ENUM-based Number Portability for Mobile Communication Networks

Whai-En Chen, Yi-Lun Ciou

Department of Computer Science and Information Engineering, National I-Lan University, Taiwan
wechen@niu.edu.tw, leileisky1127@gmail.com

Abstract

Typically, people usually enjoy new services and lower service rates. However, while changing the mobile operators, the subscribers should change the original *Mobile Station International Subscriber Directory Numbers* (MSISDNs) and notify their friends the new MSISDNs. Due to the effort of changing the MSISDNs, the subscribers may give up using the new services and lower service rates. The *Number Portability* (NP) service enables the subscribers to keep their original MSISDNs while changing their mobile operators. Thus, the NP service is very important in 4G/5G mobile communications. To provide the NP service for 4G/5G, this paper proposes the call routing mechanisms and the enhancement based on *E.164 NUmber Mapping* (ENUM) and the *IP Multimedia Subsystem* (IMS) architecture.

Keywords: ENUM, IMS, Number portability, SIP, URI

1 Introduction to the NP Service

Different mobile operators may offer their unique application services and different service rates to attract the customers (i.e., the subscribers). In addition, people usually enjoy new services and lower service rates. However, when the subscribers change their mobile operators, the subscribers should change the original *Mobile Station International Subscriber Directory Numbers* (MSISDNs) and notify their friends the new MSISDNs. Due to the effort of changing the MSISDNs, the subscribers may give up using the new services and lower service rates. The *Number Portability* (NP) service enables the subscribers to keep their original MSISDNs while changing their mobile operators. Without the NP service, the subscribers may not have enough motivation to try new services and change to the mobile operators providing lower service rates. The NP service benefits both the subscribers and the new mobile operators.

[1] identifies that the NP service makes the telecommunication market in China more competitive. The NP service benefits both the subscribers and the new mobile operators. The NP service enables the subscribers to have more choices and select the operators with lower service rates [2]. In addition, the NP service provides a fair-competition environment to the mobile operators [3].

The design and deployment of the NP service require careful consideration and analysis. Typically, the NP service should follow a country's dialing plans and various local regulations [4]. Thus, the NP service is implemented by various call routing mechanisms and produce different costs to the mobile operators.

Figure 1 illustrates an architecture for NP service. We utilize this architecture to describe the call routing mechanisms for the NP service.

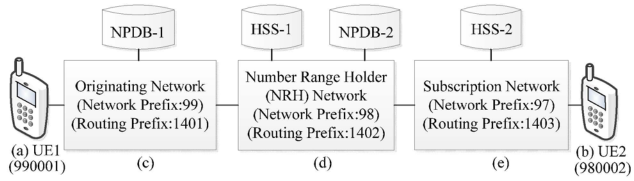

Figure 1. The Architecture for ENUM-based NP

In this paper, we assume that the called party (i.e., UE2) is ported to a new operator's network (i.e., the subscription network). The originating network is the network that the calling party (i.e., UE1) is subscribed and located at. The *Number Range Holder* (NRH) network is the network that the ported number (e.g., UE2's MSISDN 980002) has been allocated to. The subscription network is the network that the called party (i.e., UE2) is ported to. The *Home Subscriber Server* (HSS) is the major database that contains the subscription-related information, performs *Authentication, Authorization and Accounting* (AAA) and maintains the subscribers' location. The *Number Portability DataBase* (NPDB) provides the routing information (i.e., the routing number or routing prefix) of the ported MSISDN. Note that the NPDB instead of the HSS stores the routing information of the ported MSISDN.

The standard organizations *3rd Generation Partnership Project* (3GPP) and *Internet Engineering Task Force* (IETF) propose the call routing

*Corresponding Author: Whai-En Chen; E-mail: wechen@niu.edu.tw
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mechanisms in TS 23.066 [18] and RFC 3482 [19] for offering the NP service in 2G/3G system and the *Global Switched Telephone Network* (GSTN), respectively. Specifically, IETF RFC 3482 and 3GPP TS 23.066 propose four and three call routing mechanisms to implement the NP service. In IETF RFC 3482, the call routing mechanisms include *All Call Query* (ACQ), *Onward Routing* (OR), *Query on Release* (QoR) and *Call Dropback*. 3GPP TS 23.066 specifies *Originating call Query on Digit analysis* (OQoD), *Terminating call Query on Digit analysis* (TQoD) and *Query on HSS Release* (QoHR) call routing mechanisms. Several call routing mechanisms are the same. To analyze the above mechanisms, we classify and list them in Table 1.

Table 1. Comparison of Call Routing Mechanisms in Different Specifications

Standard Organization	3GPP	IETF
Corresponding Call Routing Mechanisms	Originating call Query on Digit analysis (OQoD)	All Call Query (ACQ)
	Terminating call Query on Digit analysis (TQoD)	–
	Query on HSS Release (QoHR)	Onward Routing (OR)
	–	Query on Release (QoR)
	–	Call Dropback

In the TQoD mechanism, the originating network forwards the call to the NRH network. Upon receipt of the call, the NRH network queries the NPDB to find the routing information of the called party's MSISDN and routes the call to the subscription network. In the QoHR and OR mechanisms, the originating forwards the call to the NRH network. Upon receipt of the call, the NRH network searches the called party's MSISDN in the HSS but the MSISDN is not found. Then the NRH network queries the NPDB to look up the routing information of the called party's MSISDN and then routes the call to the subscription network. In the QoR mechanism, the originating network forwards the call to the NRH network. Upon receipt of the call, the NRH network queries the NPDB, redirects the call and notifies the originating network that the called party's MSISDN may have another route. Then, the originating network queries the NPDB to find the alternative routing information of the called party's MSISDN and routes the call to the subscription network. In the *call dropback* mechanism, the originating network forwards the call to the NRH network. Upon receipt of the call, the NRH network redirects the call and provides the routing number of the called party's MSISDN. Then, the originating network utilizes the routing number to route the call to the subscription network.

Among the above mechanism, the OQoD and ACQ mechanisms are the same, and the QoHR and OR mechanisms are the same. The other three mechanisms are the different (i.e., TQoD, QoR, call dropback). The NPDB query can be performed in either the *originating* network or the *NRH* network. 3GPP does not consider the *redirect* cases, and IETF does not consider that the NRH network first queries the *NPDB*.

In 4G/5G all-IP networks, the *IP Multimedia Subsystem* (IMS) provides high quality multimedia services including the high-quality *Voice or Video over LTE* (VoLTE) for mobile communications. The signaling of these services are based on *Session Initiation Protocol* (SIP). In order to achieve fair competitions among the mobile operators, 4G/5G specifications should define the *Number Portability* (NP) service based on the IMS architecture. Although 3GPP TS 23.228 specifies [7] the IMS services and mentions that *E.164 NUmber Mapping* (ENUM) can be used to provide the NP service, [5] and [6] identify that there is no clearly defined solution providing the NP service in the mobile communications standards.

Besides the standards, several related papers propose the call routing mechanisms. [17] proposes a *Signaling Relay Function* (SRF)-based solution and an *Intelligent Network* (IN)-based solution for call routing in circuit-switched network. [5] proposes an application server-based scheme for NP service in the IMS network. However, the article does not present the *message flows* of the call routing mechanisms. [6] proposes the IMS-based call routing schemes by using the SIP response codes **300**, **301**, **302** and **380**. However, the article does not consider the TQoD case defined in 3GPP TS 23.066. [21] proposes the call routing between IMS and PSTN networks. The NP query only can be performed once based on RFC 4694 [16], but the NP query is performed twice in [21]. The above articles introduce the call flows of the NP service without the performance improvement for the call routing mechanism. [22] improves the performance by using the cache scheme. To provide the NP service for 4G and beyond, we elaborate the call routing mechanisms in IMS architecture based on 3GPP TS 23.228 and propose two enhanced call routing mechanisms for the NP service. To demonstrate the proposed call routing mechanisms for the NP service, the elements of the IMS network architecture in Figure 1 are introduce as follows.

UE1 [Figure 1(a)] is the calling party and UE2 [Figure 1(b)] is the called party. The MSISDNs of UE1 and UE2 are **990001** and **980002**, respectively. The network prefix of the originating network [Figure 1(c)] is **99**, which means the number range of the originating network is **990000~999999**. The routing prefix [20] of the originating network is **1401**. The network prefix of the NRH network [Figure 1(d)] is **98**, the number range is **980000~989999** and routing prefix is **1402**. The network prefix of the subscription network [Figure 1(e)] is **97**, and the routing prefix of the subscription network is **1403**. Assume that the called party (UE2) is ported to a new mobile operator's network. Each network contains a HSS. The originating network and the NRH network contain a NPDB.

The rest of this paper is organized as follows. This paper proposes the call routing mechanisms according to the specifications defined in 3GPP and IETF in section 2. Specifically, this paper elaborates the *message flows* and the *major parameters* of the call routing mechanisms. In section 3, to improve the performance of the call routing procedures, this paper proposes a *hybrid* mechanism that routes the call based on the number porting ratios and a *cache* mechanism that looks up the route in the cache. Then, this paper presents the analysis results of the call routing mechanisms in both quality and quantity in section 4. Finally, the conclusions are given in the last section.

2 The IMS Call Routing Mechanisms for NP Service

Either the IMS in the originating network (i.e., the originating IMS) or in the NRH network (i.e., the NRH IMS) can query the ENUM-based NPDB or the HSS to find the subscribers' location. Based on the above conditions, 3GPP TS 23.006 [18] specifies three call routing mechanisms for mobile communications: *Originating call Query on Digit analysis* (OQoD), *Terminating call Query on Digit analysis* (TQoD), *Query on HSS Release* (QoHR). Note that the originating network looks up the HSS if and only if the originating network is the terminating network and thus there is no OQoHR. Moreover, [6] utilizes the SIP **3xx** responses [12] to perform the *redirect* mechanism. In this section, we introduce the ENUM-based NPDB query and the IMS call routing mechanisms.

2.1 The ENUM-based NPDB Query Procedure

ENUM is a system for telephone number mapping, which maps the MSISDN with the internet identifications (e.g., the *Uniform Resource Identifiers*; URIs) [8]. ENUM utilizes the *Domain Name System* (DNS) [9] to store the mapping records and resolve the MSISDNs into the *tel URIs* [10-11]. Specifically, the IMS (e.g., S-CSCF) issues the ENUM queries with the MSISDN information to retrieve the tel URI from the ENUM database.

In 3GPP specifications, the IMS adopts SIP [12] as the signaling protocol of call routing. The SIP messages contain the URI to identify the MSISDN of the called party [7, 13]. IETF RFC 4769 [14] proposes the type "pstn" and subtype "tel" to identify the tel URI for ENUM. In the tel URI, the *NP Database Dip Indicator* (npdi) tag and *Routing Number* (rn) tag are also proposed in [15-16] for the NP service. The "npdi" tag indicates that an NP query has already been performed for retrieving the tel URI. The SIP/IMS servers should not perform the NP query again when the tel URI contains an "npdi" tag [16]. The "rn" tag carries the routing number information. If the queried MSISDN is ported to another mobile operator, the "npdi" and "rn" tags are added to the tel URI where the "rn" tag includes the routing information designating to the new mobile operator. Otherwise, only the "npdi" tag is presented in the tel URI where the "npdi" tag indicates that the NPDB query is performed and there is no tel URI for the new route.

Figure 2 demonstrates the NP query procedure. Upon receipt of an **INVITE** message at Step 1, the IMS checks whether the MSISDN is a fully qualified E.164 number (e.g., +886-980002) [11]. If not (e.g., 980002), the IMS translates the MSISDN to a fully qualified E.164 number by adding a prefix (e.g., +886 for Taiwan). Then the IMS removes all characters '+' in front of the number (e.g., 886980002), inverts the order of the digits (e.g., 200089688), sets dots '.' between two digits (e.g., 2.0.0.0.8.9.6.8.8) and adds the suffix ".e164.arpa." and interpret as a domain name. The IMS translates the E.164 number to a *Fully Qualified Domain Name* (FQDN) **2.0.0.0.8.9.6.8.8.e164.arpa** and utilizes the FQDN to perform **the NP query** at Step 2. The NP query is a DNS query message to retrieve the *Name Authority Pointer* (NAPTR) record. At Step 3, upon receipt of the NP query, the NPDB retrieves the NAPTR record that records UE2's URI by using the FQDN as the search index. Since UE2's MSISDN is ported to the subscription network, the NPDB replies the result (i.e., **tel:+886-980002;npdi;rn=+886-1403980002**) to the originating IMS. According to the result (i.e., the routing number **1403**), the IMS forwards the **INVITE** message to the subscription network.

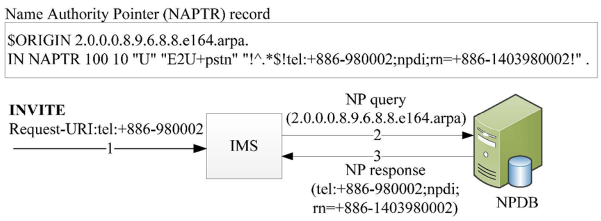


Figure 2. The ENUM-based NPDB Query for IMS

2.2 Originating Call Query on Digit Analysis (OQoD) Mechanism

The NP query is performed at the originating IMS. By querying the NPDB, the originating IMS checks whether the MSISDN of the called party is ported to another network. If yes, the originating IMS forwards the **INVITE** message to the subscription network. Otherwise, the originating IMS forwards the **INVITE** message to the NRH IMS. The detailed procedure illustrated in Figure 3 is elaborated as follows.

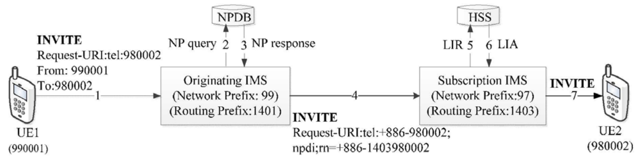


Figure 3. Originating call Query on Digit analysis (OQoD)

Step. 1: When the calling party dials the MSISDN **980002**. UE1 issues an **INVITE** message to establish the multimedia sessions with the called party (i.e., UE2). The **INVITE** message contains a *Request-URI* **tel:980002**, a *from* header field, and a *to* header field. The *Request-URI* **tel:980002** indicates the called party. The *from* header field indicates the calling party (i.e., **990001**) and the *to* header field indicates the called party (i.e., **980002**). To resolve the MSISDN of the called party retrieved from the *Request-URI*, UE1 sends the **INVITE** message to the originating IMS.

Step. 2: Upon receipt of the **INVITE** message, the IMS translates the MSISDN **980002** in the *Request-URI* to a fully qualified **E.164** number (i.e., **+886980002**) by adding the country code **+886**, and translates the fully qualified E.164 number to a FQDN **2.0.0.0.8.9.6.8.8.e164.arpa**. The originating IMS then sends an NP query with the FQDN to the NPDB. This step is the same as Step 2 in section 2.1

Step. 3: Upon receipt of the NP query, the NPDB retrieves the NAPTR record of the called party (i.e., UE2) by using the FQDN. The NAPTR record contains a tel URI **tel:+886-980002;npdi;rn=+886-1403980002**. The NPDB replies the tel URI to the originating IMS through the NP response. This step is the same as Step 3 in section 2.1

Step. 4: The originating IMS replaces the *Request-URI* **tel:980002** by using the NP query result **tel:+886-980002;npdi;rn=+886-1403980002**. The originating IMS forwards the **INVITE** message to the subscription IMS according to the "**rn**" tag (i.e., **+886-1403980002**) in the *Request-URI*.

Step. 5: Upon receipt of the **INVITE** message, the IMS detects that the *Request-URI* is retrieved from the NPDB based on the "**npdi**" tag. The IMS compares its routing prefix **1403** with the number **+886-1403980002** in the "**rn**" tag and detects that it's the terminating IMS. Then, the subscription IMS queries the HSS for UE2's location information by sending a *Location-Info-Request* (LIR) message.

Step. 6: The HSS replies a *Location-Info-Answer* (LIA) message with UE2's location to the subscription IMS.

Step. 7: Upon receipt of the **LIA** message, the subscription IMS forwards the **INVITE** message to UE2.

Note that the subsequent SIP request messages are processed in the same way as the **INVITE** message, and the SIP response messages (e.g., 200 OK) are routed to UE1 along the reverse path as the **INVITE** message according to the *Via* header fields.

2.3 Terminating Call Query on Digit Analysis (TQoD) Mechanism

In this mechanism, the NP query is performed at the NRH IMS. The NRH IMS queries the NPDB to check whether the called party's MSISDN is ported to another network. In this case, the tel URI is found in the NPDB and the **INVITE** message is forwarded to the subscription IMS. The detailed procedure is illustrated in Figure 4 and elaborated as follows.

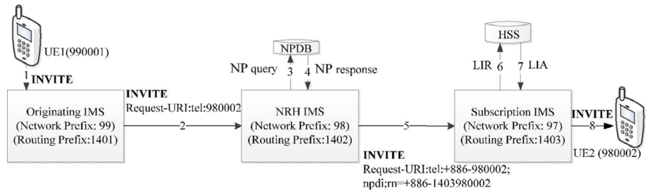


Figure 4. Terminating call Query on Digit analysis (TQoD)

Step. 1: When the calling party dials the MSISDN **980002**, the **INVITE** message is sent to the originating IMS. This step is the same as Step 1 in section 2.2.

Step. 2: Upon receipt of the **INVITE** message, the originating IMS looks up its routing table by using the MSISDN **980002** in the *Request-URI*. The originating IMS forwards the **INVITE** message to the NRH IMS since the NRH's network prefix is **98**.

Step. 3: Upon receipt of the **INVITE** message, the IMS confirms that it's the NRH IMS because the MSISDN **980002** matches its network prefix **98**. The *Request-URI* does not contain the "**npdi**" tag. The NRH IMS converts the MSISDN to the FQDN **2.0.0.0.8.9.6.8.8.e164.arpa.** The NRH IMS then issues an NP query with the FQDN to the NPDB. The NP query procedure is the same as Step 2 in section 2.1

Step. 4: Upon receipt of the NP query, the NPDB retrieves the routing number of UE2 by using the FQDN and replies the tel URI with UE2's routing number **tel:+886-980002;npdi;rn=+886-1403980002** to the NRH IMS. The NP query procedure is the same as Step 3 in section 2.1

Step. 5: The NRH IMS replaces the *Request-URI* by the tel URI **tel:+886-980002;npdi;rn=+886-1403980002**. The NRH IMS forwards the **INVITE** message to the subscription IMS based on the value of the "**rn**" tag.

Step. 6: Upon receipt of the **INVITE** message, the IMS detects the *Request-URI* is retrieved from the NPDB by the "**npdi**" tag. The IMS compares its routing prefix **1403** with the "**rn**" tag **+886-1403980002** and detects that it's the subscription IMS of UE2. Then, the subscription IMS queries UE2's location by sending a **LIR** message to the HSS.

Step. 7-8: The HSS replies a **LIA** message with UE2's location to the subscription IMS, and the subscription IMS forwards the **INVITE** message to UE2.

Note that if the called party's MSISDN is not ported and in the NRH network, the NPDB will reply a response at Step 4 without the "**rn**" tag. Then, the NRH IMS queries the HSS to find UE2's location and forwards the **INVITE** message to UE2.

2.4 Query on HSS Release (QoHR) Mechanism

In this mechanism, the NRH IMS queries the HSS to find the location of the called party. The record is not found in the HSS. The NRH IMS then queries the NPDB to retrieve the called party's routing information (e.g., the tel URI) and forwards the call to the subscription IMS. If the record is not found in the NPDB, the NRH IMS notifies the user that the call cannot be routed. The detailed procedure illustrated in Figure 5 is elaborated as follows.

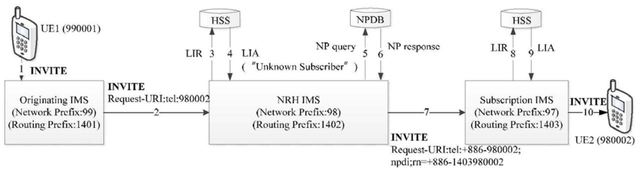


Figure 5. Query on HSS Release (QoHR)

Step. 1-2: When the calling party dials the MSISDN **980002**, the **INVITE** message is sent to the originating IMS. Then the originating IMS looks up its routing table and forwards the **INVITE** message to the NRH IMS. Those steps are the same as Steps 1 and 2 in section 2.3.

Step. 3: Upon receipt of the **INVITE** message, the IMS retrieves the MSISDN from the *Request-URI* and confirms it's the NRH IMS by comparing the MSISDN and its network prefix **98**. Unlike the TQoD mechanism, the NRH IMS queries UE2's location by sending a **LIR** message to the HSS instead of the NPDB.

Step. 4: Since the called party is ported to the subscription IMS, The HSS replies a **LIA** message with "**Unknown Subscriber**" to the NRH IMS.

Step. 5: To confirm whether the MSISDN of UE2 is ported to other network, the IMS translates the MSISDN in the *Request-URI* to a FQDN **2.0.0.0.8.9.6.8.8.e164.arpa**. The NRH IMS then sends an NP query with the FQDN and the **NAPTR** type to the NPDB. The NP query procedure is the same as Step 2 in section 2.1

Step. 6: Upon receipt of the NP query, the NPDB utilizes the FQDN to retrieve UE2's routing number and replies the tel URI **tel:+886-980002;npdi;rn=+886-1403980002** to the NRH IMS. The NP query procedure is the same as Step 3 in section 2.1

Step. 7-10: The NRH IMS replaces the *Request-URI* by the tel URI obtained from Step 6. The NRH IMS forwards the **INVITE** message to the subscription IMS. Then, the subscription IMS queries the HSS and forwards the **INVITE** message to UE2. Those steps are the same as Steps 5-8 in section 2.3.

Note that if the MSISDN of UE2 is in the NRH network, the HSS will reply a **LIA** response at Step 4 to indicate that UE2's MSISDN is not ported to other network. Then, the NRH IMS queries UE2's location from the HSS and forwards the **INVITE** message to UE2.

2.5 Redirect on HSS Release (Redirect) Mechanism

The NRH IMS acts as a SIP redirect server and utilizes the SIP **380** status code to notify the originating IMS that the call may have another route [12]. Upon receipt of an incoming call, the NRH IMS queries the HSS to obtain the called party's location. If the location is found, the NRH IMS forwards the call to the called party. Otherwise, the NRH IMS redirects the originating IMS to check whether the called party has an alternative route or service. The detailed procedure illustrated in Figure 6 is elaborated as follows.

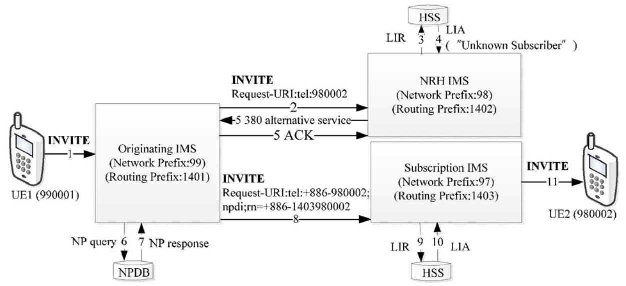


Figure 6. Redirect on HSS Release (Redirect)

In Figure 6, Steps 1-4 are the same as Steps 1-4 in section 2.4 in the QoHR mechanism. Since UE2's MSISDN is ported to the subscription IMS, the NRH IMS replies the originating IMS by a SIP **380** response at Step 5. Upon receipt of the **380** response, the originating IMS performs the NP query and receives UE2's new URI (i.e., **tel:+886-980002;npdi;rn=+886-1403980002**) at Steps 6-7. The originating IMS updates the *Request-URI* and forwards the **INVITE** message to the subscription IMS at Step 8. The rest Steps 9-11 are the same as Steps 8-10 in section 2.4.

Note that in [6], the NRH IMS performs the NP query to retrieve the UE2's routing number from the NPDB and replies the SIP response message with **302** status codes. The UE2's routing number is embedded in the "tel" URI of the **302** response and sent to the originating IMS. When the originating IMS receives the tel URI with the "**npdi**" tag, it should not query the NPDB again [16]. In such cases, the originating IMS should trust the NRH IMS and utilizes the received tel

URI directly.

In this paper, we utilize status code **380** instead of **302** to notify the originating IMS. The originating IMS can perform the NP query and confirm the porting information of the called party.

3 The Enhanced IMS Call Routing Mechanisms

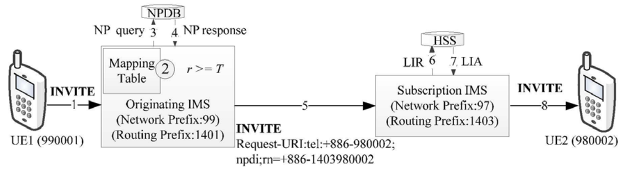
In this section, we propose a hybrid mechanism and a cached OQoD mechanism to improve the performance of the call routing mechanisms. When the porting ratio is *high*, most subscribers are ported to the new subscription networks. The originating IMS utilizes the OQoD mechanism to quickly find the subscription IMS of the called party. On the contrary, if the porting ratio is *low*, most called parties are in their NRH networks and the *redirect* mechanism is the most effective way to reach the called party. Thus, we propose a hybrid mechanism that dynamically selects the OQoD and *redirect* mechanisms. Specifically, the hybrid mechanism utilizes a porting ratio *r* to choose the OQoD or *redirect* mechanism. On the other hand, the article [22-23] identifies that some telephone numbers are dialed frequently in a period of time. To improve the lookup latency, we propose a cached OQoD mechanism that caches the frequently used records in the IMS's local memory (e.g., cache). We consider the procedures when cache hit, cache miss and cache stale. Based on the above mention, we propose two call routing mechanisms for IMS. The message flows for these mechanisms are elaborated as follows.

3.1 Hybrid of OQoD and Redirect (Hybrid) Mechanism

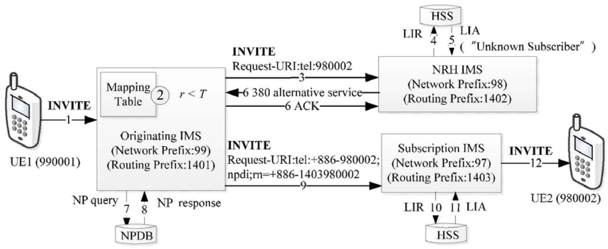
When the porting ratio of an NRH network is high, most subscribers are ported to the new subscription networks. In this case, the most efficient way is that the originating IMS queries NPDB, retrieves the called party's subscription network and forwards the call to the subscription network. In this way, the call setup messages and the media traffic are not sent to the NRH network. Specifically, the hybrid mechanism adopts the OQoD mechanism to forward the incoming call. If the called party is in the NRH network, the extra cost is querying the originating network's NPDB.

On the contrary, when the porting ratio is low, few subscribers are ported and most subscribers can be found in the NRH network. In this case, the most efficient way is that the originating IMS forwards the call setup message to the NRH IMS. The NRH IMS queries the HSS to obtain the location of called parties and then forwards the call setup messages to the called parties. If the called party is not found in the HSS, the NRH IMS returns a SIP **380** response message to the originating IMS to indicate that the called party is not found but there may be another route. Thus, the originating IMS adopts the *redirect* mechanism in this case.

Based on the above analysis, the hybrid mechanism utilizes a porting ratio r_i to identify the porting ratio of the *i*th NRH network. The ratio can be off-line calculated by using the NPDB. The originating network builds a mapping table to record the porting ratios and network prefixes of the NRH networks. If $r_i \geq T$, the originating IMS performs the OQoD mechanism. If $r_i < T$, the originating IMS performs the *redirect* mechanism. The detailed procedure illustrated in Figure 7 is elaborated as follows.



(a) Hybrid Mechanism Performs OQoD Mechanism



(b) Hybrid Mechanism Performs Redirect Mechanism

Figure 7. The Hybrid Mechanism

Step. 1: When the calling party dials the MSISDN **980002**, the **INVITE** message is sent to the originating IMS. This step is the same as Step 1 in section 2.2.

Step. 2: Upon receipt of the **INVITE** message, the originating IMS looks up the mapping table by using the MSISDN **980002** and confirms that the MSISDN **980002** matches the network prefix **98**. Assume that the porting ratio r_i larger than the threshold *T*. The originating IMS performs the OQoD mechanism.

Step. 3: The IMS translates the MSISDN **980002** in the *Request-URI* into a fully qualified E.164 number (i.e., **+886980002**) by adding the country code **+886**, and translates the fully qualified E.164 number to a FQDN **2.0.0.0.8.9.6.8.8.e164.arpa**. The originating IMS then sends an NP query with the FQDN to the NPDB. This step is the same as Step 2 in section 2.1.

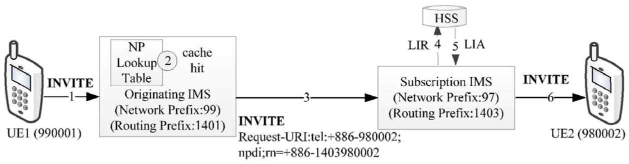
Step. 4: Upon receipt of the NP query, the NPDB retrieves the NAPTR record of the called party (i.e., UE2) by using the FQDN. The NAPTR record contains a tel URI **tel:+886-980002;npdi;rn=+886-1403980002**. The NPDB replies the tel URI to the originating IMS through the NP response.

Step. 5-8: The NRH IMS replaces the *Request-URI* by the received tel URI **tel:+886-980002;npdi;rn= +886-1403980002**. Then the NRH IMS forwards the **INVITE** message to the subscription IMS according to the "**rn**" tag (**+886-1403980002**). Then, the subscription IMS forwards the **INVITE** message to UE2 by querying its HSS. Those steps are the same as Steps 4-7 in section 2.2 (i.e., the OQoD mechanism).

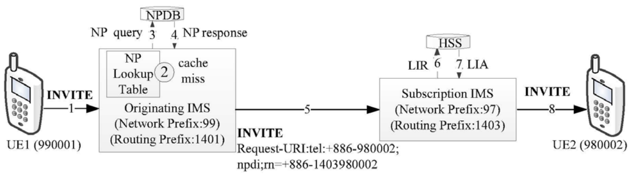
Note that, if the porting ratio r_i less than a threshold *T* at Step 2, the originating IMS performs the *redirect* mechanism [see Figure 7(b)]. The originating forwards the **INVITE** message to the NRH IMS at Step 3. Since the call is not found in the NRH IMS, the NRH IMS notifies the originating IMS by a SIP **380** response. The rest Steps 4-12 are the same as Steps 3-11 in section 2.5 (i.e., the *redirect* mechanism).

3.2 Cached OQoD (Cached) Mechanism

[23] identifies some telephone numbers are accessed frequently. In addition, [22] also indicates that in NP service some of the ported numbers are frequently dialed. Based on the above phenomenon, we propose a cached OQoD mechanism where the IMS records the replied routing number into an NP lookup table in its local memory. The NP lookup table records the MSISDN, "**rn**" tag. The "**rn**" tag is used to identify the subscription network of the called MSISDN. Since the NP lookup table is in the IMS's memory, querying the NP lookup table is faster than querying the NPDB if the called MSISDN is found in the NP lookup table (i.e., cache hit). The detailed procedure illustrated in Figure 8(a) is elaborated as follows.



(a) Cache Hit Procedure



(b) Cache Miss Procedure

Figure 8. The Cached OQoD Mechanism

Step. 1: When the calling party dials the MSISDN **980002** of the called party, UE1 establishes the call by issuing an **INVITE** message. The **INVITE** message is sent to the originating IMS. This step is the same as Step 1 in section 2.2.

Step. 2: Upon receipt of the **INVITE** message, the originating IMS searches the NP lookup table by using the MSISDN **980002**. Assume that the record is found in the lookup table (i.e., cache hit). The originating IMS retrieves the *tel* URI (**tel:+886-980002;npdi; rn=+886-1403980002**) from the NP lookup table.

Step. 3-6: The originating IMS replaces the *Request-URI* of the **INVITE** message with the obtained tel URI. The originating IMS forwards the **INVITE** message to the subscription IMS based on **rn=+886-1403980002**. Upon receipt of the **INVITE** message, the subscription IMS queries the then HSS and forwards the **INVITE** message to UE2. Those steps are the same as Steps 4-7 of in section 2.2.

At Step 2, if the record cannot be found in the NP lookup table (i.e., cache miss), the originating IMS performs the OQoD mechanism and updates the lookup table [see Figure 8(b)]. Specifically, the originating IMS queries the NPDB at Step 3 and obtains the tel URI of the called party at Step 4. Then the originating IMS updates the lookup table based on the selected cache update algorithm. Based on [22], the *least recently used* (LRU) is selected as the cache update algorithm.

Consider that the record is found in the NP lookup table but the record is out-of-date (i.e., incorrect). In this case, the MSISDN **980002** is ported to a new subscription IMS, the NPDB is updated, but the NP lookup table is not updated. Figure 9 illustrates the mechanism and the record in the NP lookup table is incorrect. The "**rn**" tag of record of the MSISDN **980002** is not updated in the NP lookup table. The originating IMS queries the NP lookup table and forwards the **INVITE** message to the NRH IMS (or the old subscription IMS) at Steps 2-3, but the NRH (or the old subscription) IMS cannot find the MSISDN in the HSS at Steps 4-5. The NRH (or the old subscription) IMS redirects the **INVITE** message to the originating IMS at Step 6 by using a 380 message.

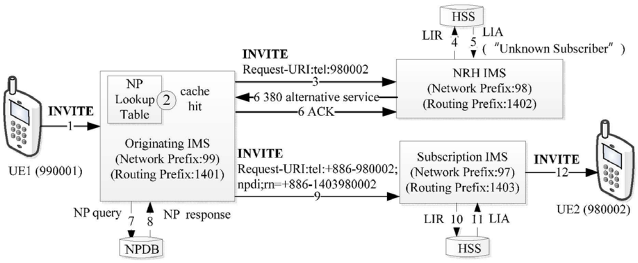


Figure 9. The Cached Record is Stale

Upon receipt of the **380** message, the originating IMS queries the NPDB and forwards the **INVITE** message to the new subscription IMS at Steps 7-9. At Step 8, upon receipt the ENUM response, the originating IMS updates the called party's "**rn**" tag record in the NP lookup table. Upon receipt of the **INVITE** message, the subscription IMS queries the HSS and forwards the **INVITE** message to UE2 at Steps 10-12.

4 Comparison and Performance Analysis

In this section, we analyze the performance of the call routing mechanisms in terms of the comparison of call routing mechanisms, the extra call setup cost on different porting ratios, the extra call setup cost of the hybrid mechanism, and the extra call setup cost of the cached OQoD mechanism.

4.1 Comparison of Call Routing Mechanisms

Table 2 shows the comparison results of different call routing mechanisms in terms of the routing independence, the *effect on porting ratio, the calculation porting ratios, the cache routing information and the voice transmission path.*

Table 2. Comparison of Call Routing Mechanisms

Mechanisms \ Call Routing	OQoD	TQoD	QoHR	Redirect	Hybrid	Cached OQoD
Routing Independence	High	Low	Low	Medium	Medium	High
Effect on Porting Ratio	No	Yes	Yes	Yes	Yes	No
Calculation Porting Ratios	No	No	No	No	Yes	No
Cache Routing Info.	No	No	No	No	No	Yes
Voice Transmission Path	O→S	O→N→S	O→N→S	O→S	O→S	O→S

O: Originating IMS. **N**: NRH IMS. **S**: Subscription IMS.

We first analyze the degrees of independence of the call setup procedures in Row 2 of Table 2. In the OQoD and cached OQoD mechanisms, the originating IMS performs the NP query and directly forwards the call to the subscription IMS without passing through the NRH IMS. Therefore, the degree of routing independence of the OQoD and cached OQoD mechanisms are *high*. In the TQoD and QoHR mechanisms, the call setup signaling messages are forwarded to the NRH IMS. Thus the degrees of routing independence for these mechanisms are *low*. In the *redirect* mechanism, only the *first* signaling message is forwarded to the NRH IMS, and thus the degree of routing independence of the *redirect* mechanism is *medium*. The hybrid mechanism may perform the OQoD or *redirect* mechanism, and the degree of routing independence is *medium*.

Row 3 of Table 2 identifies whether the call routing mechanisms are affected by porting ratio or not. In all mechanisms except the OQoD and cached OQoD mechanisms, the extra call setup cost increases as the porting ratio increases. In the TQoD, QoHR, *redirect* and hybrid mechanisms, if the called party is ported to the subscription network, these mechanisms produce the extra signaling costs in the call setup procedures. Therefore, these mechanisms are affected by the porting ratio.

Row 4 of Table 2 identifies whether the originating IMS should calculates the porting ratios or not for the call routing mechanisms. Among the mechanisms, only the hybrid mechanism should calculate the porting ratios. In the hybrid mechanism, the originating IMS calculates the porting ratios for the NRH networks based on the NPDB. The originating IMS performs the OQoD or *redirect* mechanism according to the porting ratios.

Row 5 of Table 2 identifies whether the originating IMS caches the routing information or not for the call routing mechanisms. Among the mechanisms, only the cached OQoD mechanism has this requirement. In the cached OQoD mechanism, the originating IMS records the routing information into a NP lookup table in its local memory. Then the originating IMS utilizes the NP lookup table to improve the lookup latency of the NP query process.

Row 6 of Table 2 lists the voice transmission paths for different call routing mechanisms. In The OQoD, *redirect*, hybrid and cached OQoD mechanisms, the voice can be transmitted between the originating and subscription IMS networks directly. In the TQoD and QoHR mechanisms, the originating IMS forwards voice packets to the NRH IMS and then to the subscription IMS by default. Note that to reduce the traffic loading, the NRH IMS may skip the voice traffic by revising the *Session Description Protocol* (SDP) fields.

4.2 The Extra Call Setup Cost on Different Porting Ratios

The extra call setup cost is the extra signaling messages produced by the call routing mechanisms for the NP service. Assume that c_s is the average cost of sending a signaling messages (e.g., a SIP or DNS messages) and the costs of sending the SIP and DNS messages are the same.The c_F is the cost of call setup messages exchanged between the two IMS networks (e.g., the NRH IMS and the subscription IMS). There are total 9 messages (i.e. $c_s = 9c_F$) according to the 3GPP TS23.228 [7]. The ratios p_1, p_2 and p_3 are the porting ratio, the cache miss ratio and the cache stale ratio, respectively. In the OQoD mechanism, the originating IMS queries the NPDB for all calls, and thus the extra call setup cost is $2c_s$. In the TQoD mechanism, the NRH IMS queries the NPDB first for all calls. If the call is ported to the subscription IMS, the NRH IMS forwards the call to the subscription network. Otherwise, the NRH IMS queries the HSS to obtain called party's location and there is no extra cost. The average extra call setup cost of the TQoD mechanism is $2c_s + p_1 \times c_F$. In the QoHR mechanism, the NRH IMS queries the HSS instead of the NPDB for all calls. If the MSISDN of the called party is ported, the NRH IMS queries the NPDB and forwards the call to the subscription IMS. The subscription IMS forwards the call to the called party after querying the HSS. Therefore, the extra call setup cost of the QoHR mechanism is $p_1 \times (4c_s + c_F)$. In the *redirect* mechanism, the NRH IMS queries the HSS for all calls. If the call is ported, the NRH IMS sends a **380** message to the originating IMS. The originating IMS queries the NPDB and then establishes the call with the subscription IMS. The subscription IMS forwards the call to the called party after querying the HSS. The extra call setup cost for the *redirect* mechanism is $p_1 \times 7c_s$. In the cached OQoD mechanism, the originating IMS obtains the called party's record from the NP lookup table in its local memory and the extra call setup cost is c_s. If cache misses, the originating IMS performs the OQoD mechanism and the extra call setup cost is $3c_s$. On the other hand, if cache hits and the cached record is not stale, the called party's MSISDN is forwarded to the NRH or the subscription network. The extra cost is c_s. When cache hits and the cached record is stale, the call is forwarded to the wrong destination. In this case, the call will be redirected to the originating IMS and the originating IMS performs OQoD mechanism. The extra call setup cost is $8c_s$. The expected extra cost for the cached OQoD mechanism is $(1-p_2)\times(1-p_3)\times c_s + (1-p_2) \times p_3 \times 8c_s + p_2 \times 3c_s$.

Figure 10 plots the extra setup cost on various porting ratios. In Figure 10, all mechanisms except the OQoD and cached OQoD mechanisms, the extra cost increases as the porting ratio increases.

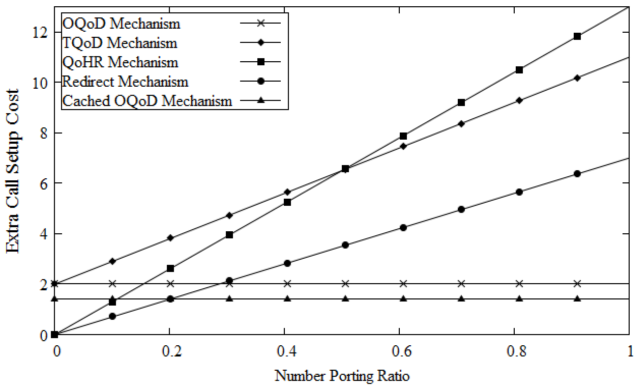


Figure 10. The Extra Call Setup Cost on Porting Ratio (cache miss ratio = 20%, cache stale ratio = 0%)

We observe that the TQoD and the QoHR mechanisms have an intersection point. To obtain this value of the intersection point, we let the extra call setup costs of these two mechanisms be equal. We obtain $p_1 = 50\%$. That's when the porting ratio is 50%, the TQoD and QoHR mechanisms have the same extra call setup cost. When the porting ratio is less than 50%, the QoHR mechanism outperforms the TQoD mechanism. That's because the most called parties are found in the HSS without querying the NPDB. When the porting ratio is more than 50%, the TQoD mechanism is better than the QoHR mechanism. That's because the TQoD mechanism queries the NPDB first and most called parties are found in the NPDB. Since the called party's MSISDM is ported, the call is forwarded to the subscription IMS directly without querying the HSS.

In the *redirect* mechanism, if the called party is not ported to another network, there is no extra call setup cost. Otherwise, the extra call setup cost contains the cost of query HSS is $2c_s$, the cost of redirecting to originating IMS is $3c_s$ (i.e., **INVITE**, **ACK** and **380** messages), the cost of querying NPDB is $2c_s$. The average extra call setup cost is $p_1 \times 7c_s$. In the OQoD mechanism, no matter the called party is ported or not, the extra cost is $2c_s$.

We observe that the redirect and the OQoD mechanism have an intersection point. By setting the extra call setup cost of these mechanisms be equal and we get $p_1 = 28.6\%$. At the porting ratio is 28.6%, the OQoD and *redirect* mechanisms have the same extra call setup cost. When the porting ratio less than 28.6%, the redirect mechanism is better than the OQoD mechanism. Otherwise the OQoD mechanism is better.

Figure 10 plots the extra call setup cost of the cached OQoD mechanism with the cache stale ratio 0%. The cached OQoD mechanism is not affected by the porting ratio when the cache stale ratio is 0%.

4.3 The Extra Call Setup Cost of the Hybrid Mechanism

Figure 10 shows the extra call setup cost of the OQoD, TQoD, QoHR, and *redirect* mechanisms. When the porting ratio is less than 28.6%, the extra call setup cost of the redirect mechanism is less than other existing call routing mechanisms. When the porting ratio is more than 28.6%, the extra call setup cost of the OQoD mechanism is less than other existing call routing mechanisms.

To minimize the extra call setup cost, this paper proposes a hybrid mechanism. Assume that the r_i is used to identify the porting ratio of the *i*th NRH network. The c_i is used to identify the extra call setup cost of the *i*th NRH network. In the hybrid mechanism, the originating IMS queries the mapping table for all calls and the extra call setup cost is c_s. If r_i is larger than a threshold *T*, than the OQoD mechanism is performed, and the extra call setup cost is $3c_s$. Otherwise, the *redirect* mechanism is performed, and the extra call setup cost is $c_s + r_i \times 7c_s$.

In the previous section, we note that the extra call setup cost of the *redirect* and OQoD mechanisms have an intersection point at $p_1 = 28.6\%$. Before the intersection, the *redirect* mechanism is better than the OQoD mechanism. On the other hand, after the intersection, the OQoD mechanism outperforms the *redirect* mechanism. Thus, we set the threshold T =28.6% (i.e., $r_i = \frac{2}{7}$). The average extra call setup cost of the *i*th NRH network is $c_i = \begin{cases} c_s + r_i \times 7c_s, r_i < \frac{2}{7} \\ 3c_s, r_i \geq \frac{2}{7} \end{cases}$.

Note that the α_i is used to identify the call ratio of the *i*th NRH network. If the NRH network is the i^{th} NRH network, $\sum_{i=1}^{n} \alpha_i = 1$ and the extra call setup cost of hybrid mechanism is $\sum_{i=1}^{n} \alpha_i \times c_i$.

4.4 The Extra Call Setup Cost of the Cached OQoD Mechanism

Figure 11 plots the extra call setup cost on different cache miss ratios. The extra call setup cost for the cached OQoD mechanism is $(1-p_2)\times(1-p_3)\times c_s +$ $(1-p_2)\times p_3 \times 8c_s + p_2 \times 3c_s$. When the cache stale ratio is $p_3 = 28.6\%$, the extra call setup cost becomes a constant $3c_s$. In this case, the extra call setup cost is not affected by the cache miss ratio.

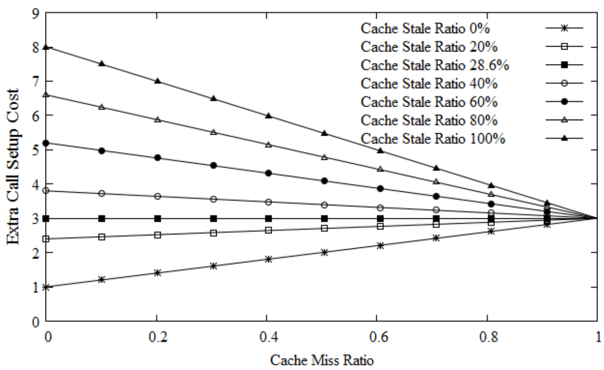


Figure 11. The Extra Call Setup Cost on Cache Miss Ratio

In Figure 11, when the cache stale ratio is less than 28.6%, the extra call setup cost increases as the cache miss ratio increases. After cache hits, most calls are correctly found in the NP lookup table. Then, the originating IMS forwards the calls to the called parties without querying the NPDB. On the other hand, when the cache miss ratio increases, more NPDB queries are performed and thus the extra call setup cost increases.

When the cache stale ratio is more than 28.6%, the extra call setup cost decreases with the cache miss ratio increases. When cache hits, the calls may be forwarded to the wrong destinations and then redirected to the originating IMS. After the originating IMS queries the NPDB, it forwards the calls to the called parties. The extra call setup cost of the redirect process is much more than that of the NPDN query. When the cache miss ratio increases, more NPDB query are performed and thus the extra call setup cost decreases.

Figure 12 plots the extra call setup cost on different cache stale ratios. We observe an intersection for various cache miss ratios. To find the intersection, we set the extra call setup cost of the cached OQoD mechanism with the cache miss ratio 0% and cache miss ratio 100% be equal. We obtain the intersection point is at $p_3 = 28.6\%$.

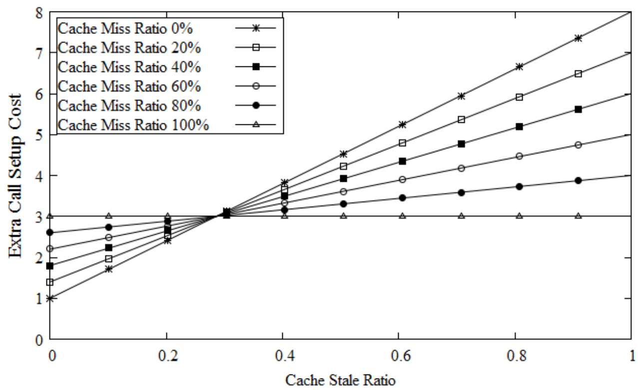


Figure 12. The Extra Call Setup Cost on Cache Stale Ratio

Generally, the call setup cost increases as the cache stale ratio increases and the mechanism with the smaller cache miss ratio increases faster. When the cache miss ratio increases, there are more NPDB queries and the extra cost is more closed to $3c_s$. In the cache miss ratio is low, most calls are found in the NP lookup table. The originating IMS forwards the call to the NRH or subscription IMS instead of querying the NPDB. On the other hand, the cache miss ratio is high, most calls are not found in the NP lookup table. The originating IMS queries the NPDB to obtain the call's routing information and forwards the call to destination according to call's routing information.

5 Conclusion

This paper proposes the call routing mechanisms such as the OQoD, TQoD, QoHR and Redirect mechanisms based on the 3GPP IMS architecture. To improve the performance of the NP Query process, the paper proposes a hybrid mechanism and a cached OQoD mechanism. Based on the analysis results, the proposed hybrid and cached OQoD mechanisms can improve the extra call setup cost for the NP service. The mobile operators can choose the call routing mechanism according to the analysis and their situations.

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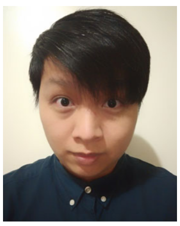
Biographies

Whai-En Chen received his BS degree in EE from Tam Kang University in 1997, and received a Ph.D. in Computer Science from National Tsing Hua University in 2002. He began serving as a Research Assistant Professor in National Chiao Tung University from 2002 to 2007. Since August 2007, Dr. Chen joined Institute of Computer Science and Information Engineering (CSIE) as an Assistant Professor at National Ilan University and served as the division head at network division of Computer Center. During 2008-2013, he served as the director of Institute of CSIE. Since 2010, he has been promoted as an Associate Professor in Department of CSIE. During 2014-2016, he served as the director of Library and Information Center. He is a Professor of Department of CSIE at National Ilan University since 2016. His research interests include IPv6 Transition, VoIP Deployment, Mobility Management, IMS, 4G/5G.



Yi-Lun Ciou received his master degree in CSIE from National Ilan University. He is a member of VoIP Laboratory and his research interests include ENUM, IMS and VoIP.