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Power Failure Emulator for Communication Network in Disaster Situation#

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ABSTRACT

Communication networks often experience failures during natural disasters such as floods, making it difficult for affected individuals to access critical information. This research proposes a power failure emulator that reproduces the interdependencies between communication failures and power supply during flood events. The emulator models the behavior of ground-based substations and determines the power supply status in flood-affected areas. It is designed to work in coordination with multiple interdependent simulators and systems, including a flood analysis simulator, an evacuation simulator, a communication failure emulator, and an evacuation route information system, using a federation strategy. The power failure emulator exchanges information with other components via a federation bus, communicating the state of power supply to the communication failure emulator, thus reproducing the impact on communication networks. The objective is to generate more realistic scenarios that consider the interdependencies between power supply and communication networks during natural disasters, enabling the analysis of the impact of communication failures on information access for affected individuals and facilitating the development of more effective disaster response strategies.

Keywords: flood disaster, communication failure, federation system, power supply failure

NONMENCLATURE

Abbreviations	
ADAPEN	Advances in Applied Energy
Symbols	
n	2024

1. INTRODUCTION

The number of disasters and the number of human casualties is steadily increasing in the world due to the complex intertwining of changes in the global climate system and global warming caused by greenhouse gases [1][2]. By 2050, urban populations are projected to surpass 6 billion, with a staggering 68% of this population concentrated in urban areas vulnerable to disasters [3]. Among various types of disasters, floods have proven to be the most devastating in terms of human casualties. In 2018 alone, approximately 3.39 million people were affected by flood disasters [4], and these numbers are expected to continue climbing in the future.

To address these growing challenges, smart city technology holds the key to creating resilient cities that can withstand the impacts of disasters. By leveraging Internet of Things (IoT) sensors, smart cities collect vast amounts of data on various aspects of urban life, including traffic flow, people flow, and weather conditions [5]. This data is then processed using artificial intelligence (AI) algorithms, enabling real-time assessment and prediction of supply and demand dynamics. The ultimate goal of smart cities is to enhance the quality of life for people living in urban areas prone to high disaster risks by building resilience into the fabric of the city itself.

The realization of smart cities relies on advancements in various technological domains, including cyber-physical systems, the Internet of Things (IoT), cloud computing, and other software technologies. These advancements enable the seamless integration of sensors, actuators, and other devices into the physical urban environment, leveraging a wide range of technologies and computational techniques. Among the fundamental technologies underpinning smart cities, simulation technology plays a pivotal role in forecasting service demand within physical spaces and conducting

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predictive analyses in virtual environments. Simulation has long been a fundamental technology for replicating real-world events, but the advent of cyber-physical systems has introduced a new approach involving the modeling of physical elements within a virtual space. In an effort to realize cyber-physical systems in disaster scenarios, our team has developed a system that employs a federation strategy to create scenarios incorporating the impact of communication failures during flood events.

Communication failures, including power outages and damage to communication systems, are common during floods. In recent years, 70% of floods have led to failures attributed to damaged communication systems. The physical nature of these failures is considered to have a profound impact on disaster victims, as their recovery often necessitates the relocation of physical systems. Given the critical role of information access during disasters, human behavior during disasters is heavily influenced by the type of information obtained by those affected. Today, which is highly dependent on information and communication technology, it is crucial to evaluate the potential situations in which disaster victims' access to information may be compromised and how this will impact their behavior. As a strategy for disaster response, simulating these scenarios in advance can provide valuable insights into the challenges that may arise.

Therefore, on the contrary, it is equally essential to consider how the occurrence of communication failures during disasters can affect victims' access to information. By understanding the implications of these failures on information accessibility, we can develop more effective strategies to mitigate their impact and ensure that critical information reaches those who need it most. This approach can ultimately contribute to more resilient and adaptive disaster response efforts, which prioritize the needs of those affected by the crisis.

2. RELATED WORKS

Many studies have been conducted on the impact of communication networks during disasters. Communication networks become even more critical during disasters, and the impact on disaster response when they are disrupted is significant. Reference [6] proposes a simulation framework for evaluating the vulnerability of communication networks during earthquake disasters, analyzing the impact of communication failures by considering factors such as earthquake intensity, network topology, and traffic demand. Reference [7] investigates the optimal recovery process for restoring network capacity progressively after a major disruption, considering limited repair resources. The proposed concept of progressive network recovery represents a paradigm-shift in resilient and survivable networking to handle large-scale failures, and is expected to inspire further research in network design and other applications. Reference [8] reports on the destroyed communication infrastructure within the New Orleans metropolitan area due to the impact of Hurricane Katrina, which hindered the exchange of vital information between emergency responders and the public. It suggests that well-designed communication and information infrastructure can enhance community resilience to recurring risks. Reference [9] reports on the power outage status of the network and user traffic trends during the Great East Japan Earthquake that occurred on March 11, 2011. During this event, some network nodes in the epicenter area were disconnected for up to 70 hours due to power outages. However, it states that the network was able to continue operating thanks to redundancy. Reference [10] analyzes the impact of the Great East Japan Earthquake on communication infrastructure and points out the importance of infrastructure development in the reconstruction of affected areas.

While communication disruptions have a tremendous impact, it is also necessary to clarify how communication networks behave during disasters. Reference [11] points out that critical national infrastructures for power, emergency services, finance, and other industries tend to be highly reliable, but large-scale failures can occur, especially when disasters are unfolding, potentially leading to cascading effects on other dependent infrastructures. This paper describes recent natural disasters in the United States, namely hurricanes Katrina, Rita, and Wilma, and shows how their impact on power outages and flooding led to failures in dependent critical infrastructure. Reference [12] uses a mathematical approach, employing probabilistic seismic hazard analysis to estimate the state of network elements after an earthquake and evaluate the strength of the network. The simulation shows that nodes fail according to the fragility curves of buildings, and similarly, links fail according to a failure rate that depends on the intensity and characteristics of the cable. Reference [13] summarizes the principles and best practices of disaster-resilient communication networks and discusses various evaluation methods, including simulation.

We have previously proposed a system for creating scenarios that reflect the impact of communication failures during floods [14]. Communication failures during disasters include power outages, damage to communication systems, and congestion due to concentrated communication, but communication failures caused by power outages and damage to communication systems are more common during floods. Our goal is not to simulate a single specific communication failure event. We aim to build a system that generates scenarios reproducing communication failures by utilizing a federation strategy that enables the coordinated implementation of multiple simulators. We incorporate multiple factors such as the impact of natural disasters, human behavior, the impact of disasters on information and communication, and information services as flood analysis simulators, evacuation simulators, communication failure emulators, and evacuation routes information systems, respectively, focusing on their interdependencies to generate scenarios of human impact. By developing such a system, it becomes possible to analyze the behavior of communication networks during disasters in various regions and under different disaster phenomena, as well as their impact on evacuees and disaster response measures. In our previous research, we developed a system that incorporates the behavior of communication networks. However, communication failures are closely related to power supply. Our previous system did not include a simulator for power failures. Therefore, we incorporate simulators for communication networks and power failures into the system to reproduce failures that include the interdependencies between communication and power.

Studies that demonstrate the relationship between communication failures and power supply during disasters include the following. Reference [15] analyzes the impact of major natural disasters that occurred between 2005 and 2011 on communication infrastructure and power supply, presenting lessons learned from on-site surveys. Reference [16] points out that infrastructure systems are particularly vulnerable to climate disasters such as floods, wildfires, cyclones, and temperature variations, and organizes recent advances in quantitative climate risk analysis in key infrastructure sectors such as water and sewage, telecommunications, health and education, transportation (ports, airports, roads, railways, inland waterways), and energy (power generation, transmission, distribution). It argues that there is a lack of research focusing on specific combinations of climate hazards and infrastructure types, and that validating models is becoming increasingly difficult. Reference [17] models infrastructure vulnerability, response, and recovery at the system level for power supply and communication in the United States for several hurricanes that have occurred, using post-event data and geostatistical methods. It also explains the relationship between power supply and communication systems.

While these papers demonstrate the dependencies between communication and power, they do not examine how the occurrence of such communication failures during disasters affects the information access of affected people. We construct a power failure simulator from the perspective of how people in areas that have become hazardous due to disasters are affected in their information access by communication and power failures, and build a system that can reproduce the dependencies with the communication failure simulator.

3. POWER FAILURE EMULATOR FOR COMMUNICATION NETWORK

3.1 Federation strategy

The primary objective of this paper is to develop a power failure emulator based on a federation strategy. This strategy involves the cooperative operation of five different simulators / systems: a flood analysis simulator, an evacuation simulator, an evacuation route service system, a communication failure emulator, and a power failure emulator (Fig.1). To achieve this collaborative functionality, it is essential to address various aspects of the system, including the exchange of physical data between simulators and systems, as well as the control of processing timing.

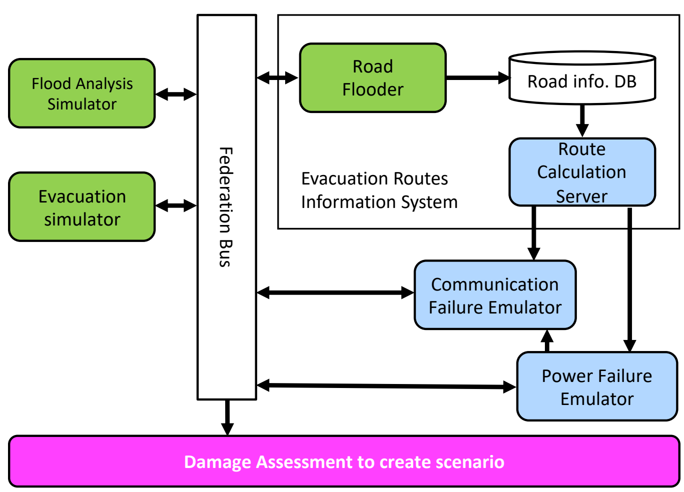

Fig. 1 Federation Concept

We aim to accomplish this goal by employing a federation strategy that involves the development of a larger framework, which incorporates these simulations and systems as a single, unified function. The process of implementing the federation strategy consists of several phases, all of which are provided on a single platform. Our previous work has focused on the design and implementation of simple data exchange and processing timing control for pre-verification purposes [18], as well as real-time data exchange and processing timing control for practical services [19].

In this paper, we conduct a feasibility study utilizing the simple data exchange and processing timing control described in [18] to facilitate the cooperative operation of the simulations and systems. The primary contribution of this work is the proposal of a power failure emulator that leverages the federation strategy to create a cyber-physical system capable of capturing the impact of power failures during flood events.

3.2 Federation Mechanism

In our federation strategy, the federation bus plays a crucial role in facilitating data exchange and timing control between the various components of the system. The federation bus consists of two main elements: an MQTT broker for Publish-Subscribe message exchange and a federation manager for time-synchronized progress management. The data exchange function, as the name suggests, is responsible for exchanging data between simulators and systems and is composed of an MQTT broker. Each simulator or system outputs its calculation results for each step as MQTT messages, which other simulators and systems can subscribe to based on pre-defined information. These messages are then used as input data for their respective calculations. Despite the varying computation times of each simulator, we achieved the cooperation of multiple simulators/systems by employing this timing control manner.

The processing timing control function, implemented as a server, manages the processing timing and coordinates the operation of five simulators/systems. Acting as a coordination manager, it ensures time-synchronized progress management. When starting the overall simulation, this function sends a simulation start order to all simulators / systems. Upon completing the first step of each calculation, the simulators/systems publish an MQTT message indicating the completion of the first step along with the calculation results. The processing timing control function determines that the first step calculation is complete once it receives messages from all simulators / systems. It then sends an order to all simulators / systems to commence the second step of the calculation. By iterating this process, the calculation proceeds with multiple simulators / systems working cooperatively.

The incorporation of the power failure emulator into our system enables us to reproduce the impact of power failures on information access. This addition allows for a comprehensive analysis of the behavior of disaster victims and their access to information, as calculated by the evacuation simulator. By simulating power failures alongside other disaster scenarios, we can gain valuable insights into the complex interplay between infrastructure disruptions and human behavior during emergency situations.

3.3 Communication Failure Emulator and its Relationships

Our communication failure emulator is designed to simulate communication failures related to smartphones during flood events. The emulator comprises several key components, including a mobile base station, a mobile relay station, a wired communication line connecting the base station and relay station, and a power supply for both the base station and relay station. The mobile base station transmits radio waves within a defined range, allowing evacuee agents within that range to access information. However, if the flood water level rises in the flood analysis simulator and either the mobile base station itself or its power supply function becomes flooded, the base station loses its communication function. The wired communication lines between the mobile base station and relay stations are connected via the shortest path, and any damage to these lines due to flood flow results in the connected mobile base station losing its communication function. Additionally, when a power outage occurs due to flooding, the power supply to the mobile base stations and relay stations is interrupted, simultaneously disconnecting the communication function.

The communication failure emulator plays a crucial role in the overall system by sending the availability status of the mobile base station via MQTT messages over the federation bus. It determines which base station an evacuee agent should use based on their location and transmits the availability status of that base station back to the evacuation simulator. If the mobile base station is active, evacuee agents in the evacuation simulator will have access to shelter routes and alerts. Conversely, if the base station is unavailable, the evacuee agents will be unable to access this critical information. Through these steps, the communication failure emulator effectively simulates information access during a flood event.

To ensure accurate simulation, the communication failure emulator receives MQTT messages for timing control from the Federation bus. Upon receiving these messages, it calculates the communication status and power supply status of base stations, fiber optic lines, and relay stations based on the flood values received from the flood analysis simulator. The emulator then publishes MQTT messages containing the location, communication range, and status of each base station according to the calculation results.

3.4 Proposed Power Failure Emulator

The power failure emulator, developed as part of this paper, is designed to simulate power failures related to communication disruptions during flood events. The emulator's architecture consists solely of ground-based substations, which indicate the presence or absence of power supply for each designated area. These substations supply power within a defined area and are responsible for providing power to the communication facilities within their range. In the event that the flood water level rises in the flood analysis simulator and a ground-based substation becomes submerged, the affected facility loses its power supply function. The status of power supply for each area is then communicated to the communication failure emulator. The power supplied by these substations is crucial for the operation of mobile base stations and relay stations. When a power outage occurs due to flooding, the power supply is interrupted, and consequently, the communication function is also disconnected simultaneously.

The power failure emulator plays a vital role in the overall system by sending the state of the power supply via MQTT messages over the federation bus. It communicates the presence or absence of power supply for each area covered by the ground-based substations to the communication failure emulator. When power is available, the mobile base stations and relay stations in the communication failure emulator remain operational, allowing smartphones connected to those base stations to access routes to the shelter and receive alerts. Conversely, if the power supply is lost in a particular area, the base stations in that region become unavailable. Through these steps, the power failure emulator effectively simulates communication failures during a flood event.

To ensure accurate simulation, the power failure emulator receives MQTT messages for timing control from the Federation bus. Upon receiving these messages, it calculates the power supply status of the ground-based substations based on the flood values obtained from the flood analysis simulator. According to the calculation results, the emulator publishes MQTT messages indicating the location and status of each area.

4. PERFORMANCE TEST

4.1 Overview

The purpose of this paper is to develop an emulator for power outages that affect communication failures during flood disasters using a federation strategy. It is known that communication failures occur during disasters such as floods. These communication failures are often caused by the impact of power outages. We develop an emulator for power outages that affect communication failures and examine how communication failures during disasters impact the information access of affected people. By linking this emulator with the federation strategy, we construct a power outage emulator that considers the impact of communication and power failures on information access, creating a system that can reproduce the dependency between the communication failure emulator and the power outage emulator.

In this section, we test the performance of this system to determine how communication failures during disasters affect the information access of affected people. For this purpose, we federate a flood analysis simulator, a communication failure emulator, a power

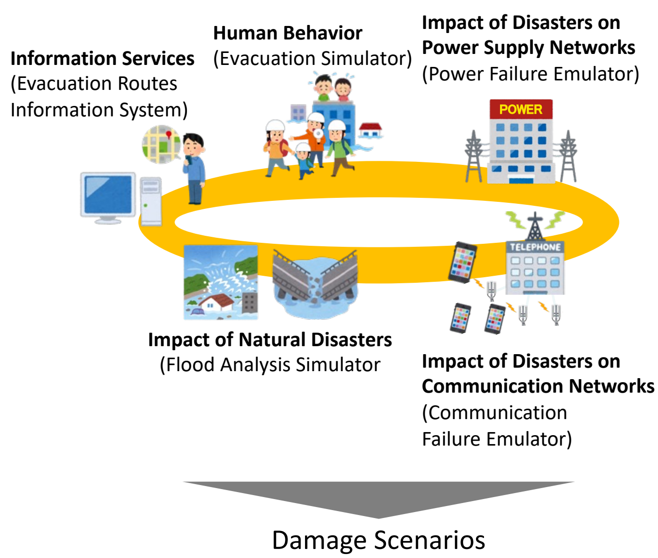

Fig. 2 Performance Test

outage emulator, an evacuation simulator, and an evacuation routes information system, and confirm their operation (Fig. 2). The flood analysis simulator uses flood data assumed to occur in the event of heavy rainfall in Joso City, Ibaraki Prefecture, Japan. The communication network and power network are set up hypothetically, and mobile base stations and power supply functions are constructed. The system generates scenarios by changing the distribution status of alerts that trigger the start of evacuation and the simulation time. Using the generated scenarios, we confirm that the power outage emulator and the associated communication failure emulator operate as expected and that the impact on information access is reflected.

4.2 Setup

For the flood analysis simulator setting, a specific single point is selected as the levee breach point, and time-series inundation data is used for the case when the maximum assumed flood occurs. For the communication failure emulator, seven base stations are randomly set in the emulator on a trial basis. The optical fiber routes for base station communication are linked on a trial basis and differ from the actual routes. The power outage emulator sets up several power supply functions. Each simulator operates on a virtual machine placed in the same network, exchanging data via MQTT.

In the performance test, the following points were experimented and examined. For a hypothetical flood disaster in Joso City, power outages caused by flooding are generated, and the impact of communication failures during that time is investigated. This test uses a federation strategy that links the flood analysis simulator, communication failure emulator, power outage emulator, evacuation simulator, and evacuation routes information system to determine whether the dependency between power outages and communication failures during a flood disaster can be reproduced.

4.3 Damage scenario result and discussion

Fig. 3 shows the results of operating the flood analysis simulator, communication failure emulator, and power outage emulator in federation. Fig. 3 a) shows the communication situation in the city before the flood occurs. The green-colored areas on the map indicate areas where communication is possible, and the yellow-colored areas indicate areas where power supply is available. The green dots and lines represent the locations and routes of base stations. The uncolored area in the upper right of Fig. 3 a) is assumed to have no power

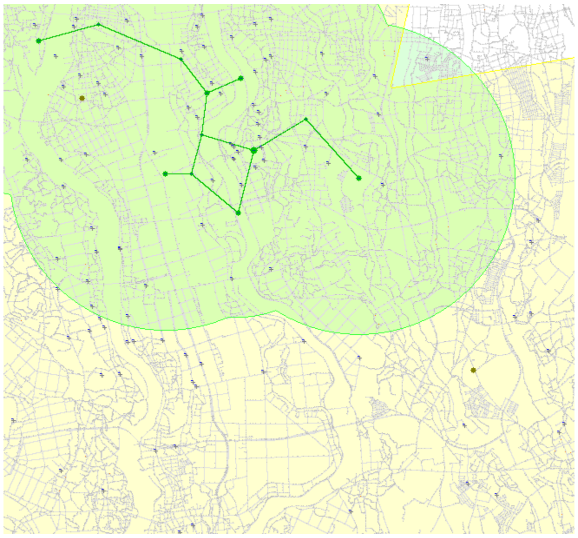

Fig. 3 a) Communication failures and evacuees before flood

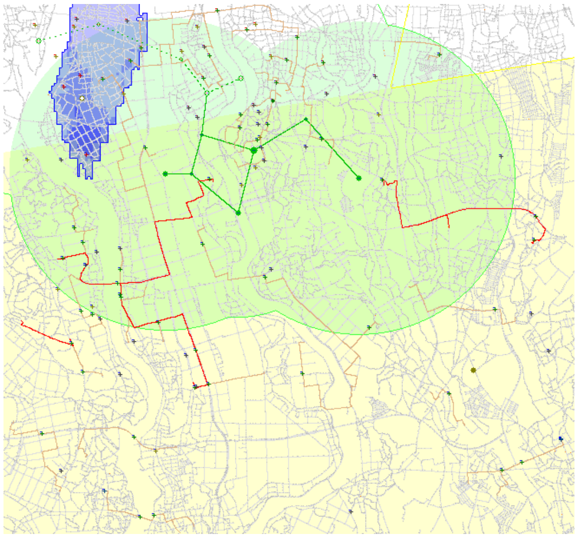

Fig. 3 b) *Communication failures and evacuees after flood*

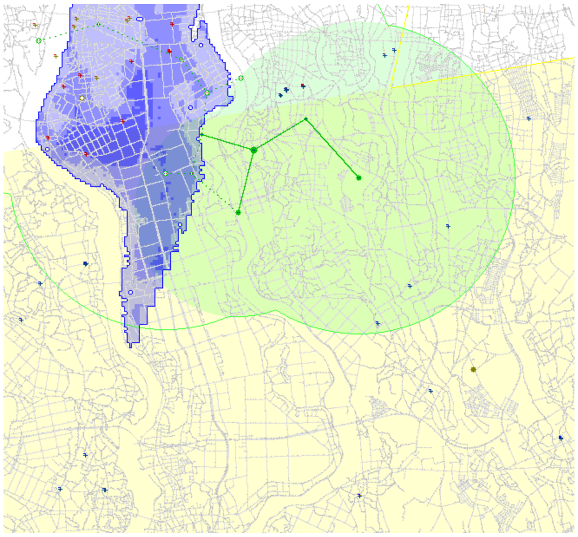

Fig. 3 c) *Communication failures and evacuees after flood expands* supply for the purpose of distinction. The navy-colored markers indicate the positions of evacuee agents. Before the flood occurs, both communication and power supply are functioning without any issues.

Fig. 3 b) shows the situation of the communication network and power supply areas after the flood occurs. From the levee breach point in the upper left of the figure, a flood occurs and inundates the power supply functions. The power supply functions cease operation, and the power supply in that area is lost. To show this operation, the yellow-colored area in the upper left of the figure becomes uncolored. At the same time, the base stations of the communication emulator that were receiving power from that power supply lose their power supply and stop functioning. The change from solid to dotted green lines indicates the base stations affected by this change. This demonstrates that the power supply functions in the power outage emulator stop operating due to the influence of the flood analysis results calculated by the flood simulator, and the base stations in the communication failure emulator are also affected by this impact. Such realistic failures can be reproduced by the emulators.

Next, we focus on the operation of the evacuation simulator in Fig. 3 b). In the flooded area in the upper left of the figure, the colors of the evacuee agents change to red or green. The red agents represent agents that have become unable to move due to the flood. When evacuation-related information is announced, the evacuee agents in the evacuation simulator start evacuating to the nearest shelter. When the evacuee agents reach the shelter, they are considered to have completed evacuation, and their display disappears. The green agents represent agents that have received evacuation-related information from the evacuation routes information system and have started evacuation behavior. Additionally, the red solid lines connected to the agents represent the evacuation routes received from the evacuation routes information system, and the orange lines represent the actual routes the evacuee agents are taking for evacuation. Some evacuee agents become unable to move due to the flood and are shown in red. Also, some evacuee agents receive evacuation-related information from the evacuation routes information system and start evacuation behavior.

Our explanation further moves to Fig. 3 c), where the flood has expanded. As the flooded area expands and the base stations themselves become inundated, the area where communication is possible becomes even narrower compared to Fig. 3 b). Although the area where power supply is possible remains unchanged, this system can reproduce the occurrence of communication failures solely due to the influence of the flood, making communication impossible. Furthermore, the navy-colored evacuee agents in the upper part are staying in areas where communication is possible but have lost power supply. Therefore, if they attempt to access information using means other than smartphones (e.g., television), it becomes difficult for them to obtain information.

As described above, in this paper, we were able to reproduce the interrelationship between communication failures and power outages through the construction of emulators and cooperative collaboration using the federation strategy. In particular, we confirmed that we were able to clearly reproduce communication failures caused by power outages and communication failures caused by inundation. In this performance test, many assumed values are used in the settings, so the placement of facilities and the number of affected people who can complete evacuation differ from reality. However, we believe that we were able to demonstrate the interrelationship between communication failures and power outages and reproduce to some extent the impact on evacuees.

5. CONCLUSIONS

In this paper, we proposed a power failure emulator designed to reproduce the interdependencies between communication failures and power supply during flood disasters. The emulator was developed as part of a larger system that employs a federation strategy to enable the coordinated operation of multiple simulators and systems, including a flood analysis simulator, an evacuation simulator, a communication failure emulator, and an evacuation route information system.

The power failure emulator models the behavior of ground-based substations and determines the power supply status in flood-affected areas. By communicating the state of power supply to the communication failure emulator via a federation bus, the power failure emulator effectively reproduces the impact of power outages on communication networks during flood events.

To evaluate the performance of the proposed system, we conducted a case study based on a hypothetical flood disaster in Joso City, Ibaraki Prefecture, Japan. The results demonstrated that the power failure emulator and the associated communication failure emulator operated as expected, accurately reproducing the interrelationship between power outages and communication failures during the simulated flood event. The system successfully captured the impact of these infrastructure disruptions on the information access of evacuee agents, as calculated by the evacuation simulator.

Although the performance test utilized many assumed values in its settings, resulting in differences between the simulated and real-world placement of facilities and the number of affected people who could complete evacuation, we believe that the proposed system effectively demonstrated the interrelationship between communication failures and power outages and reproduced, to a certain extent, the impact on evacuees.

The development of this power failure emulator and its integration into a larger, federated system represents a significant step towards creating more realistic and comprehensive disaster scenarios. By considering the interdependencies between power supply and communication networks during natural disasters, this research enables a more accurate analysis of the impact of communication failures on information access for affected individuals. This, in turn, can facilitate the development of more effective and resilient disaster response strategies that prioritize the needs of those most vulnerable during crisis situations.

Future work will focus on refining the emulator's settings and assumptions to more closely align with real-world conditions, as well as expanding the system to incorporate additional factors that may influence communication failures and power outages during disasters. By continuing to improve and build upon this research, we aim to contribute to the creation of smarter, more resilient cities that are better equipped to withstand the challenges posed by an increasingly uncertain future.

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REFERENCE

[1] Intergovernmental Panel on Climate Change Fifth Assessment Report (AR5), Retrieved from https://www.ipcc.ch/report/ar5/

[2] Milly, P. Christopher D., Wetherald, Richard T., Dunne, K. A., Delworth, Thomas L, Increasing Risk of Great Floods in a Changing Climate, Nature, Nature Publishing Group, Vol.415, No.6871, page514, 2002.

[3] United Nations Department of Economic and Social Affairs, 2018 Revision of World Urbanization Prospects, 2018.

[4] United Nations Office for Disaster Risk Reduction, 2018:Extreme weather events affected 60m people, Retrieved from https://www.undrr.org/news/2018 extreme-weather-events-affected-60m-people

[5] Yamagata, Y., Maruyama, H., Urban Resilience -A Transformative Approach-, Springer International Publishing, 2016.

[6]Gomes, T., Tapolcai, J., Esposito, C., Hutchison, D., Kuipers, F., Rak, J., de Sousa, A., Iossifides, A., Travanca, R., André, J., Jorge, L., Martins, L., Ugalde, P., O., Pašić, A., Pezaros, D., Jouet, S., Secci, S., Tornatore, M., A Survey of Strategies for Communication Networks to Protect Against Large-scale Natural Disasters, In Proceedings of 8th IEEE International Workshop on Resilient Networks Design and Modeling (RNDM), pp.11--22, 2014.

[7] Wang, J., Qiao, C., Yu, H., On Progressive Network Recovery after a Major Disruption, In Proceedings of IEEE INFOCOM, pp. 1925--1933, 2011.

[8] Comfort, L. K., Haase, T. W., Communication, Coherence, and Collective Action: The Impact of Hurricane Katrina on Communications Infrastructure. Public Works Management & Policy, Vol.10, No.4, pp.328--343, 2006.

[9] Fukuda, K., Aoki, M., Abe, S., Ji, Y., Koibuchi, M., Nakamura, M., Yamada, S., Urushidani, S, Impact of Tohoku earthquake on R&E network in Japan, In Proceedings of the Special Workshop on Internet and Disasters, 2011.

[10] Shunichi Koshimura, Satomi Hayashi, Hideomi Gokon, The impact of the 2011 Tohoku Earthquake Tsunami Disaster and Implications to the Reconstruction, Soils and Foundations, Vol.54, No.4, pp.560--572, 2014.

[11] O'Reilly, G., Jrad, A., Nagarajan, R., Brown, T., Conrad, S., Critical Infrastructure Analysis of Telecom for Natural Disasters, In Proceedings of 12th International Telecommunications Network Strategy and Planning Symposium, pp.1--6, 2006.

[12] Jiménez, D., Barrera, J., Cancela, H., Communication Network Reliability Under Geographically Correlated Failures Using Probabilistic Seismic Hazard Analysis, IEEE Access, vol. 11, pp.31341--31354, 2023.

[13] Mauthe, A., Hutchison, D., Çetinkaya, E. K., Ganchev, I., Rak, J., Sterbenz, P.G., J., Gunkelk, M., Smith, P., Gomes, T., Disaster-resilient Communication Networks:

Principles and Best Practices, In Proceedings of the IEEE, Vol.104, No.6, pp.1178--1196, 2016.
[14] Hiroi, K., Kohiga, A., Fukaya, S., Shinoda, Y., Disaster Victim Impact Analysis System using a Communication Failure Emulator、In Proceedings of International Workshop on Infomatics 2023, pp.181-188, 2024.
[15] Kwasinski, A. Effects of Notable Natural Disasters from 2005 to 2011 on Telecommunications Infrastructure: Lessons from On-site Damage Assessments. In Proceedings of 2011 IEEE 33rd International Telecommunications Energy Conference, pp.1--9, 2011.
[16] Verschuur, J., Fernandez, A., Mühlhofer, E., Nirandjan, S., Borgomeo, E., Becher, O., Voskaki, A., Oughton, E., Stankovski, A., Greco, S., Koks, E., Pant, R., Hall, J., Quantifying Climate Risks to Infrastructure Systems: A Comparative Review of Developments Across Infrastructure Sectors, PLOS Climate, 2024.
[17] Wang, S., Reed, A. D., Vulnerability and Robustness of Civil Infrastructure Systems to Hurricanes , Frontiers in Built Environment, Vol.3, 2017.
[18] Hiroi, K., Inoue, T., Akashi, K., Yumura, T., Miyachi, T., Hironaka, H., Kanno, H., Shinoda, Y., ARIA: Interactive Damage Prediction System for Urban Flood using Simulation and Emulation Federation Platform, In Proceedings of the 2019 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2019 ACM International Symposium on Wearable Computers, pp.284--287, 2019.
[19] Hiroi, K., Kohiga, A., Fukaya, S., Shinoda, Y., An Orchestrator Framework for IoT-based Disaster Prevention Simulation, In Proceedings of the 2016 IEEE SENSORS, pp.1--4, 2023.