Performance analysis of two schemes for managing information related to incall registration in wireline UPT networks

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Abstract

In universal personal telecommunication (UPT) environments, UPT networks retain information related to incall registration in UPT user service profiles in order to provide incoming UPT calls for UPT users at any terminal in any location. As UPT networks support incall registration, terminal users can be different from terminal owners, and several UPT users can register on a single terminal for their incoming calls. Therefore, appropriate third-party protection procedures are needed to protect the rights of terminal owners from UPT users. A database called the terminal profile is needed to store the information of the terminal states and the incall UPT users registered on the terminal in order to carry out third-party protection procedures. In order to manage information within the terminal profile and the service profile, this article proposes two schemes, a request-based scheme and a timer-based scheme. The performance of the two schemes is compared in terms of the number of signaling messages transferred between a service switching point (SSP) and a service control point (SCP) per incall registration reset for a terminal. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Since a universal personal telecommunication (UPT) service enables users to originate and receive calls at any terminal through personal identification numbers [1], the UPT service will be one popular telecommunication service. ITU-T has recommended network capabilities to support UPT services [2], service procedures for UPT [3], and service descriptions and operational provisions for UPT service sets 1 [4] and 2 [5]. UPT networks have been studied in several research areas such as UPT functional architectures [6–12], information localization schemes [13,14], service control schemes [15–17], and performance evaluations [18]. In Ref. [18], Kwiatkowski simply evaluated the performance of an example of UPT networks, which consists of several circuit-switched networks, in terms of service control point (SCP) utilization for incoming UPT calls, outgoing UPT calls, and incall registration/ deregistration.

In UPT environments UPT users must register incalls on current terminals to receive calls [4,5]. Incall registration provides a means for a UPT user to indicate where the incoming calls are to be delivered. Incall registration may be cancelled in one of the following ways: a new registration request, an explicit deregistration request, a counter/timer expiration, a service provider request, and a third-party request [4,5]. To effectively support incoming UPT calls, UPT networks retain information related to incall registration in UPT user service profiles. Each UPT user service profile is associated with a single UPT user.

As UPT networks support incall registration, terminal users can be different from terminal owners, and several UPT users can register on a single terminal for their incoming calls. Therefore, appropriate third-party protection procedures are needed to protect the rights of third parties, i.e. terminal owners. For example, if UPT users who are registered on a terminal leave the terminal without making incall deregistration, then incoming UPT calls are still delivered to the terminal. In this case the terminal owner may want to reset incall registration for the terminal. Third-party protection procedures, including reset of registration for incoming UPT calls, are still under study in ITU-T study group 11 [4]. To implement these procedures a database
called the terminal profile for each terminal is needed to store the information of the terminal states and the UPT users registered on the terminal.

Although UPT networks can be implemented in a number of ways, UPT network architecture is considered with terminal profiles and service profiles located in adjuncts (ADs) and service data points (SDPs), respectively. The performance of the network may vary according to different information management methods in the terminal profile and the service profile. This article proposes two schemes: a request-based scheme and a timer-based scheme, to manage information within the terminal profile and the service profile for incall registration/deregistration and incall registration resets. The performance of the two schemes is compared in terms of the number of signaling messages transferred between an service switching point (SSP) and an SCP between two successive incall registration reset requests for a terminal.

This paper is organized as follows: Section 2 describes the architecture of wireline UPT networks with terminal profiles and service profiles, and two schemes are proposed for managing information in the terminal and the service profiles. Section 3 describes signaling message procedures for incall registration/deregistration, for incoming UPT calls, and for incall registration resets in the proposed schemes. Section 4 derives cost functions for the proposed schemes, and then also derives the mean numbers of signaling messages from the cost functions. Section 5 gives numerical examples for performance comparisons of both schemes in terms of the mean number of signaling messages. Finally, Section 6 gives conclusions.

2. Profile management schemes

In this section an architecture of wireline UPT networks is introduced, and a request-based scheme and a timer-based scheme are proposed for managing information in terminal and service profiles. Fig. 1 shows an example of wireline UPT network architecture consisting of an SCP, SDPs, SSPs, ADs, and terminals. Each SSP is connected to its AD and the SCP through direct lines and signaling networks, respectively. Any SSP can access service profiles in SDPs through the SCP and the signaling networks. Each SDP and each AD include UPT user service profiles and terminal profiles, respectively. The service profiles contain information related to UPT users, e.g. user location information, in order to provide users with UPT services. The terminal profiles contain information regarding terminal states and the incall UPT users who are registered. Each service profile and each terminal profile are associated with a single UPT number and a single terminal address, respectively.

For simplicity, incall registration/deregistration, incoming UPT calls, and resets for incall registration are considered. In the request-based scheme, information related to incall registration in both a terminal profile and a service profile is updated whenever a UPT user requests incall registration/deregistration for a terminal, or when the owner of a registered incall terminal requests the reset of incall registration.

In the timer-based scheme, both a terminal and a service profile have a timer. The value of each timer in the terminal and service profiles is set at T whenever there is an incall
registration request or when an incoming call arrives. The timer in the service profile has a role to determine whether information related to incall registration is restored in the terminal profile or not. However, the timer in the terminal profile has a role to delete information related to incall registration from the terminal profile. In the service profile, information is stored whenever a UPT user requests incall registration for a terminal. The information is deleted: (1) whenever a UPT user requests either a new incall registration or an explicit incall deregistration for a terminal; (2) when the owner of a registered incall terminal requests the reset of incall registration during working period of the associated timer; or (3) when an incoming call arrives at a terminal after the terminal is reset by the owner (refer to Fig. 2). In the terminal profile, information related to incall registration is stored whenever a UPT user requests incall
Fig. 3. Incall registration and deregistration scenarios in a request-based scheme.

Fig. 4. Incall registration reset scenario and incoming UPT call scenario after an incall registration reset is performed in the request-based scheme.
registration for a terminal, and restored when an incoming call arrives at a terminal after the associated timer is expired. The information is deleted when a timer expires or when the owner of a terminal requests the reset of incoming UPT call registration.

3. Signaling message procedures

Signaling message flows are described in cases of incall registration/deregistration, incoming UPT calls, and incall registration resets.

3.1. Request-based scheme (Scheme I)

Fig. 3 shows incall registration and deregistration scenarios in a request-based scheme. Incall registration procedures are described as follows.

**Step 1:** An incall registration request message for terminal \(a\) (\(T_a\)) is sent from UPT user \(A\) (\(U_A\)) to his service profile through a service switching point “1” (SSP1) and a service control point (SCP).

**Step 2:** An incall registration update request message is sent to the terminal profile through the SCP and SSP1.

**Step 3:** \(U_A\)’s UPT number is updated in the terminal profile for \(T_a\). Then, an incall registration update completion message is sent to the service profile for \(U_A\) through the SSP1 and SCP.

**Step 4:** The registered incall terminal address is set for 
\(U_A\)’s service profile. Then, an incall registration completion message is sent to SSP1 through the SCP, and the SSP1 informs \(U_A\) that the incall registration request is accepted.

Suppose that \(U_A\) registering on \(T_a\) moves to \(T_b\) attached to SSP2 and that \(U_A\) requests an incall registration for \(T_b\). \(U_A\) first sends an incall registration request message for \(T_b\) to the service profile through the SSP2 and SCP (Step 5). If \(U_A\)’s incall registration information was deleted from the service profile due to a reset request by the owner of \(T_a\), the service profile sends an incall registration update message to \(T_b\)’s terminal profile (Step 6). Upon receiving this message the terminal profile deletes \(U_A\)’s UPT number and an incall registration cancellation completion message is sent to \(U_A\)’s service profile through the SSP1 and SCP (Step 7). The subsequent procedures are performed as the above described procedures for Steps 8–10. In case that \(U_A\) requests an explicit incall deregistration for \(T_b\) at \(T_a\) instead of an incall registration for \(T_b\), explicit incall deregistration procedures are the same as for an incall registration for \(T_b\), except for Steps 8 and 9.

Incall registration reset for a terminal explicitly deregisters all UPT users who have registered incalls on the terminal [4]. For simplicity it is assumed that a single UPT user has registered an incall on a terminal. Fig. 4 shows message flow for the incall registration reset (Steps 1–4) and for an incoming call delivery after the incall registration reset (Steps 5 and 9). When the owner of \(T_a\) requests an incall registration reset for \(U_A\), an incall registration reset request message is transferred to its associated terminal profile (Step 1), then to the service profile of \(U_A\) (Step 2) in order to delete the terminal address from the service profile. The service profile sends an incall registration cancellation completion message to \(T_a\)’s terminal profile (Step 3). The terminal owner is then informed that the incall registration for \(U_A\) has been reset (Step 4). When \(U_A\) makes a call to \(U_B\) after the incall registration for \(U_A\) is reset at \(T_a\)’s terminal profile, an incoming call request message is sent to \(U_A\)’s service profile (Step 5). If \(U_A\) registered an incall on \(T_c\) attached to SSP1 as default, the service profile informs the SSP2 of \(U_A\)’s temporary roaming/routing number through the SCP (Step 6). The SSP2 sends a call setup request message to SSP1 through a signaling network (Step 7), then receives a call setup completion message from the SSP1 (Step 8). Finally, the SSP2 informs \(U_B\) that the incoming call request has been accepted (Step 9). However, if there is no incall terminal registered as default, the SCP informs \(U_B\) that the incoming call request has been rejected (Steps 6 and 9).

An incoming call is now considered when the registered UPT user’s terminal address which is called is stored in the service profile. Suppose that there is no reset for \(T_a\) after \(U_A\) registers an incall on \(T_a\) and that \(U_B\) makes a UPT call to \(U_A\) through \(T_b\) attached to SSP2. Fig. 5 shows message flow for an incoming call delivery. An incoming call request
The message is sent to $U_A$’s service profile through the SSP$_2$ and SCP to determine a temporary roaming/routing number for $U_A$ (Step 1). The service profile informs the SSP$_2$ of $U_A$’s temporary roaming/routing number through the SCP (Step 2). The SSP$_2$ sends a call setup request message to SSP$_1$ through a signaling network (Step 3), then receives a call setup completion message from the SSP$_1$ (Step 4). Finally, the SSP$_3$ informs $U_A$ that the incoming call request has been accepted (Step 5).

### 3.2. Timer-based scheme (Scheme II)

The incall registration scenario is the same as for Scheme I except that the value of each timer, which is located in both the terminal and service profiles, is set at $T$. After the incall registration, these values are set at $T$ again when an incoming call arrives. However, if no incoming UPT calls arrive at the terminal for a duration of time $T$ before the timer expires in the terminal profile, incall registration information is deleted from the terminal profile.

In this scheme, incall deregistration is carried out without accessing terminal profiles because information is deleted from the terminal profile with timer expiration. Therefore, incall deregistration procedures are the same as for Scheme I (refer to Steps 5 and 8–10 in Fig. 3).

Suppose that a terminal owner resets the incall registration for $U_A$. If the timer has not expired, then the reset procedure is the same as for Scheme I. If the timer has expired and there is no information for $U_A$ in the terminal profile, this reset request is suspended. In this case the incall registration for $U_A$ is reset upon arrival of a new incoming call from another user to $U_A$.

Regarding incoming UPT calls, when a UPT user makes a call to a UPT user after the called UPT user registers an incall on a terminal there are four types of incoming call scenarios. The incall registration information stored in both the service profile of the called UPT user and the terminal profile of the registered terminal. The called UPT user is said to be in states 1, 2, 3, or 4 as follows:

**State 1:** The information for the called UPT user is stored in both the service profile and the terminal profile of the registered terminal.

**State 2:** The information for the called UPT user is not stored in the terminal profile of the registered terminal due to timer expiration.

**State 3:** The information for the called UPT user is not stored in the service profile.

**State 4:** The information for the called UPT user is stored in the service profile and there are incall registration resets for the registered terminal after an incall on that terminal is registered.

Suppose that $U_B$ makes a call for $U_A$, who registered an incall on $T_a$ through $T_b$ attached to SSP$_2$. Fig. 6 shows an incoming call scenario for $U_A$ in state 1. This incoming call scenario is the same as for Scheme I when the incall registration information is stored in both $U_A$’s service profile and $T_a$’s terminal profile (refer to Fig. 5), except that the timer value is newly set at $T$ in both the terminal and service profiles.

Fig. 7 shows an incoming call scenario for $U_A$ in state 2. As the incall registration information for $U_A$ was deleted from $T_a$’s terminal profile, $U_A$’s service profile sends an incall registration update request message, including $U_A$’s
UPT number and the incall registration time for $T_a$, to the terminal profile through the SCP and SSP$_1$ in order to restore the incall registration information for $U_A$ (Step 2). The service profile receives an incall registration update completion message from the terminal profile (Step 3). The subsequent procedures are then the same as for the incoming call scenario in state 1.

An incoming call scenario for $U_A$ in state 3 is the same as for scheme I when the incoming call registration for $U_A$ is reset by the owner of $T_a$ (refer to Steps 5–9 in Fig. 4).

Fig. 8 shows an incoming call scenario for $U_A$ in state 4. In this case, on receiving an incall registration update request message, the terminal profile determines if the incall registration for $U_A$ is valid, then informs the $U_A$’s service profile of the result (Step 3). As the incall registration for $U_A$ is not valid in state 4, the following procedures on the incoming call request are different as the information within the $U_A$’s service profile. If there is no incall terminal registered as default, the incoming call request is rejected (Steps 4 and 7). However, if $U_A$ registered an incall on $T_c$ attached to SSP$_3$ as default, the incoming call request is delivered to $T_c$ (Steps 4–7).

4. Performance analysis

4.1. Request-based scheme

In order to evaluate the performance of the request-based scheme, the following assumptions are made:

- incoming call arrivals for a UPT user occur according to a Poisson process with parameter $\mu$;
- incall registration requests for a terminal occur according to a Poisson process with parameter $\gamma$;
- a terminal owner resets all incall registration for the terminal at time $t = 0$ [4];
- there is no reset request during $(0,t)$, where $t$ is the time instant of reset for incall registration.

It is also assumed that the incoming call arrival process, the incall registration/deregistration request process, and the reset request process of incall registration are mutually independent. The following notations are made:

- $t_{\text{reg}}$: time instant of an incall registration request
- $G$: incall registration duration for a UPT user
- $V_{\text{eff}}$: effective incall registration duration for a UPT user
- $N(t)$: number of UPT users registered for incalls on a terminal at time $t$
- $X(t)$: number of incall registration requests during $(0,t)$
- $Y(t)$: number of incall deregistration requests during $(0,t)$
- $M(t)$: number of incoming call arrivals until time $t$ for a UPT user who registered an incall at time $x$, $0 < x < t$
- $L(t)$: number of incoming call arrivals from time $t$ to the time instant of an associated incall deregistration request for a UPT user who registered an incall at time $x$, $0 < x < t$

Then, $N(t)$ is the system size of an $M/G/\infty$ queuing system [19] where the incall registration duration time is represented as the generally distributed service time.
number of UPT users registered for incalls on a terminal at time \( t \) is given by
\[
E\{N(t)\} = \gamma q(t)t, \tag{1}
\]
where
\[
q(t) = \int_{0}^{t} \Pr\{G \geq t - t_{\text{reg}} | t_{\text{reg}} = x\} \frac{1}{t} \, dx. \tag{2}
\]
The mean numbers of incall registration and deregistration during \((0, t]\) are given by
\[
E\{X(t)\} = \gamma t.
\tag{3}
\]
\[
E\{Y(t)\} = \gamma (1 - q(t))t.
\tag{4}
\]
Let \( W \) and \( f_{W}(w) \) denote the time between two successive reset requests and its probability density function, respectively. Eliminating the condition of the reset request time \( t \) in Eq. (1), the mean number of UPT users registered for incalls on a terminal at the epoch of the next reset request is obtained as
\[
E\{E\{N(W)|W\}\} = \int_{0}^{\infty} \gamma q(t)f_{W}(t) \, dt. \tag{5}
\]
Eliminating the condition of the reset request time \( t \) in Eqs. (3) and (4), the mean numbers of incall registration and deregistration requests between two successive incall registration reset requests for a terminal are given by
\[
E\{E\{X(W)|W\}\} = \int_{0}^{\infty} \gamma f_{W}(t) \, dt, \tag{6}
\]
\[
E\{E\{Y(W)|W\}\} = \int_{0}^{\infty} \gamma (1 - q(t))f_{W}(t) \, dt. \tag{7}
\]
To find the number of incoming call arrivals between two successive incall registration reset requests, an effective incall registration duration, \( V_{\text{eff}}(t, x) \), is defined at time \( t \) for a UPT user, who requested incall registration on a terminal at time \( x \), as follows:
\[
V_{\text{eff}}(t, x) = \begin{cases} 
t - x, & \text{if } t - x < G, \\
G, & \text{if } t - x \geq G. 
\end{cases} \tag{8}
\]
The probability density function of \( V_{\text{eff}}(t, x) \) is given by
\[
\rho V_{\text{eff}}(y; t, x) = f_{G}(y)U(-y + t - x) \\
+ \delta(y - t + x) \int_{-x}^{\infty} f_{G}(u) \, du, \tag{9}
\]
where \( f_{G}(\cdot), U(\cdot) \), and \( \delta(\cdot) \) denote the probability density function of incall registration duration, a unit step function, and a unit delta function, respectively. The mean number of incoming call arrivals until time \( t \) for a user, who registered an incall on a terminal at time \( x \), is given by
\[
E\{M(t)\} = \int_{0}^{\infty} \mu y \int_{0}^{t} \frac{1}{t} \rho V_{\text{eff}}(y; t, x) \, dx \, dy. \tag{10}
\]
The mean number of incoming call arrivals between two successive incall registration reset requests for all users registered on the terminal is obtained as
\[
E[E\{M(W)X(W) | W\}] = \int_{0}^{\infty} E\{M(t)\} \gamma f_{W}(t) \, dt. \tag{11}
\]
The mean number of incoming call arrivals for all users who registered on a terminal after reset for the incall registration is obtained as
\[
E[E\{L(W)X(W) | W\}] = \mu E[G]E\{X(W) | W\} \\
- E[E\{M(W)X(W) | W\}]. \tag{12}
\]
In order to construct a cost function that is associated with transport and intelligent node elements, with the signaling network, and with the signaling and transport networks, the following notations are made:
\[
C_{U} \quad \text{cost for a query or for updating a UPT user service profile}
\]
\[
C_{T} \quad \text{cost for a query or for updating a terminal profile}
\]
\[
C_{\text{SCP}} \quad \text{cost for handling a message at the SCP}
\]
\[
C_{\text{SSP}} \quad \text{cost for handling a message at the SSP}
\]
\[
C_{\text{sig}} \quad \text{cost for transferring a signaling message between the SSP and the SCP through a signaling network}
\]
\[
C_{\text{sig-trans}} \quad \text{cost for transferring a signaling message related with a connection setup between two SSPs through the signaling and transport networks}
\]
Referring to Figs. 3–5, the following costs are considered:
\[
h_{\text{reg}}^{1} \quad \text{cost for an incall registration request}
\]
\[
h_{\text{reg}}^{1}\text{dereg-req-explicit} \quad \text{cost for an explicit incall deregistration request when its associated incall registration has not been reset.}
\]
\[
h_{\text{reg}}^{1}\text{dereg-req-incall} \quad \text{cost for an incall deregistration request due to incall registration when its associated incall registration has not been reset.}
\]
\[
h_{\text{reg}}^{1}\text{dereg-req-explicit} \quad \text{cost for an explicit incall deregistration request when its associated incall registration has been reset.}
\]
\[
h_{\text{reg}}^{1}\text{dereg-cost-incall} \quad \text{cost for an incall deregistration request due to incall registration when its associated incall registration has been reset.}
\]
\[
h_{\text{reg}}^{1}\text{dereg-cost-explicit} \quad \text{cost for an explicit incall deregistration request when its associated incall registration has been reset.}
\]
\[
h_{\text{reg}}^{1}\text{cost} \quad \text{cost for updating information in a terminal profile due to an incall registration reset request.}
\]
\[
h_{\text{reg}}^{1}\text{cost-explicit} \quad \text{cost for updating information in a service profile due to an incall registration reset request.}
\]
\[
h_{\text{neg-req}}^{1}\text{cost} \quad \text{cost for an incoming UPT call request when its associated incall registration has not been reset.}
\]
\[
h_{\text{neg-req-explicit}}^{1}\text{cost} \quad \text{cost for a rejected incoming UPT call when}
its associated incall registration has been reset.

\( h_{\text{incoming post-reset def}} \) cost for an incoming UPT call delivered to a terminal, which is set as default, when its associated incall registration has been reset. These cost parameters can be written as

\[
\begin{align*}
    h_{\text{reg}}^1 & = C_U + C_T + 4C_{\text{SCP}} + 4C_{\text{SSP}} + 4C_{\text{sig}}, \\
    h_{\text{dereg post-reset incall}} & = C_U + C_T + 2C_{\text{SCP}} + 2C_{\text{SSP}} + 2C_{\text{sig}}, \\
    h_{\text{dereg post-reset explicit}} & = C_U + 2C_{\text{SCP}} + 2C_{\text{SSP}} + 2C_{\text{sig}}, \\
    h_{\text{reset}} & = C_T + 2C_{\text{SSP}}, \\
    h_{\text{incoming post-reset explicit}} & = C_U + 2C_{\text{SCP}} + 5C_{\text{SSP}} + 2C_{\text{sig}} + 2C_{\text{sig-trans}}.
\end{align*}
\]

Consequently, for Scheme I, the total cost per reset is given by

\[
C_I = h_{\text{reg}}E[X(W)[W] + \left( P_{\text{explicit}}h_{\text{dereg post-reset explicit}} + P_{\text{dereg post-reset incall}} \right)E[Y(W)[W] + \left( P_{\text{explicit}}h_{\text{dereg post-reset explicit}} + h_{\text{reset}} \right)E[N(W)[W] + h_{\text{reset}} + h_{\text{incoming post-reset}}E[M(W)X(W)[W] + \left( P_{\text{rej}}h_{\text{incoming post-reset def}} + P_{\text{def}}h_{\text{incoming post-reset def}} \right)E[L(W)X(W)[W]],
\]

where \( P_{\text{explicit}} \) and \( P_{\text{dereg}} \) denote the probabilities that incall registration is cancelled due to an explicit incall deregistration request and a new incall registration request, respectively, and \( P_{\text{rej}} \) and \( P_{\text{def}} \) denote the probabilities that an
incoming call is rejected and delivered to another terminal set as default, respectively.

4.2. Timer-based scheme

A user who registered an incall on a terminal at time $x$ is said to be in the on state at time $t$ if the information is stored in the terminal profile because the timer does not expire, and to be in the off state at time $t$ if the information was deleted from the terminal profile due to the timer expiration. The following notations are made:

- $V$: virtual incall registration duration for a UPT user
- $N_{on}(t)$: number of users staying in the on state at time $t$
- $N_{off}(t)$: number of users staying in the off state at time $t$
- $R(t)$: number of incoming call arrivals for a UPT user who is in state 2, until time $t$

A virtual deregistration time is defined as \{a timer value $T$ the time of the last incoming UPT call arrival for a UPT user before the incall is deregistered from the registered incall terminal\}. A user whose virtual deregistration time is greater than the current time is said to be virtually registered. The virtual incall registration duration is also defined as \{the virtual deregistration time—the incall registration request time\}, as shown in Fig. 9.

The probability $P_{on}(t)$ that a UPT user who requested incall registration on a terminal at time $x$ is virtually registered on that terminal and is in the on state at time $t$ is given by

$$P_{on}(t) = \Pr\{V \geq t - t_{reg} \text{ and on state} | t_{reg} = x\} = \Phi_{on}(t - x)(1 - B_V(t - x)),$$  \hspace{1cm} (14)

where $B_V(t)$ is the cumulative distribution function of a virtual incall registration duration in the terminal profiles (refer to Appendix A). Note that $\Phi_{on}(t - x)$ is the probability that a user is in the on state given that the user initially registered at time $x$ and that the virtual deregistration time is greater than $t$ (refer to Appendix B).

The probability $P_{off}(t)$ that a UPT user who requested incall registration on a terminal at time $x$ is virtually registered on that terminal and is in the off state at time $t$ is given by

$$P_{off}(t) = \Phi_{off}(t - x)(1 - B_V(t - x)),$$  \hspace{1cm} (15)

where $\Phi_{off}(t - x)$ is $1 - \Phi_{on}(t - x)$ (refer to Appendix B).

Eliminating the condition of the incall registration request time $x$ in Eqs. (14) and (15), the probabilities that a UPT user who is virtually registered in the terminal profile is in the on state and in the off state are obtained as

$$q_{on}(t) = \int_{0}^{t} [1 - B_V(t - x)]\Phi_{on}(t - x) \frac{1}{t} \mathrm{d}x,$$  \hspace{1cm} (16)

$$q_{off}(t) = \int_{0}^{t} [1 - B_V(t - x)]\Phi_{off}(t - x) \frac{1}{t} \mathrm{d}x.$$  \hspace{1cm} (17)

Then, the mean numbers of users in the on and off states at

![Fig. 10. $R_{\text{sig}}$ for varying the timer value $T$ ($\mu = 1/3600 \text{ s}^{-1}$, $\gamma = 1/36,000 \text{ s}^{-1}$, and $1/\alpha = 24 \text{ h}$).](image-url)
the epoch of the next reset request are obtained as

\begin{equation}
E[N^\text{on}(W)|W]] = \int_0^{\infty} \gamma q^\text{on}(t) f_W(t) \, dt,
\end{equation}

\begin{equation}
E[N^\text{off}(W)|W]] = \int_0^{\infty} \gamma q^\text{off}(t) f_W(t) \, dt.
\end{equation}

Under the condition that the number of incoming call arrivals for a UPT user in state 2 who registered for an incall on a terminal at time \( x \) is \( h^\text{II} \) during his effective call registration duration \( (\nu^\text{eff}) \), the \( n \) arrivals of \( S^1, \ldots, S_n \) have the same distribution as the order statistics corresponding to \( n \) independent random variables uniformly distributed on the interval \((x, x + \nu^\text{eff})\) \[20\]. The conditional density of \( S_k \) and \( S_{k-1} \) under the above condition \((2 \leq k \leq n)\) is obtained as

\begin{equation}
f(s_{k-1}, s_k) = \frac{n!}{\nu^\text{eff}} \frac{(s_k - x)^{k-2} ((x + \nu^\text{eff}) - s_k)^{n-k}}{(k-2)! (n-k)!},
\end{equation}

\( x < s_{k-1} < s_k < x + \nu^\text{eff} \leq t \).

The mean number of incoming call arrivals for the UPT user at time \( t \) is given by

\begin{equation}
E[R(t)] = \int_0^t \int_0^t \left[ \sum_{n=2}^{\infty} \text{Pr}(S_1 > T) \sum_{k=2}^{n} \text{Pr}(Z_k > T) \right]
\times \left( \frac{\nu^\text{eff}}{n!} \right)^n \exp(-n\nu^\text{eff}) f^\nu^\text{eff}(\nu^\text{eff}; t, x) \, dx \, d\nu^\text{eff}
+ \int_0^t \int_0^t \frac{1}{t} \text{Pr}(S_1 > T)
\times \nu^\text{eff} \exp(-\nu^\text{eff}) f^\nu^\text{eff}(\nu^\text{eff}; t, x) \, dx \, d\nu^\text{eff},
\end{equation}

where \( Z_k = S_k - S_{k-1}(2 \leq k \leq n) \).

The mean number of incoming call arrivals for all users who are in state 2 between two successive incall registration reset requests is obtained as

\begin{equation}
E[E[R(W)X(W)|W]] = \int_0^{\infty} E[R(t)] \gamma f_W(t) \, dt.
\end{equation}

When a UPT user requests an incall registration, the cost, \( h^\text{II}\text{reg} \), for managing information in the terminal and service profiles is the same as for Scheme I. In contrast, when a UPT user requests, respectively, explicit incall deregistration and a new incall registration, the costs, \( h^\text{II}\text{dereg}\text{explicit} \) and \( h^\text{II}\text{dereg}\text{incall} \), for managing the information are given by

\( h^\text{II}\text{dereg}\text{explicit} = C_U + 2C_{\text{SCP}} + 2C_{\text{SSP}} + 2C_{\text{sig}} \)
\( h^\text{II}\text{dereg}\text{incall} = 0 \)

because it is not necessary to access the terminal profile. The cost for managing information within the terminal and service profiles is considered here when an incall registration reset is requested by a terminal owner. If the user is in the on state, the costs \( h^\text{II}\text{reset}_t \) and \( h^\text{II}\text{reset}_u \) are the same as for \( h^\text{I}\text{reset}_t \) and \( h^\text{I}\text{reset}_u \) in Scheme I, respectively. In the off state \( h^\text{I}\text{reset}_t \) and \( h^\text{I}\text{reset}_u \) are equal to \( h^\text{I}\text{reset}_t \) and \( h^\text{I}\text{reset}_u \), respectively, because there is no information in the terminal profile.

Incoming calls for UPT users who registered incalls on the terminal require different costs for network states, as described in Section 3. The costs for incoming calls in states 1–4 are, respectively, given by

\( h^\text{II}\text{incoming}_1 = C_U + C_T + 5C_{\text{SCP}} + 2C_{\text{sig}} + 2C_{\text{sig-trans}} \)
\( h^\text{II}\text{incoming}_2 = 2C_U + 2C_T + 7C_{\text{SCP}} + 4C_{\text{SCP}} + 4C_{\text{sig}} + 2C_{\text{sig-trans}} \)
\( h^\text{II}\text{incoming}_3 = h^\text{II}\text{incoming}_4 = h^\text{I}\text{incoming}_\text{reset} \)
\( h^\text{II}\text{incoming}_4 = 2C_U + C_T + 7C_{\text{SCP}} + 4C_{\text{SCP}} + 4C_{\text{sig}} + 2C_{\text{sig-trans}} \)

Consequently, the total cost per reset for Scheme II is given by

\( C^\text{II} = (h^\text{I}\text{reset}_t + P_{\text{def}} h^\text{I}\text{dereg}\text{incall} \text{E}[E[X(W)|W]])
+ h^\text{I}\text{reset}_u \text{E}[E[N^\text{on}(W)|W]] + h^\text{I}\text{reset}_u \)
+ h^\text{II}\text{incoming}_1 \text{E}[E[M(W)X(W) - R(W)X(W)SW]]
+ h^\text{II}\text{incoming}_2 \text{E}[E[R(W)X(W)|W]] + (P_{\text{reg}} h^\text{II}\text{incoming}_u + P_{\text{def}} h^\text{II}\text{dereg}\text{incall} \text{E}[E[N^\text{off}(W)|W]])
+ (P_{\text{reg}} h^\text{II}\text{incoming}_u + P_{\text{def}} h^\text{II}\text{dereg}\text{incall} \text{E}[E[N^\text{off}(W)|W]]).
\)

\section{4.3. Performance measures}

Given values of cost parameters \( C_U, C_T, C_{\text{SCP}}, C_{\text{SSP}}, C_{\text{sig}}, \) and \( C_{\text{sig-trans}} \), the total costs \( C_1 \) and \( C^\text{II} \) per reset for Schemes I and II are obtained from Eqs. (13) and (23), respectively. However, it is difficult to determine the values of cost parameters because the values of cost parameters may vary according to different UPT network architectures. The performance of the two schemes is different according to how to determine the values of cost parameters. In this study, the performance of the two schemes is compared in terms of the number of signaling messages transferred between an SSP and an SCP per incall registration reset for a terminal. For \( C_{\text{sig}} = 1, C_U = 0, C_T = 0, C_{\text{SCP}} = 0, C_{\text{SSP}} = 0, \) and \( C_{\text{sig-trans}} = 0 \), the numbers of signaling messages transferred between the SSP and the SCP for...
Schemes I and II can be obtained using Eqs. (13) and (23), respectively.

It is assumed that both the incall registration duration for a UPT user and the interarrival time between incall registration reset requests for a terminal owner follow exponential distributions with parameters $\lambda$ and $a$, respectively. The numbers of signaling messages per reset, $N_{\text{sig}}^I$ and $N_{\text{sig}}^{\text{II}}$, for Schemes I and II are obtained as follows:

$$N_{\text{sig}}^I = 4 \frac{\gamma}{a} + (P_{\text{explicit}}^I + P_{\text{incall}}^I) \frac{\gamma \lambda}{a(\lambda + a)} + (P_{\text{explicit}}^I + 2 + P_{\text{incall}}^I) \frac{\gamma}{\lambda + a} + 2 \frac{\gamma \mu}{\lambda(\lambda + a)} + 2 \frac{\gamma \mu}{a(\lambda + a)}.$$  \hspace{1cm} (24)

$$N_{\text{sig}}^{\text{II}} = (4 + P_{\text{explicit}}^I) \frac{\gamma}{a} + 2 \frac{\gamma \mu[1 - \exp(-aT)]}{a(\lambda + a)} + 4 \frac{\gamma \mu \exp(-aT)}{a(\lambda + a)} + 2 \frac{\gamma \mu}{a(\lambda + a)} + 2 \frac{\gamma \mu}{\lambda(\lambda + a)}.$$ \hspace{1cm} (25)

5. Numerical evaluations

To compare the performance of Schemes I and II the relative ratio of the numbers of signaling messages, $R_{\text{sig}} = \frac{N_{\text{sig}}^{\text{II}}}{N_{\text{sig}}^I}$, is introduced. From Eqs. (24) and (25), both $N_{\text{sig}}^I$ and $N_{\text{sig}}^{\text{II}}$ depend on the value of $P_{\text{explicit}}$ ($P_{\text{incall}} = 1 - P_{\text{explicit}}$). As a general tendency on $R_{\text{sig}}$, it does not change as the value of $P_{\text{explicit}}$ varies, it is here assumed $P_{\text{explicit}} = 1$.

When $\mu = 1/3600$ s$^{-1}$, $\gamma = 1/36,000$ s$^{-1}$, and $a = 1/24$ h, Fig. 10 shows $R_{\text{sig}}$ for varying the timer value $T$. $R_{\text{sig}}$ becomes larger in an ascending order of incall registration duration for all values of $T$ because the mean numbers of users in the on and off states for Scheme II and the mean number of incoming calls for an effective incall registration duration increase as incall registration duration increases for a fixed value of $T$. The value of $T$ which minimizes $R_{\text{sig}}$ also increases as the incall registration duration increases. When incall registration durations are 1, 2, 4, and 24 h, the minimum $R_{\text{sig}}$ values are 0.82, 0.86, 0.91, and 0.99, respectively. When the incall registration duration is 24 h $R_{\text{sig}}$ is nearly equal to or larger than 1 for all values of $T$.

In order to determine the value of $T$ which minimizes $R_{\text{sig}}$, the behaviors of UPT users and terminal owners must be characterized. The value of $T$ is set for all users and terminal owners and the fixed value of $T$ is determined by considering the general characteristics of UPT users and terminal owners. Suppose that the values of $\lambda$ and $\mu$ for users are 1/4 and 1 h$^{-1}$, respectively, a value of $a$ for terminal owners is 1/24 h$^{-1}$, and a value of $T$ which minimizes $R_{\text{sig}}$ is 3.83 h$^{-1}$. For $\mu = 1/3600$ s$^{-1}$, $\gamma = 1/36,000$ s$^{-1}$, and $T = 3.83$ h$^{-1}$, Fig. 11 shows $R_{\text{sig}}$ for varying the interarrival time between
incall registration reset requests. $R_{\text{sig}}$ decreases as the interarrival time between incall registration reset requests increases because the portion of the mean number of signaling messages due to incoming call deliveries in state 2 decreases in Scheme II. When the interarrival time between incall registration reset requests is 1 day and incall registration durations are 1, 4, 9, and 48 h, $R_{\text{sig}}$ values are approximately 0.83, 0.91, 0.96, and 1.0, respectively. When incall registration duration is 48 h the mean number of signaling messages for Scheme II is equal to or larger than for Scheme I for all values of interarrival time between incall registration reset requests.

For $\gamma = 1/36,000$ s$^{-1}$, $\lambda = 1/4/3600$ s$^{-1}$, and $T = 3.83$ h, Fig. 12 shows $R_{\text{sig}}$ for varying the interarrival time between incall registration reset requests. The results show that $R_{\text{sig}}$ decreases as the interarrival time between incall registration reset requests increases. $R_{\text{sig}}$ becomes larger in an ascending order of incoming call arrival rates because the mean number of signaling messages for UPT users in state 2 decreases as $\mu$ decreases. When the interarrival time between incall registration reset requests is 1 day and incoming call arrival rates are 0.5, 1, 2, and 5 h$^{-1}$, $R_{\text{sig}}$ values are approximately 0.88, 0.91, 0.93, and 0.96, respectively.

6. Conclusions

A request-based scheme and a timer-based scheme are proposed for managing information related to incall registration in UPT user service and terminal profiles. In the request-based scheme when an incall registration is requested by a UPT user the request message is transferred to the terminal profile to update the information related to incall registration of the UPT user in the terminal profile. In the timer-based scheme the information related to incall registration in the terminal profile is updated by every incall registration and by every incoming call delivery request. The information is deleted from the terminal profile if no incoming UPT calls arrive at the terminal registered for a duration $T$ after the request of an incall registration or after the last arrival of an incoming UPT call. Information updating algorithms in the request-based scheme are simpler than in the timer-based scheme. From the results in Section 5, general tendencies on $R_{\text{sig}}$ are summarized as follows:

- The value of $R_{\text{sig}}$ does not change as the value of incall registration request rate ($\gamma$) varies.
- The value of $R_{\text{sig}}$ increases as the value of incall registration duration ($1/\lambda$) increases.
- The value of $R_{\text{sig}}$ increase as the value of incoming call arrival rate ($\mu$) increases.
- The value of $R_{\text{sig}}$ decreases as the value of interarrival time between incall registration reset requests ($1/a$) increases.

The fixed value of parameter $T$ can be determined by considering the general characteristics of UPT users and terminal owners. For values of parameters $a$, $\mu$, $\lambda$, and $\gamma$ equal to $1/24$, $1/4$, and $1/10$ h$^{-1}$, respectively, the value of $T$ is approximately 3.83 h. If a UPT user with $\mu = 1$ and $\lambda = 1/4$ h$^{-1}$ uses a terminal whose owner has $a = 1/24$ h$^{-1}$, the timer-based scheme reduces the mean number of signaling messages required between two successive reset events by 9% compared to the request-based scheme. If the
parameter value $a$ for terminal owners is changed from 1/24 to 1/120 h$^{-1}$, the timer-based scheme reduces the mean number of signaling messages required between two successive reset events by 12%. However, for $\mu = 1$ h$^{-1}$, $\lambda = 1/48$ h$^{-1}$, and $a = 1/24$ h$^{-1}$, the mean number of signaling messages in the timer-based scheme is equal to in the request-based scheme.

Appendix A

The following notations are made:

- $G$: incall registration duration for a UPT user
- $S_n$: time between an incall registration request and the $n$th incoming call arrival
- $J$: number of incoming calls during an incall registration duration
- $V$: virtual incall registration duration in the terminal profile

If $V = S_n + T$, the cumulative distribution function of $V$ is given by

$$B_V(v) = \int_0^v f_{S_n}(v - T) \, dv.$$  \hfill (A4)

Appendix B

It is assumed that incoming call arrivals follow a Poisson process with parameter $\mu$ and that the timer value $T$ is fixed for all users. It is also assumed that a UPT user requests an incall registration for a terminal at time $x$, and that the UPT user is still registered for the terminal at time $t$.

When $t - x < T$, the probability that the UPT user is in the on state at time $t = 1$ because the timer has not expired. However, if $t - x \geq T$, the probability is the same as the probability that the number of customers in an M/D/$\infty$ queuing system is greater than or equal to 1. Thus, the probabilities that a UPT user is in the on and off states is given by

$$\Phi_{on}(t - x) = \begin{cases} 
1, & \text{for } t - x < T, \\
1 - \exp(-\mu q_1(t - x)(t - x)), & \text{for } t - x \geq T,
\end{cases}$$  \hfill (B1)

where

$$q_1(t - x) = \int_x^T [1 - B_{q_2}(t - w)] \frac{1}{t - x} \, dw = \frac{T}{t - x}.$$  

$$\Phi_{off}(t - x) = \begin{cases} 
0, & \text{for } t - x < T, \\
\exp(-\mu q_1(t - x)(t - x)), & \text{for } t - x \geq T.
\end{cases}$$  \hfill (B2)

References

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