Characterizing the End-to-End Performance of Indoor Powerline Networks

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Introduction

- Powerline communication (PLC) takes advantage of existing cabling to create a data network.
- Equipment superimposes signal at much higher frequency (2-28 MHz) than power frequency (50-60 Hz).
- System does not operate through step up or step down power transformers.
- Was considered to deliver internet to the home via higher voltage cables, but deemed impractical given prevalence of DSL and cable connections and transformer problems.
- Still viable for within home networking, especially in homes without Ethernet (expensive to wire).
- Has the potential to avoid problems with Wifi (spectrum crowding and network reach).

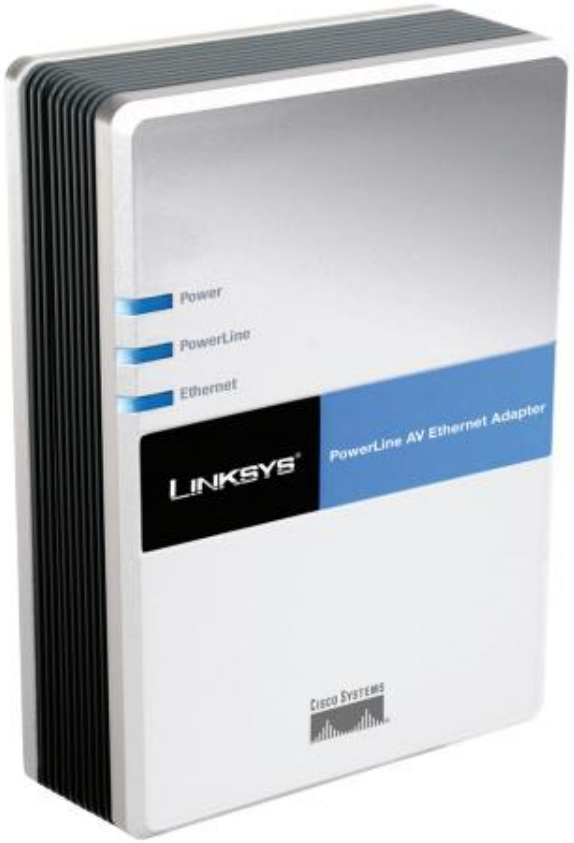
Purpose of Research

- Performance of PLC equipment is not well understood.
- Independent verification of manufacturer performance claims is difficult to find.
- Initial research suggests that PLC is very susceptible to line noise.
- Need to better understand impact of PLC on higher layers of networking stack.
- Commercially available equipment does not use an open architecture, essentially a black box.
- Equipment from competing vendors may not interoperate.
- MAC and physical layer protocols are not published.
- Network cannot be sniffed at the MAC layer without special equipment.
- Difficult to set up “clean” testing environment to verify manufacturers claims.
- Only method to investigate performance is end-to-end testing with commercially available equipment.

Focus of Paper

- **Research is conducted to see if PLC technology has matured enough for broad use.**
- **Study analyzes if Powerline networks are:**
- Impacted by distance
- Have high capacity
- Low latency
- Support multiple transmitters and heterogeneous traffic patterns
- Can cope with interference from household electrical appliances.

Test Equipment Used



Linksys Homeplug AV PLK200
Physical Layer Data Rate: 200 Mbps
Information Data Rate: 150 Mbps
Frequency: 2-28 Mhz
Employs various modulation schemes to counteract noise.

Connection to a Desktop Computer

Testing Setup

- Same model adaptors used on all ends, no intermixing of standards or equipment.
- 3 environments: dormitory, house, and office building.
- Dormitory is over 120 years old with upgraded wiring in the 1990's.
- House was built in the 1992 and is 700 square meters.
- Dorm and house employs 2 adaptors.
- Office building has 7 adaptors and various types of electrical equipment (microwaves, blenders, refrigerators) that introduce line noise.
- The additional use of a 575 ft extension cable plugged into an AC outlet was selected as a control to isolate testing from noise (in the office).
- Some noise would still be introduced, but it could be better controlled.
- Standard tools were selected to perform analysis including iperf, ping, and tcpdump.
- An ad hoc Wifi network (802.11g) was also set up for performance comparison.

Effect of Distance

- TCP throughput and RTT were measured.
- Testing was constrained by location of outlets.
- Wifi test was performed at sending and receiving locations, using a one hop ad hoc network
- At furthest distance, Wifi achieved 22 Kbps vs 14.81 Mbps for PLC.
- Extension cord test was also performed.
- Throughput (80 Mbps) and RTT were steady all along the extension cord, likely due to relatively short length.

Effect of Distance

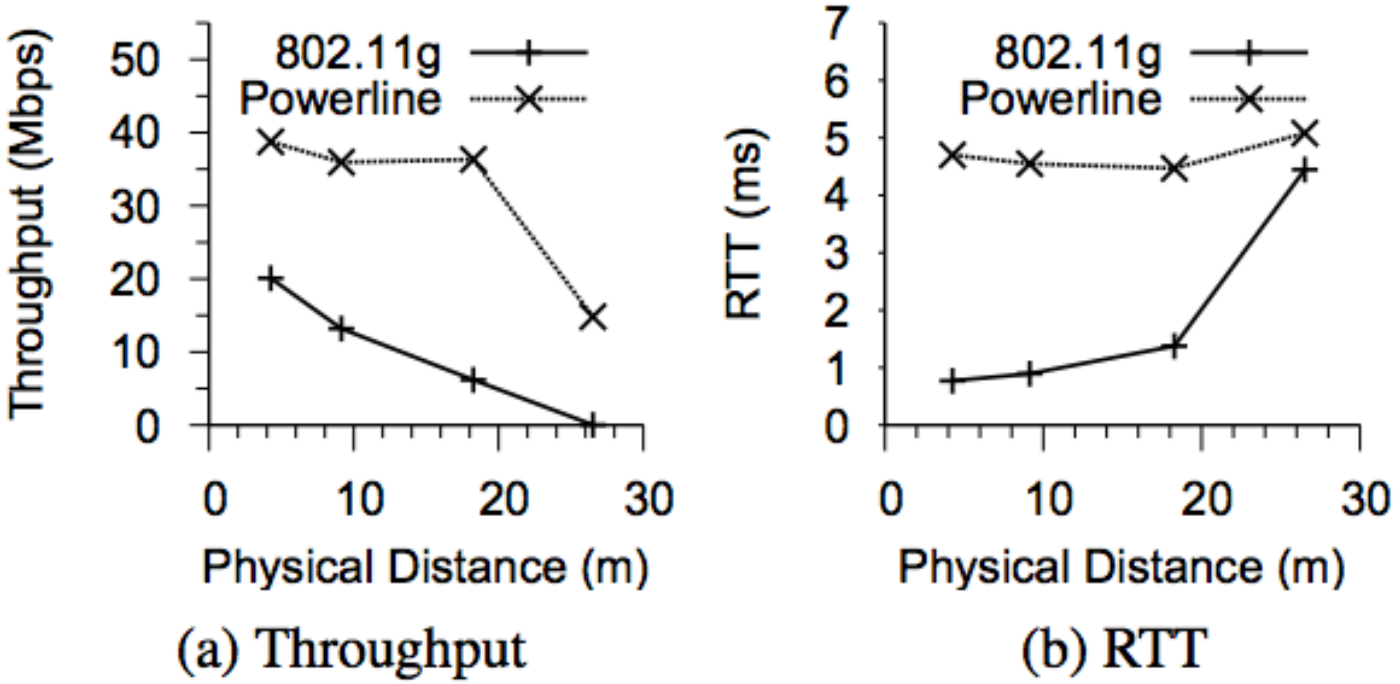


Figure 1: *Comparison of powerline performance against a one hop 802.11g link in the home environment*

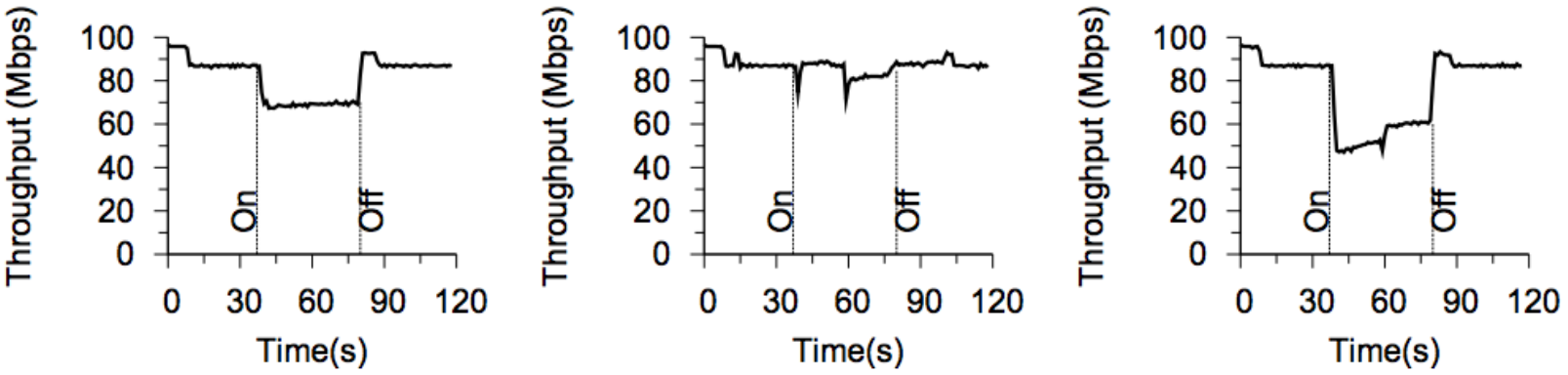
Effect of Electrical Appliances

- UDP transmission between two nodes was performed.
- Appliances were turned on for short periods to gauge impact.
- Long term simulation was performed to see impact of normal daily interference.
- Throughput and RTT varied throughout the day as equipment changed modulation scheme to counteract noise.
- Electrical equipment with more capacitive equipment seemed to have a bigger impact.

Effect of Electrical Appliances

Device	Wattage
Phone charger	5
Lamp	150
Blender	350
Microwave Oven	1200

Table 1: *Wattage for various household electrical appliances*



(a) Phone charger (EC) (b) Lamps (EC) (c) Blender (EC)

Figure 2: *UDP Throughput variation between a pair of nodes on the EC*

Effect of Electrical Appliances

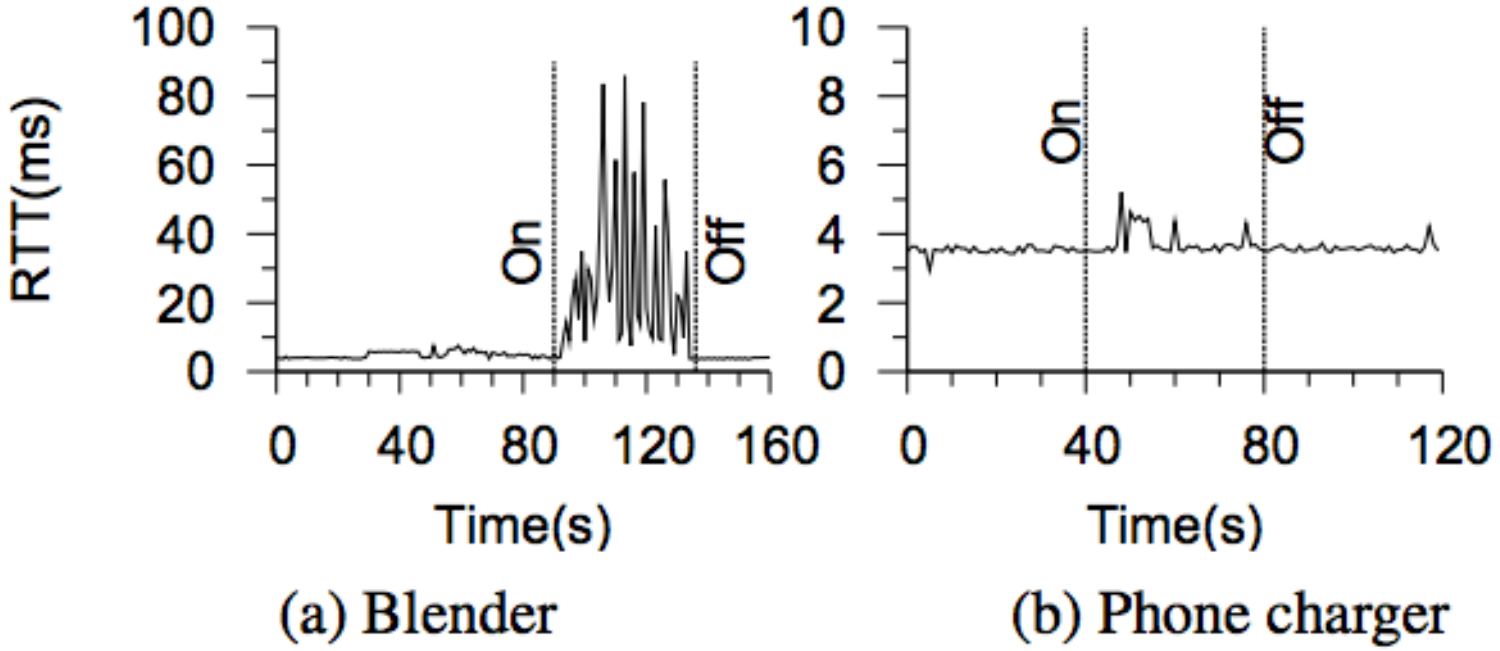


Figure 3: *Impact of electrical appliances on RTT between two nodes*

Effects of Electrical Appliances

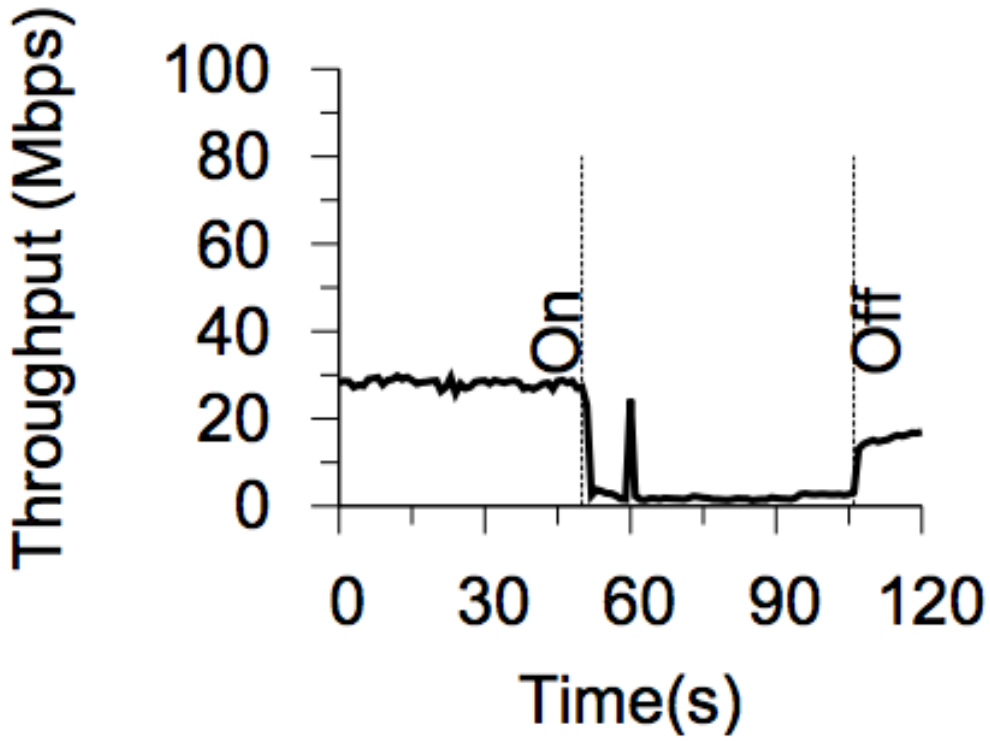


Figure 4: *Impact of a microwave oven on throughput in a home environment*

Effect of Electrical Appliances

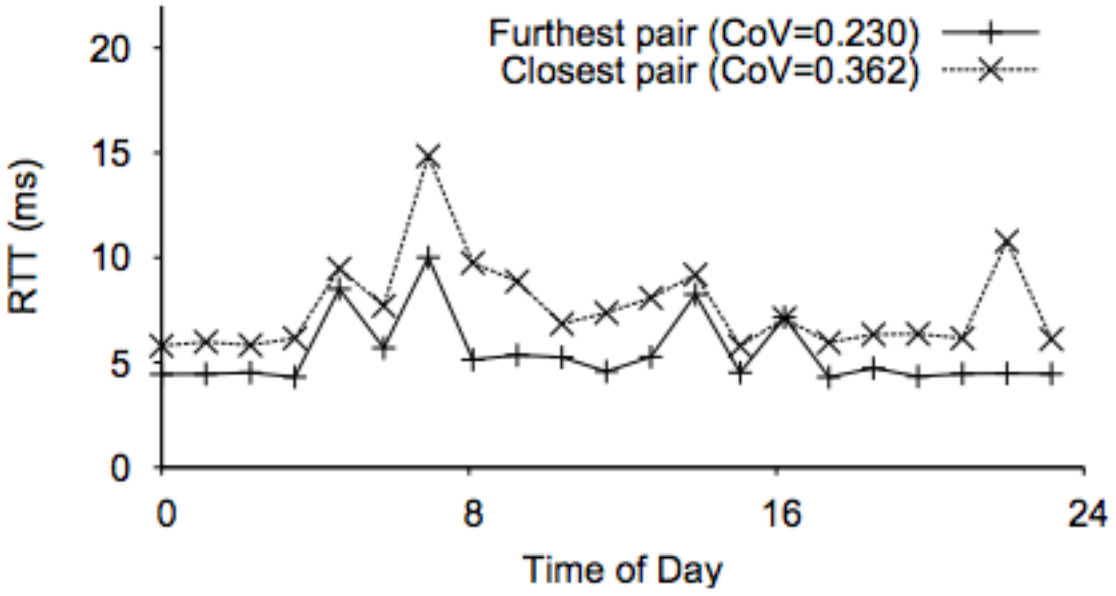


Figure 5: *RTT variation between a two pairs of nodes in the office over a 24 hour time period*

Simultaneous Transfers and Cross Traffic

- Simultaneous communication on a network is common and needs to be simulated.
- First one device was selected as the sink with multiple sources.
- Multiple sinks were also tested.
- Total network capacity was generally evenly divided between transmitters on the extension cord.
- Different types of traffic require different bit rates (Skype vs checking email).
- Test was set up to vary a cross traffic bit rate and see the impact of the rest of the network's performance.
- Median RTT and RTT spread increased as cross traffic bit rate increased.
- Certain active nodes could bring down performance the of whole system, but not as much as with a Wifi network.

Simultaneous Traffic

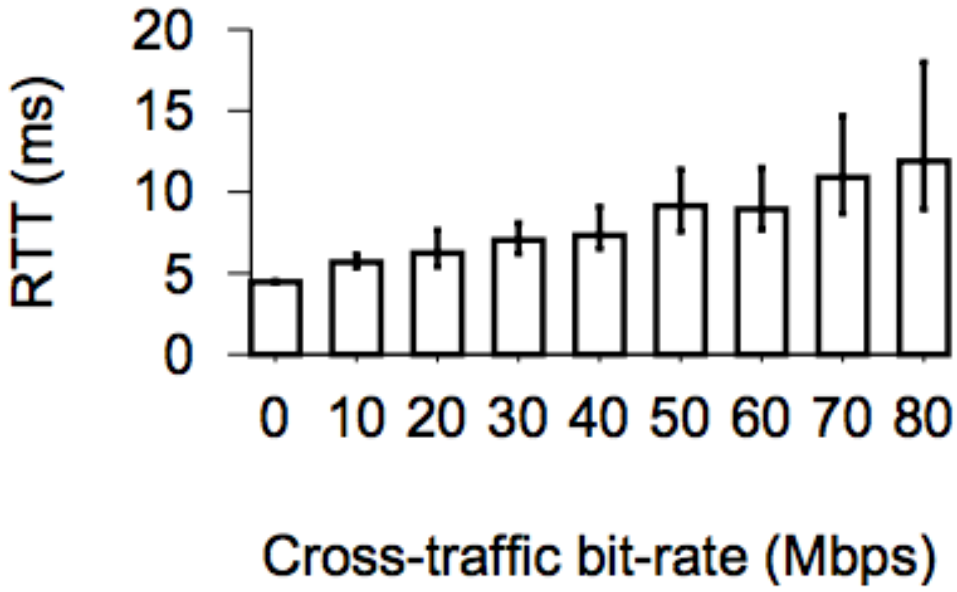


Figure 6: *Impact of cross-traffic (of increasing bit-rate) on RTT with 25th and 75th percentile error bars for powerline and ethernet*

Simultaneous Traffic

Alone = one sink
Pairs = multiple sinks

Better performance on the extension cord is observed.

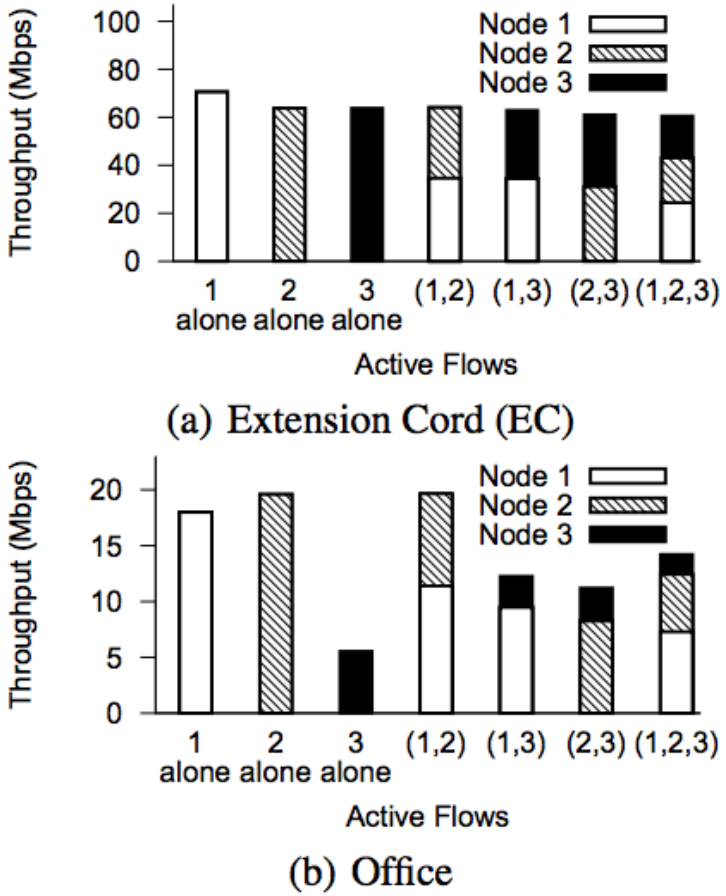


Figure 7: *Network capacity being shared when multiple nodes transmit simultaneously to a common sink*

Media Access Control

- Set up two PLC nodes to constantly unicast data to a third node on the extension cord to determine how access to network is handled.
- Plot consecutive data frames sent.
- With Wifi, each sender has equal access to network, meaning close to only one packet is sent at a time before another sender can transmit.
- With PLC, once transmitter is granted access, multiples of 10 packets are sent.

Media Access Control

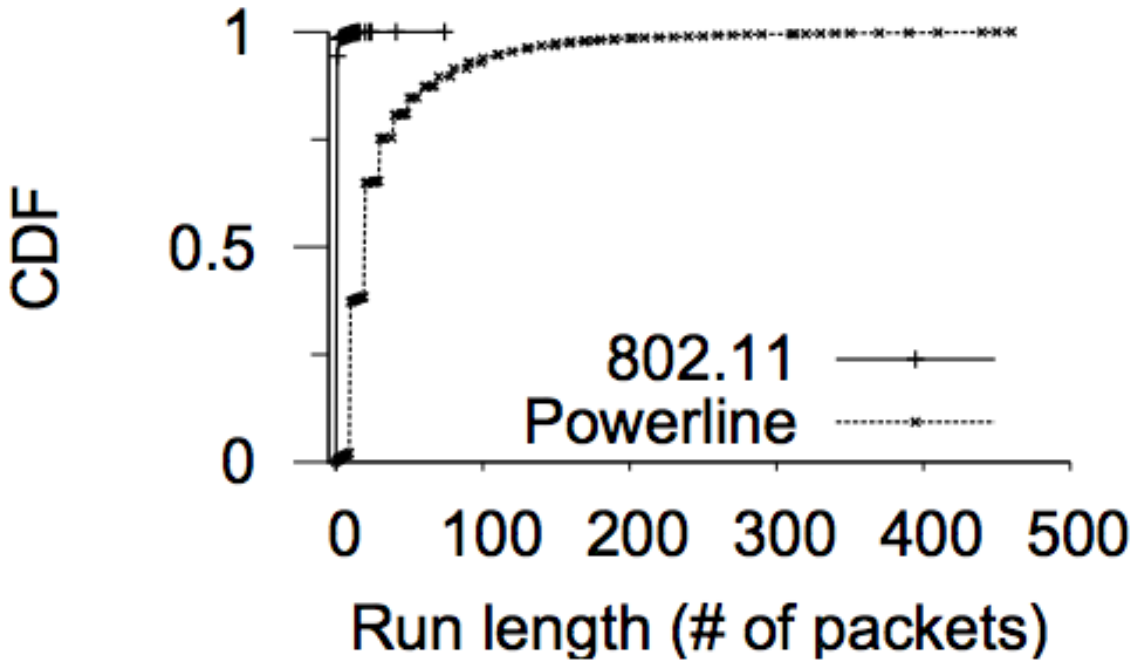


Figure 8: *CDF of run length for two contending nodes in 802.11 wireless vs Powerline*

Channel Asymmetry

- Wifi channels tend to be asymmetrical, while Ethernet is symmetrical.
- Asymmetry can cause problems in higher networking layers.
- Set up two nodes on either end of the extension cord and measure TCP throughput in both directions.
- Took ratio of higher and lower throughputs.
- Good symmetry with data rate of 60 Mbps.
- Added a blender in the middle of the line and reran the tests.
- Found that the blender not only reduced throughout, but introduced asymmetry in the communication channel.
- 40 Mbps one direction, 19 Mbps the other.
- Significant asymmetry was also found in the office setting.

Channel Asymmetry

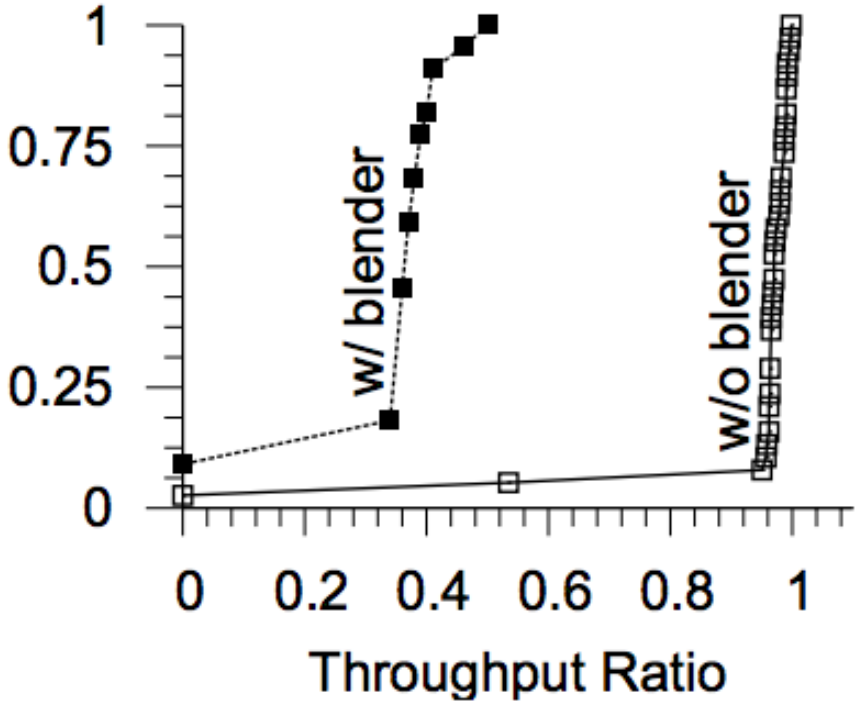


Figure 9: *Channel symmetry measured using the throughput between two nodes on the EC. The x-axis is the ratio between the lower throughput in one direction and the higher throughput in the opposite direction*

Conclusions

- PLC devices are very sensitive to AC noise levels.
- Common household devices will cause great variation in network performance throughout the day.
- They also do no work across surge protectors or other voltage suppressing devices.
- PLC devices should not be used for applications requiring very low RTT.
- PLC performance is much lower than the figures advertised by manufacturers.

Critical Review

Positives

- Used commercially available equipment.
- Tested equipment in fairly realistic environments.
- Simulated various conditions that may impact certain applications.

Negatives

- All environments had relatively new electrical systems (may not apply to a lot of homeowners).
- Didn’t provide an electrical layout or map of outlet location and distances.
- Above information would be helpful to analyze the impact of the wiring layout on network performance.

Questions?