國立交通大學

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碩 士 論 文

線路交換與封包交換網路間語音通話連續性之通道保留機制

Bearer Reservation with Preemption for Voice Call Continuity

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摘　　要

UMTS (Universal Mobile Telecommunications System) 的核心網路包含線路交換領域(Circuit-Switched Domain) 與封包交換領域(Packet-Switched Domain)。UMTS手機可以在線路交換領域或是封包交換領域撥打或接聽電話。在通話過程中，使用者可以在不同的領域間切換，稱之爲領域轉換(Domain Transfer)。領域轉換的重要議題之一是轉換延遲時間。爲達到快速的轉換，本論文提出通道保留機制(Bearer Reservation with Preemption)，並以理論推導和模擬驗證對通道保留機制進行效能分析。研究結果顯示，通道保留機制的優異效能在使用者行爲愈不規則時成效愈顯著。

Bearer Reservation with Preemption for Voice Call Continuity

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Abstract

In *Universal Mobile Telecommunications System* (UMTS), the core network consists of two service domains: the *circuit-switched* (CS) and the *packet-switched* (PS) domains. A UMTS handset can initiate or receive a call in either the CS or the PS domain. During the call, the user may switch from one domain to another. The switching overhead is an important concern of domain transfer. In this thesis, we propose the Bearer Reservation with Preemption (BRP) scheme to support fast domain transfer, and develop both analytic analysis and simulation experiments to investigate the BRP performance. Our study indicates that when user behavior is more irregular, the advantage of the BRP scheme becomes significant.

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I would first like to express my sincere thanks to my advisor, Prof. Yi-Bing Lin. Without his supervision and perspicaious advice, I can not complete this thesis. Thanks also to the colleagues in the Laboratory 117. Special thanks and appreciation to Meng-Hsun Tsai. I learned very much from him. Without his ingenious guidance and helpful discussions, this thesis would not have been possible. I would also like to express my thanks to my master committee members, Dr. Jeu-Yih Jeng and Dr. Yuan-Kai Chen for their encouragement and suggestions.

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Chapter 1

Introduction

Universal Mobile Telecommunications System (UMTS) is one of the major standards for the third generation (3G) mobile telecommunications. In UMTS, the core network consists of two service domains: the *circuit-switched* (CS) and the *packet-switched* (PS) domains [1]. *IP Multimedia Core Network Subsystem* (IMS) is developed in the PS domain to provide multimedia services. A UMTS handset can initiate or receive a call in either the CS or the PS domain. The user may switch from one domain to another during the call. In order to maintain call continuation, the connection in the old domain is released, and a connection is established in the new domain. This process is called *domain transfer*. The technique to transfer a voice call between the CS and the PS domains is called *Voice Call Continuity* (VCC) [2].

Figure 1.1 illustrates a simplified UMTS network architecture that accommodates VCC [2, 3]. This architecture consists of the radio access network (Figure 1.1 (a)), the CS domain (Figure 1.1 (b)), the PS domain, i.e., the *General Packet Radio Service* (GPRS) network (Figure 1.1 (c)), and the IMS network (Figure 1.1 (d)). In this architecture, *Home Subscriber Server* (HSS; Figure 1.1 (1)) is the master database containing all user-related subscription information, which supports mobility management of the users. A mobile user utilizes a *User Equipment* (UE; Figure 1.1 (2)) to access CS and PS services. In the CS domain, the *Mobile Switching Center* (MSC; Figure 1.1 (3)) is responsible for call control, including the processing of user data and control signals. In the PS domain,

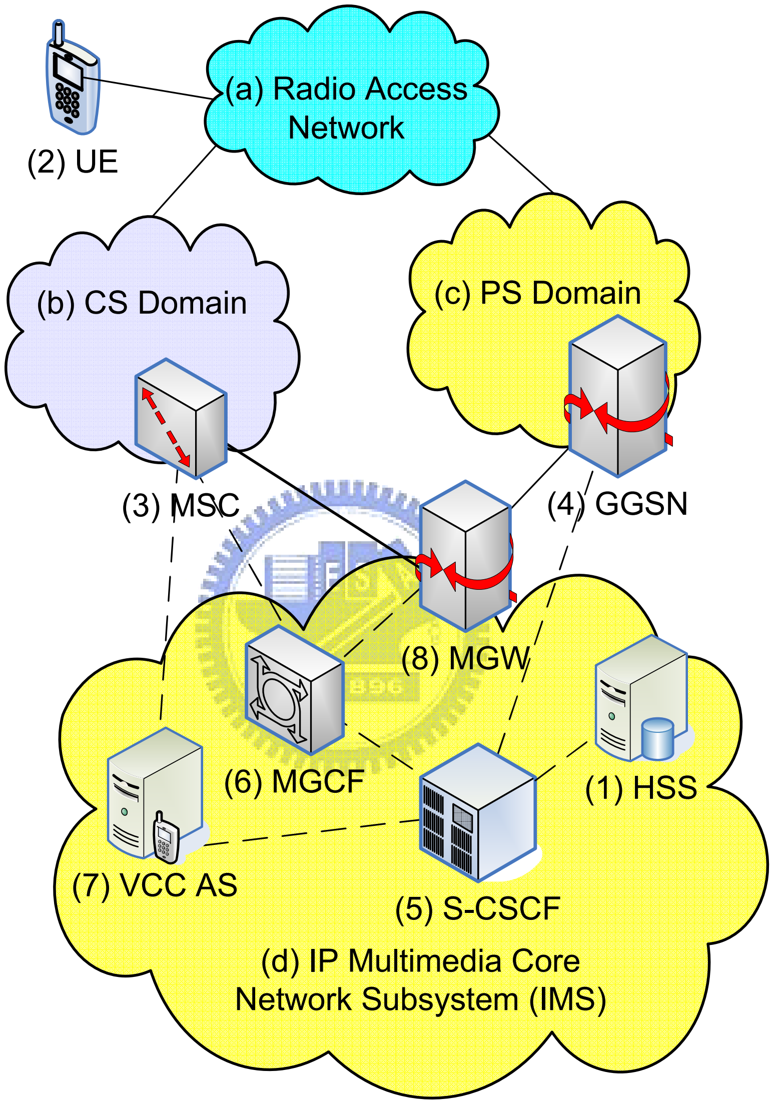

Figure 1.1: The UMTS Network Architecture (Dashed lines: Signaling; Solid lines: Signaling/Data)

the GPRS network connects to the IMS network through the *Gateway GPRS Support Nodes* (GGSNs; Figure 1.1 (4)). In the IMS, the transport of user data is separated from that for control signals. The IMS signaling is carried out by the *Serving Call Session Control Function* (S-CSCF; Figure 1.1 (5)), the *Media Gateway Control Function* (MGCF; Figure 1.1 (6)) and the *VCC Application Server* (VCC AS; Figure 1.1 (7)). The IMS user data traffic is transported through the *Media Gateways* (MGWs; Figure 1.1 (8)) controlled by the MGCF.

When the UE switches from one domain to another during a voice call, the call is domain-transferred by the VCC AS. A major problem of domain transfer is a large number of message exchanges and resource reservation that result in long switching latency. To support fast domain transfer, we propose the Bearer Reservation with Preemption (BRP) scheme. Chapter 2 describes 3GPP VCC Call Setup and Domain Transfer. In Chapter 3, we propose the BRP scheme. In Chapter 4, we develop an analytic model for the BRP scheme. The proposed analytic model is validated against simulation experiments. Chapter 5 investigates the performance of BRP scheme.

Chapter 2

VCC Call Setup and Domain Transfer

This chapter describes the VCC call setup and domain transfer procedures defined in 3GPP [4].

2.1 VCC Call Setup

To support domain transfer, the VCC AS is inserted into the signal path of the call. This is achieved by adding some VCC service triggering criteria (called initial filter criteria or iFC [5]) into the UE's profile in the HSS. When a UE registers to the IMS, the S-CSCF downloads these iFC of the UE from the HSS. When a call arrives at the S-CSCF, the call is evaluated against the iFC. If the VCC service criteria are matched, the call is routed to the VCC AS for further processing. The VCC call path is partitioned into two segments: the UE-MGW segment and the MGW-Callee segment. When the UE moves from one domain to another during a call, the UE-MGW segment is switched, and the MGW-Callee segment remains unchanged.

Suppose that a UE has attached to both the CS and the PS domains, and has performed the IMS registration. This UE can initiate or receive a call in either domain. Without loss of generality, we only describe the VCC call origination in the PS domain in this thesis. The reader is referred to [4] for VCC call origination in the CS domain and

VCC call termination in both domains. Figure 2.1 illustrates the message flow for VCC call origination in the PS domain with the following steps:

Step A.1 The UE sends the Session Initiation Protocol (SIP) INVITE message to the S-CSCF through the PS domain. This message contains the media information (e.g., IP address, port number and codec) for user data connection.

Step A.2 The S-CSCF evaluates the SIP INVITE message against the iFC of the UE. If the VCC service criteria are matched, the S-CSCF forwards the message to the VCC AS.

Step A.3 Based on the received SIP INVITE message, the VCC AS records the call information (e.g., From, To and Call-ID headers), and then forwards the SIP INVITE message to the MGCF through the S-CSCF.

Steps A.4 and A.5 Based on the media information retrieved from the SIP INVITE message, the MGCF exchanges the H.248 Add and Reply messages with the MGW to allocate media resources for this call.

Steps A.6 and A.7 The MGCF modifies the media information contained in the SIP INVITE message and forwards the modified message to the callee. Then the callee replies a SIP 200 OK with its media information to the MGCF.

Steps A.8 and A.9 The MGCF retrieves media information from the SIP 200 OK message, and finalizes the MGW media resources for this call by exchanging the H.248 Add and Reply messages with the MGW.

Steps A.10 and A.11 The MGCF provides the final media information and forwards the SIP 200 OK message to the VCC AS. Then the VCC AS forwards this message to the UE. The UE retrieves media information from this message, and the call path in the UE-MGW segment is established.

Steps A.12-A.14 The UE sends a SIP ACK message to the callee through the S-CSCF,

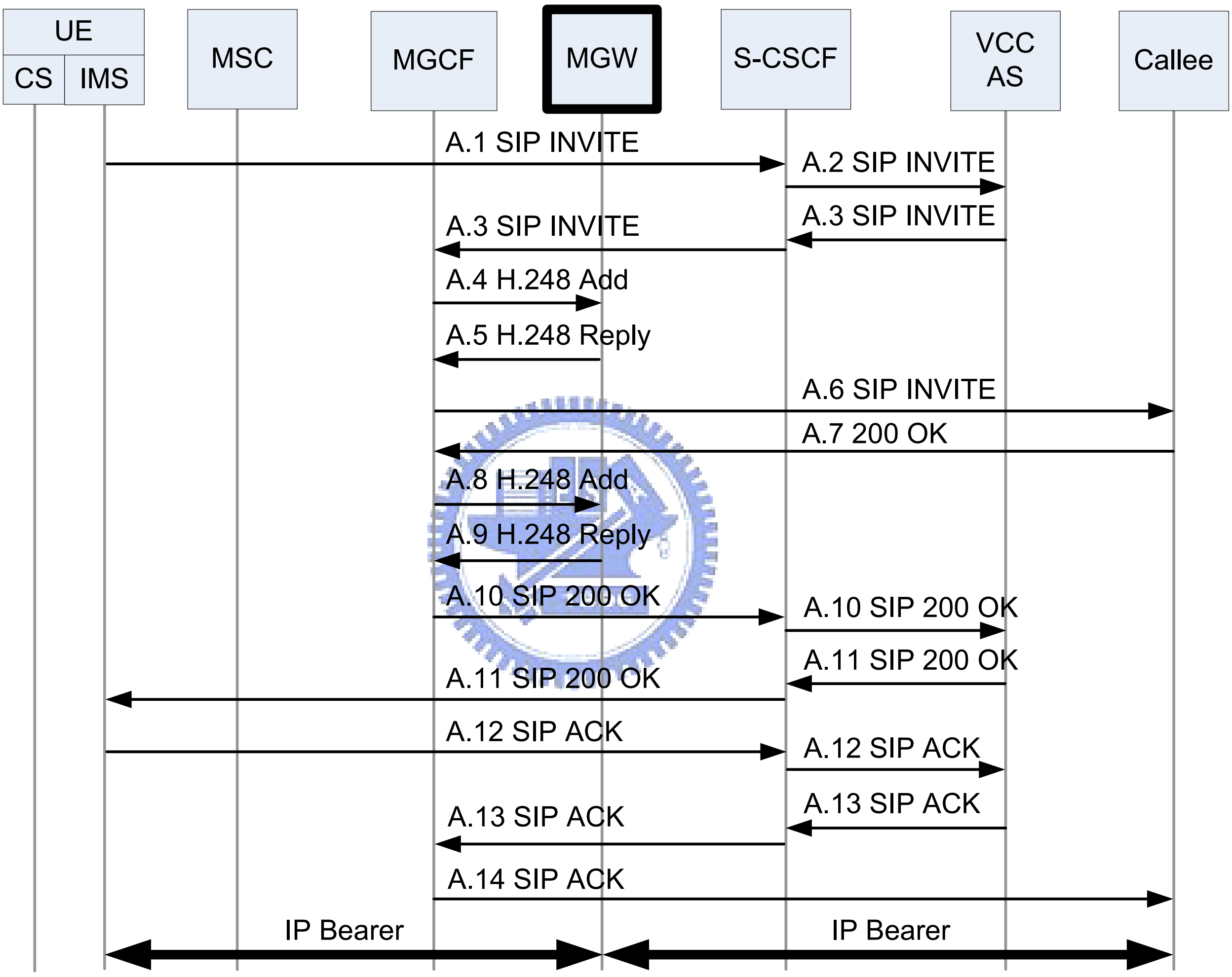

Figure 2.1: VCC Call Origination in the PS Domain

the VCC AS and the MGCF. After the callee has received the acknowledgment, the VCC call is established.

2.2 3GPP Domain Transfer

In the CS domain, VCC service control is provided through the *Customized Applications for Mobile Network Enhanced Logic* (CAMEL) [6], where the VCC service logic is implemented in the VCC AS. When a UE decides to transfer its VCC call from the PS domain to the CS domain, a new call is initiated in the CS domain with a specific called number *VCC Domain Transfer Number* (VDN). This number is then translated into a routable number *IP Multimedia Routing Number* (IMRN) through the VCC service logic. The IMRN is used to route the call from the CS domain to the VCC AS in the PS domain. After the call setup signal arrives at the VCC AS, the VCC AS updates the UE-MGW segment. The message flow is illustrated in Figure 2.2 with the following steps:

Step B.1 Through the CS domain, the UE sends a Call Control (CC) SETUP message with the specific called VDN to the MSC.

Step B.2 The MSC sends a CAMEL Application Part (CAP) Initial Detection Point (IDP) message to the VCC AS. This message contains the calling number of the UE and the called VDN.

Step B.3 Based on the calling number in the CAP IDP message, the VCC AS identifies the ongoing call of the UE and allocates an IMRN for this call. Then the VCC AS replies a CAP CONNECT message with the IMRN to the MSC.

Step B.4 The MSC sends an ISDN User Part (ISUP) Initial Address Message (IAM) to the MGCF to set up the CS bearer. This message includes the IMRN received at Step B.3 as the called party number.

Steps B.5 and B.6 Upon receipt of the ISUP IAM message, the MGCF retrieves media information, and exchanges the H.248 Add and Reply messages with the MGW to

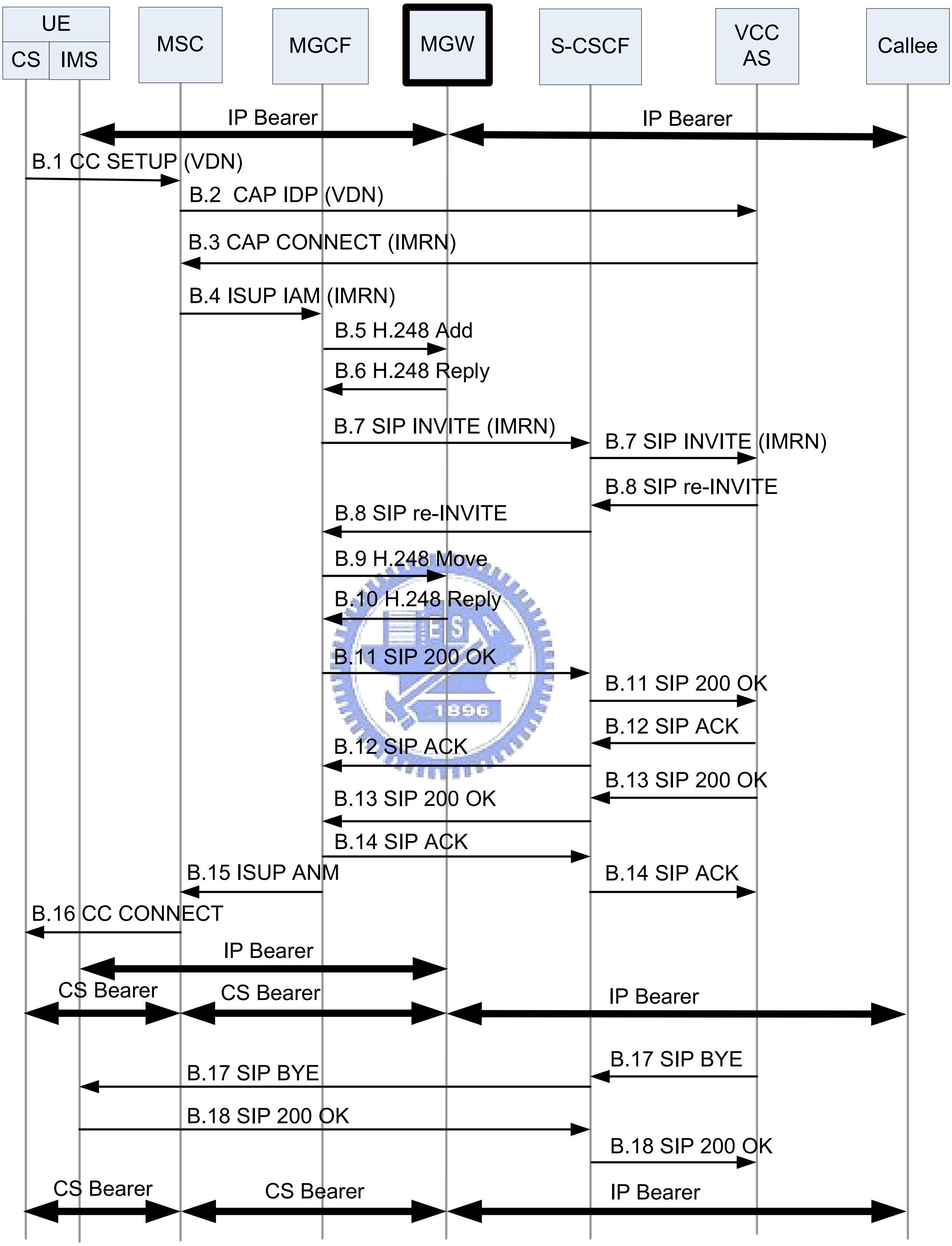

Figure 2.2: PS-to-CS Domain Transfer (3GPP TS 24.206)

allocate media resources for CS bearer between the UE and the MGW.

Step B.7 The MGCF sends a SIP INVITE message with the called IMRN to the VCC AS through the S-CSCF.

Step B.8 Based on the calling party's identity in the received SIP INVITE message, the VCC AS retrieves the ongoing call information (i.e., the call information recorded at Step A.3) of the UE, and then sends a SIP re-INVITE message to the MGCF to switch the call path in the UE-MGW segment.

Steps B.9 and B.10 Upon receipt of the SIP re-INVITE message, the MGCF retrieves media information, and exchanges the H.248 Move and Reply messages with the MGW to switch the ongoing call in the PS domain to the new call in the CS domain.

Steps B.11 and B.12 The MGCF exchanges the SIP 200 OK and the SIP ACK messages with the VCC AS to indicate successful switching of the call path in the UE-MGW segment (corresponding to the re-INVITE message at Step B.8).

Steps B.13 and B.14 To complete the establishment of the CS bearer, the VCC AS exchanges the SIP 200 OK and the SIP ACK messages with the MGCF (corresponding to the INVITE message at Step B.7).

Steps B.15 and B.16 The MGCF sends an ISUP Answer Message (ANM) towards the MSC. Then the MSC sends the CC CONNECT message to the UE. At this moment, the CS bearer for the UE-MGW segment is established.

Steps B.17 and B.18 When the SIP ACK message arrives, the VCC AS exchanges the SIP BYE and the SIP 200 OK messages with the UE to release the previously-established IP bearer in the UE-MGW segment.

After the call has been successfully switched to the CS domain, the UE may decide to switch the call back to the PS domain again. To trigger CS-to-PS domain transfer, the UE initiates a new call in the PS domain with a specific called identity *VCC Domain Transfer Uniform Resource Identifier* (VDI). When the new call arrives at the VCC AS, the VCC AS updates the UE-MGW segment for the UE. Figure 2.3 illustrates the message flow with the following steps:

Step C.1 The UE sends a SIP INVITE message with the called VDI to the S-CSCF.

Step C.2 The S-CSCF evaluates the SIP INVITE message against the iFC of the UE. If the VCC service criteria are matched, the S-CSCF routes the call to the VCC AS.

Step C.3 Based on the calling party's identity in the received SIP INVITE message, the VCC AS retrieves the ongoing call information (i.e., the call information recorded at Step A.3) of the UE, and then sends a SIP re-INVITE message to the MGCF through the S-CSCF to switch the call path in the UE-MGW segment.

Steps C.4 and C.5 Upon receipt of the SIP re-INVITE message, the MGCF retrieves media information, and exchanges the H.248 Move and Reply messages with the MGW to switch the ongoing call in the CS domain to the new call in the PS domain.

Steps C.6 and C.7 The MGCF exchanges the SIP 200 OK and the SIP ACK messages with the VCC AS to indicate successful switching of the bearer in the UE-MGW segment (corresponding to the re-INVITE message at Step C.3).

Steps C.8 and C.9 To complete the IP bearer establishment, the VCC AS exchanges the SIP 200 OK and the SIP ACK messages with the UE (corresponding to the INVITE message at Steps C.1 and C.2). At this point, the IP bearer for the UE-MGW segment is established.

Step C.10 To release the previously-established CS bearer, the VCC AS sends the SIP BYE message to the MGCF.

Steps C.11 and C.12 The MGCF exchanges the H.248 Subtract and Reply messages with the MGW to release the CS bearer between the MSC and the MGW.

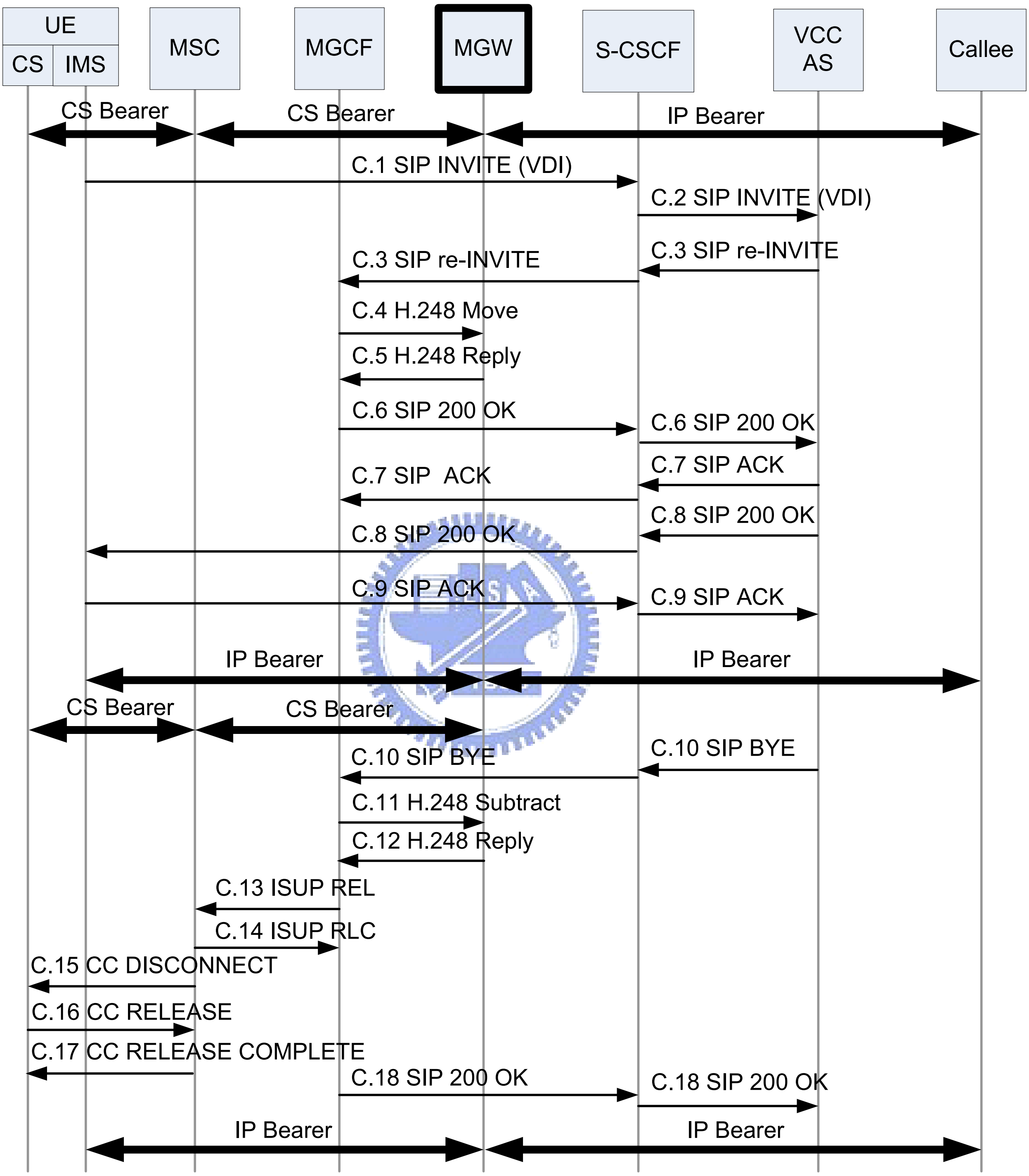

Figure 2.3: CS-to-PS Domain Transfer (3GPP TS 24.206)

Steps C.13 and C.14 To complete the CS bearer release between the MSC and the MGW, the MGCF exchanges the ISUP RELEASE (REL) and the RELEASE COMPLETE (RLC) messages with the MSC.

Steps C.15-C.17 The MSC exchanges the CC DISCONNECT, the CC RELEASE and the CC RELEASE COMPLETE messages with the UE to release the CS bearer between the MSC and the UE.

Step C.18 Upon receipt of the ISUP RLC message at Step C.14, the MGCF sends a SIP 200 OK message to the VCC AS to indicate successful release of the CS bearer.

Chapter 3

BRP Domain Transfer

In the CS-to-PS domain transfer procedure in Figure 2.3, the CS bearer of the UE-MGW segment is released after the IP bearer is established. If the UE moves back to the CS domain again, the released CS bearer must be re-established. Such bearer re-establishment contributes extra overload to the domain transfer. To speed up the subsequent switchings, we may not release the CS bearer at the CS-to-PS domain transfer, and postpone the bearer release until the VCC call is complete. If the user moves back from the PS domain to the CS domain, the bearer re-establishment is eliminated. Same argument applies to the IP bearer re-establishment.

Based on the above intuition, we propose the Bearer Reservation with Preemption (BRP) scheme that speeds up the domain transfer process. The BRP scheme utilizes *enhanced Multi-Level Precedence and Pre-emption* (eMLPP) service [7] and *Multimedia Priority Service* (MPS) [8] to provide reservation and preemption of CS and IP bearers. In BRP, two eMLPP priority levels are defined: the *high* priority and the *low* priority. When there is no available channel at the MSC, a call arrival with high priority can preempt a call with low priority, i.e., the high priority call is established, and the low priority call is force-terminated.

In BRP, a VCC call before domain transfer is set up with high priority. When the UE switches this call from the CS domain to the PS domain, instead of releasing the CS bearer in the UE-MGW segment, this CS bearer is reserved with low priority. When the

UE switches the call back to the CS domain, the domain transfer process simply raises the priority level of the reserved CS bearer to high priority. If the reserved CS bearer with low priority is preempted (and the preempted channel is used by an incoming high-priority call), the CS bearer is released. In this case, the VCC call is not terminated because the IP bearer is used. When the call is switched back to the CS domain, the procedure in Figure 2.2 is executed.

3.1 CS-to-PS Domain Transfer in the BRP Scheme

Figure 3.1 illustrates the BRP message flow for CS-to-PS domain transfer with the following steps:

Steps C.1-C.5 Same steps as in Figure 2.3 initiate the establishment of the IP bearer in the UE-MGW segment.

Step C*.6 The MGCF lowers the priority level for the CS bearer, and sends an ISUP Facility Request (FAR) message with the parameter "low priority" to the MSC.

Step C*.7 According to the priority level indicated in the received ISUP FAR message, the MSC lowers the priority level for the CS bearer, and sends an ISUP Facility Accepted (FAA) message to the MGCF.

Steps C.6-C.9 Same steps as in Figure 2.3 exchange the SIP 200 OK and ACK messages to complete the IP bearer establishment in the UE-MGW segment.

By adding two messages (Steps C*.6 and C*.7), the BRP scheme eliminates eleven messages (Steps C.10-C.18) in Figure 2.3. Therefore, the message exchange cost is reduced by 36%. Also note that after the transfer, the CS radio link to the UE may be disconnected, but the CS bearer at the MSC is still maintained. This idea is similar to the "always on" concept of GPRS [3].

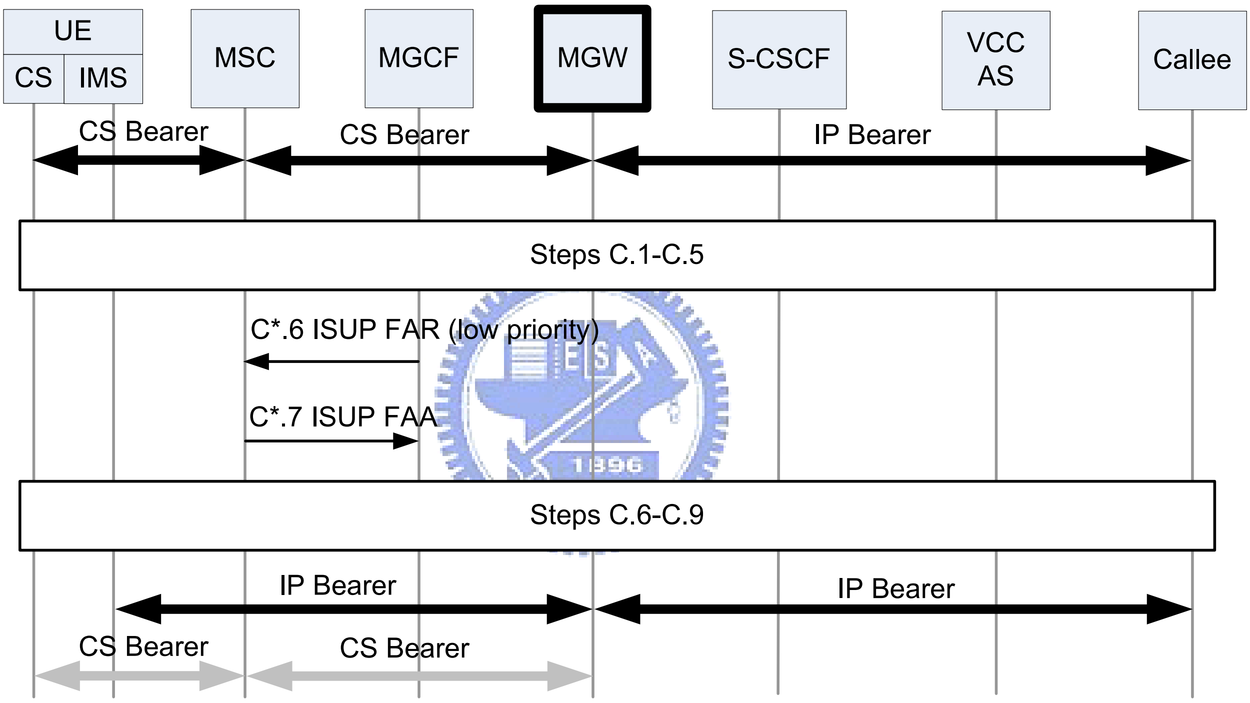

Figure 3.1: CS-to-PS Domain Transfer (BRP)

3.2 PS-to-CS Domain Transfer in the BRP Scheme

After the call has been successfully switched to the PS domain, the UE may decide to switch the call back to the CS domain again. If the reserved CS bearer has not been preempted, the UE does not need to initiate a new call for establishing the CS bearer in the UE-MGW segment. Instead, the UE only needs to raise the priority level of the reserved CS bearer to high priority. Also, unlike the procedure in Figure 2.2, the IP bearer is not released. Therefore, IP bearer needs not be re-established when the call switches back to the PS domain. Figure 3.2 illustrates the BRP message flow for PS-to-CS domain transfer with the following steps:

Step B*.1 The UE sends a Call Management (CM) SERVICE REQUEST message to the MSC to raise the priority level of the CS bearer in the UE-MGW segment.

Step B*.2 The MSC raises the priority level for the CS bearer. Then the MSC sends an ISUP FAR message with the parameter "high priority" to the MGCF.

Steps B*.3 and B*.4 The MGCF raises the CS bearer's priority, and lowers the IP bearer's priority. Then the MGCF exchanges H.248 Move and Reply messages with the MGW to switch the UE-MGW segment from the PS bearer to the reserved CS bearer.

Steps B*.5 and B*.6 To complete this priority update, the MGCF sends an ISUP FAA message to the MSC. Then the MSC sends a CM SERVICE ACCEPT message to the UE to indicate successful priority update of the CS bearer. At this point, the UE-MGW segment is switched from the IP bearer to the CS bearer.

In the BRP scheme, six messages (Steps B*.1-B*.6) modify the priorities of the CS and the PS bearers. On the other hand, the 3GPP procedure in Figure 2.2 exchanges twenty-six messages (Steps B.1-B.18) to establish a new CS bearer, and release the old IP bearer. Therefore, the message exchange overhead is reduced by 77%.

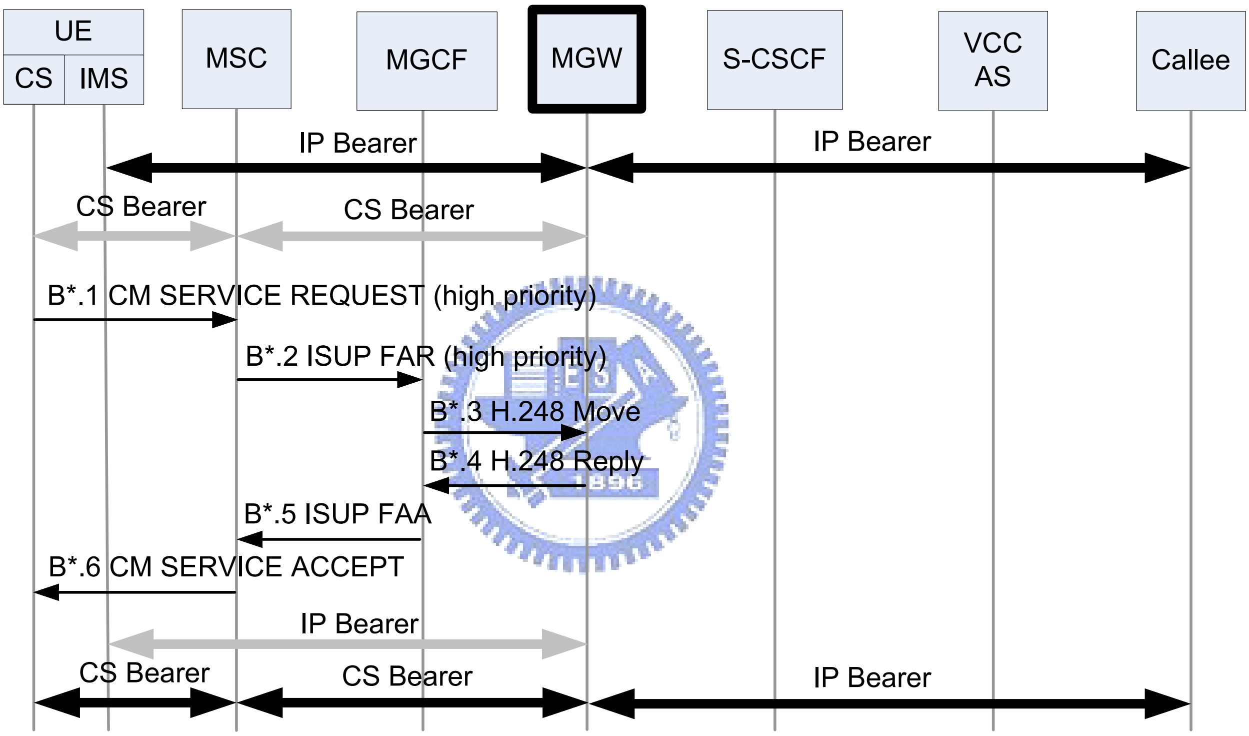

Figure 3.2: PS-to-CS Domain Transfer (BRP)

Chapter 4

Analytic Modeling of BRP

This chapter proposes an analytic model to study the performance of the BRP scheme. Without loss of generality, we investigate the BRP performance in the CS domain. Similar conclusions also apply to the PS domain, and the details are omitted. Suppose that a UE has switched its VCC call from the CS to the PS domain. In the BRP scheme, the CS bearer is reserved with low priority. When the UE switches from the PS domain back to the CS domain at time τ, there are three possibilities:

Case I. Before the UE switches back to the CS domain, the reserved CS bearer has been preempted, and there is no available resource (i.e., no channel in the MSC) at time τ. The call is force-terminated. Let p_f be the probability that this case occurs.

Case II. The reserved CS bearer has been preempted before τ, but the resource becomes available when the call is switched back to the CS domain at τ. The CS bearer is re-established at the PS-to-CS domain transfer by executing the procedure in Figure 2.2. Let p_r be the probability of this case.

Case III. The reserved CS bearer is not preempted. The UE only needs to raise the priority level of the reserved CS bearer to high priority by executing the procedure in Figure 3.2. The probability of this case is p_n.

It is clear that p_f is the same for both the 3GPP and the BRP schemes. Therefore, the smaller the p_r value (i.e., the larger the p_n value), the better the BRP performance.

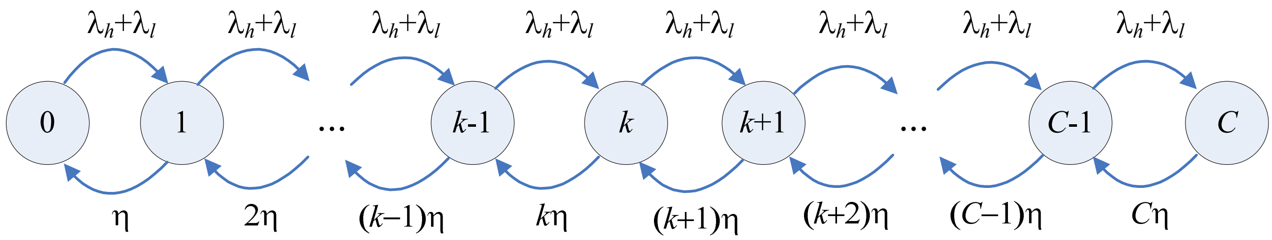

Figure 4.1: State Transition Rate Diagram for the BRP Scheme

The following input parameters are considered in this study:

- The inter-arrival times of VCC and non-VCC CS calls (with high priority) are a random variable t_h with mean $1/\lambda_h$.
- The inter-arrival times of VCC PS calls (reserved CS calls with low priority) are a random variable t_l with mean $1/\lambda_l$.
- A high-priority (low-priority) call utilizes (reserves) a channel at the MSC for a sojourn time t_s before it is switched to another domain or is completed. Let t_s be a random variable with distribution function $F(\cdot)$ and mean $1/\eta$.

For mean value analysis, we assume that t_s is exponentially distributed (this assumption will be relaxed in simulation experiments). We conduct the mean value analysis to provide understanding on the "trend" of performance [9]. Furthermore, this exponential-based analytic analysis is used to validate the simulation model. Then the validated simulation model will relax the exponential assumptions to accommodate more general (and therefore more practical) scenarios.

The BRP scheme is modeled by a stochastic process. Let C be the capacity (number of channels) of the MSC. We assume that t_h and t_l are exponentially distributed. Figure 4.1 illustrates the state transition rate diagram of the stochastic process where state k denotes that there are k calls (either high-priority or low-priority) in the MSC. Note that a CS-to-PS domain transfer contributes to a low-priority call arrival, and a PS-to-CS domain transfer contributes to a high-priority call arrival. Let π_k denote the steady-state

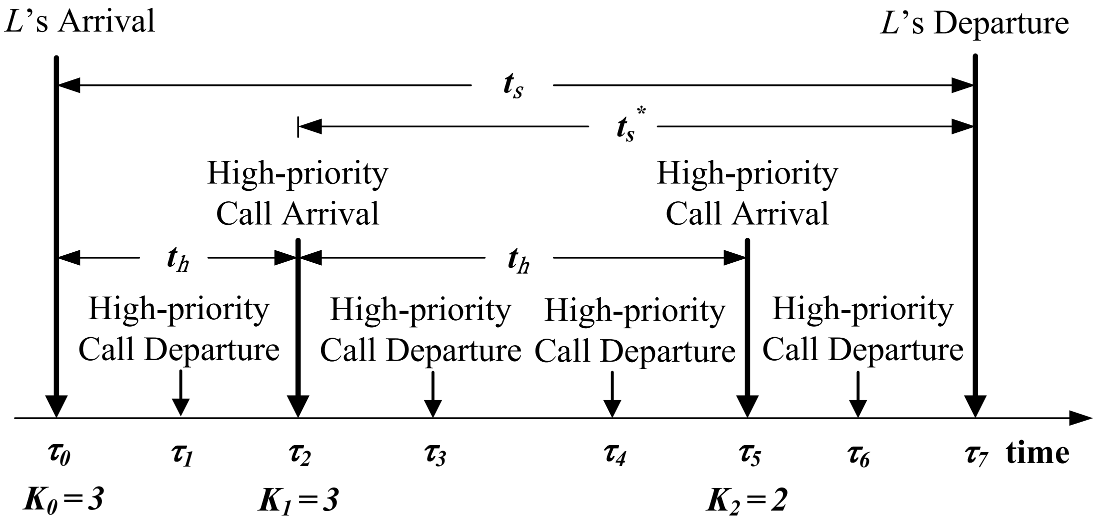

Figure 4.2: Events that may Occur in L's Sojourn Time

probability that there are k calls in the MSC. From the standard technique [10], we have

$$\pi_k = \pi_0 \left[\frac{(\lambda_h + \lambda_l)^k}{(k!)\eta^k} \right] \quad \text{for } 1 \le k \le C \tag{4.1}$$

and

$$\pi_0 = \left[\sum_{j=0}^{C} \frac{(\lambda_h + \lambda_l)^j}{(j!)\eta^j} \right]^{-1} \tag{4.2}$$

After a VCC call L switches from the CS to the PS domain, it becomes a low-priority call at the MSC. Figure 4.2 illustrates the timing diagram during L's sojourn time t_s, where L arrives at the MSC at τ_0 (i.e., it transfers from the high to the low priority at τ_0), and leaves the MSC at τ_7 (i.e., it completes or transfers back with the high priority). There are two high-priority call arrivals at the MSC at τ_2 and τ_5, and there are four high-priority call departures at τ_1, τ_3, τ_4 and τ_6. When $k = C$, a high-priority call arrival will preempt an existing low-priority call. The order of preemption is based on the *Last-Come-First-Preempted* scheme [11]. Let $\bar{p}_n = 1 - p_n$ be the probability that a low-priority call L is preempted during its sojourn time. Let K_0 be the number of calls in the MSC seen by L at domain transfer (i.e., at τ_0), where L is not included in K_0. Note that from L's viewpoint, these K_0 calls are "high-priority" (i.e., none of them will be preempted before L is preempted). According to the *Poisson Arrivals see Time Averages* (PASTA) property [10], L is a random observer. Then from (4.1) and (4.2), we have

$$\Pr[K_0 = m] = \frac{\pi_m}{1-\pi_C} = \left[\frac{(\lambda_h+\lambda_l)^m}{(m!)\eta^m}\right]\left[\sum_{j=0}^{C-1}\frac{(\lambda_h+\lambda_l)^j}{(j!)\eta^j}\right]^{-1} \quad \text{for } 0 \le m \le C-1 \tag{4.3}$$

After τ_0, L can only be preempted by a high-priority call arrival, and we simply observe the moments when a high-priority call arrives. After τ_0, for $i \ge 1$, let K_i be the number of high-priority calls in the MSC (from L's view point, the low-priority calls counted in K_0 are also included in these "high-priority" calls) when the i-th high-priority call arrives, where this high-priority call is included in K_i. In Figure 4.2, if $K_0 = 3$ at τ_0, then $K_1 = 3$ at τ_2 (because there is one high-priority call departure in $[\tau_0, \tau_2]$), and $K_2 = 2$ at τ_5 (because there are two high-priority call departures in $[\tau_2, \tau_5]$).

For the i-th high-priority call arrival ($i \ge 0$; by convention, L represents the 0-th call arrival), let $p_{(m,n)}$ be the one-step transition probability from state $K_i = m$ to state $K_{i+1} = n$. That is, $p_{(m,n)}$ is the probability that there are $m - n + 1$ high-priority call departures during the inter-arrival time t_h between the i-th and the $(i+1)$-th high-priority call arrivals. Therefore, $p_{(C-1,C)}$ is the probability that when $K_i = C-1$, L will be preempted by the $(i+1)$-th high-priority call arrival. Note that for $0 \le n \le C$, $p_{(C,n)} = 0$ because L has already been preempted by the i-th high-priority call arrival. In addition, for $0 \le m \le C$, $p_{(m,0)} = 0$ because the $(i+1)$-th high-priority call arrival is included in K_{i+1}, and therefore K_{i+1} is always larger than 0. Also, $p_{(m,n)} = 0$ if $n > m+1$ (because the $(i+1)$-th high-priority call is the only new call that contributes to K_{i+1}). In Figure 4.2, let the inter-arrival time t_h of high-priority calls be a random variable. Let t_s^* be the excess life (residual life) of t_s upon a high-priority call arrival, and $F^*(\cdot)$ be the distribution function of t_s^*. Since t_s is exponentially distributed, t_s^* has the same distribution as t_s due to the memoryless property. Therefore, when $m \ne C$, $n \ne 0$ and

$n \le m+1$, $p_{(m,n)}$ is derived as

$$\begin{aligned} p_{(m,n)} &= \int_{t_s^*=0}^{\infty} \int_{t_h=0}^{t_s^*} \binom{m}{n-1} F^*(t_h)^{m-n+1} \left[1 - F^*(t_h)\right]^{n-1} \lambda_h e^{-\lambda_h t_h} \eta e^{-\eta t_s^*} dt_h dt_s^* \qquad (4.4) \\ &= \int_{t_s^*=0}^{\infty} \int_{t_h=0}^{t_s^*} \binom{m}{n-1} \sum_{j=0}^{m-n+1} \binom{m-n+1}{j} (-1)^j \lambda_h e^{[-(n+j-1)\eta - \lambda_h] t_h} \eta e^{-\eta t_s^*} dt_h dt_s^* \\ &= \sum_{j=0}^{m-n+1} \binom{m}{n-1, j} \left[\frac{(-1)^j \lambda_h}{\lambda_h + (n+j)\eta} \right] \qquad (4.5) \end{aligned}$$

Equation (4.4) says that if $K_i = m$ and $K_{i+1} = n$, then among these m calls upon the i-th high-priority call arrival, the residual sojourn times of $n-1$ calls are larger than t_h (and therefore remain in the MSC at the end of t_h). The other $m-n+1$ calls have shorter residual sojourn times than t_h (and leave the MSC before the end of t_h). For $l \ge 2$, let

$$p_{(m,n)}^{(l)} = \sum_{j=0}^{C} p_{(m,j)}^{(l-1)} p_{(j,n)} \qquad (4.6)$$

be the probability that the stochastic process moves from state m to state n with exact l steps (i.e., there are l subsequent high-priority call arrivals). By convention, $p_{(m,n)}^{(1)} = p_{(m,n)}$. Then for $i \ge 1$, $\Pr[K_i = n]$ is expressed as

$$\Pr[K_i = n] = \sum_{m=0}^{C-1} \Pr[K_0 = m] p_{(m,n)}^{(i)} \qquad (4.7)$$

For $i \ge 2$, (4.7) can be recursively computed by using (4.6), and

$$\Pr[K_i = n] = \sum_{m=0}^{C-1} \Pr[K_0 = m] \left[\sum_{j=0}^{C} p_{(m,j)}^{(i-1)} p_{(j,n)} \right]$$

From (4.3), (4.5) and (4.7), the preempted probability $\bar{p}_n$ is derived as

$$\bar{p}_n = \sum_{i=0}^{\infty} \Pr[K_i = C-1] p_{(C-1,C)} \qquad (4.8)$$

Note that we typically do not see infinite high-priority call arrivals during L's sojourn time. From (4.7), it is clear that $\lim_{i \to \infty} \Pr[K_i = C-1] = 0$. Therefore, it suffices to consider $i \le 50$ in (4.8).

The above analytic model is used to validate against the discrete event simulation experiments. The discrete event simulation model is described in Appendix A. As shown in Table 4.1, the analytic analysis is consistent with the simulation results. In our study, p_f can be analytically derived using the technique in [12], and p_r is computed as $p_r = \bar{p}_n - p_f$.

Table 4.1: Comparison of Analytic and Simulation Models ($\lambda_h = 2\lambda_l$, $C = 5$)

λ_h/η	0.5	1	1.5	2	2.5
$\bar{p}_n$ (Analytic)	0.0016	0.0226	0.0799	0.1649	0.2596
$\bar{p}_n$ (Simulation)	0.001597	0.02259	0.07988	0.1648	0.25959
Error	0.16 %	0.04 %	0.018 %	0.069 %	0.003 %

Chapter 5

Numerical Examples

Based on the simulation experiments, this chapter investigates the performance of the BRP scheme. Let t_c be the call holding time, and t_d be the domain residence time of a VCC call. It is clear that the sojourn time $t_s = \min(t_c, t_d)$. Suppose that t_c has Lognormal distribution with the mean $1/\mu$ and the variance V_c. The Lognormal distribution is selected because it has been shown that the call holding time distribution can be accurately approximated by a mix of two or more Lognormal distributions [12]. Similarly, we assume that t_d has the Gamma distribution with the mean $1/\delta$ and the variance V_d. The Gamma distribution is considered because the distribution of any positive random variable can be approximated by a mixture of Gamma distributions (see Lemma 3.9 in [13]), and is often used to represent the inter-moving times [9, 14, 15]. We can measure VCC call holding times and domain residence times from the commercial operation and then generate the Lognormal and Gamma distributions from the measured data. The effects of the input parameters are investigated as follows.

Effects of V_c and V_d on p_r : Figure 5.1 plots p_r against V_c and V_d, which indicates that p_r decreases as V_d increases. This phenomenon is explained as follows. When the domain residence times become more irregular (i.e., V_d increases), more short domain residence times are observed. Since $t_s = \min(t_c, t_d)$, more short sojourn times are also observed. For a CS-to-PS domain transfer, the reserved CS bearer is less likely to be preempted if the call is more quickly switched back to the CS

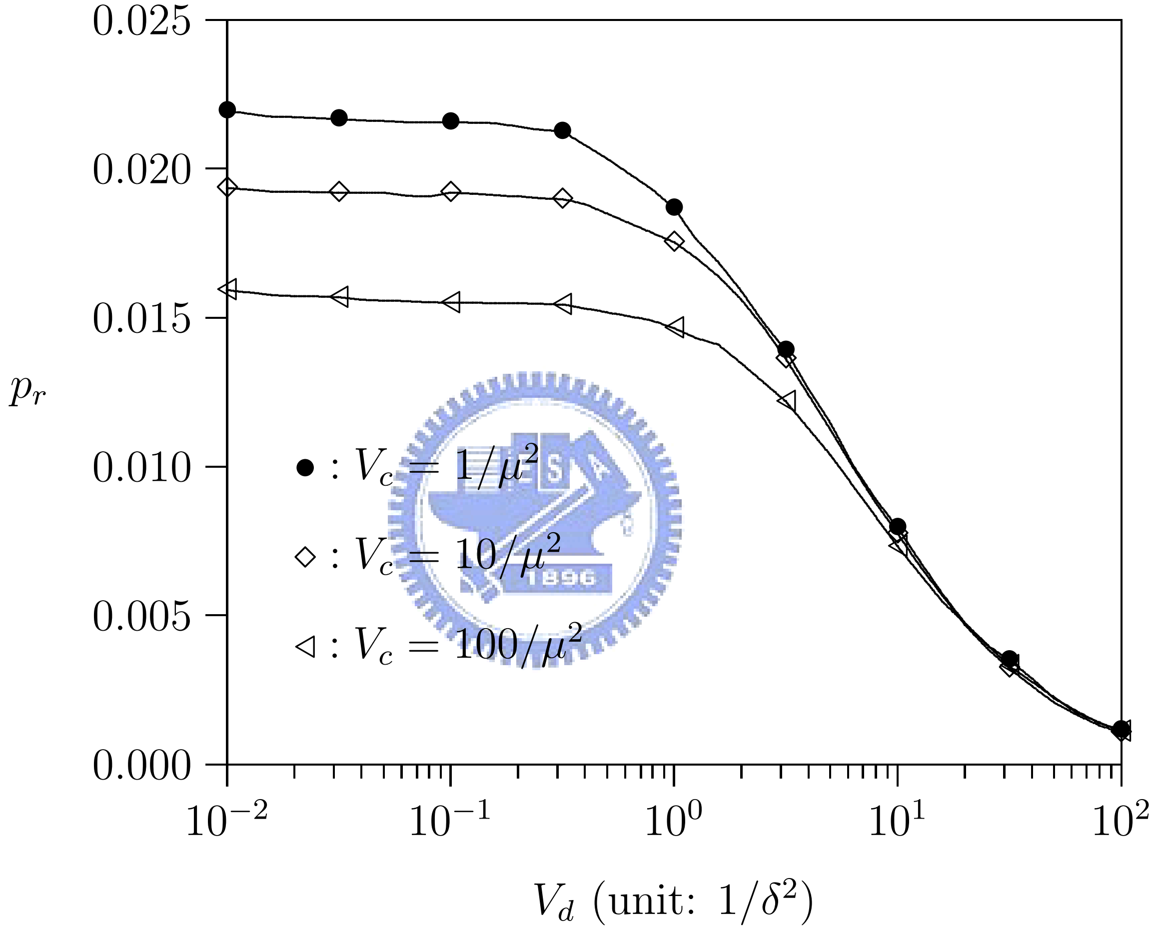

Figure 5.1: Effects of V_c and V_d on p_r ($C = 5, \delta = 5\mu, \lambda_h = 2\mu$)

domain (i.e., t_d is shorter). Therefore, p_r decreases as V_d increases. For the same reason, p_r decreases as V_c increases. The figure also indicates that when $V_d > 10/\delta^2$, p_r is not significantly affected by V_c.

Effects of V_c and V_d on p_f : Figure 5.2 plots p_f against V_c and V_d. This figure shows that p_f decreases as V_c or V_d increases. This phenomenon is similar to that of V_d and V_c on p_r, and is consistent with that observed in [14]. When $V_d > 30/\delta^2$, p_f is small and is not sensitive to the change of V_c.

Effect of C on p_r : Figure 5.3 plots p_r against V_d and C. The figure illustrates trivial result that p_r decreases as C increases. The non-trivial result is that we quantitatively show that when $C < 7$, adding more channels at MSC significantly reduces p_r. When $C \geq 7$, p_r is sufficiently small, and increasing C simply wastes the resources. The figure also shows that the user behavior (i.e., V_d) significantly affects the resource (i.e., C) allocated at the MSC to achieve the same performance (i.e., p_r). For example, if the mobile operator wants to limit p_r to 0.6% under the condition $\delta = 5\mu$, $\lambda_h = 2\mu$ and $V_c = 1/\mu^2$, then only 4 channels are required at the MSC when $V_d = 1/\delta^2$, while 6 channels should be supported when $V_d = 0.1/\delta^2$ (when user behavior is regular). In addition, when $V_d > 10/\delta^2$ (user behavior becomes more irregular), p_r is sufficiently small, and there is no need to add extra resources (i.e., to increase C) at the MSC.

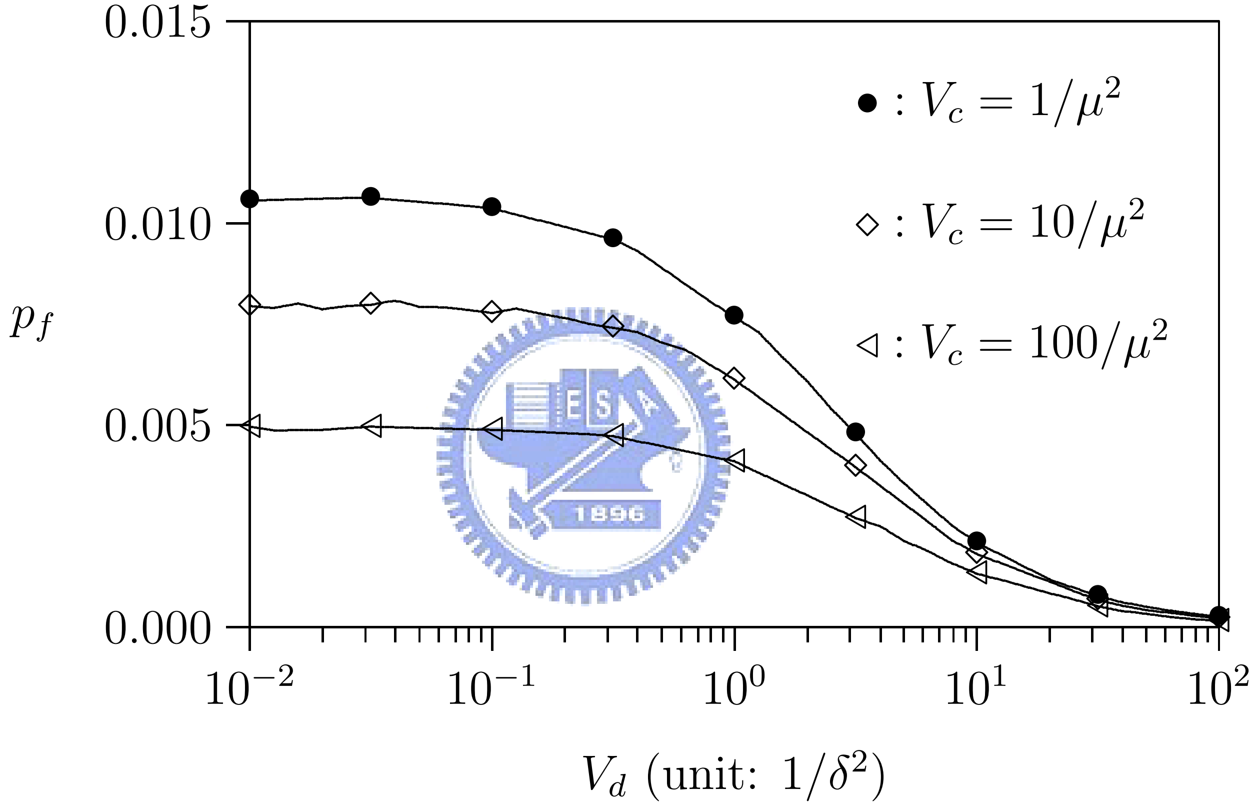

Figure 5.2: Effects of V_c and V_d on p_f ($C = 5, \delta = 5\mu, \lambda_h = 2\mu$)

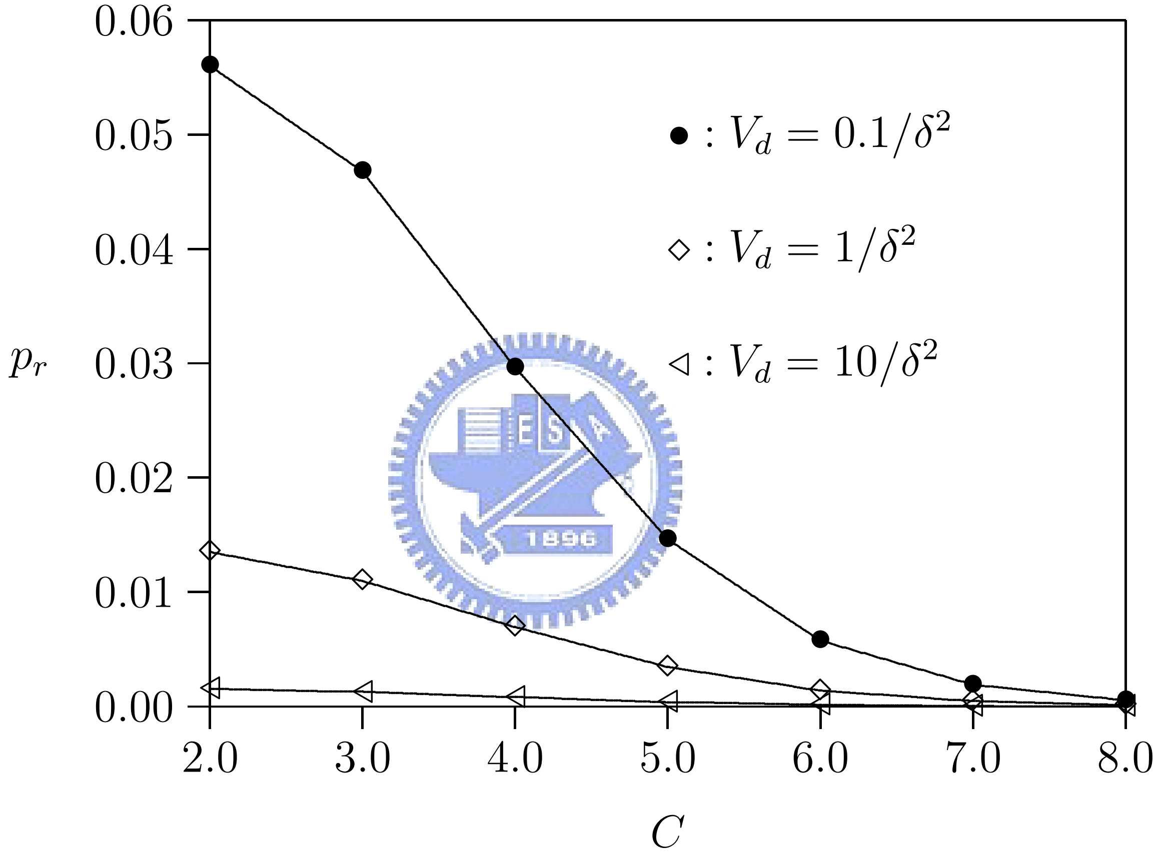

Figure 5.3: Effect of C on p_r ($\delta = 5\mu, \lambda_h = 2\mu, V_c = 1/\mu^2$)

Chapter 6

Conclusions

This thesis investigated Voice Call Continuity (VCC) technique that transfers a voice call between the CS and the PS domains. When a UE switches from one domain to another during a VCC call, the bearer in the old domain is released, and a bearer is established in the new domain. This thesis proposed the Bearer Reservation with Preemption (BRP) scheme to support fast domain transfer. When the UE switches the call from the CS domain to the PS domain, instead of releasing the CS bearer, this CS bearer is reserved with low priority. When the UE switches the call back to the CS domain, the domain transfer process simply raises the priority level of the reserved CS bearer to high priority. Through the preemption mechanism, the reserved bearers in the BRP scheme do not occupy the resources in the MSC for other normal calls. Compared to the 3GPP scheme, the BRP scheme reduces 36% of message exchange for CS-to-PS domain transfer, and 77% for PS-to-CS domain transfer. From the BRP performance study, we observe the following:

- p_r and p_f decrease as V_d or V_c increases.
- When V_d is large, p_r and p_f are not sensitive to the change of V_c.
- When C or V_d is large, p_r is sufficiently small, and increasing C simply wastes the resources at the MSC.
- V_d significantly affects the resource (i.e., C) allocated to achieve the same p_r per-

formance.

The above observations indicate that when the user behavior (either in terms of call holding time or movement pattern) is more irregular, the advantage of the BRP scheme becomes more significant.

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Appendix A

Simulation Modeling of BRP

This appendix describes a discrete event simulation model for the BRP scheme. Three types of input parameters are considered in the simulation model.

System Parameter: There are C channels in the MSC.

Traffic Parameters: The CS call arrivals to the MSC form a Poisson stream with rate λ. We assume that all calls are VCC calls. The expected call holding time is $1/\mu$ with variance V_c.

Mobility Parameter: The expected domain residence time for each domain is $1/\delta$ with variance V_d.

In our simulation model, the following attributes are defined for an event.

- The **type** attribute indicates the event type. An **Arrival** event represents a VCC CS call arrival (i.e., a high-priority call arrival in the MSC). A **CS2PS** event represents that a VCC CS call switches to the PS domain. A **PS2CS** event represents that a VCC PS call switches back to the CS domain. A **Completion** event represents a call completion.
- The **callId** attribute specifies the ID of the call.
- The **priority** attribute indicates high-priority (with value 1) or low-priority (with value 0). This attribute is used in a **Completion** event.

- The **tc** attribute indicates the remaining call holding time.
- The **td** attribute indicates the domain residence time in the current domain.

All events are inserted into the event list, and are deleted/processed from the event list in the non-decreasing timestamp order. A simulation clock is maintained to indicate the simulation progress, which is the timestamp of the event being processed.

In this simulation model, the N_l counter records the number of low-priority calls in the MSC, and the N_c counter records the number of available channels in the MSC. The output measures of the simulation are the total number N of **PS2CS** events, the total number N_r of CS bearer re-establishments and the total number N_f of force-terminations. From the above output measures, we compute

$$p_f = N_f/N,\ p_r = N_r/N, \text{ and } \bar{p}_n = p_f + p_r \tag{A.1}$$

The simulation model uses a queue LQueue to maintain the low-priority calls in the MSC. When a **CS2PS** event occurs (i.e., the VCC CS call becomes low-priority at the MSC), the **callId** attribute of this event is inserted at the tail of LQueue. If an **Arrival** event occurs when $N_c = 0$ and $N_l > 0$, according to the First-Come-Last-Preempted rule, the **callId** at the tail of LQueue is deleted (i.e., the high-priority call arrival preempts a low-priority call).

Figure A.1 illustrates the simulation flow chart for the BRP scheme. In this flow chart, Step 1 initializes the parameters. Step 2 generates the first **Arrival** event **h** where **h.priority = 1** and this event is inserted into the event list. At Steps 3 and 4, the first event **e** in the event list is processed based on its type described as follows:

Arrival: Step 5 generates the next **Arrival** event **f** where **f.priority = 1** and inserts it into the event list. Step 6 checks whether $N_c > 0$ (i.e., there is available channel in the MSC). If so, N_c is decremented by one at Step 7 (i.e., this CS call occupies a channel in the MSC). Otherwise, Step 8 checks whether $N_l > 0$ (i.e., there exists a

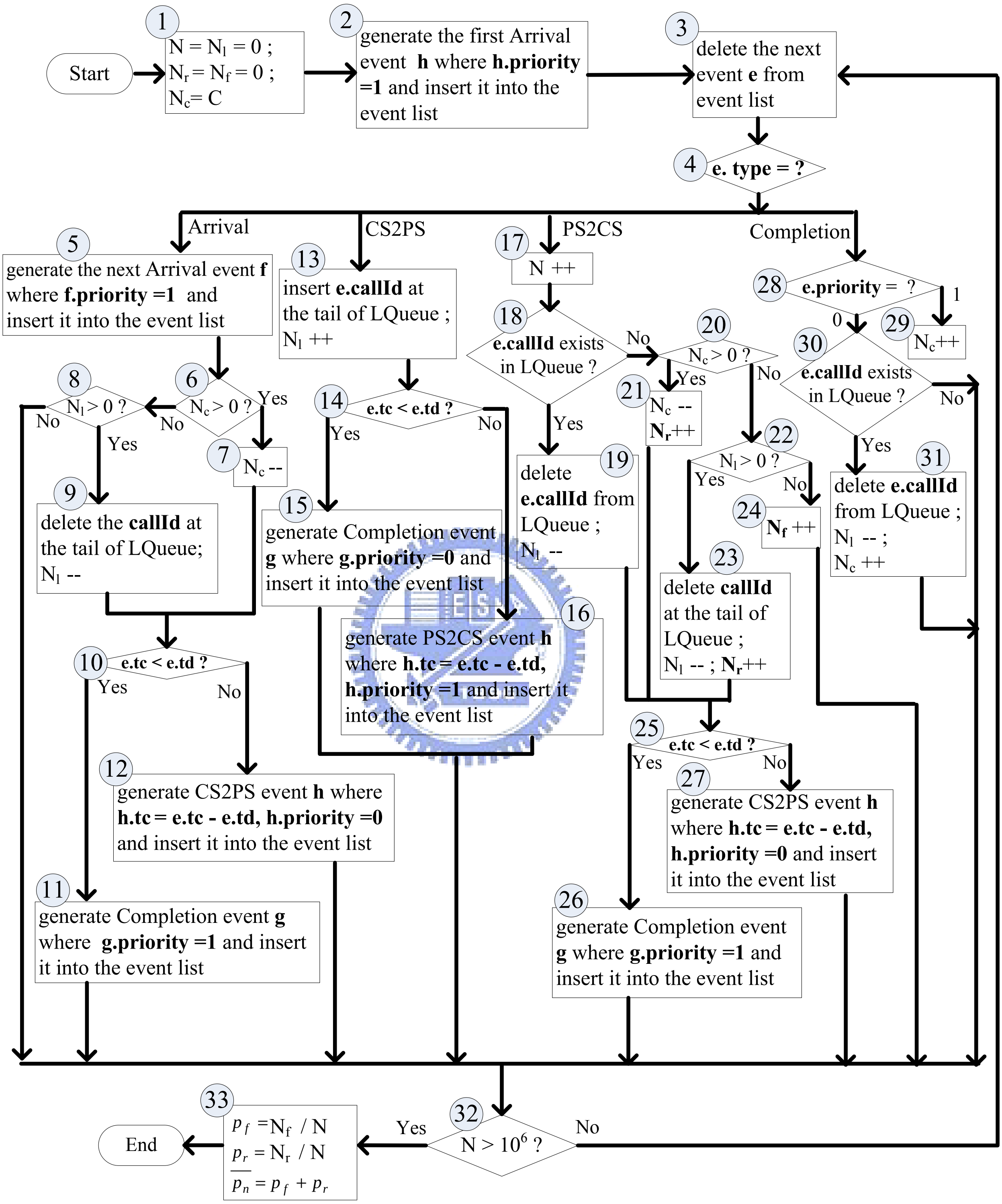

Figure A.1: Simulation Flow Chart for the BRP Scheme low-priority call for preemption in the MSC). If so, the **callId** at the tail of LQueue is deleted, and N_l is decremented by one at Step 9 (i.e., the last-coming low-priority call is preempted). Finally, if $N_c > 0$ at Step 6 or $N_l > 0$ at Step 8 (i.e., a channel is available), Step 10 compares the remaining call holding time **e.tc** and the domain residence time **e.td**. If **e.tc** < **e.td** (this call completes before it switches to the PS domain), Step 11 generates a **Completion** event **g** where **g.priority = 1** for this high-priority call completion, and inserts it into the event list. Otherwise, Step 12 generates a **CS2PS** event **h** where **h.tc = e.tc - e.td** and **h.priority = 0**, and inserts it into the event list.

CS2PS: Step 13 inserts **e.callId** at the tail of LQueue, and increases N_l by one. If **e.tc** < **e.td** at Step 14, then Step 15 generates a **Completion** event **g** where **g.priority = 0** for this low-priority call completion, and inserts it into the event list. Otherwise, Step 16 generates a **PS2CS** event **h** where **h.tc = e.tc - e.td** and **h.priority = 1**, and inserts it into the event list.

PS2CS: N is incremented by one at Step 17. If **e.callId** exists in LQueue at Step 18 (i.e., the reserved CS bearer is still available), then Step 19 deletes **e.callId** from LQueue, and N_l is decremented by one. Otherwise, Step 20 checks whether $N_c > 0$. If so, N_r is incremented by one, and N_c is decremented by one at Step 21 (i.e., the CS bearer is re-established). If $N_c = 0$ at Step 20, Step 22 checks whether $N_l > 0$. If so, the **callId** at the tail of LQueue is deleted, N_r is increased by one, and N_l is decreased by one at Step 23 (i.e., the last-coming low priority call is preempted). If $N_c = 0$ and $N_l = 0$, N_f is incremented by one at Step 24 (i.e., this call is force-terminated). If **e.callId** exists in LQueue, $N_c > 0$ or $N_l > 0$, Step 25 compares the remaining call holding time **e.tc** and the domain residence time **e.td**. If **e.tc** < **e.td**, Step 26 generates a **Completion** event **g** where **g.priority = 1** and inserts it into the event list. Otherwise, Step 27 generates a **CS2PS** event **h** where **h.tc = e.tc - e.td** and **h.priority = 0**, and inserts it into the event list.

Completion: There are two cases at Step 28:

e.priority = 1. N_c is incremented by one at Step 29 (i.e., a channel in the MSC is released).

e.priority = 0. If **e.callId** exists in LQueue at Step 30, then Step 31 deletes the **e.callId** from LQueue, decreases N_l by one, and increases N_c by one.

At the end of each iteration, Step 32 checks if $N > 1,000,000$. If so, Step 33 computes the output measures by (A.1), and the simulation terminates.