Utilizing 3G/WLAN Dual-Mode Terminals to Enhance the Efficiency of Mobile Number Portability Service

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ABSTRACT

Querying routing information is all-call-based during the process of translating portable numbers. Long delays in database searches make portable number translation the bottleneck of providing mobile number portability (NP) service. In this article we propose the mitigation of the traffic load through querying an NP database (NPDB) to alleviate the portable number translation delay. We also present a mechanism that utilizes the routing information on dual-mode MSs to alleviate the traffic load of NPDB and thus enhances the efficiency of mobile NP service. To conclude, we evaluate the performance of the proposed mechanism by simulation.

INTRODUCTION

Mobile communication has become a prevailing communication style. The maturity of mobile communication techniques is attracting more and more operators to join the market. As a result, customers have more opportunities to change service providers. However, customers were tired of having to distribute new phone numbers to others when changing operators. Having a number portability (NP) service that allows a user to keep a unique number becomes essential in such cases. Conventionally, a telephone number indicates the location or subscription network of a subscriber. Non-NP calls are routed via switches of the core network to the destination or routing addresses directly using the prefix of the dialed number. Portable numbers, on the other hand, do not provide definite routing information for call routing. It follows that a mechanism to translate portable numbers to physical addresses will be the basis of an NP service. The logic of portable number translation can be embedded in switches (on-switch) or maintained separately in the core network (off-switch) [1]. Off-switch solutions are usually adopted because routing information can be updated easily, and switching systems do not need to be altered. In off-switch solutions, an NP database (NPDB) is used to maintain the mapping of all portable numbers and routing addresses pertaining to the numbers' subscription networks [2]; every call terminated in a portable number requires an NPDB query. When the number of NP subscribers increases rapidly following the popularization of NP services, NPDB will grow to an unmanageable size, and querying the database will generate a heavy traffic load. In addition, extra processing time and bandwidth are consumed when doing portable number translation. Service providers must bear the expenditure of extra communication resources consumed; users have to endure the prolonged response time in making NP calls due to the holding up in resolving the routing information. The long delay time of all-call-based NPDB search and the long queuing time in NPDB for the heavy traffic load are both reasons why querying routing information is the bottleneck of NP services.

The telecommunication network hierarchy is designed to assemble the routing and signal-processing information in the centre. The NPDB is usually maintained in the core network. Because the size of the NPDB grows enormously, searching routing information is time-consuming. Many studies have claimed that implementing caches in telecommunications systems would improve the efficiency of information query [3, 4]. However, large amounts of routing information queries result in heavy traffic load and congestion of the NPDB; enhancing the efficiency of queries alone is not sufficient for improving the overall performance of NP services. Only when routing addresses of portable numbers are resolved at an early stage can the traffic load of the NPDB be eased and the delay time of querying routing information lessened.

The study of [5] discovered that 99 percent of calls had been made within a week before. Strong dialed number locality is the property that supports the idea of implementing portable number translation on the terminal side. If the routing information of portable numbers is confirmed on the terminal side, NPDB query can be omitted so that the NPDB traffic load can be mitigated. But as systems before enhanced sec-

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ond generation (2.5G) were not designed for data transmission, distributing routing information to terminals is expensive. Although data channels are available in 2.5G and third-generation (3G) systems, distributing routing information to end users in the centralized operation model is also costly. The distribution of routing information will consume a large amount of computation resources and bandwidth, or the requests from user terminals will congest the core network.

We found that numbers dialed from an organization usually exhibit strong locality. Keeping routing information of frequently dialed numbers in organization-based (OGB) networks is easy, and it shifts the workload of portable number translation to OGB networks [6, 7]. Consequently, the traffic load of the NPDB is alleviated. Nevertheless, this mechanism benefits only the users in the service region of an organization's network. Beyond the service region, users still need to query the NPDB for portable number translation. Maintaining routing information of portable numbers in OGB networks is not a comprehensive and satisfactory solution to NP services.

A new opportunity for solving the mobile NP problem lies in the emergence and popularity of 3G/wireless LAN (WLAN) dual-mode handsets. 3G/WLAN dual-mode handsets provide a way to combine the distributed data computational WLAN with knowledge-centralized 3G networks. In the dual-mode communication environment the routing knowledge can be distributed from NPDB to WLAN, and the handsets can contact the WLAN to renew routing information without altering the existing switching and signaling system. To take advantage of early-stage portable number translation, the routing information shall be conveyed in call origination requests. Users often set up calls to numbers stored in the address books of their mobile handsets. Keeping routing information in users' terminals realizes portable number translation at the end user; thus, a call can be routed directly without querying the NPDB, and the heavy traffic load on the NPDB can be eased. Consequently, we propose to extend the address book of the dual-mode handset to keep the mapping of a user's frequently dialed numbers and the corresponding routing addresses, and omit time-consuming NPDB queries to mitigate the NDPB traffic load.

Also, a mechanism that is convenient for distributing and renewing routing information to users' terminals is required. The routing information must be conveyed and be recognized in the process of NP call setup. In this article we describe the operation model of dual-mode handsets with extended address books, and the method to communicate and transmit the confirmed routing information of portable numbers. We investigate the NP call setup time and the traffic load of the NPDB to evaluate the performance of the proposed method. The cooperation and routing information distribution between the 3G network and WLAN are introduced. We then propose a mechanism to utilize address books of dual-mode mobile stations (MSs) for omitted NPDB queries. We give the performance evaluation followed by a conclusion.

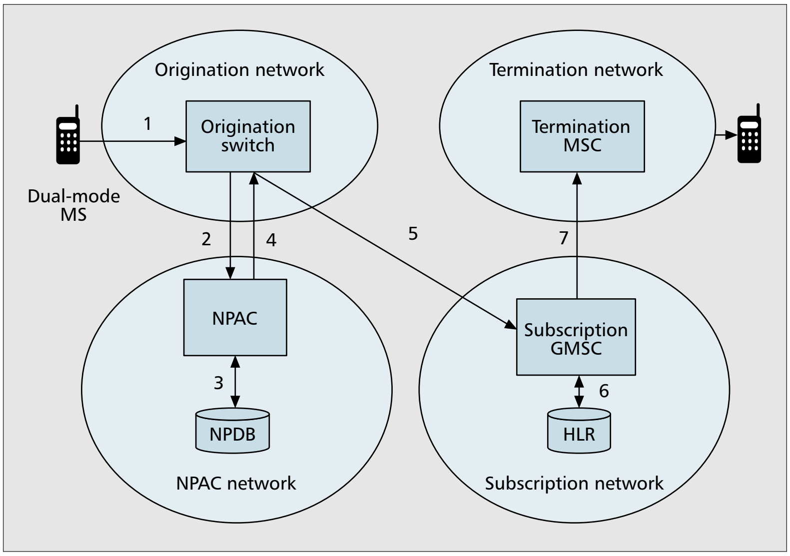


Figure 1. *Mobile NP call routing.*

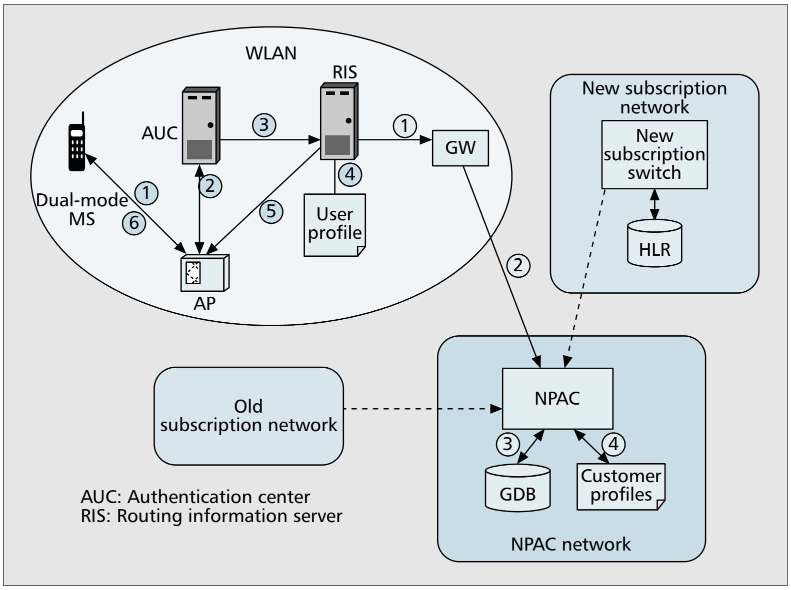
System Background

In this section we introduce the procedure of mobile NP call setting to explain the bottleneck of providing mobile NP service. We also discuss the feasibility of distributing routing information to the end user.

Providing Mobile NP Service

Recognizing portable numbers and determining the destination addresses of portable numbers is the most essential process for providing mobile NP service. Operators must be able to identify portable numbers, determine the subscription network of a portable number, and translate the dialed numbers to the corresponding routing addresses. When numbers are ported out or into an NP service provider, the service provider needs to update the NPDB. Because updating and queries of routing information are frequent, a global and sharable NPDB that keeps identical routing information of all the portable numbers of every network is necessary. Usually, this is a neutrally operated number portability administration center (NPAC) with a global NPDB established and operated by a third party organization, or through the cooperation of the operators in the environment. Operators can obtain the routing information of portable numbers by querying the NPAC.

Figure 1 illustrates the simplified process of setting a mobile NP call. The *origination network*, to which the calling party connects, receives a call initiation request from a subscriber (step 1); it determines the dialed number, which indicates an NP subscriber, and issues an INAP *initalDP* to the NPAC network for querying the routing address of the *subscription network*, which is the network with which the called party is registered (steps 3, 4). Following the routing address, the origination network routes the IAM message to the subscription network (step 5). The subscription network queries the home location register (HLR) for the MSRN of the called party (step 6) to reach the termination network, and forwards the IAM message to the termination



■ **Figure 2.** *Routing information retrieval and delivery for a WLAN.*

mobile switching center (MSC) (step 7) to set up the call.

Unfortunately, not only portable numbers trigger NPDB queries. When a number is recorded as a portable number, the entire group of numbers is taken as portable numbers [2]; every call set to these numbers triggers the process of portable number translation. The considerable number of routing information queries enlarges the load of the NPDB. The time to process queries, look up information in NPDB, and transmit information prolongs the response time of the NP service. Messages for database queries and number translations consume bandwidth and demand extra interoperations of different service networks. Moreover, the bandwidth reserved for the caller is occupied during the process, but operators make no profit on the additional bandwidth consumption, message transmission, signal processes, and database queries. When the amount of users grows rapidly, managing numerous data and accommodating arriving queries in NPDB are crucial to the efficiency of routing information query; NPDB query becomes the bottleneck of the NP service. A mechanism is needed to enhance the efficiency of NPDB queries.

The Distribution and Maintenance of Routing Information

The performance of database searching is limited and the size of a DB will grow cumbersome with increasing NP users. If the translation of portable numbers can be resolved in the early stages of the call setup process, the NPDB traffic load can be mitigated and the routing information query delay shortened to enhance the efficiency of the mobile NP service. We propose to keep the routing information of portable numbers in users' MSs. Thus, most of the dialed portable numbers can be resolved at the user equipment without querying the NPDB.

For utilizing the user's MS to perform the service of portable number translation, a mechanism to distribute and renew the routing information of portable numbers from the NPDB to users' MSs is required. The study of [5] discovered that most of the calls are set to the numbers called in the previous week. Keeping the routing information of a user's most frequently dialed numbers in the user's MS can resolve the routing addresses of most of the dialed numbers, which is a low-cost and effective solution to ease the delay time of querying routing information. But providing personalized computing and customized data is costly in the 3G system. The communication model of a 3G system is centralized. The knowledge for signal processing and information routing is concentrated in the core network [8]. Processing and transmission of customized information consume considerable computational costs and network resources. The 3G/WLAN dual-mode handset combines the distributed computation feature of WLAN and the global mobile communication ability of the 3G network to empower customized service in the mobile telecommunication system. The development of 3G/WLAN dual-mode handsets presents a way to keep routing information in user equipment.

WLAN is designed as a packet-based data communication network that can also provide speech communications. It differs from telecommunication systems in the feature of distributed storage and computation. Several WLANs can connect as a community. Users can access information and data of a WLAN by an authentication process [9]. The distributed storage and computation properties of WLAN are appropriate to perform customized services in the client/server operation model [10]. Distribution and update of routing information can be performed as an add-on service of a WLAN that can distribute the routing information corresponding to the numbers in the address book of a user's MS.

A WLAN routing information server (RIS) downloads the altered routing information from a neutral NPAC where a global NPDB is available, and the RIS can distribute the routing information to the subscribers of the WLAN according to previously registered user profiles. Because the user service identity module (USIM) and address book are shared resources of the 3G and WLAN systems [11], the predownloaded routing information in address books can be used to solve the routing addresses of portable numbers and mitigate NPDB queries in the two network systems. Based on USIM, WLAN can provide customized services to users.

Figure 2 presents the operation of retrieving and distributing routing information in the 3G/WLAN dual-mode communication environment. All the routing information of every portable number is maintained in the NPAC. When a number is ported out from the old subscription network, the old subscription network issues an update message to the NPAC for removing the related routing information from the NPDB; when a number is ported to a new subscription network, the new subscription network requests the NPAC to update the new routing address of the number in the NPDB. For consistency of routing information to prevent loss of calls, usually the updated routing information is postponed for at least a couple of hours before it goes into effect. Accordingly, the RIS of the WLAN updates the altered routing information periodically rather than instantly, and the process can be performed offline in the off time.

Figure 2, steps 1 to 4 (in lighter circles), illustrate the process by which an RIS retrieves altered routing information for a portable number from the NPAC. When a service provider network queries the NPAC for altered routing information, the NPAC determines the user authority and the timestamps to retrieve related information and sends it to the querying network.

Dual-mode MS users must interact with their subscription WLAN to update the routing information on their MS. A WLAN subscriber can register a profile of his or her address book in the RIS; thus, the WLAN can provide customer-dependent services to the user. Figure 2, steps 1 to 6 (in darker circles), illustrate the process of updating routing information for a dual-mode MS. When a register message is originated from a dual-mode MS to the WLAN (step 1), the message is forwarded to the authentication center (AUC) for user authentication (step 2). If the user is authorized, the AUC notifies the RIS to check whether the altered routing information is available for the user (step 3). The RIS filters the routing information according to the profile of the user (step 4), and issues a message to notify the MS of the user to update the altered routing information (steps 5 and 6). Even when users move beyond the service region of their registered WLAN, they can access and update the renewed routing information if they can access the WLAN by the Internet or another WLAN.

The routing information update process can be triggered when users turn on terminals in the service region of a WLAN or connect their terminals to computers to synchronize data. The synchronization of routing information can be transferred through the Internet connection or via WLAN. The transfer speed of an 802.11a/g WLAN is 54 Mb/s, which is more efficient than a 384 kb/s 3G radio access network (RAN).

THE IMPLEMENTATION OF DUAL-MODE MOBILE NP SERVICES

While the dialed numbers of a user usually exhibit strong locality, we propose to enlarge the address book of users' MSs to keep the routing information of a user's frequently dialed numbers. Thus, most of the portable numbers dialed by the user can be translated to the corresponding routing addresses in the user's terminal without querying the NPDB. In addition, the routing information must be borne in the call origination signals such that the calls can be routed to the appropriate networks directly.

For this purpose, the address book of the MS shall be extended to keep the routing information, and the signaling system must be able to recognize the extra information in call origination signals. Using user-provided routing information for call routing, the validity and correctness of the information is important.

Name	MSISDN	Subscription network ID
Alice	+8869315678	+88601
Benson	+8869264627	+88603
Carolyn	+8869192768	+88602
…	…	…

Table 1. *Extra information in the address book of the dual-mode MS.*

Information element	M: Mandatory O: Optional	Length (octet)
…		
Setup message type	M	1
Facility	**O**	**2–?**
Calling party subaddress	**O**	**2–23**
Called party subaddress	O	2–23
…		
SS version	**O**	**2–3**
…		

Table 2. *The information elements of a SETUP message.*

UTILIZE SS INFORMATION TO ENHANCE MOBILE NP SERVICE

Every mobile network has a unique network ID that can be utilized to identify the subscription network of a portable or non-portable number. For keeping the routing information in the address book, every entry in the address book is extended to include the subscription network ID, as shown in Table 1.

The call origination procedure starts with a SETUP message sent from the user terminals to the switching network. The SETUP message carries information on the called party's address and supplementary service (SS). The content of a SETUP message is listed in Table 2. When the address book of the dual-mode MS is extended to keep the subscription network of mobile numbers, the SETUP messages shall carry corresponding information to the switching network. Where the *Facility* indicates that an SS is enabled, the *SS version* is the version of the SS attached to the subscription network of the dialed number. The *Called party subaddress* can be used to indicate the subscription network of the dialed number.

The call is routed according to the subscription network ID. The switching network receives

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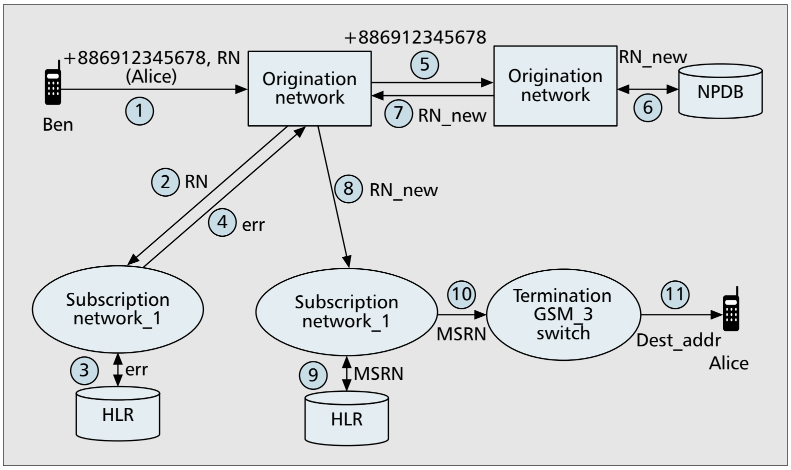

Figure 3. *The worst case of NP call routing.*

the SETUP message and finds that an SS is enabled, which means the dialed address is translated. Then the call is routed to the subscription network of the dialed number directly. The subscription network of the dialed number consults its HLR for the routing address of the termination network, and the call can be routed to the called party directly without querying the NPDB.

This process can be implemented as an SS of the 3G network, which omits routing messages to the NRH network and the time-consuming NPAC query, and is backward-compliant with 2G and 2.5G systems. When more users dial the numbers in their address books, more workload of portable numbers translation is shifted to the user terminal, and the efficiency of NP service is enhanced.

THE WORST CASE

Even the update process can be carried out anytime a user can access a WLAN or the Internet to prevent overdue routing information. However, once networks are unavailable and the routing information on users' terminals cannot be updated, the obsolete routing information can lead to misrouted calls. As shown in Fig. 3, the obsolete routing information will route a call to a wrong destination (steps 1–4). The origination network needs to consult NPAC for the correct routing information of the dialed number (steps 5–7), then uses the information to reach the subscription network of the called party to get the destination address to set up the call (steps 8–11). This results in the consumption of extra communication resources and prolongation of the NP call setup time.

Although call misrouting is unpredictable and irresistible, the NP call service cannot fail when the routing information on the user terminal is wrong. If misrouting occurs, the calling network must be able to reissue an NPDB query to the callee's NRH network. For this purpose, the dialed phone number must be carried in the call origination message. Once the routing information on a user's terminal is obsolete, the origination network can query NPAC by the dialed number to obtain the exact routing address of the callee's subscription network, then route the call to the called party.

PERFORMANCE AND COST ANALYSIS

The performance of the conventional NP service depends on the limited capacity and service rate of NPAC. Once NPAC cannot manage the offered workload, the waiting delay of every request is prolonged, and the performance of NP service decays.

The routing information of portable numbers in the 3G/WLAN dual-mode MS allows the call to be routed to the subscription network directly without consulting NPDB; thus, the response time of NP call setup can be shortened. As a large number of NPAC queries are omitted, the workload of NPAC is mitigated and can provide better performance of NP services to more customers.

We study the benefit of our method by evaluating the shortening of NP call setup time, alleviation of NPAC traffic load, and saved average response time for the NP call setup process.

THE EVALUATION OF CALL SETUP TIME AND NPDB TRAFFIC LOAD

While NPDB queries are all call-based, every call set up to a number of the portable number group initiates an NPDB query for number translation. The expansion of NP subscribers leads to an irresistible approach of huge NPDB and long searching delay. Here we evaluate the traffic load of NPAC and the NP call setup time to study the benefit of the proposed mechanism.

NP call setup time (denoted t_c) includes the time for call processing (including signal processing, codec, and channel reservation), call setup signal transmission, and routing information query, denoted t_s, t_{trans}, and t_{query}, respectively, where $t_c = t_s + t_{trans} + t_{query}$.

Consulting address books of dual-mode MS has the results of:

- Cache miss, following the conventional NP call routing process
- Cache hit and the data is correct, which can effectively reduce routing information query delay
- Cache hit but the data is overdue, which results in misrouting and the worst case

Let t_{NPAC} and t_{cache} represent the delay time of NPAC query and address book query. Where $t_{NPAC} >> t_{cache}$, the information query delay in the conventional case is much longer than that of consulting an address book ($t_{query\_conv} >> t_{cache}$).

- Case 1: When it is a cache miss, the NP call setup time (t_{c1}) of this case is very close to that of the conventional case because t_{cache} is very small and can be omitted. The time to query routing information is
  $t_{query\_1} = t_{cache} + t_{query\_conv}$,
  $t_{trans\_1} = t_{trans\_conv}$, and
  $t_{c1} = t_s + t_{trans\_1} + t_{query\_1}$.
- Case 2: Cache hits and the data is correct; the routing information query delay is
  $t_{query\_2} = t_{cache} << t_{query\_1}$,
  $t_{trans\_2} = t_{trans\_conv}$;

the call setup time t_{c2} is
$t_{c2} = t_s + t_{trans\_2} + t_{query\_2}, t_{c2} << t_{c1}$.

- Case 3: Cache hits but the data is overdue; the call is routed to a wrong address (routing time is t_{trans_err}), and the call origination network has to reissue an NPAC query to obtain the exact routing information of the callee's subscription network. The time for call setup (t_{c3}) is

$t_{c3} = t_{c2} + t_{trans\_err} + t_{trans\_conv} + t_{query\_conv}$.

This is the worst case; t_{c3} is larger than ($t_{c2} + t_{c1}$). It is time consuming.

Reducing NPAC queries can alleviate both call setup delay and network resource consumption. Assuming the proportion of utilizing the routing information in address books to make NP calls is p, m proportion of the cached data is correct, and $(1 – m)$ will lead to misrouting calls. The average call setup delay can be represented as

$$(1-p)\, t_{c1} + p\, [m \times t_{c2} + (1-m)\, t_{c3}]$$

Let 2 percent of the routing information in the address book is overdue. In a service area of the dual-mode communication environment with 10 thousands of users, every user generates 4 calls per day in average. Assume 30 percent of the calls are set to portable numbers, every routing information query is 1.5 s on average (including query, transmission, and queuing delay) and 70 percent of the routing information is obtained from the address book. 7.2 h information query delay is saved per day for the service area.

The NPAC traffic load is linearly proportional to the utilization of the address book of the dual-mode MS. Under the same condition, the extended address book can relieve the NPDB of about 14000 NPDB queries; that is, 35 percent of the NPDB traffic load is alleviated.

The more users obtain routing information from the address book of their MS, the more noticeably the NPAC workload is mitigated. Although some of the local routing information is obsolete and causes misrouting of calls, utilizing the address book of a dual-mode MS provides better NP service efficiency than conventional NPAC queries.

THE WAITING DELAY EVALUATION

Consider NPAC as a single-server queuing system with a Poisson input of arrival rate λ and the service time generally distributed with mean

$$\tau = \int_0^{\infty} t h(t)\, dt,$$

where $h(t)$ is the density function of the service time. Assume the utilization factor ρ = ?τ < 1. We use an M/G/1 model and the method of the embedded Markov chain to investigate the average queue length and waiting time. Let the queue length be N_q, the number of customers in the system N, the waiting time W, the average number of customers in the system $E[N] = E[N_q] + \rho$. We have

$$E[N_q] = \frac{2\rho(1-\rho)+\sigma}{2(1-\rho)} - \rho = \frac{\sigma}{2(1-\rho)};$$

$$E[W] = E[N_q]/\lambda = \frac{\sigma}{2\lambda(1-\rho)},$$

where

$$\sigma = \lambda^2 \int_0^{\infty} t^2 h(t)\, dt.$$

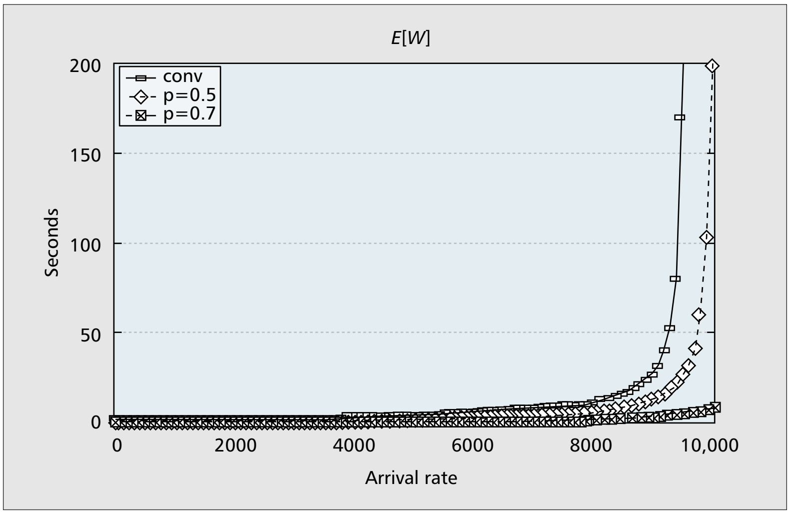

Figure 4. *The average waiting delay of an NP call setup process.*

The relation of expected waiting time and offered traffic of the NP service network is illustrated in Fig. 4. Let p denote the proportion of using routing information in an MS instead of querying NPAC, and assume 2 percent of the local routing information is obsolete. When the offered traffic load is enormous and the limited service capacity of NPAC cannot support the severe traffic load, the response time of routing information queries is prolonged so remarkably that the performance of NP service becomes poor.

Routing information stored in users' MSs alleviates NPDB query traffic. With the same computation power, keeping routing information on users' MSs can provide NP service to more users. Also, the delay time of waiting for NPAC service can be reduced notably.

CONCLUSION

This article discusses the fact that obtaining the routing information of portable numbers is the emphasis of NP service, and is also the most time-consuming stage of providing NP service. Keeping routing information in the 3G/WLAN dual-mode MS has the benefit of reducing the response time of routing information queries. Users usually have dialed number locality, and often utilize the address books in MSs. The performance of the NP service system increases as the probability of utilizing the address books of mobile MSs increases. The routing information on users' terminals effectively alleviates traffic congestion and workload on NPAC to reduce the response time of portable number translation.

Our proposed method benefits both users and NP service providers by saving call setup time for users, and computing and communication resources for NP service providers. NP service providers can provide better performance to more users without extending equipment and computing power. Without changing the existing signaling system and network architecture, the proposed mechanism is a low-cost, effective, and efficient solution for improving the performance of mobile NP service.

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