Near-realtime Location Specific Messaging During Extreme Bushfire Events

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Abstract:

Providing information to emergency responders and citizens is one of the most critical aspects during bushfire events. In many cases ground-based infrastructure might be malfunctioning or destroyed and satellite communication might appear the only option. This paper concentrates on the use of the QZSS satellites to provide short messages early warning. The paper provides a preliminary overview of the initial investigations, development and testing of an emergency management system for preparedness and response to extreme bushfire events in Australia. We examine how emergency modelling data can be used to assist a central command centre in generating location-based information during a crisis.

1. Introduction

Australia has seen an increase in severity and unpredictability of bushfire events as a result of climate change[1]. The 2019-2020 Australia bushfire season know as ‘Black summer’ was the most severe and intense bushfire in the record of Australia and caused devastating human, economic and environmental losses. The bushfires affected about 243,000 square kilometres, destroyed over 3,000 buildings and killed at least 34 people. It is also estimated that three billion terrestrial vertebrates were affected among which many endangered spices.

There have been considerable debates about the cause and the management procedure since then. Amongst the many issues, an efficient emergency warning service for the population to prepare and activate emergency plans has been seen critical to respond and reduce the impact of bushfires and reduce the environmental and economic loss. The Australian national telephone-based service, enhanced with location-based capabilities, has been widely used since 2009. However, the telecommunications-based warning services are vulnerable to bushfire disruptions, damages to the telecommunication infrastructure and network overload. The current Australian emergency alert mechanism would greatly benefit from a complementary option of delivery through space-based channels to be able to cover the large areas that lack mobile phone connectivity. A satellite-based capability is not expected to replace the ground-based, telecommunication solution, but it will augment the service and provide increased coverage.

The Michibiki system provides a layer of augmentation and the ability to send messages to specific locations and situations independent of terrestrial networks. Michibiki is a Japanese Quasi Zenith Satellite System (QZSS) used to complement GPS, and orbits in a figure-eight tundra orbit above the Asia and Oceania regions. The system can send 250-bit early warning messages directly to widely used Global Navigation Satellite System (GNSS) receivers, such as smartwatches and smartphones (Nishino et al 2016). This resource presents an opportunity to offer a supplementary avenue of messaging for Australians requiring communications during hazard events (Chay et al 2020) and its effectiveness in disseminating warnings in the Australian region has been assessed by simulation (Nishino et al 2022).

This paper reports on the preliminary preparation for field test o the Michibiki system for EWM in Australia. The paper provides an overview of the actors and the procedures for bushfire managements in Australia and briefly outlines the commonly used tools for fire simulation and the Australian early warning principles.

2. Procedures for emergency management in Australia

Of particular interest to this research, periurban areas face a set of challenges where suburban development interfaces with bushland. In the Australian state of New South Wales (NSW), there are two separate organisations responsible for management and response to fires; the Rural Fire Service (RFS) is responsible for rural and regional areas, and Fire and Rescue NSW (FRNSW) are responsible for (sub)urban metropolitan areas and townships. Depending on which jurisdiction a fire incident occurs, the respective organisation is appointed as the lead combat agency that must then coordinate all other services and operations. The State Emergency Operations Centre (SEOC) is located at Sydney Olympic Park with desks for representatives from all emergency related organisations, collaborative mapping tables and a large led wall providing information feeds from multiple sources.

Another important actor in the bushfire management is the Community Fire Units (CFUs). CFUs are volunteer teams of local residents living in peri-urban areas interfacing bushland. The CFUs are managed by FRNSW. These teams are regularly trained and equipped to make informed decisions about whether to evacuate from a fire threat or to stay and protect their property. This takes pressure off the RFS and FRNSW units who are deployed to directly engage the fire front.

[1] See: https://soe.dcceew.gov.au/extreme-events/environment/bushfires-and-wildfires

3. Bushfire simulation models

The behaviour and characteristics of a fire can be forecast with predictive services such as the in-house SPARK tools integrating several fire dispersion models[2] and providing tools to compute fuel loads, vegetation structure and density, temperatures, wind. This intelligence is calibrated with actual measurements from the field to improve accuracy using UAV's and aircrafts equipped with LiDAR[3], infrared, thermal and optical sensors to scan vegetation, roads and detect obstacles. The data are further processed to accurately estimate fuel load (Barton et al 2020), or compute access pathways before and after a fire front. The simulation results are visualised currently as a set of time-related predictions but can also be augmented to be visualised in 3D environments (Moreno et al 2012). The real-time measurements and simulation results can further be structured in appropriate way to provide information assisting in recovery from aftermath such as loss estimation and where cleanup/repair/rehabilitation is required.

4. Early warning messaging

Australia's Warning Principles emphasize the importance of lifesaving, timely, and clear public warnings to protect communities during emergencies. Warnings need to empower individuals by providing trusted, authoritative information that is verifiable across multiple channels. They must be scaled based on risk and tailored to reach at-risk and vulnerable populations effectively. The messages should clearly convey the expected impacts of hazards and include specific calls-to-action. To ensure wide accessibility, warnings should be disseminated through various channels, with strategies in place for rapid distribution and adaptability in case of technology failures.

ISO 22322:2022 provides guidelines for developing effective public warning systems in emergencies. It emphasizes the importance of timely, accurate, and clear communication to protect lives, property, and the environment. The standard outlines the entire warning process, including planning, message creation, dissemination, and review. It stresses the need for coordination among authorities and the use of multiple channels to reach diverse audiences. The standard also advocates for regular evaluation and improvement of warning systems to enhance their effectiveness in future emergencies, ensuring that communities are well-informed and prepared to respond appropriately.

The Australian Warning System is a Nationally consistent set of symbols representing three levels of hazard warning[4]. The first yellow level provides situational advice of incidents. Orange denotes watch and act, and red represents the most serious life-threatening level. These warning are issued through many different channels to best ensure contact. The *Hazards Near Me* app is an example of a bespoke point of call for disseminating warning messages. The warning messaging are indicative informing about the type and severity of the disaster but do not provide guidance to safe areas or shelters considering avoidance of affected or dangerous areas. Several researchers have reported approaches for obstacle avoidance on different platforms and under diverse conditions (Nedkov and Zlatanova 2012, Wang, Steenbruggen Zlatanova, 2017 or Wang, Zlatanova and van Oosterom, 2017),

Using the Michibiki system, warning messages can be issued by statutory providers and various agencies at state and local levels. This requires a coordinated approach with no conflicting instructions. As a centralised hub for emergency managers, the SEOC is well placed to issue these messages. The system is managed via ArcGIS to provide location-specific and timely messages, in accord with standard Australian Warning System protocols (Murphy et.al 2018) and in compliance A11y Guidance to React Library.[5]

This project intends to extend the current messaging to include additional guidance to safe locations and assist the responsible units in guiding communities to safe locations during the evacuation process. In this respect, the location of the recipient of EWM is of major importance for delivering the accurate message (Ogawa et al 2011). The current telecommunication messaging system is unable to accurately select the targeted group. To mitigate this effect, the current messaging approach is to include names of the streets, neighbourhoods and areas which should follow the emergency advice.

5. Scenario Testing

Here we present the Australian testing phase, using several dozen devices[6] during simulated emergency exercises. To provide the evidence-base to validate further development, the research and development team have defined evaluation points, collect user feedback and develop user requirements based on a systems engineering approach.

The testing scenario will be set at Mt Gibraltar, between the towns of Bowral and Mittagong in the Southern Highlands, of the state of New South Wales, Australia. *Figure 1* shows the Mt Gibraltar precinct contains a 130 Ha nature reserve protecting the Mt Gibraltar Forest, a registered endangered ecological community.

Figure 1: Location map of the Mt Gibraltar precinct between the townships of Mittagong and Bowral.

As the Reserve is on the western side of the mountain, it is exposed to western sun and dry westerly winds, creating potentially dangerous conditions for wildfire. On top of the mountain, adjoining the reserve to the east is periurban residential development, much of which is within Fire Prone Areas, as illustrated in *Figure 2*.

[2] See: https://research.csiro.au/spark/
[3] See: https://geomatics.com.au/geiger/
[4] See: https://www.australianwarningsystem.com.au/
[5] See https://github.com/reactjs/react-a11y
[6] See: https://qzss.go.jp/en/usage/products/list.html for list of receivers.

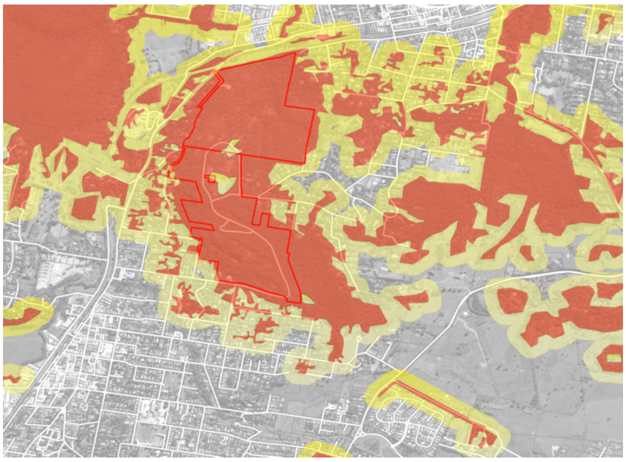

Figure 2: Map of bush fire prone land surrounding the Mt Gibraltar Reserve.

The mountain has only two roads that can be used by cars when evacuating; one to the north into Mittagong and one to the south, to Bowral. The testing scenario will assume an initial simulated bush fire event, referred to as Fire 1, igniting to the east of the precinct under a westerly wind. Figure 3 shows the location of the Fire and Groups A and B:

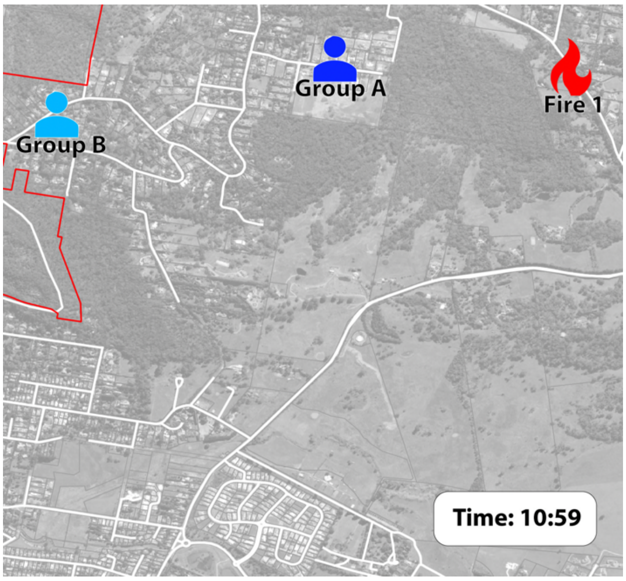

Figure 3: Fire 1 start and is reported.

Upon reporting of Fire 1 at 10:59am, the first advisory message is sent from the RFS SEOC to all the receivers within the oval coverage illustrated in Figure 5:

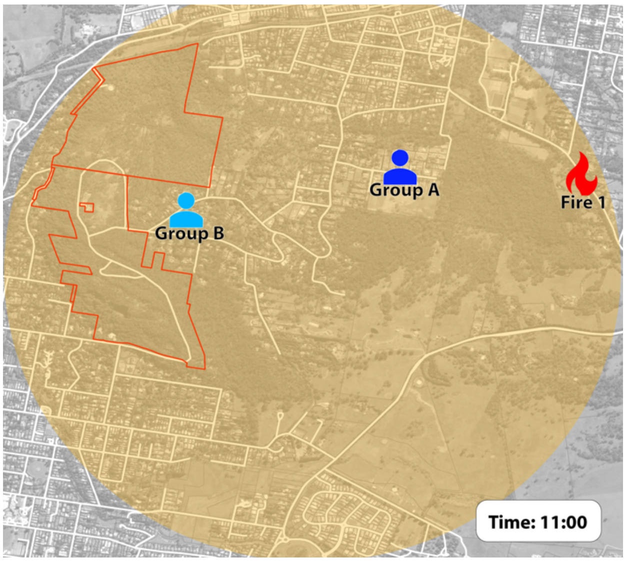

Figure 4: Sending the first message from the RFS SEOC.

This is a test. New South Wales Rural Fire Service bush fire warning. There is a dummy bush fire in the [Range Road] area. Follow your Bush Fire Survival plan and stay up to date.

Figure 5: First message: Advisory for Range Road Area

Assuming Fire 1 has increased in intensity, a second message is issued for Group A’s area to evacuate. When the alert is received, Group A begin their evacuation towards Mittagong (Winifred Reserve), designated as Evacuation Goal X.

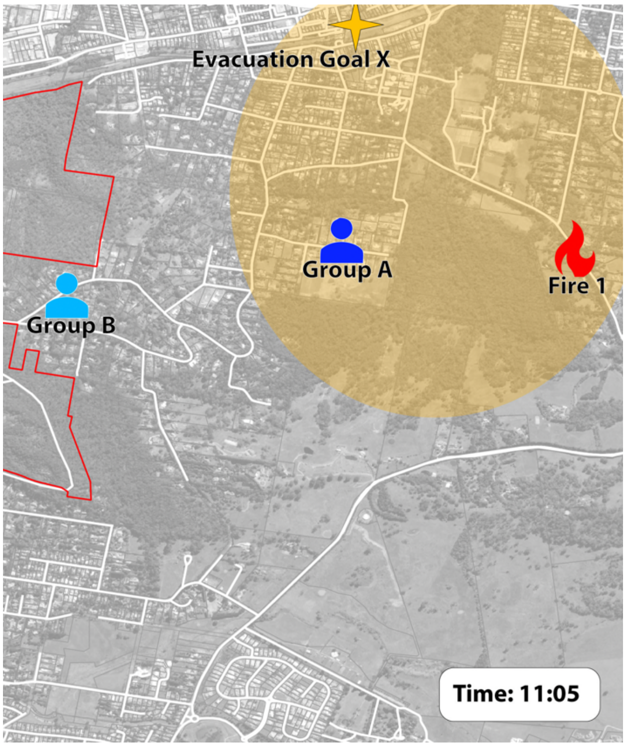

Figure 6: Group A sent a message to evacuate.

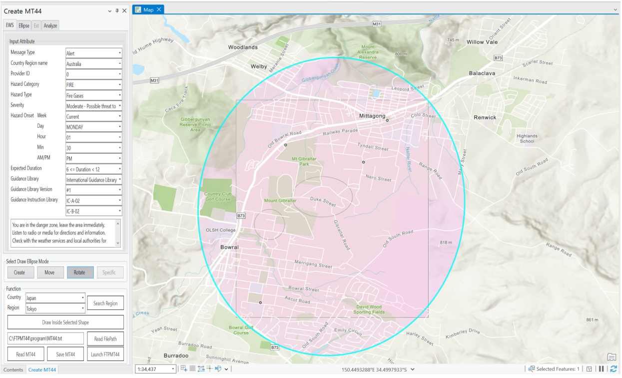

Figure 7: ESRI plug-in interface for sending messages to specific coverages by drawing polygons.

Figure 7 shows the interface for creating and deploying messages to the Michibiki satellite. The coloured oval defines the geographic extent for the message to be transmitted to. The messages being issued need to conform to NSW RFS protocols and the standard Emergency Warning and Emergency Alert format. To reduce the potential for false alerts, the messages are marked with “This is a test” and the event referred to as a “dummy bush fire”, as shown in *Figure 8*:

This is a test. New South Wales Rural Fire Service emergency bush fire warning. There is a dummy bush fire in the [Range Road] area. If your plan is to leave go to the evacuation centre at [Winifred Reserve]. Only travel if the path is clear. If you have doubts or the path is not clear protect yourself from the heat of the fire. Follow your Bush Fire Survival Plan and stay up to date.

Figure 8: The second message from the RFS SEOC.

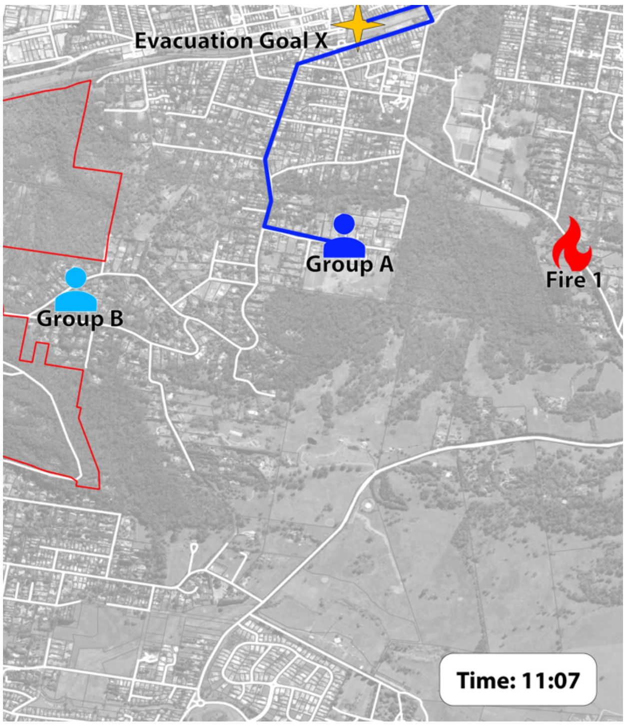

Figure 9: Group A evacuate to Goal X.

The next step provides a testing scenario for real-time communication and adaptability in emergency situations. To create a scenario representing unpredictable circumstances arising during emergency conditions, we assume Group A have safely made it to the evacuation point, however now the evacuation of Group B must be ordered as the wind has now changed to a stronger easterly wind threatening a different coverage.

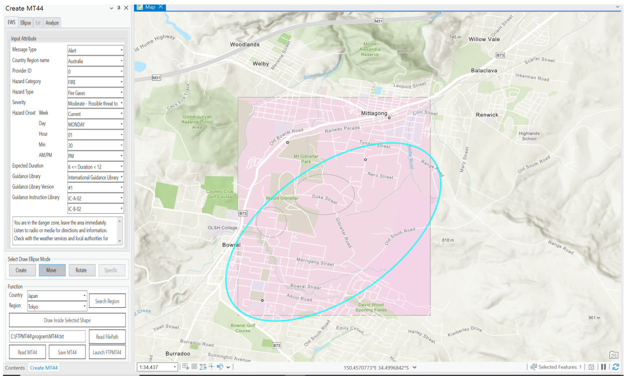

Figure 10: A new polygon is drawn to cover a larger area.

The scenario now assumes Fire 1 has spread to ignite a secondary blaze, Fire 2, making the initial safe route to Mittagong no longer viable. The situation has now changed. Group B now needs updated information and a new directive.

The RFS SEOC send a new message to Group B, redirecting them away from the now hazardous route to Mittagong and guiding them towards Bowral (Looseby Park), designated as Goal Y as shown in *Figure 11* and 12:

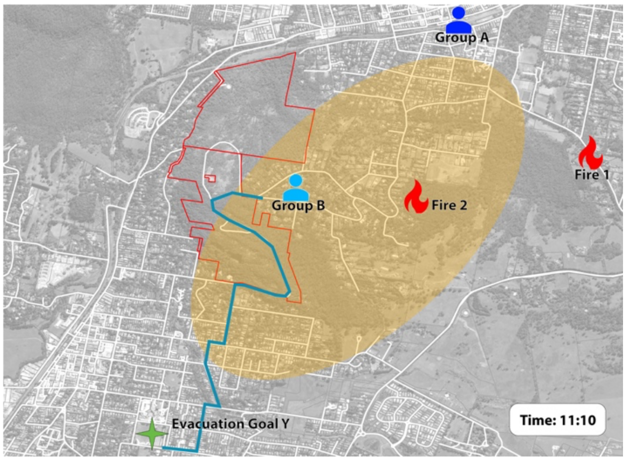

Figure 11: A new polygon defines the area for an undated emergency evacuation message using a different goal.

This is a test. New South Wales Rural Fire Service emergency bush fire warning. There is a dummy bush fire in the [Mt Gibraltar] area. If your plan is to leave go to the evacuation centre at [Looseby Park]. Only travel if the path is clear. If you have doubts or the path is not clear protect yourself from the heat of the fire. Follow your Bush Fire Survival Plan and stay up to date.

Figure 12: The third message from the RFS SEOC room.

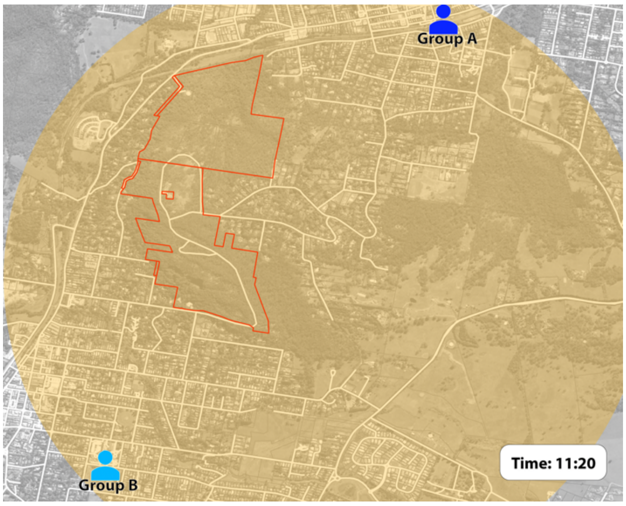

Figure 13: Sending the fourth message from the RFS SEOC.

This is a test. New South Wales Rural Fire Service bush fire all clear message. The dummy bush fire in the [Mt Gibraltar] area is now under control. Continue to monitor the situation. Follow your Bush Fire Survival Plan and stay up to date.

Figure 14: The All Clear message from the RFS SEOC.

Once the fires are under control, both evacuated groups are sent and ‘all clear’ notification as shown in *Figure 13* and 14.

Through this exercise, we aim to evaluate the reliability and responsiveness of the early warning system, ensuring that it can effectively guide communities to safety even as hazardous conditions may rapidly evolve.

6. Evaluation Points

In assessing the effectiveness and efficiency of a critical alert messaging system, both the sending and receiving applications are assessed according to a series of evaluation points. Each application will be tested to best ensure interoperability with existing environments, accuracy and speed of operations, and ability to handle real-time data updates.

Sending Application		
Points	**Methods**	**Indicators**
Can the system be implemented in an existing environment?	Have the user operate software installed on a PC at the site	To be operated correctly
Can fire information from existing sources be entered to the system?	Have the user input dummy information data into the software	To be entered correctly
Can the system respond to information updated in real time?	Have users enter new information into the software according to the timeline	To be entered correctly
Can the system create an alert message based on the information entered?	Have the user create a message using the software	To be created correctly
Can alert messages be sent?	Have the user send a message using the software	To be transmitted correctly
Can alert messages be sent immediately?	Measure the time it took to send a message	To be within certain minutes

Table 1: Evaluation points for the sending application.

Error! Reference source not found. shows the evaluation points for the sending application. The primary concern is its capacity to be implemented in an existing technological setup. Users are tasked with operating the software on-site, ensuring that the system functions correctly within its intended environment.

The software's capability to ingest data from existing sources is tested by having users input the dummy information for the scenario testing, ensuring that the data is entered accurately, and that the system can accommodate the nuances of the pre-existing framework.

The ability of the sending application to respond to real-time updates is another critical factor. Users enter new information according to the specified timeline, simulating the dynamic nature of real-world scenarios. The system's success is measured by its ability to process and integrate these updates correctly. Following this, the system's core functionality of creating alert messages based on the input data is tested.

Once created, the focus shifts to the transmission of these alerts. Users send messages using the software, where the transmission process is monitored to ensure that the messages are sent without errors. Additionally, the system’s efficiency is evaluated by measuring the time it takes to send an alert, with a benchmark set to determine if messages are dispatched within an acceptable timeframe.

Error! Reference source not found. lists the evaluation points for the receiving application, where the emphasis is placed on the system's ability to correctly implement and display incoming alerts.

Receiving Application		
Points	**Methods**	**Indicators**
Can the system be implemented in an existing environment?	Have the user operate a device with the application installed	To be operated correctly
Can the system receive alert messages?	Ensure that the application receives a message automatically	To be received and displayed correctly
Can the system receive alert messages immediately?	Measure the time it took to receive a message	To be within certain minutes

Can the correct contents of alert message be received according to users' location?	Check the contents of the message displayed in the application	To match what was sent
Can users in multiple locations receive alert messages simultaneously?	Record the time of receiving of message for users at each location	To match within a margin of error of certain seconds
Is the alert message updated?	Check the contents of the message displayed in the application	To be updated according to the timeline
Can users understand the contents of the alert message?	Interview with users	To understand the contents
Can users act according to the contents of the alert message?	Record users' activities by GPS logs and video	To move to the goal
Can users reach the goal immediately?	Measure the time it took for the user to reach the goal	To be within certain minutes

Table 2: Evaluation points for the receiving application.

The immediacy of receiving these messages is measured by timing how long it takes for alerts to appear after being sent. The contents of the received messages are then cross-checked with what was originally sent, ensuring accuracy across different user locations. The simultaneous reception of these alerts by multiple users is also tested, with precise timing ensuring that the system functions reliably across various geographic locations.

The sender's ability to update alert messages in real-time is tested to ensure any changes in the situation are communicated accurately and promptly. The final layers of testing focus on the human behaviours: whether users can comprehend the message content and can understand and respond to the alerts effectively, ultimately ensuring that they can reach the intended goal within a specified timeframe.

This evaluation framework ensures that both the sending and receiving applications are not only functional but also capable of performing under the pressure of real-time demands, providing a robust system for managing critical alerts in an emergency.

7. Conclusion and further research

Using a satellite-based system for early warning and emergency management during bush fires provides a platform to integrate critical data, near-real-time observations, processing and simulation modules. An extra layer of functionality, i.e. a QZSS enabled navigation/guidance capability will be also provided by the Michibiki system to help with pathfinding and guiding evacuation, as with provision of directions to a shelter in event of forced road closures.

As mentioned above, the responsibilities of each unit in the bushfire emergency is well-defined with legislative documents and can be further formally modelled to classify the required information and support the data management (Dilo and Zlatanova, 2011). Such a data classification and management of information will allow for systematic analysis and employing Artificial Intelligence models to identifying patterns and improving response procedures.

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