ATIS-0700020

FEASIBILITY STUDY FOR EARTHQUAKE EARLY WARNING SYSTEM

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ATIS-0700020, *Feasibility Study for Earthquake Early Warning System*

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ATIS Feasibility Study on

Feasibility Study for Earthquake Early Warning System

Alliance for Telecommunications Industry Solutions

Approved July 2015

Abstract

This feasibility study evaluates the feasibility of the commercial LTE cellular networks in supporting public earthquake notifications as part of the proposed California Earthquake Early Warning System (EEWS). Although this feasibility study is initially targeted to California, it is applicable to other earthquake warning systems that may be deployed anywhere in the United States and its territories.

Foreword

The Alliance for Telecommunication Industry Solutions (ATIS) serves the public through improved understanding between carriers, customers, and manufacturers. The **Wireless Technologies and Systems Committee** develops and recommends standards and technical reports related to wireless and/or mobile services and systems, including service descriptions and wireless technologies. WTSC develops and recommends positions on related subjects under consideration in other North American, regional, and international standards bodies. WTSC coordinates and develops standards and technical reports primarily relevant to wireless/mobile telecommunications networks in the U.S. and reviews and prepares contributions on such matters for submission to the appropriate U.S. preparatory body for consideration as ITU contributions or for submission to other domestic and regional standards organizations. WTSC will maintain liaison with other ATIS Committees as well as external fora as appropriate. WTSC will coordinate closely with other standards developing organizations (e.g., TIA, IEEE, ETSI, etc.) on wireless issues to ensure that the work programs are complementary.

The mandatory requirements are designated by the word SHALL and recommendations by the word SHOULD. Where both a mandatory requirement and a recommendation are specified for the same criterion, the recommendation represents a goal currently identifiable as having distinct compatibility or performance advantages. The word MAY denotes an optional capability that could augment the document. The document is fully functional without the incorporation of this optional capability.

Suggestions for improvement of this document are welcome. They should be sent to the Alliance for Telecommunications Industry Solutions, **WTSC**, 1200 G Street NW, Suite 500, Washington, DC 20005.

At the time of consensus on this document, **WTSC**, which was responsible for its development, had the following leadership:

WTSC Chair: Mark Younge, T-Mobile

WTSC Vice Chair: Don Zelmer, AT&T

WTSC SN Chair: Peter Musgrove, AT&T

WTSC SN Vice Chair: Greg Schumacher, Sprint

The **Systems & Networks (SN)** Subcommittee was responsible for the development of this document.

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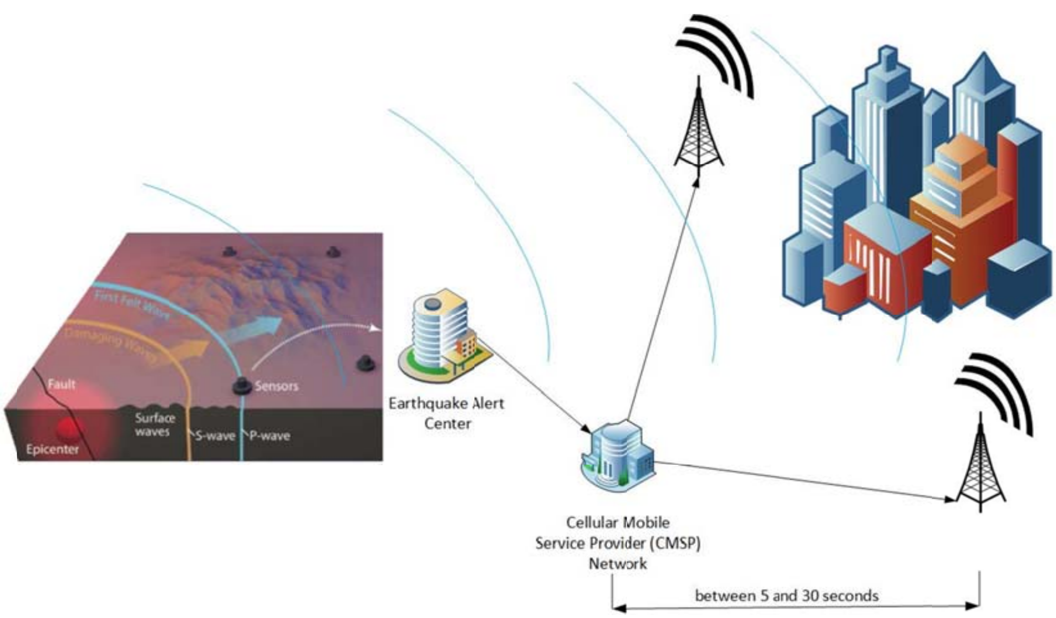
Executive Summary

ATIS completed this feasibility study to evaluate techniques to distribute Earthquake Early Warning (EEW) notifications to the general public through cell phones via the cellular network as a way to complement the California Integrated Seismic Network (CISN). An EEW system has been conceptualized for the West Coast of the United States within existing operational environments of three regional seismic networks in southern California (Southern California Seismic Network, SCSN) and northern California (Northern California Seismic System, NCSS). The Pacific Northwest (Pacific Northwest Seismic Network, PNSN) and other Advanced National Seismic System (ANSS) areas in North America (e.g., the New Madrid Seismic Zone, etc.) are beyond the scope of this study. The study took into consideration the basic EEW System service model consisting of components that are used, or planned to be used, in EEW systems around the world. This report provides a summary of this feasibility study.

As a conclusion of this study, ATIS determined that a cellular wireless broadcast EEW notification is a viable concept designed within the constraints and limitations of the cellular wireless networks. This study describes a proposed architecture for the EEW system for the distribution of time sensitive EEW notifications using capabilities in the LTE broadcast channel. This architecture uses broadcast capabilities in the cellular network. Broadcast has the potential to reach millions of users in seconds to minutes in an inherently geo-targeted fashion, whereas trying to reach the same number of users via traditional SMS or push data services ("apps") would swamp the network, slowing the delivery of EEW notifications to a crawl.

The EEW notification area is assumed to be a circle specified by the estimated surface location of the epicenter and an associated radius where the EEW notification should be broadcast. The cellular networks operators will make the best approximation to map the EEW notification area to the associated set of cell sites which are to broadcast the EEW notification.



Earthquake Early Warning System (EEWS)

Based on the completed study, ATIS is confident that North American standards can be specified to enable LTE cellular network broadcast of EEW notifications originated by an earthquake alert center. 3G networks have technology limitations and are infeasible for supporting EEW notifications; non-cellular (e.g., Wi-Fi) networks are out of scope of this study. Specifically, Early Warning notifications to machine-to-machine (M2M) devices, Internet of Things (IoT) devices, and non-human recipients (e.g., elevators, trains, planes, bridges) are out of scope for this feasibility study.

In the course of this study, ATIS also evaluated other technologies and determined they are not feasible to meet EEW notification requirements. For example, Wireless Emergency Alerts (WEA) is designed to provide imminent threat alerts, however the WEA system is not designed for or capable of distributing time-sensitive EEW notifications. An EEW system must support time-sensitive delivery requirements that are beyond the ability of WEA, where delivery time may be measured in minutes. WEA is appropriate for less-time sensitive alerts providing authorized alerting authorities a means to provide information to citizens, for example in the aftermath of an earthquake. The U.S. Geological Survey (USGS) and ATIS must collaborate to understand the limitations and latencies in the IPAWS/WEA system.

Upon agreement to proceed into the standardization phase by all stakeholders, the proposed ATIS standards will specify all the relevant interfaces and protocols for an end-to-end system starting from the earthquake alert center all the way to broadcast to the cell phone that will notify the users of an imminent earthquake. It is recommended ATIS standardize cellular network aspects of system security and engineering, alert messages and distribution, and overall system performance for the EEWS. The EEWS solution proposed by ATIS will take several years to develop and deploy, starting with developing the new ATIS standards, updating cellular operators' networks, designing new cell phones that can receive EEW notifications, educating the public on the new service, and deploying the interfaces to the earthquake alert center. To that end, close collaboration between USGS, CISN, ATIS, cellular network operators, and other relevant parties will be required to ensure a successful and timely standardization, planning, development, testing, and deployment of an EEW system. ATIS should be involved in the development of ANSS and CEEWS standards to identify impacts to the CMSP and EEWS. It is also assumed ATIS will collaborate in the development of standards for the maximum allowable telemetry latency and minimum quality of service for data sources so an end-to-end latency budget can be determined, as well as defining the end-user perspective for an EEWS. There are public education and public outreach activities that must accompany these efforts.

Deployed cellular networks and cell phones (at the time of this study) do not support EEW capabilities. The recommended architecture and solution must be developed, standardized, tested, and deployed prior to supporting EEW.

It is estimated that it will take a minimum of 3-4 years to complete standards and fully deploy EEW capabilities in wireless networks, and begin introducing new cell phones which support EEW alerting. This duration starts once the deployment plan and budget for the sensor network and automated decision making framework of the EEW system has been approved.

Accordingly, all stakeholders should understand that it will be approximately 5-7 years from the date of this report, assuming its recommended actions are implemented immediately, before a substantial number of cellular network users (e.g., > 25%) will have EEW capabilities in their devices. Consumer adoption of EEWS will be via normal market behavior.

Using the approach of normal market driven cell phone replacement cycles for providing the penetration of EEW capable cell phones among consumers, it is estimated it will take an additional 2-3 years for EEW capable cell phones to represent 80% or more of all cell phones in use.

In summary, the wireless industry looks forward to working with the USGS, the CISN, and other states and stakeholders looking to deploy an EEW system.

1 Scope, Purpose, & Application

1.1 Scope

The scope of this feasibility study is limited to earthquake early warning notifications to cell phones used by human subscribers on LTE networks. Early warning notifications to machine-to-machine (M2M) devices, Internet of Things (IoT) devices, and non-human recipients (e.g., elevators, trains, planes, bridges) are out of scope for this feasibility study.

Also, the scope of this feasibility study is limited to Commercial Mobile Service Provider (CMSP) solutions. Other solutions such as Over-The-Top (OTT) applications, Wi-Fi only devices, and radio and TV broadcast warnings are outside the scope of this feasibility study.

1.2 Purpose

The purpose of this feasibility study is to evaluate the feasibility of the commercial LTE cellular networks in supporting public earthquake notifications as part of the proposed California Earthquake Early Warning System (EEWS). Although this feasibility study is initially targeted to California, it is applicable to other earthquake warning systems that may be deployed anywhere in the United States and its territories. Specifically, this feasibility study will:

- Provide a survey of the global earthquake warning systems for cell phones.
- Define the ATIS understanding and assumptions for the EEW system.
- Describe the ATIS recommended overall end-to-end solution for EEW notifications to cell phones.
- Define the ATIS recommended solution for EEW notifications to cell phones for LTE networks.
- Provide a high-level summary of technologies that are not suitable for EEW solution.
- Provide conclusions and recommendations.
- Define the next steps with general timelines for topics such as standards development, solution implementation, solution deployment, and cell phone development.
- Identify a parking lot of open issues that need to be addressed before the next steps can be completed. These open issues could be questions regarding the EEWS functionality or questions that need further detailed analysis in the standards development organizations.

1.3 Application

This feasibility study is applicable to cellular network operators, the USGS, CISN, CalOES and other governmental stakeholders, and to the members of the project team developing the EEWS proposal.

2 References

2.1 Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

[Ref 1] 3GPP TS 23.041, *3rd Generation Partnership Project; Technical Specification Group Terminals; Technical realization of Cell Broadcast Service (CBS)*.[1]

[1] This document is available from the 3rd Generation Partnership Project (3GPP) < http://www.3gpp.org/ >.

[Ref 2] FCC CSRIC IV Working Group 2, *Geographic Targeting, Message Content and Character Limitation Subgroup Report*, October 2014.[2]

[Ref 3] 3GPP TS 22.268, *3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Public Warning System (PWS) Requirements*.[1]

[Ref 4] ATIS-0300105, *Next Generation Interconnection Interoperability Forum (NGIIF) Auto Dialers Reference Document*, December 2014.[3]

2.2 Informative References

[Ref 100] Decision criteria for Earthquake Early Warning Applications by Wu, Beck & Heaton, *Proceedings of the Fifteenth World Conference on Earthquake Engineering*, Portugal, 2012.[4]

[Ref 101], Kieffer, Susan. "Mexico's 7.2 earthquake and its early warning system", *Geology in Motion*, April 18, 2014.[5]

[Ref 102] Allen, Gasparini, Kamigiachi, and Bose. "The Status of Earthquake Early Warning around the World: An introductory overview", *Seismological Research Letters* 80:5, 682-963.

[Ref 103] Espinosa-Aranda, Cuéllar, Ibarrola, Islas and García. "The Seismic Alert System of Mexico (SASMEX) and their Alert Signals Broadcast Results", *Proceedings of the Fifteenth World Conference on Earthquake Engineering*, Portugal 2012.[4]

[Ref 104] Mert, Alçik, Erdık, Gül, Özel and Fahjan. "Istanbul Earthquake Rapid Response and the Early Warning System", *Proceedings of the Thirteenth World Conference on Earthquake Engineering*, Canada 2004.[4]

[Ref 105] Wang, Pan and Chen. "A General Introduction of the Earthquake Early Warning System in Wenchuan, China", *Proceedings of the Fifteenth World Conference on Earthquake Engineering*, Portugal 2012.[4]

[Ref 106] Lin, Huang, Chiang and Shen. "Development of the On-site Earthquake Early Warning System in Taiwan", *Proceedings of the Fifteenth World Conference on Earthquake Engineering*, Portugal 2012.[4]

[Ref 107] Tablot, David, 80 Seconds of Warning for Tokyo, *MIT Technology Review*, March 11, 2011.[6]

[Ref 108] Earthquake Early Warnings leaflet, Japan Meteorological Agency.[7]

[Ref 109] 緊急地震速報 (Kinkyu Jishin Sokuho). "What is an Earthquake Early Warning?" Japan Meteorological Agency.[8]

[Ref 110] Burkett, Erin R., Given, Douglas D., and Jones, Lucile M. "ShakeAlert Fact Sheet, ShakeAlert—An Earthquake Early Warning System for the United States West Coast". U.S. Geological Survey, Earthquake Hazards Program, Earthquake Early Warning. U.S. Geological Survey. [9]

[Ref 111] Given, D.D., Cochran, E.S., Heaton, T., Hauksson, E., Allen, R., Hellweg, P., Vidale, J., and Bodin, P. "Technical Implementation Plan for the ShakeAlert Production System—An Earthquake Early Warning System for the West Coast of the United States". U.S. Geological Survey.[10]

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[2] This document is available from the FCC at: < http://transition.fcc.gov/pshs/advisory/csric4/CSRIC_CMAS_Geo-Target_Msg_Content_Msg_Len_Rpt_Final.pdf >.

[3] This document is available from the Alliance for Telecommunications Industry Solutions (ATIS) at: < https://www.atis.org/docstore/product.aspx?id=26137 >.

[4] This document is available from the WCEE Online Proceedings: < http://www.nicee.org/wcee/index2.php >.

[5] This content is available at: < http://www.geologyinmotion.com/2014/04/mexicos-72-earthquake-and-its-early.html >.

[6] Article available at: < http://www.technologyreview.com/news/423274/80-seconds-of-warning-for-tokyo/ >.

[7] Leaflet is available at: < http://www.jma.go.jp/jma/en/Activities/EEWLeaflet.pdf >.

[8] Article is available at: < http://www.jma.go.jp/jma/en/Activities/eew1.html >.

[9] This document is available at: < http://pubs.usgs.gov/fs/2014/3083/pdf/fs2014-3083.pdf >.

[10] This document is available at: < http://pubs.usgs.gov/of/2014/1097/ >.

[Ref 112] *CEEWS Steering Committee Findings and Recommendations: Technical Standards Committee* submitted to CalOES, January 9, 2015.

[Ref 113] Earthquake Early Warning Starting 1 October 2007 leaflest, Japan Meteorological Agency.[11]

[Ref 114] Heaton, T., Given, D., Allen, R., "CISN ShakeAlert Earthquake Early Warning Project Frequently Asked Questions", California Integrated Seismic Network.[12]

[Ref 115] Wikipedia Earthquake Early Warning (Japan). [13]

[Ref 116] *Emergency Information Broadcast Distribution System Technology Report*, NTT DoCoMo Technical Journal Vol. 9 No. 4. [14]

[Ref 117] "EEW: Earthquake Early Warning". University of California Berkeley Seismological Laboratory.[15]

[Ref 118] Brennan, Pat. "Proposed quake warning system could add seconds to react". Orange County Register. Jan 28, 2013[16]

3 Definitions, Acronyms, & Abbreviations

For a list of common communications terms and definitions, please visit the *ATIS Telecom Glossary*, which is located at < http://www.atis.org/glossary >.

3.1 Definitions

3.1.1 EEW Notification – This is the notification sent to the cellular phone indicating that an earthquake of significant magnitude has been detected and the user needs to take immediate action for personal protection. An EEW Notification is the notification broadcast by the CMSP network to cell phones in a specified geographic area following receipt of an indication from the Automated Decision Making Framework that an EEW Notification should be broadcast. An EEW Notification contains limited information (indication of imminent danger using a standard display of a short earthquake warning message which is pre-configured in the cell phone, equivalent to the Primary Notification in the ETWS standards).

3.1.2 EEW-Enabled Cell Phone – This is a cell phone which has the functionality required to detect, receive, and present EEW notifications to the cell phone user.

3.2 Acronyms & Abbreviations

ANSS	Advanced National Seismic System
ATIS	Alliance for Telecommunications Industry Solutions
CalOES	California Governor's Office of Emergency Services

[11] Leaflet is available at: < http://www.jma.go.jp/jma/en/Activities/EEWLeaflet.pdf > and <http://www.jma.go.jp/jma/en/Activities/EEW_Starting_1_October_2007_Dos_and_Donts.pdf>

[12] Available at: < http://www.eew.caltech.edu/docs/CISN_EEW_FAQ_v7.pdf >.

[13] Information regarding the document is available from Wikipedia. < http://en.wikipedia.org/wiki/Earthquake_Early_Warning_%28Japan%29 >. [Last Accessed on May 29, 2015]

[14] Available at: < https://www.nttdocomo.co.jp/english/binary/pdf/corporate/technology/rd/technical_journal/bn/vol9_4/vol9_4_004en.pdf.>.

[15] Available at: < http://seismo.berkeley.edu/research/early_warning.html >.

[16] Available at: < http://www.ocregister.com/articles/system-409557-warning-seconds.html >.

CBC	Cell Broadcast Center
CBE	Cell Broadcast Entity
CBS	Cell Broadcast Service
CEEWS	California Earthquake Early Warning System
CISN	California Integrated Seismic Network
CMAS	Commercial Mobile Alert System
CMSAAC	Commercial Mobile Service Alert Advisory Committee
CMSP	Commercial Mobile Service Provider
DRX	Discontinuous Reception
EAS	Emergency Alert System
EEW	Earthquake Early Warning
EEWS	Earthquake Early Warning System
ETWS	Earthquake and Tsunami Warning System
FEMA	Federal Emergency Management Agency
GSM	Global System for Mobile communications
IoT	Internet of Things
IPAWS	Integrated Public Alert and Warning System
ISA	Internet Security Agreement
KPAS	Korea Public Alerting System
LTE	Long Term Evolution
M2M	Machine to Machine
NCSS	Northern California Seismic System
OTT	Over-the-Top
PNSN	Pacific Northwest Seismic Network
PWS	Public Warning System
RRC	Radio Resource Control
SCSN	Southern California Seismic Network
SIB	System Information Block
UMTS	Universal Mobile Telecommunications System
USGS	U.S. Geological Survey
WEA	Wireless Emergency Alerts

4 Earthquake Early Warning Principles

The objective of earthquake early warning is to rapidly detect the initiation of an earthquake, estimate the level of ground shaking to be expected, and issue a warning before significant ground shaking begins.

An earthquake generates a series of waves that penetrate the entire Earth and travel at and through its surface. Each wave has a characteristic time and its own mode of travel. There are four basic types of seismic waves; two preliminary body waves that travel through the Earth and two that travel only at the surface (L waves). Combinations, reflections, and diffractions produce an infinity of other types, but body waves are the main interest in this discussion.

Body waves are composed of two principal types; the P (primary) wave, comparable to sound waves, which compresses and dilates the rock as it travels forward through the Earth; and the S (secondary) wave, which shakes the rock sideways as it advances at barely more than half the P-wave speed.

The P-wave is designated the primary preliminary wave because it is the first to arrive at a seismic station after an earthquake. It travels at a speed usually less than six kilometers per second in the Earth's crust and jumps to 13 kilometers per second through the core.

The S-wave is the secondary wave to be recorded. It follows paths through the Earth quite similar to those of the P-wave paths, except that no consistent evidence has yet been found that the S-wave penetrates the Earth's core.

The network approach to earthquake early warning utilizes many seismic sensors that are distributed across a wide area where earthquakes are likely to occur. This network of sensors sends data to a central site where ground motion signals are analyzed, earthquakes are detected, and warnings are issued. The network approach uses information from many stations to confirm that the ground motion detected is actually from an earthquake and not from some other source of vibration. Using a network of seismic sensors has the advantage that these stations are used constantly for monitoring daily small earthquakes so the system will be maintained and exercised routinely. Only a regional network of sensors is capable of characterizing large, complex earthquakes as they evolve. Thus, forecasts gain accuracy as more data are recorded and analyzed.

When an earthquake occurs, both compressional (P) waves and transverse (S) waves radiate outward from the epicenter. The P-wave, which travels fastest, trips sensors placed in the landscape, causing alert signals to be sent ahead, giving people and automated electronic systems some time (seconds to minutes) to take precautionary actions before damage can begin with the arrival of the slower but stronger S-waves and later-arriving surface waves.

Using P-wave information, the EEW system can first estimate the location and the magnitude of the earthquake. This is then used to estimate the anticipated ground shaking across the region to be affected. The method can provide warning before the S-wave, which brings strong shaking that usually causes most of the damage, arrives.

Earthquake early warning is possible only when EEW notifications can be sent through communication systems ahead of the seismic waves. Seismic waves travel through the shallow Earth at speeds ranging from one to a few kilometers per second (0.5–3 miles/sec). This means that the shaking can take some seconds or even minutes to travel from where the earthquake occurred to the alert area. The farther a location is from the epicenter, the greater the possible amount of warning time. To maximize warning time, the system must minimize delays in data processing, communication, and delivery of alerts.

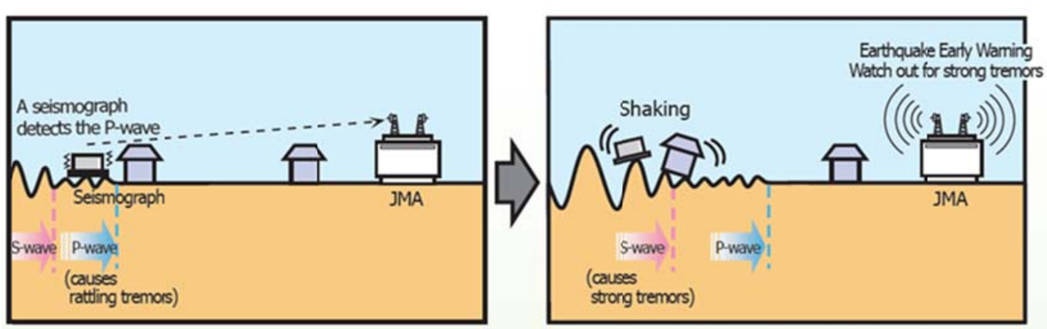

Figure 4.1 – Earthquake P-Wave and S-Wave [Ref 113]

The amount of warning time at a particular location depends on its distance from the earthquake epicenter. Locations very close to the earthquake epicenter that are within the ‘blind zone’ will receive no warning. Locations far removed from the earthquake epicenter would receive more warning time but may not experience damaging shaking. For locations in between, the warning time could range from seconds to minutes. The benefits of EEW are greatest for earthquakes greater than magnitude 7 where the area of strong shaking is large. EEW would be most effective in a case where the earthquake begins on a fault far from your location and the rupture propagates toward your location. For example, this would be the case for an earthquake beginning at the northern end of the San Andreas Fault and rupturing south towards the San Francisco Bay Area, or an earthquake starting near the Salton Sea and rupturing north toward Los Angeles. The chart below [Ref 114] explains the distance dependence of warning times.

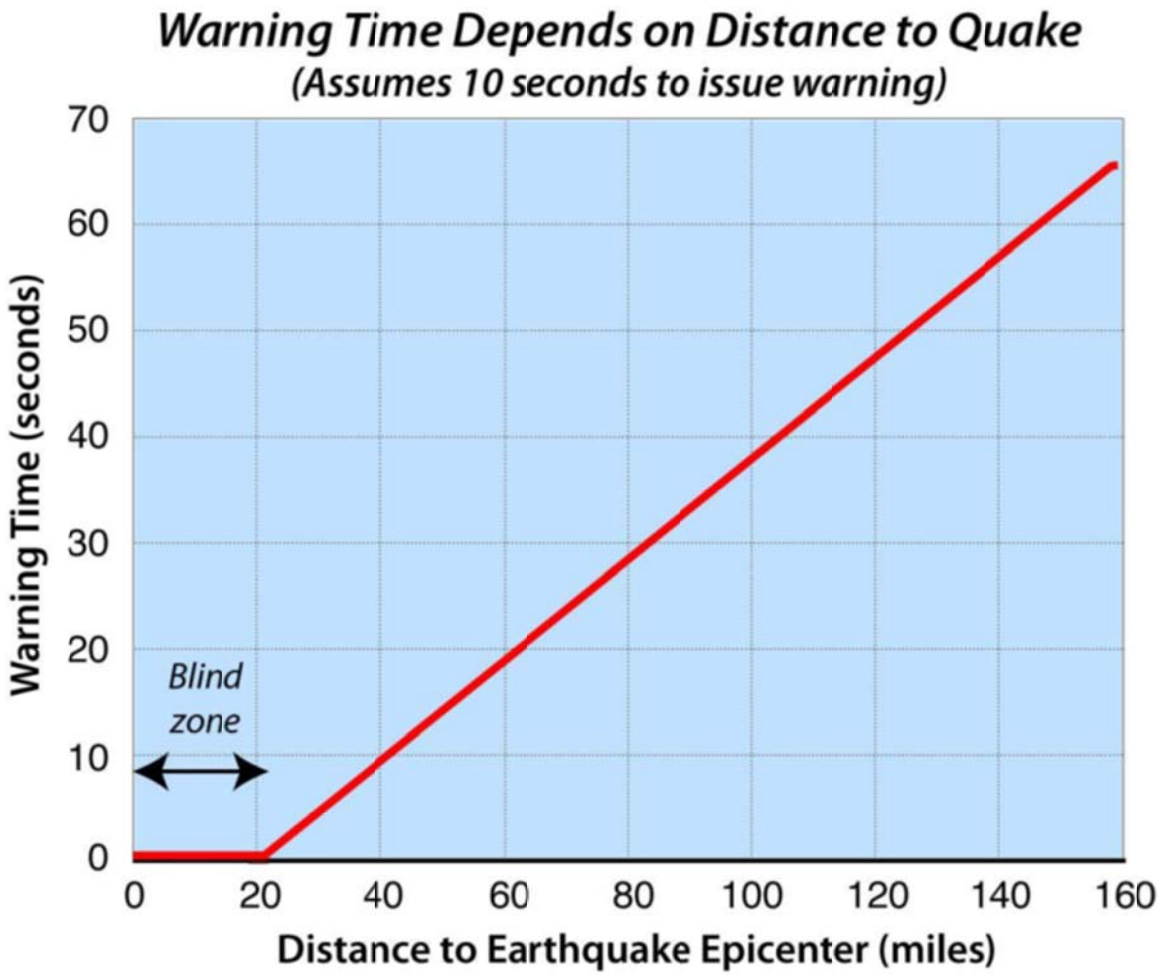

Figure 4.2 – Warning Time versus Distance to Earthquake Epicenter

Warning time depends on your location’s distance from where the earthquake begins. The slanted red line shows how warning time increases with distance from the epicenter. In this case, warning time increases beyond the 21 mile-radius blind zone with, for instance, approximately 10 seconds warning at 40 miles distance. Ongoing research is focused on reducing the size of the blind zone.

The following figure depicts how the warning time may be applied within an EEW system:

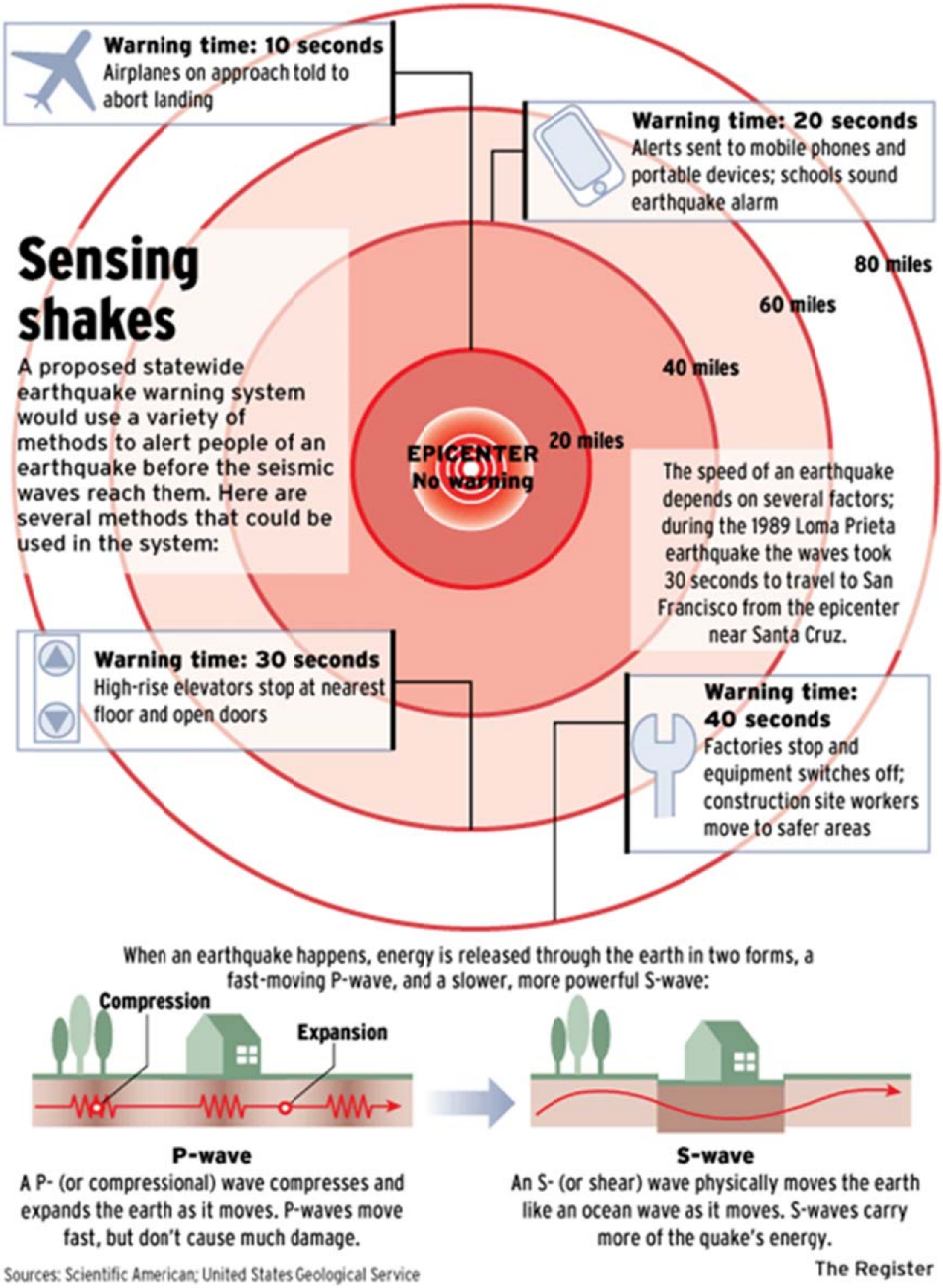

Figure 4.3 – Sensing Shakes [Ref 118]

As an example in [Ref 106], in 2011, residents of Tokyo had about 80 seconds of warning before a devastating quake rumbled through the city after striking 373 kilometers away, off Japan's northeast coast. It would have taken about ten seconds for sensors to detect enough signals to conclude the quake was serious and issue the alerts. Since the more damaging secondary waves travel at about 4 kilometers per second, it would have taken them about 90 seconds to travel the 373 kilometers to Tokyo.

The ability to send adequate warning before shaking arrives depends on:

- A network of sensors that are densely spaced and close to faults.
- Quick and robust telecommunication from sensors.
- Computer algorithms to quickly estimate an earthquake's location, magnitude, and fault rupture length, and to map resulting intensity.
- Quick and reliable mass notifications.
- End users educated about what specific actions to take upon receipt of the alerts.

5 Survey of Global Earthquake Warning Solutions

5.1 EEW Systems in other Regions

This clause examines existing Earthquake Early Warning systems deployed in other countries which have integrated mass EEW notification distribution through cellular networks. The EEW service provides a simple procedure and low action cost application – Warning broadcast – as defined in Figure 2.2 in [Ref 100].

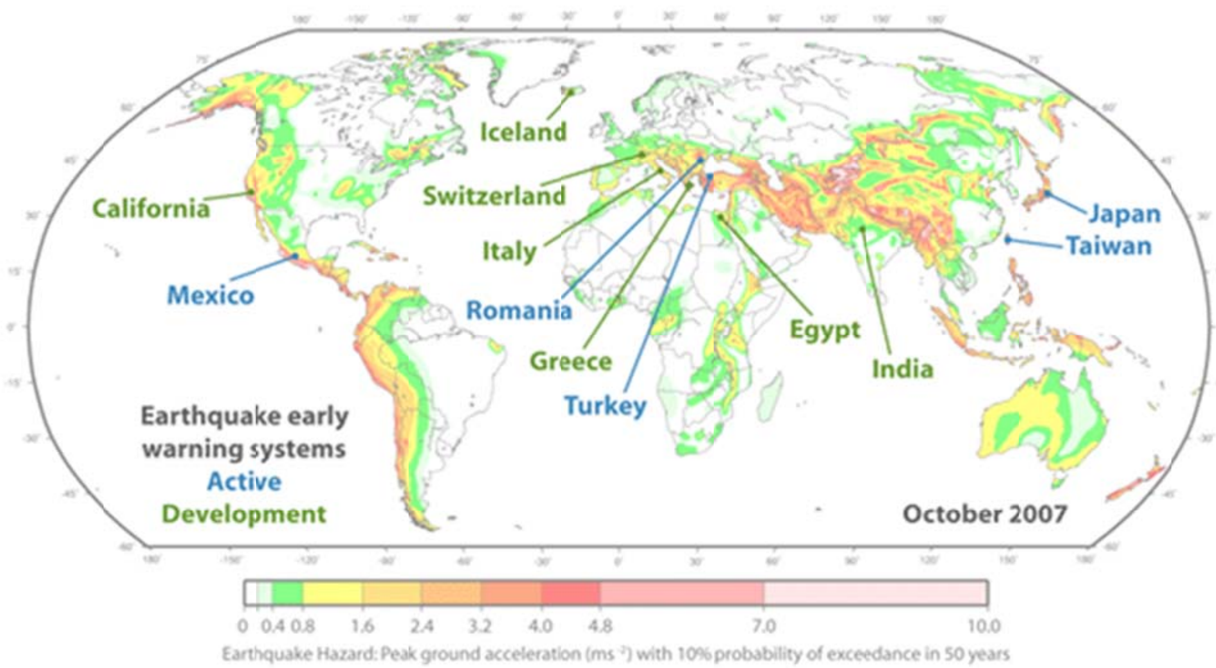

Figure 5.1 – Earthquake Early Warning Around the World [Ref 117]

As of 2009 [Ref 102], Mexico, Romania, Turkey, Japan, and Taiwan were providing warnings at some level and Switzerland, Italy, and China were undergoing real-time testing. At the time of this feasibility study, only Japan's EEW (known as ETWS) has an integrated capability to broadcast EEW notifications by cellular networks. For further information on other EEW systems which currently do not have any integrated capabilities to broadcast EEW notifications by cellular networks, see [Ref 101], [Ref 103] for Mexico's SASMEX, [Ref 105] for China's EEW in the Wenchuan area, [Ref 106] for the national EEW system being developed for Taiwan, and [Ref 104] for Turkey's IERREWS.

5.2 Japan ETWS

Of all the EEW systems currently deployed and operational around the world, Japan's Earthquake and Tsunami Warning Service (ETWS) [Ref 3] or 緊急地震速報 is the only EEW service which integrates mass EEW notification distribution through commercial cellular networks. The Japan Meteorological Agency (JMA) is responsible for the EEW system and issues two different types of alerts [Ref 102]. These two alerts are known as the primary notification and the secondary notification. The primary notification automatically issues alerts via television and cell phones shortly after the first, less harmful, earthquake shock wave is detected, providing time for many people to prepare for the more powerful shock wave that follows. The public warning intended for distribution to the general public is issued for earthquakes and tsunamis of an intensity defined by the JMA. The public alerts are broadcast by commercial television and radio stations, cellular networks and to municipalities – some who use public loudspeaker systems to announce EEW messages.

Upon detection of a P-wave from any two or more seismometers installed throughout Japan (total of 4,235 as of 1 April 2010), the JMA automatically analyzes and predicts the rough area of the earthquake's epicenter. These rough predictions allow JMA to warn people in affected prefectures if strong shaking is expected. After receiving a warning, a person may have a few seconds or in some cases, a minute or more to take action. However, areas near the epicenter may experience strong tremors before any warning.

There is an official connection between Japan's EEW system and the current Japanese cellular operators. When an earthquake is detected with an intensity that the JMA decides a public warning is needed, the JMA will issue an EEW notification which is sent by the cellular network as a primary ETWS notification [Ref 3]. This primary notification is broadcast via the cellular infrastructure in the affected area within 4-10 seconds of being received by the cellular network. It has very limited contents, merely indicating the imminent arrival of earthquake tremors, tsunami waves or both. This primary notification is intended to inform the user to take actions appropriate to their immediate situation and is based on public training, exercises, and education on earthquake and tsunami preparedness. The secondary notification can convey larger amounts of information or data for such purposes as what to do, where to get help, maps of evacuation routes, food distribution schedules, etc. [Ref 3]. The secondary notification does not have as strict delivery latency requirement as for the primary.

The JMA has two Earthquake Early Warning schemes. One is for the National Meteorological and Hydrological Services and the other is for the general public.

RC Solution Co. has developed an iPhone application for Japan named "Yurekuru Call for iPhone" to receive EEW, which is distributed on the Apple App Store for free; the application is now also available for Android. Notification of an EEW using this application might be delayed or blocked if communication lines are congested [Ref 115].

The following diagram from [Ref 108] shows the flow of an earthquake early warning in the Japanese system:

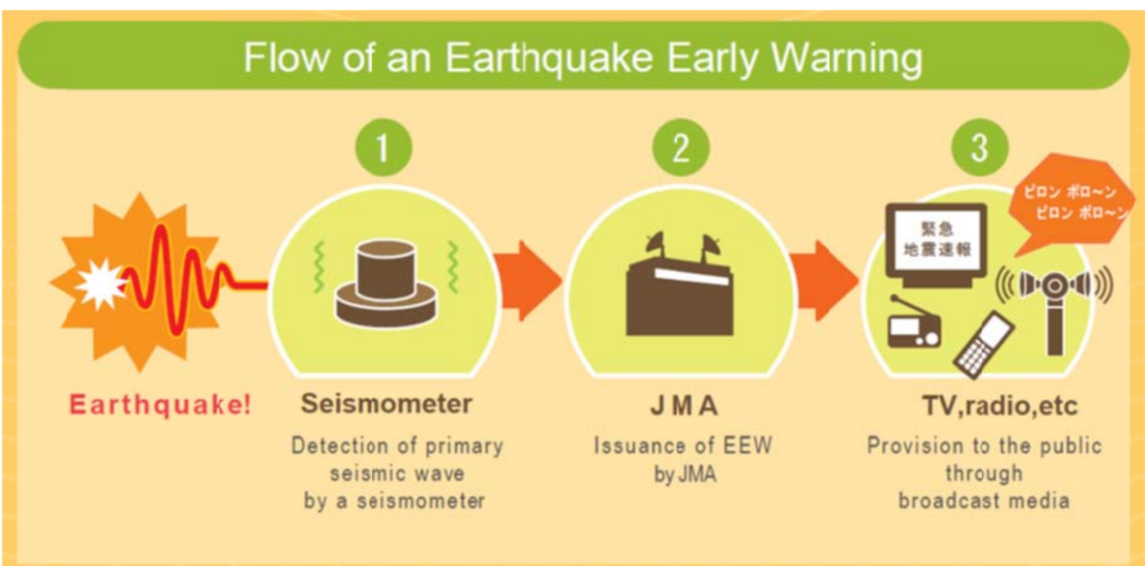

Figure 5.2 – Japanese Earthquake Warning Flow

The following figure from [Ref 109] shows how the Japanese Earthquake Early Warning system provides advance announcement of the estimated seismic intensities and expected arrival time of principal motion.

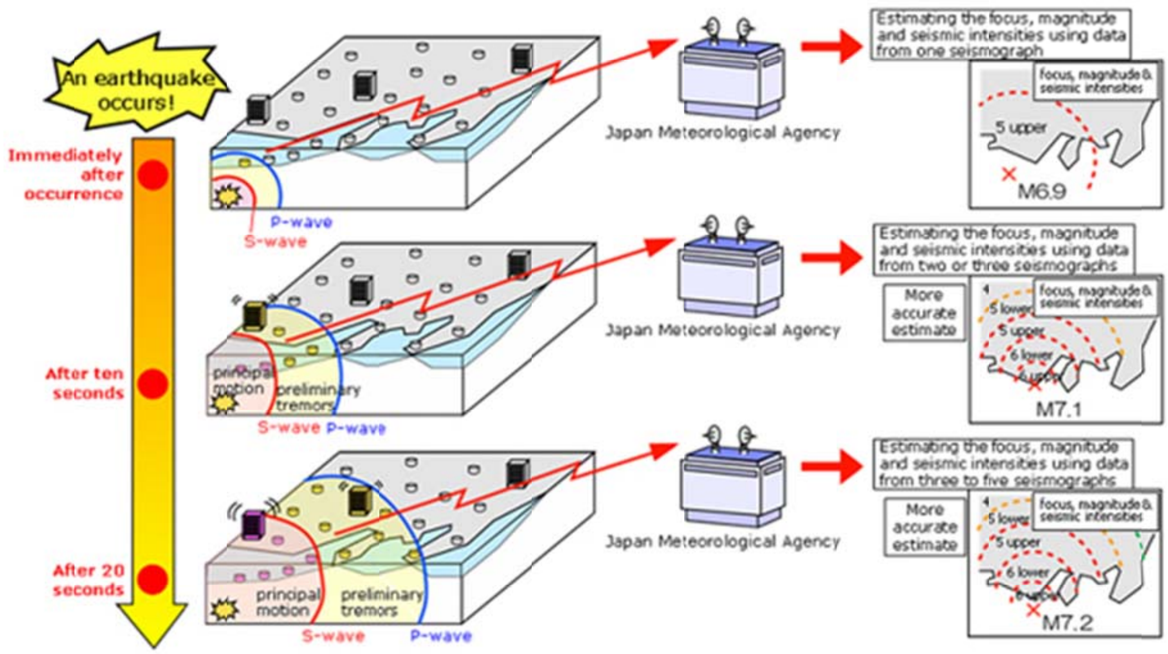

Figure 5.3 – Japanese Earthquake Early Warning System Advance Announcement

A selected bibliography on Japan ETWS is provided in Annex B.

6 ATIS Understanding & Assumptions of EEWS

6.1 Basic EEW System Service Model

There are four essential system components that are identified in EEW systems in use or planned around the world and apply equally to potential ANSS.

- **The Sensor Network** – A network of sensors that are strategically placed near or around earth fault lines to measure and report any earth movement or tremors. These sensors feed their measurements to a central location for monitoring and evaluation.
- **The Automated Decision Making Framework** – As explained in [Ref 100] and [Ref 111], this automated decision framework monitors the sensor network and based on various models will decide whether an earthquake of sufficient magnitude or intensity is occurring that should be reported through one or more dissemination channels. Telecommunications systems reliably transmit real-time intensity data from the sensor network to the Automated Decision Making Framework locations with minimal latency (delay). Computer algorithms analyze seismic and geodetic data to rapidly detect earthquakes, reject non-earthquake signals, determine earthquake characteristics, and estimate resulting ground motions.

Decision algorithms evaluate and manage these results. This intensity level may be used to select the dissemination means for which the EEW notification should be sent. The automated decision making framework will also predict the extent and range of the earthquake forces and may indicate this area to the dissemination means. For the purpose of this feasibility study, only public warning through cellular systems is considered.

- **The Dissemination Channel** – The mechanism used to distribute the EEW notification received from the Automated Decision Making Framework to the geographic target area. The information sent is appropriate for cellular network distribution. Earthquake early warning is possible only when EEW notifications can be sent through communication systems ahead of the seismic waves.
- **The Recipient** – The recipient of the EEW notification, and is expected to take appropriate action based on the local situation. This recipient is a cellular subscriber in this feasibility study.

The California EEWS standards are identified in Annex C.

6.2 Assumptions

The following assumptions provide the basis for the remaining clauses of this feasibility study; namely the recommended architecture and the determination of notification dissemination technologies not feasible for an EEW system. The parking lot of open issues is contained in Annex D.

[A100] It is assumed that the cellular network EEW notification dissemination considered in this feasibility study will only focus on warning broadcasts – one of the simple procedure and low action cost application defined in [Ref 100]. An EEW Notification is the notification broadcast by the CMSP network to cell phones in a specified geographic area following receipt of an indication from the Automated Decision Making Framework that an EEW Notification should be broadcast. An EEW Notification contains limited information (indication of imminent danger using a standard display of a short earthquake warning message which is pre-configured in the cell phone, equivalent to the Primary Notification in the ETWS standards).

[A200] This feasibility study only applies to the dissemination of EEW notifications through the cellular network. The following elements are outside the scope of this feasibility study (and are assumed to be in scope of the EEWS):

- Completion of the sensor network used to detect earthquake activity in the target areas (see also [A1600] below).
- The automated decision making framework [Ref 100] which analyzes the sensor input and decides whether an earthquake is occurring and predicts the affected areas. It is assumed that the definition of the geographic area within which EEW notifications are to be distributed is determined by the automated decision making framework.
- The automated or manual decision to disseminate any additional or supplemental EEW or other related public safety notifications.

[A300] It is assumed that there will be a distinctive alert tone and cadence used by the cellular phone when it receives an EEW notification that will apply to all ANSS deployments.

NOTE: [Ref 112] states EEWS alert tones will be standardized to ensure consistent messaging and to help establish these warnings as a valuable public resource. CalOES and other governmental stakeholders will seek input to ensure that CEEWS alert tones are consistent with other hazards warnings. EEWS alert tones shall be used only to accompany timely and specific information about impending ground motions from an earthquake. Information that is not timely (i.e., reasonably assured to arrive after the onset of shaking) or specific to the recipient of the warning (i.e., general earthquake information or information reasonably expected to be inaccurate at the user's location) shall not be announced using EEWS alert tones.

[A400] It is expected that the recommended approach described in this study, while applying initially to EEWS, will apply without modification to any other time-sensitive earthquake early warning service that may be deployed in the United States and its territories and uses a cellular network for notification dissemination. ATIS needs to be involved in the development of a strategy and roadmap to extend EEW to the other regions of the United States [Ref 111]. This should cover both new and existing ANSS.

[A500] In order to maximize the likelihood of cell phones receiving the EEW notification, it is expected that an EEW notification will be periodically re-broadcast at a specified re-transmission period for a specified duration per CMSP policies. Such retransmission durations are expected to be short as the arrival of the S-wave will occur within seconds to minutes.

[A600] It is expected that EEW notification dissemination will only take place over LTE networks. Legacy 2G and 3G networks as well as non-cellular (e.g., Wi-Fi) networks are out of scope.

[A700] It is assumed that the delivery of the EEW notification to the wireless operators will be standardized by ATIS.

[A800] It is assumed the broadcast of the notification of earthquake events will occur in a timely manner, typically within 20 seconds after the EEW notification (sent by the Earthquake Alert Center) is received by the CMSP.

[A900] It is assumed that only one EEW notification will be broadcast to the alert area associated with a single earthquake occurrence meeting the criteria for sending an EEW.

[A1000] It is assumed that at any given time for any given area, there will be only one EEW notification being broadcast by the CMSP network irrespective of the number of notifications from the Earthquake Alert Center for a given area.

[A1100] It is assumed that the specified alert area will be a circle specified by the estimated surface location of the epicenter and an associated radius where the EEW notification should be broadcast.

[A1200] It is assumed that the EEW notification described in this feasibility study is only provided for cell phones with a valid cellular subscription.

[A1300] It is assumed that cellular phones which receive multiple EEW notifications within a time period set by operator policy will only indicate the first EEW notification received and processed to the user and ignore subsequent EEW notifications within this time period.

[A1400] It is assumed that existing security principles within the cellular network are applicable to EEW.

[A1500] It is assumed that the EEW notifications will not be received and presented on the EEW-enabled cell phone when that cell phone is being used for a voice call.

NOTE: WEA alerts have the same behavior.

[A1600] It is assumed that there will be a dense network of sensors to ensure that there are enough of them near all possible earthquake sources. Such a dense network can reduce the area near the epicenter for which reliable warning is not possible because the earthquake source is too close for an EEW notification to outpace the seismic waves.

NOTE: The sensors, currently operated by the West Coast ANSS seismic networks, are not sufficiently dense in all areas to accomplish EEW without unacceptable delays; therefore, new stations must be added and existing stations must be upgraded to achieve station density needed for EEW [Ref 111].

[A1700] It is assumed that existing cell phones will not be capable of receiving EEW notifications.

[A1800] It is assumed that the large-scale architecture of a West Coast system calls for Earthquake Alert Centers at the three existing Advanced National Seismic System (ANSS) “Tier 1” regional network centers in northern California, southern California, and Seattle [Ref 111].

[A1900] It is assumed that data and message formats will be standardized throughout the system, especially the interface and protocol between the Earthquake Alert Center(s) and the CMSP infrastructure.

[A2000] It is assumed ATIS will collaborate in the development of standards for the maximum allowable telemetry latency and minimum quality of service for data sources so an end-to-end latency budget can be determined, as well as defining the end-user perspective for an EEWS.

[A2100] It is assumed that EEW information is highly uncertain and provides only a limited amount of warning time [Ref 100]. The lead time before seismic waves arrive at a site may range from a few seconds to a minute or so, corresponding to the time at which the strong shaking arrives at a site t(arr) and current time t, i.e., T(lead) = t(arr) – t.

7 ATIS Recommended Overall End-to-End Architecture

This clause provides a high level architecture view of a new Earthquake Early Warning System (EEWS) for earthquake warning notifications. This clause also provides, as background information, an overview of the existing system that handles the Wireless Emergency Alerts (WEA) that is used for less time-sensitive alerts.

7.1 Proposed Architecture for Earthquake Early Warning System (EEWS)

ATIS proposes a new Earthquake Early Warning System (EEWS) for the distribution of earthquake notifications as shown in Figure 7.1. This architecture uses broadcast capabilities in the cellular network. Broadcast has the potential to reach millions of users in seconds to minutes in an inherently geo-targeted fashion, whereas trying to reach the same number of users via traditional SMS would swamp the network, slowing the delivery of messages to a crawl.

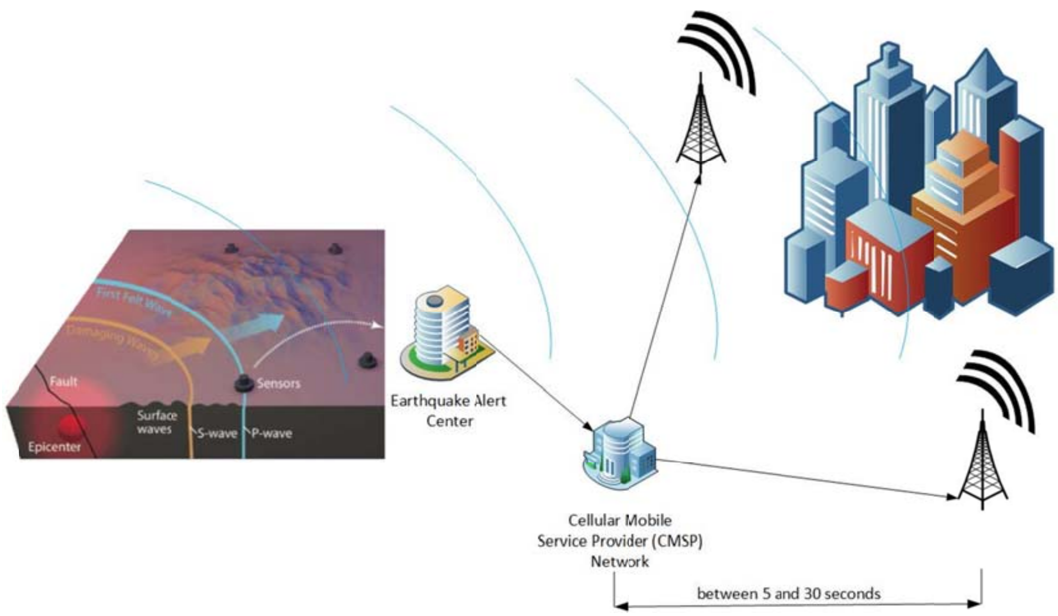

Figure 7.1 –Earthquake Early Warning System (EEWS)

This system enables the notification of earthquake events in a timely manner, typically within 20 seconds after receipt of the EEW notification by the CMSP.

Characteristics of this system will be detailed in clause 8.

7.2 Wireless Emergency Alert (WEA)

WEA system is an existing and deployed system that allows authorities to send Wireless Emergency Alerts (WEA) using Commercial Mobile Service Providers (CMSP) networks. An architecture view of a WEA system is shown in Figure 7.2.

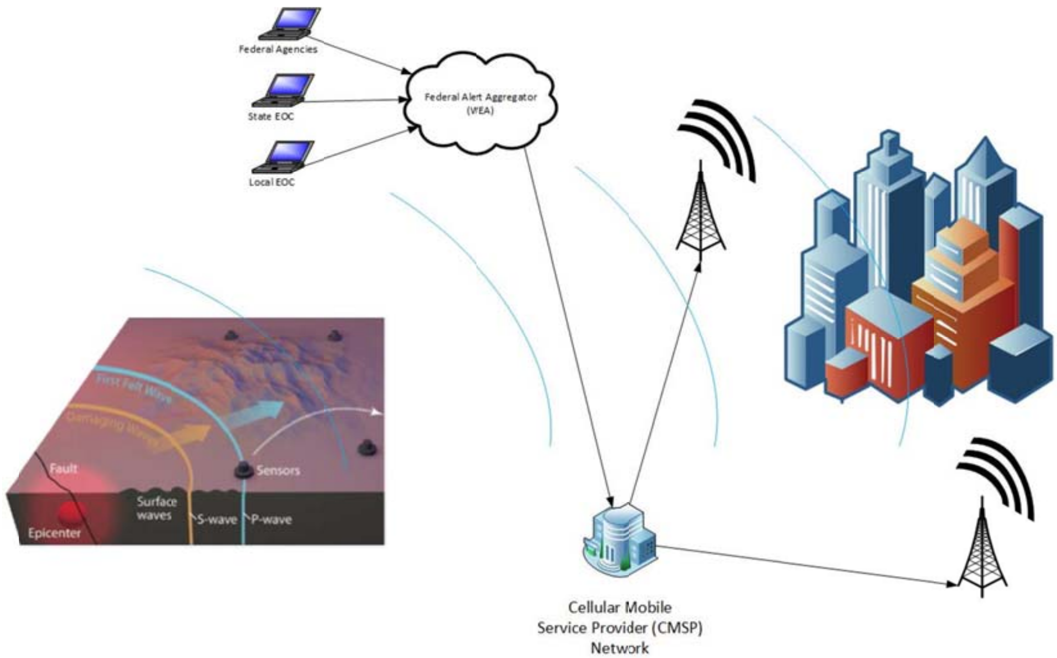

Figure 7.2 – Wireless Emergency Alerts (WEA) System

While WEA is designed to provide imminent threat alerts, this system is not designed for nor can be modified to handle time-sensitive alerts. For example, an EEWS must support a delivery requirement within 20 seconds from receipt of the EEW notification, which is beyond the ability of WEA. WEA is appropriate for less time-sensitive alerts providing authorized alerting authorities a means to provide information to citizens. For more information about sending WEA alert messages, see the FEMA Alert Origination Service Providers web page located at https://www.fema.gov/alert-origination-service-providers.

WEA supports three types of alerts:

- Presidential Alerts during a national emergency.
- Extreme weather and other threatening emergencies in your area.
- AMBER Alerts.

In addition, a recent FCC Communications Security, Reliability, and Interoperability Committee (CSRIC) report [Ref 2] recommended that WEA may be used to provide Emergency Government Information related to an imminent threat alert, such as shelter locations, etc.

8 ATIS Recommended Solution

This clause describes a high level overview of the EEWS solution as used in California. Since ShakeAlert is a distributed system with several interconnected components [Ref 111], the solution identified is expandable to other ANSS (e.g., Oregon, Washington, Alaska, etc.) that may deploy an EEWS.

The ATIS-proposed EEWS solution enables the ability of the cellular network to disseminate Earthquake Early Warning (EEW) notifications to EEW-enabled cell phones within the affected area within 20 seconds after the EEW notification is received by the Commercial Mobile Service Provider (CMSP) from the authorized EEWS Notification Entity (which is referred to as Earthquake Alert Center in this clause). In order to meet these time-sensitive requirements, the proposed solution assumes the re-use of existing capabilities on the LTE broadcast channel similar to the methods described in Annex A.

Only one EEW notification will be broadcast within the alert area associated with a single earthquake occurrence meeting the criteria for sending an EEW notification. At any given time for any given area, there will be only one EEW notification broadcast by the CMSP network.

Because of the time-sensitive nature of these EEW notifications, the EEW-enabled cell phones will receive this notification as quickly as technically feasible. However, given the nature of wireless networks and radio propagation, there is no guarantee that a cell phone will receive the EEW notification in a timely manner, and in some cases may not receive the EEW notification at all. Since all cell phones may not receive the initial broadcast of the EEW notification[17], the EEW notification will be broadcast by the CMSP network in the alert area for a maximum time limit with very small intervals between the repeated broadcasts; the maximum time limit for these rebroadcasts is recommended to be short since the ground shaking will arrive very shortly after the EEW notification. The CMSP infrastructure will broadcast the EEW notification to the EEW-enabled cell phones in the alert area using broadcast techniques which are compatible with the LTE based network and cell phones.

The figure below illustrates these points at a conceptual level:

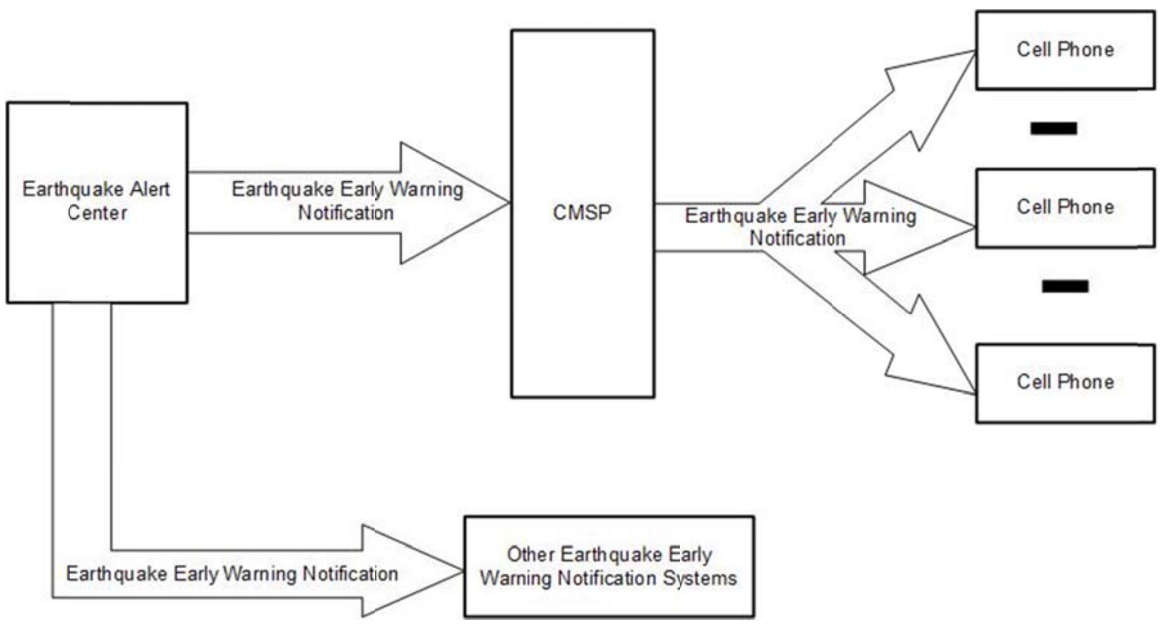

Figure 8.1 – Earthquake Early Warning Notification

For discussion purposes, the EEWS Notification Entity, including the seismograph network, is specified as the “Earthquake Alert Center” in this diagram. When the “Earthquake Alert Center” detects an earthquake event and, according to EEWS policy, decides to issue an earthquake early warning notification to wireless cell phones, the “Earthquake Alert Center” sends participating CMSPs an EEW notification request which contains the associated alert area. ShakeAlert assumes the notification between the Earthquake Alert Center and the CMSP are distributed as XML messages that are updated at least once per second as the earthquake occurs [Ref 111]. However, the significance of this “updated at least once per second” and implications to the CMSP is for further study during the standards process.

It is assumed that the specified alert area will be a circle specified by the estimated surface location of the epicenter and an associated radius where the EEW notification should be broadcast. The CMSP infrastructure will use the specified alert area provided by the “Earthquake Alert Center” to identify cell sites within the CMSP network that will enable the broadcast of the EEW notification to the best approximation of the specified alert

[17] Examples of when the cell phone may not receive the initial broadcast of the Earthquake Early Warning Notification could be because the cell phone has entered the alert area after the initial broadcast, the cell phone was powered on only after the initial broadcast, or the cell phone is temporarily out of cellular coverage (e.g., in an elevator, in a basement).

area. Note that due to cell network topology, cell site geography, and RF characteristics, the EEW notification will only approximate the specified alert area.

When determining the broadcast area of the EEW notification, the CMSP infrastructure will identify a set of cell sites which, based on cell topology and other factors, deem to be the best approximation of the specified alert area. The broadcast area is dependent on the location of the cell sites and the radio parameters and characteristics of each cell site. Since cell site locations and radio parameters vary by CMSP, the best approximation of the broadcast area for the EEW notification will vary by CMSP.

The CMSP infrastructure will broadcast the EEW notification from the cell sites in the broadcast area using a broadcast capability compatible with LTE networks. Due to the time sensitive nature of the EEW notifications, these EEW notifications will be broadcast on radio channels which are constantly monitored by the cell phones (e.g., radio control channels), as opposed to using SMS or “Apps” which will have delays in delivery.

The EEW-capable cell phones will receive and present to the cell phone user the EEW notification. The presentation of the EEW notification is recommended to include a standardized special alert tone, a special vibration cadence, and a standard display of a short earthquake warning message which is pre-configured in the cell phone.

Since the cell phone may not receive the initial broadcast of the EEW notification (see footnote #17), the CMSP infrastructure repeatedly broadcasts the EEW notification for a CMSP configured time limit (seconds to perhaps a minute or so) with CMSP configured small time interval between the repeated broadcasts.

9 Technologies Not Feasible for EEWS

Several technologies were evaluated for the ATIS recommended solution described in clause 8. This clause identifies these other technologies and describes why they are not recommended as a solution for EEWS.

9.1 Short Message Service (SMS)

The wireless industry and the FCC Commercial Mobile Service Alert Advisory Committee (CMSAAC) have evaluated the feasibility of using SMS for authority-to-citizen emergency alerting. The following are the main reasons why SMS is not suitable for any type of emergency alerting including the California Earthquake Early Warning System notifications:

a. SMS is not designed for critical real-time authority-to-citizen emergency alerting purposes.

b. SMS is a store-and-forward service which can delay the delivery of the SMS message by minutes or even hours.

c. SMS is a point-to-point technology instead of a broadcast technology. Point-to-point technologies can experience significant delivery delays when attempting to deliver messages to a large number of recipients in a short period of time. Also, SMS based notifications could put a significant load on the CMSP’s network when a large number of users are receiving notifications during an earthquake. This load comes at a time when the CMSP network must be available to those in need.

d. SMS messages are addressed to phone numbers and not to users within a specific alert area.

e. SMS messages are not delivered to a particular location or are not based on a cell phone’s location. SMS cannot determine which cell phones are within a specific alert area. The initiator of the SMS alert message does not know which cell phones are within the alert area. The SMS alert initiation systems could only know about telephone numbers that were provided at subscription time into the SMS alert initiation system. Consequently, the following will occur:

    i. Users who are subscribed to this SMS alert message system will receive the SMS alert messages even when they are outside the alert area including being in other states and other countries.

    ii. Roamers from other parts of California, other states, or other countries would not be known by the SMS alert initiation systems, and thus, such roamers would not receive the SMS alert.

f. SMS does not have security protections and can be easily spoofed by individuals who wish to cause public disruption due to false earthquake alert messages.

g. SMS has no prioritization mechanisms. The earthquake warning SMS alert messages would be queued with all other types of SMS messages.

h. If the cell phone received an SMS based earthquake warning message, it would be stored in the cell phone message queue with the other received SMS messages.

i. SMS messages can only be received by the users who have a subscription to a SMS message or text messaging service from their wireless operator.

9.2 OTT Smartphone Apps

The Technical Implementation Plan for the ShakeAlert Production System—An Earthquake Early Warning System for the West Coast of the United States [Ref 111] suggests development of a smartphone app to receive EEW messages on multiple platforms. The use of over-the-top (OTT) smartphone apps is not considered to be suitable for an Earthquake Early Warning System for the following reasons:

a. The server generating the alert message to the smartphone apps does not know which smartphones are within the specified alert area. As a result, the server has to send the notification to every smartphone registered with that specific app regardless of whether or not the smartphone is within the alert area. Delivery of alert messages to smartphones within the alert area could be delayed while the alert message is being delivered to smartphones which happen to be outside of the alert area.

b. The connection between the server generating the alert message and the smartphone is not a broadcast technology. Point-to-point technologies can experience significant delivery delays.

c. If the smartphone apps use a “push” model for the retrieval of the alert information, the smartphone app may need to first receive an SMS message to instruct the smartphone app to then retrieve the alert message from the server. This method could have significant delays in delivery of the earthquake alert message because (1) a two-step method is required and (2) the inherent delays from SMS messages (see clause 9.1).

d. If the smartphone apps use a “pull” model for the retrieval of the alert information, the smartphone apps would need to periodically connect with the server to see if there are any alerts. The reception of the earthquake alerts would be delayed by the length of time between the periodic connections and by the time required to establish the periodic connection with the server.

e. If the smartphone app does receive an earthquake alert message, the smartphone app would need to determine whether or not the cell phone is within the specified alert area. If the cell phone user has turned-off location services for privacy or battery saving purposes, the smartphone app may not be able to determine its current location.

f. If the smartphone app approach is used, only those smartphones which have previously installed the app would be able to receive the alert messages. Roamers from other states or other countries probably would not have a smartphone app for earthquake notifications.

g. The smartphone subscriber must have a data services subscription with their wireless operator in order for the smartphone apps to receive alert notifications via the wireless operator’s cellular network.

h. The smartphone app approach has economic and technical complexity implications for consumers, which will limit the consumer penetration of the smartphone app approach.

9.3 IPAWS/EAS/WEA

The Integrated Public Alert and Warning System (IPAWS) is an integration of the nation’s alert and warning infrastructure. Emergency Alert System (EAS) and Wireless Emergency Alerts (WEA) are components of IPAWS. EAS is used to send emergency alerts to radio and television broadcasters. WEA is used to send emergency alerts to cell phones. IPAWS alert messages are processed in the FEMA Emergency Operations Center in Mount Weather, Virginia and then distributed to the appropriate radio and television broadcasters for EAS messages and the appropriate wireless operators for WEA alerts.

The Technical Implementation Plan for the ShakeAlert Production System—An Earthquake Early Warning System for the West Coast of the United States [Ref 111] suggests the USGS will become an “alert authority” for the IPAWS system and EEW developers will participate in the IPAWS development process to ensure that operators of these systems consider the low latency requirements of earthquake early warning notification in their planning. However, the end-to-end latency in IPAWS over cellular networks includes delivery of the alert to the CMSP and the latency within the cellular network. The USGS and ATIS must collaborate to understand the limitations and latencies in the IPAWS/WEA system.

While the FCC rules do not specify a time for CMSPs to broadcast WEA alerts once received from the FEMA IPAWS, WEA typically receives and broadcasts alerts within several (up to ten) minutes. FCC rules for EAS specify that an alert other than a Presidential alert should be broadcast by primary stations within 15 minutes.

Given these delays, WEA is not suitable for the earthquake early warning notifications generated at the detection of the p-waves. However, WEA is the best mechanism for the delivery of subsequent earthquake alert messages (i.e., after the primary notification is sent via some other means). Subsequent earthquake messages could include information pertaining to estimated ground shaking, expected warning time, and associated uncertainties [Ref 112] and may also include other information as recommended by the CEEWS Education Committee.

Further study and standardization is required to determine how other types of EEWS messages defined in [Ref 112] would be integrated into EEW or WEA; specifically, automated cancellation of an alert, weekly/monthly tests, and manually generated operator update messages, as well as effective alert messages to meet the needs of specialized audiences (non-English speakers or persons with specialized needs). Any use of WEA for EEWS messages must conform to FCC rules.

9.4 Mass Notification Auto Dialer Systems

There are several commercial products on the market which are mass notification systems via auto dialers. Some of these products have been deployed in various California counties for emergency alerting especially for wildfire conditions. Such mass notification systems are not suitable for the California earthquake early warning alerts messages for the following reasons:

a. The earthquake notifications are inherently delayed because of having to wait for the user to answer the ringing cell phone and to listen to the audio message.

b. Regardless if the auto dialer is calling a landline or cell phone, the networks can only support a limited number of simultaneous voice calls. When that limit is exceeded, any subsequent mass notification calls will either be directed to voice mail or will receive a busy signal. In either case, the alert message is not delivered to the user in a timely manner.

c. The mass notification systems do not know which cell phones are within the alert area. The mass notification systems only know about telephone numbers that were provided at subscription time into the system. Consequently, cell phone subscribers within the alert area may not receive the alert and roamers from other parts of California, other states, or other countries would not be known by the mass notification systems.

d. At subscriber time, the user may have provided a primary address for their cell phone but the user and their cell phone may not be at that address when the mass notification alert is sent. For example, the user may be at work or traveling.

Mass notification systems have the potential to severely impact both wireline and wireless telecommunications services including blocking emergency calls to 9-1-1. The ATIS specification ATIS-0300105 [Ref 4] provides additional information about auto dialer systems and how they can avoid adverse impacts to the telecommunications network.

9.5 Legacy Cellular Networks

The second generation (2G) wireless networks and the third generation (3G) wireless networks are considered to be legacy networks and will eventually be replaced by fourth generation (4G) or beyond wireless networks. The design and capabilities of 2G and 3G wireless networks do not provide the functionality required to support the dissemination of earthquake early notification message within the required short time interval. Standardization, development and deployment efforts would be required for the 2G and 3G networks. However, the wireless industry standardization and development efforts are concentrated on the 4G and beyond wireless networks and devices.

Specifically, the ATIS recommended solution requires standardization efforts and modifications to cell phones in order to receive the earthquake early warning notification. While there are some 3G cell phones are still available on the market, there are no efforts to develop new 3G cell phones with enhanced functionality.

If the existing legacy cell phones are WEA capable, such cell phones would be able to receive the subsequent WEA based earthquake alert messages but would not receive the initial earthquake early warning notification.

10 Timelines

Deployed cellular networks and handsets (at the time of this study) do not support EEW capabilities. The recommended architecture and solution must be standardized, planned, developed, tested, and deployed prior to supporting EEW.

It is estimated that it will take about 3-4 years to fully deploy EEW capabilities in wireless networks and begin introducing cell phones which support EEW alerting. This duration starts once the deployment plan and budget for the sensor network and automated decision making framework of the EEW system has been approved. Using the approach of normal market driven cell phone replacement cycles for providing the penetration of EEW capable cell phones among consumers, it estimated that it will take an additional 2-3 years for EEW capable cell phones to represent 80% or more of all cell phones in use.

Further approximate development and implementation phasing is as follows:

- Standards development.
- After the standards have been developed and an EEW plan and budget for a sensor network and the automated decision making framework have been approved, network product development, cell phone product development, and network deployment planning can begin:
    - Core network element and radio base station product development.
    - Cell phone chipset development.
    - Cell phone development (using developed chipsets).
- Near the end of development, increasing levels of testing can begin:
    - Lab testing.
    - System testing including test interfaces to an automated decision making framework.
- After testing, operating network deployment and cell phone rollout can begin:
    - System integration testing with the deployed automated decision making framework.
    - Initial EEW capable cell phone rollout to marketplace.
    - Consumer adoption via normal market behavior.

11 Conclusions & Recommendations

As a conclusion to this study, ATIS determined that a cellular wireless broadcast EEW notification is a viable concept designed within the constraints and limitations of the cellular wireless networks. This study describes a proposed architecture for the EEW system for the distribution of time sensitive EEW notifications using capabilities on the LTE broadcast channel. This architecture uses broadcast capabilities in the cellular network. Broadcast has the potential to reach millions of users in seconds to minutes in an inherently geo-targeted fashion, whereas trying to reach the same number of users via traditional SMS or push data services (“apps”) would swamp the network, slowing the delivery of EEW notifications to a crawl.

ATIS is confident that North American standards can be specified to enable LTE cellular network broadcast of EEW notifications originated by an earthquake alert center. 3G networks have technology limitations and are infeasible for supporting EEW notifications.

In the course of this study, ATIS also evaluated other technologies and determined they are not feasible to meet EEW notification requirements. For example, Wireless Emergency Alerts (WEA) is designed to provide imminent threat alerts, however the WEA system is not designed for or capable of distributing time-sensitive EEW notifications. An EEW system must support a time-sensitive delivery requirement that is beyond the ability of WEA, where delivery time may be measured in minutes. WEA is appropriate for less-time sensitive alerts providing authorized alerting authorities a means to provide information to citizens, for example in the aftermath of an earthquake. The U.S. Geological Survey (USGS) and ATIS must collaborate to understand the limitations and latencies in the IPAWS/WEA system.

Upon agreement to proceed into the standardization phase by all stakeholders, the proposed ATIS standards will specify all the relevant interfaces and protocols for an end-to-end system starting from the earthquake alert center all the way to broadcast to the cell phone that will notify the users of an imminent earthquake. It is recommended ATIS standardize cellular network aspects of system security and engineering, alert messages and distribution, and overall system performance for the EEWS. The EEWS solution proposed by ATIS will take several years to develop and deploy, starting with developing the new ATIS standards, updating cellular operators' networks, designing new cell phones that can receive EEW notifications, educating the public on the new service, and deploying the interfaces to the earthquake alert center. To that end, close collaboration between USGS, CISN, ATIS, cellular network operators, and other relevant parties will be required to ensure a successful and timely standardization, planning, development, testing, and deployment of an EEW system. ATIS should be involved in the development of ANSS and CEEWS standards to identify impacts to the CMSP and EEWS. It is also assumed ATIS will collaborate in the development of standards for the maximum allowable telemetry latency and minimum quality of service for data sources so an end-to-end latency budget can be determined, as well as defining the end-user perspective for an EEWS. There are public education and public outreach activities that must accompany these efforts.

Based on the conclusions of this study, the following are recommendations for the Earthquake Early Warning Notifications via cell phones:

1. Close collaboration is required between the USGS, CISN, ATIS, cellular network operators, and other relevant parties to ensure a successful and timely standardization, planning, development, testing, and deployment of an EEW system.
2. The West Coast ANSS seismic networks must be completed in coordination with the development and deployment of the EEWS.
3. ATIS should standardize the cellular network aspects of system security and engineering, alert messages and distribution, and overall system performance for the EEWS.
4. ATIS should be involved in the development of ANSS and CEEWS standards to identify impacts to the CMSP and EEWS.
5. ATIS should provide CalOES and other governmental stakeholders input to ensure that EEWS alert tones are consistent with other hazards warnings, and standardize the alert tones as part of the ATIS standards process.
6. The USGS, CISN, and ATIS must collaborate to understand the limitations and latencies both in cellular networks and in the IPAWS/WEA system.

Deployed cellular networks and cell phones (at the time of this study) do not support EEW capabilities. The recommended architecture and solution must be standardized, developed, tested, and deployed prior to supporting EEW. It is assumed ATIS will collaborate in the development of standards for the maximum allowable telemetry latency and minimum quality of service for data sources so an end-to-end latency budget can be determined, as well as defining the end-user perspective for an EEWS.

It is estimated that it will take a minimum of 3-4 years to complete standards and fully deploy EEW capabilities in wireless networks, and begin introducing new cell phones which support EEW alerting. This duration starts once the deployment plan and budget for the sensor network and automated decision making framework of the EEW system has been approved.

Accordingly, all stakeholders should understand that it will be approximately 5-7 years from the date of this report, assuming its recommended actions are implemented immediately, before a substantial number of cellular network users (e.g., > 25%) will have EEW capabilities in their devices. Consumer adoption of EEWS will be via normal market behavior.

Using the approach of normal market driven cell phone replacement cycles for providing the penetration of EEW capable cell phones among consumers, it is estimated it will take an additional 2-3 years for EEW capable cell phones to represent 80% or more of all cell phones in use.

Annex A: Overview of 3GPP ETWS Functionality

(informative)

General Background

3GPP TS 23.041 [Ref 1] has specified a warning message distribution platform based on the Cell Broadcast Service (CBS) as Public Warning System (PWS). PWS Rel-8 included the Earthquake and Tsunami Warning System (ETWS) for Japan; PWS Rel-9 added the U.S. Commercial Mobile Alert System (CMAS). EU-Alert for the European Union started in PWS Rel-10. PWS Rel-11 includes both EU-ALERT and Korea Public Alerting System (KPAS).

The following describes how PWS works taking ETWS as an example. The architecture of PWS is depicted in Figure A.1.

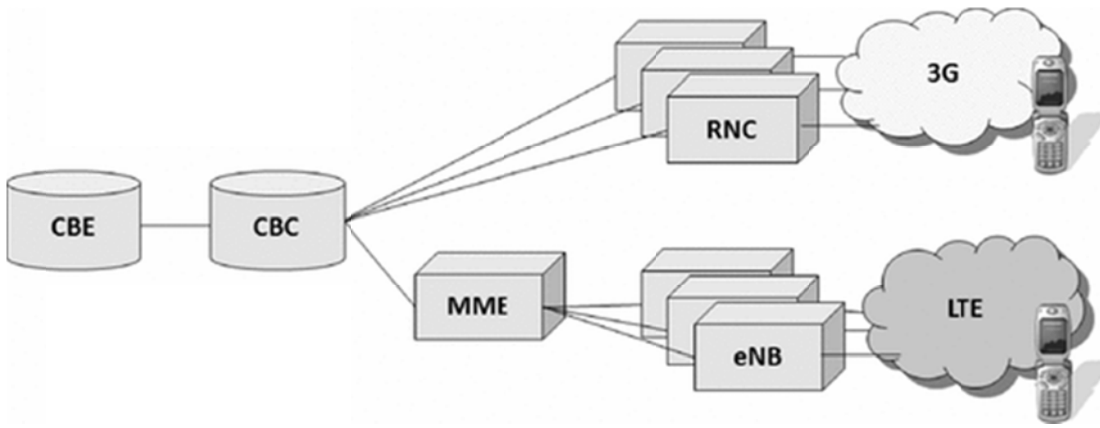

Figure A.1 – PWS Architecture

In the PWS architecture, the Cell Broadcast Center (CBC) is connected to Cell Broadcast Entity (CBE) and the CBE receives the warning message from an external source.

3GPP PWS ETWS

Once the warning information is delivered to the CBC, the broadcast is activated using the CBS platform. As illustrated in Figure A.2, there are two types of ETWS warning messages:

1. Primary Notification, which contains an indication of imminent danger.
2. Secondary Notification, which contains more detailed data in text format.

Figure A.2 – ETWS Architecture

In ETWS, the Primary Notification contains only the 'Warning Type' such as 'earthquake' and 'tsunami'. The Primary Notification may be followed by the Secondary Notification with further information such as seismic intensity, epicenter, etc.

In GSM/UMTS, the Primary Notification is contained in the RRC Paging Request message. The Secondary Notification is sent as a CBS message. In LTE, the Paging Request triggers the cell phone to receive the Primary Notification and Secondary Notification in the System Information Blocks (SIB10 for Primary and SIB11 for Secondary).

Primary Notification is sent for a short duration of time at a rapid frequency. For this reason, a CBS message (which cannot be repeated within 2 seconds in GSM/UMTS) is not used for this purpose in GSM/UMTS. Instead, the Primary Notification is sent in the Paging Request continuously for a period of time. Once the Paging is completed, the DRX mode of operation is enabled for the cell phone to receive the Secondary Notification. In LTE, the Primary Notification is sent using SIB10 for a short duration of time at a frequency (it can be as small as 80ms) and Secondary Notification is sent using SIB11 for a longer duration of time with a difference frequency (it can be as long as 5.12 sec).

The message flow for ETWS distribution in UMTS is shown in Figure A.3.

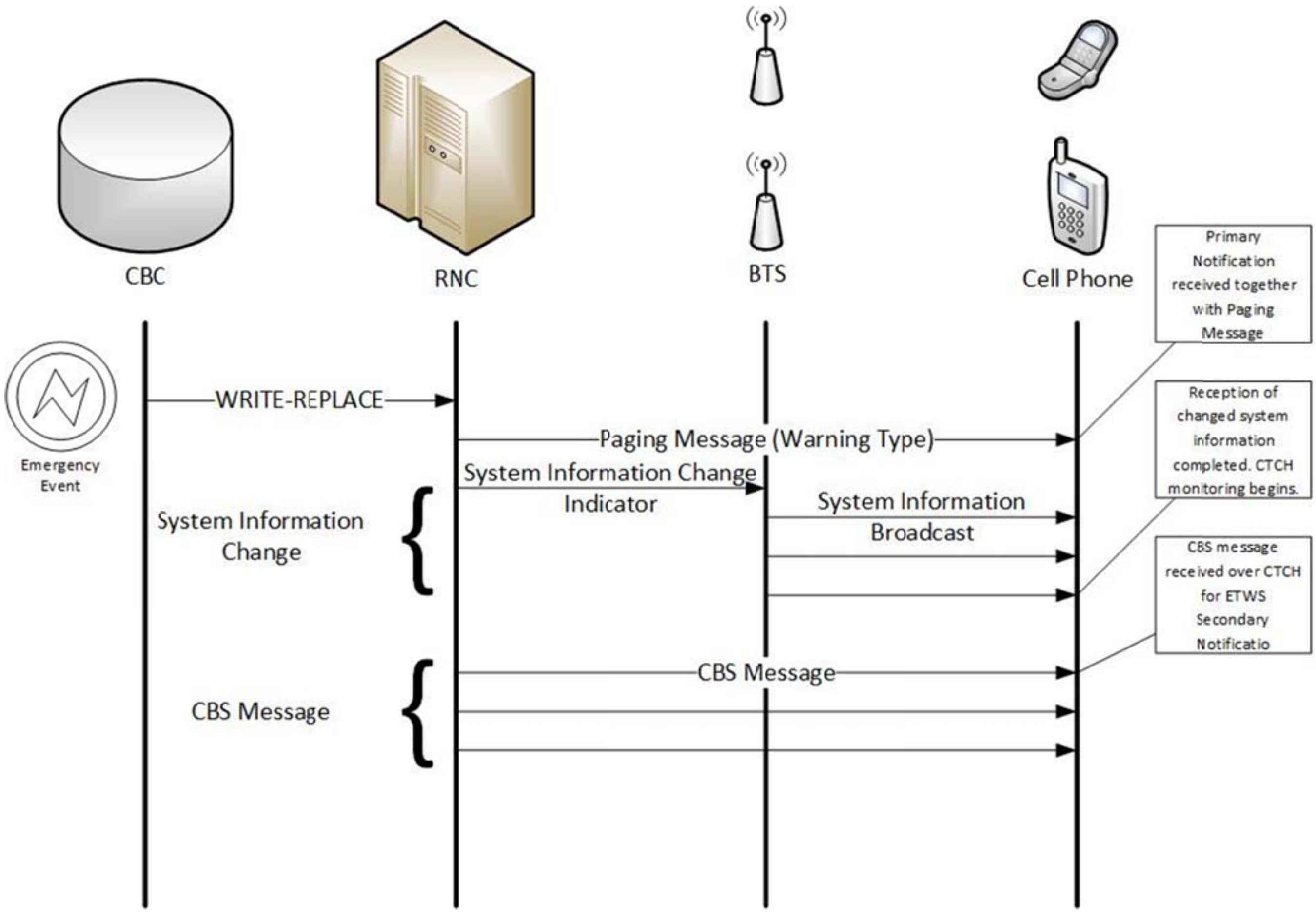

Figure A.3 – UMTS ETWS Message Flow

The message flow for ETWS distribution in LTE is shown in Figure A.4.

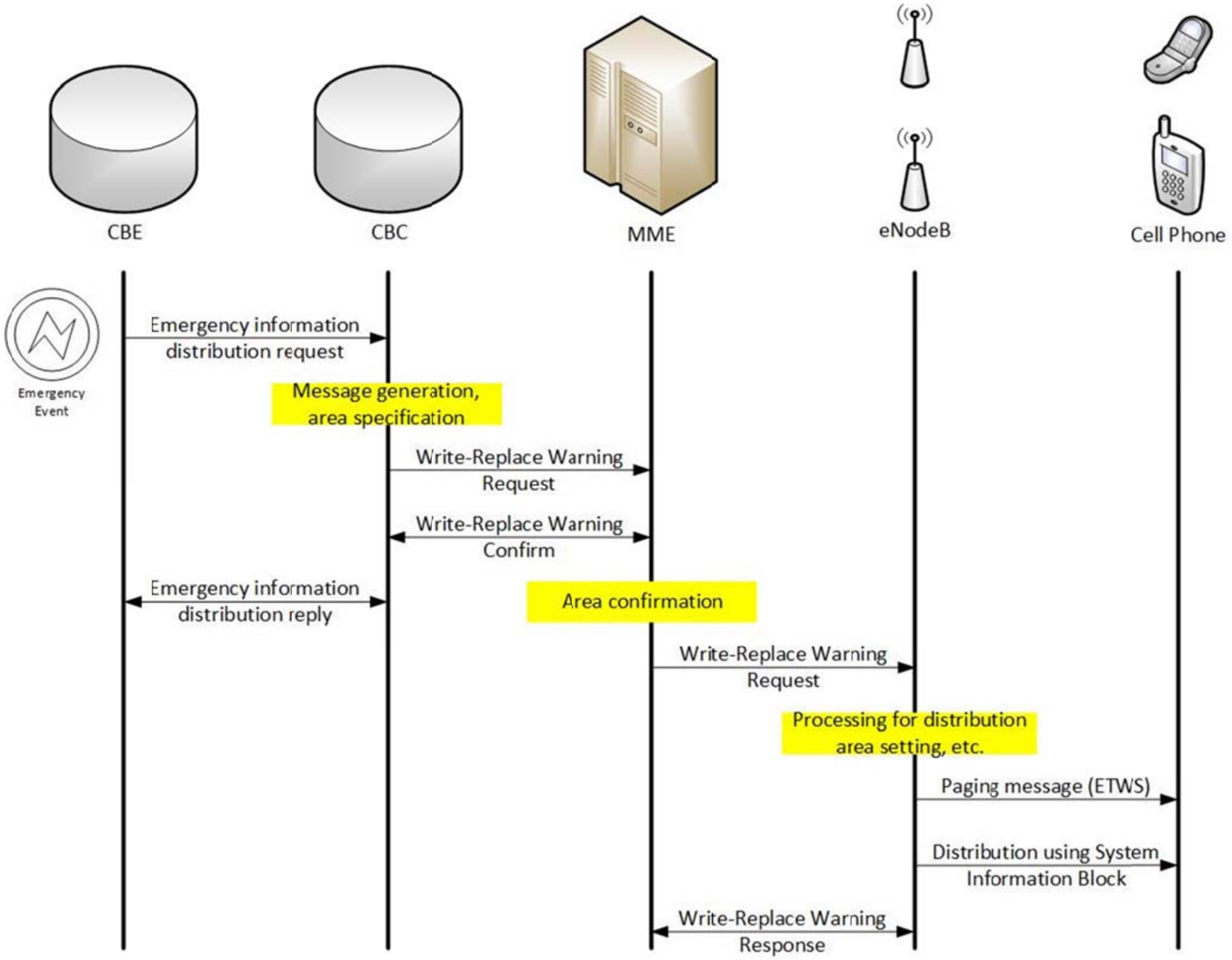

Figure A.4 – LTE ETWS Message Flow

There has been some indication that the ETWS system deployed by NTT DoCoMo may have some unique characteristics that could make it different, but possibly compatible, with that of 3GPP PWS. These changes may be due to the fact that synchronization among the CBCs is very challenging in order to achieve 4 seconds distribution of the Primary Notification. One potential approach could be for the CBCs to immediately blast the warning message without checking or storing it. Figure A.5 shows NTT DoCoMo's broadcast method [Ref 116].

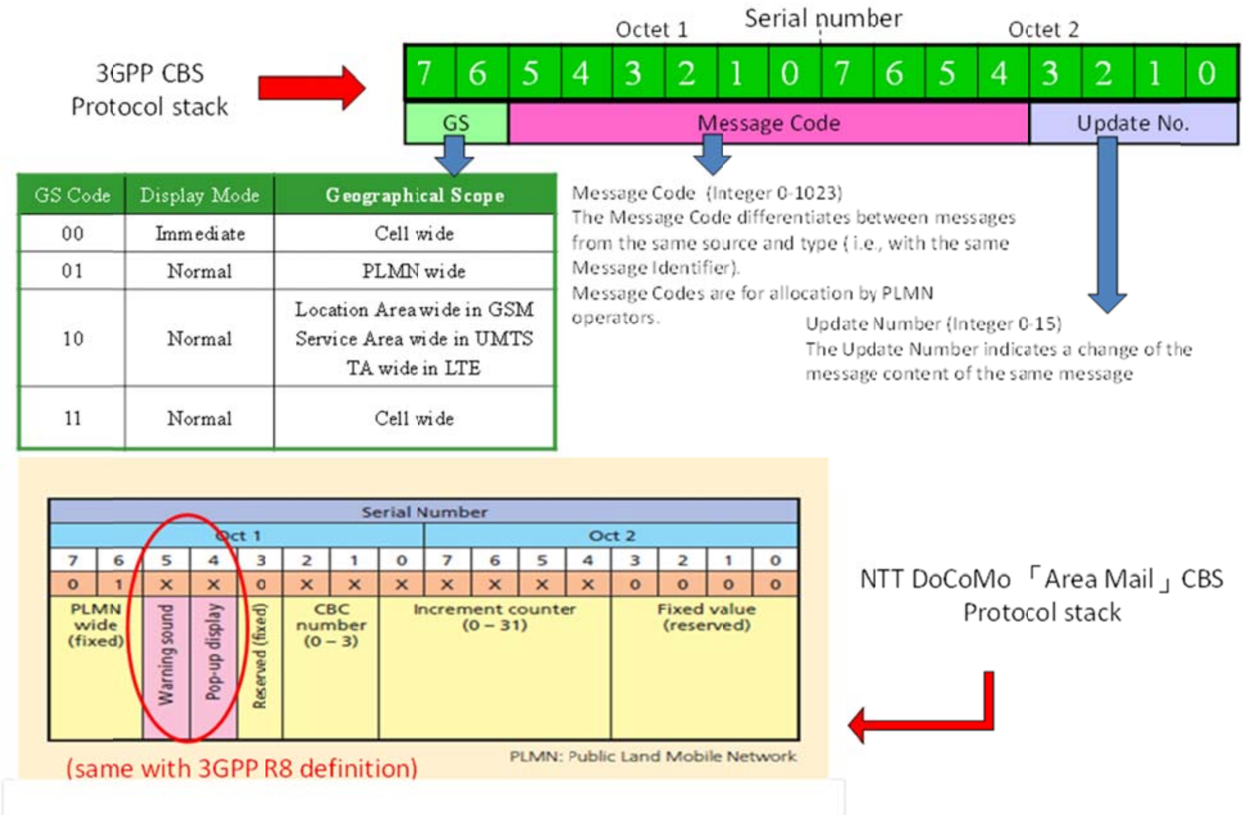

Figure A.5 – NTT DoCoMo Broadcast

Annex B: Selected Bibliography on Japan ETWS

(informative)

This bibliography provides selected sources providing additional background information and detail on ETWS (Japan's EEW system.)

- 3GPP TS 23.041, *3rd Generation Partnership Project; Technical Specification Group Terminals; Technical realization of Cell Broadcast Service (CBS)*.
- 3GPP TS 22.268, *3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Public Warning System (PWS) Requirements*.
- Allen, Gasparini, Kamigiachi, and Bose, "The Status of Earthquake Early Warning around the World: An introductory overview", Seismological Research Letters 80:5, 682-963.
- Ishiwatari, "Tsunami and Earthquake Warning Systems", 2012 World Bank Knowledge Note 2-5.
- Yamasaki, "What We Can Learn from Japan's Earthquake Warning Service", 2011. https://sites.sas.upenn.edu/sites/default/files/momentum/files/yamasaki.pdf.

Annex C: California EEWS Standards

(informative)

The CEEWS Steering Committee Technical Standards Committee recommends standards to focus in six areas [Ref 112]:

(1) Instrumentation and input data formats,
(2) System security and engineering,
(3) Earthquake early warning algorithms,
(4) Alert messages and distribution,
(5) Overall system performance, and
(6) Affiliated operator perspective.

The Technical Standards Committee recommends System Security and Engineering standards should address:

a) Federal Standards for computer and networking system security.
b) Software coding, testing, and certification.
c) Testing of algorithms and maintenance of results in a database for future troubleshooting.
d) Components that will provide ongoing monitoring of performance.
e) Methods and tools needed to evaluate performance into the ANSS Quake Monitoring System (AQMS).
f) Use of datasets of historic waveforms to test newly developed code.
g) Use of synthetic waveforms to test newly developed code to test for very large events that are not available in existing datasets.
h) Command and control of seismic sensors needed for robust operations.

The Technical Standards Committee also recommends CEEWS technical performance standards for alert message and distribution should include:

a) Length, content, and means of delivering messages.
b) Minimum likelihood threshold for issuing a public alert.
c) Maximum acceptable latency to distribute alert messages.
d) Message format standards for EAS or social media alert messages.

Applicability of the above to cellular EEW is for further study.

The Technical Standards Committee also recommends CEEWS technical performance standards for overall system performance should include:

a) End-user perspective for public CEEWS.
b) Expected performance matrix.
c) Total system latency.
d) Expected total system uptime.
e) Communication of uncertainty in the predicted ground motion.
f) Variability of end user locations (including distributed facilities and mobile users).

ANSS standards governing the design, operation, and performance of CEEWS are required to ensure a robust system that is optimized to meet end user requirements. As part of the Advanced National Seismic System (ANSS), CEEWS will need to conform to existing national standards for management, system performance, data quality and completeness, sharing seismic data, and validation of methods for the creation and distribution of public earthquake information.

It is recommended ATIS standardize cellular network aspects of the system security and engineering, alert messages and distribution, and overall system performance standards development for the CEEWS.

Annex D: Parking Lot of Open Issues

(informative)

The following is the parking lot of open issues that need further investigation and analysis and will be addressed during the standards development phase:

[i100] Related to assumption [A300] – Will the tone and cadence for an EEW notification need to be distinct from the WEA alert tone and cadence? It is assumed yes, however CalOES and other governmental stakeholders will seek input to ensure that EEWS alert tones are consistent with other hazards warnings. This will be determined during the standards development phase.

NOTE: [Ref 112] states EEWS alert tones will be standardized to ensure consistent messaging and to help establish these warnings as a valuable public resource. CalOES and other governmental stakeholders will seek input to ensure that CEEWS alert tones are consistent with other hazards warnings. EEWS alert tones shall be used only to accompany timely and specific information about impending ground motions from an earthquake. Information that is not timely (i.e., reasonably assured to arrive after the onset of shaking) or specific to the recipient of the warning (i.e., general earthquake information or information reasonably expected to be inaccurate at the user's location) shall not be announced using EEWS alert tones.

[i200] There is a need to develop an end-to-end latency budget along with a high level component model. For example, a sensor detection and reporting phase, a decision making framework processing phase, a cellular dissemination phase, and a receiving user processing phase. Technical Standards Committee recommends CEEWS technical performance standards for overall system performance.

[i300] Will there need to be testing capabilities for public safety system readiness verification? If yes, what are the scenarios for the public safety readiness verification and which elements are deemed critical for verification? Further study and standardization is required to determine how other types of EEWS messages defined in [Ref 112] integrate into WEA; specifically, automated cancellation of an alert, weekly/monthly tests and manually generated operator update messages, as well as effective alert messages to meet the needs of specialized audiences (non-English speakers; or persons with specialized needs). Any use of WEA for EEWS messages must conform to FCC rules.

[i400] Will there be the need to have the capability of using EEW notifications as part of public safety and public training exercises? Further study and standardization is required to determine how other types of EEWS messages defined in [Ref 112] integrate into WEA; specifically, automated cancellation of an alert, weekly/monthly tests and manually generated operator update messages, as well as effective alert messages to meet the needs of specialized audiences (non-English speakers; or persons with specialized needs). Any use of WEA for EEWS messages must conform to FCC rules. If yes, what are the scenarios of how public safety and public training exercises will occur and how will the cell phone user receiving the notification know that the notification is part of the exercise and not a real earthquake event?

[i500] Since the monitoring of the sensor network is continuous even through earthquakes, changes in the sensor readings may occur after an initial EEW notification is disseminated. Will the automated decision making framework revise its predictions or conclusions and will updated, revised, or replacement EEW notifications be subsequently disseminated? ShakeAlert assumes the notification between the Earthquake Alert Center and the CMSP are distributed as XML messages that are updated at least once per second as the earthquake occurs [Ref 111]. Further study is required to determine how this applies to cellular dissemination and broadcast.

[i600] Will the presentation of the EEW notification override any existing communication activities (e.g., voice call or data service) including emergency calls to 9-1-1? The current working assumption is that the answer to this question is No.

[i700] Related to assumption [A1400] – [Ref 112] states EEWS will provide computer network security standards for all EEWS participants that will be outlined in the Internet Security Agreement (ISA) signed by EEWS participants. The ISA will be renewed annually. In addition, [Ref 111] states system security standards will be developed that, at a minimum, conform to applicable government standards, including Federal Information Security Management Act of 2002 (44 U.S.C. § 3541, et seq.) Applicability of these to the cellular dissemination portion of the architecture needs to be determined. It is further assumed that ATIS will be involved in the development of the Security

Assessment Report to be completed prior to certification and implementation of the system [Ref 112].

[i800] Related to assumption [A1800] – Further study is required to determine how many centers a CMSP would have to connect to and what the interaction between those centers would be.

[i900] Related to assumption [A1900] – Outgoing EEW notification XML formats exist and are documented [Ref 111]. These XML messages contain information about an earthquake's location, magnitude, and likelihood. Additional optional information includes finite-fault parameters and stations that have detected ground motion. Because the format is XML, it can be expanded to accommodate additional information as new sensor types or data streams are developed. The current standard data communication protocol is ActiveMQ, an open-source data communications protocol [Ref 111]. In addition, [Ref 111] states the Common Alert Protocol messages will be generated and submitted to the Integrated Public Alert and Warning System (IPAWS) for public distribution, assuming the EEW system decides the level of likelihood that public notifications will be sent. However, IPAWS distribution is not recommended (see 9.3). Further study is required for the standardized data and message formats, interface, and protocol between the Earthquake Alert Center(s) and the CMSP infrastructure.

[i1000] It is assumed the National Earthquake Prediction Evaluation Council (NEPEC) will review and approve the EEW system before public notification can be issued. NEPEC is the official entity for validation of prediction and related scientific research for USGS, in compliance with the Federal Advisory Committee Act. The NEPEC may, at its discretion, delegate this task to the California Earthquake Prediction Evaluation Council [Ref 111]. Further study is required to determine if this dissemination applies to the CMSP network.

[i1100] Further study is required to determine the process for activation of the proposed EEWS solution.