IMS EMERGENCY SERVICES: A PRELIMINARY STUDY

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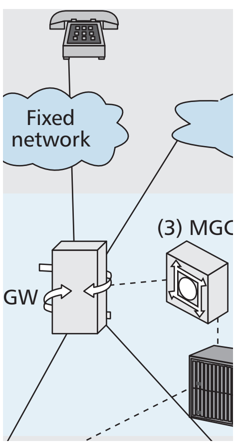

Deficiencies in communications during emergencies can be resolved by the emergency call and the Push-to-talk over Cellular services in IP Multimedia Subsystem network. The authors conduct a preliminary study on how these two services can be effectively exercised in IMS.

ABSTRACT

Emergency call and walkie-talkie are two services utilized in emergency situations. During Typhoon Morakot in 2009, we experienced the deficiency of emergency call service that cannot continuously track callers in real time and walkie-talkie communications where a speaker may not be granted the permission to talk. These issues can be resolved by the emergency call and push-to-talk over cellular services in IP Multimedia Subsystem. This article conducts a preliminary study on how these two services can be effectively exercised in IMS.

INTRODUCTION

IP Multimedia Subsystem (IMS) supports IP-based multimedia services. IMS was originally designed by the Third Generation Partnership Project (3GPP) to deliver Internet services over general packet radio service (GPRS) in 3G networks such as Universal Mobile Telecommunications System (UMTS). IMS was later updated to support other access networks including wireless LAN, CDMA2000, and fixed line. For the purpose of this article, Fig. 1 illustrates a simplified IMS network architecture (the reader is referred to [1] for detailed descriptions of IMS).

The IMS (Fig. 1b) connects to both mobile and fixed telecommunications networks (Fig. 1a) for *fixed mobile convergence* (FMC). IMS is not intended to standardize applications or services. Instead, it provides a standard approach for voice/multimedia application access from user equipment (UE; 1, Fig. 1) in wireline and wireless networks. This goal is achieved by having horizontal control that isolates the access networks from the service and application networks (Fig. 1c).

In the IMS, the transport of user data is separated from that for control signals, where IETF protocols such as Session Initiation Protocol (SIP) [2] are used to ease the integration with the Internet. For example, the call session control function (CSCF, 5, Fig. 1) is a SIP server, which is responsible for call control. The media gateway control function (MGCF, 3, Fig. 1) controls the connection for media channels in a media gateway (MGW, 4, Fig. 1). The MGW connects toward the legacy fixed and mobile networks to provide user data transport. The home subscriber server (HSS, 2, Fig. 1) is the master database containing all user-related mobile subscription and location information. In 2004 Chunghwa Telecom deployed the first commercial IMS in Taiwan to provision commercial telecommunications services such as voice, video, and Internet-based multimedia services. The initial capacity was 125,000 subscribers. Current IMS capacity can accommodate about 500,000 subscribers in daily commercial operation.

During Typhoon Morakot in August 2009, Taiwan experienced serious damage from flooding and mudslides (Fig. 2, left), and the rescue missions solely relied on GSM and satellite communications that offer basic services (Fig. 2, right) such as emergency call without location tracking. From Typhoon Morakot, we learned that it is desirable to accommodate emergency services in IMS with a 3G network including *emergency call* and *push-to-talk over cellular* (PoC).

A GSM user in Taiwan can make an emergency call by dialing 110, 112, or 119. However, the existing GSM emergency call service only identifies the location of the caller at the time of call setup and does not track the user's location during the call. In Typhoon Morakot many people waiting for rescue could not be accurately located through their phone calls, which increased the difficulty of the rescue missions.

PoC is a *walkie-talkie*-like service defined in Open Mobile Alliance (OMA) specifications [3, 4]. In 2004 Chunghwa Telecom first launched this service in Asia using 2.5G technology. Our experience with 2.5G PoC included long PoC call setup time (13 s) and handoff time (2.5–3 s for reconnecting a PoC client when it moved from one base station to another). These problems have been resolved by IMS-based PoC established on 3G networks. For example, the 3G PoC call setup time is less than 6 s. Although it is not clear if PoC will be a successful residential service, it has proven useful for business corporations and government organizations such as the National Security Bureau in Taiwan.

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In the past three years, we have studied emergency call [5] and PoC [6]. During Typhoon Morakot in 2009, emergency calls and walkie-talkies were important means of communications in rescue missions. Clearly, it is desirable to support emergency services in IMS for disastrous events. Therefore, this article conducts a preliminary investigation on IMS emergency call and PoC.

LOCATION TRACKING FOR EMERGENCY CALL

An important feature of emergency call is that the system can track the location of a calling UE (1, Fig. 1) during the conversation. To support IMS emergency call, three network nodes are deployed. When the UE originates an emergency call, the call is established by a special CSCF called an emergency-CSCF (E-CSCF, 5, Fig. 1), which dispatches the call to the nearest public safety answering point (PSAP) based on the location information of the UE. The PSAP (7, Fig. 1) is an IMS application server that processes emergency calls according to the types of emergency events. For example, in a fire event the PSAP connects the UE (the caller) to the fire department (8, Fig. 1). The PSAP interacts with the E-CSCF by using SIP, and the voice conversation path is set up through the MGW (4, Fig. 1) to the UE by using Real-Time Transport Protocol (RTP) [7]. The gateway mobile location center (GMLC, 6, Fig. 1) supports a location service (LCS) [8]. Through Signaling System Number 7 (SS7) Mobile Application Part (MAP) [1], the GMLC interacts with the HSS and mobile network to obtain the accurate location of UE. The GMLC provides the location information to the PSAP and E-CSCF.

The LCS merits further discussion. This service utilizes one or more positioning methods between the mobile network (Fig. 1a) and UE to determine the location of the UE [9]. The cell-ID-based positioning method determines the UE's position based on the coverage of service areas (SAs). An SA includes one or more cells (base stations). The observed time difference of arrival (OTDOA) and uplink time difference of arrival (U-TDOA) positioning methods utilize trilateration to determine the UE's position based on the time differences between downlink and uplink signal arrivals, respectively. The Assisted Global Positioning System (A-GPS) method speeds up GPS positioning by downloading GPS information through the mobile network. In Chunghwa Telecom A-GPS is utilized for location-based services.

Without loss of generality, we consider the cell-ID-based method. After emergency call setup, the PSAP may need to monitor the UE's location in real time. In the 3GPP 23.167 specification [10], the UE's location is tracked through *polling*, where the PSAP periodically queries the UE's location. For description purposes, we refer to the 3GPP 23.167 approach as the *location polling* scheme. In this scheme, if the UE does not change its location between two queries, the second query is wasted (this is called *redundant polling*). On the other hand, if the UE has visited several locations between two location queries, the PSAP may lose track of the UE in this time period (this is called *mistracking*). To resolve these issues, the active location reporting scheme was proposed in [5]. This scheme reports the UE's location upon change of its SA. This section describes location polling and active location reporting, and comments on their performance.

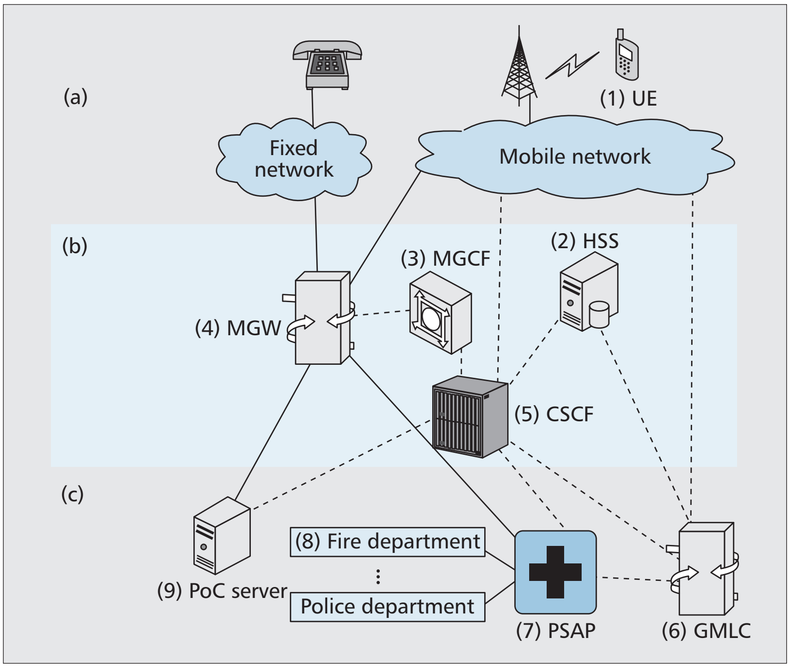

Figure 1. *A simplified IMS network architecture (dashed lines: control signaling; solid lines: user data/control signaling): a) fixed and mobile telecom networks; b) IP Multimedia Subsystem; c) service and application networks.*

EMERGENCY CALL SETUP

Figure 3 illustrates IMS emergency call setup message flow with the following steps [10]:

Step A.1 The UE establishes IP connectivity to the IMS through the mobile network [1].

Step A.2 The UE sends a SIP INVITE message to the E-CSCF. This message includes the supported positioning methods of the UE (cell-ID-based in our example).

Step A.3 The E-CSCF uses the received information to select a GMLC and sends the Emergency Location Request message to the GMLC.

Steps A.4 and **A.5** The GMLC exchanges the SS7 `MAP_SEND_ROUTING_INFO_FOR_LCS` and acknowledgment message pair with the HSS to identify the mobile network node responsible for connection to the UE. In UMTS this node is a serving GPRS support node (SGSN).

Step A.6 The GMLC sends the SS7 `MAP_PROVIDE_SUBSCRIBER_LOCATION` message.

Step A.7 The mobile network and UE exercise the cell-ID-based positioning procedure to obtain the location estimate information of the UE (i.e., the SA identity of the UE).

Step A.8 The mobile network returns the SA identity to the GMLC through SS7 `MAP_PROVIDE_SUBSCRIBER_LOCATION_ack` message.

Step A.9 The GMLC selects a suitable PSAP according to the SA of the UE and replies the Emergency Location Response message (with the selected PSAP address) to the E-CSCF.

Redundant polling creates extra network traffic without providing useful location information. Furthermore, mis-tracking may result in wrong positioning in case of emergency situations. These issues are resolved by Active Location Reporting.

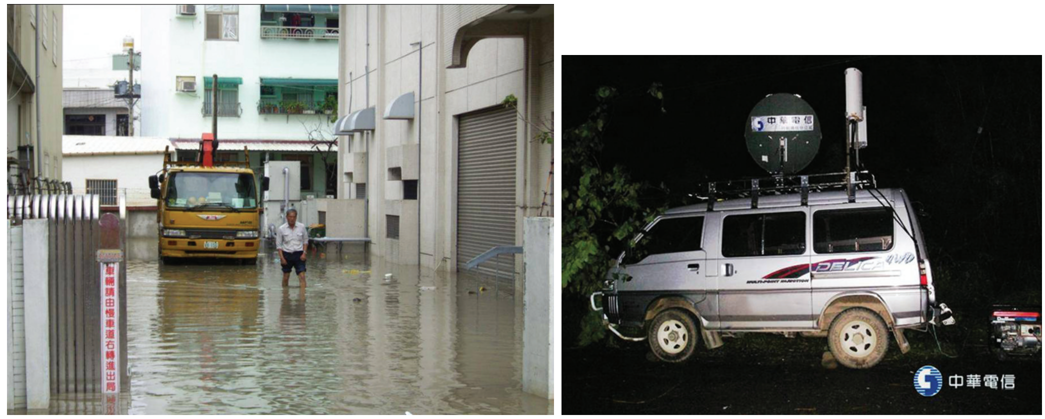

Figure 2. *Telecommunications services in Typhoon Morakot: (left) deploying temporary cables in flooded areas; (right) GSM/satellite communications through a vehicular base station.*

Steps A.10–A.12 The E-CSCF forwards the SIP INVITE to the PSAP to set up the call. The PSAP and the UE exchange the 200 OK and the SIP ACK messages through the E-CSCF. After the PSAP has received the SIP ACK message, the emergency call is established.

Step A.13 The GMLC sends the location information obtained at step A.8 to the PSAP after the call has been established, where the PSAP address is resolved by the GMLC at step A.9.

Location Polling

UE may move during an emergency call, and the PSAP needs to monitor the UE's location in real time. In location polling, the PSAP periodically queries the UE's location. In each query, the following steps are executed (Fig. 4) [8]:

Step B.1 The PSAP sends the Location Information Request message to the GMLC.

Steps B.2–B.6 These steps retrieve the UE's SA identity, which are similar to steps A.4–A.8 in Fig. 3.

Step B.7 The GMLC returns the SA identity of the UE to the PSAP.

Steps B.8–B.10 When the emergency call is terminated, the E-CSCF exchanges the Emergency Location Release and Response message pair with the GMLC to terminate location tracking.

Active Location Reporting

To resolve redundant polling and mistracking issues in location polling, the active location reporting scheme was proposed in [5], which reports the UE's location upon change of its SA. This scheme introduces a new locationEstimateType *initiateActiveReport* (to trigger active location reporting) in the `MAP_PROVIDE_SUBSCRIBER_LOCATION` message (at step A.6). Since the IP connectivity exists during the IMS emergency call, the UE is in the cell-connected state and is tracked by the mobile network at the cell level [1]. Therefore, the mobile network can detect when the UE moves from one base station to another, and report the new SA identity to the GMLC. In this approach the GMLC maintains a UE-PSAP mapping table to store the (UE, PSAP) pair at step A.9. The GMLC does not need to query the HSS to identify the mobile network node responsible for connection to the UE (i.e., steps B.2 and B.3 are eliminated). The active location reporting scheme is illustrated in Fig. 5 with the following steps:

Step C.1 When the UE moves to a new SA, the mobile network detects this movement at the cell tracking mode and then triggers the positioning procedure.

Step C.2 After the positioning procedure is executed, the UE's SA identity is obtained.

Step C.3 The mobile network sends the SS7 `MAP_SUBSCRIBER_LOCATION_REPORT` message with the SA identity to the GMLC.

Step C.4 From the UE-PSAP mapping table, the GMLC retrieves the PSAP address of the UE stored at step A.9 and then sends the updated location information to the PSAP.

When the emergency call is terminated, the following steps are executed:

Step C.5 When the IMS call is released, the UE moves from the cell-connected mode to the idle mode, and the mobile network no longer tracks the movement of the UE.

Step C.6 The E-CSCF sends the Emergency Location Release message to the GMLC to terminate location tracking.

Step C.7 The GMLC returns the Emergency Location Response message to the E-CSCF and then deletes the (UE, PSAP) mapping from the UE-PSAP table.

Note that steps C.1 and C.2 in active location reporting automatically detects the movement of UE, which is different from steps B.1–B.5 in location polling.

Preliminary Performance Evaluation

It is clear that redundant polling creates extra network traffic without providing useful location information. Furthermore, mistracking may result in wrong positioning in case of emergency situations. These issues are resolved by active location reporting. However, it is desirable to evaluate the performance of location polling to justify the modifications to the existing location tracking procedure in active location reporting.

Suppose that the SA residence time has a Gamma distribution with mean $1/\mu$ and variance

In the PoC service several predefined group members participate in one PoC session. Since PoC utilizes half-duplex communications, only one PoC member speaks at a time, and others listen.

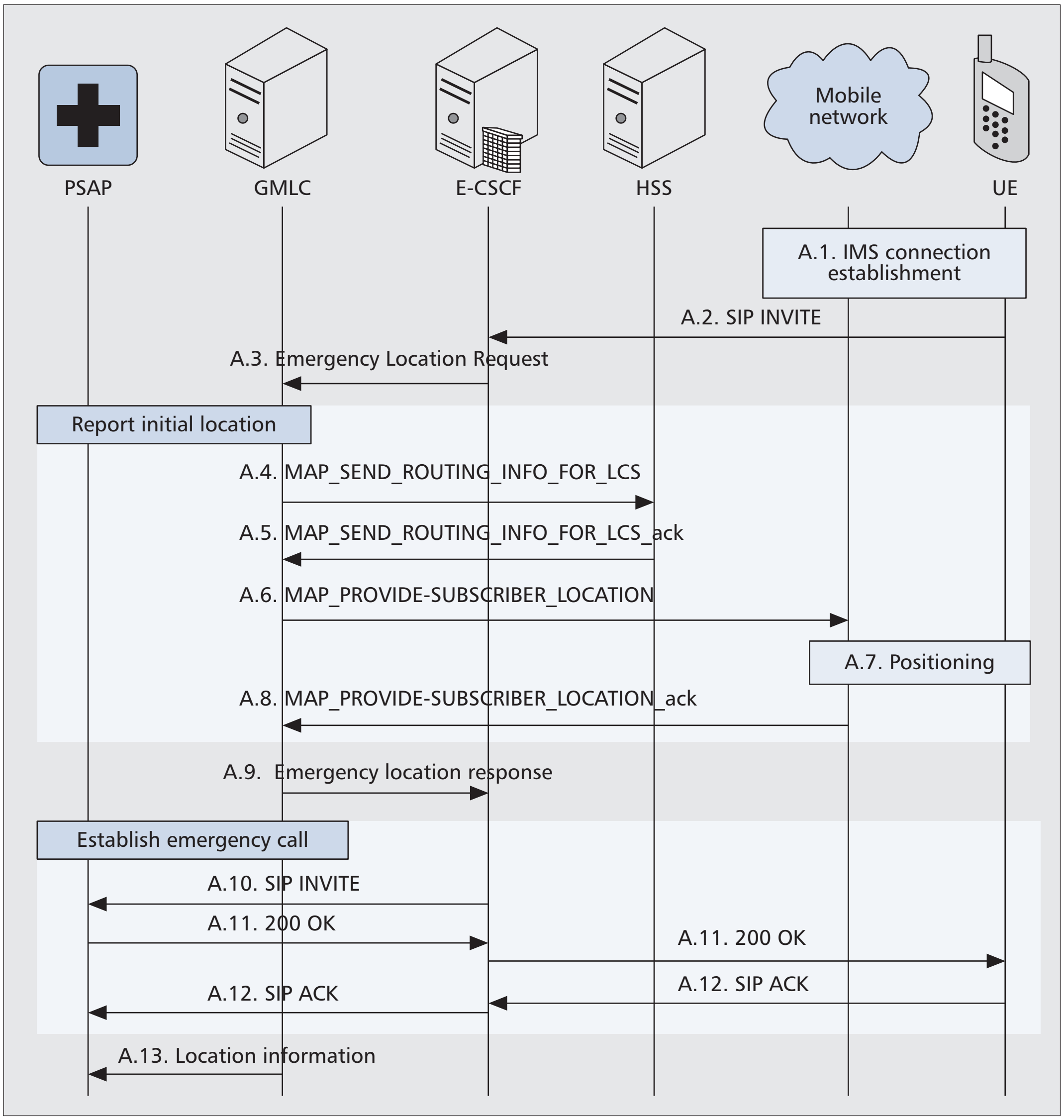

Figure 3. *IMS emergency call setup.*

V_m (other distributions have shown similar results [5]). The inter-query interval is a fixed period $1/\lambda$ in location polling. Several output measures are studied. Let α be the mistracking probability. An SA crossing is mistracked if there is no query between this and the next SA crossings (i.e., the system does not know that the user has visited this SA). Let β be the probability that redundant queries exist between two SA crossings. The larger the α or β values, the worse the performance of location polling.

Figure 6a shows intuitive results that as the polling frequency λ increases, α decreases and β increases. We describe two effects of V_m:

- **Effect 1**: When the SA residence time intervals become more irregular (i.e., V_m increases), more SA residence time intervals without any query are observed.
- **Effect 2**: When V_m increases, if a query arrives in an SA residence time interval, more than one query will tend to arrive in this interval.

Effect 1 implies that as V_m increases, more SA crossings are mistracked, and we have a nontrivial observation that α increases as V_m increases. Similarly, when λ is large (e.g., $\lambda \geqq 5\mu$), effect 1 is significant, and β is a decreasing function of V_m. The impact of V_m on β is more subtle when $\lambda = \mu$. In this case β increases and then decreases as V_m increases, which implies that when V_m is small, effect 2 is more significant. On the other hand, when V_m is large, effect 1 dominates. An important observation is that when $0.1/\mu^2 < V_m < 10/\mu^2$, both α and β values are non-negligibly large, and poor performance of location polling cannot be ignored.

Besides mistracking and redundant polling probabilities, we would also like to investigate the following output measures:

- T_i: The expected period in which the PSAP cannot correctly track the UE's location (i.e., T_i is the period between an SA crossing and when the next query arrives). In this period the system does not know the user's correct location.
- N_R: The expected number of redundant queries between two SA crossings (i.e., N_R is the number of queries issued within two consecutive SA crossings).

In emergency situations, important messages may not be delivered in walkie-talkie like communications if the message sender cannot obtain the permission to talk. Therefore, a mechanism is desirable to guarantee that a PoC client has a fair chance to talk. This issue can be resolved by PoC with queuing option.

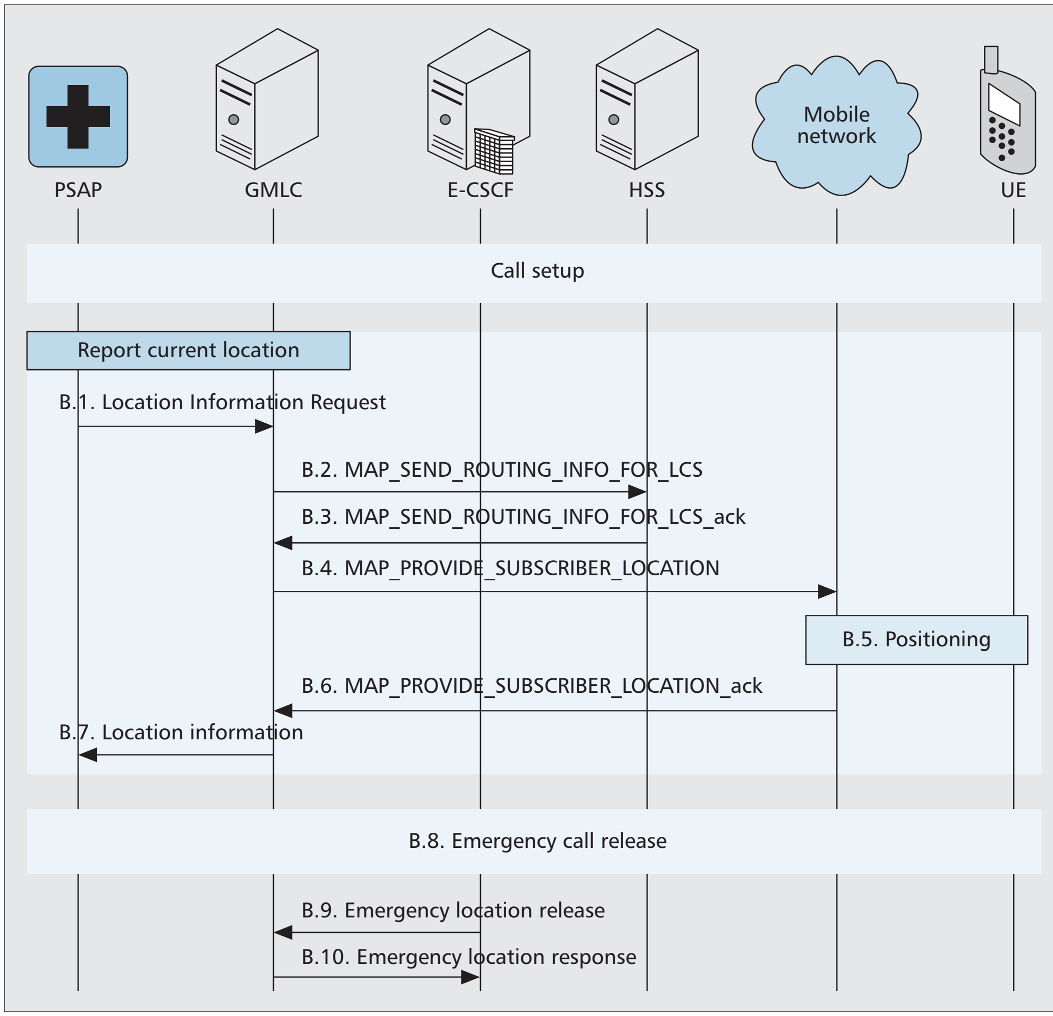

Figure 4. *Location polling.*

The larger the above output values, the worse the performance of location tracking. Figure 6b plots T_i against λ and V_m (the solid curves), where T_i is measured by $1/\mu$. T_i is a decreasing function of λ and is not affected by V_m. We notice that for $\lambda < 10\ \mu$, the PSAP will mistrack UE more than 5 percent of the time, which may not be acceptable in emergency situations.

It is clear that when $\lambda > \mu$, $N_R \doteq (\lambda/\mu) - 1$. Let N_R^* be the number of redundant queries between two SA crossings under the condition that there is at least one redundant query in this interval. Figure 6b plots N_R^* (the dashed curves). Clearly, N_R^* is an increasing function of λ. When $V_m < 1/\mu^2$, $N_R^* \doteq N_R$. When $V_m > 1/\mu^2$, N_R^* significantly increases as V_m increases. This phenomenon implies that when the UE's movement pattern becomes irregular, the PSAP will receive many redundant (useless) location reports after it has received a correct location update.

Push-to-Talk over Cellular

In the PoC service several predefined group members participate in one PoC session. Since PoC utilizes half-duplex communications, only one PoC member speaks at a time, and others listen. When a PoC member attempts to speak, he/she presses the push-to-talk button of his/her UE (Fig. 1 (1)) to ask for permission. This UE with the PoC application installed is called the *PoC client*. The *PoC server* (9, Fig. 1) is responsible for handling PoC session management (create or delete a PoC session). It arbitrates speak permission through the talk burst control mechanism [4]. SIP and Session Description Protocol (SDP) [11] are utilized for session establishment. After the PoC session is established, each of the PoC clients has built an RTP session with the PoC server through the MGW (Fig. 1 (4)). The talk burst control messages between the PoC clients and the PoC server are carried out by Real-Time Transmission Control Protocol (RTCP) packets [7].

In SIP a new parameter, tb_grant, is added in SDP's attribute field so that the PoC server can arbitrate the speak permission during a session. If tb_grant = 1, the PoC client is granted the permission to speak. Otherwise (i.e., tb_grant = 0), the PoC client is not permitted to talk.

In emergency situations, important messages may not be delivered via walkie-talkie-like communications if the message sender cannot obtain permission to talk. Therefore, a mechanism is desirable to guarantee that a PoC client has a fair chance to talk. This issue can be resolved by PoC with queueing option.

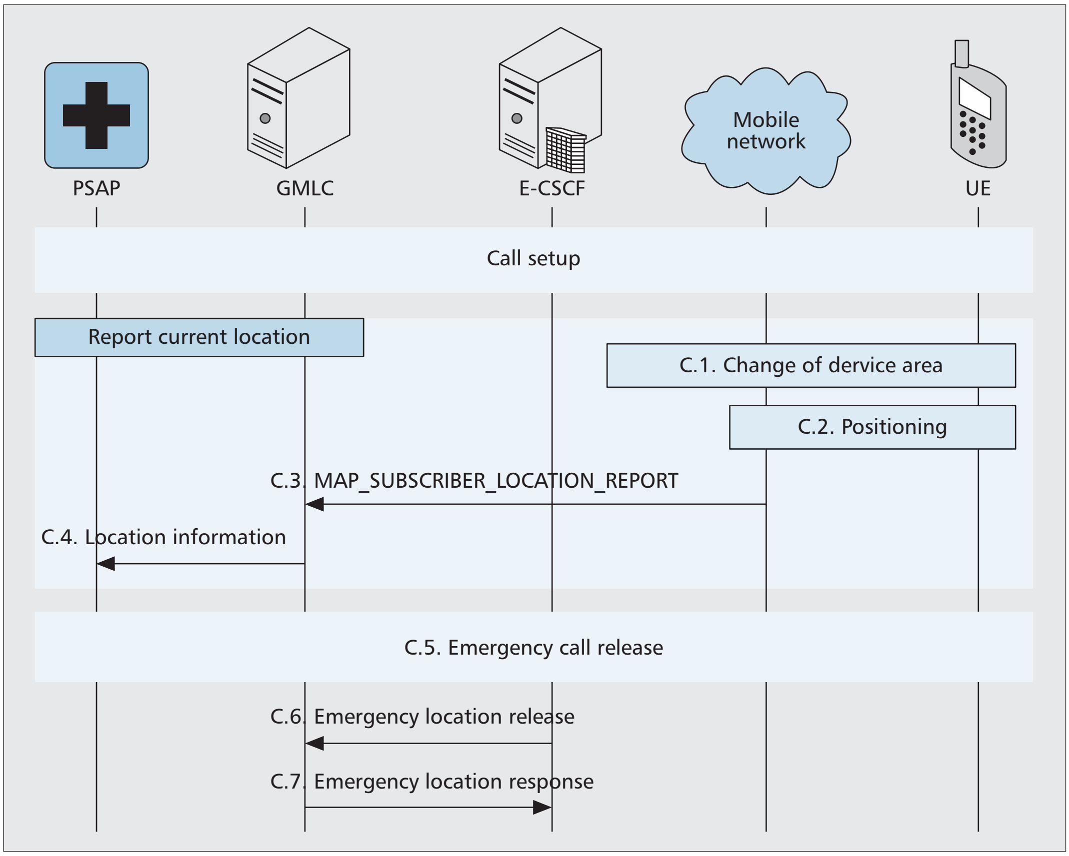

Figure 5. *Active location reporting.*

A queueing option is provided in the talk burst control mechanism. If this option is selected, then the ungranted requests are buffered in the queue at the PoC server instead of being denied.

TALK BURST CONTROL MECHANISM

The talk burst control mechanism is implemented by finite state machines (FSMs) on both the server and client sides. Figure 7 illustrates simplified talk burst control FSMs for PoC server (called FSM_G) and PoC client (called FSM_U). For every PoC session, there is one FSM_G in the PoC server and an FSM_U in each of the PoC clients. Two timers are defined in FSM_G. Timer T2 is used to determine whether the PoC client speaks too long. If a PoC client talks longer than the T2 period, he/she is asked to release the permission. Timer T3 is used to gracefully terminate the talk burst. After the PoC client gives up permission, the transient RTP packets it generated in T2 are continuously forwarded by the PoC server in the T3 period. When T3 expires, the PoC server allows the next PoC client to talk.

Session Initiation — For the PoC clients and PoC server involved in a PoC session, their FSMs are initialized at the *start-stop* state. The *session initiator* (a PoC client) starts a PoC session by sending a SIP INVITE message to the PoC server. The PoC server then broadcasts SIP INVITE messages with tb_grant = 0 to the *invited* PoC clients (i.e., PoC group members other than the session initiator). Each of the invited PoC clients answers with a SIP 200 OK message, and its FSM_U enters *has no permission* (transition 2, Fig. 7b). This PoC client is not permitted to speak.

After receiving the first SIP 200 OK message from each of the invited PoC clients, the PoC server replies a SIP 200 OK with tb_grant = 1 to the session initiator, and FSM_G enters *TB_Taken* (transition 1, Fig. 7a). This state means that some PoC client (the session initiator in this case) has obtained the permission. FSM_U of the session initiator enters has permission (transition 1, Fig. 7b), and the PoC client is allowed to speak. The session initiator becomes the *permitted* PoC client (i.e., the PoC client allowed to speak), and the invited PoC clients become *listening* PoC clients (i.e., the PoC clients not permitted to speak). At this moment, the session initiator speaks, and all invited PoC clients listen.

Permission Releasing — After finishing the talk, the permitted PoC client X releases the permission by sending the `TB_Release` message to the PoC server, and its FSM_U enters *pending TB_Release* (Transition 6 in Fig. 7b). In this state, client X stops sending media packets and waits for the response from the PoC server. FSM_G enters *pending TB_Release* after the PoC server has received the `TB_Release` message (transition 2, Fig. 7a). In this state the PoC server keeps forwarding the transient media packets issued from client X before the `TB_Release` message. When the last transient media packet has been processed or T3 expires, FSM_G enters *TB_Idle* (transition 3, Fig. 7a). In this state no PoC client is granted permission to speak. The PoC server broadcasts the `TB_Idle` message to all PoC clients. FSM_U of client X enters *has no permission* upon receipt of the `TB_Idle` message (transition 7, Fig. 7b). A listening PoC client remains in *has no permission* when it receives the `TB_Idle` message (Transition 14 in

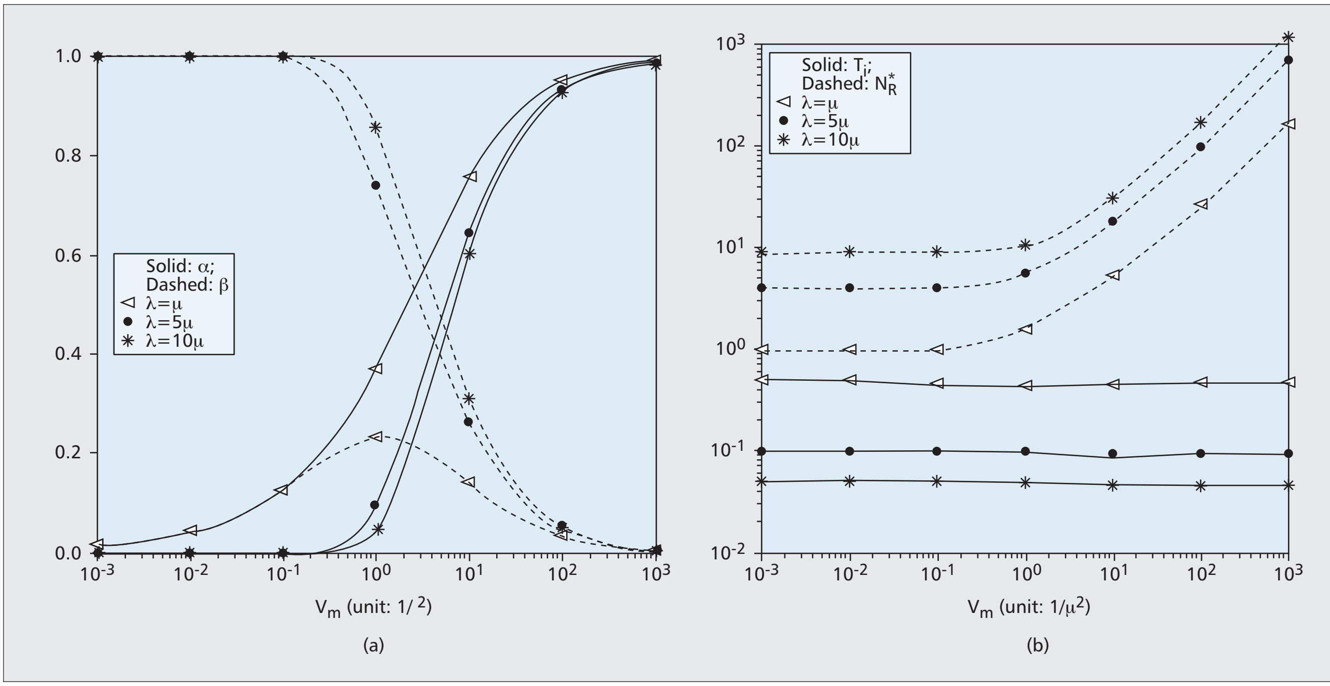

Figure 6. *Emergency performance measures: a)* α *and* β*; b)* T_i *(unit: 1/*μ*) and* N_R^**.*

Fig. 7b). At this point, all PoC clients can compete for permission to speak.

Permission Requesting — To obtain permission, a listening PoC client X sends the `TB_Request` message to the PoC server. Client X becomes a *requesting* PoC client (for speak permission), and its FSM_U enters *pending TB_Request* (transition 3, Fig. 7b). This state indicates that client X is waiting for arbitration from the PoC server. If some other PoC client has been granted permission, the PoC server sends the `TB_Deny` message to client X, and FSM_U of client X moves back to *has no permission* (transition 4, Fig. 7b). If the PoC server grants permission to client X, it sends the `TB_Granted` message to client X and the `TB_Taken` message to other PoC clients. FSM_G enters *TB_Taken* (transition 4, Fig. 7a), and FSM_U of client X enters has permission (transition 5, Fig. 7b). When a listening PoC client receives `TB_Taken`, its FSM_U remains at *has no permission*, and it is not allowed to request permission. After client X has become the permitted PoC client, T2 at the PoC server is started. This timer is used to monitor if this client X speaks too long (and therefore should be revoked).

Permission Revoking — If permitted client X speaks longer than the T2 period, the PoC server will send the `TB_Revoke` message to reclaim the permission and start the T3 timer. Upon receipt of the `TB_Revoke` message, FSM_U of client X enters *pending TB_Revoke* (transition 8, Fig. 7b). FSM_G enters *pending TB_Revoke* (transition 5, Fig. 7a). In this state the PoC server keeps forwarding transient media packets of client X until T3 expires. Then FSM_G enters *TB_Idle* (transition 6, Fig. 7a). The PoC server sends the `TB_Idle` message to all PoC clients. FSM_U of client X enters *has no permission* (transition 9, Fig. 7b) upon receipt of the `TB_Idle` message. When a listening PoC client receives `TB_Idle`, its FSM_U remains at *has no permission*. At this point, all PoC clients can compete for permission to speak.

Permission Queuing — A queueing option is provided in the talk burst control mechanism. If this option is selected, the ungranted requests are buffered in the queue at the PoC server instead of being denied. In this option, after the permitted PoC client finishes talking, the PoC server grants the next request from the queue. The state *queued* in FSM_U (dark oval, Fig. 7b) indicates that a request of the client is buffered in the PoC server and will be granted later.

After PoC client X has obtained permission, the PoC server may receive the `TB_Request` message from another requesting PoC client Y. With the queueing option, FSM_G is in the *TB_Taken* state, and FSM_U of client Y is in the *pending TB_Request* state. The PoC server buffers the `TB_Request` message in the queue and replies with the `TB_Queued` message to client Y. FSM_G stays in *TB_Taken*, and FSM_U of client Y enters queued (transition 10, Fig. 7b). Client Y is called a *queued PoC client*. If a queued PoC client is not patient, it will send the `TB_Release` message to the PoC server to cancel the request, and its FSM_U moves back to *has no permission* (transition 11, Fig. 7b). In this case, the PoC server removes the corresponding request from the queue. The period between when a PoC client enters the queued state and when it enters the *has no permission* state is called the *patient time*. After the permission is released (or revoked), FSM_G will enter `TB_Idle`, and FSM_U of the permitted PoC client will enter *pending TB_Release* (transition 6, Fig. 7b) or *pending TB_Revoke* (Transition 8, Fig. 7b). If the queue is not empty, the PoC server grants permission to the next queued request instead of sending the

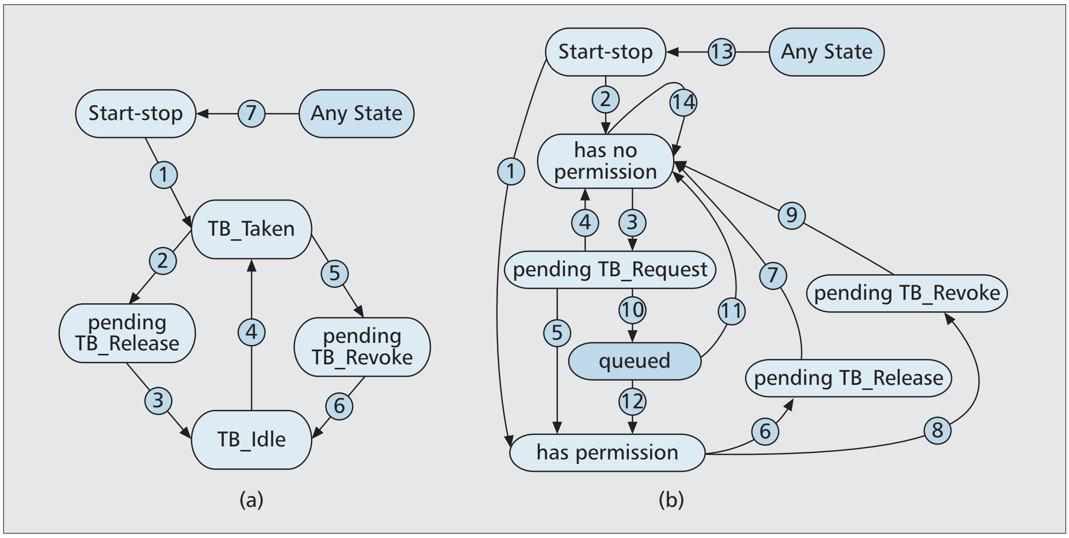

Figure 7. *Talk burst control finite state machines for: a) PoC server* (FSM_G)*; b) PoC client* (FSM_U).

Our study indicates that PoC with queueing can comfortably accommodate twice as many participants as PoC without queueing, where the waiting time for a PoC participant to be granted permission is reasonable short.

`TB_Idle` message. The next queued PoC client will receive the `TB_Granted` message from the PoC server, and its FSM_U enters *has permission* (transition 12, Fig. 7b). This queued PoC client becomes the next permitted PoC client. At the same time, other PoC clients receive the `TB_Taken` message from the PoC server. Client X becomes a listening PoC client, and its FSM_U enters *has no permission* (transition 7 or 9, Fig. 7b). FSM_U of every listening PoC client remains *has no permission*, and FSM_U of every queued PoC client remains *queued*.

Session Termination — When a PoC client leaves the PoC session, its FSM_U moves back to *start-stop* (transition 13, Fig. 7b). The PoC session remains active for other PoC clients. After all PoC clients have left the PoC session, the session is implicitly terminated. FSM_G moves back to *start-stop* (transition 7, Fig. 7a).

Performance Evaluation

Based on [4], we investigate the performance of the PoC talk burst control mechanism with queueing (approach Q) and without queueing (approach NQ). Define the *revoking* timer as T_R = T2 + T3. Let the permission request arrivals of a PoC client form a Poisson process with rate λ. The speak time is a random variable with mean $1/\mu$. The patient time is a random variable with mean $1/\omega$. Both speak and patient times are assumed to be Exponentially distributed. Other distributions show similar results, and the reader is referred to [6] for details. Let M be the number of PoC clients in a PoC group. In Chunghwa Telecom's commercial PoC service, M is limited to 20 (i.e., at most 20 members can participate in a PoC session). In this study we assume that $5 \leq M \leq 40$. Two output measures are considered:

- P_D: The denied probability that the request of a PoC client is not granted because this client is not patient in approach Q or the PoC server rejects the request in approach NQ.
- W: The expected waiting time between when a PoC client requests permission to speak and when it is granted permission under the condition that the PoC client is not immediately granted permission. The W measure excludes the waiting times of immediately granted requests (which are 0) so that we can answer the question "If you have to wait, how long will you wait?"

Under the conditions that $\lambda = 0.01\mu$ and $T_R = 3/\mu$, Fig. 8a indicates that for the same P_D performance, approach Q can support at least twice as many clients as approach NQ. For example, to maintain $P_D = 0.038$, approach NQ can only support $M = 5$, while approach Q can support $M = 10$ (for $\omega = \mu$) and $M = 40$ (for $\omega = 0.1\mu$).

Figure 8b illustrates the expected waiting time performance (W_Q for approach Q and W_{NQ} for approach NQ) before a PoC client is granted permission to speak (if he/she is not immediately accepted by the PoC server). To make a fair comparison, we set $\omega = 0$ for approach Q so that W_Q will not be shortened by impatience. For approach NQ, when a PoC client fails to obtain permission, it keeps requesting until permission is granted. Therefore, W_{NQ} is the period between its first try and when it is granted permission. Figure 8b plots W_Q and W_{NQ} (measured by $1/\mu$) against M. The figure indicates that W_Q is much shorter than W_{NQ}. Furthermore, even if the number of PoC participants is large (e.g., $M = 40$), W_Q is reasonably short (less than $2.5/\mu$).

Conclusions

This article has conducted a preliminary investigation of two emergency services for IMS: emergency call and push-to-talk over cellular (PoC). In the IMS emergency call study we observe that the existing location tracking mechanism (called location polling) might mistrack the caller and cause unnecessary signaling overhead. We describe a modified mechanism called active location reporting, which may potentially enhance the performance of location polling. Based on this conclusion, most location-based services in Chunghwa Telecom have utilized an active-location-reporting-like mechanism. In the future this mechanism will be provided in IMS.

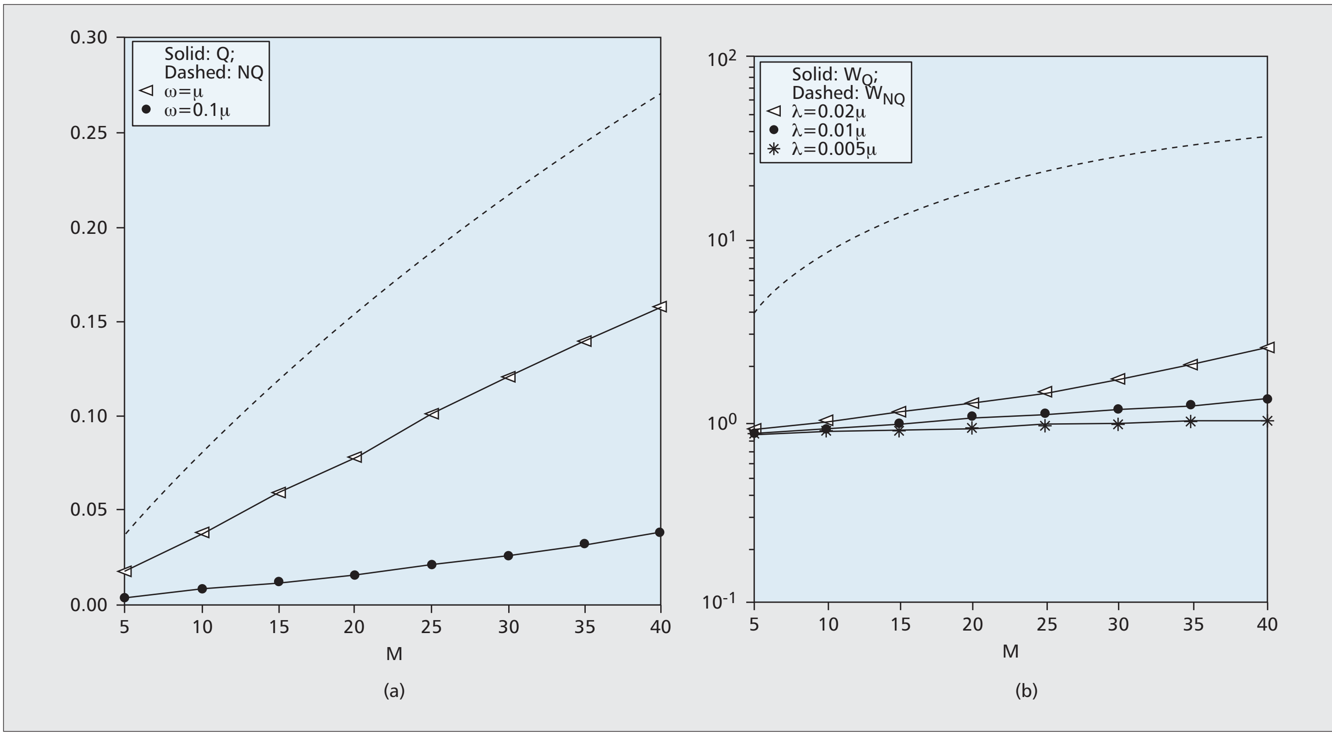

Figure 8. *Effects on* P_D, W_Q, *and* W_{NQ} *(*$T_R = 3/\mu$*): a)* P_D *(*$\lambda = 0.01\mu$*); b)* W_Q *and* W_{NQ} *(unit:* $1/\mu$*), (*$\omega = 0$*).*

For PoC, to guarantee that everyone can always obtain permission to talk in emergency situations, the queueing option of PoC should be selected. Our study indicates that PoC with queueing can comfortably accommodate twice as many participants as PoC without queueing, where the waiting time for a PoC participant to be granted permission is reasonably short. In the future, we will also consider the trade-off between priority and fairness in the queueing mechanism.

In summary, our preliminary study provides guidelines to deploy emergency call and PoC in a commercial IMS network.

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