Results of the Telecom Canada High Performance Routing Trial

France Caron
BNR
3, Place du Commerce,
Ile-des-Soeurs, Québec,
Canada H3E 1H6

Abstract
This paper describes the High Performance Routing (HPR) trial in the Telecom Canada toll network. The trial confirmed the effectiveness of this centralized, adaptive call routing system under normal and stressed conditions. It also brought valuable information on administering an HPR network.

1. Introduction

From April 21 1987 to July 31 1987, a major field trial in the Canadian toll network served as a preliminary step for future implementation of the Telecom Canada HPR network. HPR uses Dynamically Controlled Routing* (DCR), a centralized adaptive routing method, operating in near real-time, whose performance was successfully tested on the metropolitan network of Toronto in 1979 [1]. It takes advantage of the digital switches' ability to transmit and collect information to provide better efficiency and survivability to the network than was possible with the traditional Fixed Hierarchical Routing (FHR) method.

The heart of the HPR system is the central Network Processor (NP) with which all HPR switches communicate. During an HPR session, each participating switch reports to the NP every 10 seconds with information on its trunking status, overflow traffic, and CPU occupancy. Using this information, the NP directs each switch, within 5 seconds, on how it should treat overflow traffic until the next reporting cycle. These instructions take the form of simple updates to the routing tables which are used whenever traffic cannot be routed directly.

A call routed by HPR uses at most two HPR links. The connection path is either direct or through a single tandem. This tandem is chosen by the NP on an availability basis from all the HPR switches that can relay the call. There is no trunk classification or switch hierarchy as there was with FHR. Alternate routes are thus chosen on a near real-time basis so as to make better use of the available resources. This approach permits congestion control and incorporates network management functionality by automating expansive actions and some restrictive actions.

The objectives of this trial were to test the technology and to evaluate the operation and administrability of an HPR network – that is, operation of the routing rules within a HPR network and at the FHR/HPR interface, and the adequacy of the HPR servicing system Operational Measurements. It also provided real test cases to study the network management aspects of HPR centralized administration by the National Network Operation Center. The Operational Measurements (OMs) obtained during the trial enabled estimates of the point-to-point Grade-of-Service (GOS) for the Origin-Destination pairs and allowed an appreciation of HPR performance within the trial network.

* Trademark of Northern Telecom.
2. Field Trial Description

2.1 Network Description

The Telecom Canada High Performance Routing field trial was a major experiment involving four of the Telecom Canada companies: Bell Canada, Alberta Government Telephones, Manitoba Telephone System, and Saskatchewan Telecommunications. Telecom Canada funded and coordinated the project, and BNR provided technical assistance and the expertise for traffic analysis.

The trial lasted three months (April 21 - July 31) during which HPR and FHR alternated every two or three weeks.

Six high traffic volume DMS-200* switches, distributed across Canada, were used in the trial (fig.1). Their software was modified to enable HPR, and all six switches were allowed to originate, terminate and tandem HPR calls.

![HPR Trial Network Connectivity](image)

**Fig. 1** HPR Trial Network Connectivity

Except for one link which is missing (Quebec-Regina), the HPR trial network was fully connected with two-way direct trunk groups, but it was not sized for HPR. Most trial switches occupy key positions in the FHR network (fig.2).

Because the toll network has an FHR component (and will still have one in the final system because not all switches are software controlled), it was necessary to design a protocol for transferring calls between networks. For servicing and forecasting purposes, a set of rules known as the Unique Entry - Unique Exit protocol (fig.3) was used. It allocates to each non-HPR originating node a single HPR origin, its Unique Entry into HPR. In the same manner, each non-HPR destination node has a corresponding Unique Exit HPR destination. Calls originating or terminating outside the HPR network may be both FHR- and HPR-routed.

Due to the limited choice of tandems in the small HPR trial network, there was the possibility of no alternate route being available for an origin-destination pair. In that case, the Network Processor was to give a CONTINUE recommendation to forward the affected HPR overflow calls to an Exception Route List that would return them into the large FHR network.

During the trial, some HPR trunks carried a portion of FHR traffic (e.g. mass calling and overseas calling).

* Trademark of Northern Telecom.
2.2 System Environment

A DNC-500* was the designated NP for the trial. With a Distributed Processing architecture, it enables the decomposition of the routing algorithm for rapid calculations, and allows reports and statistics to be generated simultaneously. It was located at the National Network Operation Center, and connected to the participating switches via DataPac**, the Canadian packet-switched network.

Transmission between the NP and the switches was performed using the X.25 layered interface Network Operation Protocol* running at 9600 baud.

To accommodate HPR, two main areas of development were required in the DMS switch: communications and call processing. The new communications feature permitted the switch to provide congestion data and process recommendations at call processing priority, within the prescribed update cycle interval. The call processing development included new pointers

---

* Trademark of Northern Telecom.
** Trademark of Bell Canada.
inserted at the specific locations where the HPR recommendations were to begin routing control of the call.

3. Data Processing For GOS Analysis

3.1 Operational Measurements

The data used for the analysis consists of Operational Measurements (OMs) pegged by each switch and designed for HPR servicing. Some are on an origin-destination (O-D) basis: number of first-offered calls, number of these which overflowed, etc.; others are on a link basis: number of HPR calls which used the link as first tandem leg, number of these which overflowed, etc. Most of the traditional DMS-200 OMs used in the analysis are on a trunk group basis: number of attempts, number of overflow calls, number of deflected calls, trunk usage, etc.

The Network Processor provides an additional OM. For each O-D pair, this OM gives a summary of the NP recommendations. Every possible recommendation has its own register where the OM is incremented each time the recommendation is selected by the NP.

Because of the logical relationships that exist among different OMs, simple mathematical equations could be derived and used in the trial as validation tests for the routing as well as for the OM pegging itself. Failure of some validation tests could also lead to the clear identification of specific network problems, e.g. switch status change from HPR to FHR.

Exclusively for the trial, switch OMs were recorded on tapes on a half-hourly basis, aggregated and sorted on a mainframe computer; using a time consistent half-hourly aggregation, the NP OM was collected on an M6000 micro-computer, and then forwarded to the same mainframe computer.

3.2 Grade-of-Service Computations

Servicing in an HPR network is based on point-to-point blocking as opposed to blocking on finals in FHR. This ensures a satisfactory GOS for all traffic offered to the network. Point-to-point blocking is estimated from the HPR customized OMs.

For the purpose of this study, an HPR call is considered HPR-blocked if it was not successfully routed on the direct link or via its recommended tandem, although it may have completed over the Exception Routes.

Therefore, an HPR overflow call is declared HPR-blocked if one of the following is true:

(a) it was recommended by the NP to the Exception Route List, or
(b) it overflowed the NP-recommended first tandem leg (misrouted-1), hence proceeding to the Exception Route List, or
(c) it overflowed the NP-recommended second tandem leg (misrouted-2), and was blocked.

The HPR-blocked calls that fall into categories (a) and (b) are pegged directly on an O-D basis.

However, misrouted-2 calls are pegged on a link basis rather than an O-D basis. HPR blocking due to misrouted-2 calls for each O-D pair is therefore estimated**.

* Trademark of Northern Telecom.

** The method used for estimating this number was tested by simulation. Since the resulting relative error was less than 0.5%, the method was judged adequate.
4. Performance

The objectives of the GOS analysis were to monitor the system and verify HPR behavior. Under normal operating conditions, the HPR network carried more than 99.7% of the traffic outside the busy hour.

During the busy hour, this figure dropped to 99%. This does not represent total call completion because of the 1% overflowing the HPR network, a large proportion would complete via the Exception Routes. The busy hour gave us an opportunity to observe HPR’s adaptability in optimizing call completion for a full load on an unbalanced network.

Consider the busiest “busy hour” during the HPR trial. The way HPR treated overflow traffic is shown in Figure 4.

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>From</th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Edmonton</td>
<td>Montreal</td>
<td>Quebec</td>
</tr>
<tr>
<td>EDTN</td>
<td>0.5  0.0</td>
<td>0.0  0.0</td>
<td>0.0  0.0</td>
</tr>
<tr>
<td>MTRL</td>
<td>1.9  0.0</td>
<td>0.0  0.0</td>
<td>0.0  0.0</td>
</tr>
<tr>
<td>QUBC</td>
<td>0.0  0.0</td>
<td>0.0  0.0</td>
<td>0.0  0.0</td>
</tr>
<tr>
<td>REGN</td>
<td>0.0  0.0</td>
<td>0.0  0.0</td>
<td>100.0 0.0</td>
</tr>
<tr>
<td>TORO</td>
<td>5.8  3.3</td>
<td>0.6  1.9</td>
<td>26.4 6.3</td>
</tr>
<tr>
<td>WNPG</td>
<td>0.0  0.0</td>
<td>7.9  0.0</td>
<td>0.0  0.0</td>
</tr>
</tbody>
</table>

Fig. 4 Overflow Traffic, June 30, 9:00 to 10:00

HPR successfully completed all calls with the exception of some Toronto traffic. The reason lies in the nature of the trial network. The HPR Toronto8 node is a Class-4 and is not heavily connected to the other trial switches. In FHR, Toronto8 traffic overflows in a large proportion via the 624 trunk final group to its home, the Class-2 Toronto7 switch (fig.2). This switch is better connected to the rest of the network – for example, Toronto7-Quebec3 has 96 trunks on the direct link whereas Toronto8-Quebec3 has only 24.

However, HPR was still able to route almost all traffic from and to Toronto8 by taking advantage, on a real-time basis, of any spare capacity on one of the five links to route overflow traffic. As a result, all Toronto8 HPR links were fully utilized, each of them having an average occupancy higher than 91%. Most HPR-blocked calls were stopped at source (and then forwarded to Exception Routes) while Toronto8 was never recommended as a tandem during this busy hour, thereby demonstrating HPR’s ability to divert automatically alternate routed traffic from a congested area.

4.1 Facility Failures

All facility failures which occurred during periods of light or moderate traffic load were handled smoothly by HPR.
June 16, 18:00 – 22:00
A severe thunderstorm in the Brandon area (Manitoba) damaged a transmission link between Grassmere (Manitoba) and Regina. Many HPR trunk groups were affected but all calls were completed. Between 19:00 and 20:00, no Regina-Toronto calls could use the direct link but all were completed within the HPR network.

June 30, 11:00 – 11:30
The already small trunk group Regina-Toronto lost part of its capacity because of a failure. All overflow calls were completed within the HPR network.

Even during periods of high traffic, HPR reacted effectively to facility failures. For example, on May 27, between 13:35 and 13:44, just in the afternoon peak, an electrical storm caused the failure of a major transmission cable between Montreal and Toronto. It affected Edmonton-Montreal, Toronto-Montreal, Regina-Montreal, Winnipeg-Montreal and Edmonton-Quebec trunk groups.

All traffic to Montreal (except Quebec-Montreal) experienced heavy overflow. Despite its large trunk group to Montreal, the Quebec switch was rarely used as a tandem (Regina does not have a direct link to Quebec, Edmonton-Quebec link was damaged and it was a busy period for the Toronto-Quebec direct traffic). Therefore, most overflow of the traffic destined for Montreal received a CONTINUE recommendation. The Winnipeg-Montreal traffic used its small 24-trunk group to Quebec. As a result, 12 of 19 attempts reached the large Quebec-Montreal link and were successfully completed. This did not disturb the light direct traffic on the Winnipeg-Quebec link where only one of the 33 direct calls overflowed.

Figure 5 summarizes the HPR treatment of calls to Montreal during this failure. No network management control was applied due to the short duration of the failure. Network managers noted that HPR reacted quickly to the situation and performed well with the network available.

<table>
<thead>
<tr>
<th>From</th>
<th>Offered Calls</th>
<th>% Dir</th>
<th>% Via Tandem</th>
<th>% Blocked Calls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CONT</td>
</tr>
<tr>
<td>Edmonton</td>
<td>115</td>
<td>53.04</td>
<td>2.61</td>
<td>42.61</td>
</tr>
<tr>
<td>Quebec</td>
<td>887</td>
<td>100.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Regina</td>
<td>328</td>
<td>31.90</td>
<td>0.00</td>
<td>68.90</td>
</tr>
<tr>
<td>Toronto</td>
<td>507</td>
<td>87.38</td>
<td>0.00</td>
<td>12.62</td>
</tr>
<tr>
<td>Winnipeg</td>
<td>100</td>
<td>62.00</td>
<td>15.00</td>
<td>15.00</td>
</tr>
</tbody>
</table>

Fig. 5 HPR-Blocking of Calls Destined for Montreal – May 27, 13:30-14:00

4.2 Focused Overload
One of the crucial test cases for HPR occurred unexpectedly on the last day of the trial. On July 31, at 15:15, Edmonton was hit by a tornado. Canadians were progressively made aware of the catastrophe and a huge volume of calls started converging on Edmonton.

At 17:30, the Edmonton switch crossed the HPR overload threshold. It then began alternating between the normal, overload and severe overload conditions. The NP reacted accordingly. Not once was Edmonton recommended as tandem. When the switch was in severe overload, only direct calls were allowed to try to reach Edmonton – tandem calls were blocked at source.
Nevertheless, direct calls were coming from everywhere in an unprecedented number. At 18:11, the switch started experiencing trouble in sending the congestion data to the NP. At 18:57, network managers applied controls on direct traffic. The half-hour between 18:00 and 18:30 is of great interest because the switch was already overloaded and no controls had been applied yet. At that time, Montreal and Toronto were only starting to react to the news and could still be offered as tandems. Figure 6 describes this period.

<table>
<thead>
<tr>
<th>From-To Calls</th>
<th>MTL-EDM</th>
<th>RGN-EDM</th>
<th>TOR-EDM</th>
<th>WPG-EDM</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offered</td>
<td>266</td>
<td>5,714</td>
<td>623</td>
<td>3,000</td>
<td>9,603</td>
</tr>
<tr>
<td>Via Dir</td>
<td>252</td>
<td>1,053</td>
<td>616</td>
<td>802</td>
<td>2,723</td>
</tr>
<tr>
<td>Via Tdm</td>
<td>11</td>
<td>314</td>
<td>0</td>
<td>329</td>
<td>654</td>
</tr>
<tr>
<td>CONTINUE</td>
<td>3</td>
<td>3,716</td>
<td>7</td>
<td>1,783</td>
<td>5,509</td>
</tr>
<tr>
<td>mlsr-1</td>
<td>0</td>
<td>321</td>
<td>0</td>
<td>0</td>
<td>321</td>
</tr>
<tr>
<td>mlsr-2</td>
<td>0</td>
<td>310</td>
<td>0</td>
<td>86</td>
<td>396</td>
</tr>
</tbody>
</table>

Fig. 6  HPR-Blocking of Calls Destined for Edmonton - July 31, 18:00-18:30

Consider Regina-Edmonton traffic. 5714 calls were offered, of which 1053 (18%) were carried on the direct link, 3716 (65%) were HPR-blocked at source, and the remaining 945 (17%) were recommended to an alternate route (Montreal or Toronto). This demonstrates the network management functionality of HPR to block at source overflow calls with poor chances of completion and, on identifying an available route, to send the corresponding recommendation to the originating switch.

500 Regina-Edmonton calls were offered to Montreal which they all reached due to the large Regina-Montreal final. They arrived at Montreal in a bursty manner. We estimate 20 10-second bursts of 25 calls for a potential intensity of 75 erlangs. Since the 72 trunk Montreal-Edmonton group was already carrying direct traffic at an intensity of 40 erlangs, 62% Regina-Edmonton calls overflowed the second leg. The 266 Montreal-Edmonton direct calls were not really affected (5% overflow).

445 Regina-Edmonton calls were offered to Toronto. Again, these calls were bursty and the small 24-trunk Regina-Toronto could not accommodate them all. 321 calls overflowed and proceeded to Exception Route. The 10 Regina-Toronto direct calls were all carried on the direct route. The blocking on the second leg was small (5%).

Rather than blocking all overflow calls at source, the NP tried routing them when all these three conditions were verified:

1. Edmonton switch was not severely overloaded
2. there was available capacity reported on both legs
3. no direct traffic was expected to be harmed

From this experience, the following conclusions can be drawn:

- When the network was under focused overload, HPR performed well in incorporating network management restrictive action to the routing.
- Direct traffic was protected.
- This real test case confirmed the value of the studies that are being conducted on the extension of HPR to direct traffic control.
5. Comparison with FHR

Because data was also collected on FHR weeks, a comparison between FHR and HPR was possible. But since Calgary and Toronto were not included in the trial, a point-to-point blocking comparison could not be supported.

However, a comparison could be made on link occupancies. HPR, because of its load spreading feature, is expected to distribute traffic more evenly to the available facilities. To test this hypothesis, a model of the link occupancy was proposed:

\[ O_{l,r,d,h} = \mu_h + L_{l,r,h} + D_{d,h} \]  

where

- \( O_{l,r,d,h} \) is the mean link occupancy on link \( l \) when calls are routed by method \( r \), on business day \( d \) during half-hour \( h \),
- \( \mu_h \) is the mean value of all link occupancies for half-hour \( h \),
- \( L_{l,r,h} \) is the link effect,
- \( D_{d,h} \) is the day effect.

Proving that in HPR the traffic is distributed more evenly among the links then becomes equivalent to showing that the variance among the link effects is smaller with HPR.

This defines a linear regression problem which was solved for every half-hour, using all available data for HPR and FHR days.

On Figure 7, the variances of the link effects in FHR and HPR for each half-hour of the analysis are plotted on two different curves. It can be observed that when the variance is high (during traffic peaks), HPR reduces it. The results would have been much more significant, had there been more overflow traffic and wider tandem selection. Because FHR and HPR carried directly the same proportion of traffic, HPR's load spreading ability did not compromise the network efficiency.

6. Network Management and Administration

Throughout the trial, the administrability of the HPR network was studied by each member company, the Network Management (NM) and the Forecasting, Servicing and Administration (FSA) sub-committees. The special tests and the knowledge gained from the experience allowed a global appreciation of the implications of administrating an HPR network.

6.1 Routing Translations

The routing translations are the set of instructions, datafilled in each switch, that direct each outgoing call to the appropriate route.

The trial proved the administrability of HPR translations in a mixed environment. Consequently, FHR traffic and HPR traffic can be separated in the routing and OM pegging processes, and still be able to use common trunk groups.

This demonstrates the feasibility of a gradual introduction of HPR into an existing FHR network.
6.2 Network Management

When the FHR network does not accommodate the demand, Network Management applies reroutes and other controls to enhance call completion if spare capacity exists and to limit traffic with a poor chance of completion.

It was generally accepted by member companies that HPR reduces the need for Network Management actions on business days, during discount periods, and on peak days. Network managers feel that HPR will reduce blocking by taking advantage of load variations that arise between business and residence calling patterns, seasonal calling rates and non-coincident busy hours in different time zones.

- Even with the small trial network, the algorithm did seek out spare capacity resulting from varying calling patterns.
- On a peak day (Father's Day), HPR performed Network management functions with better speed of response than possible manually. In network congestion, the system always protected direct traffic first and only tandemed overflow calls when valid tandem capacity was available. All HPR links were fully utilized.
- In HPR, pressure controlling is totally unnecessary. The algorithm distributes tandem availability to all, irrespective of the number of attempts.
- The algorithm recognized quickly the reduction of trunking capacity in facility failures and reacted effectively.

With a new feature that would extend the application of HPR to direct traffic, the algorithm would reduce even more the need for manual intervention. And if a manual action appears to be necessary, network managers agree, based on hands-on experience gained during the trial, that it should be coordinated from a central point.
6.3 Servicing and Forecasting

The trial proved the adequacy of the HPR Operational Measurements for estimating GOS with a view to servicing the HPR network. Moreover, the OM validation tests were found to be reliable indicators of the network conditions. Therefore, trouble periods will be identified and rejected from the servicing and forecasting averages.

The Load Set methodology recently developed in BNR and Telecom Canada allows forecasting in an HPR environment. Again, point-to-point data is used. Traffic matrices for each hour of each day during the year are collapsed into several load-sets which retain the traffic features significant for dimensioning. The load sets are projected to represent future traffic.

Using the Multi-hour dimensioner [2] for servicing and forecasting requirements in the final HPR network will permit the realisation of trunk savings as well as a more uniform GOS across the same network.

7. Conclusion

The trial was a success. HPR was proven to be sound and effective. Routing and OM pegging were performed correctly. The HPR Operational Measurements were shown to be reliable and adequate for servicing.

The GOS results of the trial are good and very encouraging when one considers the many handicaps with which HPR had to work: the trial network was small, unbalanced, with a very limited choice of tandems; it did not have all the switches and the trunking facilities that are required on this part of the network; it still carried some FHR traffic over which HPR had no control. In the final system, HPR will not have to contend with these detrimental factors. With a larger network, it will be better able to improve GOS and survivability.

The trial also demonstrated the value of centrally coordinated administration, routing and management of the network. Finally, HPR was confirmed to be administrable in the transition phase of a network.

As a result of the field trial Telecom Canada has approved the deployment of the HPR final product.

8. References


