Comparative Performance Analysis of Recent Powerline and Wireless Technologies for Multimedia Home Networking

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***Abstract*—This paper provides a comprehensive performance analysis of recent wireless and powerline technologies for home and small office environments. The recently developed 200Mpbs Powerline modems (HomePlug AV, UPA-DHS and HD-PLC) and IEEE 802.11g and 802.11n wireless technologies are compared and evaluated in a 2200 square feet home in Florida, USA. The paper presents a brief discussion of the respective PLC and wireless technologies and then gives the results of comprehensive experimental measurements and testing of these technologies with the UDP and TCP protocols as well as with High Definition TV streaming media at 25 Mbps.**

***Keywords*—Home networks, Power Line Communication, IEEE 802.11, Home Plug AV, Multimedia, Streaming Media, Quality of Service.**

I. INTRODUCTION

A major driving force for the development of advanced high speed in home networks is the need to support the ongoing deployment of high definition digital television at rates of about 25 Mbps. HDTV signals may originate at one point in the home from a media center player or via satellite or cable TV. It will then be the necessary to transport the HDTV signal throughout the home for playing the video and audio at multiple locations or for remote recording. Streaming HDTV places very stringent Quality of Service (QoS) requirements on the underlying home networking technology in terms of delays, jitter and packet loss probabilities. Many home-networking technologies have been competing for preeminence as the multimedia home networking technology of choice.

HDTV is usually encoded in about 25Mbps, and so to stream one or more HDTV signal requires networks with sustained data rates of more than 30Mbps at the application layer. While traditional Ethernet networks with appropriate QoS enabled switches may be one desirable choice for this purpose as it is a mature technology that supports very high bit rates, this may not be viable solution for deployment in existing buildings due to the inconvenience in laying the Ethernet cables around the house with the associated drilling through dry walls or even concrete walls. Thus wireless and the so-called ‘no new wires’ solutions become the top contenders for retrofitting a home network in existing buildings

For some time there has been strong interest in the 802.11x wireless LAN technologies as key candidates for home networking as these wireless technologies provide the ultimate convenience and mobility to users. The widely used 802.11b is now considered to be less desirable for streaming HDTV because of its low data rate. However, the IEEE 802.11g [1] provides raw data rates up to 54Mbps which may provide enough application level bandwidth to support streaming HDTV. The IEEE Draft 802.11n standard [2] has also been proposed for higher throughput and QoS enhancements. It is expected to provide raw data rates up to 600Mbps and interoperability with IEEE 802.11a/b/g.

In the class of ‘no new wires’ networks, Power Line Communication (PLC), MoCA and HomePNA re-use existing wires for communication and claim multimedia in home streaming capabilities for one or more channels of HDTV. MoCA uses coaxial TV cable for communication and provides raw data rate as high as 270Mbps, however the lack of available access points limits its applications. The HomePNA has similar drawback as the number of telephone jacks in a home are limited and are usually in a very inconvenient locations for installing HDTV players or recorders or the similar devices.

Power Line Communication (PLC) uses the existing in home power circuit to deliver digital data and is considered to be a potentially desirable candidate for home networks as there are plenty of outlets in a home and they are in convenient locations. In PLC, there are several competing groups – The Home Plug Power Line Alliance and The Universal Power line Association (UPA) as well as Consumer Electronics Power line Communication Alliance (CEPCA). The Home plug AV[3] standard is the most recent enhancement of the 14 Mbps HomePlug 1.0 standard released by the Home Plug Power line alliance and it provides 200Mbps raw data rate explicitly targeted to support distributing data and high quality, multistream videos like HDTV and SDTV. UPA [4] proposed the Digital Home Specification (DHS) with the chip-sets designed by DS2, Spain. It provides 200 Mbps data rate for AV streaming while the HD-PLC (High Definition power line communication) [5] by Panasonic, is able to support raw data rate up to 190 Mbps.

The main contribution of this paper is to analyse and conduct a real world performance assessment of the above recent wireless and PLC network technology for home and small office environments. The rest of the paper is organized as follows: Section II gives a brief overview of PHY and MAC schemes used in each technology. Section III describes the experimental setup and presents the results of the comprehensive field tests. Section IV shows experimental result of HDTV streaming. Conclusions are given in Section V.

II. PHY AND MAC SCHEME COMPARISONS

This section gives a brief overview of PHY and MAC schemes used in the wireless and power line communication technologies considered in the rest of the paper.

A *IEEE 802.11x Wireless LAN*

There are two accessing methods in IEEE 802.11x technology, one is DCF (Distributed Coordination Function) and the other is PCF (Point Coordination Function). The infrastructure network works with DCF and PCF while ad hoc network uses DCF.

The principal approach of DCF is Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). The basic DCF Access scheme is shown in Figure 1.

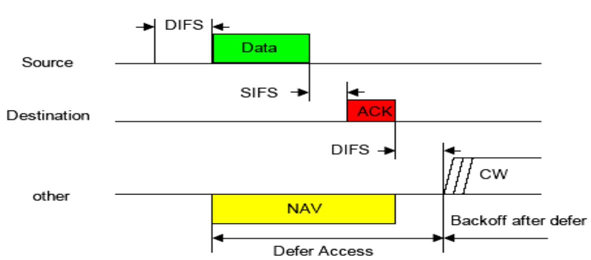

Figure 1 - DCF access scheme

To avoid collision, physical carrier sense and virtual carrier sense are used and the physical layer uses these techniques to sense whether the medium is busy or idle. Whenever a machine decides to send a frame, a duration is specified in the duration field of the frame to indicate the ending time of the transmission. Other machines that receive the message update their local NAV (Network Allocation Vector) thus avoiding the possible collision resulting from more than one node sending frames at the same time.

The IEEE 802.11g is operated at 2.4GHz band using Orthogonal Frequency Division Multiplexing (OFDM). The use of the same frequency band makes 802.11g interoperability with IEEE 802.11b while providing a compatible data rate with IEEE 802.11a which uses 5 GHz band. The default minimum contention window size in IEEE 802.11b is 31 slots and the slot time is 20µs. IEEE802.11g for compatibility, uses the same parameters. However, when no IEEE 802.11b stations are present in the network, IEEE 802.11g will use 15 slots as the minimum window size and 9 µs for slot time to provide lower protocol overhead and higher throughput.

The IEEE802.11n uses OFDM-MIMO (Multi Input Multi Output) technology and supports not only 20 MHz channel like IEEE 802.11a/b/g standards but also 40 MHz channels in physical layer. The performance at MAC layer of IEEE 802.11n is enhanced by aggregating several frames into one transmission frame. The frame aggregation can decrease the transmission time of preamble and frame header under ideal channel conditions. However, the corruption of aggregation frame will reduce the MAC efficiency as the long channel time is wasted.

B *Power Line Communication*

The Home plug AV operates in the 2-28MHz band and it uses windowed OFDM and Turbo Convolution Code (TCC) in the physical layer. The MAC layer uses a mix of TDMA and CSMA and supports QoS (Quality of Service). There is a Central Coordinator (CCo) in each of the PLC networks. The CCo broadcasts a periodical beacon frame with information of TDMA and CSMA allocations at the beginning of each beacon period. This beacon period is synchronized with the AC line cycle. Figure 2 shows the Home Plug AV's beacon period structure.

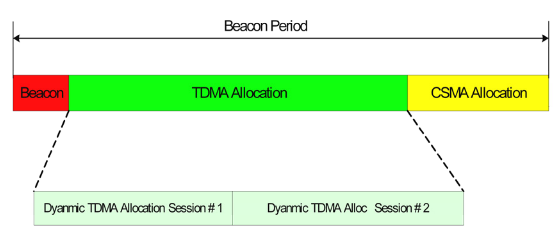

Figure 2 - Beacon period structure of Home Plug AV

The TDMA allocation is for applications that demand QoS while the CSMA allocation is used by applications that do not have strict QoS requirements. The allocations of TDMA slots in Home Plug AV is dynamic. The CSMA access scheme in Home plug AV is the same as Home Plug 1.0[6], which is a modified CSMA/CA protocol with priority that allows Home Plug 1.0 stations to communicate with each other without any centralized coordination. The space between the last frame and the incoming frame is called CIFS (Contention Window Inter-Frame Spacing) while the space between the last frame and the response is RIFS (Response Inter-Frame Spacing). Home Plug 1.0 provides four priority classes - CA3, CA2, CA1 and CA0. The Priority Resolution Period (PRP) in front of contention window allows higher priority packets to enter the contention window while blocking low priority packets. For the lower two priority (CA1 and CA0) classes, the back off window size is 8-16-32-64 slots, otherwise back off window size is 8-16-16-32 slots for the two higher priority (CA2 and CA3) classes. This Homeplug 1.0 MAC scheme is shown in Figure 3.

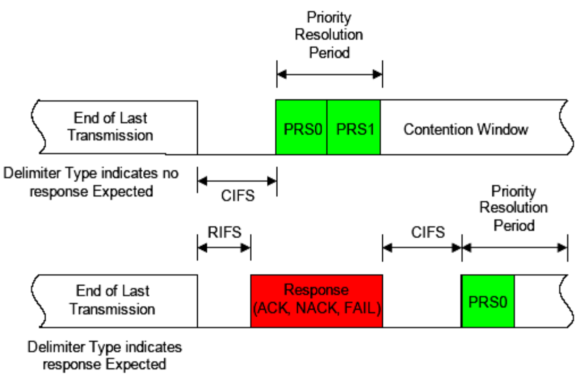

Figure 3 - Home Plug 1.0 MAC Scheme

The UPA DHS (Digital Home Specification) uses OFDM modulation technique and is operating in the frequency band of 2-30MHz. The MAC scheme of UPA DHS is based on TDMA and adopts a token to assign the access right to the nodes. Only one node has the right to transmit at any moment, however, the possibility of duplicate tokens and token loss is not avoidable. The UPA DHS uses a master-slave system where the slave does not have the right to send any packets unless it is granted this right by the master node. This sequence is repeated for the rest of the transmission period.

The HD-PLC (High Definition power line communication) uses Wavelet-OFDM modulation technology and operates at 4-30MHz frequency band. The MAC layer of HD-PLC uses both TDMA and CSMA.

III. Experimental Setup and Results

A. Experimental setup

The experiment was conducted in a 2200 square feet house in Gainesville, Florida. The objective of this test was to determine the performance of recent PLC and wireless technologies in a real world environment. The interior walls of this house are made of wood and drywall. This can give a significant advantage for wireless technology's performance comparing to the same setup in a bricked or concrete wall environment. Figure 4 shows the floor plan and the testing locations of this house.

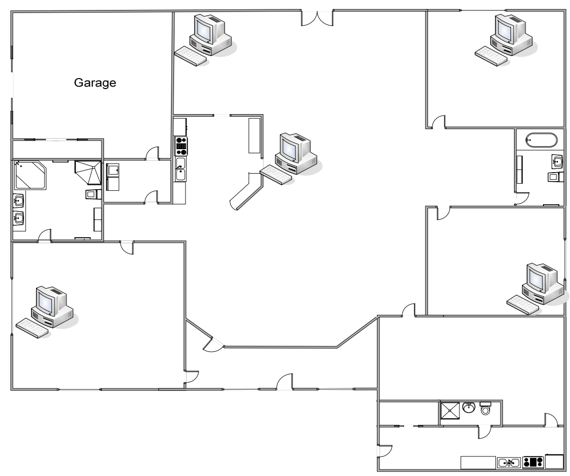

Figure 4 - Test floor plan

In this experiment, we used one desktop computer as a receiver and one laptop computer as a transmitter. The desktop computer had a 3.0GHz Pentium IV processor with 512 MB Ram and windows XP professional SP2. The laptop was equipped with a 1.87GHz Pentium IV processor, 512MB RAM and running on top of windows XP professional SP2.

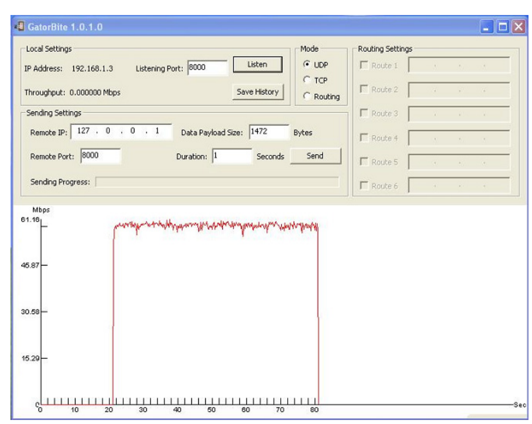

Figure 5 - Snapshot of Gatorbytes

The software used for this test was Gatorbytes, a network throughput measurement software developed by the University of Florida and Charleston Southern University [7]. This program is able to provide real time data visualization that shows the network status in real time. A snapshot of the Gatorbyte output screen is shown in Figure 5.

Both TCP and UDP protocols are used in this test to evaluate the performance of IEEE 802.11g/n and PLC technology. The TCP tests used 64240 byte segments while 1472 bytes packets were sent in the UDP tests. Each test lasts for 60 seconds. This test gives us an idea of the optimal throughput of each technology. The setup for the PLC tests are depicted in Figure 6, while the PLC adaptors used in the test are described in Table 1.

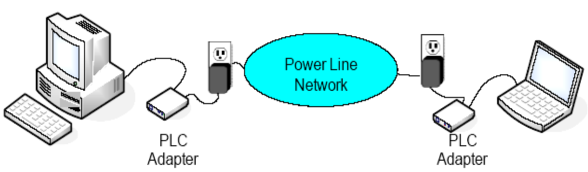

Figure 6 - PLC test configuration.

Table1. PLC Adaptors

Model	Maker	Chipset	Technology
RD 6300	Intellon	Intellon	Home Plug AV
HDX101	Netgear	DS-2	UPA-DHS
BL-PA100	Panasonic	Panasonic	HD-PLC

HDX101 and BL-PA100 power line adapter used were the over the shelf products while RD-6300 Homeplug AV power line adaptor is a reference design provided by Intellon corporation.

An Ad-Hoc configuration was used in the wireless network experiments. The configuration is shown in Figure 7. The equipment used in the wireless experiments was Linksys, WUSB300N. Both of the receiver's and transmitter's antenna were placed randomly and the manufacturer's default settings were used.

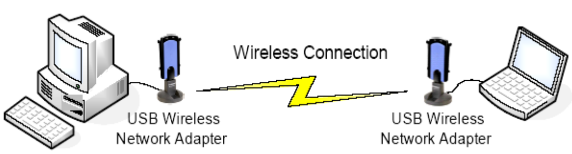

Figure7 - IEEE 802.11g/n test configuration

B. TCP and UDP protocol Test Result

The experiments were conducted in 18 paths with TCP and UDP protocols. All PLC and IEEE 802.11g/n technologies have full whole house coverage in this test meaning that there was some connection along every path tested. The Netgear's PLC adapter, HDX101 we used had the amateur radio tones turned on while the other PLC adapters did not use the amateur radio bands. In the results presented, the HDX101 data rates are reduced by 20 % to correct for the amateur radio bands.

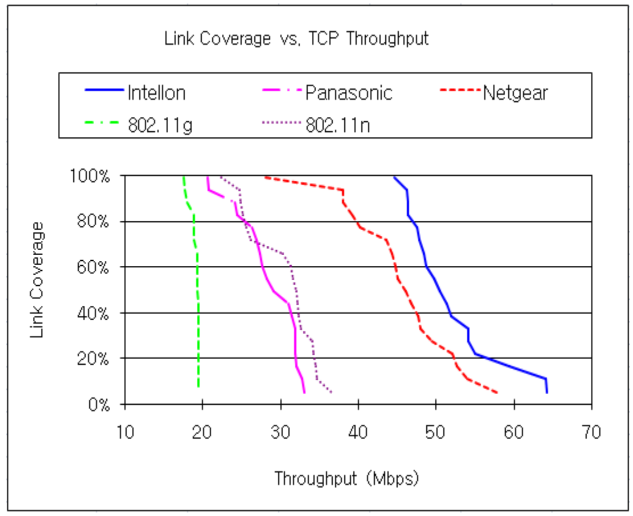

Figure 8 - Link coverage versus TCP throughput

Figure 8 shows the percentage of links that exceed the TCP throughput value noted at the X-axis. The experiment shows that Intellon's PLC adapter RD 6300 has the highest Maximum TCP performance. Figure 8 shows that around 77% of connections operated at more than 47 Mbps. For the Netgear's PLC adaptor, HDX101, 77% of the connections operated above 40 Mbps. For IEEE 802.11n ad hoc mode and Panasonic's PLC adapter BL-PA100, 77% of connection operated above 25 and 26 Mbps respectively. IEEE 802.11g ad hoc mode has lower TCP performance compared with other products but gave the most stable output for wireless TCP performance.

Figure 9 shows the percentage of links that exceed the UDP throughput value indicated on the x-axis. The Intellon's PLC adapter RD 6300 has the highest maximum and minimum UDP throughput. The minimum throughput of RD 6300 observed in the experiment was 57.65 Mbps and 77% of connections operated above 64 Mbps. Notably, this product had highest UDP throughput at all paths. For Netgear's PLC adaptor, HDX101, 77% of connections operated above 36 Mbps for UDP. But our experiment revealed this product is vulnerable to be affected by interference.

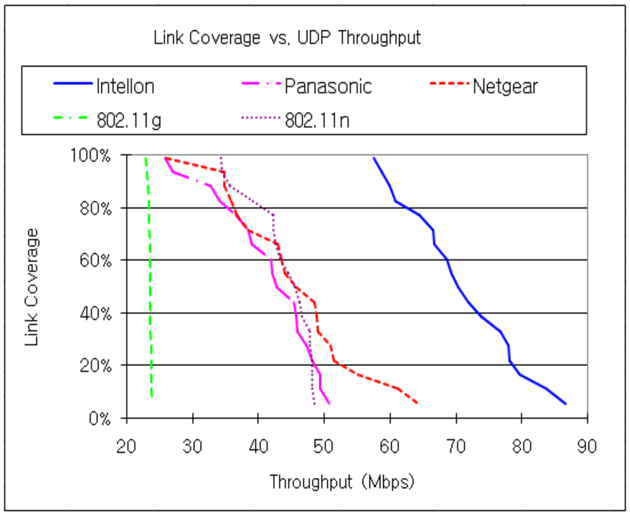

Figure 9 - Link coverage versus UDP throughput

As shown in Figure 9 the minimum throughput of HDX101 is 25.99 Mbps which is an extremely low value compared with its maximum throughput. For the Panasonic PLC adapter BL-PA100 and IEEE 802.11n in ad hoc mode, 77% of connections operated above 36 and 42Mbps respectively. This experiment shows Maximum UDP throughput of BL-PA100 is higher than that of IEEE 802.11n ad hoc mode but IEEE 802.11n has higher minimum throughput than that of Panasonic's PLC adaptor BL-PA100. IEEE802.11g ad hoc mode has lowest throughput as we know but again gave the most stable throughput. The deviation of maximum and minimum UDP throughput is just 1.07 Mbps. In this experiment the IEEE802.11g/n standards were operated as ad hoc mode. We can expect that the throughput would be reduced to below half of our test values for IEEE 802.11g/n operating in infrastructure mode which is normally used in home and small area networks.

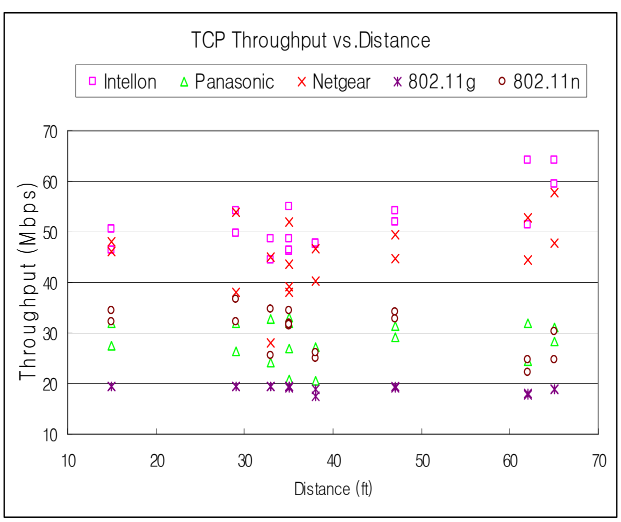

Figure 10 - TCP throughput versus distance of direct path

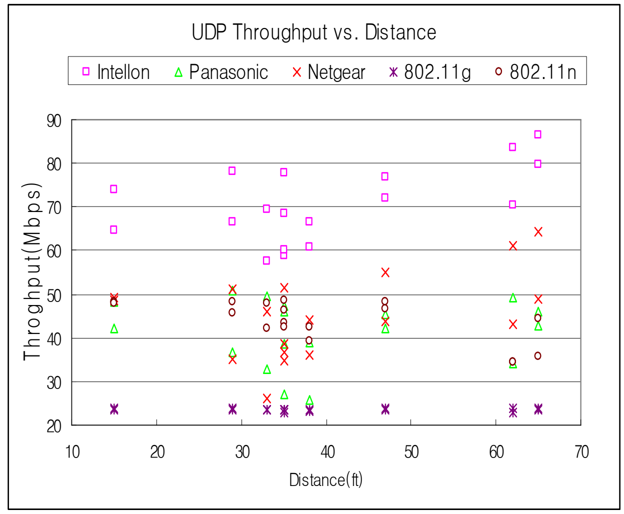

Figure 11 - UDP throughput versus distance of direct path

The scatter plot of the TCP and UDP throughput as a function of distance is shown in Figures10 and 11. Normally wireless communication has direct relation between distance and performance. But in this experiment we could not find any direct relationship between distance and throughput. Especially IEEE 802.11g has almost the same performance irrespective of path distance. The performances of PLC systems have no correlation with the line of sight distance measure in this experiment. This is because PLC signals are transmitted through the convoluted power network cables which reach the destination.

IV. HDTV STREAMING TEST

To assess the feasibility of the distribution of a single HDTV stream in the home, a 25Mbps HDTV stream was transmitted and received using each of the technologies studied. In this experiment we made a connection between the laptop and the desktop computer using PLC and IEEE 802.11g/n technologies and the HDTV stream was played over the power line and wireless network using the PowerDVD multimedia player. A momentary video freeze phenomenon during playback occurred if the overall bit rate of the videofile was close to or exceeded the capacity the path for the selected technology. We conducted this evaluation on 5 paths in the same house. Table 3 shows the quality evolution for HDTV streaming. We evaluated the quality of video streaming in 4 categories-"Great", "Good", "Not good" and "Bad". Table 2 shows the classifications used.

In the experiment with MPEG-2 file with a bit rate of 25Mbps, we observed a serious video freeze and go (halting) phenomenon with IEEE 802.11g and n technology.

Table 2. Classification of video streaming

Classification	Playback condition
Great	Video streaming is smooth and no packet drop is observed. Or it is hard to realize the packet drop
Good	video streaming has slight discontinuity or delay
Not good	Video streaming has evident discontinuity or delay but a term of delay is not significant
Bad	Video streaming has serious discontinuity and delay so quality of video is not tolerable.

Table 3.Quality of 25Mbps, HD video streaming

Product	Path 1	Path2	Path3	Path4	Path5
Intellon RD6300	Good	Great	Not Good	Not Good	Good
Netgear HDX101	Not Good	Great	Not Good	Good	Not Good
Panasonic BL-PA100	Bad	Not Good	Bad	Bad	Bad
Linksys 802.11G	Bad	Bad	Bad	Bad	Bad
Linksys 802.11N	Bad	Bad	Bad	Bad	Bad

The delay of IEEE 802.11g is more serious than that of IEEE802.11n. Panasonic's BL-PA100 PLC adaptor also shows bad video quality. Intellon's RD6300 and Netgear's HDX101 PLC adaptor shows better performance than other technologies as we expected. But these could not support a 25 Mbps HD video signal successfully at all paths. (Note: the Netgear HDX101 adapters had the amateur bands turned on for these tests)

V. CONCLUSION

This study presents a comprehensive evaluation of the performance of recent wireless and PLC technologies for home and small office environments. The throughput of IEEE 802.11 g/n and High speed PLC technologies in a real world environment was measured. The experiments were conducted along 18 paths with TCP and UDP protocols in 2200 square feet house. HDTV streaming was also evaluated over five paths. All power line and wireless technologies tested in our experiment provide full connectivity with each other.

Our overall experimental results shows PLC adapter from Intellon outperforms other PLC products and the IEEE802.11n/g for UDP and TCP throughput and HDTV streaming performance.

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