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 paper, we propose the Bearer Reservation with Preemption (BRP) scheme to support fast domain transfer, and present both analytic model and simulation experiments to investigate the BRP performance. Our study indicates that when user behavior is irregular (i.e., either the variance of the domain residence times or the variance of the call holding times is large), the advantage of the BRP scheme becomes significant.**

***Index Terms*—Domain transfer, IP multimedia core network subsystem (IMS), universal mobile telecommunications system (UMTS), voice call continuity (VCC).**

NOMENCLATURE

p_f	The probability that there is no available resource when the UE switches back to the CS domain.
p_r	The probability that the reserved CS bearer has been preempted, but the resource becomes available when the UE switches back to the CS domain.
p_n	The probability that the reserved CS bearer is not preempted.
θ_{P2C}	The percentage of re-connection overhead saved by our approach for PS-to-CS domain transfer as compared with the 3GPP approach.
θ_{C2P}	The percentage of re-connection overhead saved by our approach for CS-to-PS domain transfer as compared with the 3GPP approach.
λ	Inter-VCC CS call arrival rate.
t_c	The call holding time.
$1/\mu$	The expected value of t_c.
V_c	The variance for the t_c distribution.
t_d	The period that a VCC call resides at a domain before it is switched to another domain.
$1/\delta$	The expected value of t_d.
V_d	The variance for the t_d distribution.
t_s	The period that a high-priority (low-priority) call utilizes (reserves) a channel at the MSC before it is switched to another domain or is completed.
$1/\eta$	The expected value of t_s.
C	The capacity (number of channels) of the MSC.
K_0	The number of calls in the MSC seen by a low-priority call arrival L.
K_i	The number of high-priority calls in the MSC when the i-th high-priority call arrives.
π_k	The steady-state probability that there are k calls in the MSC.
t_h	The inter-arrival time between the i-th and the $(i+1)$-th high-priority call arrivals.
$p_{(m,n)}$	The one-step transition probability from state $K_i = m$ to state $K_{i+1} = n$.
$p^{(l)}_{(m,n)}$	The probability that the stochastic process moves from state m to state n with exact l steps.

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I. 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 [2]. In existing commercial operation, the CS domain provides full service coverage with limited bandwidth. On the other hand, the PS domain typically provides zonal coverage with larger bandwidth and cheaper services. Therefore, when the PS connection is available, the UE will switch to the PS domain. When the PS connection is not available, the UE switches to the CS domain. A UMTS handset can attach to the CS and the PS domains individually or simultaneously, and initiate or receive a call in either 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) [3].

Figure 1 illustrates a simplified UMTS network architecture that accommodates VCC [3], [4]. This architecture consists of the UMTS Terrestrial Radio Access Network (UTRAN)

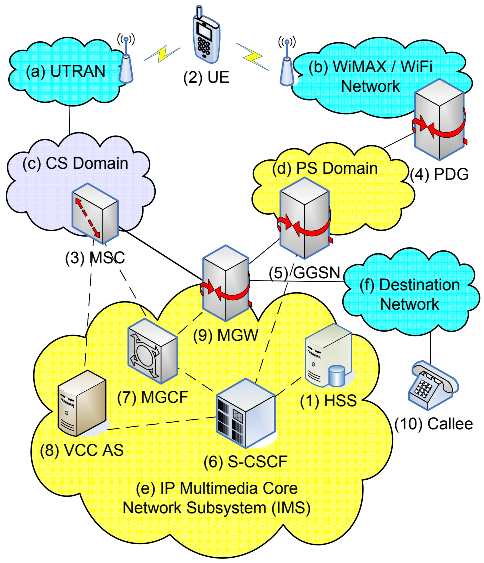


Fig. 1. The UMTS network architecture (dashed lines: signaling; solid lines: signaling/data).

(Figure 1 (a)), the Worldwide Interoperability for Microwave Access (WiMAX) or the Wireless Fidelity (WiFi) network (Figure 1 (b)), the CS domain (Figure 1 (c)), the PS domain, i.e., the *General Packet Radio Service* (GPRS) network (Figure 1 (d)), and the IMS network (Figure 1 (e)). In this architecture, *Home Subscriber Server* (HSS; Figure 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 (2)) to access CS and PS services. In the CS domain, the *Mobile Switching Center* (MSC; Figure 1 (3)) is responsible for call control, including the processing of user data and control signals. In the PS domain, the WiMAX/WiFi network connects to the GPRS network through the *Packet Data Gateways* (PDGs; Figure 1 (4)); the GPRS network connects to the IMS network through the *Gateway GPRS Support Nodes* (GGSNs; Figure 1 (5)). 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 (6)), the *Media Gateway Control Function* (MGCF; Figure 1 (7)) and the *VCC Application Server* (VCC AS; Figure 1 (8)). The IMS user data traffic is transported through the *Media Gateways* (MGWs; Figure 1 (9)) controlled by the MGCF. When the UE makes a call to a call party (Figure 1 (10)) in a different network (Figure 1 (f)), the call is first routed to the MGW. Then the MGW routes the call to the callee through the destination network.

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. We present an analytic model for the BRP scheme. The proposed analytic model is used to validate against the simulation model. Then we conduct simulation experiments to investigate the BRP performance.

II. VCC Call Setup and Domain Transfer

This section describes the VCC call setup and domain transfer procedures defined in 3GPP [5].

A. 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 [6]) 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.

For the reader's benefit, the VCC call origination in the PS domain is described in Appendix A. The reader is referred to [5] for VCC call origination in the CS domain and VCC call termination in both domains.

B. 3GPP Domain Transfer

In the CS domain, VCC service control is provided through the *Customized Applications for Mobile Network Enhanced Logic* (CAMEL) [7], where the VCC service logic is implemented in the VCC AS. This subsection describes how 3GPP domain transfer works. Detailed description of 3GPP domain transfer is given in Appendix B.

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. When the call setup signal arrives at the VCC AS, the VCC AS updates the UE-MGW segment. Details of PS-to-CS domain transfer are given in Steps B.1-B.16 in Figure 10.

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. Details of CS-to-PS domain transfer are given in Steps C.1-C.9 in Figure 11.

III. BRP Domain Transfer

In the 3GPP CS-to-PS domain transfer procedure, 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

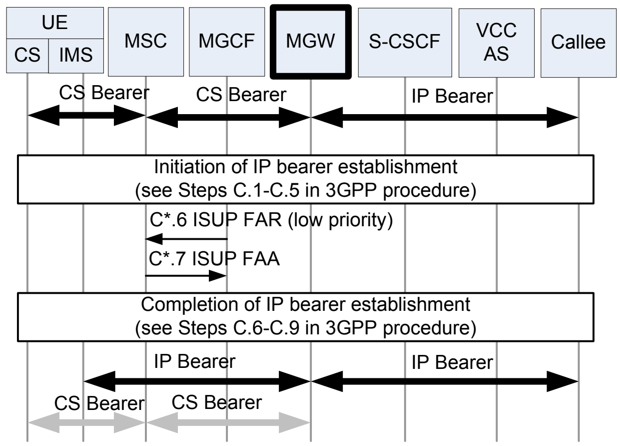


Fig. 2. CS-to-PS domain transfer with IP bearer establishment (BRP).

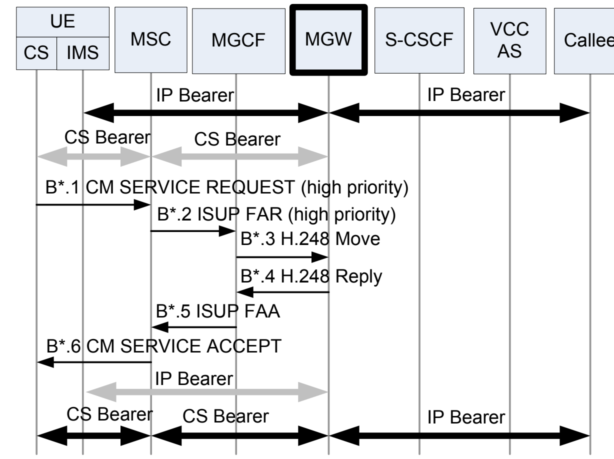


Fig. 3. PS-to-CS domain transfer without CS bearer establishment (BRP).

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 [8] and *Multimedia Priority Service* (MPS) [9] 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 CS bearer needs to be re-established.

A. CS-to-PS Domain Transfer in the BRP Scheme

Figure 2 illustrates the BRP message flow for CS-to-PS domain transfer with IP bearer establishment with the following steps:

Steps C.1-C.5 Same steps as in the 3GPP CS-to-PS domain transfer procedure (see Figure 11 in Appendix B) 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 ISDN User Part (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 the 3GPP CS-to-PS domain transfer procedure (see Figure 11 in Appendix B) exchange the Session Initiation Protocol (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 11. Therefore, the message exchange cost is reduced by 36%. If the IP bearer has been reserved and not preempted before the domain transfer occurs (not shown in this paper), the message exchange cost is reduced by 68%. 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 [4].

B. 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 10, 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 illustrates the BRP message flow for PS-to-CS domain transfer without CS bearer establishment 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 10 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%. If the CS bearer has been preempted before the call is switched back to the CS domain (not shown in this paper), the message exchange cost is reduced by 15.4%.

IV. Analytic Modeling of BRP

This section 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 when the new calls arrive at the MSC are VCC calls (i.e., we do not consider non-VCC calls). 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. In this case, only 15.4% message overhead is saved by our approach. 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. In this case, our approach saves 77% message overhead as compared with the 3GPP approach. 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. Probabilities p_r and p_n are used to actually compute the overhead saved by our approach. We use θ_{P2C} (or θ_{C2P}) to represent the percentage of re-connection overhead saved by our approach as compared with the 3GPP approach for PS-to-CS (or CS-to-PS) domain transfer. Specifically,

$$\begin{aligned}\theta_{P2C} &= 15.4\% \times \frac{p_r}{p_n + p_r} + 77\% \times \frac{p_n}{p_n + p_r},\\ \theta_{C2P} &= 36\% \times \frac{p_r}{p_n + p_r} + 68\% \times \frac{p_n}{p_n + p_r}\end{aligned} \quad (1)$$

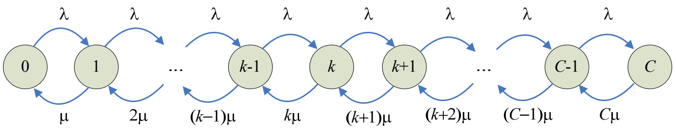


Fig. 4. State transition rate diagram for the BRP scheme.

For the illustration purpose, we only consider θ_{P2C} in this paper. Similar conclusions also apply to θ_{C2P}. The following input parameters are considered in this study:

- The arrivals of new VCC CS calls are a Poisson stream with rate λ.
- The call holding time is a random variable t_c with mean $1/\mu$ and variance V_c.
- A VCC call resides at a domain for a period t_d before it is switched to another domain. Let t_d be a random variable with mean $1/\delta$ and variance V_d.
- 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. It is clear that $t_s = \min(t_c, t_d)$. Let t_s be a random variable with mean $1/\eta$.

In the analytic model, we assume that t_c and t_d are exponentially distributed. Therefore, t_s is also exponentially distributed. The above exponential assumptions result in mean value analysis [10] (this exponential assumption will be relaxed in simulation experiments). We conduct the mean value analysis to provide understanding on the "trend" of performance. Furthermore, this exponential-based analytic model 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. We first derive the number of channels occupied (either used or reserved) by the calls at the MSC. Let C be the capacity (number of channels) of the MSC. Figure 4 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. We note that during the call holding time t_c of a VCC call, the call may be switched between the CS and the PS domains, and the channel at the MSC is always occupied by the call. Therefore, the stochastic process can be modeled by a simple M/M/C/C queue with the parameters λ and μ. Let π_k denote the steady-state probability that there are k calls in the MSC. From the standard technique [11], we have

$$\pi_k = \pi_0 \left[\frac{\lambda^k}{(k!)\mu^k}\right], \pi_0 = \left[1 + \sum_{j=1}^{C} \frac{\lambda^j}{(j!)\mu^j}\right]^{-1} \quad \text{for } 0 \le k \le C \quad (2)$$

After a VCC call L switches from the CS to the PS domain, it becomes a low-priority call at the MSC. Figure 5 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 high priority). There are two high-priority call arrivals at the MSC at τ_2 and τ_5, and there are four high-

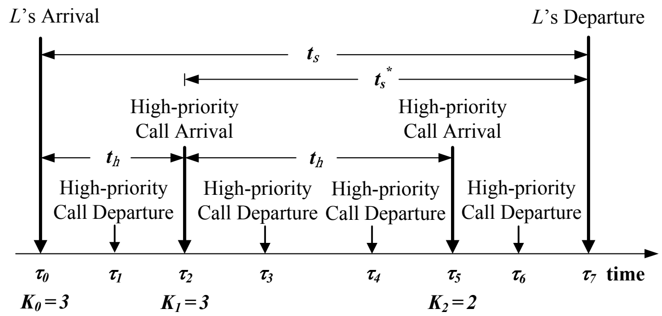


Fig. 5. Events that may occur in L's sojourn time.

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 (i.e., the last call arrival will be preempted first) [12]. 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). Since t_d is exponentially distributed, $\Pr[K_0 = m]$ can be derived based on the "flow rate" concept [13]. Under this concept, $(m+1)\delta\pi_{m+1}$ represents the number of calls that leave the MSC through domain transfers in a time unit when the system is at state $m+1$ (where $\delta = 1/E[t_d]$ is the domain transfer rate for a call; see page 59 in [13]), and $\sum_{j=0}^{C-1}(j+1)\delta\pi_{j+1}$ represents the total number of domain-transferred calls that leave the MSC in a time unit. From (2) and the "flow rate" concept, $\Pr[K_0 = m]$ is derived as

$$\begin{aligned}\Pr[K_0=m] &= \frac{(m+1)\delta\pi_{m+1}}{\sum_{j=0}^{C-1}(j+1)\delta\pi_{j+1}} \\ &= \left[\frac{\lambda^{m+1}}{(m!)\mu^{m+1}}\right]\left[\sum_{j=0}^{C-1}\frac{\lambda^{j+1}}{(j!)\mu^{j+1}}\right]^{-1} \quad (3)\end{aligned}$$

After τ_0, L can only be preempted by a high-priority call arrival or by a PS-to-CS domain transfer. For simplicity, we do not consider PS-to-CS domain transfers, and we simply observe the moments when a high-priority call arrives. After τ_0, for $i \geq 1$, let K_i be the number of high-priority calls in the MSC (from L's viewpoint, 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 5, 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 ($i \geq 0$; 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 $0 \leq n \leq C$, $p_{(C,n)} = 0$ because L has already been preempted by the i-th high-priority call arrival. In addition, for $0 \leq m \leq C$, $p_{(m,0)} = 0$ because the $(i+1)$-th high-priority call arrival is included in K_{i+1}, and 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 5, let t_s^* be the excess life (residual life) of t_s upon a high-priority call arrival, which has the density function $f^*(t_s^*)$ and the distribution function $F^*(t_s^*)$. Since t_s is exponentially distributed, t_s^* has the same distribution as t_s due to the memoryless property. Therefore, when $m \neq C$, $n \neq 0$ and $n \leq m+1$, $p_{(m,n)}$ can be derived by considering the relationship between t_s^* (for L and the m existing high-priority calls) and t_h (the inter-arrival times of two high-priority calls):

$$\begin{aligned}p_{(m,n)} &= \int_{t_s^*=0}^{\infty}\int_{t_h=0}^{t_s^*}\binom{m}{n-1}F^*(t_h)^{m-n+1} \\ &\quad [1-F^*(t_h)]^{n-1}\,\lambda e^{-\lambda t_h} f^*(t_s^*)dt_h dt_s^* \quad (4)\\ &= \int_{t_s^*=0}^{\infty}\int_{t_h=0}^{t_s^*}\binom{m}{n-1}\sum_{j=0}^{m-n+1}\binom{m-n+1}{j}(-1)^j \\ &\quad \lambda e^{[-(n+j-1)\eta-\lambda]t_h}\eta e^{-\eta t_s^*}dt_h dt_s^* \\ &= \sum_{j=0}^{m-n+1}\left(\begin{array}{c} m \\ n-1, j\end{array}\right)\left[\frac{(-1)^j\lambda}{\lambda+(n+j)\eta}\right] \quad (5)\end{aligned}$$

Equation (4) says that if $K_i = m$ and $K_{i+1} = n$, then among these m calls, 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 $l \geq 2$, let

$$p_{(m,n)}^{(l)} = \sum_{j=0}^{C} p_{(m,j)}^{(l-1)} p_{(j,n)} \quad (6)$$

In (6), $p_{(m,n)}^{(l)}$ is 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 $i \geq 1$, $\Pr[K_i = n]$ is expressed as

$$\Pr[K_i = n] = \sum_{m=0}^{C-1}\Pr[K_0 = m]p_{(m,n)}^{(i)} \quad (7)$$

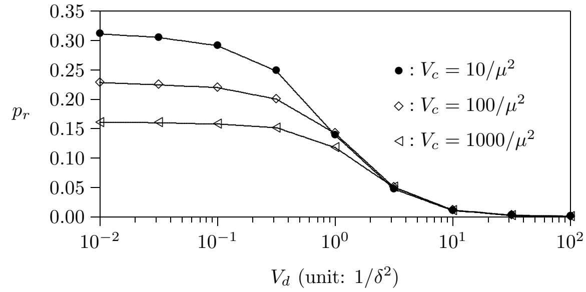
For $i \geq 2$, (7) can be recursively computed by using (6), and we have

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

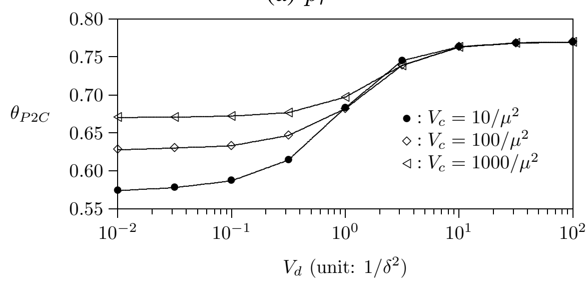
From (3), (5) and (7), the preemption probability $\bar{p}_n$ is derived as

$$\bar{p}_n = \sum_{i=0}^{\infty}\Pr[K_i = C-1]p_{(C-1,C)} \quad (8)$$

Note that we typically do not see infinite high-priority call arrivals during L's sojourn time. From (7), it is clear that $\lim_{i\to\infty}\Pr[K_i = C-1] = 0$. Therefore, it suffices to consider $i \leq 50$ in (8). In this analytic model, p_f can be analytically derived using the technique in [14], and p_r is then computed as $p_r = \bar{p}_n - p_f$.



(a) p_r



(b) θ_{P2C}

Fig. 6. Effects of V_c and V_d on p_r and θ_{P2C} ($C = 5, \delta = \mu/5, \lambda = 2\mu$).

The above analytic model is used to validate against the discrete event simulation experiments described in [15]. Our study indicates that the analytic results are consistent with the simulation results (see Table 1 in [15]; the differences are within 1.7%).

V. NUMERICAL EXAMPLES

Based on the simulation experiments, this section investigates the performance of the BRP scheme. Suppose that t_c has Lognormal distribution with mean $1/\mu$ and 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 [14]. Similarly, we assume that t_d has the Gamma distribution with mean $1/\delta$ and 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 [16]), and is often used to represent the location residence times (inter-moving times) [10], [17], [18]. 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. Experience from commercial operation shows that $\delta = \mu/10 \sim 10\mu$ is reasonable. In our numerical examples, we set $\delta = \mu/5$. The results for other δ values are similar, and are not presented. The effects of the input parameters are investigated as follows:

Effects of V_c and V_d on p_r and θ_{P2C} : Figure 6 (a) 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 t_s 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 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. Since θ_{P2C} is a decreasing function of p_r in Equation (1), θ_{P2C} is an increasing function of V_d and V_c as illustrated in Figure 6 (b).

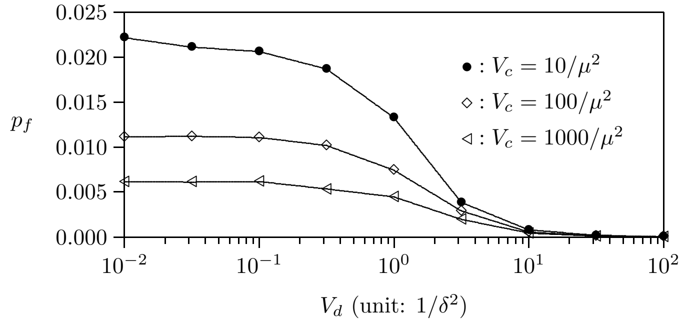
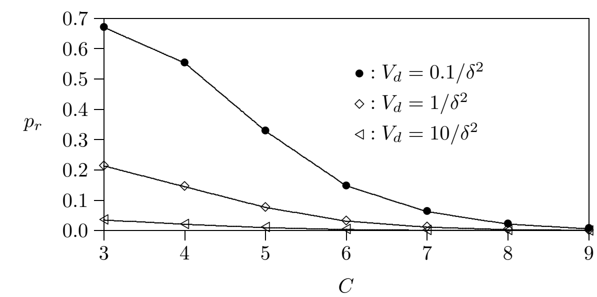
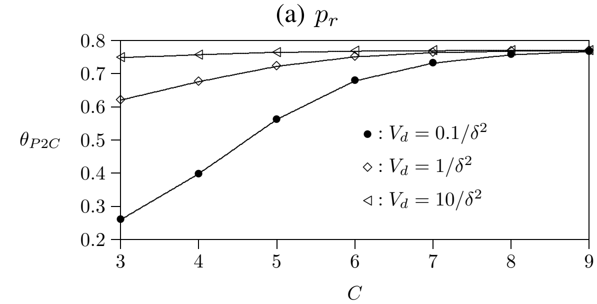


Fig. 7. Effects of V_c and V_d on p_f ($C = 5, \delta = \mu/5, \lambda = 2\mu$).



(a) p_r



(b) θ_{P2C}

Fig. 8. Effect of C on p_r and θ_{P2C} ($\delta = \mu/5, \lambda = 2\mu, V_c = 1/\mu^2$).

Effects of V_c and V_d on p_f : Figure 7 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 [17]. 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 and θ_{P2C} : Figure 8 plots p_r and θ_{P2C} against V_d and C. The figure illustrates the trivial result that p_r is a decreasing function of C, and θ_{P2C} is an increasing function of C. The non-trivial result is that we quantitatively show that when $C < 7$, adding more channels at MSC significantly reduces p_r (and therefore significantly increases θ_{P2C}). When $C \geq 7$, p_r is sufficiently small (θ_{P2C} is sufficiently large), and increasing C simply wastes the resources. The figure also shows that the user behavior (i.e., V_d) significantly affects the resource allocated at the MSC (i.e., C) to achieve the same p_r and θ_{P2C} performances. For example, if the mobile operator wants to limit p_r to 15% (which ensures that $\theta_{P2C} \geq 67\%$) under the condition $\delta = \mu/5, \lambda = 2\mu$ 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 θ_{P2C} is sufficiently large), and there is no need to add extra resources (i.e., to increase C) at the MSC. Note that V_c has the same effect on p_r and θ_{P2C} as V_d does, and the details are omitted.

VI. Conclusions

This paper 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 paper proposed the Bearer Reservation with Preemption (BRP) scheme to support fast and seamless 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. The percentage of re-connection overhead saved by BRP over the 3GPP procedures is denoted by θ_{P2C} for domain transfer from the PS domain to the CS doamin. From the BRP performance study, we observe the following:

- As V_d or V_c increases, θ_{P2C} increases. When V_d is large, θ_{P2C} is not sensitive to the change of V_c.
- V_d and V_c significantly affects the resource (i.e., C) allocated to achieve the same θ_{P2C} performance. When C, V_d or V_c is large, θ_{P2C} is sufficiently large, and increasing C simply wastes the resources at the MSC.

The above observations are also true for domain transfer from the CS domain to the PS domain, which 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.

Appendix A
VCC Call Setup

Suppose that a UE is 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. Figure 9 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) [4], [19] 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.

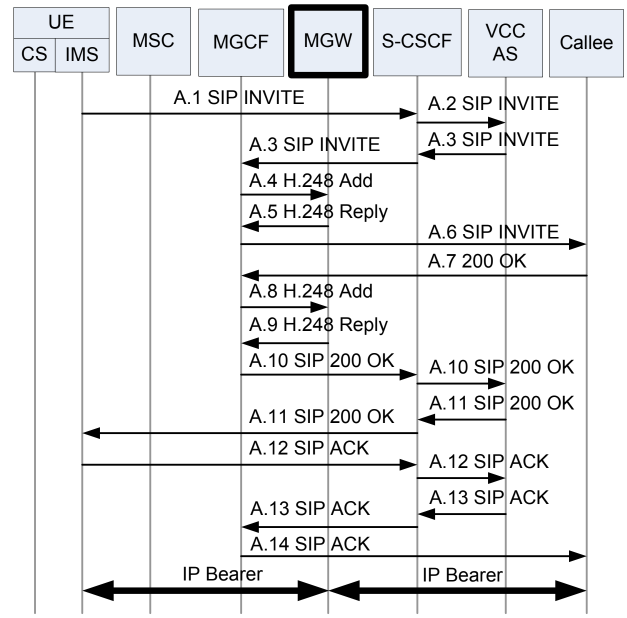


Fig. 9. VCC call origination in the PS domain.

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

Appendix B
3GPP Domain Transfer

The message flow for PS-to-CS domain transfer is illustrated in Figure 10 with the following steps:

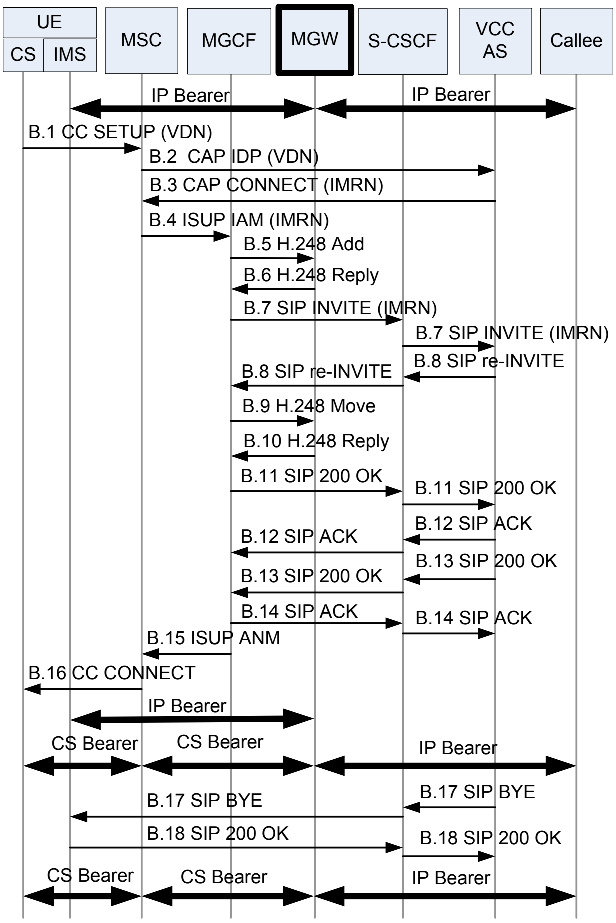


Fig. 10. PS-to-CS domain transfer (3GPP TS 24.206).

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 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 modify 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) to 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.

Figure 11 illustrates the message flow for CS-to-PS domain transfer 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

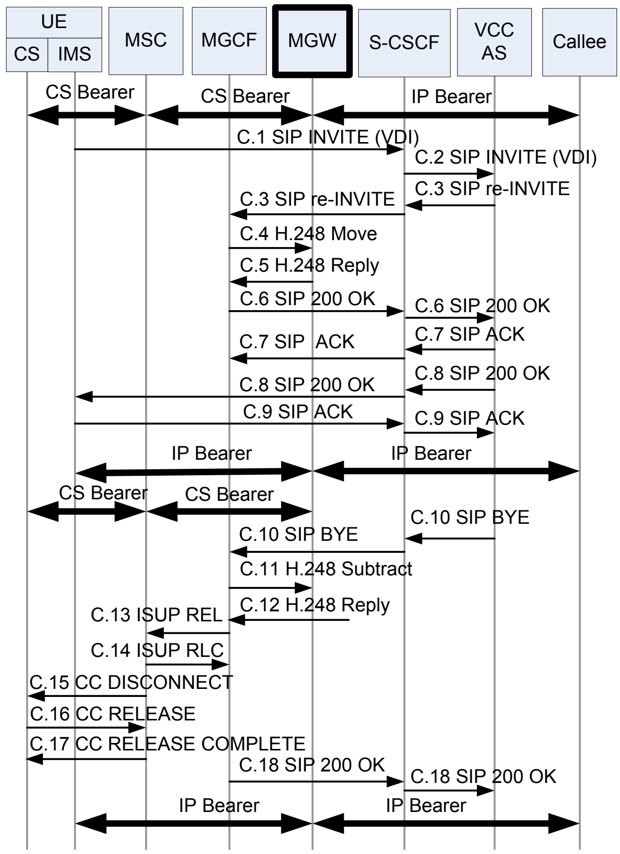


Fig. 11. CS-to-PS domain transfer (3GPP TS 24.206).

CS bearer between the MSC and the MGW.

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 disconnect 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.

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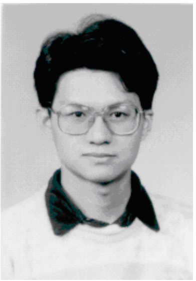

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