A PBX-BASED APPROACH FOR TELECOMMUNICATION NUMBER PORTABILITY SERVICE

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Abstract: Number portability (NP) service has become an important factor in enhancing the competitiveness of a service provider. Although NP service is available now, NP database (NPDB) query and portable number translation are all-call-based, and the time required to process a NP call is long. It is an overhead to the operator and the user. How to reduce the impact of NP call process is an important issue. Considering an organization often has dialled number locality, we suggest applying caches to PBX to keep the routing information of portable numbers. In this paper, the interoperation of PBX and operator network is introduced. We also demonstrate the workload of portable number translation is shared out to PBX, the delay time of querying routing information is shorten, and the efficiency of NP call process is enhanced.

1 INTRODUCTION

The service of number portability (NP) that allows a subscriber to keep a unique telephone number even when changing service providers is an important factor for fair competition among telecommunication operators (Gans, King & Woodbridge 2001).

At present, approaches to support number portability in switching circuit networks (SCN) are often implemented on the Intelligent Network (IN) architecture (Lin & Rao, 2003). A number portability database (NPDB) is required for an operator to maintain the mapping between portable numbers and destination addresses. Number translation is all-call-based. Every NP call requires a NPDB query for portable number translation. In addition, when a number was ported out, the whole cluster of numbers were taken as portable numbers. With the increase of NP subscribers, NPDB grows cumbersomely, the workload of NPDB is heavy, and the delay time for NPDB query increases to prolong the call setup process.

Many researches tended to enhance the call setup efficiency by improving the performance of database query. (Carpenter et al, 2000) pointed out that caches can offload a substantial amount of traffic at a database. To alleviate the workload of NPDB, a cache keeping the destination address of portable numbers can be applied to the system to reduce the delay time of portable number translation. But implying caches to the NP service still has problems.

Once a cache is implemented to the switching center of the operator, the numbers dialed from the numerous subscribers are scattered. To increase the cache hit ratio, the cache size must be large to accommodate the amount of dialed numbers. This could burden the effort of cache query and management. If the cache is applied to terminals, the altered routing information of portable numbers must be updated from operators to all terminals; that may consume considerable communication resources, but the service provider makes no profit from it.

Caches profit when the variation of data is occasional or the accessed data has locality. From the telecommunication network hierarchy, we found that a lot of telecommunication traffic was generated by organizations. Organizations usually have sets of frequent contact targets, thus the locality of the dialed numbers is distinguishable. When the frequently dialed numbers are portable numbers, the total time delay for waiting NP call setup is

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appreciable. Moreover, every NP call setup requires NPDB queries and consumes extra communication resources, but service providers rarely make profit from the process. Organization usually established PBX (Private Branch Exchanges) for saving telecommunication cost. We propose to apply caches to PBX. By evaluating the costs and benefits of applying caches to PBX, we show that PBX with cache is a reasonable solution that can remarkably alleviate the traffic and workload of databases and improve the efficiency of NP services.

The rest of this paper is organized as follow. Section 2 gives an overview of related work. Section 3 introduces caches to the telecommunication system to enhance the efficiency of NP call process. Section 4 investigates the performance of caches in NP service. Finally, section 5 draws the conclusion.

2 RELATED WORK

NP implementation schemes can be classified into on-switch and off-switch solutions (Black 1998). Methods of on-switch solutions implement routing knowledge on switching centers of the service network. When an *originating network*, which a caller connects to, receives a call, it routes the call to the *donor network*, which first assigned the telephone number to the callee, by the prefix of the dialed number. The donor network routes the call to the destination network by the information of the mapping of dialed numbers and the destination addresses in the gateway switches. The operation logic of a switching center alters whenever a number is ported out or in. The frequent alteration decreases the stability of communication services and increases the cost of system operation and maintenance.

To prevent the alteration of switching networks, off-switch solutions use Intelligent Network (IN) as the implementation basis (Lin & Rao 1999). An NPDB is implemented for maintaining portable numbers and the corresponding destination addresses. Here we assume a global NPDB (GDB) which is centrally maintained by a neutral organization (Number Portability Administration Center, NPAC) is available. All portable numbers of every operator are recorded in GDB. Operators may make a copy of NPDB to their networks to omit the delay of long term GDB.

There are four off-switch schemes for solving the NP problem: all call query (ACQ), query on release (QOR), call dropback (also known as return to pivot, RTP), and onward routing (OR) (Kim & Yong 2003). The four schemes exist in the NP solutions of different countries: UK, Finland, France, Germany, Span, Singapore, etc. <http://www.arcome.com>, <http://www.ida.gov.sg>, <http://www.tct.hut.fi>. The considerations of which scheme to adopt include the network resources, the policy of addressing and routing, the impacts on the signaling system, and the interworking with other services. ACQ and call dropback are the two most popular solutions.

- All call query (ACQ): The originating network initiates a query to NPAC when determining the dialed number is a portable number. NPAC returns the destination address of the number, then the originating network routes the call to the destination address to set up the call. It is the most efficient of using the network transmission facilities.
- Call dropback: The originating network receives a call and routes the call to the donor network by the prefix of the number. The donor network determines the number was ported out, it returns the routing address of the number's new subscription network and release the call. Then the origination network re-routes the call to the destination network. The routing information is maintained in the donor networks of portable numbers. However, transmission resources are occupied during the routing of calls. This may reduce the efficiency of source network.

The drawback of the existing methods results from the growing database size. Every call terminated to a portable number initiates a database query. Numerous NP service subscribers incur a cumbersome database that severely encumbers the efficiency of routing information query and call setup process.

3 APPLYING CACHES TO PSTN

3.1 Analysis of calling behavior

Cache performs well when the data variation is infrequent and the data has access locality. Implementing caches to switching centers the size of the cache either is too large to be practical or the hit rate is too low to be efficacious. On the other hand, caches on terminals suffer from the alteration of subscription networks, which will cause the change of caches in all terminals.

In fix-lined telecommunication systems, an organization (e.g., a company, an enterprise, a campus, or a government department) often establishes PBX for saving telecommunication cost. A PBX is an exchange which enables organization members to call each other freely, and to make and receive calls from users served by the public network.

The communications within a PBX service region are routed by the PBX, without using the communication resource beyond. A PBX has one or more physical channels that connect to a local exchange, the communications beyond the PBX are routed to the public network through the local exchange (Black 1998).

The communication targets of an organization usually have locality. For example, organizations like government departments or retail businesses have frequent contact objects to solve problems or to supply merchandise. The communication targets of an organization may be diffused, but always include a set of cooperation subjects. From the view of telecommunication network hierarchy, the quantity of users within a PBX service region is moderate, and the locality of PBX contact targets is distinguishable.

Portable numbers are determined as external calls of PBX that is routed to local exchanges. The local exchange determines whether the request can be processed locally, or should be routed to a higher layer switch. If a switch can translate a portable number, it consults NPDB to determine the routing information of the number to routes the call; otherwise, it routes the request to the higher layer switches for number translation.

3.2 Applying caches to PBX

3.2.1 The operation of caches in the fix-lined telecommunication system

For maintenance and long-term operation, operators generally adopt off-switch schemes for NP communication services. The purpose of caches on PBX is to share the workload of portable number translation, and to alleviate the traffic load of NPDB for shortening the call setup time and enhancing the utilization of communication resources.

Caches on PBX keep the routing information of dialed numbers (both portable and non-portable numbers) to omit the delay of NPDB queries. A mechanism is needed for PBX to inform the confirmed routing information of the called parties to the public switching system, thus the call can be routed directly without querying NPDB.

The communication beyond PBX must through the public communication system. Conventionally, PBX route every external call to the public network through local exchanges. When caches are applied to PBX, a PBX checks the internal cache before routing an external call. A cache hit indicates that the destination address of the dialed number is confirmed, and the NPDB queries can be omitted. PBX adds a special code (e.g., *14*, *30*) in front of the dialed number to indicate the destination address of a dialed number was confirmed and appended to the call originating request. The public switching system recognizes the code and routes the call by the appended routing information without querying GDB or donor NPDB.

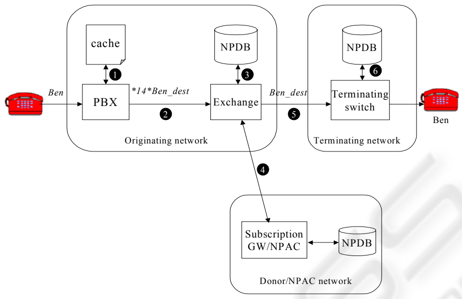

Figure 1: A special code is used to indicate a cache hit

Figure 1 illustrates the basic NP call process. A call is made from a PBX to an external user *Ben*. PBX determines the request is an external call and checks cache for the destination address of *Ben* (step 1). In the case of cache hit, PBX appends a special code "**14**" and the obtained destination address to the call originating request. The request is sent to a local exchange (step 2). The public switching system routes the call to the called party *Ben* without querying NPDB (step 5 & 6).

When a cache miss, the routing information of the called party should be solved by higher level exchanges. The PBX routes the call originating request to the local exchange without modifying the request or adding any special code. The public switching system determines that is a NP call, and consults NPDB to translate the number (step 3 & 4), and routes the call to the called party (step 5 & 6).

The signaling systems of operators usually have the function to process special codes (e.g., the code "*67" in USA prohibits displaying the caller's telephone number to the called party). Applying caches to PBX requires adding a rule for new special code in the signaling system without altering the operation logic. It is feasible for operators to implement the new service.

3.2.2 Issues of applying caches to PBX

Following the communication model of PBX with caches, the issues of cache implementation encompass the policy of establishing a cache, the update of cached data, and the size of the cache.

- **The policy of cache establishment**

Caches should keep as many as possible the destination addresses of portable numbers, but the size of a cache is restricted that the data can be kept in is limited. The cache hit rate increases when the accessed data has locality. To improve the cache hit ratio to enhance the efficiency of NP call setup, the cache needs to expose the communication habits of users of the PBX service region.

There are two approaches for cache establishment: The dynamic cache policy supposes the most recently dialed numbers shall be cached for they might be dialed repeatedly in a span; from another point, the static cache policy believes the frequently dialed numbers must be cached for they represent the most frequently contact targets for a long-range observation.

When the subscription network of a cached number changed, the cached routing information becomes obsolete. This will bring about miss-routing calls that consume extra signaling and transmission resources and prolongs the call setup time. Follow the dynamic cache policy, the altered routing information must be updated dynamically, thus the signaling system of the public network must be modified to notify PBX to renew the routing information immediately. Besides, cache replacement happens whenever a new data is inserted to the cache; this may replace expected data and decline the hit rate. The costs to modify the signaling system of public networks, to management a dynamic cache, and to update routing information in caches are expensive. Consequently, dynamic cache policy is not feasible for PBX caches to enhance the performance of NP service.

On the contrary, a static cache keeps the most frequently dialed numbers (FDN) of the PBX. The establishment and alteration of a static cache is manually performed by the system administrator of an organization. When a member joined an organization, the member proposed a set of FDN to the system administrator. The system administrator sends the FDN set to a contracted operator to obtain the corresponding routing information. This is a batch process that can prevent inconsistent data in the cache. When a contact target changes subscription network, the contracted operator sends messages to registered PBX to notify the alteration. While the contact targets of an organization have locality, and the change of members is infrequent, the variation of FDN is gentle. The complexity of establishing and maintaining a static cache is much less than that of a dynamic cache. The hit rate of a static cache is proportional to the probability the FDN be dialed.

- **Cache update**

The cache update can be initiated by PBX or by operators. Operators can provide a service for PBX to consult the routing information, and the consulting can be processed off-line in off-time to reduce the impact on operators and PBX, even can be served through Internet. Or a PBX can register a profile of FDN to the contracted operator, thus the operator can notify the PBX to renew altered routing information.

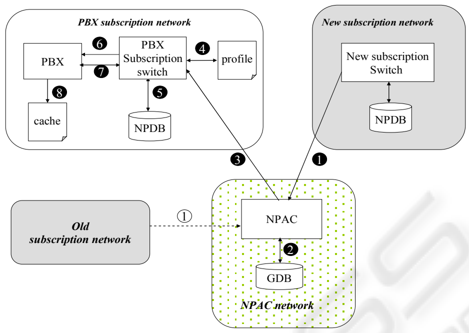

Figure 2: The process of cache update

Assuming a neutral GDB is available, the update of caches is illustrated in Figure 2. When a portable number changes subscription network, the new subscription network updates the new destination address of the number to NPAC (step 1 & 2). NPAC notifies the alteration to contracted operators (step 3). When received a notification of altered routing information, the subscription network of PBX checks registered profiles (step 4), and sends a notification to PBX (step 6). Then PBX initiates a query process to query the altered information, and updates the new data to the cache (step 7).

For limiting the porting frequency of NP subscribers, we assume users can not change subscription networks too often. The effectiveness of a new ported number is postponed for couple hours to guarantee the consistency of GDB and the NPDB of old and new subscription networks.

- **Cache size**

A cache entry consists of a 10- to 15-digit telephone numbers which follows ITU-T Recommendation E.164 (Faltstrom 2000), a 4-octet destination address of the number, a 4-byte field of the latest modification time, and a 2-bit cache management tag. A cache entry occupies 186 bits.

Assume that there are s members in an organization, the FDN quota of each member is k. Suppose the probability the FDN of a member overlap with other members' is r in average, $0 \le r < 1$. Let U be the universal set of all individual FDN set u_i of member i, which can be represented as

$$U = \bigcup_{i=0}^{s} u_i - \bigcup_{i=0,j=0,i\neq j}^{s} \left(u_i \cap u_j\right) + \bigcup_{i,j,k=0,i\neq j\neq k}^{s} \left(u_i \cap u_j \cap u_k\right) + \cdots + \left(u_1 \cap u_2 \cap \cdots \cap u_s\right)$$

The minimum cache size ms_{cache} to keep the FDN set of an organization is

$$ms_{cache} = \sum_{i=1}^{s} (-1)^{i-1} \binom{s}{i} k r^{i-1}$$

$$= k \times \sum_{i=1}^{s} (-1)^{i-1} \binom{s}{i} r^{i-1} \text{, where } 0<r<1. \quad (1)$$

When the contact targets of every member is scattered that $r = 0$, the minimum size of the cache of the iNetwork is represented as

$$ms_{cache} = s \times k, \text{ where } r = 0. \quad (2)$$

In an organization with 15000 employees, each member has 100 FDN in average, when $r = 0$, the total cache size is less than 33.3 MB; when $r = 0.5$, the cache size reduced to 17 MB. It is obvious that caches are small enough to be located in memory that the search time is less than 0.01 msec memory access. Since a GDB query consumes 2 seconds or less, when GDB queries are substituted by memory accesses, the delay of querying routing information can be reduced remarkably.

4 PERFORMANCE ANALYSIS

PBX with a cache diminishes the demand of long-term database queries, and decrease the NP call setup time. But it also requires the modification of PBX. In this section the cost and the benefit of PBX with caches are evaluated.

The costs of applying caches to PBX includes the cost to modify the signaling system, the cost to establish caches and update cached data, and the time to query cached data.

The signaling system needs to add a new rule on switches to process special codes. PBX must be modified to query caches before forwarding requests, and to append the destination address and a special code to a call initiation message. These are the constant investment of system construction.

The cost of cache implementation includes the hardware cost of memory, the cost of the batch process to attain the routing information of FDN, and the cost to enter FDN manually. While memory is cheap, the entering of FDN is infrequent, and the query of routing information of FDN is an off-line batch process that can be executed in off-time, the different of conventional NP service systems and the system with caches on PBX is the cost of system operation. We study the benefit of PBX with caches by comparing the cost of call initiation process of the conventional telecom system and the cache-applied system.

When caches are applied to PBX, every external call triggers a cache query. The result of a cache query can be a cache miss when the required data is not kept in the cache, or a location hit if the cached data points to the actual destination address of the dialed number. Location miss will not occurred because of the postponed activity of NP subscribers.

The cost of call setup is represented as

$$C_{call\ setup\ with\ cache} = \theta_1\delta + \theta_2\zeta,$$

where θ_1 and θ_2 are the cost of call setup when it is a cache miss and a location hit, respectively; δ and ζ are the probability of cache miss and location hit respectively, $\delta + \zeta = 1$. θ_1 includes the costs of cache access and conventional NP/non-NP call setup process, δ equals to the probability of dialing non-FDN.

$$\theta_1 = C_{cache\ access} + C_{donor/NPAC\ NPDB\ query} + C_{message\ processing} + C_{service} + C_{message\ transmission} + C_{queuing},$$

$$\delta = P\{dial\ non\text{-}FDN\} = 1 - P\{dial\ FDN\}$$

A location hit is the most economic case of call setup. θ_2 is represented as

$$\theta_2 = C_{cache\ access} + C_{message\ processing} + C_{service} + C_{message\ transmission} + C_{queuing},$$

$$\zeta = P\{dial\ FDN\} = 1 - \delta$$

The message transfer delay of a trunk is denoted as t_{trans}. Database access time includes the time for GDB query (t_{GDB}), and for local NPDB query (t_{NPDB}). The time for cache query is t_{cache}. The total delay time of cache access, message process and transmission, service, and queuing is denoted as t_p.

Different NP schemes results in the diverseness of network operation and signal flows. We study the performance of PBX caches by analyzing the call setup delay of ACQ and call dropback.

Case 1: ACQ

- In the conventional NP call process, the call setup time t_{acq_conv} can be represented as

$$t_{acq\_conv} = t_{trans} + (t_{GDB} + t_{NPDB}) + t_p \quad (3)$$

- In the case of location hits, the call setup time t_{acq_hit} can be represented as

$$t_{acq\_hit} = t_{trans} + (t_{cache} + t_{NPDB}) + t_p \quad (4)$$
$$= (3) + t_{cache} - t_{GDB}$$

  Where t_{cache} is much less than t_{GDB} that can be ignored, and (4) is much less than (3).

- In the cache miss case, the call setup time is:

$$t_{acq\_miss} = t_{trans} + (t_{cache} + t_{GDB} + t_{NPDB}) + t_p \quad (5)$$
$$= (3) + t_{cache}$$

Case 2: Call dropback

- The call setup time t_{cd_conv} is represented as

$$t_{cd\_conv} = t_{trans} + (2 \times t_{NPDB}) + t_p \quad (6)$$

- In the case of location hits, the call setup time t_{cd_hit} can be represented as

$$t_{cd\_hit} = t_{trans} + (t_{cache} + t_{NPDB}) + t_p \quad (7)$$
$$= (6) + t_{cache} - t_{NPDB}$$

- When cache miss, the call setup time t_{cd_miss} is

$$t_{cd\_miss} = t_{trans} + (t_{cache} + 2 \times t_{NPDB}) + t_p \quad (8)$$
$$= (6) + t_{cache}$$

Assuming the call arrival rate in a PBX is a Poisson process at the rate of λ per second, the average call setup time in a PBX is

$$Total\ call\ setup\ time_{conventional} = \lambda t \times t_{conventional}$$

In the case of PBX with caches, the probability of using FDN is p in average, the call setup time is

$$\text{Total call setup time}_{cache} = \lambda t \times (p \times t_{hit} + (1-p) \times t_{miss})$$

From equations *(5)* and *(8)*, the conventional call setup time closes to that of cache miss (p= 0).

Assuming the longest connection is less than 450 km. The time to process a request needs 100msec. The time to query GDB data should be less than 2 sec (Foster, McGarry & Yu 2003), the time for NPDB query should be less than 350 msec (Gans, King & Woodbridge 2001). A PBX handles 2000 calls per hour. The delay of searching a cached entry is less than 1/100 millisecond in average. According to the increase of p, the total NP call setup time with caches decreases linearly, as shown in Figure 3.

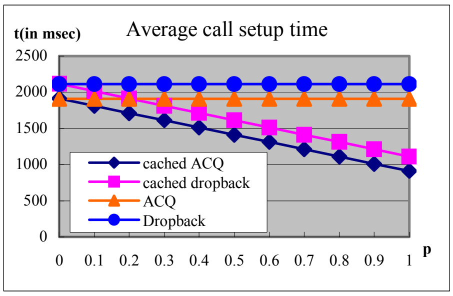

Figure 3 : The relation of FDN utility rate (p) and the average call setup time (t in msec)

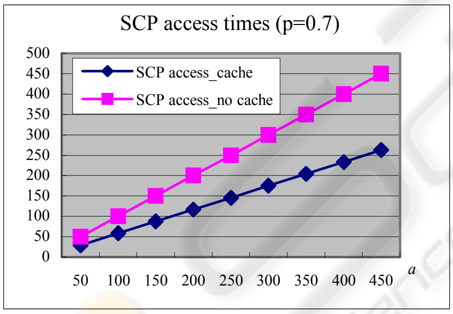

Figure 4: The SCP access times per second

The query delay dominates the NP call setup time. Numerous NP users results in substantial NPDB queries, NPDB access becomes the bottleneck of NP call process. Take ACQ as an example, if caches are not available, or the cache queries are all missed, the setup time of a call is 1911 milliseconds in average. When 70% of the dialed numbers are FDN, the call setup time decreased to 1211 msec. It reduced to almost half of that without caches.

Calls originated from organization dominate the telecommunication traffic in business hours. Assuming 70% of the calls are originated from enterprises in business hours, and 85% of enterprises has established PBX. The number of NPDB accesses per second is demoted as a. According to the increase of a, the use of FDN cache can reduce the DB load effectively (Figure 4).

5 CONCLUSION

In this article we stated the importance of NP services in telecommunication systems, and the problem of long information query delay resulted from huge NPDB. By analyzing the hierarchy of fix-lined telecom network, we proposed to apply caches to PBX to share the traffic load of NPDB, and to alleviate the delay time of querying destination addresses of portable numbers. According to the communication characteristics of organization members, we suggest adopting static cache policy, which is easy to establish and maintain.

Caches on PBX alleviate workload of NPDB, and remarkably reduce the average NP call setup time. The improved NP call setup efficiency leads to better communication resource utilization; therefore, caches on PBX benefit both the telecommunication users and service providers.

This solution needs not to modify the signaling system of the public telecommunication network. Hence, applying caches to PBX is a low-cost solution to enhance the performance of the NP service in the fixed-line telecommunication system.

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