Received 27 January 2024, accepted 15 March 2024, date of publication 20 March 2024, date of current version 27 March 2024.
Digital Object Identifier 10.1109/ACCESS.2024.3379729

RESEARCH ARTICLE

Design for Optimized Public Safety and Earthquake Disaster Mitigation With IoT

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This work was supported by Korea Meteorological Administration (Research and Development: Development of Earthquake Information Production Technology) and the Development of Earthquake, Tsunami, Volcano Monitoring, and Prediction Technology under Grant KMA2022-02121.

ABSTRACT The recent advancements in Internet of Things (IoT) technology have played a pivotal role in the development and implementation of an integrated disaster management system aimed at enhancing public safety and refining disaster mitigation strategies through a technologically sophisticated framework. This study explores the application of earthquake early warning systems in conjunction with ShakeMap data, utilizing these tools to swiftly identify regions at the highest risk of seismic damage and thereby optimize emergency response efforts in the most critical areas. The research involves designing and conducting a pilot test to validate the efficacy of an IoT-based service platform, ensuring its alignment with international standards. The pilot test not only encompassed earthquake scenarios and response models but also evaluated the platform's capability to tailor response functions based on regional intensity measures. The outcomes of this study demonstrate the categorization of response types into ''automatic opening/closing,'' ''response guidance,'' and ''automation system linkage,'' highlighting the potential of IoT devices to react rapidly and effectively in seismic events. This underscores the significant role that IoT technology can play in enhancing public safety measures in the face of seismic disaster.

INDEX TERMS Disaster management, IoT, earthquake early warning, ShakeMap, seismic intensity.

I. INTRODUCTION

In recent years, the integration of Earthquake Early Warning (EEW) systems into public safety and disaster mitigation strategies has gained paramount importance. These systems are engineered to swiftly alert the populace upon the initial detection of seismic P-waves, preceding the emergence of more intense tremors. They are instrumental in diminishing the risks associated with earthquakes [1], [2], [3]. EEW systems demand both technical robustness and a thorough grasp of operational and management facets, thereby necessitating context-specific approaches tailored to the unique needs of different countries [3], [4], [5], [6]. The customization of EEW systems takes into account the unique seismic characteristics and technological capacities of each region. Furthermore, the formulation of warning strategies in these systems necessitates a fine balance between timeliness and accuracy [7], a crucial aspect in effectively reducing the risks associated with earthquake disasters, while acknowledging the technical limitations inherent in these systems.

Within the context of public safety, it is paramount for EEW systems to be tailored to acknowledge that different areas may not necessitate the same level of alert [8]. The strategic implementation of ShakeMap [9], [10] proves to be invaluable, greatly augmenting the effectiveness and precision of EEW systems [8], [11]. ShakeMap, which employs ground motion prediction equations (GMPEs), assists in accurately identifying areas that are most vulnerable to severe damage [10]. ShakeMap's capability enables rapid and focused responses to the area most in need following an earthquake. Additionally, ShakeMap excels in illustrating the scope of potential shaking and damage, making it an indispensable tool for emergency response, damage assessment, and public information dissemination [12], [13]. Therefore,

The associate editor coordinating the review of this manuscript and approving it for publication was Jemal H. Abawajy.

the adoption of damage-centric strategies in EEW systems, bolstered by tools such as ShakeMap, goes beyond mere technological innovation, embodying a strategic imperative that enhances response efforts and markedly influences disaster mitigation.

The integration of ShakeMap into post-disaster response significantly improves emergency management capabilities [14], [15]. The integration of ShakeMap with Geographic Information Systems (GIS) and the Federal Emergency Management Agency's (FEMA) loss-estimation software, HAZUS, offers a comprehensive understanding of potential damage to local infrastructure, facilitating more effective and targeted responses [16]. HAZUS, for example, leverages ShakeMap data to produce more precise estimates of earthquake-related losses, based on the actual measured ground shaking [17]. Initially developed as a component of the TriNet Project in southern California, ShakeMap quickly generates maps of ground shaking intensity, which are vital for informed decision-making in emergency management [18].

Additionally, the usefulness of ShakeMap extends to utilities and private companies in their response and recovery efforts. For instance, the California Department of Transportation (Caltrans) uses ShakeMap to evaluate traffic flow and prioritize the inspection of bridges and overpasses [12]. Engineers and civil servants also utilize this tool to prioritize building safety inspections. In summary, ShakeMap greatly enhances earthquake preparedness by providing near real-time, detailed data on the extent and intensity of ground shaking, thereby playing a crucial role in more efficient and focused emergency response efforts.

While advancements in earthquake disaster management systems have significantly enhanced prediction and response capabilities, there remains an ongoing need for more advanced solutions, especially in situations that demand rapid action. The incorporation of Internet of Things (IoT) technology into earthquake response represents a substantial advancement. IoT's capacity to interconnect a variety of sensors and devices in real-time enables the prompt gathering and analysis of crucial data, thereby facilitating more informed and faster decision-making [19], [20]. An example of such advancement is the use of smartphones and IoT devices for rapid and extensive earthquake detection, providing both detection and alarm capabilities [21], [22], [23], [24], [25]. Nevertheless, there is room for further improvement in this technology, going beyond basic detection and warning.

Therefore, there is a pressing need to create new response strategies that utilize the capabilities of IoT technology. While EEW systems are essential, they alone are not adequate for thorough management in an earthquake scenario. An evolved response strategy might incorporate the Common Alerting Protocol (CAP) as the means for distributing alerts, coupled with predictive Intensity Measurement (*IM*). CAP, with its digital format for emergency alerts, guarantees rapid and precise communication of vital information across multiple platforms, efficiently reaching a wide audience [26], [27], [28].

The amalgamation of CAP with IoT technologies significantly enhances the speed and accuracy of information dissemination during and post-earthquake, resulting in more efficient and effective response efforts [29], [30]. In scenarios like building collapses and fires caused by earthquakes, the role of IoT becomes increasingly vital. IoT devices play a key role in identifying trapped individuals and facilitating evacuation efforts. Following an earthquake, these technologies can offer distinct, dynamic evacuation routes via IoT-enabled devices, an essential factor in densely populated urban areas [31].

This research focuses on devising strategies and guidelines for intelligent IoT solutions in earthquake-prone regions, revolutionizing earthquake preparedness and response through its real-time analytical capabilities and connectivity. The integration of IoT with systems such as EEW and ShakeMap marks the advent of a new era in disaster response, characterized by heightened responsiveness and precision, thereby augmenting the efficacy of our actions in these crucial scenarios.

II. RAPID EARTHQUAKE INFORMATION PRODUCTION

The synergy of EEW systems and ShakeMap is crucial in earthquake preparedness and response. Together, these systems collaborate to swiftly generate vital seismic information, imperative for efficient disaster management. This chapter delves into the detailed procedures of seismic information production employed by the Korea Meteorological Administration (KMA).

A. EARTHQUAKE EARLY WARNING SYSTEMS

The EEW systems implemented by the KMA use on a network approach, utilizing high-performance seismometers strategically placed throughout the country. The initial stage in EEW involves the detection of seismic P-waves. The network-based EEW system is designed to estimate the earthquake's hypocenter and magnitude upon detecting seismic waves at a minimum of three observatories. To improve the reliability and accuracy of these estimations, a threshold of at least four observatory detections is generally followed, demonstrating KMA's dedication to delivering reliable public service [7].

Upon the detection of an earthquake at four or more observatories, the KMA EEW system utilizes three distinct algorithms for epicenter determination (i.e., ElarmS [32], RTLoc [33], and Sheen model [34]). Each algorithm employs a unique method for determining the epicenter's position, and the final epicenter location is ascertained through the correlation of positions calculated by these varied algorithms. Although this paper does not explore the specific theories behind each algorithm in detail, it is crucial to recognize that all three algorithms share a fundamental principle: they estimate the epicenter based on the timing and distance of the seismic waves as detected by multiple observatories.

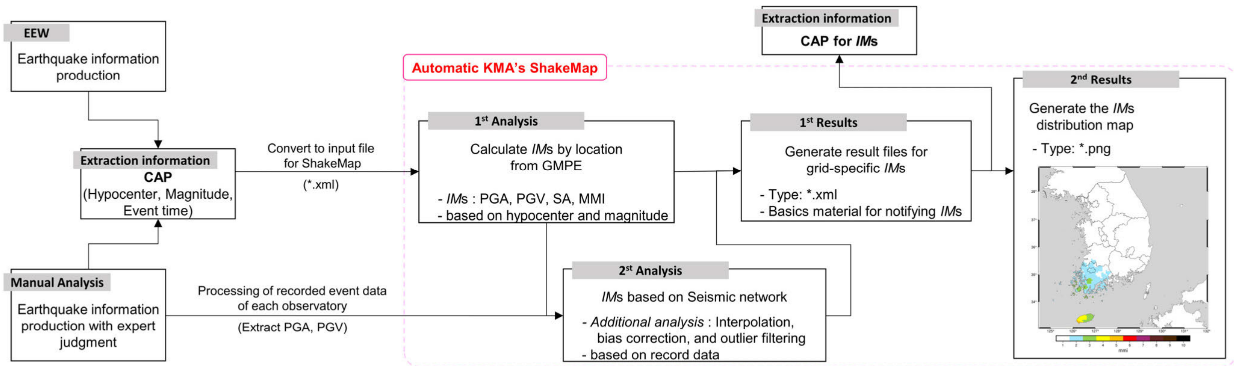

FIGURE 1. Flowchart for generation of CAP and *IMs* map.

Following the determination of the epicenter, the KMA EEW system proceeds to calculate the earthquake's magnitude. This process involves analyzing the amplitude of the P-waves as recorded at the observation stations. An empirical formula [35] is used in this magnitude scaling relation, taking into account the attenuation of the waves relative to the distance from the epicenter. Typically, the magnitude is estimated based on the P-wave amplitude within designated time windows, and this measurement is then converted into a logarithmic scale to accurately determine the magnitude.

Additionally, the KMA EEW system utilizes dynamic algorithms that constantly update magnitude estimates as more data is received from the seismic network. These algorithms take into account several factors, such as the earthquake's depth, the distance between the epicenter and seismic stations, and the properties of the seismic waves. The real-time aspect of this process is critical in EEW systems, allowing for a swift evaluation of the earthquake's potential impact and aiding in the prompt distribution of alerts and warnings to the impacted regions.

B. SEISMIC INTENSITY MEASUREMENT MAP SYSTEMS

ShakeMap, developed by the U.S. Geological Survey (USGS), is pivotal in emergency management as it provides quick maps of ground shaking intensity following an earthquake [9]. This tool is invaluable for emergency managers, as it enables them to swiftly pinpoint areas with the most severe damage. The integration of ShakeMap with the FEMA HAZUS software facilitates the effective allocation of resources based on actual ground shaking measurements, a critical aspect of disaster response [17]. In South Korea, the KMA has adapted ShakeMap to work in tandem with EEW systems, thereby enhancing response capabilities during seismic events.

ShakeMap's procedure initiates with the recording of seismic waves at various stations spread throughout a region. For the areas between these stations, it uses GMPEs to estimate shaking levels. The gathered and estimated data are subsequently interpolated to generate color-coded maps, which illustrate seismic intensity – a quantification of shaking severity specific to certain areas. These maps are crucial in pinpointing regions at an elevated risk of damage, serving a key role in reducing property damage and facilitating rapid emergency response.

KMA's ShakeMap, working in conjunction with EEW, demonstrates a swift and efficient method for earthquake management. The amalgamation of these systems allows KMA to deliver initial results within one minute following the occurrence of an earthquake. By employing version 3.5 of ShakeMap, KMA leverages its comprehensive observation network, rapid communication facilities, and the condensed geographic area of Korea. This system utilizes a wide grid size (approximately 5.5 km) to enable a macroscopic and prompt response. Such advancements in the process and integration enhance the understanding of potential infrastructure damage, thereby boosting the efficacy of emergency responses.

ShakeMap's output is meticulously crafted to provide immediate and accurate information about the extent and intensity of ground shaking. Its primary outputs include intensity maps using the Modified Mercalli Intensity (MMI) scale to illustrate spatial shaking intensity, and peak ground motion maps that display PGA, PGV, and SA. These outputs are essential for understanding the immediate effects of shaking and assessing structural responses to the earthquake. Additionally, ShakeMap offers downloadable data in GIS-compatible formats, delivering comprehensive and site-specific information in XML format, including latitude, longitude, and *IMs* (e.g., MMI, PGA, PGV, and SA). This versatility ensures the data from ShakeMap is accessible and applicable for various uses in emergency management and planning.

C. COMMON ALERT PROTOCOL

The CAP is a key component in modern emergency alert systems, offering a standardized data format that is essential for broadcasting clear and uniform alerts across numerous platforms [36], [37]. Used in accordance with various mandates like the Warning, Alert, and Response Act, CAP plays a critical role in disseminating a range of alerts, including AMBER alerts [38], severe weather warnings, and Wireless Emergency Alerts (WEA) [39]. Its adaptability and versatility

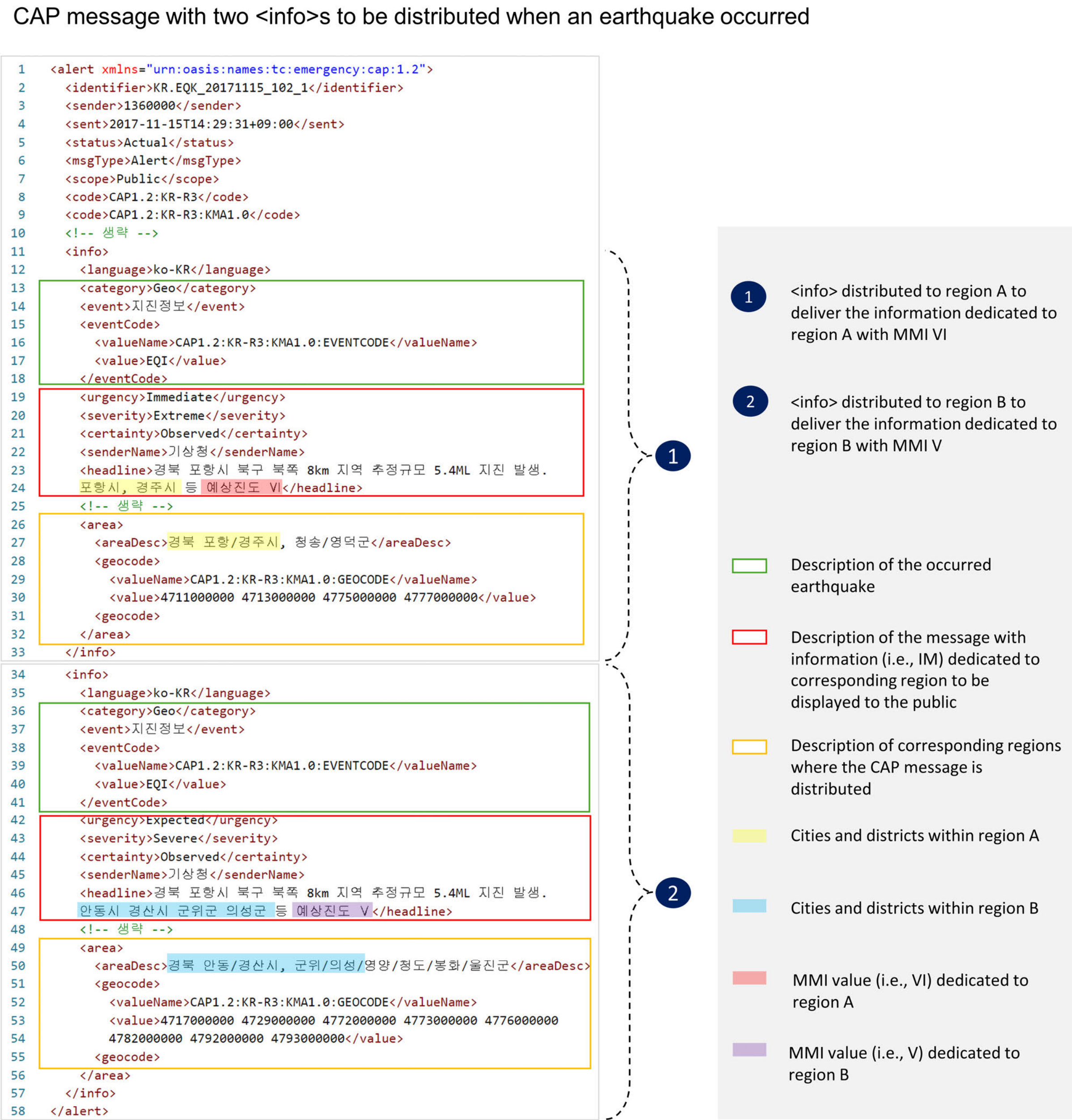

FIGURE 2. Example of differentiated information provision rules by region based on *IMs*.

render CAP an ideal choice for integrating different warning systems, thus enabling efficient and coordinated emergency responses.

The CAP serves as a digital format for the exchange of emergency alert information, ensuring uniformity in alerts regardless of the source agency or distribution platform. A core principle of CAP is its ability to disseminate alerts across multiple channels, covering traditional media such as radio and TV, as well as digital platforms like SMS, email, and social media [36]. This feature guarantees the rapid and consistent delivery of messages across different channels, broadening the scope and effectiveness of vital alerts. With its global adoption, CAP overcomes geographical and technological barriers and is used in various situations ranging from weather emergencies to public health crises. The standard highlights the necessity for a unified, flexible, and efficient approach to communicating emergency information.

In the field of earthquake response, the role of CAP is particularly vital. When combined with EEW systems and resources like ShakeMap, CAP becomes an essential tool for the rapid distribution of earthquake alerts [28]. It facilitates the immediate communication of detailed earthquake information, such as the epicenter, magnitude, and expected impact areas. This data, frequently presented in user-friendly, map-based formats, enables both individuals and emergency services to make quick, well-informed decisions.

Figure 1 depicts the step-by-step process of creating CAP files and the distribution map of *IM*s in Korea, highlighting the dual-phase method in the progression of information dissemination. In the first phase, immediately after an earthquake, the MMI is calculated based on the earthquake's magnitude and epicenter, as determined by the EEW system. This initial MMI, a predictive measure using the Ground Motion Prediction Equation (GMPE) model, does not yet include the Peak Ground Acceleration (PGA) and Peak Ground Velocity (PGV) recorded at seismic observatories. The foremost goal of this phase is to enable quick evacuation by promptly disseminating risk information. A more detailed earthquake information announcement follows within five minutes of the event. This latter phase entails re-assessing the earthquake's magnitude and epicenter, incorporating expert analysis for greater precision. Furthermore, the *IM*s data is refined and updated with observatory-recorded data. This enhanced information, including both the magnitude and location of the earthquake as well as observatory data, is essential in post-earthquake management, aiding in response and recovery efforts. KMA's two-tiered approach aims to ensure immediate public safety measures and informed, efficient management for post-disaster recovery.

In conclusion, the integration of CAP within earthquake preparedness and response frameworks significantly enhances the ability to effectively warn and inform the public. By ensuring that crucial alerts are quickly and coherently communicated across various platforms, CAP is a vital element in mitigating the negative effects of earthquakes on communities.

III. DESIGN OF IOT PLATFORM

This chapter delves into the structural design and operational aspects of the CAP, underscoring its critical role in developing emergency response strategies that are enhanced by the incorporation of ShakeMap data.

A. BASIC STRUCTURE OF CAP

The CAP supports multiple critical functions in emergency management, including the issuance, updating, and cancellation of alarms, as well as the exchange of response information. These functions are defined by the <msgType> element in CAP: "Alert" indicates new events, "Update" is used for modifications, and "Cancel" for the annulment of existing alerts. Interactions within the system are represented by "Ack" for confirmations and "Error" for problems encountered in alert reception.

In CAP, the origin and issuing entity of an alert are indicated using the <sender>, <source>, and <senderName> elements. The <sender> element provides a globally unique identifier, which is typically in a domain name format. The <senderName> element offers a human-readable description of the issuing organization. The <source> element identifies the cause or origin of the alert. CAP's <scope> element determines the intended audience for the alert, with possible values being "Public," "Restricted," or "Private." The "Restricted" and "Private" scopes are intended for specific organizations or systems, as specified by the <restriction> and <addresses> elements. For alerts or tests specific to a system, "Private" is used, and the system's address is included in the <addresses> element.

Figure 2 illustrates the distribution of a CAP message during an earthquake event, describing how different regions receive tailored information based on their specific MMI grades. It targets different regions (Region A and B) with respective MMI values (VI for Region A and V for Region B). The CAP also includes a description of the earthquake, the intended message content for the public in each region and lists the cities and districts within target regions. The structure of CAP represents how emergency information is disseminated according to regional needs during seismic events.

In CAP, uniformity within a message is maintained by mandating that all <info> elements adhere to a consistent <eventCode>. This consistency is critical for efficient filtering, routing, and validation by systems processing the alarm messages. The flexibility of CAP is further highlighted by the dynamic nature of the event classification identifiers list, allowing for revisions to accommodate operational changes.

B. EXPANSION OF CAP FOR IMS

CAP enables the delivery of differentiated information based on *IM*s, providing specific information for an earthquake event in relation to the distance from the epicenter. This allows devices within an affected area to more effectively respond according to the localized *IMs*. Figure 3 demonstrates how nuanced alert contents are delivered by adjusting the risk level in different regions for the same event within one <alert> element. The event is defined by a combination of <category>, <event>, and <eventCode> elements. Risk levels are modified using the <severity>, <urgency>, and <certainty> elements, and the <area> element conveys each area that is under alert.

The KMA generates an XML document that contains prediction intensity information (such as PGA, PGV, and MMI) for each grid based on seismic wave analysis. This information is linked to the CAP notification via an IntensityGridURI. The document includes <grid_specification> and <grid_data> elements, offering a detailed breakdown of predicted Intensity Measurements (IMs). Due to the comprehensive nature of this data, it is not directly incorporated within the CAP alarm message. Instead, essential information is condensed, as illustrated in Figure 3, where details of grid division and expected grid-specific progression are integrated into a CAP alarm message using CAP's "IntensityGridSpec" and "IntensityGrid" parameter elements.

C. DESIGN OF EARTHQUAKE WARNING SERVICE MODEL BASED ON IOT PLATFORM

We propose an IoT-based earthquake notification service model that differentiates between the warning issuance

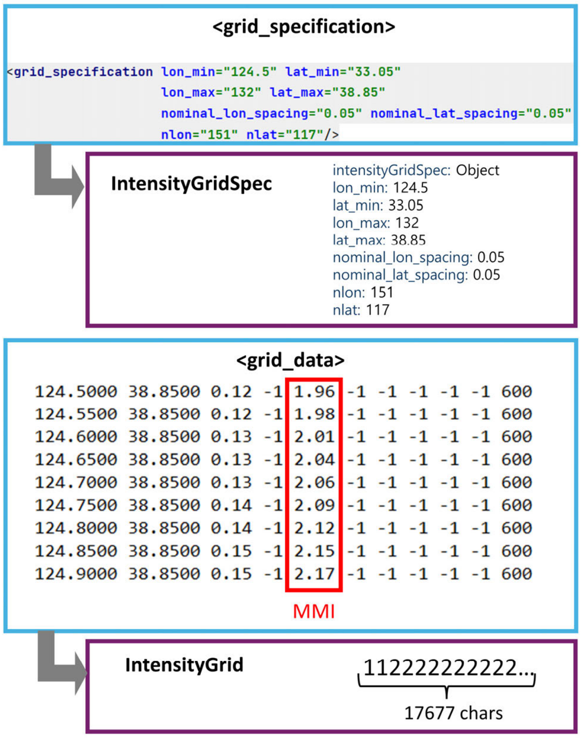

FIGURE 3. Example of extracting MMI information by region.

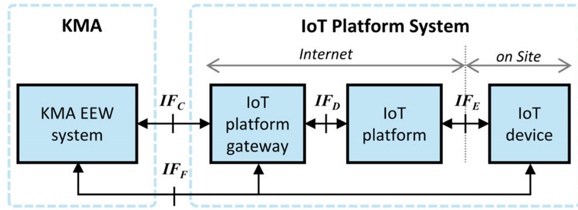

FIGURE 4. Design of IoT earthquake notification service platform.

TABLE 1. Definition of interface C (IF_C) in CAP elements by message type.

Type	Define	<status>	<msgType>
New alert	Notification of a new warning	Actual	Alert
Update alert	Update or replacement of a previous warnin	Actual	Update
Cancel alert	Cancellation of a previous warning	Actual	Cancel
System test &check	Message for technical testing	Test	Alert / Update / Cancel
Test	Connectivity test within the platform	System	Alert
Ack	Confirmation of the proper receipt of a request message	System	Ack
Error	Error feedback during the reception and processing of a request message	System	Error

agency and the IoT Service domains. The warning issuance agency is responsible for creating and transmitting alerts that comply with the CAP, while the IoT Service domain disseminates these alerts within its network, which includes IoT gateways, platforms, and devices, to manage the distribution of seismic information effectively. Figure 4 illustrates the suggested components and interfaces of this IoT-based earthquake notification service. The KMA issues earthquake notifications and information, as detailed in Chapter 2. The IoT gateway acts as a conduit to the IoT service domain, adapting KMA earthquake alerts for compatibility with the IoT platform.

The IoT Gateway is an essential component within this domain. Its main role is to translate earthquake alert messages from the KMA into a format that can be understood by the IoT service platform. Interface C (IF_C) serves as the conduit for transmitting CAP-formatted earthquake alerts to the communication systems. It oversees the flow of messages concerning the issuance, updating, and cancellation of alerts, as well as system diagnostics and connectivity tests. This range of functionalities includes managing acknowledgments (ACK, Error) for the received alert messages, as detailed in Table 1. In our reference model, the IF_C is implemented using a Representational State Transfer (RESTful) messaging approach, based on the HTTP(s) protocol.

The implementation of the IoT Platform aligns with the Infra Node Common Service Entity (IN-CSE) as defined by the oneM2M standard [40], [41], [42], [43]. Interface D (IF_D) establishes a connection and provides essential common services for IoT service operations. When an alert is received, the IoT platform, operating in a cloud environment, activates its core functions, including device management and application service integration. To address the unique demands of disaster situations, we have integrated a request dispatcher into the system. Figure 5 depicts this request dispatcher, designed to manage a multi-priority message queue based on the importance of each message. For instance, if messages ② and ③ are received while message ① with "Normal" priority is being processed, they are queued according to their respective priorities. After message ① 's processing is complete, message ③ with "Critical" priority is handled before message ②, which has a lower repair priority. We have defined five levels of task importance (e.g., Critical > High > Normal > Low > Deferred). As a result, an operational policy that employs priority weighting beyond simple comparison is utilized.

The IoT device, following Interface E (IF_E) from the oneM2M reference model, transmits sensory data and adheres to server control directives using the oneM2M protocol. IF_E plays a key role in distributing alarm messages between the IoT service platform and devices, utilizing the Message Queueing Telemetry Transport (MQTT) protocol, which is adept at 1:N communication. MQTT, a subscription-notification messaging protocol, facilitates the dissemination

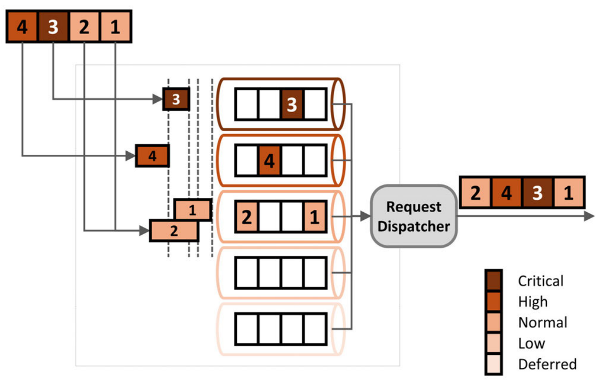

FIGURE 5. Schematic diagram of request dispatcher.

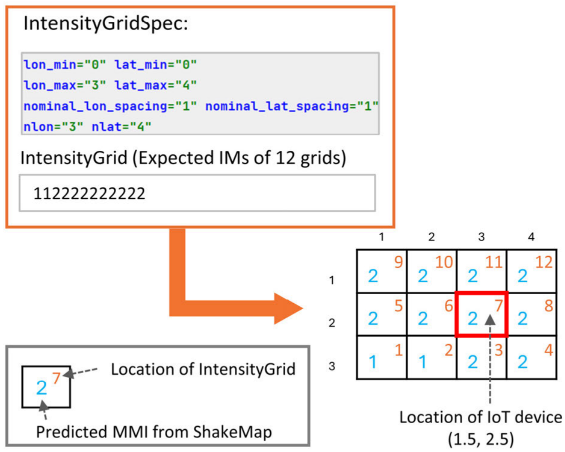

FIGURE 6. Example of device response based on MMI.

of a single message to multiple subscribers by publishing it on a specific topic.

The utilization aspect focuses on leveraging *IM*s information. KMA EEW notifications incorporate an XML document containing regional seismic intensity data within the "IntensityGridURI" parameter. The oneM2M Earthquake Notification Service Gateway utilizes this data, converting it into a format that can be effectively communicated to endpoints and subsequently delivered to devices. Figure 6 illustrates this concept, showcasing the simplified regional seismic intensity information as processed by the oneM2M earthquake notification service gateway reference implementation. The transformed data includes expected intensities for regions divided into grids, enabling the verification of regional progress using a straightforward formula.

The proposed IoT service model, strengthened by the advanced capabilities of the IoT infrastructure, offers a robust framework for quick and efficient earthquake notification and response. By seamlessly integrating with the KMA's notification system, this model advocates for a swift response strategy, enhancing preparedness and diminishing the impact of seismic events.

IV. PILOT TEST

The goal of the pilot test is to verify the functionality and reliability of an IoT service platform in compliance with international standards. This is achieved through the implementation of earthquake notification scenarios at various stages of disaster alert and the conceptual validation of service cases using the developed reference model. We designed a scenario in which an earthquake early warning is issued following seismic activity. This scenario involves evaluating differentiated response functions for each region by correlating the received regional Intensity Measurements (IMs) with the predefined response intensity thresholds for the objects.

The response types for objects in the earthquake scenario are classified into three categories: automatic opening and closing, response guidance, and automation system linkage. These types are as follows:

- The "automatic opening/closing" type pertains to smart IoT devices which, upon receipt of an earthquake alert, assess pre-defined criteria within the device against the data provided in the notification. Subsequently, they autonomously engage an emergency mode, resulting in the automatic activation or deactivation of physical mechanisms like valves or doors.

- The "response guidance" type, similar to the "automatic opening/closing" type, is designed not only to minimize damage through automatic object responses but also to facilitate human evacuation efforts. This involves delivering vocal instructions or lighting up evacuation paths, thereby assisting individuals in safely exiting the premises.

- The "automation system linkage" type expands the application of the IoT concept by implementing emergency response actions in earthquake scenarios through interactions with interconnected automation systems. These systems can include control systems for railways, manufacturing plants, elevators, drones, and more. This approach is adaptable to pre-existing automation systems that may not yet be integrated into the IoT platform, thereby providing broad applicability and enhancing the overall emergency response capability.

Figure 7 outlines the setup of target devices for the IoT platform pilot test. Each device is equipped with a terminal that can interface with the IoT Platform. This terminal is designed to transmit and receive both the device's location information and data from the IoT Platform. The response criteria specific to each device type are comprehensively detailed in Table 2.

In the given scenario, an earthquake with an anticipated magnitude of 5.4 is assumed to occur Pohang. Following this event, the KMA swiftly issues an earthquake early warning. Figure 8 illustrates the earthquake's epicenter and presents the expected seismic intensity information for various regions in response to the early warning. This visualization also includes the locations of IoT devices as outlined in Table 3, showing whether they have initiated responsive actions. In line with the scenario's defined expectations for regional intensities, the smart valve at the smart factory in Pohang enters emergency mode, triggered by the MMI indicated in the

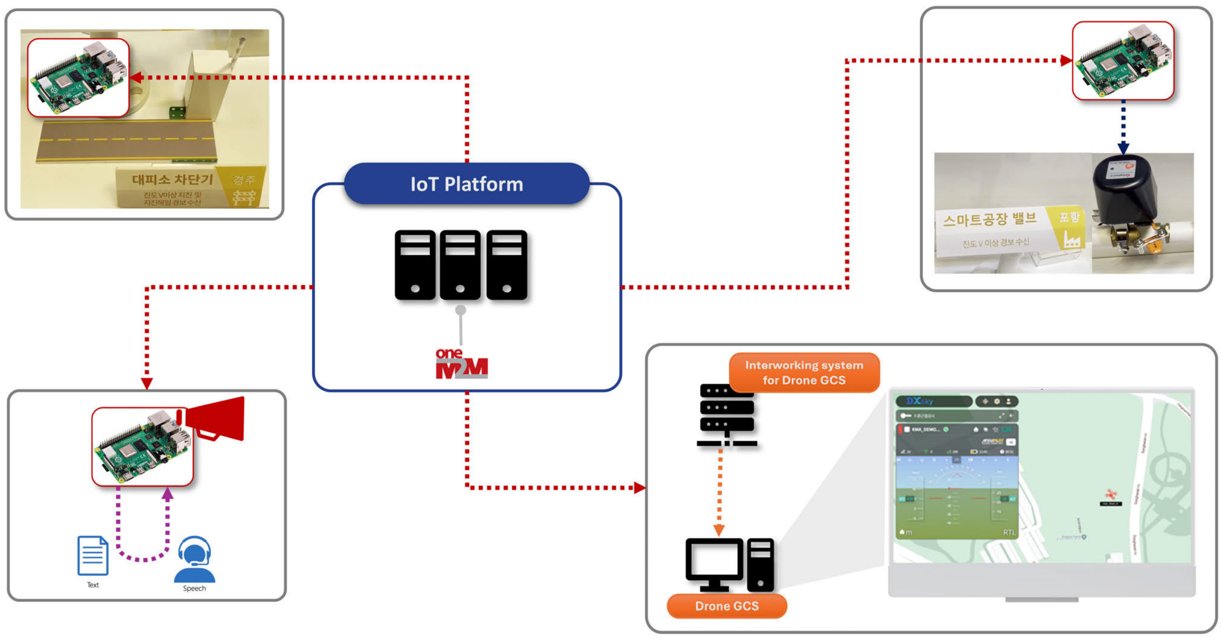

FIGURE 7. Target devices for Pilot test of IoT platform.

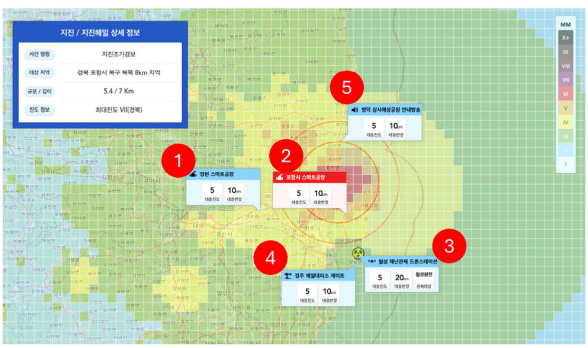

FIGURE 8. Prediction MMI by region and location-based device response from IoT Platform monitoring *(in Korean ver.)*

TABLE 2. Response criteria for IoT devices in EEW service.

Type	Response	Response Conditions
GAS Valve in Factory	Opening /Closing	Reacts to EEW with Prediction MMI of V or above
Drone Control System	System Linkage	Responds to EEW with Prediction MMI of V or above. Responds to tsunami notifications
Traffic Control System	Opening /Closing	Reacts to EEW with Prediction MMI of V or above
Voice Guidance System	Response Guidance	Responds to tsunami notifications

received alert. Simultaneously, other devices react based on the projected seismic intensity for their locations and predetermined thresholds. Devices in regions where the seismic MMI is below the threshold remain in standard operation mode, ensuring that emergency actions are only implemented where necessary.

TABLE 3. Response criteria for IoT devices in EEW service.

No	Device Type	Response	Act reason
1	GAS Valve in Factory (location: Youngchun)	No	Receiving MMI which below the set threshold in area
2	GAS Valve in Factory (location: Pohang)	OK	Receiving MMI which over the set threshold in area
3	Drone Control System (location: Woulsung)	No	Receiving MMI which below the set threshold in area
4	Traffic Control System (location: Gyeongju)	No	Receiving MMI which below the set threshold in area
5	Voice Guidance System (location: YoungDuck beach)	No	Does not respond due to non-tsunami

V. CONCLUSION

Our study developed a design method that can be connected to the IoT using EEWs and the results of ShakeMap. The proposed model is expected to improve public safety and enhance disaster mitigation strategies. We learned that integrating IoT technology with disaster management represents a significant stride forward in this field.

The pilot test of the proposed model validated the effectiveness of an IoT-based service platform operating in accordance with international standards. The classification of earthquake response types into 'automatic opening/closing,' 'response guidance,' and 'automation system linkage' demonstrates the diverse approach necessary for effective disaster management. This test showcased the system's differentiated response functions based on regional seismic *IMs* and the predefined response intensity thresholds for objects. Implementing various earthquake notification scenarios, the proposed model conceptually validates service cases with the developed reference model.

The integration of the IoT infrastructure with the KMA notification system allows for the swift dissemination of earthquake warnings and the facilitation of rapid response mechanisms. This approach not only enhances preparedness but also aids in reducing the seismic damage impact. Leveraging real-time analytical capabilities and connectivity, the proposed IoT service model revolutionizes earthquake disaster management, ushering in responsiveness and precision in emergency response strategies.

Furthermore, a major role of the CAP in the proposed model is to highlight the significance of IMs in delivering near real-time, detailed data on the scope and intensity of ground shaking. By combining ShakeMap with EEW systems and the CAP, the model ensures that crucial alerts are swiftly and coherently disseminated across multiple platforms, thereby enhancing the efficiency of emergency responses. Adapting these advanced tools to the specific seismic and technological contexts of each region is essential for developing strategic imperatives that improve response efforts and substantially contribute to disaster mitigation.

As the IoT continues to develop, its significance in earthquake detection and alarm functionalities grows more pronounced. The study's pilot test, which includes scenarios simulating the issuance of earthquake early warnings and the activation of response actions in IoT devices, showcases this evolving role. We have proposed a robust framework that lays the groundwork for future advancements in earthquake notification and response services. This framework showcases the transformative potential of IoT in redefining earthquake disaster management strategies. For instance, advancements could include disaster evacuation route guidance, IoT-enabled lighting, and equipment designed to assist individuals with disabilities during an earthquake. These developments illustrate both the current challenges and the prospects for progress in IoT-based earthquake notification and response systems.

Finally, our proposal to integrate IoT with systems like EEW and ShakeMap marks a shift in disaster response strategies, emphasizing the importance of continually developing intelligent IoT solutions for earthquake-prone regions. The proposed method aims to enhance the efficacy of disaster preparedness and response, particularly in managing critical situations more effectively. However, we developed only the framework design method for connecting with IoT devices without the algorithms for individual devices. Future research will require platforms using a management algorithm and an analysis of the workflow for each device's algorithm and process.

ACKNOWLEDGMENT

The authors thank the associate editor and reviewers for their constructive comments.

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