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RESEARCH ARTICLE

# Automatic event-triggered call-forwarding mechanism for mobile phones

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## ABSTRACT

Call forwarding is a traditional telecom service that allows a user to forward incoming calls to another telephone number. This service requires the user to manually activate and deactivate the feature and therefore may not be very convenient. This paper proposes an automatic *call-forwarding algorithm* (CFA) for mobile phones. By installing a software in a smartphone, call forwarding is automatically triggered (e.g., when the phone is plugged in a charger or is turned off) or disabled (e.g., when the phone is unplugged from the charger or is turned on). We investigate the performance of the CFA through analytic analysis, simulation, and measurement. Our study indicates that CFA is very feasible for commercial usage. Copyright © 2011 John Wiley & Sons, Ltd.

**KEYWORDS**
call forwarding; mobile telecom; UMTS

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## 1. INTRODUCTION

When a person returns home, he or she may turn off his or her *user equipment* (UE; mobile phone) or plug the UE into its charger. The person may miss the calls to the UE when he or she is in the house (but away from the UE). In this case, it would be desirable that the calls are automatically forwarded to the line phone (and its extensions) in the house so that the person can still pick up his or her calls. Call-forwarding setup can be done manually, but it is considered as a tedious process for many people. Furthermore, when call forwarding is not needed anymore, people may forget to manually disable this service and will not be able to receive calls from their original mobile phones.

Several solutions have been proposed to support automatic call forwarding. In [1], if the incoming call is not answered from the destination phone, the incoming call is automatically forwarded another pre-configured phone number. In [2], the location of the user is tracked by the sensor network so that the incoming call can be automatically forwarded to the phone nearest the user. These solutions require modifications to the telecom networks. In this paper, we propose an automatic event-triggered *call-forwarding algorithm* (CFA) that does not incur any modification to the telecom networks. Moreover, our solution can be easily installed in a smartphone (i.e., a UE).

### 1.1. Concept of call-forwarding algorithm

We first describe the concept of CFA, which is implemented by the functions in Microsoft *Windows CE* (WinCE) platform. For other smartphone platforms, the implementations are similar and will not be elaborated.

Our CFA solution consists of four parts:

Part 1. *Detection of triggering events*: The events 'when the UE is turned off' or 'when the UE is plugged into its charger' trigger the call-forwarding service. Such triggering events are automatically detected in CFA. This feature is implemented by using the WinCE function RegistryNotifyCallback [3] to monitor the battery status. Another triggering event considered in our current implementation is 'when a special short message is received' (this scenario will be elaborated in Section 4).

Part 2. *Selection of the forwarded-to number* (i.e., incoming calls to the UE are redirected to this phone number): After a triggering event is detected, the UE selects the corresponding forwarded-to number. In particular, this selection may be associated with location service. For example, the home phone number may be associated with the home's *Global Positioning System* (GPS) information. The UE then uses its current location obtained from its *assisted GPS* (A-GPS) receiver to identify the forwarded-to number. Note that A-GPS can be used in indoor environment [4]. Location ambiguity may occur because of inaccuracy of location measurement, and in this case, the UE may query the user to select one from these ambiguous forwarded-to numbers. If ambiguity does not occur, the UE automatically selects the number without bothering the user.

Part 3. *Activation of call forwarding*: After the forwarded-to number is determined, the UE automatically conducts the standard call-forwarding registration procedure with the telecom network. This feature is implemented by invoking the WinCE function lineForward [3].

Part 4. *Deactivation of call forwarding*: When the cause of the triggering event disappears, call forwarding is deactivated. For example, when the UE is unplugged from its charger, it automatically disables the call-forwarding service by executing the standard call-forwarding erasure procedure with the telecom network. As in Part 3, the call-forwarding deactivation is also supported by the lineForward function.

Note that in Part 2, if the UE's A-GPS receiver is not activated under some power-saving strategy [5], then it is automatically turned on when the UE's CFA detects the triggering event. After the UE's CFA has retrieved its GPS position, it may turn off the A-GPS receiver again to avoid power consumption of mobile phone.

### 1.2. Mobile telecom network for call-forwarding algorithm execution

We use a simplified circuit-switched *Universal Mobile Telecommunications System* (UMTS) network architecture as an example to explain how call-forwarding service works [6,7]. The call-forwarding service also can be supported in packet-switched telecom network (e.g., *IP Multimedia Subsystem*) through the standard Parlay X interface [8]. In the UMTS architecture (see Figure 1), a mobile user with a UE (UE1; Figure 1(1)) is connected to a serving *mobile switching center/visitor location register* (MSC/VLR; Figure 1(2)) to receive telecom services. The MSC and the VLR are responsible for call processing and mobility management, respectively. Each UE is assigned an E.164 mobile telephone number (e.g., 0911111111 for UE1), and every number is mapped to a *Gateway Mobile Switching Center* (GMSC; Figure 1(3)). In other words, for every incoming call to UE1, the call is first routed to its GMSC. The *home location register* (HLR; Figure 1(4)) is a database that indicates the MSC/VLR location of mobile users. The MSC/GMSC connects to the *Public Switched Telephone Network* (PSTN; Figure 1(5)). In the PSTN, the *service switching points* (SSPs; Figure 1(6) and (7)) are telephony switches that support call processing.

Based on this architecture, we will describe the message flows (Part 3 and Part 4) for CFA by using Chunghwa Telecom's call-forwarding unconditional service [7].

## 2. MESSAGE FLOWS FOR CALL-FORWARDING ALGORITHM

This section describes the message flows for CFA including activation, incoming call setup, and deactivation. In these procedures, we assume that user 1's UE (UE1 with phone number 0911111111) is installed with CFA, and the number 031111111 of user 1's line phone (Phone1; Figure 1(8)) is selected as the forwarded-to number (i.e., incoming calls to UE1 are forwarded to Phone1 when call-forwarding service is activated). Then, we investigate the performance of CFA by deriving the probability of incoming call arrival during CFA activation.

### 2.1. Call-forwarding algorithm activation procedure

When user 1 plugs UE1 into the phone charger, CFA in UE1 detects the charging status, and automatically executes the CFA activation procedure through the standard *3rd Generation Partnership Project* (3GPP) call-forwarding registration procedure [7,9]. Figure 2 illustrates the CFA activation procedure with the following steps:

Step A.1. When the WinCE RegistryNotifyCallback function detects the charging status, CFA automatically dials the special number **21 *031111111# where 21 is the service code of Chunghwa Telecom's call-forwarding unconditional service and 031111111 is the forwarded-to number (call-forwarding dialing methods for other telecom operators are similar and will not be elaborated). The MSC/VLR (Figure 1(2)) sends the call-forwarding registration request to the HLR (Figure 1(4)) by the *Signaling System Number 7* (SS7) MAP_REGISTER_SS request. This message indicates that UE1 (with the number 0911111111) wants to enable the call-forwarding unconditional service with the forwarded-to number 031111111.

Step A.2. The HLR checks if UE1 is allowed to enable the call-forwarding service. If so, the HLR stores the forwarded-to number, and returns the SS7 MAP_REGISTER_SS response to the MSC/VLR indicating that the registration

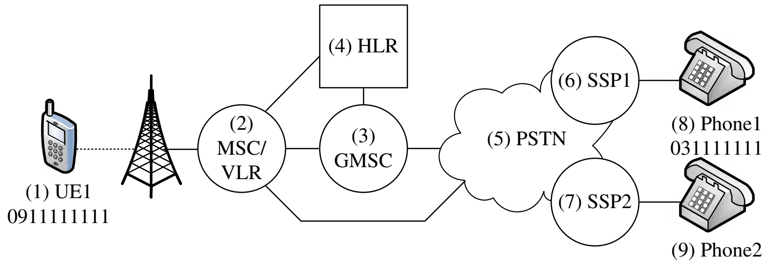


**Figure 1.** Network architecture for call forwarding. UE, user equipment; MSC, mobile switching center; VLR, visitor location register; HLR, home location register; GMSC, Gateway Mobile Switching Center; PSTN, Public Switched Telephone Network; SSP, service switching point.

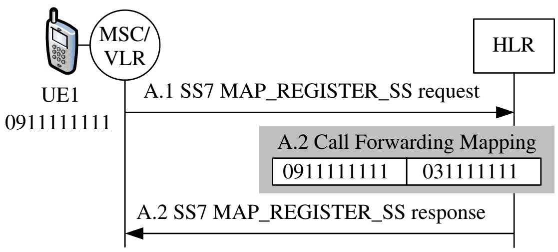


**Figure 2.** Call-forwarding algorithm activation procedure. MSC, mobile switching center; VLR, visitor location register; HLR, home location register; UE, user equipment.

procedure is successful. Otherwise, the HLR returns an error.

When this procedure is finished, all calls to UE1 are re-directed to Phone1.

## 2.2. Incoming call setup procedure

After user 1 has enabled the call-forwarding service, if user 2 (Figure 1(9)) dials user 1's mobile phone number 0911111111, the call setup procedure is illustrated in Figure 3 with the following steps:

Step B.1. SSP2 (Figure 1(7)) issues the SS7 *initial address message* (IAM) message to the GMSC (Figure 1(3)) of 0911111111 (i.e., UE1).

Step B.2. To obtain the routing information for this call, the GMSC queries the HLR via the SS7 MAP_SEND_ROUTING_INFORMATION request.

Step B.3. The HLR replies with the SS7 MAP_SEND_ROUTING_INFORMATION response that contains the routing number (the SS7 address) of SSP1 that serves the forwarded-to number 031111111 (i.e., Phone1).

Step B.4. The GMSC forwards the SS7 IAM message to SSP1.

Step B.5. SSP1 alerts Phone1 and returns the SS7 *address complete message* (ACM) message to SSP2 through the GMSC.

Step B.6. When user 1 picks up Phone1, SSP1 issues the SS7 *answer message* (ANM) to SSP2 through the GMSC.

At the end of Step B.6, user 1 and user 2 start a conversation.

## 2.3. Call-forwarding algorithm deactivation procedure

When user 1 unplugs UE1's charger, UE1's CFA detects this triggering event and automatically executes the CFA deactivation procedure to disable the call-forwarding service through the 3GPP call-forwarding erasure procedure [7,9]. Figure 4 illustrates the CFA deactivation procedure with the following steps:

Step C.1. Similar to Step A.1, when the WinCE RegistryNotifyCallback function detects the triggering event of unplugging UE1 from the charger, UE1's CFA automatically dials the special number ##21#. Then the MSC/VLR sends the SS7 MAP_ERASE_SS request to the HLR to indicate that UE1 wants to disable the call-forwarding service.

Step C.2. The HLR removes the corresponding forwarded-to number of UE1 and replies with the SS7 MAP_ERASE_SS response to indicate that the erasure procedure is successful.

After CFA deactivation is finished, all calls to UE1 are routed to UE1 instead of Phone1.

## 2.4. Call-forwarding algorithm delay analysis

After user 1 has plugged UE1 into the phone charger, he or she expects that incoming calls to UE1 should be forwarded to Phone1. However, it is possible that an incoming call arrives at UE1 before CFA activation is complete. In

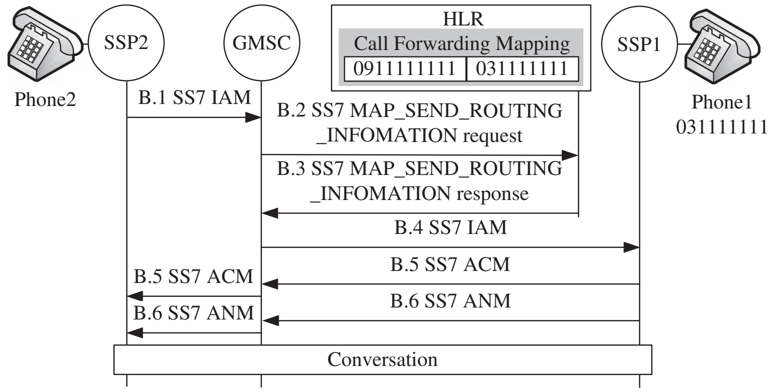


**Figure 3.** Incoming call setup procedure. SSP, service switching point; GMSC, Gateway Mobile Switching Center; HLR, home location register; IAM, initial address message; ACM, address complete message; ANM, answer message; SS7, Signaling System Number 7.

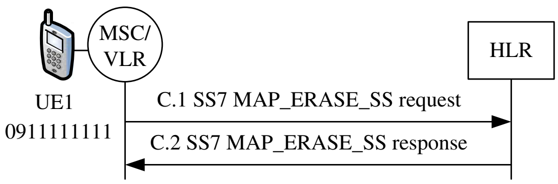


**Figure 4.** Call-forwarding algorithm deactivation procedure. MSC, mobile switching center; VLR, visitor location register; HLR, home location register; SS7, Signaling System Number 7.

this case, if user 1 expects that the call will ring Phone1, then he or she is not notified of this call until he or she removes UE1 from the charger (and is informed by the missing call list in UE1). We will formally show that such missing calls occur with very low probability, and the issue can be either ignored or resolved by a notification mechanism described in Section 3.

Let $p_c$ be the probability that an incoming call arrives at UE1 during CFA activation (before the 3GPP call-forwarding registration procedure is complete). It is clear that the smaller the $p_c$ value, the better the user experience about CFA.

Figure 5 illustrates a timing diagram for deriving $p_c$. Let $t_c$ be the inter-call arrival time and $t_a$ be the delay of CFA activation (Steps A.1–A.2 in Figure 2). The interval $\tau_c$ between when CFA starts the activation procedure

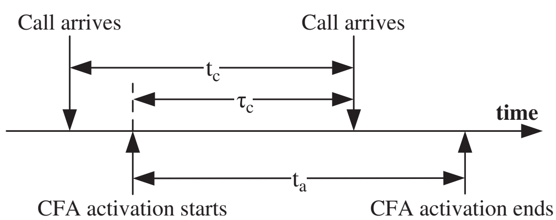


**Figure 5.** Timing diagram for deriving $p_c$. CFA, call-forwarding algorithm.

and when the next call arrives is called the excess life of the inter-call arrival time. Then, $p_c$ is the probability that $\tau_c < t_a$.

Assume that $t_c$ is exponentially distributed with the mean $1/\lambda$ (i.e., the call arrivals are a Poisson process) and $t_a$ has an arbitrary distribution with the density function $\mathrm{f}_a(\cdot)$ and the Laplace transform $\mathrm{f}_a^*(s)$. From the memoryless property of the exponential distribution, $\tau_c$ has the same exponential distribution as $t_c$, and $p_c$ is derived as

$$\begin{aligned} p_c &= \Pr[\tau_c < t_a] \\ &= \int_{t_a=0}^{\infty} \mathrm{f}_a(t_a) \int_{\tau_c=0}^{t_a} \lambda e^{-\lambda \tau_c} \mathrm{d}\tau_c \mathrm{d}t_a \\ &= 1 - \mathrm{f}_a^*(\lambda) \end{aligned} \quad (1)$$

If $t_a$ is a Gamma random variable with the Laplace transform $\mathrm{f}_a^*(s) = \left(\frac{\mu}{s+\mu}\right)^k$, where $k$ is the shape parameter and $\mu$ is the rate parameter, then Equation (1) is re-written as

$$p_c = 1 - \left(\frac{\mu}{\lambda+\mu}\right)^k \quad (2)$$

We consider the Gamma distribution because this distribution is widely used in telecom modeling; see [5,10] and the references therein. Equation (2) is validated against the Monte Carlo simulation, which generates the delays $\tau_c$ and $t_a$, and then compares the lengths of these delays to produce the $p_c$ value. The simulation experiments show that the discrepancies between the analytic (i.e., Equation (2)) and simulation results are within 0.2%.

We have also measured the $t_a$ values in the commercial UMTS system of Chunghwa Telecom. We installed CFA in a smartphone CHT 9110 (Chunghwa Telecom, Taiwan) with Microsoft Windows Mobile 6.0 operating system and collected the delays $t_a$ from more than 3000 CFA activation executions. We obtained statistics $E[t_a] = 7.88266$ s and the variance $V_a = E[t_a^2] - E[t_a]^2 = 0.0139717 E[t_a]^2$.


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With the average measured $E[t_a]$ value (i.e., 7.88266 s), we assume that $100E[t_a] \le E[t_c] \le 1000E[t_a]$ (i.e., the inter-call arrival time ranges from about 13 min to 2.18 h). Figure 6 plots $p_c$ (i.e., the probability that an incoming call arrives at UE1 before CFA activation is complete) against $E[t_c]/E[t_a]$ and $V_a$. The figure shows the trivial result that $p_c$ decreases as $E[t_c]/E[t_a]$ increases. The non-trivial result is that $p_c$ decreases as $V_a$ increases. This phenomenon is explained as follows. For a fixed $E[t_a]$ value, when $V_a$ is large ($V_a > 10E[t_a]^2$), if $V_a$ increases, there are more short $t_a$ periods than long $t_a$ periods. For short $t_a$, it is unlikely that $\tau_c < t_a$. Therefore, $p_c$ decreases as $V_a$ increases.

Measurements indicate that the $V_a$ of Chunghwa Telecom's network is very small, and 0.1% to 1% of the incoming calls may still arrive at UE1. However, such calls will occur in less than 8 s after CFA activation is executed, while user 1 is still around UE1. Therefore, user 1 will hear the ringing tone, and these calls are answered through UE1. In some telecom networks, large $V_a$ values may be observed, which result in long $t_a$. For a very long $t_a$, it is possible that incoming calls arrive at UE1 after user 1 has moved away from UE1 (before CFA activation is complete). In this case, he or she may not hear the ringing and miss the calls (with probability $p_c < 0.2\%$ in Figure 6). To resolve this issue, we propose the CFA notification procedure described in Section 3.

# 3. CALL-FORWARDING ALGORITHM NOTIFICATION AND FAILURE DETECTION

After user 1 plugs UE1 into the charger, he or she may move to another room in the house (e.g., from bedroom to kitchen). Immediately after CFA activation, it is desirable to notify user 1 that call forwarding is correctly activated to the target line phone. This section proposes a CFA notification procedure to serve for this purpose. Besides successful CFA notification, this procedure also notifies user 1 of unsuccessful call-forwarding activation through a threshold mechanism with a timer $T$. The CFA notification is executed to inform user 1 that the call-forwarding activation is either successful or failed (i.e., $T$ expires; due to possibly lost message).

## 3.1. Call-forwarding algorithm notification procedure

Figure 7 illustrates the CFA notification procedure with the following steps:

Step D.1. UE1's CFA initiates a call to Phone1 by automatically dialing the forwarded-to number 031111111. The MSC/VLR sends the SS7 IAM message to SSP1.

Step D.2. SSP1 alerts Phone1 and returns the SS7 ACM message to the MSC/VLR. Then, the MSC/VLR notifies UE1 that Phone1 starts ringing.

Step D.3. After user 1 picks up Phone1, SSP1 sends the SS7 ANM message to the MSC/VLR. Through, for example, voice announcement, UE1's CFA informs user 1 about the status of the call-forwarding setup and indicates if there are incoming calls during CFA activation. We note that 0.1%–1% calls that still arrived at UE1 (described in Subsection 2.4) will be notified to user 1 in this step. The voice announcement requests user 1 to dial

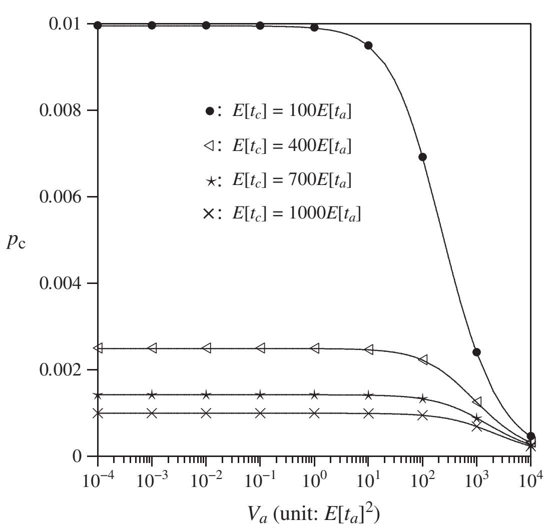


**Figure 6.** Effects of $E[t_c]/E[t_a]$ and $V_a$ on $p_c$ ($t_c$ is exponentially distributed).

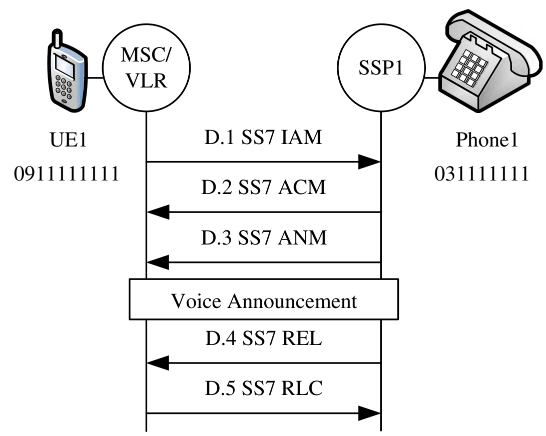


**Figure 7.** Call-forwarding algorithm notification procedure. MSC, mobile switching center; VLR, visitor location register; SSP, service switching point; UE, user equipment; SS7, Signaling System Number 7; IAM, initial address message; ACM, address complete message; ANM, answer message; REL, release; RLC, release complete.

a secret digit (e.g., '1') to confirm receipt of call-forwarding setup status. If a wrong forwarded-to number is accidentally selected, another person who picks up this call does not know the secret digit, and the call-forwarding service is canceled.

Step D.4. After user 1 has hung up Phone1, SSP1 issues SS7 *release* (REL) message to the MSC/VLR to terminate the call.

Step D.5. The MSC/VLR replies to SSP1 with the SS7 *release complete* (RLC) message. The procedure exits.

After the call-forwarding service is successfully activated, UE1 enters the charging mode. For the 'turning off UE' scenario, UE1 is actually turned off after the aforementioned procedure is complete. Note that Step D.3 ensures that call-forwarding service is correctly enabled through confirmation of user 1.

### 3.2. Call-forwarding algorithm activation failure detection

The proposed CFA activation failure detection scheme utilizes a threshold $T$ computed as follows. Every time the CFA activation is executed, the elapsed time $t_a$ is measured and stored. UE1's CFA accumulates the $m$ most recent $t_a$ samples. Let $t_{a,i}$ be the $i$th previous $t_a$ sample. When UE1's CFA executes CFA activation, $T$ is computed as

$$T = \frac{\alpha \left( \sum_{i=1}^{m} t_{a,i} \right)}{m} \quad (3)$$

where $\alpha > 1$ is a weighting factor used to ensure that $T$ is not shorter than the actual $t_a$ value. If CFA activation is not finished in the $T$ period (i.e., CFA does not receive the response from the HLR within $T$), then CFA activation is considered failed. In this case, CFA notification will inform user 1 of unsuccessful setup.

From Equation (3), if $\alpha$ is set too small, CFA may cancel a successful call-forwarding setup. On the other hand, if $\alpha$ is set too large, CFA activation failure can not be detected early. Therefore, it is important to select an appropriate $\alpha$ value. We will show that $\alpha = 1.5$ is sufficient for CFA activation failure detection in Chunghwa Telecom's network. We will also investigate the performance of the CFA activation failure detection scheme under different $V_a$ (i.e., $t_a$'s variance).

Let $p_s = \Pr[t_a < T]$ be the probability that CFA activation is complete within $T$. It is clear that the larger the $p_s$ value, the better the performance of failure detection.

Let $t_a$ be a random variable with the density function $f_a(\cdot)$ and the Laplace transform $f_a^*(s)$. Let $T$ be a random variable with the density function $f_T(\cdot)$ and the Laplace transform $f_T^*(s)$. If we re-write Equation (3) as $T = \sum_{i=1}^{m} \left( \frac{\alpha t_{a,i}}{m} \right)$, then the Laplace transform of the $T$ distribution is

$$f_T^*(s) = \left[ f_a^* \left( \frac{\alpha s}{m} \right) \right]^m \quad (4)$$

If $t_a$ is an Erlang random variable with the shape parameter $k$ and the rate parameter $\mu$, then its density function and the Laplace transform are

$$f_a(t_a) = \frac{\mu^k t_a^{k-1} e^{-\mu t_a}}{(k-1)!} \text{ and } f_a^*(s) = \left( \frac{\mu}{s+\mu} \right)^k \quad (5)$$

Substitute Equation (5) into Equation (4) to yield

$$f_T^*(s) = \left( \frac{m\mu}{\alpha s + m\mu} \right)^{km} \quad (6)$$

We selected the Erlang distribution because this distribution can be easily extended into a hyper-Erlang distribution, which has been proven to be a good approximation to many other distributions as well as measured data [11,12].

From Equations (5) and (6), $p_s$ is derived as

$$\begin{aligned} p_s &= \Pr[t_a < T] \\ &= \int_{T=0}^{\infty} f_T(T) \int_{t_a=0}^{T} f_a(t_a) dt_a dT \\ &= \int_{T=0}^{\infty} f_T(T) \left[ 1 - \sum_{i=0}^{k-1} \frac{e^{-\mu T} (\mu T)^i}{i!} \right] dT \\ &= 1 - \sum_{i=0}^{k-1} \left[ \frac{\mu^i (-1)^i}{i!} \right] \left[ \left. \frac{d^i f_T^*(s)}{ds^i} \right|_{s=\mu} \right] \\ &= 1 - \sum_{i=0}^{k-1} \left( \frac{\alpha}{\alpha+m} \right)^i \left[ \frac{(km+i-1)!}{i!(km-1)!} \right] \\ &\quad \times \left( \frac{m}{\alpha+m} \right)^{km} \end{aligned} \quad (7)$$

Equation (7) is used to validate the simulation model (following the same Monte Carlo methodology described in Section 2.4). Experiments show that the discrepancies between the analytic (i.e., Equation (7)) and simulation results are within 0.1%. In the remainder of this paper, we used the validated simulation experiments to investigate the performance of the CFA activation failure detection scheme. Specifically, we extend the validated simulation model from the Erlang $t_a$ distribution to the Gamma $t_a$ distribution. Then, we used the Gamma simulation model with $E[t_a] = 7.88266$ s and $V_a = 0.0139717 E[t_a]^2$ to approximate the measured data from Chunghwa Telecom's network (mentioned in Section 2.4). Figure 8 plots $p_s$ (the probability that CFA activation is complete within $T$) against $\alpha$ and $m$ for simulation and measurement. It is clear that $p_s$ increases as $\alpha$ increases. Figure 8(a) shows that


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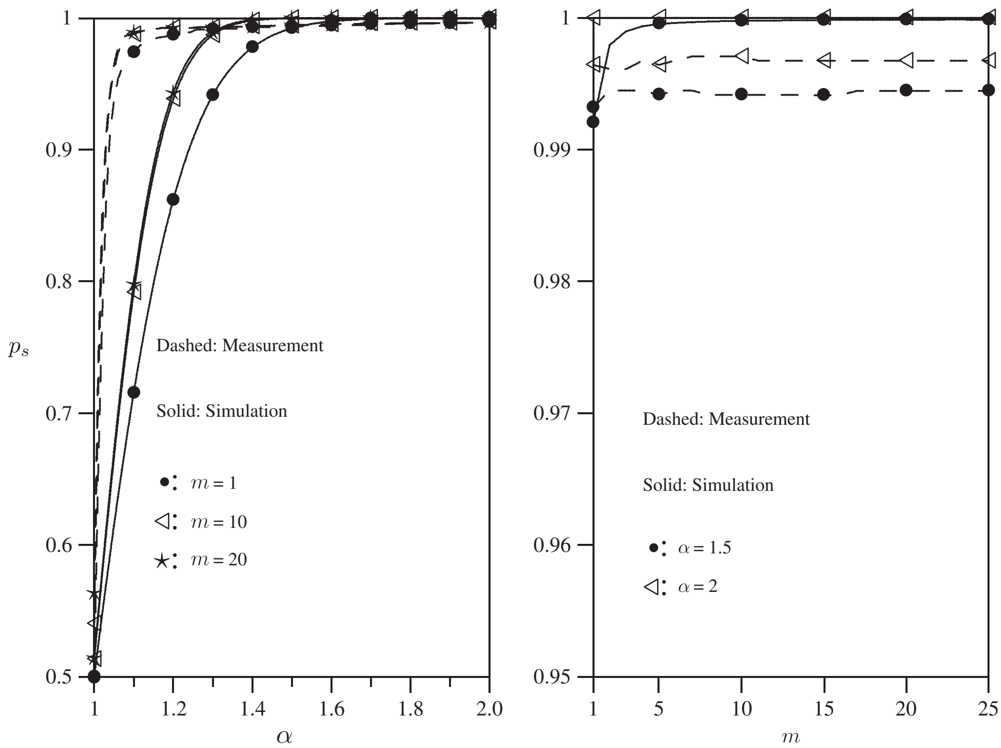


(a) Effect of $\alpha$ (b) Effect of $m$

**Figure 8.** Effects of $\alpha$ and $m$ on $p_s$ ($E[t_a] = 7.88266$ seconds and $V_a = 0.0139717E[t_a]^2$).

when $\alpha$ is small (i.e., $\alpha \leq 1.3$), the simulation results are lower bounds of the measurement. When $\alpha$ is large (i.e., $\alpha \geq 1.5$), the result reverses. The trends of $p_s$ are similar for both the Gamma $t_a$ distribution and the measured histogram, and these values are close when $\alpha$ is large (i.e., $\alpha \geq 1.5$).

Figure 8(b) indicates that when $m \geq 20$, $p_s$ is not sensitive to the change of $m$. In other words, it is sufficient to store 20 most recent $t_a$ samples in CFA for computing the $T$ value in Equation (3). When $m = 20$, the discrepancies between the simulation and the measurement are within 0.5% for $\alpha \geq 1.5$. Figure 8 also shows that selection of a small $\alpha$ (i.e., $\alpha = 1.5$) suffices to yield good $p_s$ performance (e.g., $p_s$ >0.99) in Chunghwa Telecom's network.

For a telecom network where $V_a$ is large, Figure 9 shows that $p_s$ decreases and then increases as $V_a$ increases (when $t_a$ has a Gamma distribution). This phenomenon is explained as follows. When $V_a$ is small (i.e., $V_a < E[t_a]^2$), if $V_a$ increases, more short $t_a$ and more long $t_a$ are observed. These long $t_a$ result in smaller $p_s$. When $V_a$ is large (i.e., $V_a > 10E[t_a]^2$), if $V_a$ increases, much more short $t_a$ are observed. Much longer $t_a$ are also observed. However, the number of these very long $t_a$ is much fewer than the number of short $t_a$. Therefore, a larger $p_s$ is observed. We note that if $\alpha = 4.5$ (i.e., $E[T] = 35.47197$ s) is selected, $p_s > 0.9$ for all $V_a$ values under our study.

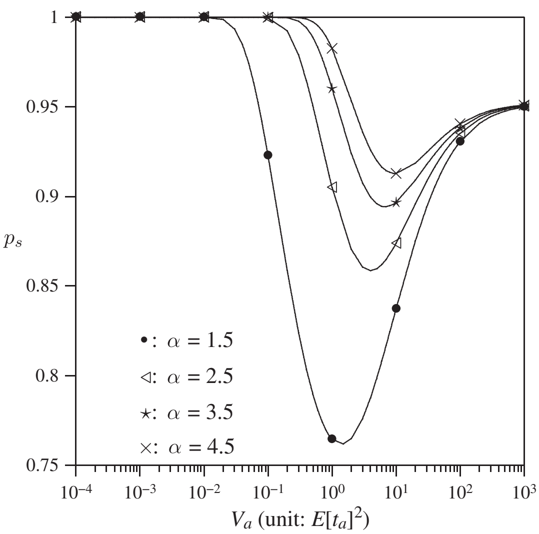


**Figure 9.** Effects of $\alpha$ and $V_a$ on $p_s$ ($m = 20$).

## 4. CALL-FORWARDING ALGORITHM FOR TELEMATICS

In telematics, a car is typically equipped with a *personal navigation device* (PND) that has GPS positioning and mobile communications capabilities (e.g., GSM, GPRS, or UMTS). In the hands-free phone service, when a person turns on the PND, all incoming calls are forwarded to the PND, and the person can receive hands-free calls (i.e. he or she can listen and talk through the car speaker and the PND's microphone). Existing hands-free car phone service is typically provisioned in two ways: the wire-line and the Bluetooth solutions. Both solutions require manual connection between the mobile phone and the communication device installed in the car.

With CFA, we can provide automatic call forwarding for telematics, assuming that user 1's PND is installed with a software that can detect the triggering event 'when the PND is turned on/off'. Many PND products manufactured in Taiwan allow such modifications to accommodate telecom operators' needs. When the triggering event is detected, the PND sends a short message to UE1 to enable/disable the call-forwarding service. The CFA works as follows. After user 1 gets on her car and turns on the PND, the following steps are executed:

- Step E.1. The PND retrieves its position from the GPS receiver and sends a short message to UE1. This short message contains the PND's GPS position and the request for enabling call forwarding to the PND's phone number.
- Step E.2. After UE1 has received the short message, UE1's CFA obtains its position from the A-GPS mechanism and compares the PND's position with UE1's position. If their positions are close enough (e.g., within 10 m), the CFA considers that UE1 is in the car and rings user 1 to ask if he or she wants to activate the call-forwarding feature. User 1 simply presses one key to accept (or reject) the call-forwarding activation request. Then, the CFA activation is executed as described in Section 2.1.
- Step E.3. UE1's CFA sends a short message to the PND to indicate the result of the activation. Then, the PND shows the result to user 1 through, for example, voice announcement.

Note that in Step E.2, another strategy is that whenever UE1 receives the short message, it always alerts user 1 that the PND is turned on (without considering the GPS information that may not be available in UE1).

When user 1 turns off the PND (e.g., turns off the car), call forwarding is disabled with the following steps:

- Step F.1. Before the PND actually shuts down, it sends a short message to UE1 to disable the call-forwarding service.
- Step F.2. Upon receipt of the short message, UE1's CFA executes the deactivation procedure described in Subsection 2.3.

If the user leaves the car while the PND is still on, the aforementioned procedure does not work. To resolve this issue, the PND may periodically check UE1 through steps similar to Steps E.1–E.3, and if the GPS locations indicate that they are too far away, then UE1 will ask the user if CFA deactivation should be performed.

## 5. CONCLUSIONS

This paper proposed an automatic CFA for mobile phone. Call forwarding for fixed line phone is typically triggered manually, which is a tedious process for a user. Unlike a fixed line phone, many triggering events may occur to a mobile phone, for example, battery charging, turn-off, and location change. By detecting these events, the CFA automatically triggers call-forwarding features.

With CFA, the user avoids tedious activation and deactivation actions of call forwarding; however, he or she must be notified if a CFA action is successful. We derived the value of a time-out period $T$ such that the user is appropriately informed of the CFA result before $T$ expires. We conducted analytic analysis, simulation, and measurement in Chunghwa Telecom's network to show that the CFA yields good performance and can be practically commercialized. As a final remark, CFA can be easily installed in a smartphone and does not make any modification to the telecom network.

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## REFERENCES

1. Erb P. Automatic Call Forwarding. U.S. Patent 6130938, 10 October 2000.
2. Want R, Hopper A, Falcao V, Gibbons J. The active badge location system. *ACM Transactions on Information Systems* 1992; **10**(1): 91–102.
3. MSDN library. Available: http://msdn.microsoft.com/en-us/default.aspx.
4. Djuknic GM, Richton RE. Geolocation and assisted GPS. *Computer* 2001; **34**(2): 123–125.
5. Yang S-R. Dynamic power saving mechanism for 3G UMTS system. *ACM/Springer Mobile Networks and Applications* 2007; **12**(1): 5–14.
6. Lin Y-B, Pang A-C. *Wireless and Mobile All-IP Networks*. John Wiley & Sons, Inc.: Indianapolis, Indiana, 2005.
7. 3GPP. 3rd Generation Partnership Project; Technical Specification Group Core Network and Terminals; Call Forwarding (CF) supplementary services;

Stage 3. *Technical Specification 3G TS 24.082 version 9.0.0 (2009-12), 2009*.

8. 3GPP. 3rd Generation Partnership Project; Technical Specification Group Core Network; Open Service Access (OSA); Parlay X Web Services; Part 10: Call handling. *Technical Specification 3G TS 29.199-10 version 9.0.0 (2009-12) 2009*.
9. 3GPP. 3rd Generation Partnership Project; Technical Specification Group Core Network and Terminals; Mobile Application Part (MAP) specification. *Technical Specification 3G TS 29.002 version 9.2.0 (2010-06) 2010*.
10. Lai Y-C, Lin P, Fang Y, Chen W-H. Channel allocation for UMTS multimedia broadcasting and multicasting. *IEEE Transactions on Wireless Communications* 2008; **7**(11): 4375–4383.
11. Fang Y, Chlamtac I. Teletraffic analysis and mobility modeling of PCS networks. *IEEE Transactions on Communications* 1999; **47**(7): 1062–1072.
12. Kelly F. *Reversibility and Stochastic Networks*. John Wiley & Sons: Chichester, 1979.

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