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From Alerting to Awareness

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***Abstract*—Wireless Emergency Alerting (WEA) is a standards-based transport and presentation service that provides a broadcast channel for communicating short text messages to subscribers in cellular systems. For emergency situations in which a single, short text message is sufficient to convey the situation, its importance and the intended action for recipients, WEA is efficient and effective. In more complex emergency situations that may require a stream of messages to convey changing situations, importance, and action, users are confronted with message sequences and must mentally digest them. Errors from out-of-order interpretation can lead to serious consequences. We present a novel approach for conveying information in such situations that re-uses much of the WEA investment in message transport but replaces the presentation with an automated digestion mechanism. We evaluate this new approach through a field experiment, showing that it measurably reduces errors of interpretation.**

***Index Terms*—CMAS, Commercial Mobile Alerting System, Situational Awareness, WEA, Wireless Emergency Alerting**

I. INTRODUCTION

In 2008, the FCC established the Wireless Emergency Alerting service (WEA, formerly the Commercial Mobile Alerting System – CMAS) [1] as a way to disseminate properly authorized 82-byte text messages to cellular telephone subscribers using the so-called SMS Cell Broadcast (SMSCB) protocol [2]. To maintain relevance to the served population, these short messages can be geographically targeted and sent only to cell towers covering an affected area. WEA is part of the Federal Emergency Management Agency's (FEMA) Integrated Public Alert and Warning System (IPAWS).

SMSCB dates back to 1997 when it was first demonstrated. It grew out of a perceived need to be able to send messages to large populations without suffering the time penalties of issuing individual text messages to mobile subscribers. Such a system is particularly useful during emergencies when traffic on the wireless networks is especially high or when network capacity has been degraded.

Since the demonstration of SMSCB in 1997, network capacities have improved dramatically (in access networks, cellular backhaul, and core networks), broadcast protocols have emerged [3], and user expectations have shifted from text messaging to rich messaging. Nevertheless, WEA remains as *the* sanctioned alerting service in the United States.

WEA is available in many smartphones today [4] and on most networks, yet it has not enjoyed widespread adoption. Our prior work [5] [6] suggests, among other things, that the rise of social media and its now-rapid adoption by police and other agencies may be displacing some of WEA's potential applications. But despite WEA's limitations, these same alert originators (AOs) view WEA as a valuable "alarm bell."

In this research, we explore a different limitation of WEA. While WEA may be suitable for alerting with a single message, asking users to mentally stitch together sequences of messages related to the same event may lead to confusion and incorrect actions. This might be exactly the situation in a complex and evolving emergency such as a large-scale earthquake. We explore the domain of alternative alerting schemes with the hope of measurably reducing user confusion in the presence of complex message sequences. Furthermore, we seek to preserve existing WEA infrastructure where possible.

This paper is organized as follows. Section III considers related work in disseminating alerts in times of emergency. The current implementation of WEA and its background are described in Section IV. Our system architecture is described in Section V. Section VI presents our field study, and Section VII summarizes.

II. CONTRIBUTIONS

We believe that this research makes two contributions to the state-of-the-art in wireless emergency alerting:

1) A new way of digesting sequences of related wireless emergency alerts, *situational awareness* (SA), that measurably reduces user confusion.
2) A methodology for introducing SA into the existing WEA service that minimally impacts WEA's existing authoring and transport mechanisms.

We claim that, together, these improvements offer the possibility of transitioning from wireless emergency alerting to wireless emergency situational awareness.

III. RELATED WORK

It is not uncommon for command-and-control teams to manage complex situations through the use of a *common operational picture* (COP – sometimes called a common *operating* picture) [7] to represent the situation and the resources that can be brought to bear. It digests streams of reports, representing changes-of-state in the situation and/or the resources, to the most-current state. War rooms with large maps and movable figures, updated using information relayed by messengers from the battlefield, are a classic example. The map captures the state of the battlefield for the sake of the leadership team's decision-making.

Today, emergency operations centers regularly use a COP [7] as part of a broader system for digesting related information streams and disseminating the resulting insights, achieving *situational awareness* (SA). SA facilitates coordinated decision-making and action. It helps to minimize errors that can occur when different parts of the organization operate with mutually-conflicting understandings. In this work, we seek to extend the notion of situational awareness beyond the command center to the served population.

IV. BACKGROUND

Wireless emergency alerting was conceived as a public safety service enabling users of suitably-equipped mobile phones to receive geographically-targeted ("geo-targeted") short text messages conveying warnings related to imminent dangers in their area [1]. The system is based on the SMS Cell Broadcast protocol and, as such, has the potential to reach a wide population much more rapidly than would be possible with individually-addressed text messages. It supports a limited form of geo-targeting based on the ability to send messages only to subscribers connected to the cellular network via a given set of cellular base stations (selective broadcasting).

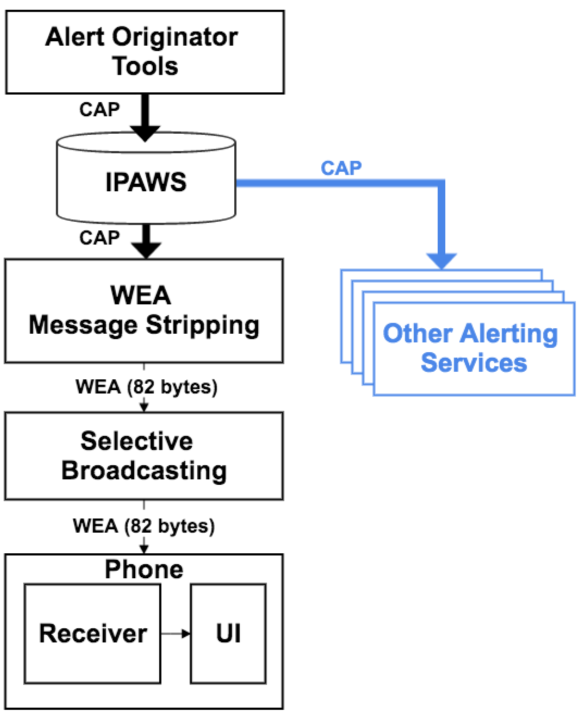

Fig. 1: Current WEA architecture in the context of the broader alert origination and dissemination system. AOs create alerts for multiple services. WEA-targeted messages are simplified.

Today, alerts are originated using CAP – the Common Alerting Protocol [8]. CAP origination includes filling in a highly structured form with semantic tags for key items (*e.g.,* urgency, severity, description, instruction, area). Interestingly, most of this structure is unused by WEA. Alerting with WEA includes steps of

- alert authoring with target-area definition,
- message approvals,
- message delivery to cellular carriers, and
- selective broadcasting within each network

Alerts received by WEA-enabled smartphones are filtered (users can opt-out of all but the so-called presidential-level messages), and those messages not filtered out are displayed, accompanied by a distinctive alert tone in some cases. Figure 1 depicts the current WEA architecture and its relationship to the Integrated Public Alert and Warning System (IPAWS).

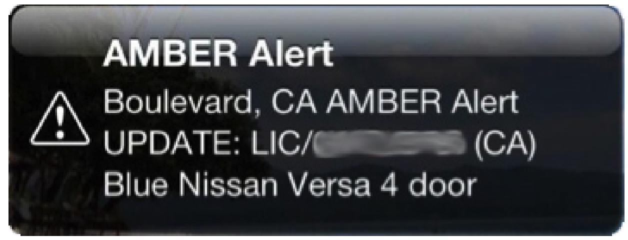

Fig. 2: A typical WEA presentation today. Each WEA message results in a separate alert.

As a means for delivering stand-alone text messages, WEA is bandwidth-efficient, and presentation of the resulting text strings easily fits the pop-up notification mechanisms of modern smartphones (Figure 2).

If the need were only to convey a single, unchanging, guaranteed-correct message per emergency situation to a large population, WEA as designed would suffice. But it is easy to imagine situations that could require require more complex and/or time-evolving instructions. In the current system, these would simply be sent as a stream of many messages. Is it right to assume users will correctly digest these sequences and updates? Will they have the most accurate information in mind when they are making potentially life-threatening decisions about where to go and what to do?

We focus on using WEA as a means to guide and direct the actions of a large population during a situation of sufficient complexity as to require the sending and digestion of multiple messages. These situations might span different but related incidents, each of which might change over time. With this time-evolution, AOs will need to send updates as the situation evolves. The content of any given message might augment or even contradict one or more prior messages.

In this study, we use the term *scenario* to represent the topmost level of such a situation in which there may be many related but distinct *incidents*. Each incident may give rise to multiple *alerts*. Alerts may be individual messages or time-ordered sequences.

Consider the example of a large-scale earthquake that causes initial physical damage (*e.g.,* collapsed bridges) followed by fires, traffic jams, and other incidents such as the release of toxic airborne contaminants. AOs might issue an initial message identifying the earthquake scenario and the bridge collapse incident with guidance (*"avoid the Dumbarton Bridge and its approaches"*). As the scenario unfolds and fires erupt, AOs may issue shelter-in-place messages related to those incidents. With the release of toxic material, prior shelter-in-place messages might be revised to call for evacuation of targeted areas. As the toxic plume moves and additional fires erupt, the correct instructions may continue to change, rendering prior instructions moot or, in the worst case, incorrect. Such a barrage of messages, particularly those with updates and changes-of-tactics, requires individuals to receive and digest them in time sequence, maintain a mental model of the latest instructions, and be able to recall these when acting. The mental complexity of this process, combined with the high stress of the scenario, could easily lead to errors of action on a wide scale.

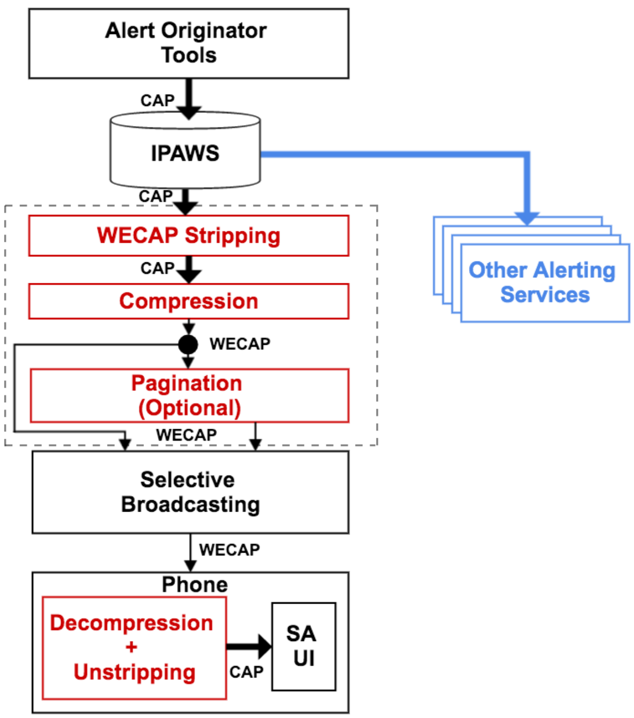

Fig. 3: Proposed new WEA architecture. CAP-like structure is preserved end-to-end, replacing the current unstructured text approach.

We propose an alternative (Figure 3) to the current wireless emergency alerting architecture that, we contend, will lead to fewer errors of interpretation. Specifically, we imagine a system that improves

Expressiveness: Alerts are originated using the full expressive power of CAP, not just a single text field.

Efficiency: CAP messages directed to WEA channels are encoded in such a way that they can be packed for and conveyed over the existing WEA 82-byte transport mechanism while preserving the structure of CAP. We refer to this new encoding as *WECAP*.

Interrelationships of messages: Messages are identified such that sets and sequences of messages are easily recognized. With proper identification, messages that are missing (for whatever reason) are more easily detected, and the user can be alerted that the information may be incomplete or incorrect.

Situational Awareness: WECAP messages arriving at the smartphone are unpacked, organized into sets of sequences (based on message identifiers), and presented as a set of digests, one digest per sequence. Digests are created by "playing back" temporally-ordered message sequences, recording the most recent information for each coded CAP field. Such an approach may also support improvements of presentation based on user context.

We contend that such a scheme can be realized while preserving much of the existing WEA transport mechanisms and while replacing the presentation with a new, digested format.

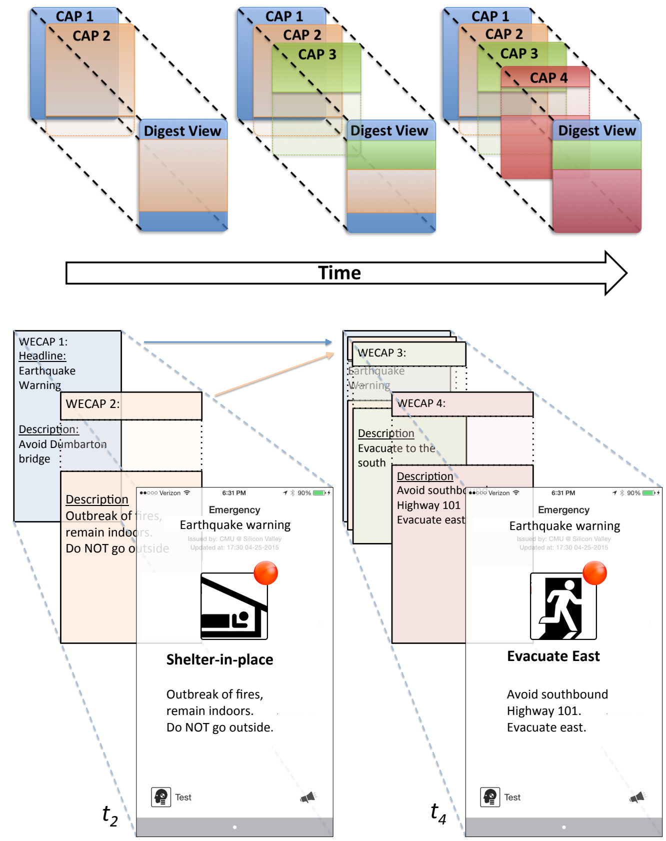

Fig. 4: Message digesting: a sequence of messages related to the same incident arrive at the smartphone, are unpacked, and "replayed," yielding a display that presents only the most recent information.

Consider the above earthquake scenario and the related alerts as illustrated in Figure 4. AOs issue a first wide-area alert at t_1 with instructions to avoid the bridge. With the outbreak of fires, they issue a *shelter in place* update at t_2. Then, when the toxic plume is detected, another update at t_3 is issued to *evacuate to the south*. Evacuation-related traffic jams to the south then prompt a revision at t_4 to *evacuate east – avoid southbound Highway 101*. With today's WEA, individuals receiving the alerts will be faced with four messages and the need to read them in time-order so as to take the correct action. Under our proposal, calling up the presentation of alerts will *only* show the most recent and relevant directive, avoiding confusion.

We now describe the details of these proposed changes and show how they can be retrofitted to the current WEA service.

V. SYSTEM ARCHITECTURE

Extending WEA as we have proposed necessitates consideration of how streams of related CAP messages can be coded to fit the existing WEA service, how messages are to be identified

TABLE I: WECAP Stripping: extracting only those CAP fields needed by the WEA service

CAP Fields	CAP	WEA	WECAP
`identifier` <id>	*text*	*text*	*text*
`headline` <head>	*text*	-	*text*
`description` <cDesc>	*text*	-	*text*
`instruction` <cInstr>	*text*	-	*text*
`incidents` <inc>	*text*	-	*32-bit int*
`onset` <on>	*text*	-	*32-bit int*
`expires` <exp>	*text*	-	*24-bit int*
`status` <stat>	*enum:5*	-	*enum:5*
`msgType`	*enum:5*	-	-
`scope`	*enum:3*	-	-
`severity` <sev>	*enum:5*	-	*enum:4*
`responseType` <rType>	*enum:9*	-	*enum:8*
`event` <eType>	*text*	-	*enum:3*
`category` <eCat>	*enum:12*	-	*enum:12*
`urgency` <urg>	*enum:5*	-	*enum:4*
`certainty`	*enum:5*	-	-
`CMAS Text`	*text*	*text*	-

TABLE II: WECAP Transport Message Format: optimized CAP encoding to match WEA requirements and the 82-byte transport mechanisms.

$$
\begin{aligned}
\langle\text{wecap}\rangle &\models \langle\text{id}\rangle\langle\text{head}\rangle\langle\text{bLen}\rangle\langle\text{cBody}\rangle \\
\langle\text{head}\rangle &\models \langle\text{dStatus}\rangle\langle\text{sev}\rangle\langle\text{rType}\rangle\langle\text{eType}\rangle\langle\text{eCat}\rangle\langle\text{urg}\rangle\langle\text{inc}\rangle \\
\langle\text{dStatus}\rangle &\models \langle\text{stat}\rangle\langle\text{on}\rangle\langle\text{exp}\rangle \\
\langle\text{bLen}\rangle &\models \langle\text{dLen}\rangle\langle\text{iLen}\rangle\langle\text{hLen}\rangle \\
\langle\text{cBody}\rangle &\models \langle\text{cDesc}\rangle\langle\text{cInstr}\rangle\langle\text{cHead}\rangle \\
\langle\text{on}\rangle &\models \langle\text{dateTime}\rangle \;; \textit{time in seconds from epoch} \\
\langle\text{exp}\rangle &\models \langle\text{dateTime}\rangle \;; \textit{time in seconds from } \langle\text{on}\rangle \\
\langle\text{inc}\rangle &\models \langle\text{parentIncident}\rangle \mid 0
\end{aligned}
$$

and linked, how encoded representations are to be transported to the phone, and how message streams are to be digested on the smartphone and presented to the user. We consider each of these in turn.

A. *Coding Alert Streams*

CAP messages are highly structured [8]. This structure was conceived as a common way to represent alerts for different services including television, radio, highway displays, WEA, and NOAA (the National Oceanic and Atmospheric Administration) weather radio. CAP's logical structure can be encoded in XML, JSON, or other formats. Transporting encoded CAP messages to smartphones is logically possible. But additional bit-efficiency can be achieved by taking a closer look at the semantically essential portions of CAP messages intended for wireless alerting and then summarizing, simplifying, and more densely coding these.

In CAP, a message is divided into `alert` and `info` elements. `alert` carries the key meta-data and `info` is the content. Each `alert` includes the mandatory parameters `identifier, sender, sent, status, msgType` and `scope` that establish the identity of the message and its author. `info` includes `category, event, urgency, severity` and `certainty`. `info` also contains a zero-to-many relationship with optional fields like `resource` and `area`. This relationship allows geo-target-identifying polygons and rich media, like images or maps, to be included in the message.

Today, WEA makes little use of this structure. Alert originator tools add a text message via an optional field of CAP called `CMAS text`. Once the message reaches a cellular carrier and the geo-targeting information is extracted, the entire CAP message, save for this field, is discarded (Figure 1). By contrast, our proposed system uses the structure present in CAP and, with careful coding, preserves this structure end-to-end.

Because WEA-targeted CAP is only a subset of CAP, we can eliminate some CAP fields and code others by enumeration. We call this process of simplification *WECAP Stripping* (Table I). After WECAP Stripping, messages are further reduced in size by encoding and field-specific compression (Figure 3). Short text fields (*e.g.,* `description`, `instruction` and `headline`) are compressed with SMAZ, and polygons are compressed using an algorithm developed specifically for WEA by members of our team [9]. Timestamps are converted to binary-coded seconds-from-epoch. Table II depicts the structure of the resulting encoded and compressed message.

B. *Message IDs*

Situational awareness necessitates a formal relationship between messages. All WECAP messages must bear globally unique identifiers, and with careful selection of identifier structure, message relationships can be represented. While CAP includes fields for message identification and message relationships, CAP does not fully define a suitable mechanism for creating identifiers. The CAP 1.2 specification simply calls for message identifiers to be

> *Unambiguous identification of the message from all messages from this sender, in a format defined by the sender and identified in the "sender" field...*[8]

We propose a naming scheme rooted in the message origination process. In our proposal, each message is logically identified by an `(AO, scenario, incident, alert)` tuple. The tuple is expressed as a path-name-structured URI beginning with the alert originating agency's identity, followed by the identity (in the AO's context) of the scenario, followed by the incident's identity, and a unique identifier within the incident. References to messages, then, are structured in this way:

`wea:/USA/DOC/NOAA/NWS/CA/2016-0306/Tornado/3`

Here, `/USA/DOC/NOAA/NWS` uniquely represents the alert-originating organization, and `/CA/2016-0306` is their name for this particular scenario. `/Tornado` identifies the incident within the scenario, and `/3` identifies a specific alert for this incident.

The properly-formatted WECAP message so identified would carry `/USA/DOC/NOAA/NWS/CA/2016-0306` in the the `identifier` field. This message would further carry `/Tornado` in the `incidents` field. The enforcement of this naming scheme is done through suitable CAP authoring tools.

For more efficient transport, well-known entity names at each hierarchical level can be converted to enumerations and then turned back to strings in the same way that other enumerations are handled (Section V-A).

C. Transporting Coded Alert Streams

Because we will support extended descriptive texts, even with careful coding and compression, we have no *a priori* assurance that WECAP messages will fit the 82-byte limit. To handle possible overflow, we define a pagination (segmentation) and reassembly protocol that resides just above the level of message transport. Considering current practice as represented by a corpus of approximately 10,000 previously-issued National Weather Service alerts, and using the proposed encoding described in Section V-A, we observed that only 5% of today's alerts would require more than two pages. Furthermore, no alert in the corpus would require more than five pages. Nevertheless, our proposed scheme supports up to sixteen pages.

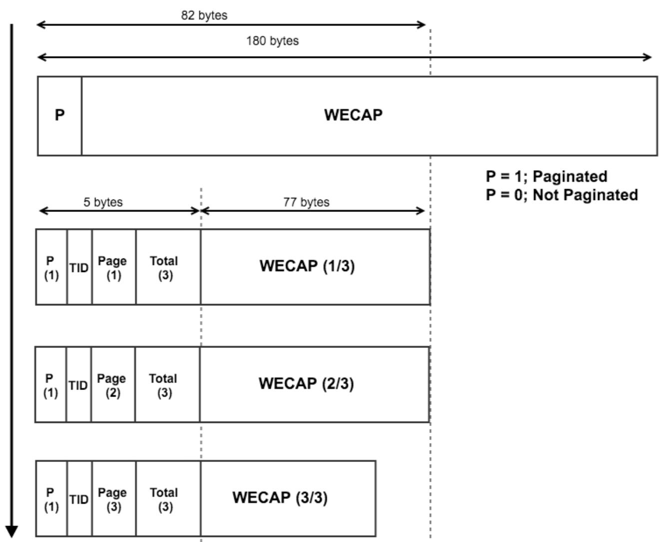

Fig. 5: Pagination of a 180 byte message into three parts.

We introduce a message header to support pagination (Figure 5). Header field `P` is a 1-bit pagination indicator flag. The 4-bit fields `Page` and `Total` allow for a maximum of 16 pages. The `TID` field is used exclusively by the transport layer to uniquely identify messages – each page of a paginated message will bear the same `TID`.

D. Digesting and Displaying Received Alerts

Once transported to the phone, paginated WECAP is de-paginated, decompressed and un-stripped. The resulting CAP-like structures are then linked based on their unique identifiers. These are then *digested* for display based on temporal ordering, a process that yields the most-up-to-date information about where to go, urgency, and relevance. The digested result is presented to the user.

As part of digestion, it is possible to detect both missing and duplicate messages based on unique identifiers. In the case of a missing message in a stream, the user is presented with the best available information together with a warning indicating that some information may be missing. Redundant broadcasting such as is presently done [2] can help fill in missing information. By preserving the hierarchy of related messages, our proposed solution ensures proper display and update in the case of out-of-order and redundant messages.

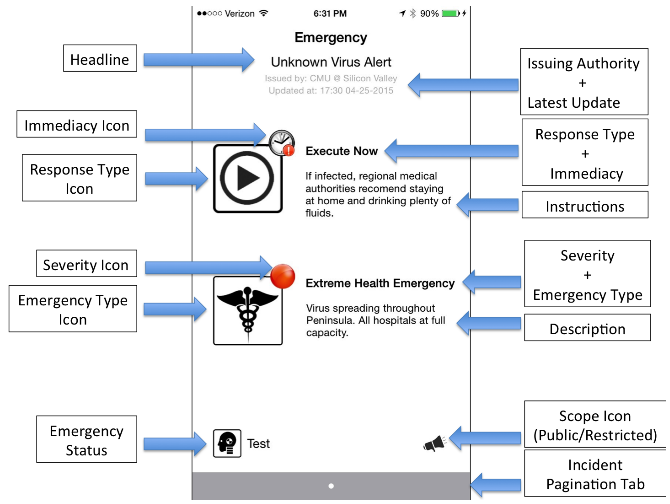

Fig. 6: The Situation Digest View

Alert displays based on digestion are depicted in Figure 6, the Situation Digest View. Our presentation of alert information emphasizes three primary aspects of an alert: *what*, *where* and *when*.

VI. Experiments and Analysis

We evaluated our proposed system by conducting a user study involving an IRB-governed experiment. In this experiment, each subject was given instructions for installing an iOS application of our design and registering the application instance (anonymously and securely) with our server. The application implemented the means to receive experimental WEA messages from our server, display these messages using either the current style or the digested style, capture user meta-data in the display of and response to messages, and test, by gathering responses to scripted questions, user understanding of the simulated emergency situation. The server and application together implemented the means to dynamically assign individual users to either a control group (current WEA) or an experimental group (proposed WEA).

The subjects' situational awareness was evaluated by multiple-question polls deployed at pre-determined times between alerts during separate, evolving scenarios of varying complexity. Rather than being based on subjects' perceptions and self-assessment, their awareness was measured, in a more objective manner, by assessing correctness of answers given. A poll's correct answer was time- and scenario-dependent. Correctness was directly tied to the subjects' confusion or understanding of a scenario. At any given time in a scenario, a subject's situational awareness was deemed high to the extent that the subject answered the poll questions correctly at that time.

TABLE III: Summary of the experimental results for awareness of the nature of the emergency (sorted by scenario complexity).

Type of Emergency	*An emergency is underway. What type of emergency is it?*				
H_0: The users' understanding of the nature of the alert is independent of the view used to present the alerts					
Scenario	# Answers		Chi-Sq.	Rej. H_0?	Odds Ratio
	WEA	SA			
Catastrophe	220	256	34.18	**Yes**	27.23
Earthquake	101	99	18.87	**Yes**	3.87
Random	67	66	7.18	**Yes**	2.98
Weather	133	120	3.30	No	1.59
Tornado	54	52	0.36	No	1.5

Since a scenario could contain multiple interleaved incidents evolving simultaneously, each poll question could have multiple correct answers at any given time. Depending on the choices selected in the answer, each question was graded as Wrong, Partially Correct, or Correct. A Wrong classification was equated with confusion or lack of understanding. If the subject selected some of the correct answers out of the set of all correct answers, but not all, then the response was graded as Partially Correct, provided that the subject's answers did not include an incorrect selection. Finally, if all of the possible correct answers were selected with no incorrect selections, the question was graded as Correct.

Through the poll questions, the subjects were evaluated on their assessment of three main aspects of the last known status of a scenario: the nature, or type, of an underlying emergency, the action to be performed as a consequence of an underlying emergency, and the immediacy of an underlying emergency. Table III shows the results obtained while evaluating the users awareness of the nature of the alerts issued in different scenarios with varying complexities. Complexity, in this experiment, was a measure of the number of times relevant alert information changed throughout the scenario.

As shown in the table, we tested the null hypothesis, H_0 – that the users' understanding of the message was independent of the way in which it was presented. In experiments where the chi-square result was above its critical value, we were able to reject the null hypotheses (Rej. H_0 = **Yes**) [10]. This meant that, in such cases, there was a statistically significant correlation between the message presentation and the users' understanding [11].

The experiment ran for one week with 93 participants. We collected a total of 3540 answers to our poll questions.

VII. Results and Conclusions

We concluded that, as the complexity of a scenario increased, the Situation Digest View measurably outperformed existing WEA [12]. For complex scenarios, the improvement through situational awareness was statistically significant with an odds ratio raging from 3.8 to 27, indicating that the population was 3 to 27 times more likely to correctly understand the scenario with the Situation Digest View rather than the regular WEA message.

Additionally, there was no downside to using Situation Digest View for simple emergency cases where the information did not change appreciably over time. Situation Digest View did not compromise any aspect of situational awareness in these scenarios. Furthermore, according to the post-experiment survey [12], over three times as many users preferred the Situation Digest View over the current WEA view. This result supports the integration of our proposed approach into a production WEA service. Users would become familiar with the Situation Digest View in simple cases, and when a more complex situation unfolds, users would be accustomed to it.

Given this result and the feasibility of integration into today's WEA, we recommend our approach for consideration as a means of transitioning from wireless emergency alerting to wireless emergency situational awareness.

VIII. Acknowledgements

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