# AN ORGANIZATION-BASED CACHE MECHANISM FOR SUPPORTING PCS NUMBER PORTABILITY SERVICE

C. W. Cheng
*Department of Computer Science and Information Engineering, National Chiao Tung University, Hsin-Chu, Taiwan*

C. G. Chung
*Department of Computer Science and Information Engineering, Chang Gung University, Kwei-Shan Tao-Yuan,Taiwan*

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Abstract: The rapidly growth of PCS market promotes the number portability (NP) service becoming essential to enhancing fair competition among operators. However, the existed NP solutions face the same problems of huge NP database (NPDB), long delay time of portable number translation, and extra communication resource consumption. Although researches pointed to caches can be utilized to alleviate the workload of NPDB and to reduce NP call processing delay, it doesn't fit for the mobile communication system. For large organizations, members move among the working space or the subsidiaries, many mobile calls are made between organization members. Furthermore, organizations usually have frequently contact targets, calls made from an organization often have locality. If caches are applied to organization-based mobile telecommunication components, the efficiency of NP service can be improved. In this paper, we propose an operation model of applying organization-based caches to the public mobile communication system. Besides, the time for NP call setup is investigated to state the feasibility and the effect of organization-based caches in the mobile communication system.

## 1 INTRODUCTION

The burgeoning techniques and the maturity of the business model attract more operators to join the market of mobile communication. Users have more opportunities to choose expedient service providers, but they are tired of distributing the new number to others every time they change service providers. Hence, number portability (NP) service that allows subscribers to keep numbers when changing service providers is an important service to attract subscribers and to enhance fair competition among operators (Gans, King & Woodbridge, 2001).

The Intelligent Network (IN)-based solutions are popularly adopted in present NP service networks. Number portability databases (NPDB) which maintain the mapping of portable numbers and the corresponding routing information are necessary. Every call to a portable number requires NPDB queries for number translation. The large amount of NP subscribers makes NPDB grows to be cumbersome. The long delay time of NPDB queries and the extra bandwidth be occupied during NP call process become the most urgent performance issue of NP service.

There were researches pointed that caches can offload the effort of database to reduce the delay of database queries. However, the position to implement caches, the policy of cache management, and the size of caches are all factors influencing the benefits of caches in a communication system. Caches on operator switching centers perform poorly for the quantity of calls from a service area is enormous and the dialed numbers are scattered. The cache size must be large to accommodate the numerous routing information to increase the cache hit rate; but the cost to manage and update such a large cache is expensive, and the search of cached data is inefficient. On the other hand, caches on user terminals confront the expensive cost for cache update. Operators must broadcast the altered routing information to all terminals that a lot of transmission resources are consumed.

Studying the operation model and the hierarchy of communication systems, we found that



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organization-based (OGB) communications hold a massive share of data- and telecommunication. Organization members often connect others by cellular phones on the move. Many mobile communications happens between organization members. Furthermore, organizations usually have regular and frequent contact-targets, mobile calls generated from an organization usually have locality. For the properties of moderate amount of users and the access locality of dialed numbers, OGB caches is another approach for enhancing mobile NP service. In this paper we introduce the IP-based iNetwork (Cheng & Chung 2003) as an example to illustrate the operation of OGB caches in mobile NP service, and to demonstrate that OGB caches can efficiently alleviate the traffic load of NPDB and remarkably enhance the efficiency of mobile NP service.

The rest of this paper is organized as follow. Section 2 gives an overview of related work. Section 3 and 4 introduce the operation model of OGB communication systems and OGB caches. Section 5 investigates the performance of OGB caches in NP service. A brief conclusion is given in section 5.

## 2 RELATED WORK

For providing mobile NP service, mobile communication networks must be able to identify portable numbers, and to obtain the routing information of the number. NPDB which keeps the mapping of portable numbers and routing information is maintained in the operator network.

The approaches for providing mobile NP service can be classified into SRF-based and IN-based. Signal relay function (SRF)-based solutions enhance the switch functions and utilize the MAP (mobile application part) protocol to enable the portable number translation. Depending on the implementation, the translation can be performed in the *NRH (number range holder) network*, which first issued a telephone number, or in the *subscription network*, which a subscriber registered to. The SRF is typically implemented on signaling transfer points (STP) in the SS7 communication model, and the interrogation of NPDB and HLR are processed via GMSC (gateway MSC).

The simplified NP call process is illustrated in Figure 1. The *origination network*, which the calling party connects to, receives a call initiation request (step 1). It identifies the callee's NRH network by the prefix of the dialed number (MSISDN), and issues an ISUP *IAM* message to the NRH GMSC to initiate a call (step 2). The NRH GMSC consults HLR and identifies the number was ported (step 3). It queries NPDB by MAP *sending routing information* message (step 4) to determine the routing address of the callee's subscription network, and forwards the *IAM* message to the subscription network (step 5). The subscription GMSC queries HLR for the address (MSRN) of the termination network (step 6), and routes the request by the MSRN to set up the call (step 7).

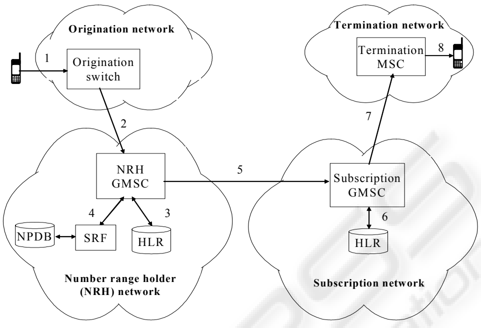


Figure 1: SRF-based NP call routing

The IN-based solutions are implemented on the service control point (SCP). The IN-based solutions differ form the SRF-based solutions in the way to access NPDB. In the SRF-based solution only GMSC can query NPDB, but in the IN-based solution every switch equipped with the IN protocol can access NPDB. The call initiation processes of IN-based and SRF-based systems are similar.

When a number was ported, the whole group of numbers were taken as portable numbers. Every NP call requires a NPDB query for the routing information to reach the subscription network. When the amount of users grows rapidly, the numerous data of users incurs long NPDB query delay. The considerable amount of queries burdens the load of NPDB and HLR. NPDB searching becomes the bottleneck of NP service. The bandwidth reserved for the caller is occupied during the call setup process, but operators rarely make profit on it.

The survey of Carpenter et al showed that caches can offload a substantial amount of traffic at the database, even with relatively small cache (Carpenter et al. 2000). However, the effect of a cache varies with the component and the hierarchy the cache was applied. Caches can be implemented to operator switching centers or to the user ends. In the former case, a large cache is required to accommodate the enormous dialed numbers and the corresponding routing information. Mobile subscribers move in and off a service realm of a switching center, the numbers dialed by the extensive amount of subscribers bring about almost randomly access to the cached data, and result in a poor cache hit rate. This approach confronts the problem that either the cache size is too large to be practical or the cache hit rate is poor to be efficacious. In the latter case, NP subscribers change operators will cause the alteration of caches in all terminals. Operators need to broadcast changed routing information to all terminals, and the cost is expensive; when subscribers move to other countries or terminals were turned off, the altered information may not be renewed to the terminal successfully, thus the obsolete information may cause incorrect routing of calls.

Studying the communication model and the hierarchy of the mobile telecommunication system, a large share of traffic load was generated from organizations (e.g., enterprises, campuses, government departments) in business hours. An organization often has regularly or frequently contact targets (e.g., agents of suppliers and business associates, etc.), the external calls generated from an organization have dialed-number locality. If the routing information of the frequently dialed numbers (FDN) is cached in OGB system, the translation of portable numbers can be processed and routed without querying NPDB. Therefore, the workload of portable number translation is shared to OGB network, the traffic load of NPDB is alleviated, and the efficiency of NP service is improved in both the global and the OGB communication systems.

# 3 ORGANIZATION -BASED MOBILE COMMUNICATION SYSTEM

Many mobile calls are set between organization members. For organization members usually move around the working space in business hours, and colleagues often need to contact others on the move. A local mobile communication system such as IEEE 802.11 based WLAN provides cost-free communication service of an organization, but the limited communication scope can not provide service beyond the organization. Users must change handsets and phone numbers when moving off the scope. By contrast, a public mobile communication system such as GSM enables global communication service to users without limiting the communication scope, but the high cost burdens to organizations and the members.

There is a need of OGB mobile communication systems which consist of the benefit of low-cost local communication services and the convenience of global mobility. The communications within an organization can be processed and routed without requiring exterior communication resources. Organization members move off the service region should not lose connection, and the communication with users beyond the organization must be enabled without the limitation of location. When setting a call to an external user, the OGB system routes it to the global communication system (e.g., GSM, PSTN) according to the prefix of the dialed number (Figure 2).

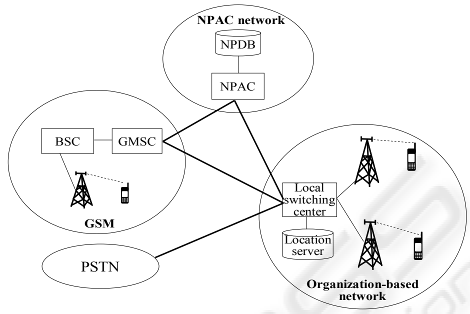


Figure 2: The concept of an organization-based communication system

We had developed an IP-based OGB mobile communication system—iNetwork—which fulfilled the requirement of cost-free inter-organization communication, and supported GSM-compliant mobile service that guaranteed global mobility beyond an organization (Cheng & Chung 2003). We introduce iNetwork as an example to illustrate the operation model of OGB caches, and investigate the benefit when applying OGB caches to mobile NP service.

## 3.1 Introduction of iNetwork

Based on the concept of providing user and terminal mobility within and beyond organizations, iNetwork was developed as a GSM-compliant OGB communication system. By contract, an iNetwork registers to a GSM operator as an add-on service. GSM BTS is adopted as wireless access point, thus users can utilize GSM-compatible terminals. The mobile service of iNetwork follows GSM because it is the most prevalent mobile system in the world, and it possesses the capability of data services.

The register process is carried out when a user moves to or turns on the terminal in iNetwork service regions; only iNetwork subscribers are allowed to access iNetwork resources. Intra- and inter-iNetwork communications are processed locally and transmitted through the IP network. When moving off iNetwork service regions, iNetwork subscribers register to the visiting GSM operator to keep connection.

When an iNetwork registered to a GSM operator as an add-on service or a business subscriber, the subscribers of the iNetwork become the subscribers of the GSM, and the numbering plan of the iNetwork became a part of the GSM's, the GSM can determine a number as an iNetwork subscriber (by IMSI). The most significant information to switch and route flows between iNetwork and GSM is the location information of subscribers. Both iNetwork and GSM should provide a means for information exchange.

## 3.2 iNetwork architecture

Figure 3 presents the iNetwork architecture. Except the off-the-shelf GSM BTS, iNetwork components are implemented as software components connected to the IP-based network.

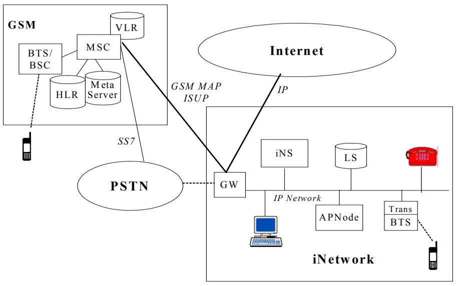


Figure 3: iNetwork architecture

Every iNetwork includes at least an iNS to provide switching and routing functions; a LS to maintain user and location information; one or more APNodes to handle requests from users, to collect user information, and to manage network resources; several BTS to support radio access to iNetwork users, and they are bound with Trans that translate protocols between the IP network and GSM system. A MetaServer is an access interface residing in GSM network that iNetwork can attain subscribers' location information. iNetwork provides GSM MAP, ISUP, and SIP interface to connect with GSM network. SIP (Session Initiation Protocol) is adopted as the signaling protocol of iNetwork system administration, session control, and call handling.

The email-like addressing mechanism (i.e., *user@host*) integrates the communication models of the IP network, PSTN, and GSM enable the intercommunication of these systems. To consist with ITU-T E.164 (Faltstrom, 2000) and the existed switching systems, the *user* portion is a decimal digit string that indicates a subscriber, *host* indicates an IP address; aliases are allowed for easy memorizing.

## 3.3 Operation model of iNetwork

When an iNetwork user initiates a call, the request is sent to an APNode. APNode forwards the request to iNS. iNS consults LS by IMSI of the caller for user authenticate. If the caller is not a registered user, the call is bypassed or routed to the subscription GSM network; otherwise, iNS consults LS by the dialed number to determine whether it is an internal or external call. In the case of internal call, iNS routes the call to the callee directly through the IP network; otherwise, the request is routed to cooperated iNetwork or GSM according to the callee's routing information.

The cooperation models of iNetwork and GSM are illustrated in the following.

### 3.3.1 The cooperation of iNetworks

To enlarge the service region, several iNetworks cooperate as a communication community to share communication resources to provide low-cost mobile communication service. iNetworks of a community share location information of subscribers to identify and authenticate subscribers. The state and location information of subscribers are informed to iNetwork by location register process, which is shown in Figure 4.

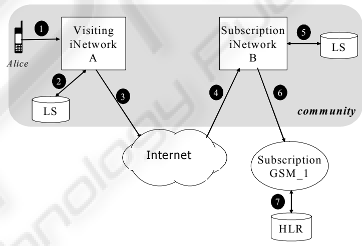


Figure 4: iNetwork register process

GSM_1 is the subscription GSM of iNetwork_B. User Alice subscribed to iNetwork_B and became a subscriber of GSM_1. When Alice visits an iNetwork, the latest location information is updated to the subscription iNetwork_B by a *MAP_UPDATE_ LOCATION_AREA* message. The register information consists of the IMSI and the MSRN (mobile station roaming number, which indicates the address of the termination switch where the MS resides) of Alice. iNetwork_B keeps the information in local LS, and forwards the register information to the subscription GSM_1. By way of register process, the location information of Alice is kept in both the subscription iNetwork_B and GSM_1. According to the maintained user and location information, iNetworks can provide services of roaming, handoff, call setup and termination services.

Intra-iNetwork-communications communications are basically IP-based. Figure 5 illustrates the call setup process in an iNetwork community. The origination iNetwork-A determines the call is set up to an iNetwork user by the prefix of the dialed number. If iNetwork-A queries LS and confirms that the callee resides in the local service region, it forwards the call to the callee directly. If callee wasn't in iNetwork-A, the routing address of the subscription iNetwork-B is appended to the dialed number (i.e., *Alice@iNetwork-B*), and a *SIP INVITE* message is issued to the subscription iNetwork-B. iNetwork-B receives the message and queries LS for the destination address (a MSRN) of the callee, then forwards the request to the termination iNetwork-C to set up the call.

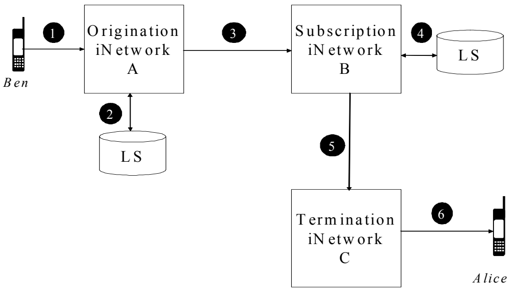


Figure 5: Call setup between iNetwork users

### 3.3.2 Interoperation with GSM

iNetwork users register to GSM network when moving off iNetworks. The location information of an iNetwork user is shared between the user's subscription iNetwork and the subscription GSM. The interoperation between iNetwork and the subscription GSM follows the SS7 signaling and communication model. The protocol for exchanging call handling messages is ISUP, routing information inquires are based on GSM MAP, and the routing of calling signals is conveyed by TCAP commands.

Every iNetwork subscriber has an iNetwork address in the format of *MSISDN@network*. When an iNetwork subscriber moves to a GSM, the location information will be sent from the visiting GSM to the subscription GSM. The subscription GSM filters the information by the numbering plan and updates the latest location information of the subscriber to the subscription iNetwork via MetaServer.

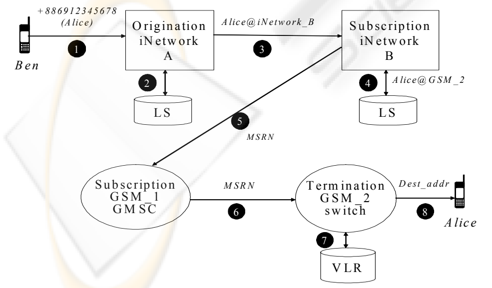


Figure 6: Call set up between iNetwork users who roam to GSM networks

Figure 6 illustrates the process of setting a call to a roaming iNetwork subscriber. Ben initiated a call to Alice. The origination iNetwork-A queries LS to determine the callee wasn't in the local service region, and routes the request to the subscription iNetwork-B of Alice according to the dialed number. iNetwork-B queries LS for the roaming information of Alice and routes the request to the termination GSM-2. If the GSM-2 is the subscription GSM of iNetwork-B, iNetwork-B forwards the request to GSM-2 directly; otherwise, iNetwork-B forwards the request to it's subscription GSM-1, then GSM-1 routes the request to the termination GSM-2 to set up the call.

# 4 APPLYING CACHES TO MOBILE NP SERVICE

Identifying portable numbers and determining the corresponding destination addresses are the foundation of NP service. The determination of portable numbers and NPDB queries are all-call-based, that prolong the time for NP call process. Besides, the bandwidth reserved for the caller is wasted during the long setup delay. As specified in the above, caches can alleviate the traffic load of NPDB and improve the efficiency of data queries. For the dialed-number locality of OGB networks, we purpose to apply caches to OGB networks. Here we apply caches to iNetwork to illustrate the operation and the benefit of OGB caches.

## 4.1 Introduce OGB caches to mobile NP service

Each cache entry in an OGB network includes the MSISDN, the subscription assigned number IMSI, and the routing address of the number's subscription network. iNetwork queries local cache for the callee's subscription network before issuing a call setup request. A cache hit indicates the routing information of a dialed number is confirmed, and a time-consuming NPDB query is omitted.

The call initiation processes of iNetwork with caches are classified to three types: intra-community, inter-community, and inter-network-system calls. The processes are illustrated in the following.

- **Intra-iNetwork-community call**

If a NP user subscribed as an iNetwork user, iNetwork needs to mark the number as a portable number, and identify the number as an iNetwork subscriber. iNetwork queries caches before consulting LS for the routing information of the called party, thus the query of the NRH network can be omitted.

Figure 7 illustrates an intra-community NP call setup process. The origination iNetwork-A receives a call initiation request (step 1) and determines the dialed number is a portable number. iNetwork-A queries LS first to identify if the callee resides in the local service region. If not, iNetwork-A queries local cache for the routing information by the callee's MSISDN (step 2). When cache hit, iNetwork-A routes the request to the subscription network directly; otherwise, it routes the request to the NRH network by the prefix of the dialed number (step3). The subscription network queries LS for the termination network (step 4), and forwards the request to the termination network (step 5). The termination network pages the callee to set up the call (step 6).

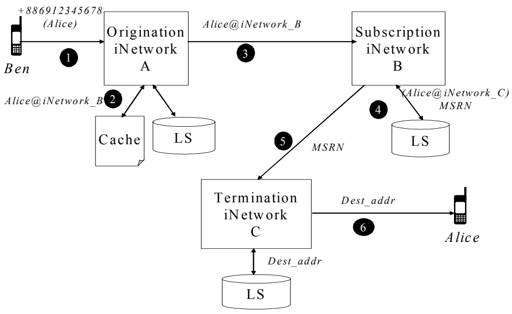


Figure 7: NP call setup in an iNetwork community

- **Inter-iNetwork-community call**

Different iNetwork communities have no duty to share information and communication resources. The process of inter-community call setup is illustrated in Figure 8.

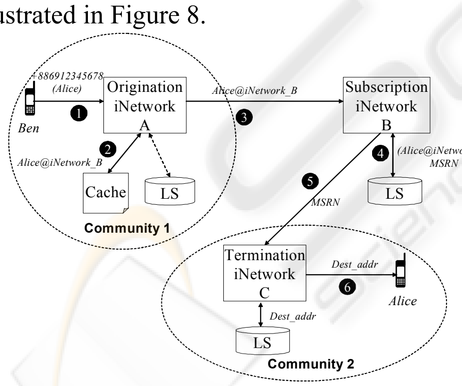


Figure 8: NP call setup among different iNetwork communities

The origination iNetwork-A determines the call is set to a portable number (step 1), it queries LS for identifying if the callee resides in the local service region. If so, the call is set up to the callee directly; otherwise, iNetwork-A queries cache for the callee's routing information (step 2) and routes the call to the subscription network (step 3). But if it is a cache miss, a NRH network query is issued to obtain the routing address of the callee's subscription network. The subscription iNetwork-B queries LS to route the request to the callee, the process is analogical to the step 4 to 6 of intra-community call.

- **Inter-network-system call**

The connection of an iNetwork and the non-subscription GSM networks often passes through the subscription GSM network of the iNetwork.

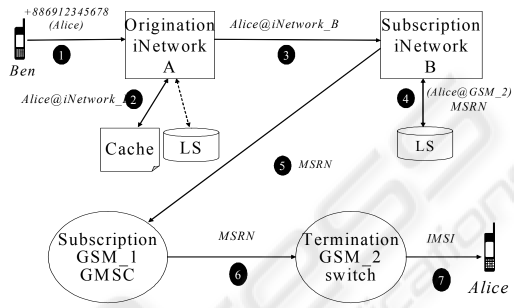


Figure 9: NP call setup among iNetwork and GSM

Figure 9 elaborates the process of setting a call from iNetwork-A to an iNetwork NP subscriber Alice who roamed to a non-subscription GSM-2. iNetwork-A determines the request is set to an iNetwork NP user (step 1). It confirms the called party does not reside in the local service region, then queries cache for the callee's subscription network (step 2). If it is a cache miss, iNetwork-A queries the callee's NRH network for the callee's subscription network; otherwise, iNetwork-A forwards the request to the callee's subscription network iNetwork-B (step 3). iNetwork-B queries LS and finds the callee roamed to GSM_2, the callee's routing number (MSRN) is returned by the LS (step 4). According to the routing number, iNetwork-B forwards the request to the termination GSM-2 through the subscription GSM-1 (step 5 to 7) without querying HLR and VLR of the subscription and the termination GSMs.

The benefit of OGB caches is to omit unnecessary NPDB and HLR/VLR queries. Along the increase of cache hit rate, the database queries decrease when setting up calls. The locality of contact targets of organizations causes small cache size and better cache hit rate.

## 4.2 Issues of cache implementation

The policy of cache establishment and the complexity of cache management influence the cost and the benefit of caches. These issues are examined in the following.

- **Cache establishment**

The data be cached should be as many as

possible to enhance the cache hit rate, but the size of a cache is restricted that the amount of data in a cache is limited. In order to improve the hit rate of caches to enhance the efficiency of the call setup process, caches should be able to expose the communication habits of users of the service region.

We propose to cache the most frequently dialed numbers (FDN) which represent the cooperative organizations, providers and suppliers, agents, etc. of the organization, also include the families and friends of every organization member. The establishment and alteration of such a cache is manually performed by the system administrator. When a member joined an organization, the member proposed a set of FDN to the system administrator. The system administrator interrogates the contracted GSM for the corresponding routing information of the FDN. The interrogation is a batch process that can be performed in off-time. When a contact target changes subscription network, the contracted operator notifies the registered iNetwork to renew the altered routing information. The contact targets of an organization have locality, and the change of members is infrequent, the variation of FDN is gentle.

- **Cache update**

iNetwork registers a profile of FDN to the contracted GSM operator. When a NP subscriber changes service provider, the effectiveness of the change is postponed for couple hours to guarantee the routing information consistency of NPDB and the old and new subscription networks. iNetwork queries contracted GSM to get the altered routing information and update cached data periodically, thus the cached data can be consistent with the routing information in NPDB.

- **Cache size**

In an OGB network with $m$ subscribers, every subscriber has $k$ FDN in average. The FDN set of an organization member may overlap with that of the others. Assume the overlap rate is $r$. Let $U$ be the universal set of all individual FDN set $u_i$ of member $i$. The universal FDN set can be represented as

$$U = \bigcup_{i=0}^{m} u_i - \bigcup_{i=0,j=0 i\neq j}^{m} \left(u_i \cap u_j\right) + \bigcup_{i,j,k=0 i\neq j\neq k}^{m} \left(u_i \cap u_j \cap u_k\right) + \cdots + (-1)^{m-1}\left(u_1 \cap u_2 \cap \cdots \cap u_m\right)$$

The minimum cache size of the organization is

$$\text{cache\_size}_{min} = \sum_{i=1}^{m} (-1)^{i-1} \binom{m}{i} k r^{i-1} = k \times \sum_{i=1}^{m} (-1)^{i-1} \binom{m}{i} r^{i-1}, \text{ where } 0 < r < 1.$$

When the contact targets of every member is scattered that $r = 0$, the maximum cache size is

$\text{cache\_size}_{max} = m \times k$, where $r = 0$.

# 5 PERFORMANCE ANALYSIS

Mobile communication realizes the communication on the move. A user may move across service areas when a call is setting to him. To decrease the overhead of miss-routing caused by obsolete routing information, the call setup time shall be short. A shorter call setup time saves time for callers without waiting a long delay for the connection to be put through, and means it saves the bandwidth which is occupied by the caller during call setup; also the communication resources for additional message processing and transmitting is prevented. We study the benefit of caches by comparing the NP call setup time with or without organization-based caches.

## 5.1 Call setup time

The time required to initiate a call (denoted as $t_c$) can be represented as

$t_c$ = *transmission delay + DB query delay + service delay*,

Let $t_{trans}$, $t_{NPDB}$, $t_{HLR}$, $t_{LS}$ denote the transmission delay, NPDB, HLR/VLR, iNetwork LS and cache query delay, respectively. The size of LS is much smaller than a HLR or a NPDB, the query delay $t_{LS} < t_{HLR}$, $t_{LS} < t_{NPDB}$, and $t_{HLR} < t_{NPDB}$. The processing delay for user authentication, for codec, and for message processing is assumed to be similar in GSM and in iNetwork, and is denoted as $t_s$.

Because $t_{LS}$ is small, the NP and non-NP call setup time of intra-iNetwork and intra-community are similar. However, the NP call setup time of conventional GSM, inter-iNetwork-community, and GSM with OGB cache are distinct.

- Setting a non-NP call in GSM requires querying the subscription HLR for the termination network, and querying VLR for the location information of the called party :

$$t_{c1} = t_{trans\ conv} + 2\times t_{HLR} + t_s \quad (1)$$

- Setting a NP call in GSM requires a NPDB query for the subscription network of the called party:

$$t_{c2} = t_{trans\ conv} + t_{NPDB} + 2\times t_{HLR} + t_s \quad (2)$$

The time for NPDB query and related message processing makes $t_{c2}$ larger than $t_{c1}$.

- Setting an inter-community NP call requires querying origination LS and subscription LS:

$$t_{c3} = t_{trans\ iN} + 2\times t_{LS} + t_s \quad (3)$$

Since $t_{LS}$ is small, $t_{c3}$ is much less than $t_{c2}$ and $t_{c1}$.

- Setting a NP call to a GSM user in FDN set, the call is routed to the subscription GSM of the dialed number:

$$t_{c4} = t_{trans\ conv} + t_{LS} + 2\times t_{HLR} + t_s \quad (4)$$

- Setting a NP call to a GSM user in FDN set, the call is routed to the subscription network of the dialed number directly:

$$t_{c5} = t_{trans\ conv} + t_{LS} + 2 \times t_{HLR} + t_s \quad (5)$$

Without querying NPDB for number translation, $t_{c5}$ is much less than $t_{c2}$.

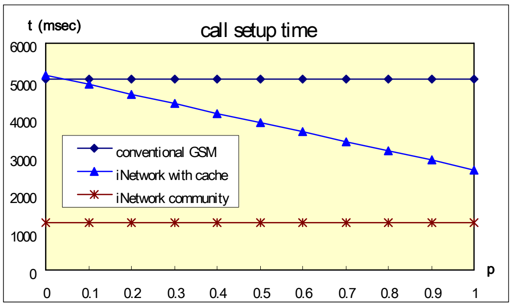


Figure 10: The time for setting up a NP call from iNetwork to a roaming GSM user

Figure 10 compares the call setup time of initiating a NP call from iNetwork. Call setup delay decreases when dialed numbers have locality and the frequency of using FDN (*p*) increases, and the bandwidth being occupied during the call setup process is saved. In an organization with 10000 members, the average calling rate is 450 per hour. Assume NPDB and HLR accesses cost 2 seconds. If 50% of the dialed numbers are FDM, for 8 hours office time, the cache saves the organization 1 man-hour cost per day. There are 22 working days per month, the cache will save 264 man-hour per year for an organization.

*8 hours× 450 calls per hour× 0.5 FDN utilization × 2 sec = 1 hour*

## 6 CONCLUSION

In this article we stated the importance of NP service in mobile telecommunication systems, and posed that querying routing information from the large NPDB prolonged NP call processing time. Besides, Operators rarely made profit from the extra consumed communication resources being occupied during the NP call process time.

Follow from the property that OGB communication has dialed number locality, we introduced OGB caches to the mobile communication system to share the load of portable number translation to enhance the efficiency of NP service. We also showed that OGB caches saved a lot of communication cost for an organization.

In this paper we proposed an operation model of OGB caches in the public mobile communication environment. This implementation neither modified the communication protocol nor changed the operation logic of the conventional mobile telecommunication networks.

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