defined as the b, g and a amendments (Table 1). The original 802.11 supports merely a maximum bandwidth of 2Mbps in theory, which is too slow to meet the demands of present applications, thus fades out from the market. However, the subsequent versions expand 802.11 gradually and provide more sprightly throughput performance for today's networking applications. [2] What's more, the forthcoming standard 802.11n is in response to higher requirement for next generation WLANs, its data throughput criteria is supposed to be up to surprisingly more than 200Mbps theoretically.

Home-plug [3] Since most of home electronic devices already use power outlets to receive electric power, the idea of Home-plug networking is to use the same electrical outlets and wires to interconnect the digital devices in a home and Internet as well. Obviously, power line is the most wide-covered network in the world, hence on the top of this, Home-plug network become more convenient than traditional phone network and furthermore we do not need to consider too much about constructing network for home because it is already there. However, because it remains immaturity - susceptible of electrical equipment interferences, the applications of this technology in the market do not work well unless you have a fairly well designed power line network at home.

The first criteria of Home-plug technology - Home-plug 1.0 specification, which was released in 2001, included a 10Mbps data rate, whole-house coverage, robustness and ease of implementation (only a software driver installation is required). However, the same issue here, 10Mbps data rate is far away from enough concerning next generation in-

home network. A new standard of Home-plug called Home-plug AV are built from ground up to meet the needs of high throughput applications, for instance, HDTV and in-home theater. Home-plug AV would provide a very good solution for high quality video distribution, guaranteed secure connection and also built-in QoS. All these features enable Home-plug to be a comparable technology with other home networking alternatives, such as Wi-Fi.

MIMO [4] Multiple-input multiple-output (MIMO) is a concept, which could significantly increase the throughput rate of system where the transmitter and receiver are both equipped with multiple antennas. The most attractive and amazing attribute of MIMO is that it is able to significantly enhance the physical transfer rate and range dramatically but without any increase in bandwidth or transmit power cost. Additionally, MIMO is expected to play a significant role in achieving 802.11n goal.

Bluetooth [5, 6] Bluetooth wireless technology was primarily designed for low power, low cost, low throughput rates and within a short range. Nevertheless by contrast, nowadays, Bluetooth is not on the same track of preliminary purpose. It supports 3Mbps data rate in communication as well as consuming much more power energy than other new low power and low throughput technologies, for example ZigBee. Since Bluetooth is more or less like a medium throughput wireless technology which could be utilized for transmitting large pictures or audio clips, it remains useful and un-substituted. There are more than one billion Bluetooth devices by the end of 2006.

ZigBee In spite of those available wireless standards in market, there are many wireless monitoring and control applications which require lower power consumption, lower data rates and less complexity. The performance and characteristics of Bluetooth do not closely meet these requirements, and then ZigBee occurs.

[7] ZigBee is a new wireless network standard designed for automation and control network. This standard aims to be a low-rate, low-cost and low-power solution for in-house digital devices.

Wibree [8] Wibree is a very new radio technology working side by side with and complement Bluetooth. Quite similar as ZigBee, Wibree is also designed for ultra low power consumption within a very short range. This technology was announced 2006-10-03 by Nokia and the first commercial version of the specification is supposed to be available during the quarter 1 2008.

3 Comparison

Among the various technologies that fall into this category, I suggest to put Home-plug, 802.11 family and MIMO into one group while ZigBee, Wibree and Bluetooth into another when making comparison, according to their throughput distinction (i.e. high bandwidth and low bandwidth).

3.1 High bandwidth

Now, we turn to a comparison of the first three high bandwidth technologies in terms of the desirable features above and Fig. 2 (at the end of the paper).

Throughput: According to the introduction and Table 2 (located at the end of this paper), 802.11b, 802.11g, 802.11a and Home-plug have theoretical throughput limit 11Mbps, 54Mbps, 54Mbps and 10Mbps, respectively. Nevertheless, we will really notice the slowness in practical use suffering from interference, protocol, distance from the base station, encryption algorithm etc. [9] The typical peak throughput of 802.11b connection under ideal conditions is actually 4 - 5Mbps while many 802.11b home network links only run at 2 - 3Mbps. When 802.11b was developed, IEEE created a second extension to the original 802.11 called 802.11a. It supports bandwidth up to 54Mbps and of course has higher cost than 802.11b, which makes it usually found on business networks. Speaking of 802.11g, it attempts to combine the advantages of both 802.11a and 802.11b: lower cost than 802.11a, the same speed as 802.11a as well as coexisting with 802.11b (speed drops rapidly to only 50[10] Unfortunately, we got real world throughput only ranging from 10 to 15Mbps for both 802.11a and 802.11g. As far as Home-plug is concerned, people boost it already supports a maximum data-throughput rate of 14Mbps other than 10Mbps, but this is also a theoretical data. [11] By speed test in real case, Home-plug is slight faster than 802.11b wireless network in the same environment.

Range: At the beginning of this paragraph, two terms: LOS (line of sight) and NLOS (non line of sight) need to be introduced. LOS means the sender and receiver are able to see each other, in other words, there are no obstacles standing between them. Conversely, NLOS means the radio transmission path is partially obstructed. As far as wireless transferring aspect is concerned, the range in LOS is always expanded much more than in NLOS. Both 802.11b and 802.11a use 2.4 GHz unregulated frequency as their radio signaling frequency to lower production costs and stretch the signal range, but in the meanwhile introduces bad interference from other appliances using the same 2.4 GHz frequency. Unlike the previous two, 802.11a supports signals in a regulated frequency spectrum around 5 GHz, but it limits the range and has more difficulty getting through walls or other obstacles. Home-plug is more or less not very suitable here to compare with others because it is wired line. In most situations, it depends on the electrical wire distribution other than range.

Interference & Interoperability: [12] The biggest and most common headache for wireless LAN deployments is Radio Frequency Interference (RF interference). Firstly, we go review quickly the basic concept of protocol used in 802.11 technologies: the wireless station tends to only transmit packets when there is no other station transmitting around at the same time. Thus, if another station exists, this one will wait until the medium is free. For 802.11b and 802.11g - 2.4 GHz wireless LANs, there are several potential sources of IR interference, such as cell phones, microwave ovens, Bluetooth appliances and so on. Some of them could be moved away from wireless domain, but quite a few are most likely inevitable in certain environment, including using 2.4 GHz mobile phones, Bluetooth enable computers and PDAs at home or in the office. According to interference issues above, 802.11b and 802.11g both have a bad performance while Bluetooth devices operating simultaneously nearby; the worse case is even a failure of wireless connection could

happen. However, RI interference problem is much easier to correct concerning 802.11a because it utilizes a regulated and less conflicting channel - 5 GHz spectrum and [13]enjoys the luxury of 12 independent, non-overlapping channels. one point we have to mention before moving to next technology is that 5 GHz spectrum is not available everywhere and neither does the channels, some contries do not have the whole 12 overlapping channels, which actually indicates the limitation of 802.11a. Then, we go on to Home-plug: Home-plug alliance declares that their technology has already overcome the challenge of using power outlets to connect devices in the home included a lack of industry specifications and multiple sources of electric noise, it will not cause interference with other techniques as well. Unfortunately, from the result of my investigation in internet, it is not as perfect as they announced: [12]For example "when the adapters shared a plug with a power strip connected to a host of peripherals, including a computer, a vacuum cleaner, a scanner, a printer, and powered speakers, it took each adapter nearly one minute longer to copy the test file". [14]In Taiwan, people also agree the impairment do exist from other electronic devices in the same circuit, including fridge, air-condition, microwave oven and so on. What is more, the unstable voltage is another problem lies in front, which occurs especially in developing countries.

Security: wireless network needs an extra level of security guarantee compare to conventional wired one, because wireless radio signals are transmitted and propagated through the air and therefore theoretically much easier for intruders to eavesdrop and intercept. [15]802.11i, also known as WPA2 and ratified on 24 June 2004, is an advanced security mechanism standard for wireless network. It makes use of Advanced Encryption Standard (AES) block cipher to replace the previous used Wired Equivalent Privacy (WEP), which was already found out to have severe security weaknesses. [3] For Home-plug, most of Home-plug 1.0 devices use 56-bit DES for security issue. Although, DES is a less secure level than most other advanced 128-bit encryption standard, but it is still considered solid enough to defend most determined hackers and snoopers since it is a wired network. Additionally, the forthcoming Home-plug AV for next generation home network will enhance the security feature by employing AES.

Products and companies support: [17, 3]undoubtedly, Wi-Fi technology has overwhelming advantages over Home-plug both on manufactured products on the commercial market (3362 versus around 100) and supported companies (more than 250 versus around 100) at present.

Supporting older hardware: building home wireless network, at least we need to purchase a wireless supporting router and the devices must have wireless adapter to receiver signals from this router. Fortunately, most sorts of laptops now have built-in wireless adapters. If not, wireless USB adapter is conveniently obtained in the market as well. For Home-plug, [3]people have conducted a field test in over 500 homes in North America; the result is very good regardless of a home's age or size. The field tests also confirmed nearly 100 percent coverage in every home tested. Nevertheless, this is far from enough, I still strongly suggest a thorough test over more developing countries before they make the

conclusion.

Other issues: Obviously, the price would unduly influence our buying decision on condition that all these technology based products are suitable for home. From the investigation in internet, the total cost of a wireless network for typical families is lower than Home-plug, let alone we could select various version from 802.11b, 802.11g and 802.11a in terms of different throughput and range requirements. However, if your house is not well suited to wireless network (e.g. you have a four-floor house and the radio signals block in floors) or you do not have too many digital networked devices, Home-plug appliance is surely a good option. Another issue here is your networking may need well increase as new appliances arrive in further, so the supported maximum simultaneous users have to be taken into consideration as well. Home-plug has only a recommended number of 16 while Wi-Fi supports many more, for instance some of the 802.11g products support 128 simultaneous users associated in theory. Aside, Wi-Fi and Home-plug have their own upcoming versions for next generation home networking: 802.11n and Home-plug AV respectively, both of which promise a 200Mbps bandwidth theoretically.

3.2 Low bandwidth

Subsequently, another three technologies are compared with respect to the significant features of low bandwidth techniques in Table 2.

Nowadays, a number of prevalent Bluetooth applications already widely exist in the market, they provide a method to connect and exchange information among devices such as cell phone, PC, PDA and printer. The newest Bluetooth version even supports up to 3Mbps data rate making it well-suited for large streaming and file transfer. Whereas, ZigBee and Wibree are designed for applications where low power consumption, small size and low cost are strictly required. *Price:* Speaking of shortcomings of Wibree, the biggest one is that it is still underway. The first commercial specification is supposed to be available in Q1 2008 and also most likely when the first Wibree chips hit the market they would be quite likely more expensive than Bluetooth (above 5\$). The users have to wait a substantial amount of time even if they will inherently lower cost approaching the price of ZigBee (under 3\$) when they are mature.

Range: [17] it is clear that ZigBee is able to operate over a larger range than other two technologies when all without any special amplifier equipment. However, range is not really significant to Wibree, which is more oriented to small, low power products, which do not require a long distance, such as mobile phones, watches, as well as mouse and keyboards.

Throughput: where low data rates are emphasized in ZigBee and Wibree, Bluetooth obviously has the advantage and can support greater range of traffic types, for example audio and large image file.

Power consumption: [18]ZigBee and Wibree are designed specifically to consume fairly low power energy and have years of battery life. Bluetooth devices have only days of life and need frequent battery change because they must be always "on" to detect available networks for them to join in.

Security: all of the three protocols have security built in - 128bit AES.

Co-existing with Bluetooth: [19]Wibree has two implementation alternatives: "stand-alone implementation" and "dual-mode implementation". Dual-mode implementation is designed for use in Bluetooth devices, which means Wibree functionality is integrated with Bluetooth, and thus this type of implementation is able to communicate with prevalent Bluetooth devices. This is a significant advantage of Wibree over ZigBee because Wibree is sprightly able to use the widely existing hardware supported by Bluetooth while ZigBee has to re-invent a total new hardware.

Operating frequency: all of the three: Bluetooth, ZigBee and Wibree are using unregulated 2.4 GHz frequency band. Therefore, finding a solution to overcome the interference issues and coexist harmlessly with other technologies, such as Wi-Fi, is also an inevitable prerequisite.

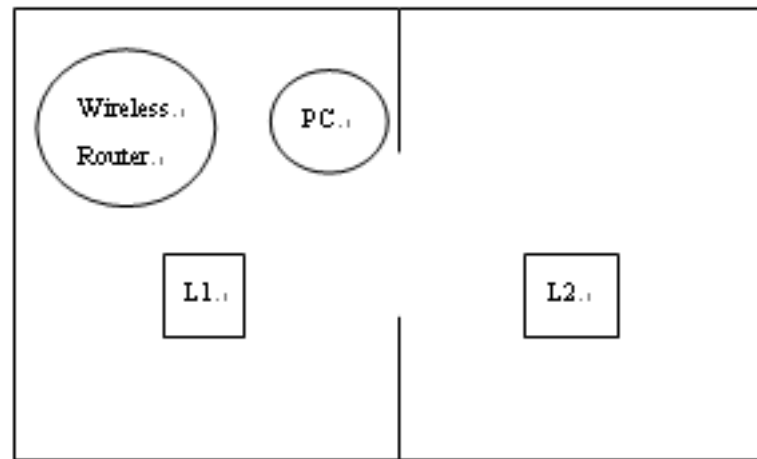


Figure 1: Experiment locations display

4 Implementation

Besides the already existing applications, Next generation home network is supposed to include several totally new services, such as IPTV, VoIP, as well as home monitoring. In table 3(locating at the end of this paper), these high and low bandwidth technologies are adapted to specific most suitable home networking services [3] according to their different prior purposes and features.

5 Experiments

As we all see, quite a few kinds of technologies are workable in 2.4GHz frequency, consisting of 802.11b, 802.11g, Bluetooth, Zigbee, as well as the forthcoming Wibree. Additionally, it is also quite likely other inference sources would occur in such a home or office environment, for example, micro-oven, wireless optical mouse, cordless phone and so on. The hottest point nowadays is how to handle all these working as efficiently as they could while affecting least interference with one another. Therefore, I did the subsequent experiment to roughly and simply demonstrate actually how bad or how little the interferences would be from different sources.

Test environment

- as in fig.1, two rooms are next to each other, a wall obstruction separates the two rooms and with only a small door accessing from one room to another.
- The wireless Wi-Fi router (LINKSYS wireless G 2.4, with 802.11b backward supporting turned off) and a PC with wireless adapter, which plays as receiver here, in a same room with distance of 4 meters.
- A file with the size of 2 Gigabytes is transmitted from a LAN server to this test PC.
- Location 1 and 2 are used to locate the interference resource
- Interference resources: micro oven, Bluetooth, another working wireless router and 2.4GHz Wireless Optical Mouse, respectively.

The result of this RI experiment is showed in Table 4 (locating at the end of this paper).From the result, another simultaneous working Wireless access point nearby could significantly deduce the testing WLAN throughput and micro oven, which is followed after, also caused a fairly bad degradation. The other two RI sources, Bluetooth device and wireless mouse, had a much less impact on the data throughput.

In conclusion, interference sources are able to impact or even impact dramatically the performance of typical WLAN data traffic. Searching for the way to deduce the impaction from other 2.4GHz RI sources is obviously noteworthy.

6 Conclusion

In this paper an extensive comparison was done to analyze advantages and disadvantages of home networking technologies. The results show that Wi-Fi technology remains dominating the high bandwidth home network market and owning comprehensive companies" supports while Home-plug is running after, in some situations even could be a better alternative for shuttling home network, but the interference of nearby electric equipments and impairment from unsteadiness of voltage remains greatest obstacles for spread of this technology; as far as low bandwidth technologies are concerned, Bluetooth has the trend to transmit larger files than its original aim, instead ZigBee and Wibree would occupy low power-consumption, short range wireless applications.

Since this paper only includes a rough practical experiment of RI , the intended future work will be to carry thoroughly much more precise experiments from different aspects and utilise professional tools to test performances and interferences from each other and conclude workable hybrid network architectures.

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Characteristic	ZigBee	Wibree	Bluetooth
Price	Under 3 \$	N/A	More than 5 \$
First specification time	2004	1994	(supposed)2008
Rang	10-75meters	10meters	10meters
Throughput	20-250kbps	Less than 1 Mbps	Maximum 3 Mbps
Network latency	15 Millisecond	Not clearly mentioned	3 Second
Power consumption	1Years	Years	Days
Security	128bit AES	128bit AES	64 or 128bit
Co-existing with Bluetooth	No	Yes	N/A
Frequency	2.4GHz	2.4GHz	2.4GHz

Table 2: Low bandwidth technologies comparison

Services	Wi-Fi	Home-Plug	Bluetooth	Zigbee	Wibree
IPTV	Yes	Yes			
Online theatre	Yes	Yes			
VoIP	Yes	Yes			
Online Game	Yes	Yes			
P2P	Yes	Yes			
Pic/audio/vedio sharing			Yes	Only for small	Only for small
Smoking detector			No	Yes	No
Lighting/heating control			No	Yes	No
Security sensor/monitoring			No	Yes	No
Input device			Not suitable	Yes	Yes
Digital toys			Not suitable	Yes	Yes

Table 3: New technologies implementation

Interference	Location 1 test	% of baseline	Location 2 test	% of baseline
Without IF	10.7			
Micro oven	3.8	35.5%	5.5	51.4%
Bluetooth	8.4	78.5%	9.4	87.9%
Wireless router	1.7	15.9%	2.8	26.2%
wireless mouse	8.4	78.5%	9.5	88.8%

Table 4: Result of IF experiment

Characteristic	802.11b	802.11a	802.11g	Home-plug	MIMO
Practical throughput	2 – 5Mbps	10 – 15Mbps	10 – 15Mbps	3-6Mbps	
Range (NLOS/LOS)	35/100meters	25/75meters	35/100meters	150m(in the same circuit)	
Interference	A lot	A few	A lot	A lot	
security	128-bit AES encryption			56-bitDES encryption	
Products & Companies	3362 & more than 250			About 100 & About 100	
Supporting older hardware	Support Ethernet wired networking, but receivers need wireless adapters			Not as good as claimed	Only MIMO Receivers
[18]rough Price	50\$/router	130\$/router	70\$/router	50-90\$/adapter	
Installation & Maintenance	Easy			Easy	
Simultaneous users	Supporting more users, especially 802.11a			Fewer (16 is recommended)	

Figure 2: High bandwidth technologies comparison