Dynamic Periodic Location Area Update in Mobile Networks

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***Abstract*—In mobile communications networks, periodic location area update (PLAU) is utilized to detect the presence of a mobile station (MS). In 3GPP Technical Specifications 23.012 and 24.008, a fixed PLAU scheme was proposed for the Universal Mobile Telecommunications System (UMTS), where the interval between two PLAUs is of fixed length. We observe that MS presence can also be detected through call activities and normal location area update (NLAU). Therefore, we propose a dynamic PLAU scheme where the PLAU interval is dynamically adjusted based on the call traffic and NLAU rate. An analytic model is developed to investigate the performance of dynamic and fixed PLAU schemes. This paper provides guidelines to select parameters for dynamic PLAU.**

***Index Terms*—Mobile communications network, mobility management, periodic location area update, Universal Mobile Telecommunications System (UMTS).**

I. Introduction

MOBILE communications networks have been evolved from the second generation (e.g., GSM) to the 2.5 generation (e.g., GPRS) and then to the third generation [e.g., Universal Mobile Telecommunications System (UMTS)] [7]. In this evolution, the concept of mobility management has remained the same. Consider the circuit-switched domain of UMTS [1], [2]. In order to track the mobile stations (MSs), the cells (the radio coverages of base stations) in UMTS service area are grouped into several location areas (LAs). To deliver services to an MS, the cells in the group covering the MS will page the MS to establish the radio link. To identify the LA of an MS, mobility management is required. In mobility management, the MS informs the network of its location through the LA update procedure. The update procedure is executed in two situations.

1) *Normal location area update* (NLAU) is performed when the location of an MS has been changed. Location change of an MS is detected as follows. The cells continuously broadcast their cell identities. The MS periodically listens to the broadcast cell identity and compares it with the cell identity stored in the MS's buffer. If the comparison indicates that the location area has been changed, then the MS sends the location area update message to the network.
2) *Periodic location area update* (PLAU) allows an MS to periodically report its "presence" to the network even if the MS does not move. A *periodic LA update timer* (PLAU timer or T3212 in [2]) is maintained in the MS. Corresponding to the PLAU timer, an *implicit detach* (ID) timer is maintained in the network. When the PLAU timer expires, the MS performs PLAU.

NLAU has been intensively investigated in the literature (see [3] and [7] and the references therein). Most studies on PLAU focused on mobility database failure restoration [4], [6]. However, a major purpose of PLAU is to allow the network to detect if an MS is still attached to the network in the normal network operation situation (i.e., the mobility databases do not fail). To our knowledge, this aspect has not been investigated in the literature. An important issue for PLAU is the selection of the period t_p for the PLAU/ID timers. In 3GPP TS 23.012 [1] and TS 24.008 [2], the t_p value is set/changed by the network and broadcast to every MS in the LA through the L3-RRC SYSTEM INFORMATION BLOCK 1 message on the broadcast control channel (BCCH). In this approach, the t_p value is the same for all MSs in an LA. There are two issues regarding this *fixed PLAU* scheme.

1) How is the t_p value determined when an MS first enters an LA?
2) Is it appropriate to have a fixed t_p value during the MS's stay in an LA?

This paper addresses the above two issues. As we will discuss in Section II, the t_p value should be selected based on the call and movement activities of the MS. Therefore, we propose a dynamic PLAU scheme in this paper. We investigate the performance of this scheme and compare it with the fixed PLAU scheme. Our study provides guidelines to select parameters for dynamic PLAU.

II. Dynamic PLAU Scheme

Before we describe our solution for PLAU, we first introduces the concept of *attach*. In UMTS, the attach procedure allows an MS to be "known" by the network. For example, after the MS is powered on, the attach procedure must be executed before the MS can obtain access to the UMTS services. In a mobile communications network, four events can be utilized by the network to detect the presence of an MS attached to the network:

1) MS call origination (the MS makes an outgoing call);
2) MS call termination (the MS receives an incoming call);
3) PLAU;
4) NLAU.

Note that we consider NLAU as the fourth event although the main purpose of NLAU is to detect the movement of an MS.

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When an MS is *detached* (disconnected) from the network due to abnormal reasons (e.g., battery removal, subscriber moving out of the service area, and so on), the MS will not originate a call. The network detects abnormal MS detach in one of the following two cases.

Case 1) The next PLAU occurs before the arrival of the next MS call termination. In this case, the network detects expiration of the ID timer and considers the MS detached. The next MS call terminations will not be delivered.

Case 2) The next MS call termination occurs before the ID timer expires. In this case, the network attempts to deliver the next incoming call to the MS but fails. After failure of the call setup, the network considers that the MS is detached and will disable future MS call terminations and PLAU timer.

In the call termination procedure, the network resources (trunks and so on) are reserved. In Case 2), these network resources are not released until the network detects that call setup fails. In other words, failed call setup wastes network resources, which should be avoided. To reduce the possibility of Case 2), one may shorten the interval t_p of PLAU. On the other hand, short t_p may result in large network signaling overhead. Therefore, t_p should be carefully selected. A perfect PLAU mechanism will satisfy the following criteria.

Criterion 1: When the MS is attached, the presence of the MS is detected through call activities (either incoming or outgoing) or NLAUs, and PLAU is never performed.

Criterion 2: When the MS is abnormally detached, the network detects the situation through a periodic update mechanism [i.e., Case 1) holds], and failure call setup [i.e., Case 2)] never occurs.

If Criterion 1 is satisfied, the PLAU cost is zero when the MS is attached. If Criterion 2 is satisfied, then the network resources will not be wasted due to call setup failure. We show how to select the t_p value with attempt to satisfy both Criteria 1 and 2. Suppose that the outgoing (MS originated) call arrival rate plus the NLAU rate to an MS is μ_o and the incoming (MS terminated) call arrival rate is μ_i. Then the net arrival rate is $\mu = \mu_o + \mu_i$. Let

$$\alpha = \frac{\mu_i}{\mu} = \frac{\mu_i}{\mu_i + \mu_o}.$$

Statistics from mobile operators [7] indicate that 40% of the call activities are incoming calls to an MS. Therefore, $\alpha < 0.4$ can be observed in a typical mobile network. When the MS is attached to the network, we expect to see a call (either incoming or outgoing) or an NLAU for every $1/\mu$ interval. If we select $t_p = c/\mu$ (where $c > 1$) and after every call arrival t_p is reset to c/μ, then there is a good chance that Criterion 1 is satisfied. Consider the example in Fig. 1(a) where calls or NLAUs arrive at τ_1, τ_2, and τ_3. For discussion purposes, we define *presence checkpoint* or *checkpoint* as the action to inform the network of the status of an MS (whether the MS is attached or not). We also define *checkpoint event* as an incoming call, an outgoing call, or an NLAU. Such an event results in checkpoint action. When the MS is attached, a checkpoint is triggered by an checkpoint event or PLAU. When the MS is abnormally detached, a checkpoint is triggered by expiration of ID timer or failure setup for MS call termination. In Fig. 1(a), a checkpoint occurs at τ_1 and the PLAU timer is reset to t_p (i.e., the next PLAU is expected to occur at time $\tau_1 + t_p$). If t_p is sufficiently large so that $\tau_2 \leq \tau_1 + t_p$, then the next checkpoint occurs at τ_2 and the PLAU timer is reset to t_p again. In this scenario, the PLAU is never performed and all checkpoints are triggered by call arrivals or NLAUs. If we select t_p so that

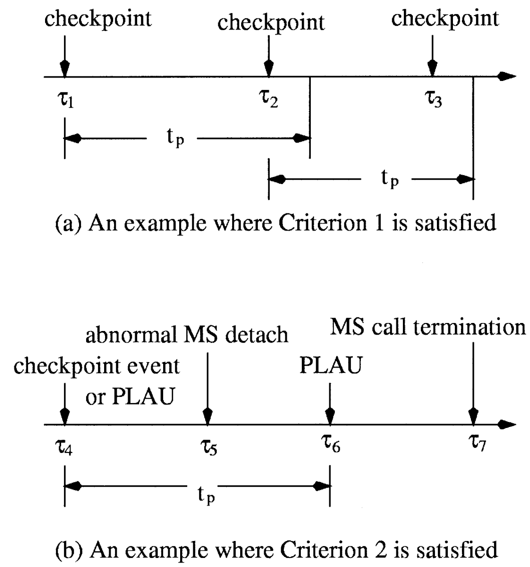

Fig. 1. Examples where Criteria 1 and 2 are satisfied.

$$t_p = \frac{c}{\mu} \geq \frac{1}{\mu} \tag{1}$$

then there is good opportunity that Criterion 1 is satisfied. However, if t_p is too large, Criterion 2 is likely to be violated.

Fig. 1(b) illustrates a scenario when Criterion 2 is satisfied. In this figure, the MS is abnormally detached between two checkpoints. The previous checkpoint occurs at τ_4. The abnormal MS detach occurs at $\tau_5 > \tau_4$. After MS detach, the next PLAU occurs at $\tau_6 = \tau_4 + t_p$. The next call termination occurs at τ_7. If $\tau_7 > \tau_6$, then the PLAU timer expires before the next call termination arrives, and Criterion 2 is satisfied. Since the MS call termination rate is μ_i, to have a good chance to satisfy Criterion 2, we suggest that c is selected such that

$$t_p = \frac{c}{\mu} \leq \frac{1}{\mu_i} = \frac{1}{\alpha\mu}. \tag{2}$$

From (1) and (2), if $\mu_o \geq 0$, it seems appropriate to select c so that

$$1 \leq c \leq \frac{1}{\alpha}. \tag{3}$$

Based on the above discussion, we propose a dynamic PLAU scheme that dynamically selects t_p according to the call and NLAU activities of an MS.

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Dynamic PLAU Scheme
Step 0. Initially a default t_p value is
given.
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Step 1. When a checkpoint event arrives,
the following steps are executed in the
network, specifically, the visitor loca-
tion register (VLR) [7]:
Step 1.1. The interval t_1 between this
checkpoint event and the previous check-
point event is computed and stored in
storage. The network stores the m most
recent intercheckpoint event arrival time
samples.
Step 1.2. The α statistics are updated.
Step 1.3. Let t_j be the intercheckpoint
event arrival time between the jth pre-
vious checkpoint event and the j+1st pre-
vious checkpoint event. The value t_p is
computed as
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$$t_p = c\left(\frac{t_1+t_2+\cdots+t_m}{m}\right) \tag{4}$$

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where c is selected following the guide-
line (3).
Step 1.4. The ID timer in the network is
reset with the value t_p. The MS is in-
formed to reset its PLAU timer.
Step 2. When the network receives the PLAU
message from the MS, the ID timer is reset
with the previously selected t_p.
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In the *fixed PLAU* scheme proposed in 3GPP TS 23.012 and TS 24.008, Step 2 is always executed, and Step 1 is never executed. Also note that in the dynamic PLAU, the MS is informed to reset its PLAU timer by the network. In the standard GSM/UMTS procedures, when an MS requests for call origination, NLAU, or PLAU, the network always acknowledges the request. The new t_p value is included in GSM/UMTS acknowledgment messages issued by the network. In call termination, the network includes the new t_p value in the call setup message. Therefore, no extra signaling messages are introduced by the dynamic PLAU scheme at the cost that the acknowledgment and call setup messages are slightly modified. Note that in 3GPP TS 24.008, the t_p value is broadcast to all MSs through the L3-RRC SYSTEM INFORMATION BLOCK 1 message on the BCCH, which cannot be used in our approach.

In a real GSM/UMTS network, the dynamic PLAU scheme can be implemented in the VLR as a microprocedure. This implementation can be vendor specific, which does not change any GSM/UMTS message flows. The message flows between the VLR and the MS follow the standard GSM/UMTS procedures.

III. Analytic Modeling

This section investigates the performance of dynamic PLAU and compares it with fixed PLAU proposed in 3GPP TS 23.012 and TS 24.008. Two performance measures are considered.

1) Let N be the number of PLAUs occurring between two checkpoint events (incoming calls, outgoing calls, or NLAUs) when the MS is attached. The smaller the N value, the lower the network signaling overhead caused by the PLAU mechanism. Criterion 1 is satisfied when $N=0$. Let $N_{d,m}$ and N_f be the N values for dynamic PLAU and fixed PLAU, respectively. We will derive the expected values $E[N_{d,m}]$ and $E[N_f]$.
2) Let β be the probability that when an MS is abnormally detached, no failure call setup for mobile termination occurs [i.e., Case 1) holds]. It is clear that the bigger the β value, the better the PLAU mechanism. Specifically, Criterion 2 is satisfied when $\beta=1$. Let $\beta_{d,m}$ and β_f be the β values for dynamic PLAU and fixed PLAU, respectively.

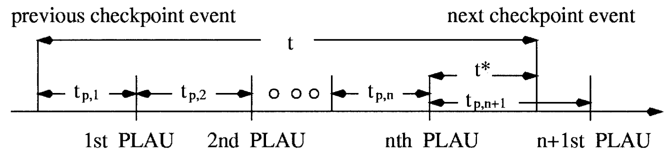

Fig. 2. The number of PLAUs between two checkpoint events when the MS is attached.

Telecommunications network operations suggest that incoming and outgoing call arrivals are Poisson streams [7], and the aggregate arrivals of the incoming and outgoing calls together with the NLAUs can be approximated as a Poisson stream. Following the above statement, we assume Poisson checkpoint event arrivals as in many other studies [4], [5], [8]. Therefore, $t_1, t_2, \ldots, t_m$ in (4) are exponentially distributed, and t_p has an Erlang-m density function $f_{p,m}(t_p)$ with mean c/μ. That is

$$f_{p,m}(t_p) = \left(\frac{m\mu}{c}\right)^m \left[\frac{t_p^{m-1}}{(m-1)!}\right] e^{-(m\mu/c)t_p}. \tag{5}$$

The Laplace transform of the t_p distribution is

$$\begin{aligned} f^*_{p,m}(s) &= \int_{t_p=0}^{\infty} f_{p,m}(t_p) e^{-st_p} dt_p \\ &= \left(\frac{\frac{m\mu}{c}}{s+\frac{m\mu}{c}}\right)^m \\ &= \left(\frac{m\mu}{sc+m\mu}\right)^m. \end{aligned} \tag{6}$$

Fig. 2 shows the scenario when the MS is attached to the network and there are n PLAUs between two checkpoint events in dynamic PLAU. For $n>0$, let $T_n = t_{p,1}+t_{p,2}+\cdots+t_{p,n}$. Then, we have (7) shown at the bottom of the next page. For $n=0$

$$\begin{aligned} \Pr[N_{d,m}=0] &= \Pr[t<t_{p,1}] \\ &= \int_{t_{p,1}=0}^{\infty}\int_{t=0}^{t_{p,1}} f_{p,m}(t_{p,1})\mu e^{-\mu t} dt dt_{p,1} \\ &= 1-\int_{t_{p,1}=0}^{\infty} f_{p,m}(t_{p,1}) e^{-\mu t_{p,1}} dt_{p,1} \\ &= 1-f^*_{p,m}(\mu). \end{aligned} \tag{8}$$

From (7), the expected number of $N_{d,m}$ is

$$\begin{aligned} E[N_{d,m}] &= \sum_{n=1}^{\infty} n \Pr[N_{d,m}=n] \\ &= \left[1-f^*_{p,m}(\mu)\right]\left\{\sum_{n=1}^{\infty} n\left[f^*_{p,m}(\mu)\right]^n\right\} \\ &= \frac{f^*_{p,m}(\mu)}{1-f^*_{p,m}(\mu)}. \end{aligned} \tag{9}$$

Substitute (6) in (9) to yield

$$E[N_{d,m}] = \left(\frac{m}{c+m}\right)^m \left[1 - \left(\frac{m}{c+m}\right)^m\right]^{-1}. \quad (10)$$

Now we derive $E[N_f]$. Consider Fig. 2 again. This figure illustrates an example when the MS is attached to the network and there are n PLAUs between two checkpoint events in fixed PLAU. In this example, for $1 \le i \le n+1$, $t_{p,i} = c/\mu$ is a fixed value, and the intercheckpoint event time t is expressed as $t = n(c/\mu) + t^*$. For $n \ge 1$, the probability that $N_f = n$ is derived as

$$\begin{aligned}\Pr[N_f = n] =& \int_{t^*=0}^{c/\mu} \mu e^{-\mu[n(c/\mu)+t^*]} dt^* \\ =& (1 - e^{-c}) e^{-nc}. \end{aligned} \quad (11)$$

For $n = 0$

$$\Pr[N_f = 0] = \Pr[t < t_{p,1}] = \int_{t=0}^{c/\mu} \mu e^{-\mu t} dt = 1 - e^{-c}. \quad (12)$$

From (11), the expected number of N_f is

$$E[N_f] = \sum_{n=1}^{\infty} n(1 - e^{-c}) e^{-nc} = \frac{e^{-c}}{1 - e^{-c}}. \quad (13)$$

$E[N_f]$ can also be derived from (10).

Consider the case when $m \to \infty$ and $s = \mu$. Equation (6) is rewritten as

$$\lim_{m\to\infty} f^*_{p,m}(\mu) = \lim_{m\to\infty} \left(\frac{m}{m+c}\right)^m = e^{-c}. \quad (14)$$

From (6), (8), and (12), we have $\Pr[N_f = 0] \ge \Pr[N_{d,m} = 0]$. Also, from (8) and (14), we have

$$\Pr[N_f = 0] = \lim_{m\to\infty} \Pr[N_{d,m} = 0] = 1 - e^{-c}. \quad (15)$$

Equation (15) is the same as (12). From (10) and (14), we have

$$E[N_f] = \lim_{m\to\infty} E[N_{d,m}] = \frac{e^{-c}}{1 - e^{-c}}. \quad (16)$$

Equation (16) is the same as (13).

Probability $\beta_{d,m}$ is derived as follows. Consider Fig. 3. Suppose that the previous checkpoint event or PLAU occurs at time τ_1, the abnormal MS detach occurs at τ_2, and the next PLAU occurs at τ_3. Define two events as follows.

Event A: No checkpoint event or PLAU occurs in period $\bar{t} = \tau_2 - \tau_1$.

Event B: No MS call termination occurs in period $t = \tau_3 - \tau_2$.

It is apparent that Criterion 2 is satisfied if and only if event B occurs under the condition that event A occurs.

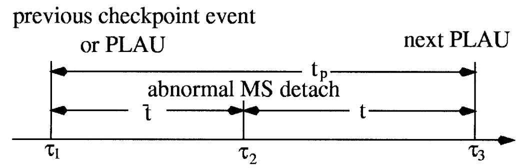

Fig. 3. Timing diagram for deriving $\beta_{d,m}$ and β_f.

That is, $\beta_{d,m} = \Pr[B|A]$. If the occurrence of abnormal MS detach is a random observer, then from residual life theorem and reverse residual life theorem [9], both $\bar{t}$ and t have the same density function $f_{\bar{p},m}$

$$\begin{aligned} f_{\bar{p},m}(\bar{t}) =& f_{\bar{p},m}(t) \\ =& \left(\frac{\mu}{c}\right) \int_{t_p=t}^{\infty} f_{p,m}(t_p) dt_p \\ =& \left(\frac{\mu}{c}\right) \left\{ \sum_{j=0}^{m-1} \left(\frac{m\mu}{c}\right)^j \left(\frac{t^j}{j!}\right) e^{-(m\mu/c)t} \right\}. \end{aligned} \quad (17)$$

Furthermore, events A and B are independent of each other and

$$\beta_{d,m} = \Pr[B|A] = \frac{\Pr[B \cap A]}{\Pr[A]} = \Pr[B]. \quad (18)$$

Let $\gamma(t)$ be the probability that there is no MS termination occurring in a period t. Since MS termination calls are a Poisson stream with rate $\mu_i = \alpha\mu$, $\gamma(t)$ is expressed as [9]

$$\gamma(t) = e^{-\alpha\mu t}. \quad (19)$$

From (17)–(19)

$$\begin{aligned} \beta_{d,m} =& \int_{t=0}^{\infty} f_{\bar{p},m}(t)\gamma(t) dt \\ =& \sum_{j=0}^{m-1} \left\{ \left(\frac{\mu}{c}\right) \int_{t=0}^{\infty} \left(\frac{m\mu}{c}\right)^j \left(\frac{t^j}{j!}\right) e^{-[(m\mu/c)+\alpha\mu]t} dt \right\} \\ =& \sum_{j=0}^{m-1} \left(\frac{\mu}{c}\right) \left(\frac{m\mu}{c}\right)^j \left(\frac{m\mu}{c} + \alpha\mu\right)^{-(j+1)} \\ =& \left(\frac{1}{\alpha c}\right) \left[1 - \left(\frac{m}{m+\alpha c}\right)^m\right]. \end{aligned} \quad (20)$$

Now we derive β_f. Consider Fig. 3 again. For fixed PLAU, $t_p = c/\mu$ is a constant. Since occurrence of abnormal MS detach is a random observer, t has a uniform distribution in interval [0, c/μ]. From (19), β_f is derived as

$$\beta_f = \int_{t=0}^{c/\mu} \left(\frac{\mu}{c}\right) \gamma(t) dt = \frac{1 - e^{-\alpha c}}{\alpha c}. \quad (21)$$

$$\begin{aligned} \Pr[N_{d,m} = n] =& \Pr[T_n \le t < T_{n+1}] \\ =& \int_{t_{p,1}=0}^{\infty} \int_{t_{p,2}=0}^{\infty} \cdots \int_{t_{p,n+1}=0}^{\infty} \int_{t=T_n}^{T_{n+1}} \left[\prod_{j=1}^{n+1} f_{p,m}(t_{p,j})\right] \mu e^{-\mu t} dt dt_{p,n+1} \cdots dt_{p,2} dt_{p,1} \\ =& \int_{t_{p,1}=0}^{\infty} \int_{t_{p,2}=0}^{\infty} \cdots \int_{t_{p,n+1}=0}^{\infty} \left[\prod_{j=1}^{n+1} f_{p,m}(t_{p,j})\right] \left[e^{-\mu T_n} - e^{-\mu T_{n+1}}\right] dt_{p,n+1} \cdots dt_{p,2} dt_{p,1} \\ =& \left[f^*_{p,m}(\mu)\right]^n \left[1 - f^*_{p,m}(\mu)\right]. \end{aligned} \quad (7)$$

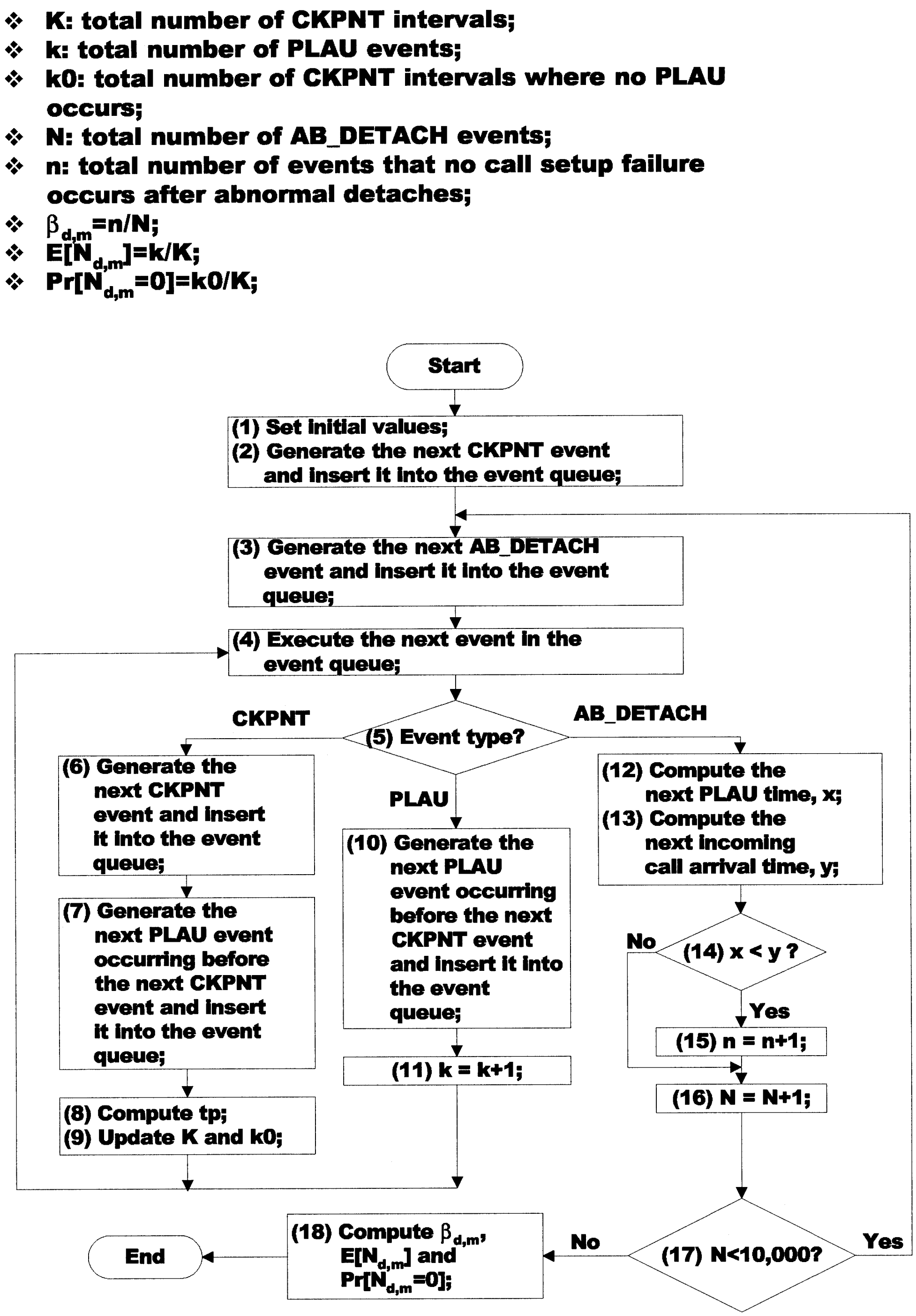

Fig. 4. The simulation flowchart.

We can also derive β_f from (20) and (14)

$$\begin{aligned}\beta_f &= \lim_{m\to\infty} \beta_{d,m}\\ &= \left(\frac{1}{\alpha c}\right)\left[1 - \lim_{m\to\infty}\left(\frac{m}{m+\alpha c}\right)^m\right]\\ &= \frac{1-e^{-\alpha c}}{\alpha c}.\end{aligned}$$

The above analytic model is validated against the simulation experiments. We use a C program to implement the simulation model that consists of three types of events: 1) Checkpoint (CKPNT); 2) PLAU; and 3) MS abnormal detach (AB_DETACH). The next CKPNT and AB_DETACH event arrival times are generated by the exponential random number generator, and all events are processed according to their timestamps. The simulation flowchart is shown in Fig. 4. For a CKPNT event, steps 6–9 are executed. For a PLAU event, steps 10–11 are executed. For an AB_DETACH event, steps 12–16 are executed. In the simulation experiments, the abnormal MS detach occurs after an attach period exponentially distributed with mean that is M

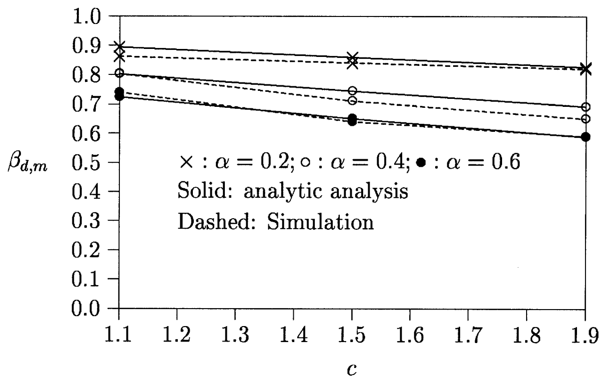

Fig. 5. Comparing analytic analysis with simulation experiments $(m = 20)$.

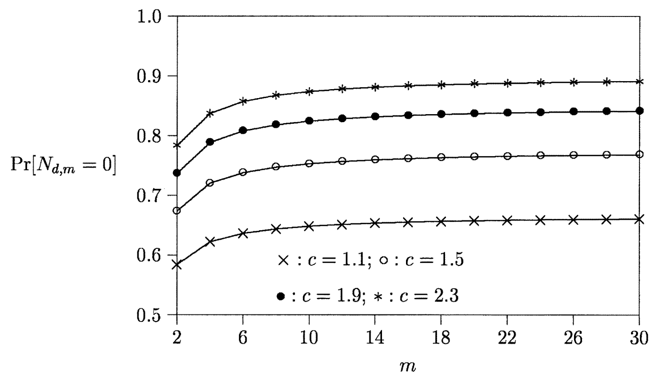

Fig. 6. The $\Pr[N_{d,m} = 0]$ performance.

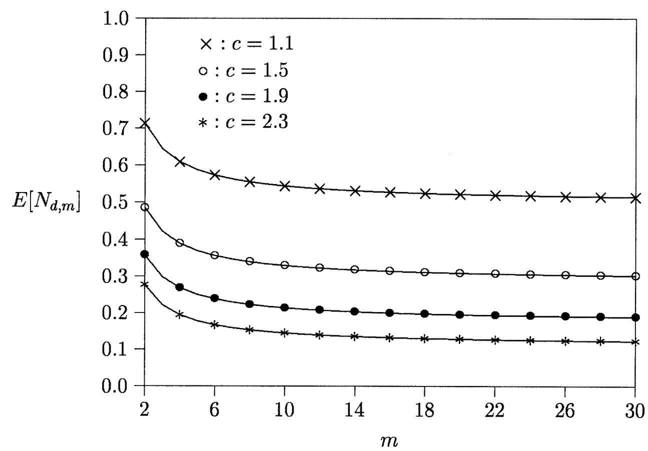

Fig. 7. The $E[N_{d,m}]$ performance.

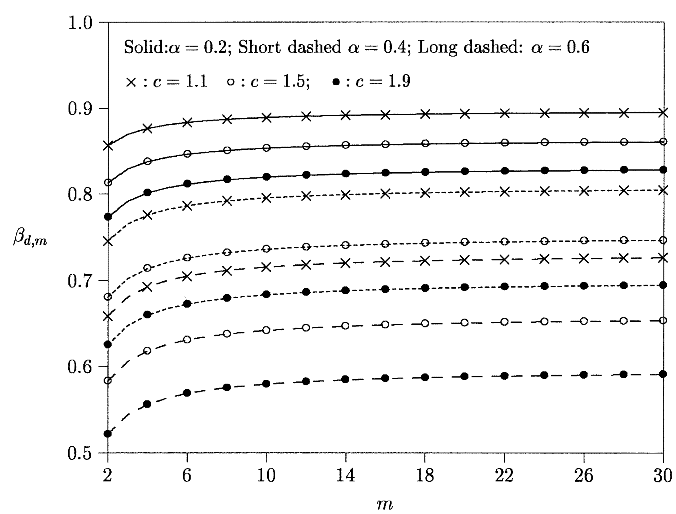

Fig. 8. The $\beta_{d,m}$ performance.

times of an intercheckpoint arrival time interval. For $M > 100$, the simulation results are not sensitive to the M values. In our simulation experiments, the confidence intervals of the 99% confidence levels are within 3% of the mean values in most cases. Fig. 5 shows that analytic analysis and simulation experiments are consistent for the β values. The comparison results for other performance measures are similar and will not be presented in this paper.

IV. Numerical Examples

Based on the analysis in Section III, we use numerical examples to investigate the performance of dynamic PLAU and compare it with fixed PLAU.

By using (8), Fig. 6 plots $\Pr[N_{d,m} = 0]$ as a function of m. The figure indicates that even if we choose a small c (e.g., $c =$ 1.1 or 1.5), Criterion 1 can be satisfied with probability higher than 0.5. In this figure, the $\Pr[N_f = 0]$ values are 0.667 13, 0.776 87, 0.850 43, and 0.899 74 for $c = 1.1, 1.5, 1.9$, and 2.3 respectively.

Based on (10), Fig. 7 plots $E[N_{d,m}]$ against m, where $1.1 \leq c \leq 2.3$. The figure indicates that $E[N_{d,m}]$ is a decreasing function of m. When m is small (i.e., $m < 6$), if dynamic PLAU measures one more intercheckpoint arrival time sample (i.e,. m is incremented by one), the $E[N_{d,m}]$ performance is significantly improved. On the other hand, when m is large $(m > 20)$, measuring more intercheckpoint arrival time samples will not improve the $E[N_{d,m}]$ performance. In Fig. 7, the $E[N_f]$ values are 0.498 96, 0.287 22, 0.175 88, and 0.111 42 for $c = 1.1, 1.5, 1.9$, and 2.3 respectively.

Based on (20), Fig. 8 plots $\beta_{d,m}$ against m, where $\alpha = 0.2, 0.4$, and 0.6, and $c = 1.1, 1.5$, and 1.9. For $m > 10$, $\beta_{d,m}$ is not sensitive to the change of m. Suppose that $m = 20$ is selected. When $\alpha = 0.2$, $0.82 \leq \beta_{d,m} \leq 0.9$ for $1.1 \leq c \leq 1.9$. When $\alpha = 0.4$, $0.6 \leq \beta_{d,m} \leq 0.8$. When $\alpha = 0.6$, $0.58 \leq \beta_{d,m} \leq 0.72$. Therefore, the $\beta_{d,m}$ performance is significantly affected by α (i.e., the frequency of incoming calls to the MS). As we mentioned before, $\alpha = 0.4$ is observed in mobile network operations, and good $\beta_{d,m}$ performance can be expected. In this figure, the β_f values are shown below. For $\alpha = 0.2$, the β_f values are 0.897 64, 0.863 94, and 0.831 94 for $c = 1.1, 1.5$, and 1.9, respectively; for $\alpha = 0.4$, the β_f values are 0.809 01, 0.751 98, and 0.700 44 for $c = 1.1, 1.5$, and 1.9, respectively; for $\alpha = 0.6$, the β_f values are 0.732 04, 0.659 37, and 0.596 65 for $c = 1.1, 1.5$, and 1.9respectively.

Note that the $\Pr[N_f = 0]$, $E[N_f]$, and β_f values corresponding to Figs. 5–7 are "optimal." That is, such good perfor-

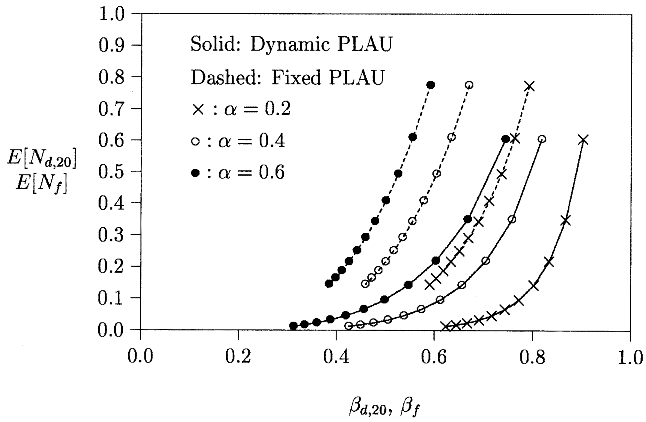

Fig. 9. Relationship between $E[N]$ and β $(m = 20)$.

mance can only be achieved when the "optimal fixed t_p values" are found. In reality, it is very difficult (if not possible) to guess such "optimal" values in advance. In Figs. 5–7, we demonstrate that by the adaptive mechanism, the dynamic PLAU scheme can achieve good performance close to the optimal fixed PLAU scheme.

The results in Figs. 7 and 8 indicate that $E[N_{d,m}]$ and $\beta_{d,m}$ have conflicting goals. In other words, it is impossible to choose the c values that minimize $E[N_{d,m}]$ and maximize $\beta_{d,m}$ at the same time. However, by choosing appropriate c values, dynamic PLAU can satisfy both $E[N_{d,m}]$ and $\beta_{d,m}$ restrictions, if such solutions do exist. For example, consider $\alpha = 0.4$. If the system requires that $E[N_{d,m}] < 0.6$ and $\beta_{d,m} > 0.7$, then a c value such as 1.1 satisfies the requirement (with $m = 20$).

Note that if the frequency of checkpoint events (call activities and NLAUs) changes from time to time, dynamic PLAU can automatically adapt to the change. Consider the scenario where $\mu = \mu_1$ for a long time (the first period) and then μ changes to $10\mu_1$ (the second period). Assume that the intervals for both the first and the second periods are the same. For dynamic PLAU, the t_p period is adjusted as μ changes so that the c value is kept as a constant (except for the short period for transition from μ_1 to $10\mu_1$). On the other hand, the period t_p is fixed in fixed PLAU. Therefore, $c = t_p\mu_1$ in the first period and $c = 10t_p\mu_1$ in the second period. In other words, the c value in the second period is ten times that in the first period. After the checkpoint rate changes, the fixed PLAU may only slightly improve the N_f performance at the cost of significantly degrading the β_f performance. The consequence is that the average performance of fixed PLAU for the above mixed checkpoint traffic is worse than that for dynamic PLAU. Fig. 9 plots $E[N]$ against β for dynamic PLAU and fixed PLAU, where $m = 20$ and $\alpha = 0.2, 0.4$, and 0.6. Note that β is a function of m, α, and c, while $E[N]$ is a function of m and c. Therefore, when we choose a specific set of (m, α, c), the corresponding β and $E[N]$ values can be computed. Then we use these computed $(\beta, E[N])$ sets to plot this figure. The figure indicates that to achieve the same β performance for the mixed checkpoint traffic patterns, much less network signaling overhead for LA updates is expected in dynamic PLAU compared with that in fixed PLAU.

V. Conclusion

In mobile communications networks, periodic location area update is utilized to detect the presence of a mobile station. In 3GPP Technical Specifications 23.012 and 24.008, a fixed PLAU scheme was proposed for UMTS where the interval between two PLAUs is of fixed length. We observe that MS presence can also be detected through call and movement activities. Therefore, we proposed a dynamic PLAU scheme where the PLAU interval is dynamically adjusted based on the call and NLAU traffic. An analytic model was developed to investigate the performance of dynamic and fixed PLAU schemes. Our study indicates that compared with fixed PLAU, dynamic PLAU significantly reduces the network signaling traffic caused by periodic location area update.

As a final remark, in dynamic PLAU, storage and the mechanism maintaining $m = 20$ or 30 intercheckpoint arrival time samples for an MS can be practically implemented in the UMTS network (specifically, in the VLR). The value t_p can be efficiently computed using the *window averaging* technique [7].

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