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## Initial Comparison of EPRs and IPRs in the Pup Internet Environment

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### Introduction

For the last several years the Bay Area Packet Radio Network (the PRNet) has been used as one of the packet transport mechanisms in the Pup internetwork system -- the PRNet provides an alternative link between two buildings about 1 mile apart in Palo Alto. In regular use, hosts connected to an Ethernet system in one building send Pups to an internetwork gateway connected to the PRNet; from there the packets are sent via the PRNet to another gateway in the other building, and finally enter the destination Ethernet [Boggs, *et al.*, 1980; Shoch, 1980].

We have previously reported on this installation: the system works reasonably well, but overall performance has been disappointing [Shoch & Stewart, 1979a, 1979b]. In particular, it appeared that the PRNet had some severe limits on the number of packets it could handle due, we speculated, to the per-packet processing time in the Experimental Packet Radios (EPRs).

Thus, we hoped that the additional processing capability in the Improved Packet Radios (IPRs) would help to alleviate these constraints. In recent months we have been able to install IPRs at the Parc and Hanover Street buildings, and in March we endeavored to replicate some of the earlier tests.

The basic series of measurements uses a test program (PupTest) that generates reliable, flow-controlled streams of bytes between two processes; location of the source and destination process are varied, to test out assorted configurations.

For an ideal comparison one would prefer that there had been no other changes in the environment since our last tests; that, of course, has not been possible. At a minimum, these changes have occurred:

- EPRs have been replaced with IPRs.
- The 1822 cable from one gateway to its radio has been lengthened.
- The basic PupTest program has been improved.
- The PRNet headers were modified (expanded to 14 words), necessitating changes to the PRNet driver in the Pup package.
- The Pup gateway program has been changed.
- etc.

These changes certainly make it hard to perform a strict comparison; in spite of this, the environment is still fundamentally the same, and we believe that this *preliminary* comparison does yield some useful information.

## Test results

The tests reported here were carried out on Saturday, March 8, 1980. The Mesa PupTest program was used to produce test traffic according to the Pup Byte Stream Protocol (BSP): a reliable, flow-controlled stream with multiple outstanding packets. In practice there are at most 5 packets outstanding at one time, with a dynamic flow control and retransmission algorithm in use.

Six test configurations were used, as reported in this table:

location of the source & destination processes	-----EPR-----				-----IPR-----			
	maximum <sup>1</sup> packets per sec. (pps)	1 word per pac. (bps)	100 wds. per pac. (Kbps)	266 wds. per pac. (Kbps)	maximum <sup>1</sup> packets per sec. (pps)	1 word per pac. (bps)	100 wds. per pac. (Kbps)	266 wds. per pac. (Kbps)
in the same machine	51	809	79	200	55	879	84.2	208
in 2 different hosts on the same Ethernet	64	988	102	267	81	1290	124	304
hosts on 2 adjacent Ethernets, with 1 gateway	51	810	80	203	67	1070	110	260
hosts on 2 Ethernets with a phone line & 2 gateways	17	267	6.8	8.3	16	264	6.8	8.0
hosts directly connected to Packet Radios	10	155	15	15.4 <sup>2</sup> 13.2 <sup>3</sup>	11	174	17.1 <sup>4</sup> 15.8 <sup>5</sup>	15.2
hosts on 2 Ethernets with Radionet & 2 gateways	8	120	11.9	12.4	11	171	17.1 <sup>2,4</sup> 14.1 <sup>3,5</sup>	15.1

### Notes:

<sup>1</sup>Computed using 1 data word/packet.

<sup>2</sup>Parc to Hanover St.

<sup>3</sup>Hanover St. to Parc

<sup>4</sup>"Good" runs only, with few packets requiring retransmission

<sup>5</sup>All runs, including those with large numbers of retransmissions

### Comments on the test results

1. Performance of the PupTest program in the first three configurations has improved significantly. Throughput has gone up 30% when sending small packets between two hosts on the same Ethernet, and it is up 32% when going through a single gateway.
2. When going through an intermediate phone line rather than the PRNet, overall throughput is basically unchanged from the prior experiments.
3. For small packets, the performance of the PRNet has improved a bit. The system can now accept up to 11 packets/sec., or over 170 user data bits/sec.
4. With larger packets containing 100 data words, however, behavior of the PRNet has been very

hard to interpret. (Note that a Pup with 100 data words can still be encapsulated within one PRNet packet.) We usually set up one configuration, and then run multiple tests -- each lasting for perhaps 1 minute. In some of the those tests the PRNet behaves flawlessly for some runs, but terribly in others.

An important measurement of interest is the number of Pup retransmissions/1000 packets required at the sender -- either because a packet has been lost in the PRNet, or because it has been severely delayed. With two hosts connected directly to the PRNet we have had runs which reported 0 retransmissions. Yet, in the same configuration we have had runs which reported 31, 68, 8, 20, 50, 30, 23, and 51 retransmissions per 1000 packets.

As before, we also find that the path from Hanover St. to Parc seems to suffer more errors and delays than the other direction. In the last configuration in the table above, on the path from Hanover to Parc, the BSP sender reported that it required 160, 247, 162, 193, 170, and 171 retransmissions per 1000 packets!

Many of these transmission appear to be caused by undue delay of some packets in the PRNet. Lengthy delay in the PRNet can cause extensive re-ordering of packets; packets received out of order at the destination may trigger a partial acknowledgement, thus triggering retransmission -- even when the original packet is still in the pipeline.

Our retransmission algorithms do work correctly, and do handle mis-ordered packets -- the stream does make progress. Unfortunately, when confronted with a widely varying delay and lots of reordering, the overall performance suffers. As we've seen before, protocol correctness under adverse conditions is an important initial concern; but overall performance under these conditions is an additional serious problem.

In spite of this, throughput with 100 word packets did improve, from 12-15 Kbps to 14-17 Kbps.

5. Full-size Pups can contain up to 266 words; these packets require fragmentation for transmission through the PRNet. In our environment, we use network-specific fragmentation: the entry gateway splits up the Pup, sending multiple PRNet packets which are reassembled at the exit gateway.

This produces a very interesting effect: the reassembly operation at the exit gateway provides an opportunity to correct much of the reordering -- the PRNet driver waits a bit, trying to collect all three parts of the large Pup. Thus, the PRNet driver is, in many ways, more forgiving than the BSP driver, and it can successfully masquerade much of the re-ordering. Thus, in the experiments with larger Pup sizes we found very low counts of retransmissions per 1000 packets; the reordering introduced in the PRNet seems to be mitigated by the network-specific reassembly, thus reducing the need for end-to-end retransmission.

Even with this effect, though, total throughput has only gone up to about 15 Kbps.

#### Some final observations

Please note that these results are very tentative, and will require further work to understand precisely what is going on. It is apparent, however, that the PRNet is still introducing widely variable delay, and there has not been a quantum jump in its current performance.

We do note, however, that both SRI and Collins are aware of some of these problems. We were delighted to note in the weekly progress report for March 24-28 that they will be working together to help improve the IPR performance.

In the weeks ahead we will be moving one of our IPRs. After that move, and after any modifications are undertaken by SRI and Collins, we plan to re-evaluate these measurements.

## Bibliography

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