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Application of satellite navigation system for emergency warning and alerting

Suelynn Choy
Royal Melbourne Institute of Technology

John Handmer
Royal Melbourne Institute of Technology

Joshua Whittaker
Royal Melbourne Institute of Technology, wjoshua@uow.edu.au

Yuki Shinohara
NTT DATA

Tomohiro Hatori
Pasco Corporation

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Abstract

One of the key responsibilities of any government is to communicate and disseminate safety information and warnings to the general public in case of an emergency. Traditionally, warnings are issued by the government through a broadcast approach using communication channels such as TV and radio. However this monopolistic approach is now challenged by new technologies and media capable of providing individualised warnings to personal mobile devices. Location-based emergency services and mobile alerts are becoming increasingly prevalent in the provision of emergency warnings. These new modes of emergency services have been adopted by several countries worldwide including Australia. One example is the Australian National Emergency Alert (EA) which is a telephone-based service enhanced with location-based capabilities. This paper introduces the concept of applying global satellite navigation systems such as the Japanese satellite system in the domain of emergency warning and alerting. The Japanese satellite warning system can be tailored to transmit real-time location-based emergency warnings to people's mobile devices while not being constrained by the limitations of ground-based communication technologies. A key advantage of satellite based communication is its high resilience to communication network overload and failure of ground systems and network infrastructure during a disaster. This enables people to obtain necessary information anywhere (outdoor) and anytime during times of disaster. A satellite-based warning system could also be integrated with existing warning services and be used as a complementary technology. This paper examines opportunities and challenges for using satellite navigation systems to deliver warnings and safety messages during emergencies and disasters.

Keywords

system, navigation, alerting, warning, satellite, emergency, application

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Application of Satellite Navigation System for Emergency Warning and Alerting

***Suelynn Choy*[1,*], *John Handmer*[2], *Joshua Whittaker*[3], *Yuki Shinohara*[4], *Tomohiro Hatori*[5], *Naohiko Kohtake*[6]**

[1]suelynn.choy@rmit.edu.au, School of Mathematical and Geospatial Sciences, RMIT University, 124 La Trobe Street, Melbourne VIC 3000
Tel: +61 3 9925 2650
Fax: +61 3 9663 2517

[2]joshua.whittaker@rmit.edu.au , School of Mathematical and Geospatial Sciences, RMIT University, 124 La Trobe Street, Melbourne VIC 3000
Tel: +61 3 9925 2418
Fax: +61 3 9663 2517

[3]john.handmer@rmit.edu.au, School of Mathematical and Geospatial Sciences, RMIT University, 124 La Trobe Street, Melbourne VIC 3000
Tel: +61 3 9925 2307
Fax: +61 3 9663 2517

[4]shinoharay@nttdata.co.jp , Global & Incubation Group,NTTDATA Corp.17F Toyosu Center Bldg. Annex, 3-9, Toyosu 3-chome,Koto-ku, Tokyo 135-8671, Japan
Tel : +81 50 5547 8255
Fax: +81 3 3532 0910

[5]tiormo6427@pasco.co.jp,
PASCO Corporation,1-1-2 Higashiyama, Meguro-ku
Tokyo 153-0043, Japan
Tel: +81-3-6412-2500
Fax: +81-3-3715-6600

[6]kohtake@sdm.keio.ac.jp
Graduate School of System Design and Management, Keio University,
4-1-1 Hiyoshi, Kohoku-ku,
Yokohama 223-8526, Japan
Tel: +81-45-564-2580
Fax: +81-45-564-2541

[*]***Corresponding author: Suelynn Choy***

Abstract

One of the key responsibilities of any government is to communicate and disseminate safety information and warnings to the general public in case of an emergency. The traditional model of a government monopolistic system delivering warnings through a broadcast approach is now challenged by new media, mobile technologies and the accompanying expectations of individualised warnings to personal mobile devices. Location-based emergency services and mobile alerts are becoming increasingly prevalent in the provision of emergency warnings. These new modes of emergency services have been adopted by several countries worldwide including Australia. One example is the Australian National Emergency Alert (EA) which is a telephone-based service enhanced with location-based capabilities. This paper introduces the concept of applying global satellite navigation systems such as the Japanese satellite system in the domain of emergency warning and alerting. The Japanese satellite warning system can be tailored to transmit real-time location-based emergency warnings to people's mobile devices while not being constrained by the limitations of ground-based communication technologies. A key advantage of satellite based communication is its high resilience to communication network overload and failure of ground systems and network infrastructure during a disaster. This enables people to obtain necessary information anywhere (outdoor) and anytime during times of disaster. A satellite-based warning system could also be integrated with existing warning services and be used as a complementary technology. This examines opportunities and challenges for using satellite navigation systems to deliver warnings and safety messages during emergencies and disasters.

Keywords: Global Navigation Satellite System (GNSS), Quasi-Zenith Satellite System (QZSS), L1-SAIF, Satellite-Based Delivery, Emergency Warnings

1. Introduction

The catastrophic consequences of emergencies and disasters are universally recognised bearing devastating human, economic and environmental losses. The Indian Ocean Tsunami in 2004, the 2009 Victorian bushfire disaster in Australia, and the 2011 Tohŏku Earthquake and Tsunami in Japan are just a few cases of tragedy, which highlighted the critical importance of preparedness, early detection and warning communications in order to mitigate losses of life, property and ecological damage. A ‘warning system’ is a means of getting information about an impending emergency, the nature of the threat, communicating that information to those who are likely to be affected by it, and facilitating informed decisions and timely response by people in danger (Mileti and Sorensen 1990). Several studies have shown that functional warning systems can be a highly effective tool for saving lives and reducing property losses (Golnaraghi *et al.* 2009).

The early warning and preparedness phase is crucial in the emergency management process for reaching an adequate level of readiness to react to potential threats. During this phase, emergency plans are developed to establish, among other procedures, evacuation and emergency escape routes. The United Nations International Strategy for Disaster Reduction identifies four interdependent elements for the provision of early warnings, including dissemination of information via communication systems that deliver timely and accurate warning messages (United Nations International Strategy for Disaster Reduction 2005). To function effectively, warning systems must be supported by robust communication networks comprised of reliable infrastructure and effectual interactions between key stakeholders, decision makers and the general public. The range of information communication technologies used by state emergency services authorities to disseminate warnings has conventionally involved one-way, top-down communication flows (Parker and Handmer 1998; Handmer 2000). Technologies such as sirens, radio and television are commonly used to deliver warnings and safety information. However, a recent re-examination of emergency warning systems demonstrates a steady progression toward incorporating two-way participatory approaches leveraging new technologies and collaborative information sharing tools such as the powerful combination of the Internet, mobile, crowd-sourcing and social networking technologies (Keim and Noji 2011; White 2011; Crowe 2012). Mobile location-based services in emergency management are now an established part of government strategies in an increasing number of countries worldwide including Australia. This marked shift from command to dialogue communication functions reflects the remarkable pace of change within contemporary communication patterns and information sharing systems.

Utilisation of satellite navigation systems for emergency warning and alerting is a relatively new and emerging technology (Mathur *et al.* 2005; Olla 2009; Handmer *et al.* 2014; Iwaizumi *et al.* 2014).There has been little research to investigate its feasibility and application. The value of such capabilities could be foreseen in the case of critical situations where ground-based communication channels are limited or unavailable; and the coordination of emergency procedures with location-awareness activities is paramount. In mid-2014, the Japanese and Australian Governments formally agreed to cooperate to promote utilisation of Information and Communications Technology (ICT) as well as strengthen cooperation for the promotion of geospatial information projects using the Japanese satellite navigation system (Prime Minister of Australia 2014). The Japanese Quasi-Zenith Satellite System or (QZSS) is an example of a satellite-based navigation system. While primarily built for users in Japan, the satellite trajectory design offers significant advantages to neighbouring East Asian countries as well as Australia. This paper introduces the concept of utilising a satellite navigation system in the domain of emergency warning and alerting. The proposed system is capable of providing real-time alerts enhanced with location-based information enabling users to take appropriate risk mitigation actions during events of disaster.

2. Mobile Warning Systems

Multiple, redundant communication channels are required for the dissemination of critical safety information and warning messages to people about impending dangers and risk of disasters. Multiple communication channels increase the effectiveness of emergency warnings by extending their reach so that if one would fail, others may get through. Furthermore, multiple means of delivering emergency information could also service as a means of confirmation reinforcement. When people receive news of an unexpected event, they often seek confirmation from other sources (Auf der Heide 1989)

Traditional communication channels such as door-to-door, signage, sirens, loudspeakers, radio, television, fixed phone network and internet have long been used to notify people of impending dangers and to disseminate safety information. Outdoor sirens and loudspeakers are effective in its attention value but have low information conveying value. Radio, television and the Internet provide details of the emergency events and cover a wide area and audience. However these can only fill the information function of warnings and convey them in a passive manner. The public needs to tune to specific channels of communication. Door-to-door notification and fixed phone network can actively notify and warn people of the impending danger but the coverage is limited to a local scale thus is not operationally effective. These different methods of communicating warning and safety information are not equally effective at providing an alert in different physical and social settings (Mileti and Sorensen 1990).

New media and communication technologies have emerged in the past decade as viable tools for delivering warning messages and safety information (Handmer *et al.* 2014). Mobile telecommunication or cellular network technologies have become ubiquitous technologies in today's society and the proliferation of mobile handsets presents an opportunity to provide 'personalised' lifeline information during emergencies and disasters. Mobile telephone warning systems have been embraced and used effectively by several governments around the world as complementary systems to the conventional well established warning channels. Perhaps the two most practical mobile telecommunication technologies that fulfil the requirements of mobile phone emergency alert information service are the common Short Message Service (SMS) and Cell Broadcast Services (CBS). With CBS, uniform text messages are sent point-to-area to potentially all users within a specific geographic area defined by cell towers. It could also be sent to all cells in a carrier network and has a large spectrum of channels which can be used to broadcast different type of service messaging (such as weather updates, public health advice etc). However users of CBS must tune their mobile phones to the specific channel in order to receive messages, just like radio signal. As a result, CBS is not susceptible to network overload. The Netherlands is the first country in the world to introduce this emergency alert system nationwide (Government of the Netherlands 2012). Wireless Emergency Alert (WEA) from the U.S. is another example of CBS.

With SMS, the text message is sent from point-to-point to a specific predefined set of phone numbers. Unlike CBS, this channel is therefore an individual addressable channel, i.e., it is known to whom the messages are addressed to. However, SMS is susceptible to network overload and message delivery failure if an immense number of SMS messages and/or phone calls have been initiated simultaneously. Delays can occur and may result in delivery failure especially during times of emergency. Nonetheless SMS is a well-established and widely accepted protocol for communication. The benefits of SMS are that it supports delivery confirmation and has a 'store and forward' mechanism. During times of an unavailable network coverage or temporary failure, the message is stored in the Short Message Service Centre (SMSC) network and delivered when the recipients becomes available (Aloudat 2010).

In Australia, in the wake of the 2009 Victorian bushfire disaster, the Council of Australian Governments agreed to take immediate steps to enhance the nation's emergency management arrangements through the development of a telephone-based emergency warning system. Emergency Alert (EA) a telephone warning system that emergency management agencies can use to send alerts to community members via landline and mobile phones based on the service address information of the subscriber. The EA system became operational on 1 December 2009 and has since been used to disseminate warnings for flood, tsunami, bushfire, storm surge, chemical incidents and missing person emergencies (Torrens Resiliences Institute 2011). The EA system is based on SMS technology.

The EA system is an official approach currently in use in Australia offering an intrusive warning message to personal devices – whether people have elected to receive it or not. In emergencies, warnings are issued via SMS text messages to mobile phones and voice messages to landlines within a threatened area based on their registered addresses. However delivery cannot be guaranteed if telecommunications networks are compromised during events of emergency (Australian Government 2009). An informal review of EA found the system was regarded as a convenient, trusted and compelling trigger for action, though possible improvements were identified in relation to the timing, content, accuracy and applicability of messages. While EA has been relatively successful since its nation-wide operational implementation (Handmer and Ratajczak-Juszko 2011), drawbacks within the system have been identified in addition to its reliance on the normal phone system. In some cases, messages are delayed and the information conveyed may be inaccurate.

3. Proliferation of Smartphones and Location-Based Services

Australian society is becoming increasingly mobile not only in the way people communicate but also in the way they acquire information (Aloudat 2010). According to a survey undertaken in 2013, there has been an increase in the proportion of Australians who own smartphones. 88% of respondents owned a smartphone compared to 76% of respondents in the previous year. Based on the purchase intentions of mobile phone owners, it is predicted that smartphone ownership will increase to 93% by August 2014 (Mackay 2013). Virtually all smartphones now include a built-in GPS receiver and maps enabling location pin-pointing. In fact the adoption of geospatial technologies has increased tremendously with smartphone uptake. Smartphones are touted as the modern digital 'Swiss Army knives' of consumer electronics, capable of performing tasks once reserved for specialized hardware like cameras, computers and GPS receivers (Lebar 2013).

Location-based emergency warning services disseminate alerts and relevant safety information to people on their active mobile devices located within a defined geographic area of the emergency. It could also be used to find the geographic location of a mobile device after the user has initiated an emergency mobile phone call or a distress SMS request for help. One example of such a service is the U.S. Enhanced-911 (E911) location-based emergency call service. E911 requires telecommunications carriers to locate a person and deliver the geographic position of his or her mobile handset to the nearest answering centre for calls to 911 (Kaplan and Hegarty 2006). Utilising location-based emergency warning services could help increase situational awareness amongst people in emergencies.

In 2013, the Australian Government launched a significant enhancement to EA enabling location-based warnings to be broadcast based on the last known location of the mobile handset at the time of the emergency as well as its registered address. With such an enhancement, mobile handsets with a registered address in the affected area as well as users who are mobile but in the affected area will be notified of the emergency. Such a system is viewed as an effective technology for providing critical information quickly within a well-defined geographical area targeted at intended recipients of the messages. However mobile telecommunications services are highly dependent on network and underlying infrastructure, which could undermine the capacity and reliability of these systems. One limitation of such system is that it becomes less effective as a geographic area gets larger and/or in areas with no mobile network. This mode of communication is effective in cities but less in smaller rural communities whereby mobile coverage is sporadic or unavailable. In 2013, 16 homes and 18 buildings were destroyed by fire in Dareel, a Victorian town located in the western district of the state. Patchy mobile coverage was found to have affected the emergency co-ordination effort at the fire (Stark 2014).

4. Navigation Satellite Warning System

Satellite-based communication is another mode of communication that is used by various countries and organisations around the world to disseminate emergency messages. The Japanese nationwide warning system called J-Alert is an example using Superbird-B2 communication satellite to broadcast warning messages. The International COSPAS-SARSAT Programme is another well-established satellite-based search and rescue (SAR), distress alert detection and information distribution system. It is best known as the system that detects and locates emergency beacons activated by aircraft, ships and backcountry hikers in distress (COSPAS-SARSAT 2014). Satellite communication services are generally robust and can be enhanced with geographical information to specify for which locations the information is relevant. However the use of a satellite phone is not as common as compared to mobile phones. Furthermore, maintenance of satellite communication service and operation are costly for both service providers and users.

Navigation satellites emergency system combines the strengths of both mobile telecommunication services and satellite-based communication. Global Navigation Satellite System (GNSS) is a standard term for satellite-based navigation systems, which include the U.S. GPS, Russia’s GLONASS, and several other new and emerging constellations such as Europe’s Galileo and China’s BeiDou systems. These systems provide precise position in three dimensions, timing, and velocity using radio navigation signals. GNSS is generally a one-way system: the receivers receive the signals and there is no interaction from the receiver to the satellites. There are also regional navigation satellite systems and Satellite Based Augmentation Systems (SBAS) like the U.S. WAAS, Europe’s European Geostationary Navigation Overlay Service (EGNOS) and India’s GAGAN, which aim to augment GNSS. In addition to creating efficiencies and reducing operating costs, the adoption of GNSS technology has helped improve efficiency in many emerging location based services (ACIL Allen Consulting 2013).

The GNSS receiver embedded in smartphones providing precise information of the users’ position could be used to correlate safety information sent from the satellite, which makes the information relevant to intended users at a specific point in time and within the defined geographical area. GNSS could be used to supplement and enhance exiting warning systems. Europe has been working on emergency message services since 2005 using the EGNOS and Galileo satellite navigation systems with the introduction of the ALIVE (Alert interface via

EGNOS) Concept (Mathur *et al.* 2005). Since then there were follow on projects investigating technical and non-technical benefits as well as advantages of utilising GNSS satellites for disaster alerting (Dixon and Haas 2008; Wallner 2011; Domínguez *et al.* 2013).

The Japanese Quasi-Zenith Satellite System (QZSS) is another example of an SBAS developed by Japan Aerospace Exploration Agency (JAXA). When fully deployed in 2018, it will consist of three QZSS satellites placed in Highly Inclined Elliptical Orbits (HEO) and one geostationary satellite providing 24 hours coverage. The orbit configuration of these QZSS satellites provides continuous coverage at a high elevation angle, providing improved satellite navigation in areas of Japan that challenge traditional GNSS satellite positioning capabilities, such as central city areas. While intended primarily for users in Japan, the orbit design offers significant advantages to neighbouring East Asia countries and Australia. Figure 1 shows the footprint of QZSS satellite. The first QZSS satellite was launched on 11 September 2010.

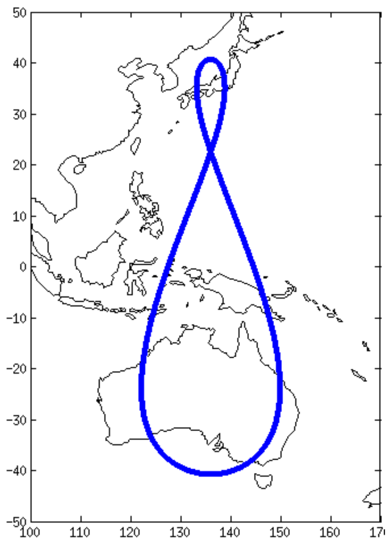

Figure 1: Ground track of QZS-1 orbit.

One unique feature of QZSS is that in addition to the standard GNSS navigation signals used for Position, Navigation and Timing (PNT), QZSS also has the capability of sending short emergency messages. The messages can be received directly from the satellite by a GNSS/GPS receiver embedded in mobile phones or in in-car navigation systems. An application software or app would interpret and display the information. Given that mobile phones use and in-car navigation systems are becoming near-universal, with almost everyone involved, the potential coverage and reach of warnings sent to these personal devices is likely to be much greater than the current approaches could achieve

Another feature of the QZSS provision for alert messaging is that in addition to the wide area coverage provided by the satellite system, the receivers also provide, through their embedded GNSS/GPS capabilities, precise position information. In this way, alert messages can be sent to a specific area depending on the type and content of the disaster information, and only those receivers within the specific area will be activated. Knowing the area of the possible disaster location, the intended users could then be warned, while those outside the disaster area would not be alerted.

The satellite based system offers a number of advantages for real-time disaster alerts over current approaches to sending warnings via personal devices. Advantages include:

1) GNSS with location-based information can be used during an emergency. This provides the ability to indicate high priority and targeted messages for specific areas and groups;

2) The service can cover a wide area simultaneously – e.g. the whole of Australia – because of its wide area broadcast footprint, and within the broadcast area, there is no limit to the number of people who can be warned simultaneously;

3) The messages can still be received even when terrestrial communications infrastructure is damaged or not available. This allows for redundancy; and

4) As the system is independent of mobile phone coverage it would reach people wherever they are, regardless of the existence of mobile phone coverage.

5. QZSS Red Rescue Project

The Red Rescue Project (for real-time disaster response using small-capacity data packets from the ubiquitous environment) was funded by the Japanese Ministry of Education, Culture, Sports, Science and Technology. It is a real-time disaster response solution, which sends emergency messages through the L1-SAIF signal from QZSS satellites to government, relevant authorities as well as the general public through smartphone equipped with GNSS chips during times of emergencies. The project commenced in 2009 as a three-year project and has recently run trials in Japan, Thailand and Malaysia for tsunami warnings. The core members of the project consist of system design specialists from Graduate School of System Design and Management in Keio University, Asia Air Survey on panoramic navigation, Pasco on disaster management and NTTDATA on disaster information systems. NTTDATA Corporation (a Japanese system integration and data company) has developed several governmental IT infrastructures for disaster management (Buist *et al.* 2013; Iwaizumi and Kohtake 2013; Iwaizumi *et al.* 2014).

The emergency message is sent to the user from the QZSS satellite using the L1-SAIF (Submetre-class Augmentation with Integrity Function) signal. This signal is broadcasted on the L1 frequency band (1575.42 MHz). The advantage of the L1 signal is that it is the most widely used signal by the mass-market GNSS/GPS receivers. All GNSS/GPS receivers are able to track and acquire this signal for positioning. The L1-SAIF signal, as the name implies, is designed to transmit precise navigation messages and integrity data with the intention to augment positioning accuracy to decimetre-level and transmit integrity information for mission critical applications. The L1-SAIF signal has a data rate of 250 bits per second (bps) and the 212 bits data area in between the navigation message could be used to deliver emergency messages. At 212 bits, each emergency message is very short, but a number of messages can be combined to produce a longer message. Figure 2 shows a schematic diagram of the QZSS alert messaging transmission system. The system consists of three parts: the Transmission, Satellite and User Segments (Iwaizumi *et al.* 2014).

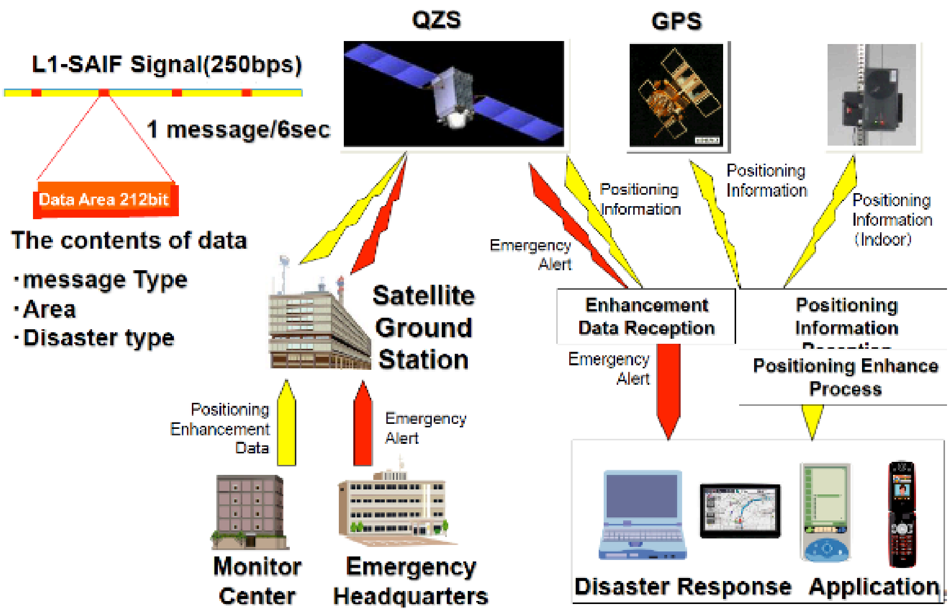

Figure 2: QZSS alert messaging transmission system.

The *Transmission Segment* consists of the Disaster Management Centre, the Monitor Centre, and the Satellite Ground Control Station. The transmission segment transmits disaster messages to the satellite segment in the following order: First, the Disaster Management Centre gathers the relevant information. Second, the Disaster Management Centre converts the information into an emergency message for transmission by QZSS. The Disaster Management Centre decides the distribution schedule for providing the information and transmits the emergency message to the Satellite Ground Control Station. Third, the Ground Control Station collects the Monitor Centre's results and generates (enhanced) navigation messages for broadcast on the L1-SAIF signal, which will be used by the user to derive precise position information The Ground Control Station uplinks both the navigation message and the emergency message to the QZSS satellites.

The *Satellite Segment* consists of both the QZSS and other GNSS satellites like GPS and QZSS. The L1-SAIF signal with the enhanced navigation message and the superimposed emergency message are transmitted to the users.

The *User Segment* (or receiving segment) receives the L1-SAIF signal and position information from QZSS as well as position information from other GNSS satellites on their GNSS receivers. The enhanced navigation message is used to provide an accurate position of the users. The L1-SAIF signal contains the emergency messages that are decoded by the users' device in order to acquire the disaster information. Once these messages are received, it triggers the app, which then provides guidance to users to take appropriate risk aversive actions, for example an evacuation route for the user at a specific location and other relevant information. Here we assume the use of smartphones with GNSS/GPS capability and other geospatial tools such as maps for evacuation guidance.

The format of the Red Rescue data is shown in Table 1. The message format is designed to be capable of sending area-based information, encoding area information for each type of disaster and matching IDs between the message and a database in applications to generate rich information content. Transaction data is used for sending messages which size is over 212 bits consisting of multiple packets using a transaction ID (Buist *et al.* 2013).

Field	**Sub-field**	**Unit**	**Description**	**Size (bits)**
Preamble	-	N/A		8
Message type	-	N/A	Identify message type (single or transaction data)	2
Transaction ID		N/A	Identifier of transaction data	8
Message ID			Messages data (e.g., identifier of disaster, time of occurrence, geographical criteria, directives etc)	194
Total				*212*

Table 1: QZSS L1-SAIF Message format (NTTDATA 2012).

For the QZSS alert messaging system, two receiving modes are being developed: One is the wide-area broadcast mode, which can send emergency messages simultaneously over a large area; the other is the area-selected broadcast mode, which can send messages to a specified area (Iwaizumi *et al.* 2014). The area-selected mode delivers several emergency messages to provide disaster information for all areas depending on the type and content of the disaster information. Therefore, the user segment of this system provides the disaster information to the users by selecting the information of the area corresponding to the location of the user from the received emergency messages (Iwaizumi *et al.* 2014).

In 2012, the Japanese team succeeded in demonstrating the potential of the QZSS emergency alert in the case of a tsunami alert based on experience from the 2011 Tohŏku Earthquake and Tsunami. It was shown that QZSS could be utilised as alternative space-based alert mechanism, which are not vulnerable to terrestrial disaster. Table 2 provides an example of the message format for an earthquake scenario in Japan.

Field	**Sub-field**	**Unit**	**Description**	**Size (bits)**
Preamble	-	N/A		8
Message type	-	N/A	Priority level alarm	2
Transaction ID		N/A		8
Message ID			Identifier of disaster according to catalogue	194
Time of occurrence			Unix type	32
Geographical criteria (Epicentrum)	Latitude	Degrees	Latitude degrees	32
	Longitude	Degrees	Longitude degrees	32
	Depth	KM		16
Magnitude	-	M		32
Predicted intensity		I		8
Name of epicentrum	N/A		Area code	8
Directives/Locations/ Evacuation info	-	N/A	Reserved for text message	24
Total				*212*

Table 2: QZSS L1-SAIF Message format for an earthquake scenario (NTTDATA 2012).

6. Conclusion

Australia's vast landmass possesses a significant operational and practical challenge for the government to provide an emergency warning solution that can disseminate time critical safety information 'wherever to whomever it is necessary' during events of disaster. It would require massive investment in establishing the network and underlying infrastructure, which may not be economically viable. The provision of safety information through a GNSS-based system is feasible as it combines the strengths of both mobile telephone-based service and satellite communications, while it overcomes their weaknesses. The key advantage of satellite based communication is its high resilience to communication network overload and failure of ground systems and network infrastructure during a disaster. It also provides scalability of coverage for mass public warning and its operation is potentially more cost effective compared to other warning systems.

In spite of pervasive presence of GNSS based technologies, application of GNSS in emergency warning and alerting in Australia is still in its infancy. To a large extent, research into the viability and implications of GNSS technology within the national emergency warning apparatus is scarcely limited. This boils down to the partial immaturity of the satellite-based warning technology which soon will change with the advent of new GNSS satellites and augmentation systems. The challenge remains in thinking beyond the immediate barriers, identifying technical and non-technical requirements and understanding operational context in which the technology can be used as 'added value' to existing warning systems.

The Japanese satellite system or QZSS has the capabilities of delivering warning messages to people's personal mobile devices. The devices could be tailored to receive location-based emergency warnings at a specific point in time and within a defined geographical area. It has the potential to therefore address some of the shortcomings of the traditional warning services. A GNSS-based warning system is not likely to replace existing systems, but it can augment and strengthen them by providing an independent means of sending location-based warnings. There is a constant need to build effective means that evolve over time by embracing newer technologies. As other GNSS systems such as Galileo and BeiDou continue to mature and be equipped with emergency alert capability, Australia will have an opportunity, by virtue of the geographical location of the continent relative to all of these global navigation satellite systems, to be an excellent test ground for GNSS-based emergency services and be first to innovate with new tools and products.

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