HomePlug Technology Field Test Results

A White Paper

The explosive growth of Internet and availability of affordable broadband access have created an increasing demand for Home Networking. With multiple outlets in every room, residential powerlines are already the most pervasive network in the home. Using this existing infrastructure to provide high-speed networking capabilities offers several benefits. First of all, there is no need for expensive rewiring of the house. Secondly, almost all devices that need to be networked are already connected to the AC wiring. Thus, home networking becomes as simple as plugging the device in the AC outlet.

Power lines were originally devised for distribution of power using 50-60 Hz Alternating Current. The use of this medium for high-speed communications provides some technically challenging problems. Electrical noise from appliances and the uncontrolled nature of the wiring result in signal distortions that need to be overcome. Several attempts to use power lines for communication have been made in the past and failed to meet consumer expectations. This was in part due to the lack of affordable processing techniques that are needed to overcome the harsh powerline environment. Recent years have seen tremendous advances in the ASIC density and speeds, which allow the use of sophisticated signal processing techniques at price points that have made powerline home networking a reality.

The HomePlug® Powerline Alliance, a non-profit industry association, was formed in March of 2000 by a group of industry leading companies to enable standards based powerline networking products. The first industry standard was released in June 2001.

The uncontrolled nature of the powerline wiring still left questions on how well the HomePlug technology would work in house based on the following:

- Geographic location
- Age of the house
- Size of the house

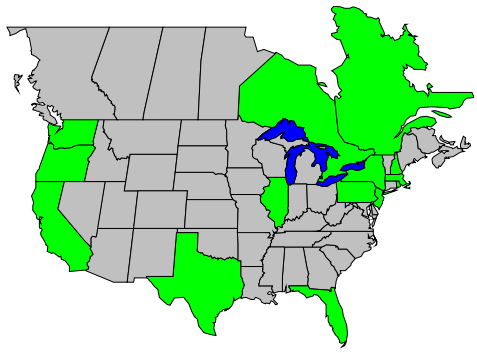
The only sure way to determine how well HomePlug technology works is by performing extensive field testing. The HomePlug powerline alliance recognized the need for such extensive testing and initiated a field test effort. Field testing was performed in more than 500 houses located in a variety of geographical areas in the US and Canada. Performance results were collected from more than 7,000 electric paths in these houses.

HomePlug field tests included two-node and five-node tests. The two-node test provides information on the performance of a powerline link between two outlets. These results can be extrapolated to understand the coverage and throughputs that can be expected by the HomePlug technology. The five-node test provides information on the performance when five nodes are simultaneously transmitting. In this paper, we present brief summary of the field test results for HomePlug powerline technology.

Two-Node Field Tests

Two-node field tests were conducted in 472 North American homes and a total of 6,690 wire paths. Fifteen companies participated in the testing, with results being gathered in a variety of geographical areas in the lower 48 states of the US and in Canada. The map in Figure 1 shows the states and provinces where testing was conducted. Table 1 summarizes the companies participating in the North American test.

Figure 1. States and Provinces where two-node testing was conducted



Two-node field tests were designed to be highly automated so that they could be run reliably by non-technical volunteers from HomePlug companies. The application used for this test was Intellon proprietary software (reviewed by an independent software consultant hired by the HomePlug alliance) called IPT32. The network protocol implemented by IPT32 is similar to User Datagram Protocol (UDP). Typical applications, such as file transfer, use Transmission Control Protocol (TCP). Extrapolated[1] results of TCP performance are also presented here.

Table 2 provides a summary of the aggregate results. These results show that HomePlug technology is highly robust and provides more than 5Mbps throughput on most links.

Company	Houses	Connections	Region
Broadcom	30	394	Northern California
Cisco	31	342	Mass, NH
Panasonic	27	401	New Jersey, PA,CA,CT
RadioShack	32	445	Texas
Motorola	29	418	Mass, RI
Intel	30	429	Oregon, WA
Conexant	66	979	Southern California
Sharp	22	281	Washington, OR
Intellon	51	740	Florida
Cogency	30	472	Ontario, Quebec
ConEdison	22	342	New York, NJ, PA
Telewise	26	373	Northern California
SonicBlue	21	312	Northern California, Washington
Valence	25	332	Ontario
Enikia	30	430	New Jersey, PA
Totals	472	6690	

Table 1. Summary of company participation in two-node field tests

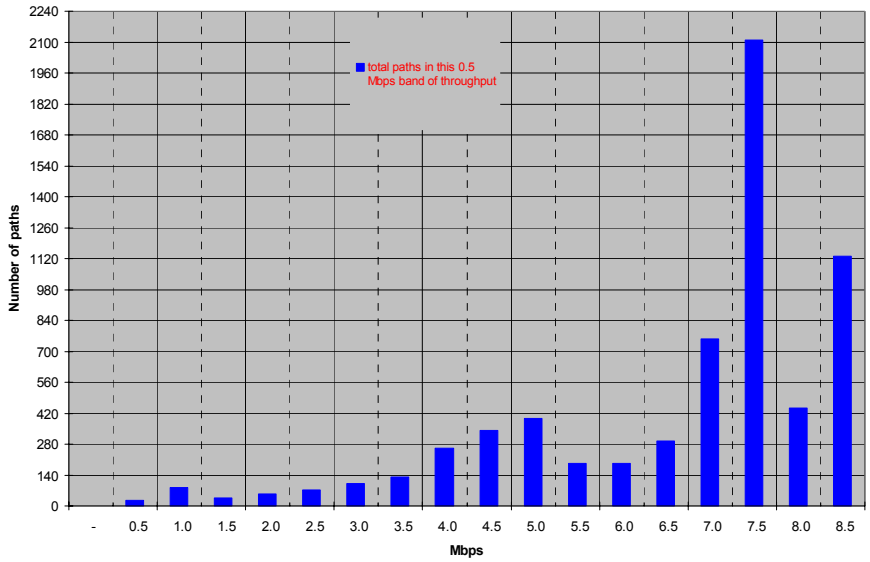
	% of connections exceeding 5Mbps	% of connections exceeding 1.5Mbps
IPT 32 (UDP -like) Throughput	77%	98%
TCP/IP extrapolated Throughput	73%	97%

Table 2. Summary of two-node field test results

[1] The IPT32 and TCP/IP throughputs are not linearly related, and in fact two different links that get the same IPT32 throughput will not necessarily get the same TCP/IP throughput. The field tests included a substantial number (1,583) of test cases where performance on a given wire path was measured with both IPT32 and with TCP. HomePlug engineers used these results to interpolate the TCP results from IPT32 results obtained in the two-node field tests.

Figure 2 shows a histogram of the various IPT32 throughputs sorted into bins of 500 kbps throughput. The y-axis shows the number of paths that fell into each bin of 500 kbps. The rightmost bar corresponds to paths that achieve the maximum rate that the technology supports, which is about 8.2 Mbps. Nearly 1,000 paths out of 6,690 achieved this rate.

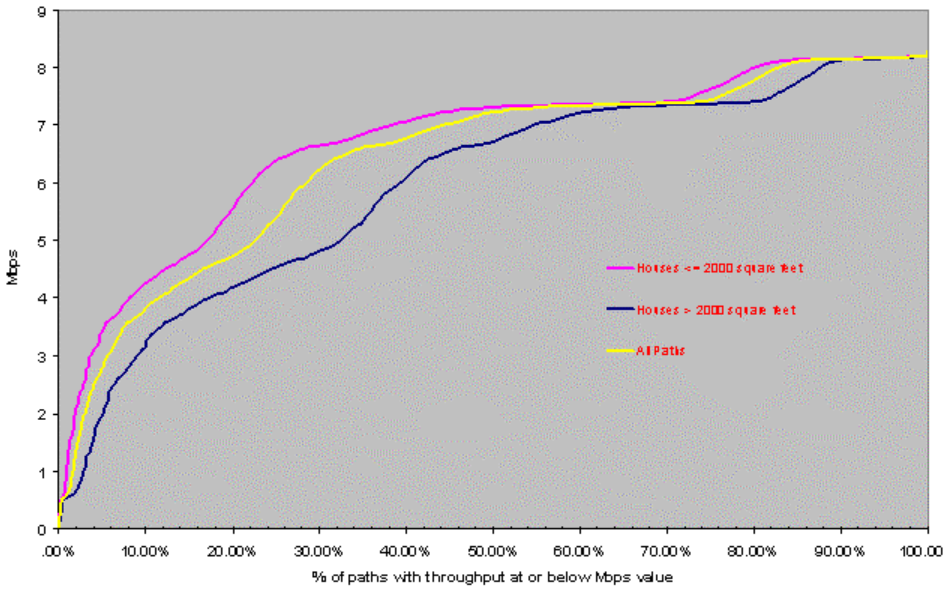
Figure 2: Two Node Testing:IPT32 Throughput Distribution



IPT32 (UDP) Throughput distribution -- Sample Size 472 houses representing 6690 outlet pairs

Figure 3 shows the same throughputs presented as Figure 2, but it also splits the distribution of throughputs into two groups: houses larger than 2000 square feet, and houses less than or equal to 2,000 square feet. As expected, there is performance degradation in larger houses, which is due to larger wiring paths. However, the results suggest that the drop in performance is modest.

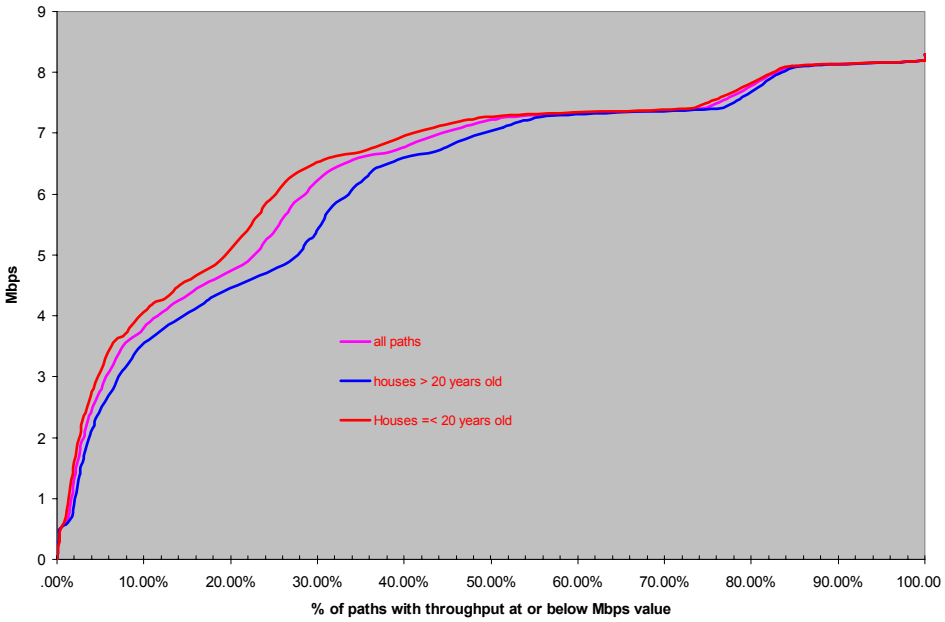
Figure 3: Two Node Testing: IPT32 Throughput distribution - Variation with House Size



IPT32 (UDP) Throughput distribution -- Sample size 472 houses representing 6,690 outlet pairs

Figure 4 shows a similar curve but divides throughput based on the age of the home, with 20 years as the dividing line between new and old. The results show that the performance of HomePlug technology is not significantly affected by the age of the house.

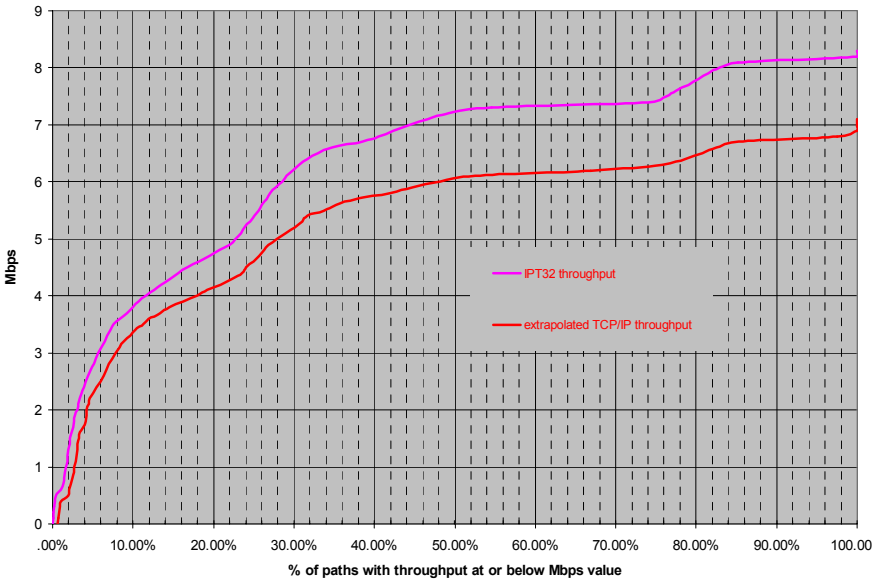
Figure 4: Two Node Testing: IPT32 Throughput distribution - Variation with House Age



IPT32 (UDP) Throughput distribution -- Sample size 472 houses representing 6,690 outlet pairs

Figure 5 compares the results of IPT32 and extrapolated TCP/IP. It has to be noted that the performance of TCP/IP degrades when there is high packet loss over the medium. Field test measurements show that the packet loss probability is less than 1% for more that 99% of the connections (excluding no connects). This results in higher TCP/IP throughput than can be expected of other less reliable networks.

Figure 5: IPT32 (UDP) verses Extrapolated TCP/IP Performance for Two Node Testing



Extrapolated TCP/IP and IPT32 (UDP) Throughput Distribution – Sample Size 472 houses representing 6,690 outlet pairs

Five-Node Field Tests

Five-node field tests were conducted in 50 houses in United States. A total of 140 pairs of outlets and 700 paths were tested. In contrast to the two-node field test, these tests were conducted by trained HomePlug engineers. Table 3 summarizes the company participation and location of these tests. These tests were conducted using both IPT32 and TTCP.

Table 3. Companies and Locations for 5 mode fully networked tests

Company	Location of Tests	Number of Houses
3Com	Illinois	5
Broadcom	Northern California	5
Conexant	Southern California	5
Radio Shack	Texas	10
Sharp	Oregon/Washington	10
Intellon	Florida	10
Enikia	New Jersey	5

Table 4 summarizes the results. These results show that HomePlug technology can sustain high throughputs even when there are several nodes in the network.

Table 4. Summary of five-node field test results

	% of connections exceeding 3Mbps
Aggregate IPT 32 (UDP -like) Throughput	93%
Aggregate TCP/IP extrapolated Throughput	90%

Figure 6 shows the aggregate throughput distribution for IPT32 and TTCP.

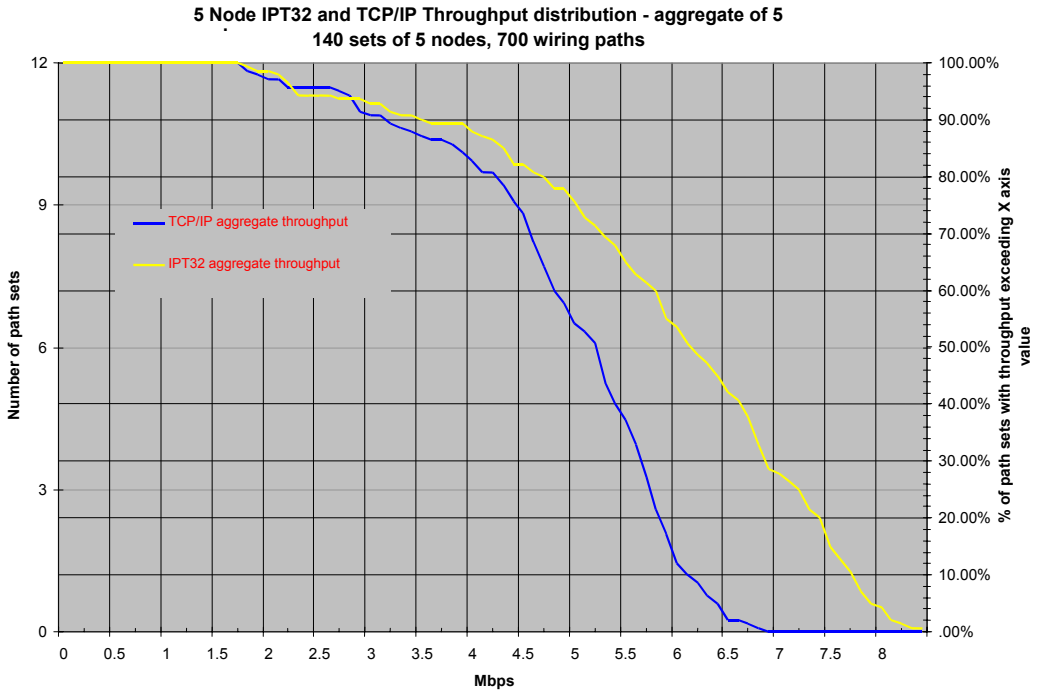


Figure 6: Aggregate IPT32 throughput and TTCP throughput for Five-node Testing