Wireless Ad Hoc Dissemination for Search and Rescue

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ABSTRACT

In search and rescue scenarios local information on victims and other finds needs to be disseminated rapidly to other rescue workers and team leaders. However, post disaster scenarios may imply the collapse of information infrastructure including cellular communication and Internet connectivity. Even if we consider wireless ad hoc communication as a means of information dissemination we should count on frequent loss of connectivity in the network due to unpredictable mobility and sparse network topologies. In this paper we present the realization of an existing manycast protocol (random walk gossip) on commodity handheld devices running the Android platform. This communication mode is used to demonstrate the potential for distributed information dissemination on victims and finds. The application layer is an adaptation of an existing surveying information tool (POSIT) which is now fully decentralized and relies on text communication to achieve energy efficiency.

Keywords

FOSS, physical testbed, disaster area networks, Android, partition-tolerant

INTRODUCTION

Imagine a post storm scenario in which electricity and communication infrastructures are almost non-existent, and the sporadic access to the cellular network or Internet is subject to massive overloads. In the aftermath of Hurricane Katrina, for example, the actors in the rescue operations struggled with access to relevant information, and emergency management coordination processes suffered considerable delays and shortcomings (Steckler, Bradford and Urrea, 2005). A major requirement in coordination of search and rescue operations is access to knowledge about the common state of affairs, referred to as situation awareness (Endsley, 2000). This is harder to achieve in a geographically dispersed rescue environment. Another pronounced requirement is a common picture of where the resources are and under which authority. Obviously any rudimentary pooling of knowledge requires a relatively reliable communication platform (Gaynor, Barnder, Pearce and Post, 2008).

The notion of hastily formed networks (Denning, 2006) has emerged as a response to the need for establishment of communication networks in an area with little or no access to infrastructure. Note that this does not contradict the availability of other means of communication further away from the core disaster area or in later weeks and months, as demonstrated by the massive activity on social networks in connection to Tsunami, wildfires, and other public hazards (Palen, Hiltz and Liu, 2007). The idea here is to fall back on any available means of communication when all else fails (Asplund, Nadjm-Tehrani, and Sigholm, 2008).

Lack of communication infrastructure and prevalence of electricity blackouts seems an obvious premise when planning for emergency preparedness and response. Many public and private actors create access to communication channels and energy resources in the form of diesel generators, container-based telephony

systems, satellite links and so on. In fact the government branches, emergency service, police, defense forces and other involved actors are investigating a move towards partly or completely infrastructure-less communication, e.g. through networks based on the TETRA (Terrestrial Truncated Radio) standard. However, most of the planned solutions are hardware-specific, and not likely to be available on a large scale, or reserved for military operations.

A parallel significant trend is the move towards free and open source software (FOSS) and commodity hardware deployment as a low cost and flexible means to organize grassroots support (Currion, Silva and Van de Walle, 2007). A notable example of such a development was the immediate response to the needs of victim families during the Asian Tsunami of 2004, through development of the Sahana tool (Shana, 2010), which has continued to develop through interest from rescue agencies, academic developers and large IT companies alike. The web-based and centralized nature of Sahana information base is a starting point, setting off a major trend for collaborative and low-cost software development. However, we envisage the need for a larger class of applications that are fully distributed and built on infrastructure-less communication.

In this paper we present a proof of concept for an information gathering tool that operates on commodity devices, based on the FOSS Android platform, and deployed over a hastily formed wireless ad hoc network. The basic communication mechanism in this system is a manycast protocol, used for disseminating information about victims and finds. A manycast protocol is useful when general broadcast of information is desirable but the identity of present nodes or even the number of the nodes available in the topology is unknown. A manycast protocol is thus configured with a parameter k. A dissemination wave terminates when k nodes have been informed of a new item.

The building blocks of the system are as follows. We use the manycast protocol Random Walk Gossip (RWG) (Asplund and Nadjm-Tehrani, 2009) which has the ability to deal with network partitions using the store-and-forward mechanism from delay-tolerant networks, and the energy-efficiency that makes an optimized use of battery resources in power-constrained scenarios. This paper presents an application of the protocol on the Android platform. The Portable Open Search and Identification Tool (POSIT) is a client-server application that assumes Internet connectivity (Gautam, Lanerolle and Morelli, 2009). The new POSIT/RWG implementation provides a lean version of POSIT-like text messaging to support energy-efficiency, and has been adapted to use the dissemination mechanism of RWG to build distributed find tables among the actors in an intermittently connected ad hoc network. There are other systems for information gathering and dissemination using mobile devices, for example, the Epicollect (Aanensen, Huntley, Feil, al-Own and Spratt 2009) have similar capabilities as Posit. However, as far as we are aware, there is no other such system that can function in ad hoc mode (i.e., without the support of fixed infrastructure).

BUILDING BLOCKS

The decentralized disaster tool presented in this paper is based on the existing search and rescue application POSIT, combined with a wireless manycast protocol, RWG. We now proceed to describe these two components, as well as an overview of the Android platform on which the system is built.

Reporting finds using POSIT

Portable Open Search and Identification Tool (POSIT) is an extensible and configurable search and rescue tool built on the Android platform. The current prototype can be used with a properly equipped phone to collect data and coordinate communications in a hypothetical disaster scenario. POSIT makes use of the phone's GPS, camera, touch-screen, and other input devices to gather and save information in the phone's database. Assuming the availability of telecommunications infrastructure, data can be uploaded to a remote server using either WiFi or telephone channels.

As shown in Figure 1, the POSIT application consists of two major components: the on-phone POSIT application, and the remote server.

The phone's POSIT instance is an Android application that serves as a search and rescue tool for a Katrina-like, disaster scenario. The application is designed to assist rescue workers in the search for disaster victims (or "finds"). Initially, a POSIT instance is downloaded from the server into the phone. During a search mission, When a new find is discovered, the phone will mark its location and generate a time stamp. Information about the find–e.g., possible identity, brief description–can be recorded in text or camera images and saved to the on-hone database. A built-in barcode reader can be used to associate a pre-printed ID-tag with the victim.
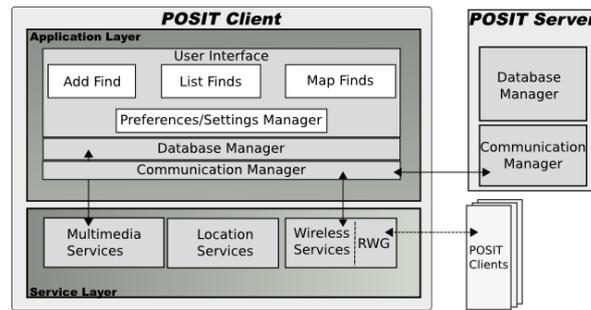
Figure 1. POSIT Architecture

When communication lines are available, the phone's data can be transmitted via Wireless services (WiFi or telephony) to local or remote POSIT servers at command and control centers. When wireless infrastructure is not available, limited information about the finds can be transmitted via RWG to other phones. In addition to transmitting data about the finds themselves, the phones can also record and transmit a complete trace of their own movements. These can be collated by the server into a single map that provides an overview of the search area.

The current POSIT prototype consists of the following modules:

- Add finds: A find is the object being searched for–i.e, disaster victims in this scenario. A touch screen, forms-based interface is used to input text, voice, video, photos and other data associated with the find. All data are saved in the phone's database.

- List Finds: This provides a list of all the finds currently in the phone's database, displaying them either as a clickable list or as clickable icons on a Google map (when in online mode).

- GPS-tracking: When activated, this module records the phone's movements. The user can set the field-of-vision parameter to indicate how wide a swath through the search area is covered by that device.

- Synchronization: Data stored on the phone are transmitted periodically using existing infrastructure to the remote server using an HTTP protocol.

Random walk gossip

RWG is the communication protocol underlying the decentralized POSIT implementation allowing finds to be shared between devices despite lack of telecommunication infrastructure. Its responsibility is to disseminate messages generated by the application layer to other nodes in the network. RWG is a manycast algorithm, meaning that it tries to deliver the message to a specified number (k) of nodes. When the required number of nodes have been reached, the message should not be propagated any more. RWG is designed to (1) deal with intermittent connectivity and network partitions, (2) assume no knowledge about network topology or identity of actors, (3) be bandwidth- and energy-efficient in the sense of few transmissions per data packet, and (4) deliver messages within a relatively short period of time. There are other dissemination algorithms for ad hoc networks, such as Hypergossiping (Khelil, Marrón, Becker and Rothermelns, 2007) and encounter-based message propagation (Cooper, Ezhilchelvan, Mitrani, 2009) however, the RWG protocol has been demonstrated to be very competitive for the case of energy-constrained networks with non-homogeneous mobility movements as is the case for disaster area networks.

Android

Android (Android, 2010) is a free and open source software (FOSS) platform for mobile phones. It consists of a Linux-based operating system, a collection of libraries, and key applications, written in Java, for mobile phones. Android was released by Google in November 2007, in cooperation with 46 other members of the Open Handset Alliance (OHA, 2010). In addition to Google, OHA is made up of telecom companies (such as Sprint Nextel, NTT DoCoMo) and handset manufacturers (such as Toshiba, Motorola, HTC, Intel, and Texas Instruments). OHA is committed to the view that an open source phone architecture will help encourage interoperability and innovation in the mobile phone market. The market share for Android is quickly growing and is already available on a range of phones such as Motorola Droid, HTC Dream, Samsung Galaxy, and Nexus One.

Decentralized POSIT

As described above, the original POSIT application used a central server to synchronize finds with other devices. In the absence of infrastructure, situational awareness data can now be shared among searchers using the RWG protocol (see Figure 1). As soon as a find is added to the database, an RWG message is created and sent out to the other devices. When a properly formatted message arrives at a node, it is added as a find to that phone's database. This way, there is an inherent form of synchronization among the phones. Since RWG can handle network partitions, a find will be propagated even if no devices are immediately reachable. In the current version of decentralized POSIT, the phones share only basic information about the finds—i.e., their GPS coordinates, the timestamp when found, and a brief text description. Images and other data are not transmitted via RWG. This will allow messages to be kept small thereby saving network resources and battery lifetime.

EVALUATION

As a proof of concept a small experiment was created to (1) perform functional testing (2) obtain some range data for reachability of phones, (3) test the applicability of the concept in a physical scenario before we plan real first-responder exercise tests. In this section we describe how the experiment was setup as well as some preliminary results that we obtained.

Experimental setup

Tests at Trinity College: The experiments consisted of five persons each carrying an Android Developer Phone running the decentralized POSIT system. The devices have a range of 300 meters when there is free line of sight, with obstacles the range decreases significantly. The nodes moved (by walking) in an area of 350mx350m. This translates to a coverage factor of $5 \cdot 300^2 \cdot \pi/(350 \cdot 350) \approx 2.3$. Since the nodes will move away from the center of the map, the network will be disconnected most of the time. A map of the area is shown in Figure 2.

Figure 1. Experiment setup (©2009 Digital Globe, ©2009 Tele Atlas, ©2009 Google)

As can be seen in the figure, there are three communication points C1, C2, C3 to which each node goes individually at least once during the experiment. At these places, the likelihood to meet some other node is higher than in the rest of the field. In the experiment area there were also 13 so called finds, F1, ..., F13, that were to reported when found by one of the actors. Upon locating a find, a manycast message was sent with the termination criteria to reach at least four nodes. Before the experiment, the clocks of all the nodes where synchronized to within one minute precision. We have repeated these experiments (i.e., run the same setup twice) and had similar results in both trials.

Table 1 shows a detailed description of the movements of each node. The experiment lasted for approximately 18 minutes. As each phone is equipped with a GPS receiver, the position of each node could be recorded at every find.

Test at Linköping University: In addition to the tests described above, we had a group of seven first-year students perform some physical tests as a component in a hands-on project course for the first semester. Students were performing tests inside long underground corridors as well as outside in street scenarios.

Results

We achieved the goals of the evaluation. In the experiment at Location A, all finds except F12 were delivered to at least four nodes, which was the delivery criteria. So for this particular experiment the success ratio was 92%.

Out of the 13 packets, 7 (54%) were unnecessarily delivered to all 5 nodes. This was expected, as the protocol does not guarantee that only the required number of nodes receives the message.

Time	Action
00:00	Node A1 starts at C1, walks to find F1 Node A2 starts at C1, walks to find F2 Node A3 starts at C1, walks to find F3 Node A4 starts at C1, walks to find F6 Node A5 starts at C1, walks to find F11
00:04	Node A2 walks to find C2
00:05	Node A1 walks to find F10 Node A3 walks to find F4
00:06	Node A5 walks to find F12

Time	Action
00:07	Node A2 walks to find F8 Node A4 walks to find F9
00:08	Node A3 walks to C1
00:09	Node A5 walks to C2
00:10	Node A1 walks to C3 Node A2 walks to find F7
00:11	Node A4 walks to C3
00:12	Node A3 walks to find F5
00:13	Node A1 walks to find F13
00:15	All nodes go to the end position E

Table 1: Experiment description

The most probable explanation for the message with F12 not being 4-delivered is that the nodes holding it did not discover any of the uninformed nodes. Unfortunately, we haven't been able to verify that this is really the cause.

An unexpected outcome of the experiment was the fact that some of the messages were delivered more than once to the application layer. This was caused by the RWG implementation expunging a message m as soon as it was k-delivered. This would not cause any problems except for the fact that there can still be other nodes who are not aware that m has already reached k nodes, so they keep transmitting it, thus causing duplicate deliveries.

The tests at Location B showed that messages are successfully delivered over two hop links and that messages can be carried by one phone to deliver a message in a scenario where there never is any end-to-end connectivity.

Demonstration Session

We have demonstrated this platform at the organized voluntary group in Boden, a town in northern Sweden where the biggest Swedish fire in modern history in took place. The fire raged for 4 weeks in an area of 19 square kilometers. The work in our project has focused on this voluntary group since the record of the fire fighting activities have shown that the voluntary groups were of significant value in the process that lasted over several weeks. The geographical area has some low coverage spots in terms of GSM cellular phones. Our interviews in the focus groups have shown that several of the voluntary forces had been positioned in isolated areas for several hours and the communication infrastructure was of highly intermittent connectivity.

CONCLUSIONS AND FUTURE WORK

Because of its FOSS nature, and because of its adoption by the Open Handset Alliance, the Android platform holds considerable promise for stability and standardization in the mobile phone market. This can only be good news for disaster management applications.

The cooperation across two research teams, one on the application side and another on the systems side demonstrates the feasibility of using a FOSS platform for search and rescue operation support.

The literature on ad hoc networking is abound with results reported in simulation platforms (Akkaya and Younis, 2005; Basagni, 2005; Camp, Boleng and Davies, 2002). A simulation platform is a valuable tool for extensive studies of a communication algorithm in terms of performance, sensitivity to load and other environment changes, and trade offs in choice of parameters. However, a proof of concept development in a real hand set device provides the added credibility that a method is indeed workable in practice. Moreover, emulations serve to highlight some weaknesses or strengths in the algorithm or discover bugs in the detailed implementation as deviations from the expected behavior.

The performed physical tests have shown that combining our rescue application with communication using our dissemination protocol indeed works satisfactorily. It has however, pointed out a few aspects for further improvement. One aspect, the elimination of duplicate deliveries is a simple adjustment to the implementation and was already reported in the evaluation section. Another aspect was the application impact on battery

depletion. In the current prototype, killing the processes after the experiment did not stop the operation of all threads. This led to a faster than expected drainage of battery power, which has so far been traced to the client application.

Finally, in order to be able to study performance aspects such as delay it is necessary to have timestamps not just when creating messages, but also have a timestamped log of each reception. This would also aid in debugging and tracing the protocol behavior. These aspects and improvements to the user interface are points for future extension of this work, prior to a field test by real rescue agents in an exercise setting.

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REFERENCES

1. K. Akkaya and M. Younis. A survey on routing protocols for wireless sensor networks Ad Hoc Networks, Elsevier, 2005, 3, 325-349

2. D.M. Aanensen, D. M. Huntley, E. J. Feil, F. al-Own, B. G. Spratt. EpiCollect: Linking Smartphones to Web Applications for Epidemiology, Ecology and Community Data Collection, PLoS ONE 4(9): e6968. doi:10.1371/journal.pone.0006968

3. Android. http://www.android.com/. Accessed Mar. 2010.

4. M. Asplund and S. Nadjm-Tehrani. A partition-tolerant manycast algorithm for disaster area networks. In 28th International Symposium on Reliable Distributed Systems. IEEE, Sept. 2009.

5. M. Asplund, S. Nadjm-Tehrani, and J. Sigholm. Emerging information infrastructures: Cooperation in disasters. In Proc. 3rd International Workshop on Critical Information Infrastructures Security (CRITIS'08), 2008.

6. S. Basagni. Mobile Ad Hoc Networking Wiley-IEEE, 2004

7. T. Camp. J. Boleng and V. Davies. A survey of mobility models for ad hoc network research. Wireless Communications & Mobile Computing 2002, 2, 483-502

8. D. Cooper, P. Ezhilchelvan, I. Mitrani. Encounter-based message propagation in mobile ad-hoc networks Ad Hoc Networks, 2009, 7, 1271-1284

9. P. Currion, C. d. Silva, and B. Van de Walle. Open source software for disaster management. Commun. ACM, 50(3):61–65, 2007.

10. P. J. Denning. Hastily formed networks. Commun. ACM, 49(4):15–20, 2006.

11. M. R. Endsley. Theoretical Underpinnings of Situation Awareness: A Critical Review. In Endsley and Garland (Eds.) Situation Awareness Analysis and Measurement. Mahwah, NJ: Lawrence Erlbaum Associates. 2000.

12. P. Gautam, T. de Lanerolle, and R. Morelli. Posit: Portable search and identification tool: Using the google phone for disaster management. poster presentation. In Sixth International Conference on Information Systems for Crisis Response and Management (ISCRAM), Gothenborg, Sweden, May 2009.

13. M. Gaynor, S. Brander, A. Pearce, and K. Post. Open infrastructure for a nationwide emergency services network. In 5th International Conference on Information Systems for Crisis Response and Management (ISCRAM'08), 2008.

14. A. Khelil, P.J. Marrón, C. Becker and K. Rothermelns. Hypergossiping: A generalized broadcast strategy for mobile ad hoc networks Ad Hoc Networks, Elsevier Science Publishers B. V., 2007, 5, 531-546

15. Open Handset Alliance. http://www.openhandsetalliance.com/. Accessed Mar. 2010.

16. L. Palen, S. R. Hiltz, and S. B. Liu. Online forums supporting grassroots participation in emergency preparedness and response. Commun. ACM, 50(3):54–58, 2007.

17. Sahana. Free and open source disaster management system. http://www.sahana.lk/. Accessed Mar. 2010.

18. B. Steckler, B. L. Bradford, and S. Urrea. Hastily formed networks for complex humanitarian disasters. http://www.hfncenter.org/cms/KatrinaAAR, Sept. 2005.