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- IMS Emergency Services: A Preliminary Study
- Mixing Network Coding and Cooperation for Reliable Wireless Communications
- Spectrum Sensing for Cognitive Radio Systems
- Cooperative Communication in Multihop Cognitive Radio Networks Based on Multicarrier Modulation
- Topological-Based Architectures for Wireless Mesh Network

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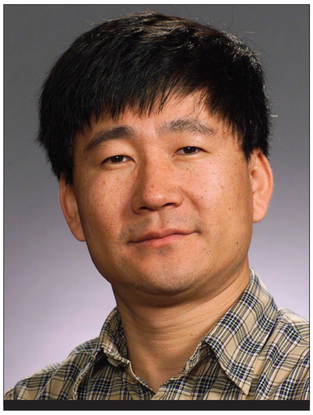
MESSAGE FROM THE EDITOR-IN-CHIEF

CALL FOR MORE WIRELESS INNOVATIONS



YUGUANG MICHAEL FANG

First of all, I am happy to report that my term as the Editor-in-Chief has been extended for one more year. I also want to report that we have been working on moving into Manuscript Central, which will be a great step toward a more efficient paper handling process. As a new year starts, we also look forward to more exciting news on wireless communications, networking, and their applications. You may have already read the first issue of *IEEE Spectrum* this year. Among the top 11 identified technologies (although it is not clear why it is 11 rather than the more commonly used 10, perhaps to avoid a copyright lawsuit from David Letterman?), smartphones are ranked on top. Unfortunately, the column does not spell out the drivers of future smartphone technologies: the deep integration technologies of smartphones with smart environments and human interactions for ubiquitous data collection, processing, data mining, communications and networking, and decision making and control. The second technology on the top 11 list is social networking, which has close ties to wireless technologies as most users have already been doing their social networking with smartphones or mobile devices, leading to the ever more popular mobile social networking. As we can see, wireless technologies have already revolutionized the way we live and have transformed our society into a completely different kind for everything imaginable. We, the engineers and scientists, are at center stage to utilize the technologies we have created to make a significantly different society, good or bad, and it is up to us to reshape it and our living environments for better quality of life. We need you to invent new technologies, including wireless technologies, and we need new ideas and new innovations from you. Our magazine offers you the platform for you to spread the word. We are searching for articles on new innovations in the wireless area and solicit new special

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issues on hot topics that are of great interest to our readership. Some of the topics we are particularly interested in are wireless technologies in cyber-physical systems, social networks, smart grids, healthcare and medical systems, urban sensing and public safety, and cloud computing systems. With the upcoming electronic paper handling process, I hope we can make the publication process much faster. For those who are engaging in hot wireless innovations, I encourage you to organize special issues to share your excitement with our general audiences.

Due to the unforeseen delay in getting articles for the planned special issue, we have decided to accommodate articles from our open call to cut the long queue of accepted papers. We have selected 10 articles in this issue; their brief summaries follow.

"IMS Emergency Services: A Preliminary Study," by Yi-Bing Lin, Meng-Hsun Tsai and Yuan-Kuang Tu, presents a study on how to support emergency call and walkie-talkie services over IP Multimedia Subsystem in wireless cellular systems.

"Mixing Network Coding and Cooperation for Reliable Wireless Communications," by Francesco Rossetto and Michele Zorzi, gives an overview of how to take advantage of both cooperation and network coding to improve the performance and error correction capabilities of radio networks and highlights the main challenges for future research.

"Securing Underwater Wireless Communication Networks," by Mari Carmen Domingo, reviews some important security design issues specific to underwater wireless communication networks and discusses possible research challenges.

"Spectrum Sensing for Cognitive Radio Systems: Technical Aspects and Standardization Activities of IEEE 1900.6 Working Group," by Klaus Moessner, Hiroshi Harada, Chen Sun, Yohannes D. Alemseged, Ha Nguyen Tran, Dominique Noguet, Ryo Sawai, and Naotaka Sato, overviews the technical issues on spectrum sensing for cognitive radio systems and the related IEEE standardization activities for sensing information exchange, particularly focused on activities from the IEEE P1900.6 working group.

"Cooperative Communication in Multihop Cognitive Radio Networks Based on Multicarrier Modulation," by Tao Luo, Fei Lin, Tao Jiang, and Mohsen Guizani, studies the multicarrier modulation schemes for multihop cognitive radio networks and shows that filtered multitone modulation performs better than orthogonal frequency-division multiplexing (OFDM) in terms of mutual interference elimination, synchronization, and transmission efficiency. Moreover, the authors combine cognitive radio capability with cooperative diversity and come up with three efficient cooperative diversity cognitive models.

"Challenges, Opportunities, and Solutions for Converged Satellite and Terrestrial Networks," by Tarik Taleb, Yassine Hadjadj-Aoul and Toufik Ahmed, investigates some important design issues related to interworking operations between the satellite and terrestrial domains in order to support a wide variety of services for users with a variety of roles (consumer, producer, or manager of communication and media), and suggests some possible solutions and their potential.

"Interference Coordination in OFDM-Based Multihop Cellular Networks toward LTE-Advanced," by Kan Zheng, Bin Fan, Yicheng Lin, and Wenbo Wang, presents an overview of the interference coordination strategies for OFDM-based multihop cellular networks and proposes several static or semi-static interference coordination schemes based on the framework of Long Term Evolution (LTE)-Advanced networks with multihop relaying to improve coverage and increase the data rate over cell edge areas.

"Distributed Automated Incident Detection with Vgrid," by Behrooz Khorashadi, Fred Liu, Dipak Ghosal, Chen-Nee Chuah, and Michael Zhang, studies an ad hoc distributed automated incident detection algorithm for highway traffic using vehicles that are equipped with wireless communications, processing, and storage capabilities. By requesting vehicles with such capability to broadcast beacon information containing their speed, location, and lane information, the detection algorithm can make better decisions and yield better performance.

"Topological-Based Architectures for Wireless Mesh Network," by Amir Esmailpour, Nidal Nasser, and Tarik Taleb, provides an overview on architectural design for wireless mesh networks, summarizes the state-of-the-art research findings, and calls for further research on this topic.

"Synchronization of Multihop Wireless Sensor Networks at the Application Layer," by Álvaro Marco, Roberto Casas, José Luis Sevillano, Victorián Coarasa, Ángel Asensio, and Mohammad S. Obaidat, proposes a method for accurate synchronization of large multihop networks, which operates at the application layer while minimizing message exchange.

I hope you enjoy reading these articles. I also wish you a productive 2011!

BIOGRAPHY

YUGUANG MICHAEL FANG [F'08] (fang@ece.ufl.edu) received a Ph.D. degree in systems engineering from Case Western Reserve University in January 1994 and a Ph.D. degree in electrical engineering from Boston University in May 1997. He was an assistant professor in the Department of Electrical and Computer Engineering at New Jersey Institute of Technology from July 1998 to May 2000. He then joined the Department of Electrical and Computer Engineering at the University of Florida in May 2000 as an assistant professor, got an early promotion to associate professor with tenure in August 2003, and to full professor in August 2005. He held a University of Florida Research Foundation (UFRF) Professorship from 2006 to 2009, a Changjiang Scholar Chair Professorship with Xidian University, Xi'an, China, from 2008 to 2011, and a Guest Chair Professorship with Tsinghua University, China, from 2009 to 2012. He has published over 250 papers in refereed professional journals and conferences. He received the National Science Foundation Faculty Early Career Award in 2001 and the Office of Naval Research Young Investigator Award in 2002, and is the recipient of the Best Paper Award from the IEEE International Conference on Network Protocols (ICNP) in 2006 and the recipient of the IEEE TCGN Best Paper Award at the IEEE High-Speed Networks Symposium, IEEE GLOBECOM in 2002. He is also active in professional activities. He is a member of ACM. He is currently serving as the Editor-in-Chief for *IEEE Wireless Communications* (2009–present) and serves/has served on several editorial boards of technical journals including *IEEE Transactions on Mobile Computing* (2003–2008, 2011–present), *IEEE Transactions on Communications* (2000–present), *IEEE Transactions on Wireless Communications* (2002–2009), *IEEE Journal on Selected Areas in Communications* (1999–2001), *IEEE Wireless Communications* (2003–2009), and *ACM Wireless Networks* (2001-present). He served on the Steering Committee for *IEEE Transactions on Mobile Computing* (2008–2010). He has been actively participating in professional conference organizations such as serving as Steering Committee Co-Chair for QShine (2004-2008), Technical Program Vice-Chair for IEEE INFOCOM'2005, Technical Program Area Chair for IEEE INFOCOM (2009–2012), Technical Program Symposium Co-Chair for IEEE GLOBECOM 2004, and member of the Technical Program Committee for IEEE INFOCOM (1998, 2000, 2003–2008).

EDITED BY YANCHAO ZHANG

Using Classification to Protect the Integrity of Spectrum Measurements in White Space Networks

O. Fatemieh, A. Farhadi, R. Chandra, and C. Gunter, in the 18th Annual Network & Distributed System Security Symposium (NDSS), San Diego, CA, February 2010

The emerging paradigm for using the wireless spectrum more efficiently is based on enabling secondary users to exploit white space frequencies that are not occupied by primary users. A key enabling technology for forming networks over white spaces is distributed spectrum measurements to identify and assess the quality of unused channels. This spectrum availability data is often aggregated at a central base station or database to govern the usage of spectrum. This process is vulnerable to integrity violations if the devices are malicious and misreport spectrum sensing results. This paper presents CUSP, a new technique based on machine learning that uses a trusted initial set of signal propagation data in a region as input to build a classifier using support vector machines. The classifier is subsequently used to detect integrity violations. Using classification eliminates the need for arbitrary assumptions about signal propagation models and parameters or thresholds in favor of direct training data. Extensive evaluations using TV transmitter data from the FCC, terrain data from NASA, and house density data from the U.S. Census Bureau for areas in Illinois and Pennsylvania show that CUSP is effective against attackers of varying sophistication, while accommodating regional terrain and shadowing diversity.

Privacy-Preserving Regression Modeling of Participatory Sensing Data

H. Ahmadi, N. Pham, R. Ganti, T. Abdelzaher, S. Nath, and J. Han, in the 8th ACM Conference on Embedded Networked Sensor Systems (SenSys), Zurich, Switzeland, November 2010

Many participatory sensing applications use data collected by participants to construct a public model of a system or phenomenon. For example, a health application might compute a model relating exercise and diet to amount of weight loss. While the ultimately computed model could be public, the individual input and output data traces used to construct it may be private data of participants (e.g., their individual food intake, lifestyle choices, and resulting weight). This paper proposes and experimentally studies a technique that attempts to keep such input and output data traces private, while allowing accurate model construction. This is significantly different from perturbation-based techniques in that no noise is added. The main contribution of the paper is to show a certain data transformation at the client side that helps keeping the client data private while not introducing any additional error to model construction. The authors particularly focus on linear regression models which are widely used in participatory sensing applications. They use the data set from a map-based participatory sensing service to evaluate their scheme. The service in question is a green navigation service that constructs regression models from participant data to predict the fuel consumption of vehicles on road segments. They evaluate the proposed mechanism by providing empirical evidence that: i) an individual data trace is generally hard to reconstruct with any reasonable accuracy, and ii) the regression model constructed using the transformed traces has a much smaller error than one based on additive data-perturbation schemes.

Reliable Clinical Monitoring Using Wireless Sensor Networks: Experiences In A Step-Down Hospital Unit

O. Chipara1, C. Lu, T. Bailey, and G. Roman, in the 8th ACM Conference on Embedded Networked Sensor Systems (SenSys), Zurich, Switzeland, November 2010

This paper presents the design, deployment, and empirical study of a wireless clinical monitoring system that collects pulse and oxygen saturation readings from patients. The primary contribution of this paper is an in-depth clinical trial that assesses the feasibility of wireless sensor networks for patient monitoring in general hospital units. The authors present a detailed analysis of the system reliability from a long-term hospital deployment over seven months involving 41 patients in a step-down cardiology unit. The network achieved high reliability (median 99.68 percent, range 95.21–100 percent). The overall reliability of the system was dominated by sensing reliability of the pulse oximeters (median 80.85 percent, range 0.46–97.69 percent). Sensing failures usually occurred in short bursts, although longer periods were also present due to sensor disconnections. The authors show that the sensing reliability could be significantly improved through oversampling and by implementing a disconnection alarm system that incurs minimal intervention cost. A retrospective data analysis indicated that the system provided sufficient temporal resolution to support the detection of clinical deterioration in three patients who suffered from significant clinical events including transfer to intensive care units.

CodeOn: Cooperative Popular Content Distribution for Vehicular Networks Using Symbol Level Network Coding

M. Li, Z. Yang, and W. Lou, IEEE Journal on Selected Areas in Communications (JSAC), special issue on Vehicular Communication Networks, vol. 29, no. 1, January 2011

Driven by both safety concerns and commercial interests, one of the key services offered by vehicular networks is popular content distribution (PCD). The fundamental challenges to achieve high speed content downloading come from the highly dynamic topology of vehicular ad hoc network (VANET) and the lossy nature of the vehicular wireless communications. This paper introduces CodeOn, a novel push-based PCD scheme where contents are actively broadcasted to vehicles from road side access points and further distributed among vehicles using a cooperative VANET. In CodeOn, we employ a recent technique, symbol level network coding (SLNC), to combat the lossy wireless transmissions. Through exploiting symbol level diversity, SLNC is robust to transmission errors and encourages more aggressive concurrent transmissions. In order to fully enjoy the benefits of SLNC, we propose a suite of techniques to maximize the downloading rate, including a prioritized and localized relay selection mechanism where the selection criteria are based on the usefulness of vehicle-possessed contents, and a lightweight medium access protocol that naturally exploits the abundant concurrent transmission opportunities. We also propose additional mechanisms to reduce the protocol overhead without sacrificing the performance.

Free Side Channel: Bits over Interference

K. Wu, H. Tan, Y. Liu, J. Zhang, Q. Zhang, and L. Ni, in the 16th Annual International Conference on Mobile Computing and Networking (MobiCom), Chicago, Illinois, September 2010

Interference is a critical issue in wireless communications. In a typical multiple-user environment, different users may severely interfere with each other. Coordination among users therefore is an indispensable part of interference management in wireless networks. It is known that coordination among multiple nodes is a costly operation, taking a significant amount of valuable communication resources. In this paper, the authors have an interesting observation that by generating intended patterns, some simultaneous transmissions (i.e., "interference") can be successfully decoded without degrading the effective throughput in the original transmission. As such, an extra and "free" coordination channel can be built.

Based on this idea, the authors propose a DC-MAC to leverage this "free" channel for efficient medium access in a multiple-user wireless network. They theoretically analyze the capacity of this channel under different environments with various modulation schemes.

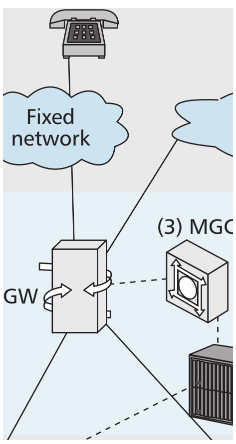
Enabling High-Bandwidth Vehicular Content Distribution

U. Shevade, Y. Chen, L. Qiu, Y. Zhang, V. Chandar, M. Han, H. Song, and Y. Seung, in the 6th International Conference on emerging Networking EXperiments and Technologies (CoNEXT), Philadelphia, PA, November 2010

This paper presents VCD, a novel system for enabling high-bandwidth content distribution in vehicular networks. In VCD, a vehicle opportunistically communicates with nearby access points (APs) to download the content of interest. To fully take advantage of such transient contact with APs, the authors proactively push content to the APs the vehicles are likely to visit in the near future. In this way, vehicles can enjoy the full wireless capacity instead of being bottlenecked by Internet connectivity, which is either slow or even unavailable. The authors develop a new algorithm for predicting the APs that will soon be visited by the vehicles. They then develop a replication scheme that leverages the synergy among (i) Internet connectivity (which is persistent but has limited coverage and low bandwidth), (ii) local wireless connectivity (which has high bandwidth but transient duration), (iii) vehicular relay connectivity (which has high bandwidth but high delay), and (iv) mesh connectivity among APs (which has high bandwidth but low coverage). The authors demonstrate the effectiveness of the VCD system using trace-driven simulation and Emulab emulation based on real taxi traces. They further deploy VCD in two vehicular networks, one using 802.11b and the other using 802.11n, to demonstrate its effectiveness.

IMS EMERGENCY SERVICES: A PRELIMINARY STUDY

YI-BING LIN, NATIONAL CHIAO TUNG UNIVERSITY
MENG-HSUN TSAI, NATIONAL CHENG KUNG UNIVERSITY
YUAN-KUANG TU, CHUNGHWA TELECOM



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.

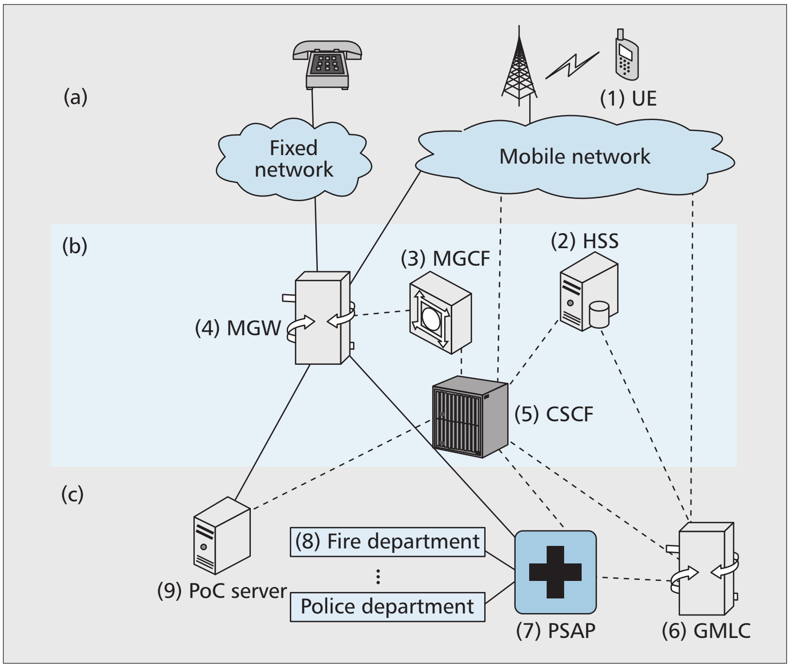

Figure 1. *A simplified IMS network architecture (dashed lines: control signaling; solid lines: user data/control signaling): a) fixed and mobile telecom networks; b) IP Multimedia Subsystem; c) service and application networks.*

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

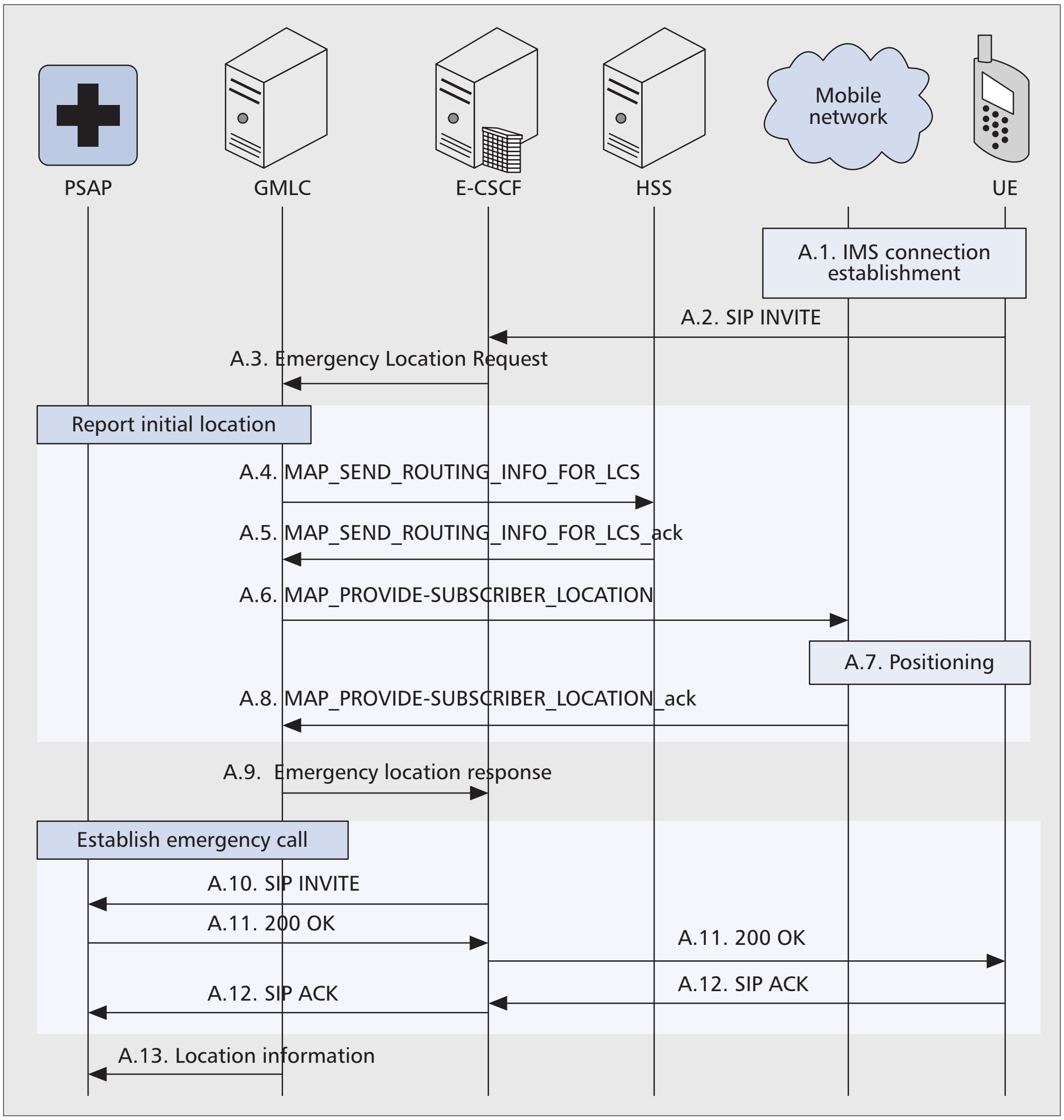

Figure 3. *IMS emergency call setup.*

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.

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).