Wireless Emergency Alerting Reconsidered

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***Abstract*—The Wireless Emergency Alerting (WEA) service is a standards-based transport and presentation channel that can deliver short text warnings to wireless subscribers through a cell broadcast mechanism. For emergency situations in which a broadcast modality and a single, short text message are sufficient to convey information, the WEA service can be efficient and effective. However, the content to be delivered may necessitate more than a single, unchanging short message. In this research, we first examine the WEA service from the perspective of alert originators. We then use the insights gained to explore the efficacy of a range of potential extensions to the service. The extensions mainly address the importance of user context and the ability to create awareness through careful attention to the integrity of the vital information. We evaluated these extensions using a WEA emulation testbed in two public usability trials. We present an analysis of the broad range of improvements as a basis for further research into improving the service. We conclude that (1) precise geo-targeting augmented with location information and maps is an important aspect of capturing users' context, and (2) presenting information in a digested form can markedly improve the actionability and the accuracy of interpretation.**

I. Introduction

The Wireless Emergency Alerting (WEA) service [1], formerly known as the Commercial Mobile Alert System (CMAS), is part of the Federal Emergency Management Agency's Integrated Public Alert and Warning System (IPAWS) [2]. Using the Short Message Service Cell Broadcast (SMSCB) protocol [3], the WEA service provides a dissemination path for alert and warning messages to the public on WEA-capable mobile devices. When an alert is sent, it is targeted using cell towers, and is delivered to all WEA-capable devices covered by those cell towers. This form of targeting is coarse at best, however. The inability to provide fine-grained targeting, combined with the limitations of text-based short messages in delivering adequate information and/or actionable advice, is frequently cited as a disadvantage that increases the likelihood of citizens to opt out of this mode of alerting or ignore alert messages. This behavior in turn reduces the effectiveness of the WEA service.

Rapid improvements in mobile and network technologies necessitate a significant re-thinking of WEA. When SMSCB was created, phones were little more than devices for making voice calls and handling text messages. Now, smartphones have capabilities exceeding those of personal computers from a decade ago. Similarly, network capacities have improved dramatically when compared to the initial demonstration of SMSCB. New protocols such as Long Term Evolution (LTE) broadcast have emerged, and user expectations have shifted from text messaging to rich messaging. Considering how both network and phone technologies have changed dramatically since the inception of SMSCB, in this work, we look for ways to overcome the WEA service's shortcomings within the framework of the current WEA architecture.

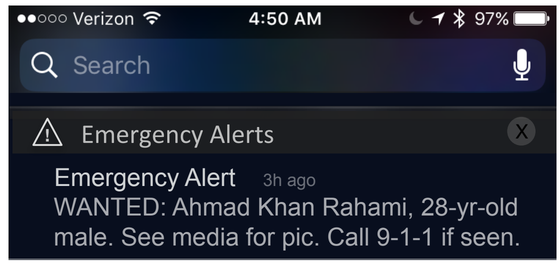

Fig. 1: Example WEA Message. This alert was sent to the citizens of New York City in an attempt to capture a bombing suspect on the morning of September 19, 2016.

The primary goals of this research are to gain insight into WEA adoption and acceptance issues, in particular with respect to perceived poor public response to alert messages, and to develop and test strategies for overcoming these issues. With these goals in mind, we performed an extensive series of studies in two phases. The timeline of the studies is given in Appendix and shows the work schedule and components, each of which is explained in more detail in this paper.

The first phase of the research focused on deepening our understanding of the challenges confronting the authorities who create the alerts, or Alert Originators (AOs). To that end, we designed and conducted two investigations with the AOs. We call this phase the AO Requirements Study (AORS). Informed by the AORS results, in the second phase of the work, we conducted two Public Usability Trials (PUT) to evaluate the impact of potential enhancements to the WEA service. This part involved the development of a flexible testbed and experimental framework called WEA+. Using WEA+, we designed and implemented a variety of extensions aimed at addressing the shortcomings identified during the AORS. The usability trials tested these extensions with over 225 subjects in simulated emergency situations. Figure 2 shows a screenshot from the interface of the WEA+ subsystem used for creating, issuing, and monitoring regular and enhanced WEA messages issued to the trial subjects. To our knowledge, this is the first study of its kind that evaluated WEA capabilities and extensions in a realistic setting with human users in real-time.

The rest of this paper is organized as follows. Section II presents related work. We introduce the AORS phase in Section III and summarize the insights that were relevant to

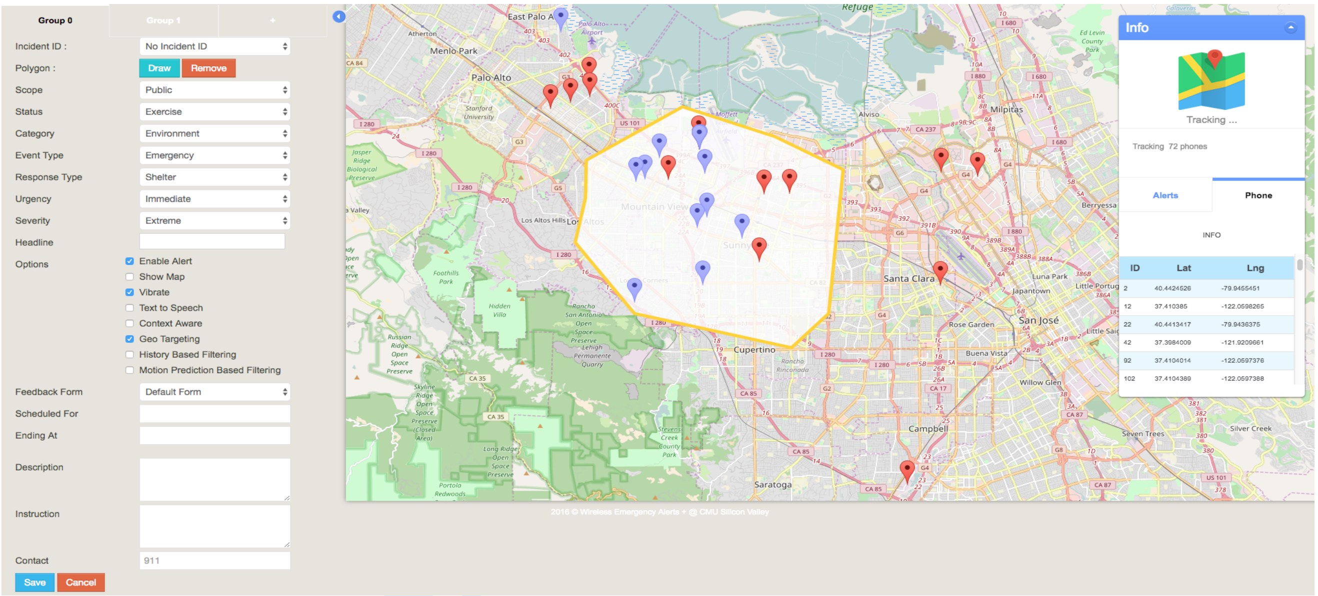

Fig. 2: The User Interface of the Alert Creation and Monitoring Subsystem of WEA+. The target region of an active alert, specified as a polygon, is overlaid on a map. The alert is delivered both in plain and enhanced form in a randomized way to a group of experiment subjects. The markers represent the positions and statuses of the subjects. The left pane shows attributes for the active alert.

the PUT phase. In Section IV, we present the PUT phase, including the development of the WEA emulation testbed and experimental framework (WEA+), experiment designs, and data analysis approach. The results of the PUT phase are presented in Section V together with the features and characteristics selected for testing. Study limitations are discussed in Section VI. This is followed in Section VII by a summary of our recommendations and a discussion of the work's impact on the evolution of the WEA service. The paper concludes with Section VIII, which discusses future work.

II. Related Work

Several previous works have reported on the effectiveness and adoption of the WEA service and similar alerting mechanisms and suggested strategies for possible improvements for WEA delivery. We summarize the most relevant ones here.

Research conducted at the Software Engineering Institute (SEI) [4], [5] identifies trust, both on the part of the AOs as well as the public, as a key factor in the success of the WEA service. Based on an analysis of the AO trust model, SEI researchers determined that maximizing AOs' use of the WEA service requires improving three key outcomes: appropriateness, availability, and effectiveness. SEI reports also suggest that the specificity of how alerts are targeted to an affected geographical region, or *geo-targeting*, is a critical component for building trust. The more precise this geo-targeting is, the more relevant the alerts are to the recipients, increasing their trust in the system. Other work on possible WEA improvements include a comprehensive study of WEA integration considerations, again by SEI, [6], which posited that the ubiquity of smartphones enable novel technical solutions both for improved geo-targeting and for addressing other current WEA limitations. We explored many of these suggestions in our research.

The importance of accurate geo-targeting was highlighted in several reports. The Department of Homeland Security's (DHS) WEA service recommendations [1] and SEI's WEA best practice recommendations [7] conjecture that AOs will use the WEA service more extensively if alert messages can be better targeted to the size and location of the geographic region impacted by the emergency event. With respect to geo-targeting granularity, Nagele and Trainor [8] stated that being able to set an appropriate polygon size could be an important factor in improving public response to alerts. However, this approach would be useful only if the actual delivery mechanism respects the finer resolution of smaller targets, which we guarantee in our work through client-side filtering. The precise, fine-grained implementation that we propose adds client-side filtering to that achieved by SMSCB at the level of cell towers: it is not meant to replace the standard base-station-based targeting, but rather to augment it.

The WEA service currently supports only text messages. The 2013 DHS report [1] recommended that WEA should also support richer media content in alerts, including both maps and other rich media forms such as images and audio. Inclusion of such artifacts could convey more information to the public about the situation and the required action. Location-based services are often most appealing when combined with maps that allow the users to visualize pertinent information in the proper context and in real time. Such maps could be called *high-information*. Though maps have been frequently used in mobile applications, their use in emergency alerts delivered to mobile devices is still not very common. A study by University of Maryland's National Consortium for the Study of Terrorism and Responses to Terrorism (UMD-START) [9] concluded that the inclusion of a high-information map specifying the alert region and the recipient's location could have a significant and positive effect on public response outcomes including interpretation and personalization, with a potential to improve protective action-taking. We leverage this result in our prototypical implementation of the enhanced WEA service.

The WEA service limitation of only supporting text messages was highlighted in other studies as well. Two National Research Council (NRC) reports [10], [11] and the 2013 DHS recommendations [1] pointed to the 90-character limitation of current WEA implementations as a hindrance, with the proposition that a modest increase in message length might be beneficial. The 2013 DHS report [1] recommended that WEA also support richer media content in alerts, including both maps and other rich media forms such as images and audio. Inclusion of such artifacts could convey more information to the public about the situation and the required action. The UMD-START report [9] concluded that visual stimuli including color, size, shape, bolding, iconography, sound, and the character of audible tones that indicate the arrival of a message could influence WEA message interpretation and subsequent message response, although the effects of such enhancements were known. Additionally, the 2013 DHS recommendations [1] as well as the 2011 NRC report [11] suggest enhancing WEA delivery by allowing the public to be notified when a WEA message is issued to their home area or to a recipient-specified area of interest. We investigate the effects of similar improvements in our study in the form of a set of context-aware WEA features.

III. Alert Originator Requirements Study (AORS)

We use the term AO to refer to emergency services personnel who work in a role that involves assessing or managing emergency situations and crafting, approving and ultimately disseminating public alert messages. As a key part of our research, we conducted a comprehensive study to update our understanding of the AO perspective given the WEA service's current use. We organized this preliminary study in two parts: (1) In-depth interviews with a small number of selected AOs; and (2) A large-scale online survey of the AO community. The AO investigations helped us validate or refute standing assumptions about the WEA service, identify its strengths and shortcomings, and solicit recommendations on how to improve its adoption, effectiveness, and relevance.

Formalized in Goal-Question-Metric (GQM) [12] terms, the purpose of the AORS was: To *Validate* previous findings and recommendations regarding the viability, limitations, advantages, and use of the WEA service (G1) *and identify* impediments and opportunities regarding the adoption of the WEA service by AOs (G2) and acceptance of the WEA service by the public (G3) *for the purpose of* prioritizing, developing, and evaluating enhancement goals and options for future wireless broadcast services (G4) *with respect to* increased geo-targeting specificity (G5) of alert messages and improved relevance (G6) to their recipients *from the perspective of* Alert Originators (G7) *in the context of* emergency alert systems and services used by different jurisdictions, agencies, and response communities throughout the nation (G8). The parts G1-G8 were further refined into specific research questions, which the the AORS attempted to answer (see the Appendix).

A. Interview Methodology and Insights

The in-depth interviews involved 13 carefully selected AOs from a convenience sample (see Appendix). All participants had either significant experience or significant familiarity with WEA. The interviews addressed several central topics related to the research questions, but also had an open component to allow emerging themes. They were conducted using a combination of semi-structured and open interviewing techniques and lasted up to an hour for each interview. Specific topics addressed included: whether and how the AOs were using WEA, and what, if any, barriers they encountered in adopting WEA; the need and perceived feasibility of more precise geo-targeting; and issues related to the relevance of WEA to and its acceptance by the general public. We also sought to uncover new requirements based on current experience with the service and opportunities afforded by smartphone capabilities, connections to social media, and inclusion of links and rich media in alerts. Interview notes were transcribed, summarized individually, and thematically analyzed during a full-day workshop based on a Grounded Theory approach [13].

The major interview themes that pertained to the PUT phase were:

1) Longer messages: Current WEA service has a limit of 90 characters per alert. Most interviewees stated that they were unable to craft meaningful messages to the general population within this constraint.

2) Better geo-targeting: The majority of the interviewees stated that increasing the geo-targeting precision of the WEA service will rectify key adoption challenges by delivering alert messages only to those impacted by an emergency.

3) WEA as a warning alarm vs. a rich information service: Some AOs perceived the WEA service as a “bell ringer” technology, akin to sounding the first alarm only. Others believed that the natural evolution of the WEA service should involve uncovering ways to directly embed additional information within the alert messages themselves and to couple them with effective interpretation, incident follow-up, and closure mechanisms.

Insights from the AO interviews primarily influenced our decisions regarding the initial WEA enhancements to tackle during the field experiments and the first trial.

B. Online-Survey Methodology and Insights

To gather additional data and to refine the results from the interviews, we deployed a 30-question survey to the larger AO community. Survey questions covered these categories: basic demographic info; perceived WEA adoption rate; adoption and opt-out reasons for AOs; suggestions for improving WEA adoption; suggestions regarding features desired in alert generation tools, mobile devices, and the WEA service itself; and the role of WEA within the larger landscape of emergency information dissemination.

The online survey was rolled out to a list of 455 potential AOs. We received 88 responses, out of which 79 were usefully complete. The majority of the respondents had significant experience in emergency alert origination (over 10 years), but nearly half (44 %) did not have prior experience with WEA.

75% percent indicated their organizations regularly issued emergency alerts. The sample was diverse, with representation from city-level, county-level, state-level, and national bodies.

Again, here we list the main findings pertaining to the PUT phase. Full results can be found in our main report [14].

1) Ways to improve WEA adoption: 55 AOs provided suggestions for improving WEA adoption by the AOs. The top suggestions were to: permit smaller geo-targets (61%); increase allowable message length (12%); and provide a mechanism to test WEA messages (10%). 54 AOs provided suggestions for improving WEA adoption by the public. The top suggestions were to: allow recipients to customize which messages they receive (13%); avoid over-warning with too many alert messages (12%); ensure that WEA messages are actionable (11%); improve geo-targeting precision (9%); and allow longer messages (9%).

2) Importance of geo-targeting: The ability to easily define a geo-target during alert creation was the top preferred front-end feature for the majority of AOs, followed by compliance with the Common Alerting Protocol (CAP) format, a standard for crafting warning messages with meta data [15]. With respect to desired geo-targeting precision, respondents were most likely to use WEA (at 81%) if minimum geo-targeting resolution were less than roughly the size of an urban neighborhood.

3) Message length: Although a small majority, 61%, of the surveyed AOs felt the current 90-character maximum length was sufficient, a larger majority felt that longer messages of up to 500 characters (93% for up to 280 characters and 67% for up to 500 characters) would be more effective *even if doing so would increase the cost and push the limits of wireless broadcast technology*. This result suggests an unqualified support for increased message length in future WEA service.

4) Role and proper use of WEA: A significant majority, 75%, of AOs thought that the AO community must rethink the vision of WEA. 99% agreed that a WEA message should give the recipient enough actionable information beyond simply sounding the alarm. 84% thought that a WEA message about an impending emergency should be followed up with regular status updates, including a closure message.

5) Links and richer media in alerts: The surveyed AOs did not give unqualified support for enhancing WEA messages with external links and rich media. A majority of the respondents disagreed that WEA messages should be enriched with maps or images *if doing so would complicate alert generation or jeopardize the willingness of carriers to participate in the WEA service.* The respondents were divided (54% for vs. 46% against) between whether embedding links to websites and social media into alert messages would be worthwhile *if doing so has the risk of overloading the communication network.*

The results of the AO survey confirmed the majority of the findings from the interviews. They also triggered modifications to the enhancements tested during the first trial of the PUT phase and influenced the additions implemented and tested during the second trial.

C. AORS Conclusions

Key observations from the AORS pertain to the WEA service's wide reach as a major advantage, importance of geo-targeting specificity, leveraging smartphone capabilities, and strategies for increasing both the capacity of an alert to prompt action and the likelihood of an alert to be relevant to the recipient via longer messages, maps, rich media, and other enhancements, provided that these enhancements do not lead to network overloading or discourage carrier participation.

IV. Public Usability Trial (PUT)

Based on the findings from the AORS, we explored both the usefulness and applicability of a range of hypothesized enhancements and extensions to the WEA service. We developed a prototype of an enhanced, emulated WEA service and experimental framework—the WEA+ system—which included an alert creation and monitoring subsystem (Fig. 2), a message delivery subsystem, and native smartphone applications for processing delivered alerts and presenting them to recipients. We then conducted two one-week-long usability trials involving three controlled experiments. The purpose of the PUT phase was to test selected WEA enhancement features with human subjects. The PUT phase included, in addition to the trials, software development for three iterations of WEA+ and the associated smartphone applications and multi-location field feasibility tests with preliminary capabilities (mostly focused on implementing precise geo-targeting). In parallel with these activities, we also developed novel algorithms for representing and encoding alert geo-targets represented as polygons for efficient embedding and transmission within alerts [16] (not discussed in this paper). During the trials, using simulated emergency scenarios, we assessed the effectiveness of new system features by measuring and comparing participant responses to alerts issued in real-time with and without any enhancements.

The high-level research questions and study designs of the experiments conducted in the trials are presented in the following subsections. Details and supporting materials can be found in the Appendix and in our full report [17].

A. Research Questions

The following high-level research questions were tackled in the two trials of the PUT phase: (a) *Potential Enhancements*: Would certain improvements to the WEA service make it more effective for the public?; (b) *Alert Characteristics*: How do certain alert characteristics impact the effectiveness of the WEA service for the public?; and (c) *Overall Impressions*: After exposure to the WEA service, does the public appreciate the benefits of the WEA service, with or without improvements?

Regarding (b) above, in two experiments, we studied certain factors that pertain to the attributes or nature of the alerts themselves, such as the timing or purpose of an alert, rather than possible enhancements or changes to the WEA service. These are what we refer to as *alert characteristics*. Regarding (c) above, we evaluated the overall impressions about WEA via a final questionnaire sent to the subjects immediately after each experiment.

B. WEA+ Framework

The trials were conducted using our experimental platform WEA+. The WEA+ system comprised an Android mobile application, an iOS application, and a back-end subsystem. The back-end included a web-based interface to create and schedule new alerts (with and without enhancements) as well as to monitor active alerts (Fig. 2), two web servers to persist and push the scheduled alerts, and a repository to store the data and the feedback sent by users.

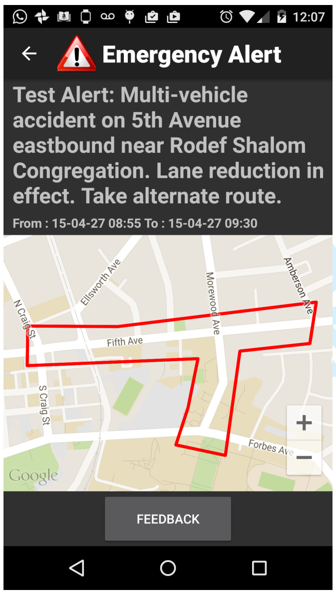

Fig. 3: A Sample WEA+ Alert for Android Users. This alert is divided into (top) alert text and (bottom) map with impacted area. The enhancement was to to test the feature high-Information map feature combined with on-phone geo-filtering.

The high-level architecture and the key technologies used in the creation of WEA+ are illustrated in Fig. 5. In the figure, two NodeJS-based web servers expose services to create and schedule alerts and to collect feedback from mobile phones. The AO user interface (previously shown in Fig. 2) communicated with these web servers for creating, modifying, deleting, and monitoring alerts. The web servers persisted the alert data and user feedback in MySQL databases. An Amazon-based push notification service was used to deliver alerts to mobile phones. Two native mobile applications—one for Android-based users (Fig. 3) and one for iOS-based users (Fig. 4)—were created to test different WEA features and characteristics.

In WEA+, the alert creation and monitoring subsystem (Fig. 2) plays a central role. It provides a web-based user interface, akin to a control center, to specify, schedule, and manage alert messages. It also allows A/B-type testing by randomly dividing the experiment subjects into two equally-sized groups. Each group receives the same alert, but the alert is presented with a distinct set of features to each group. In the experiments, to control the evaluated factor, we varied alert features one at a time between the two groups. For example, while testing the effect of text-to-speech (the factor being studied), subjects in group A received a spoken alert, whereas subjects in group B received the exact same alert in the regular way. All other factors were kept constant between the groups to isolate the factor being studied.

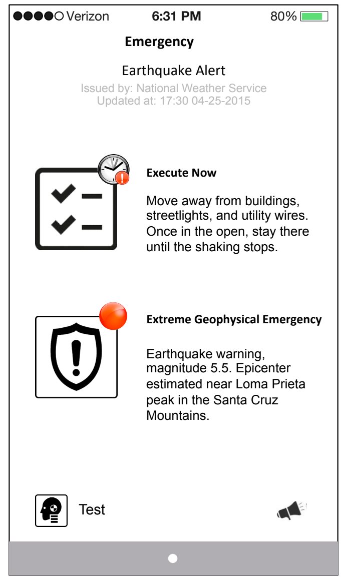

Fig. 4: Situation Digest View Display for iOS Users. The display supports situational awareness using structured alert information that aggregates content and meta data from a stream of related messages for an active emergency. Key elements are highlighted, *e.g.,* immediacy, alert nature, and headline. Icons highlighting alert severity and nature are meant to support understanding and actionability. Other active emergency incidents are accessible by swiping left/right.

Fig. 3 shows a snapshot of an enhanced alert delivered to an Android user. The alert is augmented with a high-information map centered around the alert's region. The alert shows a map overlaid with a red-framed polygon indicating the affected region. Also shown to the user are the the time period during which the alert is active, a text describing the alert content, and the alert type. If the precision geo-targeting feature is enabled for an alert, the mobile application running on the phone determines the location of the user, and shows the alert only if the user is inside the alert polygon or enters the alert polygon while the alert is still active.

Figure 4 shows the user interface designed for iOS users, which was used to test a specific feature in a dedicated experiment: the situation digest view. In this experiment, the subjects were exposed to structured information. At the top there is a *headline* (Earthquake Alert) followed by the authoring entity and a time stamp. In the center of the display, the users are presented with the immediacy of the recommended action as well the type of emergency. In smaller font, additional detail and instructions are presented. The icons on the left represent the immediacy, emergency type, and nature of instructions. On the top left of each icon is a colored circle that signifies the degree of immediacy and severity.

C. Experiment Design and Analysis

The two public usability trials involved three experiments, during which we tested these features: inclusion of high-information maps, precise geographical targeting using on-phone geo-filtering, location-history-based targeting, use of

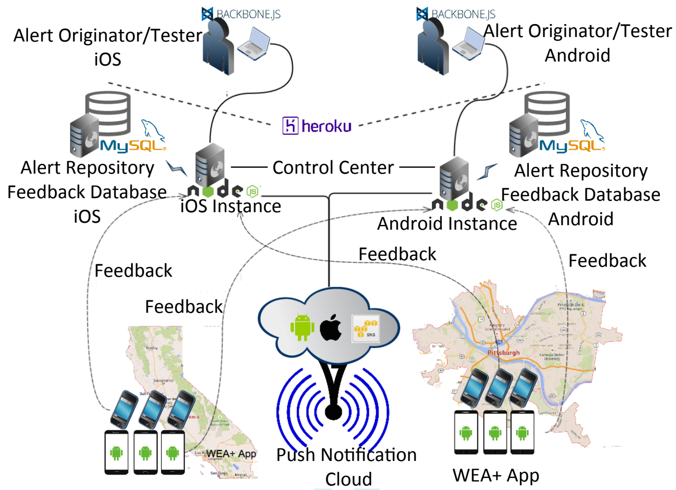

Fig. 5: Architecture of the WEA+ Testbed and Framework. WEA+ upports both Android and iOS clients. AOs create alerts on a NodeJS-based server. All data is stored in MySQL databases. Phones receive alerts via push notification managed by Amazon SNS, Google Cloud messaging service, and the iOS Push Notifications Service. Feedback is collected via question/answer screens on the phone.

a situation digest view related to a stream of connected alert message, use of text-to-speech, targeting with location prediction, and inclusion of external links. We also evaluated certain alert characteristics, such as message length and timing, as well as overall impressions about WEA after exposure to the emulated WEA service.

The experiments were conducted with 140 subjects with Android devices and 93 subjects with iOS devices. Android subjects participated in Experiments 1 and 2, and the iOS subjects participated in Experiment 3. Experiments 1 was conducted only in Silicon Valley and Experiments 2 and 3 were conducted in two locations: Silicon Valley and Pittsburgh. Experiments 1 and 2 were designed to evaluate WEA+ enhancements (except situation digest view) and used the same single-factor, randomized repeated-measures design. The single factor was binary, representing either the control (Group A) or a tested enhancement feature (Group B). Experiment 3, which evaluated situational awareness, was conducted separately as it required significant changes to the operation and user interface of the mobile app as well as the experiment design. Experiment 3 assessed the users' ability to follow information change. This meant designing an experiment that could accommodate streams of related alerts, but the same randomization approach was retained. The experimental designs used are contrasted in Fig. 6.

1) Design of Experiments 1 and 2: For these experiments, we designed fictitious, but realistic emergency scenarios. Within a span of eight days, 24 alerts were issued to a total of 52 subjects in Silicon Valley in Experiment 1. In Experiment 2, 54 alerts were issued to a total of 88 subjects in both Silicon Valley and Pittsburgh, again within a span of eight days. We assessed the effectiveness of the WEA features tested by measuring and comparing the responses of the subjects to alerts issued in real-time. We used randomized A/B testing to evaluate each feature as explained above.

To quantify public response outcomes, we asked the subjects to send feedback immediately after each alert. Feedback was given by clicking a button on the alert screen (Fig. 3), and directing the user to a small set of multiple choice questions that they could quickly answer on their mobile device. To compare the tested feature relative to the control feature, a number of outcomes were studied: (a) *Understanding*: Was the alert easy to understand? (b) *Relevance*: Was the alert relevant to the recipient given the recipient's context? (c) *Annoyance*: Would the alert annoy the recipient in a similar real emergency situation? (d) *Actionability*: Would the alert prompt the recipient to take protective action in a similar real emergency situation? (e) *Milling Behavior*: Would the alert prompt the recipient to seek confirmation from alternative sources? (f) *Adequacy*: Does the alert contain sufficient information for the recipient to assess the situation? (g) *Usefulness*: Would the recipient find the alert useful in a similar real emergency situation? At the end of each experiment, the WEA+ app also solicited the subjects' overall impressions by a final questionnaire.

2) Design of Experiment 3: In the third experiment, alerts were issued to 93 participants, again in a span of eight days. However this experiment was intended to test the subjects' understanding facing a stream of inter-related messages. This meant that the users were exposed to a set of scenarios that ran like a story, with evolving emergency alerts. During each of the scenarios we tested the users' understanding by sending a short poll at pre-determined times. For each scenario, the subjects were evenly and randomly divided into two groups similar to the other experiments: the treatment group received the alerts via the situation digest view, and the control group received them as an ordinary WEA message. However, in this experiment, understanding was measured based on the correctness of the subjects' answers to specific questions pertaining to an ongoing incident. The proportions of correct and partially correct answers were then compared. The single high-level outcome measure of this experiment was *situational awareness*, which objectively captured how well were the subjects were able to assimilate the evolving information given to them over time.

D. Data Analysis Approach

Since the subjects' responses were mostly captured via multiple choice questions with a nominal scale, a frequency-based analysis was appropriate. We therefore used the standard Chi-square independence test for all evaluated enhancements (with the null hypothesis that the evaluated enhancement is independent of the response distribution). In all Chi-square tests, the selected alpha level was 0.05. Thus we considered a test result to be significant when the p-value was below 0.05, rejecting the underlying null hypothesis. To analyze responses to questions directly asking which option a subject prefers among a given set of options, the standard Chi-square goodness-of-fit test was used to determine whether one option significantly dominated others.

In all statistical tests, we measured effect size in two different ways: (1) theoretical, using Cramer's V (C.V) statistic and (2) practical, using odds ratio (O.R.). Given the underlying

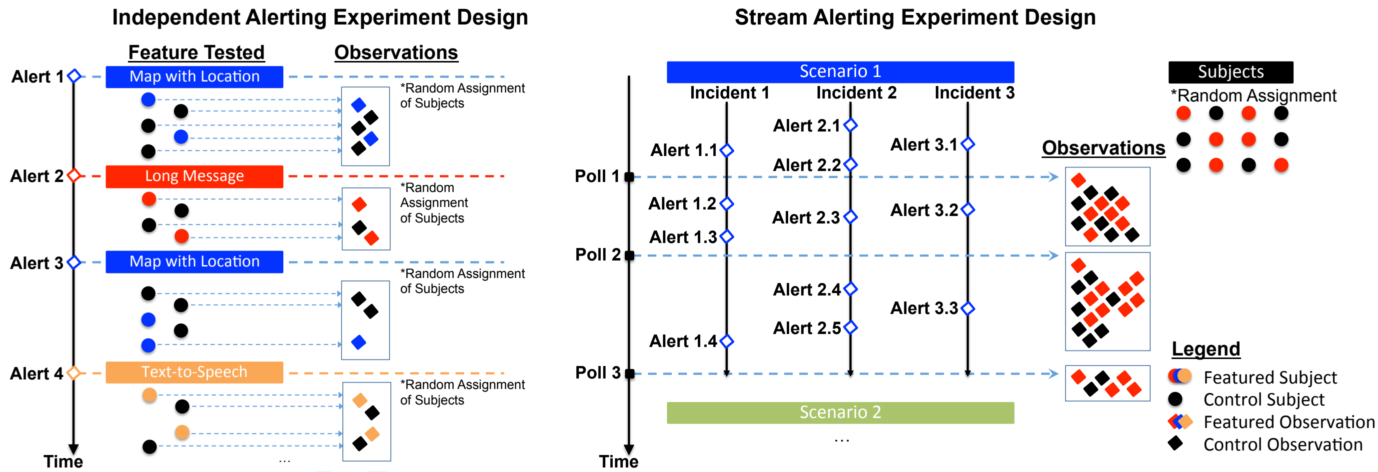

Fig. 6: Experimental Design for PUT. Left: In experiments requiring independent alerting (Experiments 1 and 2), alerts were issued to a population randomly divided on-the-fly into two groups: the feature group received an enhanced alert and the control group a regular alert. Each subject provided feedback for every alert received. Each alert tested a single feature. Right: In the stream alerting experiment (Experiment 3), complex scenarios were created where multiple incidents would occur simultaneously and get updated in an interleaved fashion. Each alert was attached to a particular incident. At pre-determined times a *poll* would be issued, assessing the subjects' understanding of the scenario at hand. The control (situation digest view) and feature (ordinary WEA view) groups were randomly populated at the beginning of each scenario in a similar way to Experiments 1 and 2, but the groups were maintained until the next scenario.

degrees of freedom, the theoretical effect sizes were interpreted as follows [18]: (a) Very small: C.V smaller than 0.1; (b) Small: C.V larger than or equal to 0.1 and less than 0.3; (c) Medium: C.V larger than or equal to 0.3 and less than 0.5; and (d) Large: C.V larger than or equal to 0.5. An effect size between 0.2 and 0.3 as measured by C.V is considered normal in studies dealing with human behavior where outcomes might be affected by multiple uncontrolled factors [18], which was the case in our experiments.

V. Results

We discuss the main findings of the PUT phase in this section. The findings are summarized in Table: I. The Appendix provides tabulated results for all experiments. The results are pooled for Experiments 1 and 2, which tested the same set of enhancements (un-pooled results can be found in the full report [17].

A. Alerts with High-Information Maps

To verify the utility of including high-information maps, we implemented map-based alerts in WEA+ (Fig. 3). In addition to displaying the alert text and alert type, the WEA+ mobile app showed the recipient a local map of the area, the affected region (using a polygon), the location of the user, and the time-period of the alert. We compared alerts displaying this visual to those that didn't. Based on the analysis of the subjects' responses, we found that alerts with high-information maps increased the relevance of the alerts to the recipients. Maps also appeared to affect the information content of alert messages, as measured by adequacy. Both improvements were significant. When explicitly asked whether the map in the alert just shown was useful, subjects overwhelmingly responded that they were. This result was highly significant. We did not find any evidence of a positive or negative effect of high-information maps on actionability, annoyance, and milling behavior.

B. Alerts with On-Phone Geo-Filtering

Since most modern phones are equipped with capable GPS receivers, it is possible to use client-side filtering to discard alerts that are not in the vicinity of a user's current location. We compared responses to geo-targeted alerts with on-phone geo-filtering to responses to generally targeted alerts. We found that precise, fine-grained geo-filtering on the phone improved alert relevance to recipients. The improvement was highly significant with a near-medium theoretical effect size as measured by C.V and considerably large practical effect size as measured by O.R. (over three times improvement in the odds). Actionability was also better with geo-filtering, but this effect was not as strong. We conclude that precision geo-filtering has a significantly positive impact on alert relevance and a small to moderate impact on actionability.

C. Alerts Filtered with Location History

Because users are likely to be interested in areas that they visit often, we wanted to evaluate the impact of using a user's past locations to filter alerts. When a geo-targeted alert was sent with the location-history feature turned on, the mobile application used the geo-target polygon embedded in the alert and location history stored on the phone to determine if the recipient had ever visited the alert region recently. If the recipient had visited the alert area in the recent past, the alert was shown; otherwise it was discarded. We compared geo-filtered alerts with and without the location history feature turned on. We found that location history improved an alert's relevance to recipients. The improvement was highly significant with a near-medium theoretical effect

TABLE I: Summary of PUT Findings and Implications.

WEA enhancement feature	Evidence in favor / Potential	Positively impacted outcome constructs	Negatively impacted outcome constructs	Feasibility	Implications
On-phone Geo-filtering	Strong / Significant	1. **Relevance** 2. Actionability 3. Adequacy	Hindsight Relevance	High	Requires embedding geo-target into alert at origin and location services to be enabled on phone for filtering. Straightforward to implement on phone with no UI changes. Invisible to AO and recipient.
Situation Digest	Strong / Significant	1. **Situational Awareness**		Medium	Requires new alert creation process/tools and use of CAP meta-data. Meta-data encoded and bundled with alert content for transmission, and unbundled or decoded on phone. Visible to both AO and recipient. Changes phone functionality, including UI. No changes to the WEA network architecture are necessary.
Location History	Strong / Significant	1. **Relevance** 2. Usefulness 3. Actionability 4. Adequacy	Hindsight Relevance	High	Used with geo-targeting. Straightforward implementation on phone possible with no UI changes. Can be invisible to AO and recipient. Effectiveness depends on prediction algorithm.
High-Information Map	Moderate / Medium	1. **Usefulness** 2. Relevance 3. Adequacy		High	Used with geo-targeting. Implementation on phone is straightforward, but requires new UI. Pre-cached maps on phones alleviate network congestion concerns.
External Link	Weak / Low	1. **Usefulness** 2. Adequacy		High	Requires only minor changes to phone app to make links clickable. Policy change is necessary to allow (restricted) links in alerts. Network congestion may be a current concern.
Location Prediction	Weak / Low	1. **Usefulness**	Hindsight Relevance	High to Medium	Used with geo-targeting. Implementation on phone possible with no UI changes. Prediction algorithm can be complex. Can be invisible to AO and recipient. Effectiveness heavily depends on prediction algorithm.
Long Message	Weak / Low	1. Actionability 2. Annoyance 3. Milling Behavior		High	No changes in alert creation side beyond AO training and modifications to existing tools to enable longer message construction. Requires policy change and Cooperation from wireless carriers is required.
Text-to-Speech	Weak / Unknown	1. Response Rate 2. Understanding 3. Actionability	Response time (short-term)	High	No changes in alert creation beyond avoidance in alert text of content not easily converted to speech. Simple changes to phone app.

size as measured by C.V and considerably large practical effect size as measured by O.R. Actionability and adequacy also improved when geo-filtering was combined with location-history-based filtering. We conclude that location history is a highly desirable enhancement that complements on-phone geo-filtering.

D. Update Alerts

In Experiment 1, using a small sample, we tested whether alerts that updated the status of an ongoing emergency (update alerts) caused a different reaction than alerts that first announced an emergency (initial alerts). We found that initial alerts were more likely to trigger information-seeking behavior as compared to update alerts (as measured by milling behavior outcome) and were more actionable. But update alerts performed better in terms of adequacy, which is a component of information content. The results were significant, but the effect sizes were small-to-medium as measured by C.V. The superior adequacy of update alerts is positive, but this result is conditional on whether the improvement leads to correct situational awareness. The standard WEA service treats update alerts in an ad-hoc manner, and this may lead to confusion in complex, rapidly changing situations.

E. Alerts using Situation Digest View

Our hypothesis was that alerting with explicit situational awareness is important for complex and evolving emergency situations. We tested this hypothesis using the situation digest view shown in Fig. 7. This mode of alerting was expected to result in a higher-level of awareness faster. In order to measure the efficacy of this concept, in Experiment 3, we compared the subjects' responses to changing information in multiple emergency scenarios. We assessed three distinct elements of situational awareness: *e.g.,* action to take, alert nature, and immediacy.

We found, as expected, that situational awareness improvement via a digest view over the current mode used in the WEA service was dependent on the complexity of the scenario presented. In complex scenarios where multiple concurrent alerts needed to be sent in order to update the subjects, the digest view performed significantly better in improving objective awareness outcomes (all components: action, nature, and immediacy), with a medium theoretical effect size as measured by C.V and a very large practical effect size as measured by O.R. In simple scenarios where a small number of alerts were sent, the digest view did not show significant improvements, but it didn't have a negative impact either. At the end of the Experiment 3, when we asked the subjects which view they preferred, a near-majority of the subjects responded with a preference for the digest view: only 14 percent preferred the regular WEA view and the remaining 38 percent were either indifferent or unsure. The results were significant with a large effect size. We conclude that supporting situational awareness through a mechanism like the digest view would be a worthwhile improvement for the WEA service.

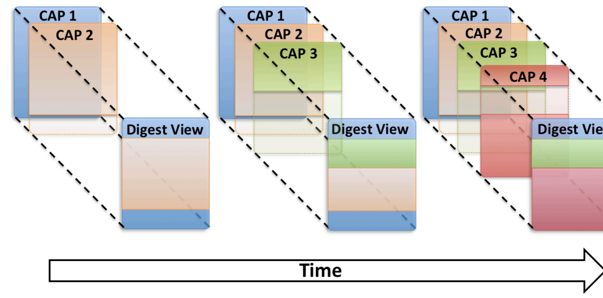

Fig. 7: Implementation of the WEA+ Digest View. The digest view supports situational awareness through an overlay mechanism to aggregate information from a stream of related alerts. Multiple incoming alerts in CAP format are received with updates to only certain fields (represented by transparency). At any point in time, the digest view shows a composition of the most recent and still valid fields from all messages in the stream.

F. Alerts using Location Prediction

On-phone geo-filtering and location history use recipients' current and past location information to filter alerts, however, they do not consider their future location, *e.g.,* in the case of a citizen moving towards a fire region covered by an active alert. Location prediction uses a person's movement information (speed and direction) to predict their future presence in the alert region. We implemented and tested this feature in WEA+. We expected this feature to improve alert outcomes, however our results did not support this expectation. Beyond the subjects' perception of the usefulness of this feature, there was no significant effect on any of the outcomes evaluated.

G. Inclusion of External Link in Alerts

Currently, inclusion of clickable links to websites and references to social media tags are disallowed in WEA messages due to fear of possible network congestion. However, this concern will become less and less valid as cellular technology advances. External links may improve the information content of alert messages by allowing easy access to additional resources. We therefore implemented link inclusion as a WEA+ feature and tested it. Although the majority of the subjects found it a desirable addition (this result was highly significant) after receiving alerts with links, other alert outcomes were not significantly affected when compared to alerts without links. External links improved the information content of alert messages as measured by adequacy (this result was significant in pooled observations, but not systematic across the two experiments), however the observed effect was small.

H. Alerts with Text-to-Speech (TTS)

Recipients alerted using different tonal modes might react to alert messages differently and at different speeds and rates. We wanted to find out if there was a difference between alerts notifying the recipient using vibration and a ringtone and those notifying the recipient with vibration and the spoken alert text instead of a ringtone. There were no significant differences in any of the alert outcomes, except a mild positive impact on understandability and actionability, with a small effect size.

We also measured response rate for this feature, and TTS-enhanced alerts had a significanlty higher response rate than regular alerts. This result may be interpreted as a precursor to real actionability as opposed to perceived actionability. In conclusion, TTS could be beneficial for actionability in proper contexts, *e.g.,* while driving.

I. Long-Message Alerts

Current WEA service limits alert messages to 90 characters. We evaluated the potential benefits of longer messages by comparing alerts significantly longer than 90 characters to alerts that obey the current character limit. The results show that actionability, milling behavior, and annoyance were most affected by message length, in favor of long messages. The significance and size of the improvements were alert-specific. The message length did not affect understanding and adequacy outcomes.

J. Alert Timing

We compared responses to alerts sent at different times (early morning, working hours, late evening, and weekend) to see whether the timing affected any of the alert outcomes. We didn't find any differences. However, this alert characteristic is both demographic-specific and difficult to isolate without a large alert sample. It is possible that the sample size was too small to assess this characteristic.

K. Overall Impressions

At the end of experiment, a final questionnaire was sent to gauge the overall perceptions of the subjects. The questionnaire included two questions on the WEA benefits: (1) Do you believe wireless emergency alerts are useful? (2) Do you believe wireless emergency alerts could save lives? Subjects nearly unanimously felt that the WEA service was useful and could save lives.

VI. LIMITATIONS

Convenience sampling poses the main threat to the external validity of the PUT results. The subjects who participated in the experiments were volunteers who were largely recruited from two Carnegie Mellon University campuses. They were predominantly technology savvy and comfortable using their smartphones' advanced capabilities. Therefore there is a risk that their responses to technology-based features may differ from those of the average citizen. Also self-selected volunteers tend to be more motivated than the general population. As an alleviating factor, selection bias applies equally to the two compared groups in an internally randomized design, which was the case in both trials.

In addition, the experiments relied on suspension of disbelief and alerts send under artificial emergency scenarios. People may behave differently in real-world situations when faced with real dangers to their safety and to their property. Short of staging actual emergencies or deceiving the subjects—neither of which would be safe—we cannot entirely eliminate this threat in a controlled study. In the post-trial questionnaires, over two-thirds of the subjects found the level of realism in the test alerts acceptable, which moderates this threat.

In Experiments 1 and 2, the outcomes were evaluated via self-assessment based on the subjects' responses to a set of questions posed after receiving each alert. Therefore we evaluated the perceived value of the tested enhancements with respect to a set of pre-determined constructs, raising an internal validity threat. For these experiments, although the outcomes were not validated by other, more objective means, we believe perceived value to be a relevant and important consideration for the public adoption and acceptance of the WEA service. In Experiment 3, the outcomes were evaluated by objectively measuring the correctness of the subjects answers, eliminating this threat.

VII. RECOMMENDATIONS AND IMPACT

Our studies have led to insights about the perceived current value of WEA and the potential future value that could come from specific improvements. We summarize the central insights next along with associated recommendations.

1) Deep integration of location-based context will improves the WEA service's value: AOs believe that increased geo-targeting resolution and precision will significantly improve the effectiveness of the WEA service. Our experiments demonstrate that this is both feasible and beneficial. Precise geo-targeting through on-phone geo-filtering can be combined with other location-aware enhancements—such as location history—to add more value, as long the geo-target can be embedded in the alert. Our work on boundary polygon encoding (discussed in [16]) demonstrates that such embedding is both feasible and efficient, even with current length limitations. The PUT results provide strong evidence for acceptance and value for these new features. We recommend that WEA alert creation tools be modified to allow embedding boundary polygons used for geo-targeting into WEA messages. We further recommend that smartphone manufacturers build flexible mechanisms into future phones to take advantage of boundary polygon information and other user context information available within the phone in making the alert delivery decision locally.

2) Rich-media integration into WEA is a question of how, not if: The AORS provided support for the integration of rich media (such use of photos, maps, and carefully typeset and laid-out text as one would find in a well-crafted web page) into the WEA service. The PUT results indicated that integrating maps enhanced with the alert region polygon and the recipient's location into WEA messages were perceived as highly desirable and has the potential improve alert outcomes significantly. The call to include rich media content in alert messages arises from the fundamentals of (a) widespread use of smartphones and (b) the pervasiveness of the World Wide Web and the ways in which the Internet sets the standard for how information is conveyed. When SMSCB was selected as the WEA information transport mechanism, cellular networks did not support broadcast of rich media. Since that time, advances in cellular network architecture (such as LTE broadcast and in-network content caching) have made rich media broadcast possible. Similarly, inclusion of maps will be facilitated by the availability of pre-cached, built-in maps in future generations of smartphones. In light of these facts and supporting study findings, we recommend a re-consideration of WEA at the level of network standards bodies and developers of WEA smartphone software to support different content forms.

3) WEA will benefit from a transition from a focus on alerting to a focus on awareness: The WEA service's fundamental nature as a 90-character text message broadcasting service may work well in situations where the descriptions of the emergency events and the recommended preparedness actions are simple and relatively unchanging. However, for situations that unfold over time and in which instructions to the public may be revised in the span of minutes to hours with many different, possibly conflicting alerts and updates issued (*e.g.,* in the case of an earthquake that causes bridges to collapse, triggers fires or the release of hazardous materials, or requires management of changing evacuation protocols), the current service's means of presenting information to the subscriber may not be well suited. Errors from interpreting individual text-based alert messages and updates out of their original order may lead to serious consequences. We demonstrated that providing software on smartphones to digest sequences and sets of related WEA messages and to present the digested information as a situational awareness view resulted in significantly better understandability compared to the standard WEA presentation of alerts on the phone. This new way of structuring and viewing streams of alert messages represents a change in the role of WEA from a focus on alerting (sending many messages) to a focus on awareness (assisting the user by digesting what has been sent into a comprehensive, up-to-date view). The WEA service's implementation today does not support such digesting. To address this, we also developed the means by which this digesting capability can be retro-fitted to the current WEA architecture.

Following the completion of our studies, the US Federal Communications Commission (FCC) has enacted new rules pertaining to WEA [19]. Commissioner Ajit Pai specifically cited our research and the recommendations for more precise geo-targeting in his statement [20], writing *"... So I proposed that we be more forward-leaning, that we commit in this Order to moving ahead with a device-based approach to geo-targeting. By enabling devices to screen emergency messages and only allow the relevant ones through, this approach would allow public safety officials to target information to specific geographic areas."*

VIII. Future Work

While our research addressed a number of issues of central importance to WEA effectiveness and adoption and provided evidence-based answers, many open questions remain and further improvements are possible. Some of our findings were sensitive to the specific schemes and algorithms used in the implementation of the features, so we recommend subsequent re-testing. For example, the location prediction algorithm could be made more robust by taking advantage of activity recognition using machine learning techniques. Map visualizations could be extended with additional information such as the recipient's distance from the alert zone, estimated time of entry into the affected area, or the nearest route for evacuation.

Newer smartphones equipped with a multiplicity of sensors have a growing awareness of their users' context. In the second trial, we had the ability to infer and categorize user activity, but did not take advantage of this information in any of the features tested. Activity information could be used to avoid distracting the recipient in dangerous situations, for instance, when one is driving at a high speed on a motorway, or changing the notification mode, for example by switching to text-to-speech. Other contextual and preference information could be explicitly set or learned. Integration with social networking apps, call histories, and/or chat histories is possible, subject to privacy concerns.

The WEA service represents a unique type of communication channel. The content is carefully controlled, the traffic is labeled, a broadcast mechanism is available, and phones are designed to process the content specially. But even with these positive attributes, the service has diverged from other communication channels on smartphones as these have evolved. A next-generation WEA service might seek to

1) Cast WEA as an app: On-phone WEA handling software could be in the form of a smartphone *app* that can be securely updated and evolved without upgrading the phone itself. This would afford continual improvements as user expectations, network capabilities, and current alerting research evolve. Legacy, build-in WEA app could be maintained in parallel for some years.

2) Extend communications for resilience and local access: As part of a survivable communications strategy [21], wireless alerting *even when the recipient's carrier network is down* could be facilitated by giving smartphones the ability to recognize (digitally signed) WEA messages from local AOs over WiFi, Bluetooth, FM radio (RDS) [22] or other wireless bearers.

3) Enrich alert creation: Enable AOs to author rich (HTML-based) content, augment CAP to carry it, and expand WEA to WECAP [23]. Rendering should use the browser mechanisms built into phones. Take advantage of LTE broadcast and remove the short-text limit. Digitally sign all alerts.

4) Close the alerting loop: Today, the WEA channel is open-loop in the sense that alerts go out and AOs only see the results in terms of the collective actions of the served population. Examine the possibility of closing the loop: provide for recipient responses in future alerting apps (*e.g.,* a button saying "this alert was not relevant for me") to enable deeper studies of alert targeting. The responses need not come back during the emergency but can be trickled back over days following an alert so as to not create inappropriate network load. Our testbed and experimental framework (WEA+) demonstrated the feasibility and usefulness of such a back channel.

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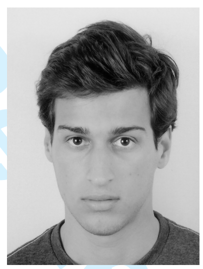

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