Crisis Management and Mobile Devices: Extending the Usage of Sensor Networks within an Integrated System Framework

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ABSTRACT

Crisis response relies on information dissemination and decisions made from real-time data. Sensor networks, especially in an environmental context, are a source of real-time data and used in both military and industrial applications for information gathering. However, sensor data usage for more pervasive system applications, especially mobile applications outside the battlefield, is limited. Mobile devices play key roles in crisis management, but little research exists on their effectiveness under duress. This research extends a previous study on user (responder) preparation in crisis management to mobile device readiness and real-time data acquisition. This paper steps beyond application use to focus on mobile device capabilities and the interface with wireless sensor networks towards an integrated mobile system framework that provides information and real-time decision data for crisis management. In particular, the approach being proposed incorporates novel strategies for maintaining battery life and connectivity among sensors and portable communication devices that are ideally suited for crisis management applications where "staying connected" is critical.

Keywords

Crisis management, sensor networks, environmental sentinels, SMS text-messaging, interoperable communication, training and simulation.

INTRODUCTION

Power failures, the destruction of mobile network base stations, and short-lived batteries on both mobile devices and sensors have all contributed to information dissemination systems that work flawlessly on paper, but still fall short on performance when it matters the most. As such ongoing improvements to wireless sensor network (WSN) applications are needed for incorporation into mobile device-based services and the integration with information systems (IS). SMS (Short Message Service) is “the most popular data service over cellular networks” and one of the most successful wireless data services in recent years (Gomez, 2010; Gomez and Bartolacci, 2007; Zerfos, Meng, Wong, 2006) and provides the baseline for our ongoing research. To date, the deployment of WSNs, especially in an environmental context, for pervasive system applications is limited and lacking in resilience. The Japan 2011 disasters (earthquake, tsunami, nuclear), Pakistan 2010 floods and Haiti 2010 earthquake demonstrate instances where WSNs could be used to report unexpected environmental change. In contrast, during the same three crises, the resilience and reliability of SMS continued to shine. We utilize SMS as the vital link in passing information to mobile devices used by emergency management personnel, governmental agency representatives, non-governmental organization (NGO) representatives and civilians in these crisis scenarios. In this paper we focus on the “push” model of operation (CNN 2010; Zerfos et al. 2006) and 160 character architecture of SMS which utilizes a separate signaling network for traffic giving SMS a distinct advantage.

This research extends from two-way SMS crisis responder usage behavior to usage behavior of SMS when acquiring sensor network data. Our initial focus is on the information (data) being transferred from sensor networks, albeit from a human sensor or from a WSN via an application program interface (API), to a human message recipient. We step beyond application use to examine mobile device capabilities and their integration with wireless sensor networks within an integrated mobile system framework that provides information and decision data for crisis management. In particular, the approach being proposed incorporates novel strategies for maintaining battery life and connectivity among sensors and portable communication devices that are ideally

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suited for crisis management applications where "staying connected" is critical. This paper introduces the role of sentinel events and WSN in crisis management, pinpoints the limitations of traditional networks for crisis management, and discusses the integration of WSNs in information systems for such scenarios. We extend our ongoing research from two perspectives: information communication technology (ICT) usage behavior (training) and sustainable best practices for survivability during "sentinel events". At present, a formal assessment of SMS resilience does not exist and even less work has been conducted which analyzes the effectiveness of the interface between sensor networks and SMS-based crisis management approaches. Effective mobile device usage introduces additional pitfalls, such as limited knowledge and practice with device capabilities, limited practice with message context and actionable response based on the function (application) being used (as with SMS).

SENTINELS, SENSOR NETWORKS AND MOBILE DEVICES

Mobile technology devices and services vary depending on the network service provider and a given user's capability requirements during normal operating conditions. Introducing the uncertainty of a crisis not only impacts the sensor networks currently in place, but also their resilience with respect to interaction via application interfaces. Moreover, new sensors including human ones could also be introduced in real-time mode during crisis response. Both the Japanese 2011 crises (earthquake, tsunami, nuclear) and the Haiti 2010 earthquake reflect the importance of both electronic and human sensors for prediction. Environmental monitoring with sensor networks is one way to detect a "sentinel event" which can be defined as an unexpected occurrence involving death, serious physical injury, or serious psychological injury, or the risk thereof, thus signaling the need for immediate investigation and response, (JCAHO, 2002). Observations, or the disturbing lack thereof, collected from a sensor network can forewarn of a sentinel event. For example, a sensor that reports air quality for critically ill asthmatics creates a sentinel event when it detects high levels of pollutants or irritants in the air being breathed. Robustness in design and functionality would be required for such a system to work under adverse conditions. On a global scale, biosurveillence is set within the context of cooperating sensor networks (human and WSN) that deal with categories of risk requiring immediate investigation and response upon the detection of sentinel events (Kass-Hout and Zhuang, 2010). The utilization of sensor networks as "sentinels" can provide a range of information within a mobile emergency response network and adds new dimensions to the notion of crisis response.

Traditional mobile telecommunication network architectures do not include wireless sensor networks (WSN). Instead they utilize a set of fixed network connection points or more commonly called mobile network base stations. These connection points—finite range of effective transmission/reception often called a cell—are also responsible for relaying traffic bound for individual users' devices in their respective coverage areas. A cell includes the number of expected users to serve (capacity), geographical topology of the surrounding land, presence of man-made or natural barriers to mobile traffic (such as tall buildings or mountains), and the number of other connection points in the area (for other network providers or other types of networks). WSN, a subset of Mobile Ad Hoc Networks (MANETs) are by definition a network of portable devices. All types of Ad Hoc Networks lack fixed infrastructure and therefore do not have fixed network connection points and a corresponding fixed topology linking these points. WSNs have a flexible network topology that can change with the positions of each member device and differ from MANETs in two important aspects: their primary functionality and device sophistication. The design of a MANET's topology at any given point in time is only limited by the mobility, communication range, and bandwidth (capacity and channels) available to each network node. WSNs, on the other hand, almost always use devices with limited computing and storage abilities and a sole function: measurement of some environmental variable or variables. Wireless sensor network devices, often called "Motes", usually have no external power source and rely on internal batteries for operation. This fact severely limits their computing, storage, and communication abilities. Thus, motes often operate on a periodic basis and are not in full operating mode all of the time. For this mode of operation, they "wake up" to measure, and possibly perform some limited preprocessing of, a designated environmental variable. The next step is that they transmit the resulting data to one or more nodes on the network. This action is then followed by reverting back to "sleep" mode where battery usage is minimal. This model of operation conserves battery life and prolongs the independent deployment life of the device since wireless transmission and computationally processing each require a relative large consumption of battery power to be carried out. The root node for a sensor network may actually be a connection point to a fixed network infrastructure or a very sophisticated node for the processing of data collected throughout the sensor network (Hac, 2003). As such, the environmental benefits of WSNs and flexibility play a vital role for crisis management (Bartolacci and Gomez, 2011).

Recognizing that SMS is a reasonably reliable architecture that exchanges packets of information between information communication technologies (McAdams, 2006), we examine the passing of information from sensor networks through the SMS architecture to ultimately arrive at a decision making point. SMS was originally conceived for GSM (Global System for Mobile Communications), but other modern mobile architectures such as CDMA (Code Division Multiple Access) and LTE (Long Term Evolution) now include this service. SMS service, being a text-based data service and not real-time voice, uses the concept of "store-and-forward" for its traffic. This allows SMS traffic to be buffered (stored) at various points during its path from sender to receiver. An advantage of the store-and-forward capability of SMS is that a message can be stored until the receiving party is able to receive the transmission. Store-and-forward traffic, by its nature, is lower priority when compared to other types of Internet and mobile network data traffic. Store-and-forward traffic is therefore more tolerant of fluctuations in network capacity and traffic. Receipt of an SMS message can be delayed in terms of seconds or minutes but will eventually arrive with a high probability which differs from other forms of less reliable wireless communication services such as voice or video that do not have queuing capabilities. Real time voice traffic, for instance, typically requires reserved capacity along an entire predetermined path between the communicating parties for full duplex transmissions. In summary, SMS continues to prevail under severe time constraints, with minimal battery consumption and limited bandwidth when compared to other mobile communication means.

RESILIENCE, SMS, AND EMERGING WIRELESS SERVICES

The 3G and 4G environments have been able to flourish by capitalizing on SMS services that were originally proposed as part of the GSM standards in the 1980's (PSTN, 2010). Adoption and technological change have advanced on an opt-in basis, meaning that human users of the technology decide when to upgrade their services. Location-based services, MMS (Multimedia Messaging Service) and real time mobile video are following the same opt-in structure as network speeds increase and the multimedia capabilities of mobile devices expand. A caveat of these services is that in a crisis, the large battery consumption and high bandwidth are not practical when resources are constrained. This leaves SMS text-messaging as a more viable alternative. In addition, the SMS architecture permits brief gaps in capacity when transmitting to and from mobile base stations. SMS also utilizes a separate network for most of its route between sender and receiver. The global variants of the SS7 (Signaling System Number 7) network carry the actual message as opposed to traditional PSTN traffic-carrying infrastructure across the globe.

To maximize SMS for crisis management, its service must be reliable and have the requisite connectivity. Reliability in this context deals with the percentage of time that the network is operable and allowing users to send and receive SMS messages. Zerfos et al. (2006) present early statistics which revealed that94% of all SMS messages are successfully delivered, leaving 5.1% unsuccessful due to retry expiration or denial of delivery. Moreover, 73.2% of SMS messages reach their recipient in 10 seconds and another 17% reach their recipient in just over one minute.

Connectivity defines the coverage area and related signal strength that facilitate the connection of a mobile device to the network. In other words, it defines the regions from which users can reliably send and receive SMS messages. Due to the proliferation of mobile devices (PDAs, cellular phones, etc.), the E-911 initiative in the U.S., and governmental incentives across the globe, mobile network coverage areas on most continents have expanded over the past several years. Unfortunately, even the most sophisticated telecommunications engineering cannot totally define the connectivity within a given area at a given point in time. Whether, the number of users in a given area, and man-made/natural sources of radio interference all affect a connection point's connectivity and therefore the ability of a user to connect and maintain a connection to a mobile network. The ability of a user to transmit or receive an SMS is crucial for emergency management purposes and the more reliable a given network is, as well as the greater its coverage area, the more ideally suited it is for these purposes.

SENTINELS, CONNECTIVITY AND MOBILE INTEGRATION – A DISCUSSION

Using environmental sentinels (WSN) for pervasive applications that impact health and well-being (life threatening) has many benefits. In contrast, there are many issues associated with connectivity that can hinder mobile integration. Ghosh and Das, (Shorey et al. 2006) discuss WSN issues including routing protocols, node placement, and topology which are known variables in times of crisis and complicate the integration of pervasive applications. Weighing the benefits of environmental sentinels with the realities of waste (energy consumption, replacement batteries, and redundant nodes), sustainable sensors (resource adaptive algorithms, coverage area) and the rapid deployment for crisis use is the basis for proposing our integrated framework. Our initial analysis indicates the importance of e-readiness when resources are constrained and connectivity is challenged. Training and practice with the actual mobile device to maximize information (data) acquisition and decision making contribute to e-readiness (Gomez, 2009). The research question for this initial part of the overall work is: *How can usage behavior and mobile device training strengthen information acquisition from unpredictable sensor network configurations in times of crisis?* This question brings to the forefront the notions of wireless services, ad-hoc networks, and constrained resources that impact the overall success of information dissemination system from a mobile device. The second research question being addressed in this overall work is: *How can sensor network data be effectively integrated into an overall information dissemination system that is robust in the face of unique crisis situation variables?* This part of the work focuses on utilizing sensor networks in conjunction with existing mobile alert systems (and properly trained/practiced users) in an integrated and robust fashion where performance degradation under less than ideal operating conditions are presented. We place emphasis on the integration of sensor networks with scalable functions (applications) on a mobile device when resources are constrained. For example, the integration of sentinel networks with mobile devices could introduce additional options for preparedness (recommender based); a more pervasive use of sensor networks for a mobile information dissemination system is proposed for emergency management that makes use of real time environmental monitoring, despite the usual disparity between types of mobile networks.

Measuring Connectivity – Offsetting Resource Demands

As a first behavior oriented solution (Watson, 2010), we posit that the ability to measure connectivity can increase response readiness along with the conservation of resources in times of crisis. As such, we propose three key ideas that can be incorporated into an integrated and robust system. The first of these is the use of sensor networks for monitoring key environmental parameters (sentinel events). An example of such a network would be a series of wireless sensors near flood-prone streams and rivers to sense flash floods in a region. Such sensors may be activated by submersion in water (thus indicating they are inundated during a flash flood) that report back to local emergency management centers. A second key idea of this integrated system is the use of a "Connectivity Decision Support System" (CDSS) to help ensure that message transmissions are reliable under adverse conditions. The general purpose of such a system is to give mobile device users feedback on how to find and maintain an acceptable level of connectivity through the utilization of mapping functionality, signal strength information, and network infrastructure location information (Nasereddin, Konak, Bartolacci, 2005). The third key idea rests on the possibility of using the mobile devices of users as part of a virtual sensor network where special software to measure environmental parameters would be installed on certain types of devices and such information could be relayed automatically or with human prompting to other users. This hybrid sensor network would not function as a true ad hoc network in that it would use the fixed infrastructure of the mobile network to communicate. Instead the network could have a unique routing mechanism such that environmental reporting within localized areas is routed to devices and users only within those areas until some threshold of relevance is reached, thus triggering reporting to adjacent areas' users and eventually a centralized control user/node.

An Integrated Framework – Initial Steps

Our integrated framework begins with training and practice to maximize the effective use of mobile devices. We capitalize on ICT literacy since no baseline measure beyond our research exists (Gomez, 2008). During training and practice, we educate our stakeholders on connectivity issues and techniques to conserve energy (battery power). At present, we are extending our web-based training application (Gomez, 2008) to include a short segment on energy conservation (battery life). In parallel we are improving the algorithm for our Connectivity Decision Support System. In the context of emergency management, a CDSS would need to be specifically designed in order to deal with the instability and uncertainty of a network operating limitations under crisis conditions. The authors are currently developing the criteria for such a design. The added benefit of a CDSS by emergency management personnel to find or maintain connectivity is that it assists with the extension of battery life. The less connectivity a mobile device has equates to a greater expenditure of power in order to transmit and stay connected to the wireless network. By guiding users towards areas of greater connectivity, a CDSS assists in the conservation of battery power which is an advantage in times of crisis. A question could arise as to how WSN devices could integrate easily with traditional hand held mobile devices such as phones and PDA's. With the advancement of mobile chipsets, the addition of a half-duplex mode that operates on a different set of frequencies is not out of the question. It was not that long ago that hand held GPS devices were separate units and considered to be a separate technology from mobile phones; but today most mobile phones have GPS chipsets or other positioning capabilities and the technologies have converged.

We focus on "opt-in" usage behavior that is supported by e-readiness training and practice in the above mentioned. The use of simulated environmental sentinel events (i.e. flooding, heat waves) for training and ongoing practice in preparation for an actual crisis response will be a subsequent training session of our web-based training application. For example, if we assume that staff working in a retirement community have been participants in our web-based training application, which is designed to increase two-way communication (message content), and understand the initial energy conservation techniques, we have a measure of staff readiness (usage behavior) for the incorporation of WSNs. Introducing the use of WSNs to measure air temperature would extend the staff's usage behavior which increases their response readiness for sentinel events. For routine use of a WSN, the staff might rely on air temperature readings to adjust temperatures of the facility during peak heat waves where brown outs occur. Taking this same example into a crisis situation, information might flow from the WSN to the staff at 10am and then produce a delayed update at 1pm instead of noon (timed 2 hour interval). Recognizing this delayed update, the staff may launch the CDSS system to verify connectivity and scale back the use of mobile services in anticipation of a prolonged brown-out.

CONCLUSIONS AND ONGOING RESEARCH

Current work related to the second research question includes: the establishment of criteria for a CDSS (Bartolacci and Gomez, 2011) suited to an emergency management system, exploration of the types of sensor networks and the necessary interfaces that are ideally suited for use in an integrated emergency management system, and the hardware and software interfaces for creating a virtual sensor network in the context of emergency management. The initial approach for an integrated framework places emphasis on data that can be "shared openly" for crises. We recognize that increased use and deployment of wireless sensor networks would require additional parameters such as security, privacy, and filtering criteria. In parallel our work supports the "call for action" from the information systems community that lags behind with contributions to the field of sustainability and energy informatics increased use and deployment of sensor networks would require additional parameters such as security, privacy, and filtering criteria.

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