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USING WIRELESS NETWORKS TO PROVIDE EARLY WARNING OF EMERGENCY INCIDENTS

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Abstract

Early warning to our citizens in case of emergency incidents, whether deliberate or accidental, can increase public safety substantially. Selective warnings and instructions can limit the negative consequences of an incident by making people on their way into, or passing through, the incident area aware of the threat, thus increasing the possibility for them to avoid the hazard. With the increased use of cellular phones and the infrastructure of the emerging high-capacity wireless networks with large geographical coverage, new possibilities arise to reach a selection of individuals in a specific area. Already today, the wireless networks have increased the ability for the public to report incidents and emergencies to rescue authorities. In this paper we explore the possibility to take additional advantage of the wireless networks in order to deliver selective early warnings to people in or close to a hazardous area. Sending appropriate information in a comprehensible format requires that the target audience can be identified, for example based on geographical location, means of transportation, movement in relation to the incident, and language preferences. We investigate criteria for selecting the target audience, means of customizing message contents, suitable media, and technical requirements and limitations. We analyze these points in relation to practical examples and discuss potential applications.

Introduction

Early warning of an emergency incident to citizens is an important instrument for saving lives, reducing injuries, and limiting property damages. Such warnings can instruct people to evacuate a hazardous area and to keep away from an area. Because many types of emergencies are impossible to predict, such as toxic spills from transportation vehicles and toxic gas leaks, it is important to communicate appropriate warnings as soon as possible to those affected by the incident.

Warnings usually come after the response teams arrive. At the scene, the arriving rescue workers and police officers take part in warning and evacuating people. However, the time between the first

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call reaches the emergency operator and the arrival of rescue workers and police officers on the scene is usually lost in terms of warning the public. Today, it is not possible to warn people from entering the area (e.g., by posting signs and blocking streets) within this early time frame.

For larger incidents, it is possible to use commercial broadcast radio and television for broadcasting a warning. However, warning people by radio and television is quite a significant step, and there is a time lag between the incident and the actual broadcast. Delays occur at several stages, such as contacting the appropriate decision maker, making the decision and preparing the message for broadcasting. Moreover, such warnings assume that people have receivers turned on and are listening or watching. In practice, broadcast warnings are rarely used because most everyday incidents are below the threshold for such general public warnings. We believe that mobile-phone networks are suitable for emergency warnings, because they can send messages promptly to a targeted group of people without involving such general broadcasts.

The proliferation of mobile phones in the 1990s has made it easier and faster for the public to contact emergency services by voice call. In this respect, mobile communication technology has helped shortening the delay between the emergency incidents occur and the arrival of rescue resources at the scenes. Meanwhile, the distribution of emergency warnings to the public has not evolved significantly during the last decades. Currently, it is not possible to take advantage of the mobile networks for emergency-warning purposes. However, there is an increased interest in using new technology to improve crises mitigation and management (The Global Disaster Information Network, 1997; Committee on Computing and Communications Research to Enable Better Use of Information Technology in Government, Computer Science and Telecommunications Board, Commission on Physical Sciences, Mathematics, and Applications, and National Research Council, 1999).

In our approach we want to take advantage of our society's investments in wireless networks and the fact that the mobile-phone penetration in most industrialized countries is relatively high, for example in the year 2000, 80 percent of the households in Sweden had access to one or more cell phones (Nodicom, 2001). This reality makes it possible to reach a large proportion of the people in an area. We believe that emergency-management systems can make multiple-use of these networks for public emergency warnings. Early warning broadcast through mobile messages, such as the Short Message Service (SMS), can complement traditional sirens and radio messages. In addition to providing basic early warning, mobile-phone networks can deliver selective warnings to a group of people. For example, by using mobile positioning, it is possible to send selective messages to people in the vicinity of the incident. Interactive warnings go beyond selective warnings by adding support for feedback from mobile phones, for example manual confirmation and movements in response to warning messages.

In this paper, we discuss the background in terms of human responses to warnings and examine the possible approaches to public warning though mobile-phone networks. We suggest three technology levels for mobile warnings, and list possible services for these levels. Finally, we discuss the implications of our approach, and draw conclusions.

Background

Before we present different approaches to emergency warnings through wireless networks we have to consider some important aspects of warning response. Drabek (1999) stated, "The first principle in understanding disaster warning responses is to recognize explicitly that *the initial response to any warning is denial"* (p. 115, original emphasis).

In the report *Effective Disaster Warning* by the Working Group on Natural Disaster Information Systems Subcommittee on Natural Disaster Reduction (2000) the individual warning reaction process is categorized into the following seven components: (1) perceiving the warning (hear, see, feel), (2) understanding the warning, (3) believing that the warning is real and that the contents are accurate, (4) confirming the warning from other sources or people, (5) personalizing the warning, (6) deciding on a course of action, and finally (7) acting on that decision.

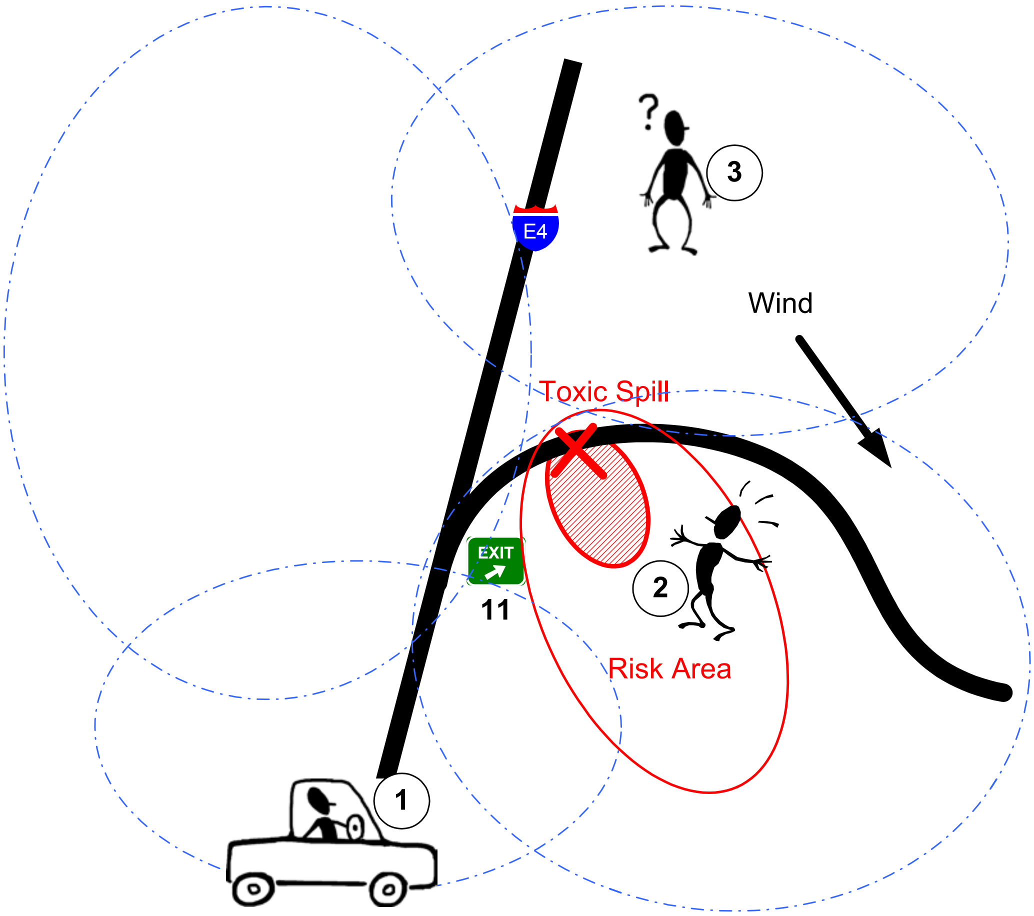
There are a number of factors that affect how people respond to a warning. *Receiver characteristics* describe how various groups of people react in different ways depending on their social, economical and ethnical situation. Receiver characteristics are primarily environmental (cues, proximity), social (network, resources, role, culture, activity), psychological (knowledge, cognition, experience), and physiological (disabilities). Furthermore, a distinction is made between sender and receiver characteristics (Nigg, 1995). *Sender characteristics* focus on the nature of the warning messages (content and style), the channels through which the messages are given (type and number), the frequency by which the messages are broadcast (number and pattern), and the persons or organisations sending the message (authoritativeness, credibility, and familiarity). *Message Characteristics* describe the questions that the warning must answer to be seen as credible to the majority of a population. Table 1 gives an overview of seven important questions when formulating a warning message. *Contextual Characteristics* tell you for example weather a person is at home, at work or travelling. *Event Characteristics* describe the situation to the person who receives the warning. Two event characteristics that have considerable influence on warning acceptance and warning denial are length of forewarning and accessibility of escape routes (Drabek, 1996, p. 261). A comprehensive review of the literature regarding communication issues in disaster management can be found in Mulilis (1998).

In addition to the cognitive aspects of warning we also have to review the technical aspects of existing system and services. The GSM Short Message Service (SMS) is a widespread service that makes it possible to send a 160-character (70 when non-Latin alphabets) message to a mobile phone user. The message can be sent from another mobile phone or from the Internet as long as the network provider supports the service. Several receivers can be addressed as a group using any mail client, either through an SMS-gateway directly from a web page, or by a dial-up PC-modem. SMS has several unique features such as confirmation of delivery to the sender and storage if the recipient is not available. The receiver is notified of an incoming message by sound and vibration. The delivery confirmation service has to be activated by typing a character combination (e.g ##), which is unique for different service providers. This service will confirm that the message has reached the receiver unit, but not whether it has been read. A problem could appear if the receiver unit or the SIM card is out of memory when a message is coming. In this case, most mobile phones will notify the user that the memory is full and that old messages has to be deleted before the new message can be received.

The reliability of SMS services vary considerably between different mobile networks because they deploy different SMS Centres. Not all mobile network operators can support SMS for time and mission critical applications.

Despite little proactive marketing by network operators, SMS growth has been steady across all markets. The GSM Association (2002) estimates that more than one billion SMS messages are sent every day throughout the world.

Figure 1: A simplified example of an emergency incident that we will use to illustrate the different technology levels for a warning system using wireless networks. (1) One person is heading north in a car on road E4. (2) Another person is close to the toxic spill and in the risk area. (3) A third person is observing the incident and does not know what to do. The four dotted ellipses show the boundaries for the cells in the network.



Introduction to the three technology levels for mobiles warnings

With the background of both the human and technical aspects of early warning we have identified three technology levels for communicating warnings to citizens: early-warning broadcast, geographical selective warning, and interactive network warning. Early-warning broadcast is a basic approach to complement sirens and radio messages. Geographical selected warning can send messages to a specific area. Finally, interactive network warning can take advantage of information feedback from mobile phones, such as movements and behaviour.

Table 1: Seven important questions when formulating a warning message.

Questions to be answered by the warning	Comment
Who is issuing the warning?	Credibility and trust. Do I trust the authority or person that is issuing the warning?
What is threatening?	What knowledge do I have about the threat type and possible consequences of the threat?
What exact geographical area is threatened?	Am I in the area? Is our home in the area?
When is it coming?	What is the time reference and is there time to act?
How probable is the event?	Has this type of situation occurred before?
Are there high-risk locations?	What areas must be avoided? Alternative routes?
What specific protective actions should be taken?	Individual training level (Liu et al., 1996) and available resources.

Figure 2: Example of a warning message sent using Short Message Service (SMS) and received on a cellular phone.

Level 1: Early Warning Broadcast

Early warning broadcast messages through mobile-phone networks can be seen as a complement to sirens and radio messages that are available in most countries today. The principle is similar, but with extended use of wireless networks to broadcast the warning. The purpose is to reach more people in case of an emergency than today. Another goal is to provide more detailed information about the emergency than just the warning message, in order to increase the warning acceptance rate among the people warned.

Figure 1 illustrates an emergency situation where a toxic spill has occurred as a consequence to a traffic incident. In addition to the people directly involved in the traffic accident, there are three persons close to the incident area when the accident occurs. Figure 2 shows a cellular phone and the beginning of the broadcast warning message sent from the fire brigade. This message is sent in parallel with the dispatch of rescue units to the incident scene. To be as effective as possible the message should answer the questions in Table 1. The complete message reads:

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Warning from the Fire Brigade.
Toxic spill at road E4, exit 11.
The accident occurred at 14:34, 14 May 2002.
Danger in and around road E4, exit 11.
Rescue units are inbound.
Do not approach the incident area.
If you live close to road E4, exit 11: Close doors and windows and stay
inside.
For further instructions and information about the incident turn on
your radio or call 911.
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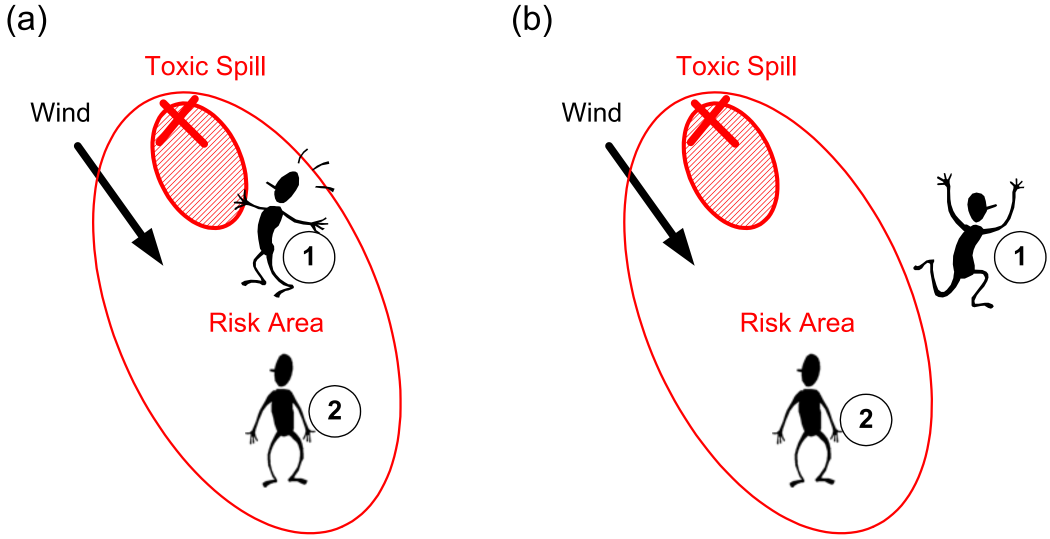
Level 2: Selective Area Warning

A problem with broadcast warnings is that several people who are not in danger are warned (The Working Group on Natural Disaster Information Systems Subcommittee on Natural Disaster Reduction, 2000). In the long run this can have a negative effect on how a relevant warning is received by a population. As a consequence the authorities are often restrictive when it comes to broadcast warnings. This is one reason why selective warnings are an attractive approach for incidents and emergencies that affect limited geographical areas.

With the use of wireless networks, for example cellular phones in GSM networks, it is possible to transmit selective warnings to individual network cells. A cell is typically 3 miles in radius, but the range depends on the geographical conditions. In this way it is possible to give tailored warnings depending on the location of the cell in relation to the incident area. Particularly, we want to use the time more efficiently between the incident and the time when the first rescue vehicle arrives at the incident scene by providing the people in and around the incident area with an early warning accompanied by instructions on how they should behave in order to protect themselves.

In the situation illustrated in Figure 1 the warning messages could be tailored and limited to the different geographical areas around the incident. In this case person number one should receive the general warning about the incident together with additional instructions to stop the car in order to avoid exit 11 and stay clear of approaching rescue vehicles. Person number two should receive the general warning message together with instructions to immediately leave the risk area in the east or south-eastbound direction. Person number three should receive only the general warning message.

Figure 3: An example of monitoring of individual behaviour after a selective warning. In Figure 3a the two persons get the warning message and instructions to evacuate. In Figure 3b, some time has elapsed and person number one has left the risk area, but person number two has not reacted.



Level 3: Interactive Network Warning

In a more advanced system the network can be used both to continuously collect information from the field and to provide early warning and monitoring of people in or close to a dangerous area.

Immediately after an incident the network can retrieve information about the circumstances at the incident scene. For example to give the basis for an early estimation about how many people are in or close to the incident area.

With the interaction capability it would be possible to check the settings for each individual phone. This could for example be used to send the warning message in the same language that the individual phone is set to, thus increasing the individual understanding of the warning. This capability could be useful in multilingual areas and situations, for example international sport events and internationally well-known tourist attractions.

With a classification of the individual subscriber in the network it would be possible to record in advance and during an incident, identify individuals with specific knowledge or competence. For example, it could be possible to find physicians, nurses, paramedics, fire and rescue personnel and police officers, on or off duty, among a large population in case of an emergency. Extended use of active members of non-governmental organisations like the Red Cross could also be possible with their permission.

A monitoring capability could make it possible to send a second alarm to people who for example are moving towards instead of away from a hazard. Table 2 shows how different sequences of warning messages could be sent to the two persons illustrated in Figure 3 during a period of time after an incident. At the time t_1 the two persons get the warning message and instructions to evacuate. In Figure 3b, some time has elapsed and person number one has left the risk area and receives a confirmation message that he has exited the risk area. At this time person number two has not reacted and a second message is sent by voice. The system could at this time automatically make a list of both responding persons and non-responding persons, to be presented for the commander of the rescue force, in order to direct rescue units to the locations with possible victims.

Table 2: Sequences of warning messages during a period of time after an incident illustrated in Figure 3.

Person in Figure 3	Time t_1	Time t_2
1	Message to evacuate	Confirmation message: You are in a safe area.
2	Message to evacuate	Repeated message to evacuate by an automatic voice call.

Discussion

There are many types of situations where emergency warnings can save lives, reduce injuries, and protect property. Examples of such situations are chemical incidents, bomb threats against large buildings, large traffic incidents, and missing persons or children. We believe that messages transmitted to mobile phones can add a new medium for emergency warnings. The messages must be carefully authored to ensure acceptance and the desired response.

Research Questions

Although this approach seems feasible technically (in terms of communication), there remain important research questions:

1. What is the level of mobile-phone customer penetration in the region? There exist statistics for mobile market penetration, which give a general idea of how widely used the mobile phones are in different countries and market segments. However, such statistics are based on ownership of mobile phones (e.g., the number of phones in the family). For emergency warnings, the interesting question is the percentage of reachable people in an area (i.e., people carrying reachable, active phones).
2. How long time does it take until you actually read (and understand) a message? Sending a textual message, such as SMS, to a mobile phone does not automatically imply that it will be read. For example, there is often a time lag between receiving a message (audio signal from the phone) and reading it (e.g., due to meetings and other activities).
3. How many messages are not read at all? A related question is the percentage of messages never read. Some people may not understand how to read messages (e.g., received SMS) because they never use this function, or they may have their phones turned off for a long period of time.
4. What is the mobile-phone penetration and message throughput required for a given task? These questions lead to the general question of what level of communication is needed for a particular emergency-warning task. Because of people-to-people communication, some task may require reaching only a small percentage of the public to get the message across (e.g., evacuation of large buildings), while other tasks require reaching almost everyone (e.g., warning people in sparsely populated rural areas of extreme weather conditions).

In addition, there are psychological aspects that warrant further research. Further work is required on how people read and understand emergency messages, especially messages delivered to their mobile phones. It is especially interesting to find approaches to formulate effective emergency messages for mobile phones, and to monitor responses to messages. We believe that reducing denial is a key factor for success. Therefore, an important goal is to develop authoring guidelines for reducing denial while avoiding unnecessary concern.

Preventive Safety Warning and Stationary Warning

As a preventive measure, wireless networks could be used to inform the public of various potential hazards. This could include warning to tourists in areas of danger in case of specific weather conditions. For example, heavy snowfall in the high mountains with increased risk for avalanche. Coastal warning in case of high winds and warning to swimmers of tidewater with strong currents are other examples where a wireless network can provide valuable information regularly or if the environmental condition changes.

The websign approach presented by Pradhan and colleagues (2001) could provide a transparent linkage between the physical world and safety critical information available on the Internet. The main idea is to dynamically present messages or websigns to the holder of a wireless device, depending on the geographical location and current situation. One of the original applications for websigns was as an electronic tourist-guide, which provided you with information associated with physical objects. We think however, that the websign approach could be used for example to alert people not to enter a subway station in case of an incident or potential threat or to select another route with their car in case of a traffic accident.

Future mobile devices

The technological development on the consumer mobile-phone market is astounding. During the 1990s, the size, weight, and cost of mobile phones were reduced as the market penetration increased. However, the manufactures did not add much communication functionality to the phones beyond voice calls and SMS. Recently, extensions to SMS (such as multimedia-based SMS), WAP, and GPRS have emerged (Ralph & Aghvami, 2001). This development is likely to continue even further with the introduction of third-generation networks (3G). In the near future, consumers will have access to mobile multimedia devices with high-speed network access.

Mobile multimedia devices will provide a new level of emergency-warning communication. High-resolution colour screens make it possible to send multimedia warnings and interactive messages. For example, video clips with instructions and maps can inform the public of hazards and streaming media can deliver broadcast news to emergency areas. Another possible use of sophisticated mobile devices is data collection from an emergency area. For example, handheld devices can stream video from an integrated camera. In some cases, portable devices may support other types of sensors, such as sensors measuring physiological variables and ambient temperature. Emergency operators can take advantage of such information for situation assessment (e.g., from the emergency area and from escape routes), and for allocating appropriate medical resources.

At the same time as these devices are becoming increasingly complex, they begin to resemble portable computers (laptops) in terms of functionality. However, from the emergency-warning perspective, there are disadvantages of such increased functionality. Examples of such disadvantages are shorter battery life (because of increased power consumption) and exposure to tampering (e.g., viruses, worms, and break-ins). This development means that such devices can be less suitable for warning messages than conventional mobile phones, because of reduced availability as message receivers. Nevertheless, we believe that mobile multimedia devices will become an important tool for emergency warnings.

Conclusion

Early warning through mobile-phone networks is a promising approach. Our general idea is to take further advantage of our society's investments in mobile-phone networks and the fact that a large part of our population has access to a mobile phone, in order to provide increased public safety by introducing the capability of early warning.

We have identified three technology levels for communicating warnings to citizens: early-warning broadcast, area selective warning, and interactive network warning. Early-warning broadcast is a basic approach to complement sirens and radio messages. Selected area warning can send messages to a specific area. Finally, interactive network warning can take advantage of information feedback from mobile phones, such as movements and behaviour.

There remain several research issues. Most of these issues concern the ability to reach a sufficient proportion of the population, and psychological responses to the message. Further research is needed before we can deploy an operational early-warning system. Nevertheless, we believe that the approach is viable and that citizens and rescue workers can benefit from early warnings to mobile phones.

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