Powerline Communications Performance Testing

Digital communications over AC power lines is a technology that has matured to a level of high-performance and worldwide deployment, but in the process competing technologies have emerged that carry the same performance brand (i.e. 200 Mbps), yet are not compatible and do not deliver the same level of performance in a home network. Evaluating the different Powerline Communications (PLC) technologies to determine the best performer is a serious challenge for consumers, service providers, publication editors and product analysts.

Both Intellon and the HomePlug Powerline Alliance want investigators to understand how to evaluate the technologies to achieve real contextual data that leads to the best technology choice and market success.

Intellon’s position is that ultimately PLC technology must be field tested within the context of real-world settings to reveal true performance and impairment-handling capability. In other words, testing must be done in the end-users’ setting parallel to typical use as seen in consumers' home networks.

The following figure, based on actual test data, illustrates this point. Real-world tests reveal the performance achieved at 90% of the AC outlets throughout the test home while clean-line results, though much higher, are of little practical use.

PLC products are marketed as home network solutions that enable whole-house coverage in which the user can spread the network from room to room throughout the residence by simply plugging the PLC bridges and PLC-enabled devices into any AC outlet. While this is true, it must be qualified with the realities presented in this document.

PLC network performance is described using the phrase “up to”, as in “up to 200-Mbps channel rate”. This is not an ‘absolute’ rating. The reason for this is that in a real user setting of whole-house networking over AC wiring, not all point-to-point (outlet-to-outlet) connections are the same. The amount of signal attenuation and noise between outlets is not the same and the makeup of neighboring AC devices sharing the outlet or circuit is not the same. The reality of these differences requires that PLC technologies be tested and performance-compared over many circuits in the presence of typical and reasonable line-noise impairments.
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1. **Best Use Practices**

All PLC network devices, regardless of the underlying technology, perform best when some very simple guidelines are followed. These guidelines should be considered ‘best practices’ for any PLC home network installation or evaluation regimen and will help ensure best results.

- Test across the home at many outlet locations.
- Test across the home under normal circumstances with lights, fans and appliances in use.
- Test for both data transfer and streaming media.
- Do not test devices physically side-by-side, plugged into the same outlet or nearby outlet.
- Plug PLC devices directly and separately into an AC wall outlet, not a power strip.

1.1. **Plug PLC Devices Directly into a Separate Wall Outlet**

PLC devices work best when they have direct and separate access to the AC line, as illustrated in Figure 1. The implication here is that the device should not be plugged into an AC outlet or power strip that powers other devices such as PCs, printers and monitors. The use of the power strip provides some distancing between the PLC device and other devices that may act as noise sources. Most power strips have surge suppression built in, but the better ones also have EMI filtering, which works to further isolate equipment noise from the line. One of two outlets, even on the same wall, may offer some improvement in performance. It should be noted here that the Intellon-based RD6000-ETH reference design powerline adapter itself has built-in surge suppression rated at 30 Joules, which is enough to allow a device of this size to be plugged directly into the wall without the need for additional surge protection.

![Figure 1: Good Separation with Separate Outlet for PLC Wall Adapter](image)

1.2. **Placement of PLC Devices**

Because not all AC wiring paths are the same, an improvement in network performance may be realized by testing devices (network nodes) in different outlet locations – move one device at a time, then check performance. Similar to that which was presented above, shifting to a neighboring outlet may provide some performance benefit. The reason for this possible improvement is that the AC line ‘looks’ different at different outlets around the room and across the home. AC line impedance varies not only with distance between nodes caused by cumulative inductance and inter-wire capacitance but also with the presence of other active (operating) household devices/appliances, which cause variations in line loading.
1.3. **Phase-to-Phase – Not a Problem**

Powerline technologies of vintages earlier than HomePlug 1.0, which operated at lower frequencies, such as X10, were hindered greatly by the signal isolation that occurred between the two power phases. Most often, these devices would not communicate if they were placed on opposite phases. ‘Power-pole’ transformer winding inductance would work to block the signals from crossing phases. With the advent of HomePlug 1.0 and above, carrier frequencies jumped from kilohertz (kHz) to megahertz (MHz). Powerline communications moved into the high-frequency (HF) radio spectrum and broke the cross-phase barrier. The HF frequency range for HomePlug AV, for example, is 1.8 to ~30 MHz. In this spectrum, the signal on one phase easily passes over to the other phase.

1.4. **Identifying and Dealing with Noise Sources**

Most appliances in the home generate some amount of noise on the AC line – some more than others. The worst, yet very common, sources of line noise are: certain types of dimmers and speed controls for lighting and fans and devices that have inexpensive motors with brushes such as hair dryers, power tools, food mixers and electric knives. Some cell phone chargers and equipment with cheap power supplies have also been known to generate impairing line noise.

The obvious guideline in dealing with these noise sources is to avoid placing PLC devices on the same circuits whenever possible. Even so, electrical noise can travel, in varying degrees, throughout the home on a particular phase and cannot be totally avoided.

Devices that serve as noise impairments have greatest impact when they are located close to the receiving PLC device. When a device is suspected to be a serious noise impairment, simply unplug it to see if the throughput improves. If improvement is realized, move the offending device to another location or plug it into an EMI suppressing power strip.

Noise cohabitation is a fact of life for PLC networks, but that does not mean that PLC networking is not practical or viable. What it does mean is that the best PLC technology must be identified and carefully selected. Not all PLC technologies are created equal and neither should all PLC technologies be judged by the poor performance of some.

Intellon HomePlug AV standard-based PLC technology will deliver superior performance over competing technologies when operated in the presence of real-world line-noise impairments – this statement is backed by facts presented as part of this paper.

1.5. **The Coax Medium**

Intellon’s HomePlug AV standard-based RD6000-ETH Ethernet Powerline Adapter Reference Design offers hybrid media capability for networking over powerline and coax. The coax medium is referred to as a “clean line”, meaning there is very little noise to serve as communication impairments. While the performance of Intellon’s reference design is superior to other PLC technologies over the more-noisy powerline medium, its performance is improved still more over the quiet coax medium. Where conveniently available, the coax medium may offer an increase in throughput. A point to note here is that the throughput rate (UDP) on a clean line is limited by the 100-Mbps Ethernet interface rather than the HomePlug AV technology.
2. **Key Metrics for PLC Technology Field Testing**

2.1. **PHY Rate vs. Application Throughput Rate**

A topic that constantly appears in publication articles is the difference between the advertised data rate and the actual realized data rate that a device delivers.

The advertised data rate for a data communications device is the physical layer rate (PHY rate), also known as the channel rate. This is the maximum total number of bits per second that the technology is designed to produce over the network medium. Some examples are:

- 200 Mbps  HomePlug AV Powerline Communications Standard
- 85 Mbps    Intellon’s HomePlug 1.0 with Turbo
- 54 Mbps    IEEE 802.11a/g Wi-Fi
- 14 Mbps    HomePlug 1.0 Powerline Communications Standard
- 11 Mbps    IEEE 802.11b Wi-Fi

The PHY rate is measured at the physical layer, meaning, the bits that are converted to analog and transmitted over some medium (air or wire). The bits, that makeup the PHY, include a great amount of very necessary overhead bits that package and protect the actual data. Some of the overhead bits are for:

- Forward Error Control and Preamble
- Redundant information (error detection and correction)
- Addressing/Routing
- Acknowledgment packets
- Retransmissions of failed packet transmissions
- Control information

Throughput monitoring software measures throughput at a level more closely associated with the actual application throughput, or payload throughput, which is naturally much lower than the PHY rate. Keep this in mind as you continue reading about TCP and UDP performance.

2.2. **TCP Performance**

The Transmission Control Protocol (TCP) is designed to protect data as it is being transferred across the network medium by methods of packet acknowledgement and requests for retransmission based on error detection. Data is transmitted in packets to a receiver. The receiver must acknowledge the receipt of each packet and request retransmission if an error has been detected. TCP is characterized as having a lower throughput rate than some other protocols, but it is more reliable in high-error-rate networks such as wireless. Consequently, TCP is used to transfer data files, which do not have the real-time requirements of streaming media.

2.3. **Coverage vs. Throughput**

Figure 2 is provided to illustrate the concept of ‘Coverage vs. Throughput’. It is a chart with TCP performance plots of four different PLC technologies. This chart shows the relationship between coverage and throughput in a typical US home for each technology. This valuable tool reveals the TCP throughput rate that exists at each percentage of outlets in the home. If you want to know what throughput rate to expect at 80% of the home’s outlets, go up the ‘Y’ axis to the 80% coverage point, cross over to intersect with the plot of interest and drop straight down to the ‘X’ axis to read the throughput rate. For Intellon’s RD6000-ETH HomePlug AV standard-based reference design, the throughput rate is at least 36.5 Mbps over 80% of the outlets in the home. We will return to this discussion momentarily, but first here is some background that briefly describes the testing methodology that generated these plots.
2.3.1. Test Background

The test home used for these tests is an 1800 sq. ft. single-floor, three-bedroom, ranch-style dwelling. The home was surveyed for probable locations at which consumer electronics and PC equipment would typically be used and 16 test outlets were chosen - four test groups of four outlets (see Section 3.8). The home was operated as normal – usual appliances were turned on such as ceiling fans, lamps, a halogen lamp, a refrigerator and an air conditioning system. The results from this home are consistent with the aggregate results of Intellon’s 500-home field test for HomePlug 1.0.

Four PLC devices, of the same type, were tested at four separate outlets with node pairs tested in both directions. MAC TCP/CSMA throughput data was collected. Each of the four nodes was comprised of a PLC Ethernet adapter connected to a notebook running Chariot test software.

The test software included: Chariot Test Tool with Chariot Runtime Utility for Node 1 and Chariot Endpoint Software in Nodes 2, 3, and 4. Node 1 collects data from all nodes. A Data Analysis Tool was used to translate the Chariot Test Results files into an Excel spread sheet from which graphs were plotted.

2.3.2. The Coverage Plot

Figure 2 is one of the plots and comparisons that can be made using the Chariot test system. This particular presentation of data has significant importance because it reveals actual throughput coverage throughout the house, not a theoretical maximum. Consider the INT6000 green-line plot. This plot for the RD6000 200-Mbps HomePlug AV standard-based device shows that the application throughput (TCP/CSMA) is at least 32 Mbps at 100 % of the AC outlets that were tested in the home. At the base of the plot, it is revealed that the maximum possible application throughput is near 60 Mbps.

Notes:
1. Amateur Radio bands are used (not notched) by the tested Competitor A devices and contribute to performance.
2. Competitors A and B are proprietary technologies, both non-compliant with the global HomePlug AV standard.
3. The relative performance of powerline communications devices depends on a number of factors that may vary from site to site, including attenuation, noise levels and types of traffic. Accordingly, the relative test results from one environment may differ in another environment.
By comparison, the coverage plots for the INT5500 Intellon 85-Mbps Turbo devices, the Competitor A devices and the Competitor B devices indicate a much lower performance. Competitors A and B are two very different PLC technologies that do not comply with the HomePlug AV standard. Because of the robust noise-mitigating features included in the HomePlug AV standard-based technology, real home-network performance is superior and the HomePlug AV products stand in a class by themselves.

It is important to not overlook the main point here. All of the devices were tested in the same real-user environment that included a wide range of outlets and the typical domestic noise impairments. Fairness is ensured by repeating the same tests under the same conditions for all technologies and reality and validity are preserved through the use of actual field conditions.

2.3.3. Understanding Coverage Metrics

2.3.3.1. 80% Coverage Rate - The Most Significant Metric
The 80% coverage data rate is the most significant of all metrics for PLC device evaluation and comparison. This data point reveals the bit-rate performance that can be expected over 80% of the household data paths, or AC outlets. Figure 2 reveals that the INT6000 HomePlug AV devices provided at least 36.5-Mbps TCP at 80% of the outlets.

The significance of this cannot be overlooked. It reveals how both similar and different PLC technologies will most likely perform in consumer home networks. It provides insights to performance that are far more real than ill-conceived adhoc testing. If the test environment is representative of real user environments, the test results will unveil true performance expectations.

2.3.3.2. 10% Coverage Rate - The Least Significant Metric
The 10% coverage data rate reveals near maximum throughput performance over a small number of outlets. This is near what is referred to as 'clean-line' performance. The communicating devices are very close to one another with little attenuation, and possibly little noise, between them. This particular metric is interesting but not very useful in practice. High performance between a few closely located AC outlets brings little advantage to the home user.

This brings us to a very important point. While the 'clean line' figure identifies the maximum data transfer rate, it has little to do with whole-house performance in a real setting that includes a wide range of attenuations and noise. So called, 'head-to-head' clean-line evaluations are not very meaningful.
2.4. **UDP Performance**

Figure 2 showed TCP performance in which packets are sent and an acknowledgment is returned – good for critical data transfer. However, performance increases significantly when the User Datagram Protocol (UDP) is used because packet acknowledgments are not requested and the data is simply streamed with ‘come-what-may’ results. UDP is used for all types of streaming media (audio and video).

The following subsections show UDP coverage field test results obtained by Intellon for competing PLC technologies.

2.4.1. **UDP Coverage Test Results for Intellon Turbo & AV Compared to Competitor A**

Figure 3 shows the comparative UDP coverage test results for INT6000 HomePlug AV devices, INT5500 HP1.0+Turbo devices and Competitor A devices. The 80% coverage level has been selected for comparison.

---

Notes:
1. Competitor A devices are as-shipped and utilize the Amateur Radio bands. See Section 4.3 for details.
2. Competitor B is not represented in this chart because attempts to acquire UDP data for the devices were unsuccessful.
3. The relative performance of powerline communications devices depends on a number of factors that may vary from site to site, including attenuation, noise levels and types of traffic. Accordingly, the relative test results from one environment may differ in another environment.
3. **Simplified Field Testing**

3.1. **No Substitute for Actual Field Tests**

There is no substitute for actual field tests. Actual field tests bring the technology out of the laboratory and into its intended setting where it is exposed to a variety of real noise impairments and widely varying line conditions. Field tests reveal how agile the technology is and what its limitations truly are.

3.2. **PLC Field Tests**

Product evaluators, such as customers, consumers, editors and analysts may want to do PLC device testing. Some meaningful testing can be accomplished without purchasing advanced software to drive elaborate tests.

Some field tests that can be run to provide relative results are:

- Large-file data transfer tests without noise
- Large-file data transfer tests with noise (hair dryer, halogen lamp with dimmer control)
- Streaming media (video and audio) without noise
- Streaming media with noise (hair dryer, halogen lamp with dimmer control)

Reasons for the tests are to determine:

- Best and worst performance of a PLC technology
- Performance of competing technologies
- Performance variations at AC outlets (communication paths) throughout a residence

3.3. **Needed Equipment and Software (Freeware)**

3.3.1. **Hardware**

At least two PLC devices and two PCs are needed to perform simple home field tests. One of the PCs can be a desktop and the other should be a notebook. The notebook PC makes it easy to move about the premises to test different outlets. Assuming that the PLC devices are Ethernet/powerline bridges, two Ethernet cables are needed for connection of the devices to the PCs.

3.3.2. **Software**

Basic communications link software will reveal the application throughput rate while data is being transferred or media is being streamed.

The PCATTCP Test TCP Benchmarking Tool is recommended for measuring TCP and UDP application throughput performance. It is easy to install and captures data quickly. PCATTCP is available free online from PCAUSA at: [http://www.pcausa.com/Utilities/pcattcp.htm](http://www.pcausa.com/Utilities/pcattcp.htm)

Video server software must exist on the source PC and player software on the receiver PC to stream video and analyze performance. VLC Media Player is free and downloadable from: [http://www.videolan.org/vlc](http://www.videolan.org/vlc) This software can be used as a server to stream MPEG-1, MPEG-2 and MPEG-4 / DivX files and live videos on the home network in unicast or multicast; or used as a client to receive, decode and display MPEG streams under multiple operating systems.

Descriptions for using PCATTCP and the VLC Media Player are to follow.
3.4. Field-test Preparation

3.4.1. Prepare Test Nodes
Preparing your test nodes in advance of field test day may be obvious, but it is important to download and install your software far enough in advance to give yourself time to become familiar with the software. Software options mentioned above include help menus and other resources.

3.4.2. Select a Test Home
Select a test home and make a drawing of the floor plan with all AC outlet locations clearly marked. Identify the likely location for broadband Internet access and the locations, or likely locations, of all entertainment centers (TV and audio equipment). See Figure 4 as an example. You may want to mark selected outlets in the home with numbered ‘sticky’ notes.

Number all of the AC outlets at which you intend to perform tests. The numbering will allow you to clearly identify paths.

3.4.3. Create Data Collection Sheets
Created blank tables in which performance data can be collected. Make one table for each technology that you are testing. Table 1 is an example, which has been setup for 5 outlets and 10 paths with bidirectional testing for each path (20 data points for each test).

<table>
<thead>
<tr>
<th>Test Location:</th>
<th>TCP (Mbps)</th>
<th>Date:</th>
<th>UDP (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tests Paths</td>
<td>TX RX</td>
<td>TX RX</td>
<td></td>
</tr>
<tr>
<td>1 - 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 - 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 - 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 - 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 - 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 - 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 - 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 - 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 - 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 - 5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When performing tests throughout the test home, make sure that the home is functioning as 'normal' with some ceiling fans turned on, room lighting turned on, refrigerator and HVAC operating normally, etc.

Note: Collecting TCP data, as described in Section 3.5, and UDP data, as described in Section 3.6, can be done simultaneously to save time. Read both sections carefully and prepare and test your batch files ahead of time.

3.5. TCP Field Testing Using the PCAUSA PCATTCP Benchmarking Tool
PCAUSA’s PCATTCP Test Benchmarking tool is used here to test TCP throughput.

3.5.1. TCP Protocol
The TCP protocol requires that an acknowledgement be returned from the receiver as each packet is received. The acknowledgement may include a request for retransmission. This careful handshaking activity ensures that the data is protected and reassembled accurately on the receive end. TCP is designed for reliability in noisy networks, not speed, and is intended for file/data transfer activity. Consequently, TCP throughput rates will be lower than other throughput measurements.
3.5.2. **PCATTCP Installation**

- Download PCATTCP to your desktop from PCAUSA at: [http://www.pcausa.com/Utilities/ttcpdown1.htm](http://www.pcausa.com/Utilities/ttcpdown1.htm)
- When unzipping the downloaded file unzip to folder: C:\PCATTCP
- Transfer a copy of this installation file to PC#2.
- Double-click on the downloaded file to install it on PC #1.
- Install the software on PC #2.

It is assumed here that you will test with two nodes - each node is comprised of a PC with installed software, a PLC device and an Ethernet cable as discussed in Section 3.4.

3.5.3. **Setting IP Addresses**

The two test nodes must be assigned IP addresses to establish a network between them before testing is attempted. Each node will have it’s own IP address, which is set as follows on each PC:

- Click on the Start Menu button and right-click on ‘My Network Places’ – select Properties. A ‘Network Connections’ window will open.
- Right-click on ‘Local Area Connection’ – select Properties. A ‘Local Area Connection Properties’ window will open.
- In the center scroll area, scroll down to ‘Internet Protocol (TCP/IP)’ and left-click to highlight. Click the ‘Properties’ button.
- Click the radio button labeled: ‘Use the following IP Address’. Enter the following:
  - For PC #1: 192.168.100.19
    - Subnet: 255.255.255.0
  - For PC #2: 192.168.100.20
    - Subnet: 255.255.255.0
- Task Completed – click OK. Close all network windows.

Note that when the PCs are returned to normal service that the IP address must be set back to ‘Obtain an IP address automatically’ in the ‘Local Area Connection Properties’ window.

3.5.4. **PCATTCP Command Batch Files for TCP Tests**

The PCATTCP Benchmarking Tool is most easily run using batch files. Here, you are instructed to create four batch files, two for each PC (one transmit, one receive). Use a text editor to create the batch files and save each file using a .bat extension. These files will tell the benchmarking tool to test for TCP throughput.

3.5.4.1. PC #1 TCP Testing Batch Files

Make a plain text file (PC1-TCP-TX.bat) for transmit with the following two-line content:

```plaintext
c:\PCATTCP\pcattcp -t -f m -l 8760 -b 65535 -n 5000 192.168.100.20
Pause
```

Make a plain text file (PC1-TCP-RX.bat) for receive with the following two-line content:

```plaintext
c:\PCATTCP\pcattcp.exe -r -f m -l 8760 -b 65535 -n 5000
Pause
```

3.5.4.2. PC #2 TCP Testing Batch Files

Make a plain text file (PC2-TCP-TX.bat) for transmit with the following two-line content:

```plaintext
c:\PCATTCP\pcattcp -t -f m -l 8760 -b 65535 -n 5000 192.168.100.19
Pause
```

Make a plain text file (PC2-TCP-RX.bat) for receive with the following two-line content:

```plaintext
c:\PCATTCP\pcattcp.exe -r -f m -l 8760 -b 65535 -n 5000
Pause
```
3.5.5. **TCP Testing**

Ensure that the two nodes are properly connected at two selected outlets in the home according to Table 1. Both PCs are turned on, connected via Ethernet cable to the PLC Device and the PLC device is plugged into the outlet. All of the steps in Section 3.4 and Section 3.5 up to this point have been accomplished.

Each path shall be tested in both directions using the batch files created above. Always start the ‘receive’ batch file first by double-clicking on the receive batch file. When you open a batch file, it opens in a DOS screen.

Testing path 1 to 2: Double-click on the PC2-TCP-RX.bat file on PC #2 at outlet 2. Then, double-click on PC1-TCP-TX.bat on PC #1. The TCP throughput rate will soon appear in the DOS window on both PCs. Record this in Table 1.

Close the DOS windows on both PCs.

Testing path 2 to 1: Double-click on the PC1-TCP-RX.bat file on PC #1 at outlet 1. Then, double-click on PC2-TCP-TX.bat on PC #2. The TCP throughput rate will soon appear in the DOS window on both PCs. Record this in Table 1.

Repeat the above for all paths listed in Table 1.

3.5.6. **Windows File Transfer TCP Testing**

Make sure the test PCs are set up for file sharing. A TCP file transfer test can be run by simply transferring a large file from one PC to the other as the throughput rate is being monitored, or the transfer is being timed. However, Windows File Sharing does not give you true TCP throughput results because it adds a lot of overhead bits to the data, thereby slowing the transfer. Results can be improved somewhat by duplicating your test file and transferring both versions at the same time. When transferring two files at the same time, you will get a higher throughput than when copying one file at a time. This is evidence that a simple Windows file transfer is not the most accurate test. For the highest accuracy, it is best to use PCATTCP to perform the tests.

3.6. **UDP Field Testing Using the PCAUSA PCATTCP Benchmarking Tool**

PCAUSA’s PCATTCP Test Benchmarking tool is used here to test UDP throughput.

3.6.1. **UDP Protocol**

Throughput performance increases significantly when the UDP protocol is used because packet acknowledgments are not requested and the data is simply streamed with ‘come-what-may’ results. UDP is used for all types of streaming media (audio and video). Streaming media does not tolerate the time constraints of the TCP protocol.

The following describes how to use the PCATTCP Benchmarking Tool to collect UDP throughput data.

3.6.2. **PCATTCP Installation**

If PCAUSA’s PCATTCP Benchmarking Tool is not installed, download and install according to Section 3.5.2.

3.6.3. **Setting IP Addresses**

If not already done, set the IP addresses of the test nodes/PCs according to Section 3.5.3.

3.6.4. **PCATTCP Command Batch Files for UDP Tests**

3.6.4.1. **PC #1 UDP Testing Batch Files**

Make a plain text file (PC1-UDP-TX.bat) for transmit with the following two-line content:

```
c:\PCATTCP\pcattcp -t -u -f m -l 8760 -b 65535 -n 5000 192.168.100.20
Pause
```

Make a plain text file (PC1-UDP-RX.bat) for receive with the following two-line content:

```
c:\PCATTCP\pcattcp.exe -r -u -f m -l 8760 -b 65535 -n 5000
Pause
```

POWERLINE COMMUNICATIONS PERFORMANCE TESTING
3.6.4.2. PC #2 UDP Testing Batch Files

Make a plain text file (PC2-UDP-TX.bat) for transmit with the following two-line content:

```
c:\PCATTCP\pcattcp -t -u -f m -l 8760 -b 65535 -n 5000 192.168.100.19
Pause
```

Make a plain text file (PC2-UDP-RX.bat) for receive with the following two-line content:

```
c:\PCATTCP\pcattcp.exe -r -u -f m -l 8760 -b 65535 -n 5000
Pause
```

3.6.5. UDP Testing

Follow the instructions of 3.5.5 and use the UDP batch files to run the tests.

3.7. Streaming Video Testing

Performing tests with actual streaming video can be very revealing. These tests will confirm the robustness of the technology as it streams video over a noisy AC line environment. You can test for the UDP rate between different paths and you can test for the effects of added line noise, which serve to challenge the noise-handling capabilities of the technology.

Use the VLC Media Player to both stream and receive video content across the AC line paths. This tool can be used to stream multiple video streams at the same time if desired. Both standard-definition and high-definition video streaming can be tested. Both standard-definition and high-definition short video files are available for download from Intellon’s Web site at: http://www.intellon.com/support/documentation.php

As the video content is streaming, additional noise can be added to the AC network by turning on a hair dryer in a bathroom or a dimmer controlled light in any room of choice. Apply the additional noise consistently for all tests and for the comparison of different PLC technologies. This visual test will reveal how robust the technology is in the presence of real household line noise.

3.7.1. VLC Media Player Installation

- Download the VLC Media Player to your desktop from: http://www.videolan.org/vlc
- Transfer a copy of this installation file to PC#2.
- Double-click on the downloaded file to install it on PC #1.
- Install the software on PC #2.

A VLC program Icon will appear on the desktop of each PC when installation is complete.

It is assumed here that you will test with two nodes - each node is comprised of a PC with installed software, a PLC device and an Ethernet cable as discussed in Section 3.4.

3.7.2. Setting IP Addresses

If not already done, set the IP addresses of the test PCs according to Section 3.5.3.

3.7.3. Video Test Procedure

- Ensure that the two nodes are properly connected at two selected outlets in the home. Both PCs are turned on, connected via Ethernet cable to a PLC Device and the PLC devices are plugged into the outlet.
- Make sure that all of the steps in Section 3.4, Section 3.5.3 and Section 3.7.1 have been accomplished.
- A video test file, or files, should have been loaded onto each PC. (available on Intellon Web site: http://www.intellon.com/support/documentation.php )
- Start the receiver node first.
  - Double-click on the VLC program icon to start it running. A small program window will open.
POWERLINE COMMUNICATIONS PERFORMANCE TESTING

- Click on the File Menu and select ‘Open Network Stream’.
- Select the ‘UDP/RTP’ check box.
- Click ‘OK’ to close.
- The receiving PC is now ready and waiting to receive the video stream.
- Start the transmitter node.
  - Double-click on the VLC program icon to start it running. A small program window will open.
  - Click on the View Menu and select ‘Play List’ – Select the ‘Repeat’ mode for short video clips.
  - Click on the File Menu and select ‘Open File’. Click on ‘Browse’ to select your video test file. Click ‘Open’
  - Select the ‘Stream Output’ checkbox.
  - Click on ‘Settings’. A Settings window appears.
    - In the ‘Output Methods’ section, select the ‘UDP’ checkbox. Enter the IP address of the receiver in the box next to the UDP checkbox. 192.168.100.19 or 192.168.100.20 depending on direction
    - In the ‘Encapsulation Method’ section, select MPEG TS.
  - Click ‘OK’.
- The video is now streaming to the receiver PC and should appear on its screen.

The quality of the connection will be obvious at the receiver as the video streams. Throughput, in this case, is a function of the bit rate of the video. If the file is a 12 Mbps video file, the throughput rate will be the same. So, for video streaming tests, it is the quality of the received video that is important.

If you feel that the received video stream does not look ‘right’ or has been impaired in some way while traversing the powerline network, move the receiver node close to the transmitting source node and stream the video again. This will give you a point of reference for comparison. You can also view the video on the source PC to compare quality.

You can add some noise impairment to the test by plugging in and using a hair dryer and/or an SCR dimmer/speed controlled appliance at some outlet between the two test outlets. PLC devices that are not designed to deal with noise impairments usually fail in obvious fashion.
3.8. Rigorous Field Testing

Rigorous field testing requires that a relatively large number of paths be tested in a home using software that is designed to run tests and collect device/path performance data. Intellon uses four sets of notebook PCs and four PLC devices. Each PC is loaded with Chariot test software. Four sets of four outlets are selected throughout the home. Each test set of 4 outlets yields 12 test paths. 48 paths in total are tested throughout the home shown in Figure 4. The collected path data is then used to create coverage plots showing the percent coverage for each throughput rate (see Figure 2).

- 1600 Square Foot Home
- Approximately 10 years old
- Contains common appliances and consumer electronic equipment
- AC outlets and line phase identified
- Electrical characteristics of house representative of a typical house in the 500 home test of HomePlug 1.0
- Outlets selected are typical of locations that would be selected for powerline networking of devices in the house.
  - Located in Major rooms of the house
  - Near personal computers
  - Near consumer electronics equipment
  - 16 outlets chosen (labeled with •).
4. Laboratory Testing

4.1. Lab Test Bench

Testing of powerline communications devices in the laboratory allows a test methodology to be employed that is reproducible and repeatable. Figure 5 illustrates a powerline physical layer test bed that allows attenuation between two powerline communication devices to be adjusted to simulate path attenuations typically found in the home. The test bed also allows various impairment devices to be added to the test environment in a manner that allows tests to be performed in a controlled and reproducible manner. Impairment devices may generate noise, attenuate the communication signal, produce transients, impedance modulate the powerline, or "jam" the communication signal.

* Belkin PureAV Isolator – F9A1033-12 or F9A833-10

Figure 5: Basic Laboratory PLC Test Bench Setup
4.1.1. **Intellon Lab Test Bench**

A laboratory test bench can be modeled after Intellon’s Lab Test Bench as illustrated in Figure 5. It includes:

- line filtering for test bench isolation (* Belkin PureAV Isolator – F9A1033-12 or F9A833-10)
- special coupling for test equipment
- a variable attenuator with BNC connectors to synthesis PLC line loss
- paralleled power strips, one on each side of the attenuator to admit PLC devices and noise impairments (metal boxes shown include additional line filtering, AC outlets, signal couplers/filters and BNC jacks)
- 50-ohm dummy loads for impedance stabilization

4.1.2. **Intellon TCP Test Bench Data Results**

4.1.2.1. Without Noise (Clean Line)

Figure 6 shows 4 TCP throughput-vs.-attenuation data plots for three different PLC technologies – 2 Intellon INT6000-based adapter plots, 2 Competitor A plots and 1 Competitor B plot. The data for these plots was collected under clean-line conditions (no noise). The two Competitor A plots are extremely different – one is the ‘Performance Mode’ and the other is the ‘Coexistence Mode’. Data for the TCP throughput rate for each technology was collected at each level of attenuation in 10 dB steps – 0 through 60. The variable attenuator was used to dial-in the amount of attenuation between the sending and receiving nodes. The portions of the plots at 30 dB of attenuation and higher are of most significance because most paths in the home will have at least 30 dB of attenuation. In addition, the plots of Figure 6 are only interesting but not of great significance because there is no noise to ground the plots in reality.

![TCP/IP MAC Throughput Waterfall (No Noise)](image)

*Figure 6: Lab Bench TCP vs. Attenuation*

**Notes:**

1. *The Competitor A device is using the Amateur Radio bands to enhance performance. See Section 4.3.3.*
2. *Competitors A and B are proprietary technologies, both non-compliant with the global HomePlug AV standard.*
3. *The relative performance of powerline communications devices depends on a number of factors that may vary from site to site, including attenuation, noise levels and types of traffic. Accordingly, the relative test results from one environment may differ in another environment.*
4.1.2.2. With Noise
A 100-W halogen lamp was plugged into the test bench and resulting data was collected for the Intellon HomePlug AV, Competitor A and B technologies. Compare the plots in Figure 7 to see the impact noise has on the technologies. Intellon’s technology far outperforms both Competitors A and B in the presence of real-world noise impairments. This is also revealed in extensive field testing.

Figure 7: Test Bench TCP vs. Attenuation Performance with Noise

Note: The Competitor A device is using the Amateur Radio bands to enhance performance. See Section 4.3.3.

4.1.3. Reproducing Test Results - What to Look For

Compare relative data, don’t look for absolutes as every test method and setting yields its own results. Results for tests of multiple devices and technologies will always be in relation to the common method (software and hardware) and setting (particular field setting, laboratory test bench). In a laboratory setting, the performance of devices should be compared against the performance of a ‘Golden Node’, which serves as a benchmark. The Intellon Production Test System, used for end-of-production-line product testing, has an internal Golden Node to which devices are compared. A Golden Node for each tested technology can also be used with the test bench to establish a baseline.

4.2. Clean-line Test Bench

Intellon has had many requests for information on head-to-head clean-line testing of PLC devices. While we do not consider a clean-line testing approach to have real-world validity, it can be used to capture near maximum throughput rates and it can be used for simple noise impairment testing where a noise-generating appliance such as a hair dryer or halogen lamp can be plugged in with the PLC adapters and the impact measured.
An interesting effect of this type of head-to-head testing is that the PLC devices often perform at a throughput rate that is nearly 10% lower than if there were actually 10 to 20 dB of attenuation between them.

Figure 8 illustrates a simple test bench that can be assembled for head-to-head clean-line and noise impairment testing.

![Figure 8: Simple Clean-line Test Bench](image)

### 4.3. Power Spectral Density Testing

#### 4.3.1. Test for International Amateur Radio Non-Interference Compliance

When testing different PLC technologies, it is important to examine the technology’s power spectral density (PSD) to ensure compliance with government regulations and to ensure that interference of Amateur Radio Services is not generated in the high-frequency (HF) Amateur Radio bands.

HomePlug 1.0 and AV standards address this issue by specifying a firmware-based ‘tone mask’ that defines which carriers are deleted from the PLC spectrum. Intellon tests have revealed that some competing PLC technologies do not give consideration to this issue, utilizing the entire HF spectrum and presenting potential interference to Amateur Radio services.
4.3.2. Intellon’s HomePlug AV Standard-based Reference Design Notches Amateur Radio Bands

Figure 9 shows a spectral graph for Intellon’s HomePlug AV standard-based RD6000-ETH Ethernet Adapter Reference Design that clearly indicates Amateur Radio band notching. This notching is ensured through the use of the HomePlug AV Tone Mask, which is part of Intellon’s firmware package.

![Figure 9: Spectral Analysis of Intellon's RD6000-ETH Shows Amateur Radio Band Notching (June 2006)](image)

4.3.3. Tests Show that Competitor A Does Not Notch the Amateur Radio Bands

Figure 10 is an actual spectral graph capture of an off-the-shelf Competitor A Ethernet/PLC adapter that does not provide notching for the Amateur Radio bands. This oversight sets the stage for interference to the Amateur Radio services and adds controversy to the deployment of PLC technology.
4.4. **Test Scenarios that Lead to False Conclusions**

4.4.1. **Head-to-Head Windows File Sharing Tests**

Testing for the Windows file sharing rate between two PLC devices may be useful to determine large-file transfer rates and to compare the performance of competing PLC technologies. However, performing this test with two PLC devices in close proximity, head-to-head, will not yield ‘real’ or ‘practical’ results. Head-to-head testing virtually removes the usual line attenuation and noise impairment factors that enter into a real-use scenario, thus masking the poor file transfer performance of a PLC technology under attenuated and noise-impaired circumstances.

4.4.2. **Don’t Compare Technologies Based on Maximum Throughput Only**

The most relevant test data for PLC devices will be at outlets with data rates matching the 70 to 80 percent coverage points. In other words, the data rates obtained from the majority of the outlets (70 to 80 percent) represent the typical user rates for that particular home network. This reveals the practical useable bit rate that the particular PLC technology and network can be expected to deliver based on path attenuations and the usual household noise impairments. Focusing on high-throughput-rate performance that is delivered to 10% or less of the total outlets in the home is of little use.
5. PLC Performance Testing Summary

5.1. Test Methods Matter
As you have seen in this paper, the methodology employed to test the performance of a particular PLC technology or to compare PLC technologies does matter. Close-in, or head-to-head, testing of adapters in the same or nearby outlets yields data that is of little use. Field testing yields useful real-world performance data from which a technology can be evaluated or compared. A real and meaningful test environment is one in which the PLC devices are challenged by line impedance variations and household AC line noise. Testing over the entire premises at a large number of outlets reveals the true capability of the technology in that environment.

5.2. HomePlug AV is Designed for Superior Performance Over Noisy AC Wiring
Both Intellon's field and lab bench tests reveal the superior performance offered by HomePlug AV technology, especially in the presence of real AC line noise impairments. HomePlug AV technology was designed specifically to deliver consistently high performance over noisy AC wiring in support of whole-home connectivity, which includes streaming SD and HD video content.

5.3. Intellon's PLC Roadmap Supports CE and PC Manufacturers and Service Providers
Intellon's product roadmap into the future, Figure 11, offers strong support for manufacturers and service providers. It includes increasing PLC performance while reducing parts count and BOM costs.
Intellon: The World Leader in Powerline Networking

- Leading contributor to HomePlug AV specification
- Patented technology chosen as the basis for HomePlug 1.0
- Complete HomePlug 1.0 and AV solutions from a single supplier
- World leader in HomePlug IC sales and product enablement
- Most real-world experience in powerline networking

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