

Netgear Powerline AV 200 XAVB2001 RTT Measurements with SPP

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Abstract—This report presents work that was performed to analyze the behaviour of traffic traversing Powerline adapters. Powerline adapters are networking equipment which modulate network traffic onto electrical wiring to transfer data. These adapters can provide up to 200 Mbps of bandwidth. In our tests, the adapters synchronized between 168 and 193 Mbps (at the physical layer) on average. We tested the adapters with TCP and UDP traffic to observe how they would behave when traffic is sent at varying rates. The TCP file transfer experienced a median RTT between 4 and 24 ms for offered rates from 1 to over 70Mbps. Uni-directional UDP traffic with offered loads from 1 and 40 Mbps experienced median RTTs between 2 and 16 ms, while offered loads over 40 Mbps led to significant increase in median RTT of almost 2000 ms.

I. INTRODUCTION

With broadband Internet connections becoming more affordable, residential customers have an increasing need to share their single Internet link between multiple devices [1][2]. Multimedia streaming, including IPTV, music, video-conferencing and videos, requires both bandwidth and reliable transmission. While CAT-5 (LAN) cables have been the de-facto medium when connecting multiple devices in a single room, a challenge arises when several rooms need to be connected. Retrofitting network cabling can prove to be expensive [1]. Homeplug Powerline Alliance, Inc (Homeplug) has released a standard called Powerline. Powerline AV adapters use this standard to modulate network traffic onto existing electrical wiring to transfer data[3].

Powerline technology uses OFDM (similar to IEEE 802.11a/g) at the physical layer for transmission and a “hybrid” MAC layer which allows it to offer capacity up to 200 Mbps while transferring IEEE 802.3 (Ethernet) frame formats. A variant of the CSMA/CA protocol used

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in wireless networks is used to moderate access to the common shared medium [1].

The Powerline AV technology was ratified in late 2010 as IEEE Std 1901-2010 [4]. This will allow products from different manufacturers to inter-operate, rendering the technology more accessible to the mainstream consumer market. The standard also specifies compatibility between older and newer models of Powerline AV adapters. The Netgear Powerline AV 200 XAVB2001 is a range of Homeplug-certified Powerline class of network adapters.

This report documents some tests carried out to analyze the performance of the Netgear Powerline AV 200 XAVB2001 adapters under varying traffic loads to discover the capacity of the adapters. The rest of this report is structured as follows. Section II explains the setup of the experiment and Section III and IV discusses the results obtained. Section V proposes some future work while section VI concludes this report.

II. EXPERIMENT

This section details each experiment and how data was collected and analyzed. Table I lists the equipment used in carrying out the tests. The testbed was setup as per Figure 1. Both endpoints are connected to the mains via a powerline adapter. The adapters act like a bridge forwarding packets from one to the next. All experiments used the default frame size with a maximum transmission unit (MTU) of 1500 bytes. The Netgear Powerline AV software reported the adapters as achieving a physical layer speed of 168 and 193 Mbps on average at the Monitor and Reference points respectively.

A. Methodology

All experiments used measurements of Round-trip time (RTT) to observe changes in behaviour of different types of traffic through the Netgear Powerline

TABLE I
EQUIPMENT USED FOR MEASURING RTT WITH SPP

Hardware	Specification
Endpoint PC 1	Intel Pentium 4 Processor 2.66 GHz 1 GB RAM FreeBSD 8.1 x86 Gigabit LAN port
Endpoint PC 2	Intel Pentium 4 Processor 2.0 Ghz 1 GB RAM FreeBSD 8.1 x86 Gigabit LAN port
2 Powerline AV Adapters	Netgear Powerline AV XAVB2001 Transfer speeds of up to 200 Mbps Firmware v0.2.0.4NA Netgear Utility

TABLE II
SCP COMMAND

```
scp -l bw testtrans.file root@192.168.1.3:
bw is the bandwidth set in kbits/s
```

XAVB2001 adapters. We used the SPP tool [5] developed at CAIA to passively calculate the RTT experienced by individual flows traversing the two endpoints. The SPP tool can process packets in real-time (live-capture) or captured packets in a tcpdump file. The data obtained from SPP is plotted to obtain the graphs of the RTT on the link for specific experiments as outlined below.

B. TCP Tests

The first experiment examined the behaviour of long-lived, uni-directional TCP flows as shown in Figure 1. This was achieved by copying a 600MB file via SCP between the two endpoints. The testbed was isolated from other networked equipment.

TCP traffic was generated at various rates by configuring SCP to transfer at a specific bandwidth. Table II shows the command used. We transferred traffic using SCP rate limits from 1 to 100 Mbps. This range of values simulate speeds that can be expected from ADSL (1, 2 and 2+) and Ethernet connections. Table III shows scenarios where selected speeds are used. These could be used when planning a home network with powerline adapters used to bridge connections to the Internet.

The reference node was configured as the primary data source, the other endpoint responded with ACKs. Tcpdump captured traffic at both ends which were later processed with SPP to obtain the RTT.

We repeated the experiment where bandwidth was limited via dummynet rather than SCP. The testbed layout was kept the same except that dummynet was implemented in one of the endpoints and SCP was used

TABLE III
BANDWIDTH APPLICATION

Bandwidth	Application
1 Mbps	Home to Internet transfers
4-16 Mbps	Internet to Home transfers
10 Mbps	Ethernet home LAN
100 Mbps	Fast Ethernet Home LAN

with its default settings - whereby it transmits at the maximum bandwidth it can achieve.

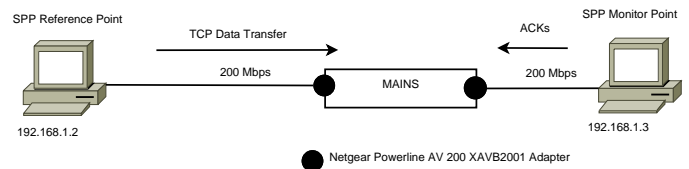


Fig. 1. Testbed Layout. SCP Traffic was sent from the reference point to the monitor point.

C. UDP Tests

A second experiment analyzed the behaviour of UDP traffic over the Powerline links. Figure 2 illustrates the UDP test layout. UDP is mostly used in delay-sensitive applications such as internet telephony and online games. Understanding its behaviour over Powerline adapters would prove useful in establishing how much traffic can be sent before delay becomes intolerable. The iPerf utility was used to generate UDP traffic. The tests streamed bi-directional UDP traffic at varying rates (1 to 60 Mbps) for a duration of 2 minutes to discover the capacity of the Powerline adapters.

As SPP matches corresponding packet-pairs, each endpoint was configured to act as both a UDP client and UDP server to generate bi-directional traffic. Tables IV and V show the commands used to configure iperf and ping. iPerf's output provides statistics including: the amount of data transferred, the bandwidth, jitter and packet loss.

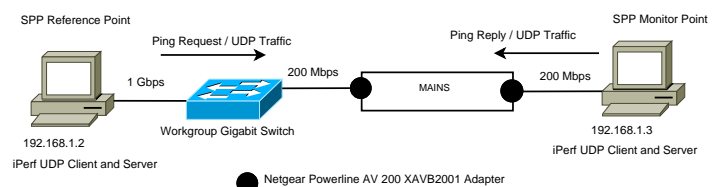


Fig. 2. UDP Testbed Layout. UDP Traffic was sent from both endpoints with pings sent from the reference point only.

Later, 512-byte pings were used to simulate the presence of "other" traffic, these were sent at a constant rate

TABLE IV
IPERF COMMANDS

Client side
<code>iperf -w 300k -u -c 192.168.1.2 -b 30m</code>
-w : sets the receive window size
-u : tells iperf to generate UDP traffic
-c : run in client mode connecting to 192.168.1.2 server
-b : specifies to bandwidth
Server Side
<code>iperf -s -u</code>
-s : operate in server mode
-u : use udp traffic

TABLE V
PING COMMANDS

<code>ping -i 0.02 -s 504 -t 180 136.186.229.102</code>
-i : ping rate in seconds
-s : ping payload (excluding 8-byte header)
-t : duration of ping
Last parameter is IP to ping

of 50 PPS. Tcpdump was used to capture traffic at both ends and filter the UDP and ICMP traffic. SPP was used to analyze the UDP datasets to obtain the RTT.

D. Limitations

The link speed mentioned for the Powerline AV XAVB2001 is based on the values reported by the Netgear Powerline AV utility. It is an average of visual samples taken at start and end of each test. The reported speeds varied from 177 to 195 Mbps for the adapter close to the reference point and from 168 to 180 for the adapter connected to the monitor point.

SSH was used to simultaneously start the experiment on each endpoint. The overhead imposed by SSH traffic through the link was not accounted for when presenting the results in this work.

III. TCP RESULTS

This section provides the results obtained for the tests detailed in section II.

A. TCP File Transfer with SCP limiting transfer rate

The TCP tests involved copying a 600MB file between two nodes via SCP to observe the change in RTT at various bandwidths. Table VI summarizes the median RTT obtained for various bandwidths while Figure 3 plots the graphs for each transfer. The powerline adapters synchronized between 173 and 180 Mbps at the physical layer during these tests.

For rates approximating ADSL bandwidth limitations (<20 Mbps), the powerline network exhibits an RTT ranging from 4.9 to 6 ms.

Data rates exceeding 20 Mbps indicate transfers between devices within the LAN. In this case we note that the observed RTT increases gradually as the offered load approaches the maximum available goodput. When the observed load exceeds this value, the observed RTT dramatically increases to greater than 18ms. This is likely due to exceeding the available bandwidth and causing queues within the network to fill up.

70 Mbps is the maximum offered rate at which queuing does not contribute to the increase in RTT. Transfers where SCP's rate limit was 75, 80, 85, 90 and 100 Mbps achieved a goodput of 65.6 Mbps (8.2 MB/s), in contrast to a goodput of 61.6 Mbps (7.7 MB/s) with SCP limited to 70 Mbps. Users wishing to use powerline adapters to copy files across a home network should limit their transfer speeds to the maximum observed goodput to get the best performance.

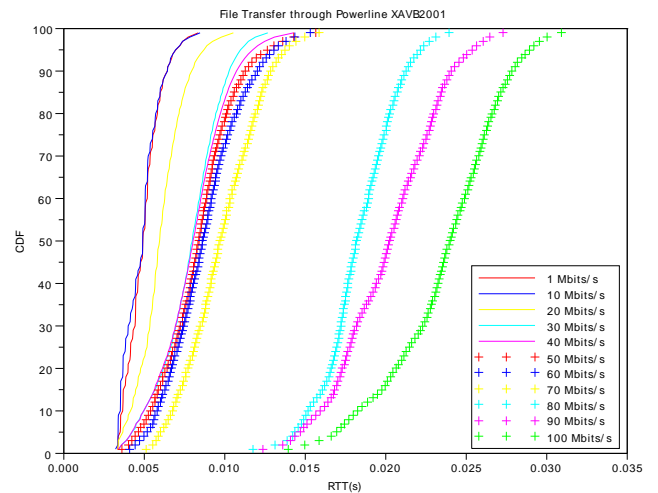


Fig. 3. 600MB TCP File Transfer with SCP rate limiting.

B. Dummynet Limited Traffic

The results obtained when dummynet was used to rate limit the bandwidth is similar to the ones obtained with SCP. Figure 4 plots the RTT for these tests. The main difference is the gap between the results for 70 and 80 Mbps results. For the SCP tests the gap was almost 10 ms whereas with the dummynet tests it is nearly 5 ms. It can also be observed, when comparing Tables VI and VII that there is slight difference in the RTT. This is likely

TABLE VI
600MB FILE TRANSFER WITH SCP RATE LIMITING

Limit (Mbps)	Median RTT(ms)	Transfer Time (HH:MM:SS)	Goodput (Mbps)
1	4.91	1:22:33	0.9
10	4.90	0:08:40	9.6
20	5.95	0:04:09	19.2
30	7.98	0:02:53	28.0
40	8.02	0:02:14	36.0
50	8.38	0:01:47	44.8
60	8.63	0:01:28	54.4
70	9.70	0:01:18	61.6
80	18.10	0:01:13	65.6
90	20.26	0:01:13	65.6
100	23.98	0:01:13	65.6

TABLE VII
600MB FILE TRANSFER WITH DUMMynet RATE LIMITING

Limit (Mbps)	Median RTT(ms)	% difference to SCP	Transfer Time (HH:MM:SS)	Goodput (Mbps)
1	4.63	-6.05	1:28:49	0.9
10	6.60	25.76	0:08:53	8.8
20	6.63	10.26	0:04:59	16.8
30	6.35	-25.67	0:03:20	24.0
40	6.60	-21.52	0:02:32	32.0
50	6.81	-23.05	0:02:02	40.0
60	7.69	-12.22	0:01:42	47.2
70	9.21	-5.32	0:01:29	53.6
80	14.38	-25.87	0:01:18	61.6
90	17.09	-18.55	0:01:16	63.2
100	20.45	-17.26	0:01:16	63.2

due to how and where the different scenarios implement rate limiting. SCP would most likely be limiting at the application layer whilst dummynet is within the kernel.

For the transfer at 80 Mbps, the dummynet test achieved an RTT of 14.38 ms - a difference of almost 4 ms when compared to the same SCP test.

IV. UDP TESTS

A. UDP tests with competing traffic

The next experiment involved the transfer of UDP traffic by sending UDP datagrams of 1470 bytes at 1 Mbps (iperf's default size and rate) with competing ping traffic sent at varying sizes and rates. Table VIII documents the results obtained while Figures 5 and 6 show the CDFs of these transfers. For all tests, the powerline adapters synchronized at a reported 166 and 192 Mbps at the physical layer.

The smaller 512-byte pings caused the median RTT to increase from 2.51 ms to 2.60 ms (+3.59%) and 2.75 ms (+9.56%) for ping rates of 50 and 100 pings/s

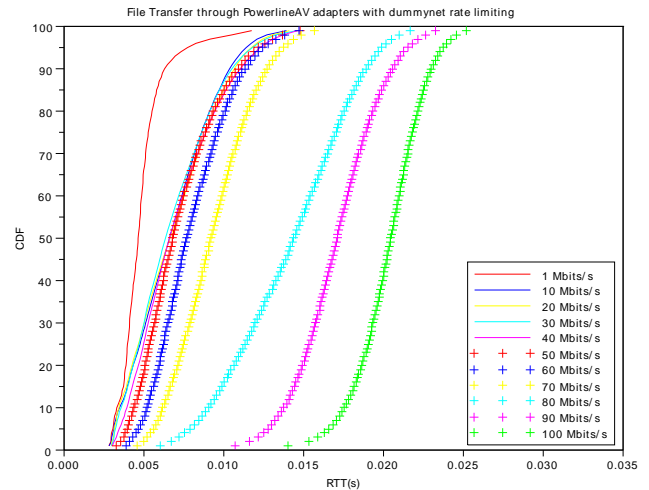


Fig. 4. 600MB TCP File Transfer with dummynet rate limiting.

respectively. When generating 1024-byte pings, the median RTT increased to 2.72 ms (+8.37%) and 2.90 ms (+15.54%) for ping rates of 50 and 100 ping/s respectively.

Larger - 2048-byte - pings were used to cause fragmentation of ICMP packets. The results of these tests are documented in Table IX and illustrated in Figure 7. In the case of 50 and 100 pings/s, back-to-back packet bursts caused the median RTT to increase from 2.51 ms to 3.07 ms (+22.31%) and 3.11 ms (+23.90%).

The shape of the "UDP only" graph is intriguing as it exhibits quantisation similar to that observed in ADSL transmission [6]. Moreover, when pings are generated together with the UDP transfer, the observed quantisation effect tends to smooth out. Several trials were run to verify this behaviour and all returned similar results. Future work will examine the cause of this.

B. Further tests

To further investigate the behaviour of the link with UDP traffic, tests were carried out by varying the UDP traffic rate and generating constant 512-bytes pings at 50 PPS. UDP traffic was transferred across the network at increasing rates (from 1 Mbps to 60 Mbps) for a duration of 2 minutes. Figures 8, 9, 10 show the RTT of UDP traffic against time at specific rates. It can be observed that for a UDP transfer rate of 1 Mbps and 40 Mbps, the RTT varies randomly over a small range of values whereas at 43 Mbps, the RTT increases over time.

Table X shows the median RTT for the different UDP rates whilst Figures 11 and 12 illustrate the CDFs of the

TABLE VIII
UDP TRAFFIC WITH VARYING PING LOADS

Ping Size (bytes)	Pings/s	Median RTT (ms)
No ping	—	2.51
512	50	2.60
1024	50	2.72
512	100	2.75
1024	100	2.90

TABLE IX
UDP TRAFFIC WITH FRAGMENTED PING LOADS

Ping Size (bytes)	Packets/s	Median RTT (ms)
No Ping	—	2.51
2048	50	3.07
2048	100	3.11

UDP traffic's RTT

The results obtained demonstrate that from 1 Mbps to 40 Mbps, the median RTT through the network was distributed within 2 to 16 ms. However, when the generated UDP traffic exceeded 40 Mbps, the RTT increased until it reached a median RTT of almost 2000 ms at 43 Mbps. Table XI documents the packet loss statistics experienced by the UDP transfers.

Figure 11 shows the RTT with UDP bandwidth ranging from 1 to 40 Mbps whereas Figure 12 presents the dramatic increase in RTT when the UDP bandwidth is set between 41 and 60 Mbps. Figure 13 shows the variation in median RTT with respect to the UDP Bandwidth.

The UDP transfer experiences dramatic packet-loss due to the traffic transfer being bi-directional. This

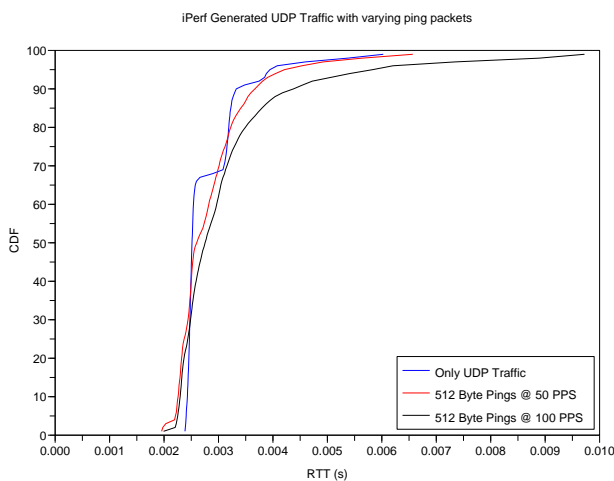


Fig. 5. UDP Traffic behaviour with 512 byte pings sent simultaneously at 50 and 100 pings per second.

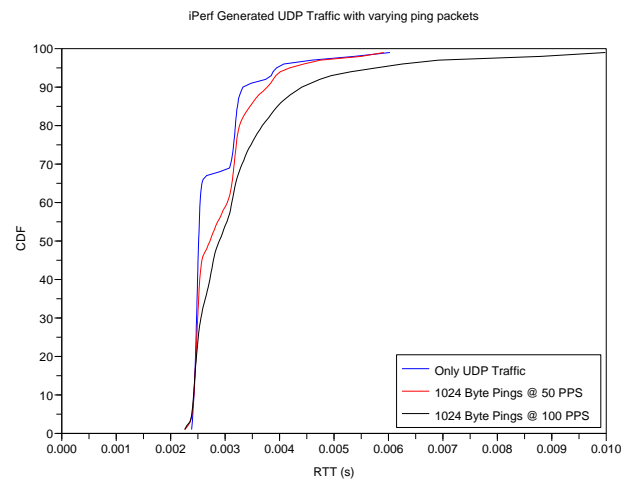


Fig. 6. UDP Traffic behaviour with 1024 byte pings sent simultaneously at 50 and 100 pings per second. We observe an increase in RTT when pings are loaded into the network at 50 PPS and more so at 100 PPS.

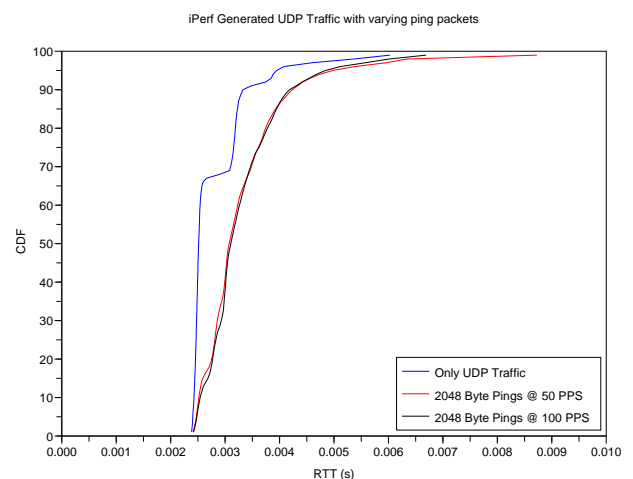


Fig. 7. UDP Traffic behaviour with 2048 byte pings sent simultaneously at 50 and 100 pings per second. We observe an increase in RTT when pings are loaded into the network at 50 PPS and at 100 PPS.

doubles the requirement for bandwidth on the powerline links. At a UDP traffic rate of 43 Mbps (uni-directional), we observe the median RTT peak to more than 1800 ms whereas at 42 Mbps the median RTT is approximately 85 ms. This increase in RTT could be due to the powerline adapters reaching their capacity and backing-off for a random period of time (collision avoidance) before resuming data transfer.

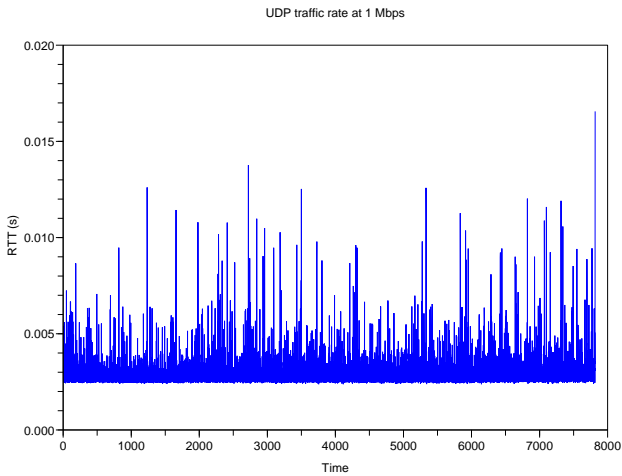


Fig. 8. RTT vs Time for UDP Traffic at 1 Mbps

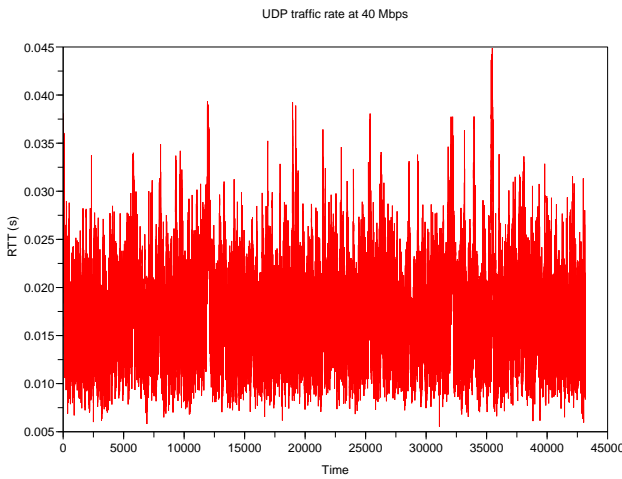


Fig. 9. RTT vs Time for UDP Traffic at 40 Mbps

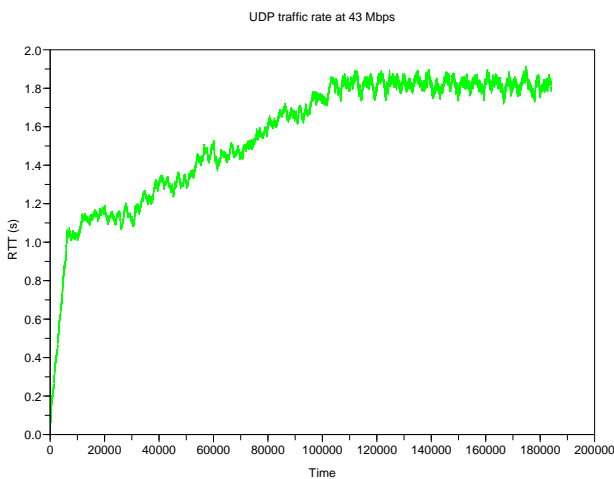


Fig. 10. RTT vs Time for UDP Traffic at 43 Mbps

TABLE X
UDP TRAFFIC STATISTICS (UNI-DIRECTIONAL)

Rate (Mbps)	Median RTT (ms)
1	2.74
5	3.11
10	3.64
15	4.17
20	4.63
25	5.30
30	6.79
35	9.82
40	16.35
41	52.61
42	85.66
43	1808.81
44	1824.83
45	1818.34
46	1820.00
47	1830.01
48	1831.35
49	1825.88
50	1830.63
55	1831.47
60	1835.06

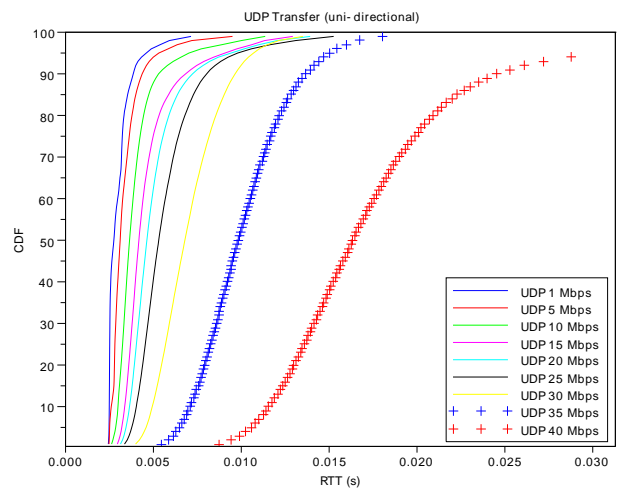


Fig. 11. UDP Traffic Behaviour with UDP bandwidth varied from 1 to 40 Mbps with 512 byte pings sent simultaneously at 50 PPS.

V. FUTURE WORK

Future work in this project will examine traffic behaviour at a finer granularity - as related to UDP and ping buffer sizes - to smooth out the results obtained in this work. The quantisation apparent in UDP traffic transfers will also be further investigated.

Traffic behaviour in more complex scenarios will be scrutinized. For example, one such scenario could have the Powerline adapters on different power-boards to

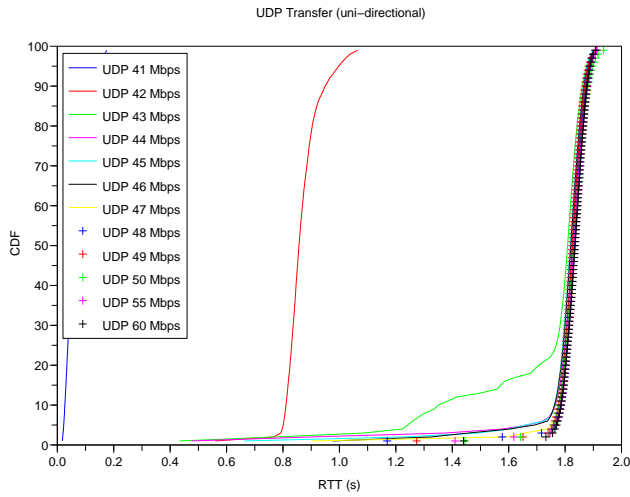


Fig. 12. UDP Traffic Behaviour focusing on UDP bandwidth from 41 to 60 Mbps with 512 byte pings sent simultaneously at 50 PPS. The dramatic increase in RTT at 43 Mbps can be compared with Figure 11.

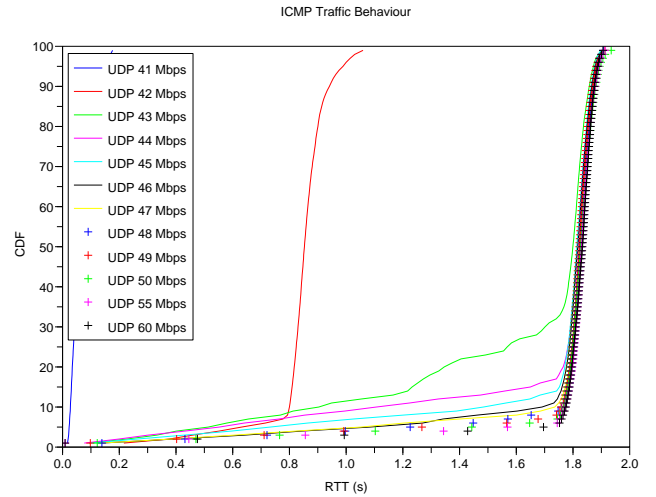


Fig. 14. The plot shows the ICMP traffic behaviour when it competes with UDP traffic. The graphs have a similar shape to Fig 12.

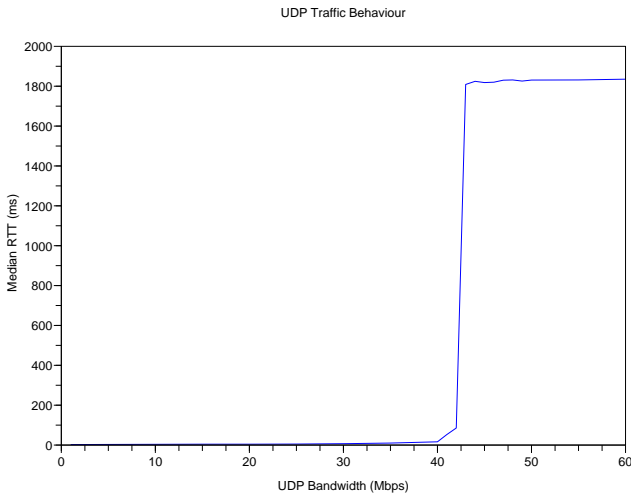


Fig. 13. The graph plots UDP traffic behaviour at varying rates.

simulate the adapters being in different rooms. This test could identify how noise in the electrical wiring can affect data transmission over various distances.

Alternatively a third PC connected to a third powerline adapter could be introduced to study the effects competing bandwidth could have on TCP transfers.

VI. CONCLUSION

The aim of this project was to study the properties of the Netgear Powerline AV XAVB2001 under different loads. A testbed was setup to study the effects of TCP and UDP traffic. Uni-directional TCP was sent through

TABLE XI
UDP PACKET LOSS FOR VARYING UDP BANDWIDTHS ACROSS
POWELINE AV ADAPTERS

Rate (Mbps)	Packet Loss (%)
1 to 40	≈ 0.0
41	0.04
42	3.1
43	9.9
44	13
45	14
46	15
47	17
48	19
49	21
50	22
55	29
60	35

the link at various rates and the RTT was measured whilst rate limiting with SCP and dummynet. The effect on UDP flows by competing ICMP traffic including traffic consisting of back-to-back packet bursts (through fragmentation) was also studied.

For the TCP file transfer tests, we found that copying a file at over 80 Mbps caused the median RTT to reach atleast 14 ms (dummynet case) as compared to 4-10 ms when the bandwidth is between 1 and 70 Mbps. For the UDP tests, we found that back-to-back ping bursts caused the median RTT to shift by more than 0.5 ms (+22.31% to +23.90%) when compared with “no ping” traffic. We also discovered that transferring (uni-directional) UDP traffic at rates greater than 40 Mbps resulted in the median RTT reaching almost 2000 ms - in

contrast with a scenario where UDP traffic rates between 1 and 40 Mbps resulted a in median RTT varying from 2 to 16 ms.

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