# ENUM-Based Number Portability for 4G/5G Mobile Communications

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**Abstract.** With the evolution of the core network, providing multimedia services is much easier in the all-IP *packet-switched* networks than that in the *circuit-switched* networks. In the 4G/5G core network, the *IP Multimedia Subsystem* (IMS) is widely deployed to provide multimedia services such as *Voice over LTE* (VoLTE). To provide a fair-competition environment for the mobile operators, the *Number Portability* (NP) service should be defined in the 4G/5G specifications. However, the up-to-date specifications only indicate that the *E.164 NUmber Mapping* (ENUM) can be used for the NP service but do not propose the detail message flows and the major parameters. Moreover, the NP scenarios in the IMS networks are different from those in the *Public Switched Telephone Networks* (PSTNs). To provide the NP service in 4G/5G, this paper proposes an ENUM-based NP service where the message flows and the major parameters are designed based on the IMS architecture.

**Keywords:** DNS · ENUM · IMS · Number portability · SIP · URI

## 1 Introduction

The *Number Portability* (NP) service enables cellular subscribers to keep their original *Mobile Station International Subscriber Directory Number* (MSISDN) while changing the mobile operators. The NP service benefits both the subscribers and the mobile operators. The NP service enables the subscribers to have more choices and to select the operators with lower price [1]. In addition, the NP service provides the fair competitions to the mobile operators [2]. Typically, the NP service is implemented according to various local regulations and a country's dialing plan [3]. The NP scenarios produce different costs to the subscribers and the mobile operators. The design and deployment of the NP service requires careful consideration and analysis. However, there is no clearly defined solution providing the NP service in the mobile communications standards [4–6].

With the evolution of the core network, the circuit-switched networks are replaced by the packet-switched networks, and the core network is migrated to an all-IP environment. Providing multimedia services are easier in the packet-switched network than that in the circuit-switched network. In 4G/5G all-IP networks, the *IP Multimedia Subsystem* (IMS) architecture is adopted to provide the multimedia services such as *Voice over LTE* (VoLTE). In order to achieve fair competitions among the mobile operators, 4G/5G specifications should define the NP service based on the IMS


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architecture. With the NP service, the VoLTE subscribers can retain their original MSISDN while changing their mobile operators. However, 3GPP TS 23.228 [6] only points out that the *E.164 NUmber Mapping* (ENUM) can be used as the NP database but does not specify the detail information such as the IMS and ENUM message flows for the NP service.

ENUM is a system for telephone number mapping, which maps the MSISDN with the Internet identifications (e.g., the Uniform Resource Identifiers; URIs) [7]. The ENUM utilizes the *Domain Name System* (DNS) [8] to store the mapping records and resolves the MSISDN into the URIs [9, 10]. Specifically, the IMS (e.g., S-CSCF) issues the ENUM queries with the MSISDN information to retrieve the URI from the ENUM database.

In 3GPP specifications, the IMS adopts *Session Initiation Protocol* (SIP) [11] as the signaling protocol. The SIP messages contain the *Uniform Resource Identifier* (URI) to identify the MSISDN of the called party [6, 12]. IETF RFC 4769 [13] 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 [14, 15] 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 do not require performing the NP query again when the tel URI contains an "npdi" tag. 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 indicates the route to the new mobile operator.

The previous articles [16, 17] presents the NP scenarios for 2G/3G mobile communications. A *Signaling Relay Function* (SRF)-based solution and an *Intelligent Network* (IN)-based solution are proposed to support the NP service. Both solutions utilize the *Number Portability DataBase* (NPDB) to store the records of the ported MSISDN. However, these articles do not include the *redirect* function which is one of the major functions in SIP/IMS. The article [5] applies the NP scenarios designed for the circuit-switched networks [18] to the packet-switched networks (e.g., IMS) and also provides the SIP redirect function. However, this article does not describe the major parameters used in the message flow and does not include the ENUM.

To provide the ENUM-based NP service based on the IMS architecture for 4G/5G, we design four NP scenarios, including the redirect function and ENUM query according to 3GPP TS 23.228 [6]. In this paper, the architecture and message flows with the major parameters are elaborated and the ENUM/DNS usage is identified. Finally, we show the analysis results of the NP scenarios in both quality and quantity.

The rest of this paper is organized as follows. Section 2 illustrates the NP architecture based on the IMS. Section 3 elaborates the proposed NP scenarios and the message flow for each scenario. Section 4 analyzes and compares different NP scenarios. Finally, the conclusions are given in Sect. 5.

## 2 ENUM-Based NP Service in the IMS Architecture

In this section, we present the ENUM-based NP service in the IMS architecture. Figure 1 illustrates the proposed architecture where UE1 [Fig. 1(a)] is the calling party and UE2 [Fig. 1(b)] is the called party. The MSISDNs of UE1 and UE2 are **990001** and **980002**, respectively.

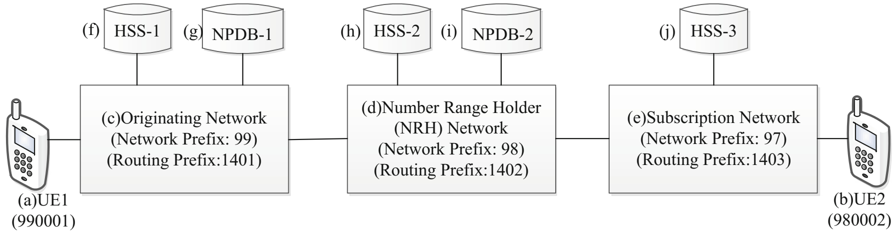


**Fig. 1.** The IMS architecture for ENUM-based number portability

The originating network [Fig. 1(c)] is the network where the calling party (i.e., UE1) is subscribed and located. In this paper, the *network prefix* of the originating network is **99**, which means the number range of the originating network is **990000–999999**. The *routing prefix* of the originating network is **1401**. The *Number Range Holder* (NRH) network [Fig. 1(d)] is the network that the ported number (e.g., UE2's MSISDN **980002**) has been allocated. The network prefix of the NRH network is **98**, the number range is **980000–989999** and routing prefix is **1402**. The subscription network [Fig. 1(e)] is a network which the called party (i.e., UE2) is ported to. The network prefix of the subscription network is **97**, and the routing prefix of the subscription network is **1403**. Assume that the called party (UE2) has a new contract with the mobile operator of the subscription network. Each network contains a *Home Subscriber Server* (HSS) and a NPDB. The HSS, which is the major database, contains the subscription-related data, performs authentication and authorization of the subscriber, and maintains the subscriber's location. The NPDB provides the routing information (i.e., the routing number or routing prefix) of the ported number. In this architecture, the HSS-x and NPDB-x represent that the HSS and NPDB in different networks, where x = **1**, **2** and **3** means that these components are in the originating network, the NRH network and the subscription network, respectively.

We use an example to demonstrate the ENUM query. Assume that UE1 sends an **INVITE** message to UE2. The *Request-URI* (i.e., a tel URI) in this **INVITE** message is "**tel:980002**". When the IMS receives the **INVITE** message, it retrieves the MSISDN 980002 from the *Request-URI* and change the MSISDN to the E.164 format (i.e., **+886980002**). Then the IMS translates the E.164 number to an FQDN **2.0.0.0.8.9.6.8.8.e164.arpa** and utilizes the FQDN to perform the ENUM query. Since UE2 is ported to the subscription network, the ENUM-based NPDB replies the result **tel: +886980002** with the "**npdi**" tag and the "**rn**" tag (i.e., rn = **1403980002**). According to the result (i.e., the routing number), the IMS forwards the **INVITE** message to the subscription network.

## 3 The Proposed Number Portability Scenarios

Either the IMS in the originating network (i.e., the originating IMS) or the IMS in the NRH network (i.e., the NRH IMS) can perform the queries to find the subscriber's location. In addition, the queries can be sent to the ENUM-based NPDB or the HSS first. Based on the above conditions, 3GPP TS 23.006 specifies three scenarios: *Originating call Query on Digit analysis* (OQoD), *Terminating call Query on Digit analysis* (TQoD), *Query on HSS Release* (QoHR). Note that *there* is no OQoHR or TQoHR because the originating network looks up the HSS if and only if the originating network is the terminating network. Moreover, the article [5] proposes using the SIP **3xx** responses [11] to perform the redirect scenario. Based on the above mention, we design four ENUM-based NP scenarios for IMS. The message flows for these scenarios are elaborated as follows.

**A. Originating call Query on Digit analysis (OQoD)**—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** to the subscription network. Otherwise, the originating IMS forwards the **INVITE** to the NRH network. The detailed procedure illustrated in Fig. 2 is elaborated as follows.

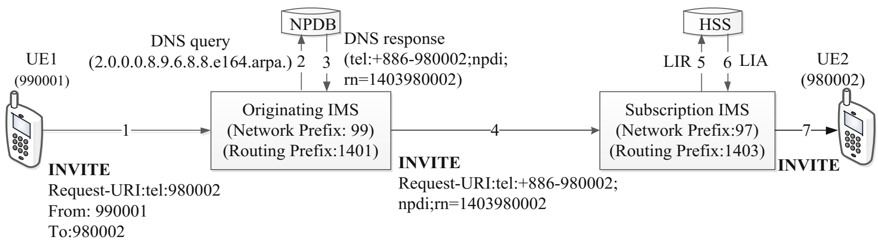


**Fig. 2.** Originating call Query on Digit analysis (OQoD)

**Step A.1:** When the calling party dials the MSISDN **980002**. UE1 issues an **INVITE** message to establish the multimedia sessions. The **INVITE** message contains a *Request-URI* **tel:9800002** that designates to the called party, a *from* header field indicates the calling party (i.e., **990001**), and a *to* header field indicates the called party (i.e., **980002**). To resolve the MSISDN of the called party **980002** retrieved from the *Request-URI*, the **INVITE** message is sent to the originating IMS, which UE1 is subscribed.

**Step A.2:** Upon receipt of the **INVITE** message, the IMS translates the MSISDN **980002** in the *Request-URI* to the E.164 format (i.e., **+886980002**) by adding the country code **+886**, and translates the E.164-formatted number to a *Fully Qualified Domain Name* (FQDN) **2.0.0.0.8.9.6.8.8.e164.arpa**. The originating IMS then sends an ENUM query with the FQDN **2.0.0.0.8.9.6.8.8.e164.arpa**. and the **NAPTR** (Name Authority Pointer) type to the NPDB.

**Step A.3:** Upon receipt of the ENUM query, the NPDB retrieves the routing number of the called party (i.e.UE2) by using the FQDN. The NPDB replies the tel URI **tel: +886980002;npdi;rn = 1403980002** to the originating IMS.

**Step A.4:** The originating IMS replaces the *Request-URI* **tel:9800002** by using the result of the ENUM query **tel: +886980002;npdi;rn = 1403980002**, and then forwards the **INVITE** message to the subscription IMS based on the "**rn**" tag in the *Request-URI*.

**Step A.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 **1403980002** in the "**rn**" tag and detects that it's the terminating IMS. Then, the subscription IMS queries UE2's location information by sending a *Location-Info-Request* (**LIR**) message to the HSS.

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

**Step A.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**) will be routed to UE1 along the reverse path as the **INVITE** message according to the *Via* header field.

**B. Terminating call Query on Digit analysis (TQoD)**—The NP query is performed at the NRH IMS. The NRH IMS queries the NPDN to check whether the called party's MSISDN is ported to another network. Assume that the called party (i.e. UE2) is ported to the subscription network. The detailed procedure is illustrated in Fig. 3 and elaborated as follows.

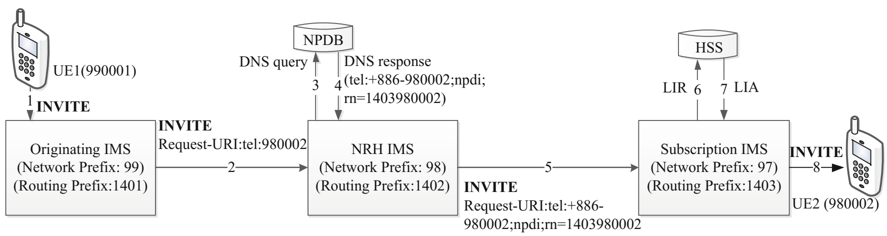


**Fig. 3.** Terminating call Query on Digit analysis (TQoD)

**Step B.1:** When the calling party dials the MSISDN **980002**, the **INVITE** is sent to the originating IMS. This step is the same as **Step A.1**.

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

**Step B.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**. Since 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 ENUM query with the FQDN and the **NAPTR** type to the NPDB.

**Step B.4:** Upon receipt of the ENUM query, the NPDB retrieves the routing number of UE2 through the FQDN and replies the tel URI with UE2's routing number **tel:+886980002;npdi;rn = 1403980002** to the NRH IMS.

**Step B.5:** The NRH IMS replaces the *Request-URI* by the tel URI **tel: +886980002;npdi;rn = 1403980002**, and then forwards the **INVITE** message to the subscription IMS based on the value of the "**rn**" tag.

**Step B.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 routing number **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.

**Steps B.7 and 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 B.4** without the "**rn**" tag. Then, the NRH IMS queries the HSS to find UE2's location and forwards the **INVITE** message to UE2.

**C. Query on HSS Release (QoHR)**—Upon receipt of an incoming call, the NRH IMS first queries the HSS to find the location of the called party. If the record is not found in the HSS, the NRH IMS then queries the NPDB to check whether the called party's MSISDN is ported to other network. If yes, the NRH IMS forwards the call to the subscription network. Otherwise, the NRH IMS notifies the user that the call cannot be routed. The detailed procedure illustrated in Fig. 4 is elaborated as follows.

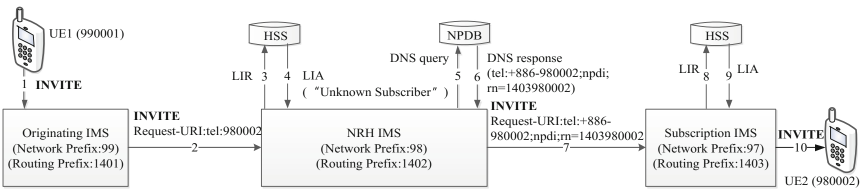


**Fig. 4.** Query on HSS Release (QoHR)

**Steps C.1 and 2:** When the calling party dials the MSISDN **980002**, the **INVITE** 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 B.1 and 2**.

**Step C.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**. Then, the NRH IMS issues a **LIR** message to the HSS to query UE2's location.

**Step C.4:** The HSS replies a **LIA** message with "**Unknown Subscriber**" to the NRH IMS.

**Step C.5:** The NRH IMS checks whether the MSISDN of UE2 is ported to other network by querying the NPDB. The IMS translates the MSISDN in the *Request-URI* to an FQDN **2.0.0.0.8.9.6.8.8.e164.arpa**. The NRH IMS then sends an ENUM query with the FQDN and the **NAPTR** type to the NPDB.

**Step C.6:** Upon receipt of the ENUM query, the NPDB utilizes the FQDN to retrieve UE2's routing number and replies the tel URI **tel:+886980002;npdi;rn = 1403980002** to the NRH IMS.

**Steps C.7–10:** The NRH IMS replaces the *Request-URI* by the tel URI, and then forwards the **INVITE** message to the subscription IMS. Then, the subscription IMS forwards the **INVITE** message to UE2 by querying the HSS. Those steps are the same as **Steps B.5–8**.

Note that if the MSISDN of UE2 is in the NRH network, the HSS will reply a **LIA** response at **Step C.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 UE2.

**D. Redirect**—The NRH IMS acts as a SIP redirect server and utilizes the SIP **380** status code [11] to notify the originating IMS that the call may have another route. Upon receipt of an incoming call, the NRH IMS queries the **HSS** to find the called party's location. If the location is found, the NRH IMS forwards the call to the called party. Otherwise, the NRH IMS replies the originating IMS a SIP **380** response which indicates that the call may have an alternative route or service. The detailed procedure illustrated in Fig. 5 is elaborated as follows.

In Fig. 5, **Steps 1–4** are the same as **Steps C.1–4** in the QoHR scenario. Since UE2's MSISDN is ported to the subscription network, The NRH IMS notifies the originating IMS by a SIP **380** response at **Step 5**. Upon receipt of the **380** response, the originating IMS performs the ENUM query and receives UE2's new URL i.e., **tel:+886980002;npdi;rn = 1403980002** at **Steps 6–7**. The originating IMS updates the *Request-URI*, and then forwards the **INVITE** message to the subscription IMS at **Step 8**. The rest **Steps 9–11** are the same as **Steps C.8–10**.

The previous work [5] proposes that the SIP **301** and **302** status codes can be used in the redirect scenario. In [5], the NRH IMS performs the ENUM query to retrieve the UE2's routing number from the NPDB. Then the UE2's routing number is embedded

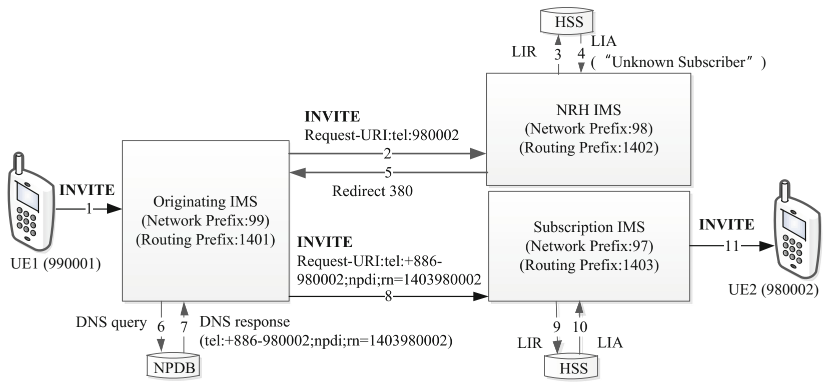


**Fig. 5.** Redirect for NP service

in the **301/302** response and sent to the originating IMS. Note that the "tel" URI contains the "**npdi**" tag that notifies the "tel" URI is queried from NPDB. When the originating IMS receives the URI with the "**npdi**" tag, it should not query the NPDB again [15]. In such cases, the originating IMS should trust the NRH IMS and utilizes the URI directly.

## 4 Analyses and Comparisons

This paper analyzes the proposed NP scenarios including **OQoD**, **TQoD**, **QoHR** and **redirect**. Table 1 shows the comparison of different NP scenarios in terms of the *routing independence*, the *extra call setup cost* and the *voice transmission path*.

**Table 1.** Comparative analysis NP scenarios

| Scenario | OQoD | TQoD | QoHR | Redirect |
|---|---|---|---|---|
| Routing independence | High | Low | Low | Medium |
| Extra call setup cost | $C_N$ | $C_N + pC_F$ | $p(C_N + C_F)$ | $p(C_N + 3C_S)$ |
| Voice transmission path | O → S | O → N→S | O → N→S | O → S |

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

Row 2 of Table 1 lists the degrees of independence of the call setup procedures. In the OQoD scenario, the originating IMS performs the ENUM query and forwards the call to the subscription IMS without passing through the NRH IMS. Therefore, the degree of the OQoD scenario is highest. In the TQoD and QoHR scenarios, the call setup signaling will be forwarded to the NRH IMS. Thus the degrees of these scenarios are lowest. In the redirect scenario, only the first signaling is forwarded to the NRH IMS, and thus the degree of the redirect scenario is medium.

Row 3 of Table 1 indicates the extra costs introduced by the NP service. Note that the call setup flow for the NP service is compared to the reference [5]. The extra call setup cost is calculated by extra signaling for the call setup procedure in the NP scenarios. Assume that $C_S$ is the average cost of sending a SIP signaling. The $C_N$ indicates the cost of the NPDB query and response (i.e., $C_N = 2C_S$). $C_F$ is the total cost of call setup between two IMS networks (i.e., $C_F = 9C_S$). Assume $p$ is the percentage of the ported MSISDNs.

In the OQoD scenario, the originating IMS queries the NPDB for all calls, and thus the extra cost is $C_N$. In the TQoD scenario, the NRH IMS queries the NPDB and forwards only the ported MSISDNs to the subscription network. The extra cost for TQoD scenario is $C_N + pC_F$. In the QoHR scenario, the NRH IMS queries the HSS for all calls. If the called party's MSISDN is ported, the NRH IMS queries the NPDB and forwards the call to the subscription IMS. Therefore, the extra cost for QoHR scenario is $p(C_N + C_F)$. In the redirect scenario, the NRH IMS sends a **380** message to the originating IMS if the called party's MSISDN ported. The originating IMS queries the NPDB and then establish the call with the subscription IMS. The extra cost for redirect is $p(C_N + 3C_S)$.

Figure 6 plots the extra costs for the NP scenarios. In Fig. 6, we observe that the extra cost for QoHR scenario is less than that for TQoD scenario except $p$ = 100%. Based on the results, the NRH IMS should query the HSS first before querying the NPDB. In addition, the redirect scenario has less extra call setup cost than the QoHR scenario. That's because the NRH IMS forwards all call setup signaling in the QoHR scenario but only redirects the first signaling in the redirect scenario. In the OQoD scenario, the originating IMS queries the NPDB for all calls, no matter the MSISDN is ported or not. Thus, the extra cost of the OQoD scenario is more than that of the redirect scenario if the $p$ is less than a threshold (e.g., 40%). On the contrary, the redirect scenario performs the redirect procedure that introduces the extra cost. Thus, the extra cost of the OQoD scenario is less than that of the redirect scenario, if the $p$ is more than the threshold.

Row 4 of Table 1 lists the voice transmission paths for different NP scenarios. In The OQoD and redirect scenarios, the voice can be transmitted between the originating

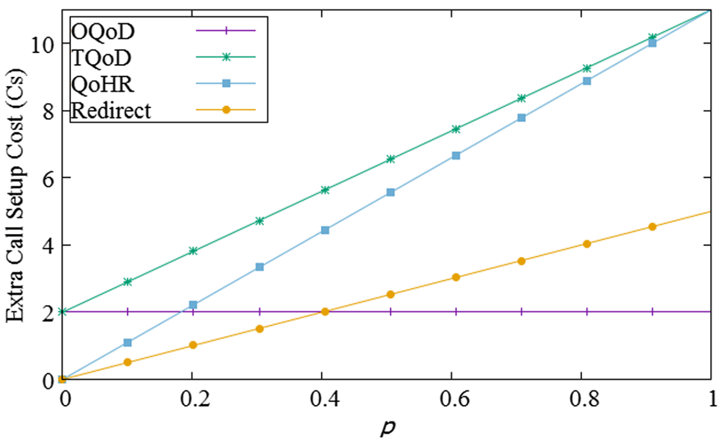


**Fig. 6.** Extra call setup cost

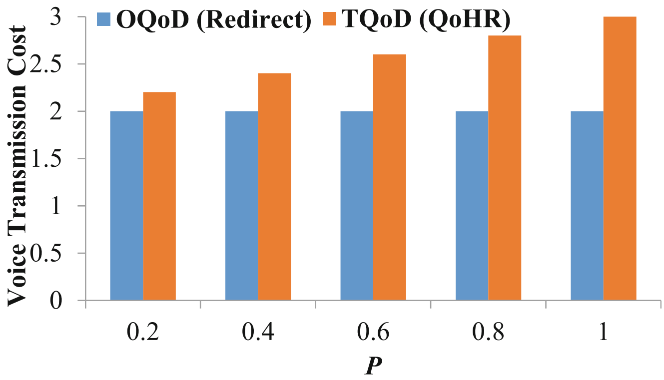


**Fig. 7.** Voice transmission cost

and subscription IMS networks directly. In The TQoD and QoHR scenarios, the originating IMS forwards voice packets to the subscription IMS through the NRH IMS in the default cases. The Voice Transmission Cost with different $p$ is shown in Fig. 7. Note that to reduce the traffic loading, the NRH IMS can skip the voice traffic by revising the *Session Description Protocol* (SDP) fields.

## 5 Conclusions

This paper proposes four ENUM-based NP scenarios (i.e., OQoD, TQoD, QoHR and Redirect) based on the 3GPP IMS architecture. The paper then analyzes these scenarios in terms of the routing independence, the extra call setup cost and the voice transmission path. Among these NP scenarios, the OQoD scenario is the scenario with the highest degree of independence. In the OQoD scenario, the originating network forwards the signaling messages to the subscription network without passing through the NRH network. If the percentage of the ported MSISDNs is over the threshold (e.g., 40%), the extra cost of the OQoD scenario is less than that of the other scenarios. Otherwise, the redirect scenario has the lowest extra cost. The voice transmission paths of OQoD and redirect scenarios are the same and the shortest.

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