Portable SIP4D: An Information Sharing System for Disaster Response Agencies in Network-Disconnected Areas

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***Abstract*—During large and diverse natural disasters, it is necessary for the Government Disaster Response Headquarters to quickly grasp the damage situation and for ministries, agencies, local governments, and designated public institutions to collaboratively respond to the disaster. The National Basic Disaster Management Plan of Japan [1] stipulates the use of the Shared Information Platform for Disaster Management (SIP4D) as a system for collecting and sharing information. However, since the SIP4D system's server is cloud-based, disaster response organizations operating in environments where the communication infrastructure is damaged and unable to connect to the internet during large-scale disasters face challenges in accessing SIP4D, uploading information, and obtaining the latest status. This paper proposes a Portable SIP4D that enables information collection, viewing, analysis, registration, and sharing using SIP4D even if public communication networks are disrupted during large-scale disasters. The implementation of its functions and verification of its operation through experiments are also discussed.**

I. BACKGROUD

In scenarios of large-scale disasters such as the Nankai Trough Megaquake, it is expected that existing communication infrastructures will suffer extensive damage, rendering mobile phones and fiber-optic internet connections to homes and businesses unusable for extended periods[2]. Even under such circumstances, it is essential for units such as fire departments, police, and self-defense forces active in the disaster area to conduct organized activities within their respective organizations. While these units utilize their private communication methods, such as digital convenient radios (DCR), fire department radios, and police radios, these primarily voice-based communication tools can cause interference when brought together from organizations nationwide, hindering effective information sharing within and between organizations. Traditionally, to facilitate inter-organizational information sharing, each organization sets up its disaster response headquarters in the same location, using large maps, bulletin boards, and whiteboards to post information collected by each organization for direct information sharing and decision-making on-site. In recent years, Japan has established the use of the Shared Information Platform for Disaster Management (SIP4D) [3][4] to support information sharing within disaster response headquarters, as outlined in the nation's Basic Disaster Management Plan [1],[5]. Various types of disaster-related information are centrally managed here and are utilized by the Government Disaster Response Headquarters, which consists of prefectural governments and ministries, to grasp the overall damage situation and make decisions on appropriate resource allocation. However, in large-scale disasters where mobile phones and the internet are unavailable, access to these cloud-based systems becomes impossible.

This paper introduces the Portable SIP4D, which we propose to enable the use of SIP4D even when public communication networks are disrupted. Section II reviews related works on existing disaster information communication systems. Section III explains the concept, components, and architecture of Portable SIP4D. Section IV presents its implementation, and section V presents the verification of the implemented system with the results of its operation. Finally, section VI concludes the paper.

II. RELATED WORKS

In the event of a large-scale disaster, the NRCC (National Response Coordination Center) under FEMA in the United States manages and coordinates responses to major disasters and emergencies. Based on the guidelines and standards of the National Incident Management System (NIMS) [6], all levels of government (federal, state, local, tribal), non-governmental organizations, and the private sector cooperate to respond to disasters in a unified manner. Many tools are used in this process, but primarily the Common Operation Picture (COP), which overlays various information on GIS, is utilized. In Europe, the Common Emergency Communication and Information System (CECIS) [7] is used to enhance information sharing and collaboration during disasters and emergencies. This system functions as a core ICT platform that facilitates information sharing and decision-making among EU member states, participating countries, and the EU's emergency response agencies. There are several open-source disaster management systems, such as the Next-Generation Incident Command System (NICS) [8] developed by MIT and Sahana [9]. However, all disaster management systems are cloud-based systems that assume Internet connectivity, so securing communication with the internet is a necessary part of their operation. In particular, during large-scale disasters where communication networks are disrupted, emergency measures such as satellite communication or private wireless communication (including ad-hoc networks) are required to restore network functionality, and specialized knowledge is necessary for field operations.

In Japan, similar systems include Shared Information Platform for Disaster Management (SIP4D) and SOBO-WEB. SIP4D, operated by the National Research Institute for Earth Science and Disaster Resilience, functions as a cross-organizational pipeline for disaster information. From April 2024, the Cabinet Office for Disaster Management has started operating a new comprehensive disaster information system called "New Comprehensive Disaster Information System: SOBO-WEB" [13]. This system includes the functions of SIP4D, allowing search and viewing of information incorporated into SIP4D. It also enables the direct upload of information collected by prefectures and designated public institutions. Furthermore, all 1,741 municipalities in Japan can view information aggregated and visualized on SOBO-WEB. SIP4D continues to be used as an interface for incorporating information into SOBO-WEB. However, SIP4D and SOBO-WEB are cloud-based services connected via the Internet, and they become unusable when the Internet connection is lost.

One application platform technology that allows services to continue operating even when disconnected from the internet is "Ditto" [10]. This system, designed as a smartphone application platform, uses a NoSQL distributed database for data synchronization and incorporates device-to-device communication via Bluetooth or Wi-Fi Direct between smartphones. This enables the construction of ad-hoc networks among smartphones and allows data synchronization even when not connected to the internet. Using this platform, applications on multiple smartphones can share information by synchronizing data via direct communication between devices, even without internet access. However, it is not realistic to synchronize and share all disaster-related information generated by various organizations nationwide during a large-scale disaster using smartphones alone. Therefore, the design should involve edge servers that prioritize data synchronization, sorting, and integration based on decision-making.

The proposal for "Portable SIP4D" is groundbreaking in its aim to create a decentralized disaster information system that does not rely on cloud connectivity. In traditional disaster response systems, the use of cloud services was essential, even during disasters, which made internet access a prerequisite. However, the ability to provide a system that continues to share information efficiently, even when the internet is unavailable, is crucial for disaster response in the field. The proposed "Portable SIP4D" allows on-premises servers to communicate directly with each other, synchronizing information without the need for an internet connection. This enables the system to operate reliably and maintain data consistency in environments with limited network infrastructure. As a result, critical disaster-related data can continue to be shared even when communication infrastructure is compromised during a disaster. Furthermore, this decentralized system operates autonomously and allows synchronization in an ad hoc network environment, making it distinct from existing edge computing solutions. By synchronizing between devices, while maintaining data consistency, this system ensures that important information can be shared swiftly, greatly improving the efficiency of disaster response. With the realization of this technology, information sharing for disaster response will become faster and more efficient, leading to significant improvements in decision-making and support activities at disaster sites.

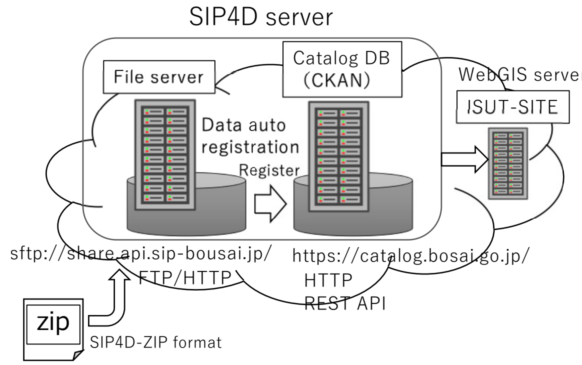

Fig. 1. SIP4D system overview.

III. Portable SIP4D

A. Overview of SIP4D

Before explaining the proposed Portable SIP4D, the system overview of the SIP4D, which serves as its foundation, is described. When a large-scale disaster occurs, disaster-related information is continuously transmitted from various organizations, such as national ministries and agencies, local governments, and designated public institutions. SIP4D was created to centralize and standardize this information at one location instead of each organization individually collecting information, allowing information unification and reuse. By aggregating information into SIP4D, smooth information sharing is facilitated among organizations involved in disaster response, such as ministries, local governments, and public institutions. The detailed specifications of SIP4D are publicly available, with its main structure shown in Figure 1.

The main functions of SIP4D include a file server function, a catalog database function, an automatic data redistribution function, and a data visualization function. The file server function primarily provides file upload and download services, accessible via several protocols such as ftp/sftp, http/https.

There are two types of accounts for accessing the file server: upload-only accounts, issued to ministries, designated public institutions, and local governments providing data to SIP4D, and download-only accounts. When uploading information to SIP4D, it is recommended to use the SIP4D-ZIP format, a zip format for archiving files with its meta information. The information provided (file formats are individually defined for each category of information), along with a geojson file describing metadata such as file format and the type of information, is bundled and archived in a zip format. Inside SIP4D, each user has a dedicated folder for uploading SIP4D-ZIP format files. When a SIP4D-ZIP file is uploaded, the automatic redistribution function reads the file and automatically registers the data in the catalog database and redistributes it based on the metadata described in the geojson file, making it available in an appropriate form. Users search for and download the required data from the various archived files in SIP4D using the catalog database function. The catalog database utilizes the open-source CKAN [11]. Users can access the CKAN server via the CKAN API or through a standard browser, perform keyword searches to find the desired data, and download it. Since these data are provided as-is from the source, users need to visualize the downloaded files on their end. For visualizing various data aggregated within SIP4D on a map, the ISUT SITE is available. Operated by the Disaster Information Support Team (ISUT), organized mainly by the Cabinet Office Japan for Disaster Management, the ISUT SITE is a web site for visualizing SIP4D information and is intended to be used as a means of information sharing among organizations gathered at the Government Disaster Response Headquarters. For more details, refer to reference [12].

B. SIP4D-Xedge

SIP4D-Xedge [14] is a WebGIS application designed for disaster response organizations to share information not only within their own organization but also across multiple organizations operating in the field. It includes features for searching and visualizing information aggregated in SIP4D on a map, inputting field information, and uploading inputted information to SIP4D. The software for this WebGIS application is constructed using open-source software and is publicly available for anyone to download. Once installed, SIP4D-Xedge can be operated on a server, allowing for customization of the screen configuration to suit the operation of each organization. The intended users are organizations involved in disaster response activities using SIP4D information (e.g., prefectures, municipalities) and disaster response operational units such as police, fire departments, and self-defense forces working in the disaster area. By connecting to the SIP4D main server on the internet (hereafter referred to as the SIP4D main), users can search, download, and overlay information from SIP4D on a map using SIP4D-Xedge. However, in environments where public communication networks are disrupted, SIP4D-Xedge cannot search for data on the SIP4D main, download the necessary information, or upload registered information to SIP4D even if SIP4D-Xedge is operated on-premise and can be used without the Internet.

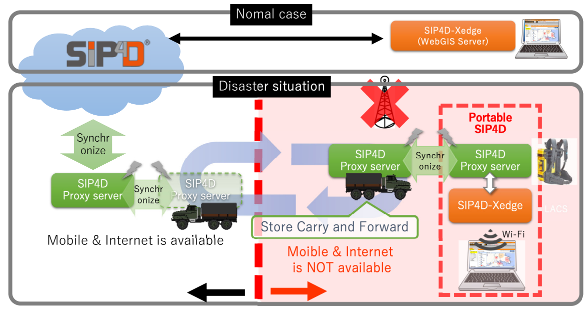

Fig. 2. Overview of Portable SIP4D.

C. Overview of Portable SIP4D

The authors have proposed Portable SIP4D, which enables disaster response organizations working in the field to search, analyze, and visualize information necessary for decision-making using SIP4D-Xedge, and share field-collected information which includes large amounts of data such as photos and video images with other organizations even when public communication networks are disrupted and internet connection or SIP4D main connection is unavailable due to large-scale disasters. The overview of Portable SIP4D is shown in Figure 2.

Portable SIP4D consists of multiple SIP4D proxy servers (hereafter referred to as proxy servers) and a system consisting of on-premise servers running SIP4D-Xedge. The proxy servers operate file server functions and catalog database functions, along with DNS servers and a suite of software for automatically recognizing connected peers and synchronizing files and databases. When connected to the SIP4D main server, the proxy servers continuously synchronize the CKAN server's database and all files uploaded to the SIP4D main server locally. When the proxy servers detect each other through close-range communication such as Wi-Fi, they automatically synchronize their differential data (catalog database and files).

When operating in areas where public communication networks are disrupted, these proxy servers and servers running SIP4D-Xedge are brought to the site. From the perspective of SIP4D-Xedge, the proxy servers act as if they are the SIP4D main server, allowing the usual operations of searching, analyzing, and visualizing information on SIP4D and uploading field-collected information to SIP4D. However, once disconnected from the internet, the information within the proxy servers is only up-to-date up to the last connection to the SIP4D main server, and any information uploaded to the proxy servers in a disconnected state will not be uploaded to the SIP4D main server. Consequently, there will be an increasing differential between the SIP4D main server and the proxy servers operating in network-disconnected areas. To update this differential information, another proxy server mounted on a mobile unit travels between internet-connected areas and network-disconnected areas, synchronizing differential infor-

Fig. 3. SIP4D Proxy hardware overview.

TABLE I
SPECIFICATIONS OF SIP4D PROXY SERVER

CPU Board	GateWorks GW6304 OS: Ubuntu 20.04 CPU: Cavium Octeon TX Quad Core CPU @1.5GHz RAM: DDR3 2GBytes Storage: SSD 500GBytes
Wi-Fi interfaces	SX-PCEAN2 x1 with implemented IEEE802.11ai WM-S150UN x1
DCR	XEDC35M 351.2MHz - 351.38125MHz (30CH) 4-FSK, 4.8kbps connected with RS-232C
LTE	WP7605 IoT Module
Ethernet	2x 1000base-T
Battery	Murata Fortelion 537Wh Operation time: 17.9h
GPS	JCA002
Weight	19kg
Size	470 x 357 x 176mm

mation between the SIP4D main server and the proxy servers in network-disconnected areas via close-range communication. This allows information uploaded to the proxy servers to be uploaded to the SIP4D main server and the updated information from the SIP4D main server to be delivered to the proxy servers in network-disconnected areas through the mobile proxy server. This mechanism ensures the use of SIP4D even in areas where communication networks are disrupted.

IV. IMPLEMENTATION

A. SIP4D Proxy server configuration

The appearance of the device used as the proxy server is shown in Figure 3, and its specifications are listed in Table 1.

The device is equipped with two wireless LAN interfaces, one operating as an Access Point (AP) and the other as a Station (STA). Hostapd is used for AP operation, running in WPA2 Enterprise mode with Radius authentication. Additionally, the Radius server function operates within the device, allowing user-specific connection control with username and password authentication for wireless LAN connections. For file synchronization, the open-source software syncthing [15] is used to automatically detect and connect peers, detect differential files within the synchronized folders, and perform synchronization. The files transmitted during synchronization are compressed, allowing efficient file transfer over limited communication bandwidth. For file synchronization with the SIP4D main server, the built-in FTP of SIP4D is utilized, with the open-source FTP client lftp used for periodic synchronization. For the catalog database, while it is possible to use CKAN's built-in CKAN Remote Harvest extension API, the implementation in this project uses the distributed database synchronization function also used in NerveNet [16][17], providing a catalog database function with the same API as the CKAN server. This enables local synchronization of the catalog database information via the API with the SIP4D CKAN server, achieving the same operation as the SIP4D CKAN server.

B. SIP4D-Xedge Configuration and Installation

SIP4D-Xedge is provided as a docker container. Users operate docker desktop on their notebook PCs (Windows) used for data input and run the SIP4D-Xedge container. This container does not include map data, but in Japan, numerical maps freely available online from the Geospatial Information Authority of Japan can be downloaded locally to the PC, allowing map data to be displayed even in an offline environment where the internet is disrupted.

1) Operation between SIP4D proxy and SIP4D-Xedge: To operate SIP4D-Xedge in conjunction with a proxy server for SIP4D, the PC running SIP4D-Xedge is connected to the proxy server via wireless LAN. The proxy server runs DHCP, and the PC is configured so that when an IP address is automatically assigned via DHCP, the DNS server and default gateway are also set to the proxy server's address. When accessing localhost from the PC's browser, the screen for SIP4D-Xedge running in a local Docker container is displayed. Additionally, the configuration is set so that DNS requests for the domain names of SIP4D's FTP server and CKAN server return the proxy server's IP address. This allows SIP4D-Xedge to operate as if it is accessing the main SIP4D server without requiring any special modifications, settings changes, or alterations to the SIP4D-Xedge software. However, while it is generally recommended to use encrypted communication channels like sftp or https for accessing the main SIP4D file server or CKAN server, which involve SSL encryption, this requires installing the certificates and private key information

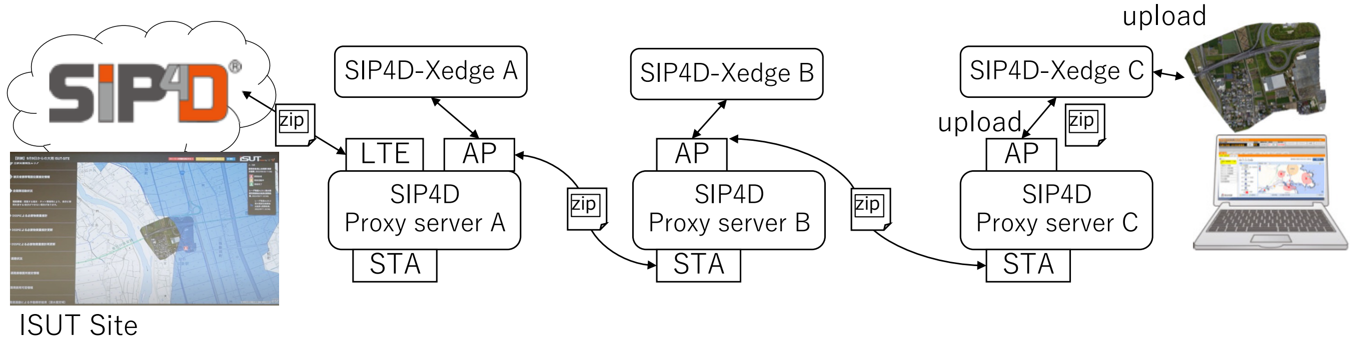

Fig. 4. Experimental setup overview.

used on the main SIP4D server onto the proxy server as well. For this instance, the operation verification was conducted using ftp and http methods, which do not involve encrypted communication channels.

V. Performance Evaluation in a Controlled Environment

To evaluate the performance of Portable SIP4D, we conducted an experiment in a controlled environment. The experimental setup is illustrated in Figure 4.

In this experiment, we prepared three proxy servers and three SIP4D-Xedge instances. Two proxy servers and two SIP4D-Xedge instances were placed in an environment without internet access, simulating a disaster site. One proxy server and one SIP4D-Xedge instance were placed in an environment with internet access, simulating an operational headquarters. Additionally, we prepared a mobile unit capable of moving between the two environments to facilitate data synchronization.

Proxy servers and SIP4D-Xedge instances were deployed in a remote area, simulating a disaster site. A mobile unit equipped with a proxy server traveled between the disaster site and a command center with internet access. Field information was collected, analyzed, and shared using Portable SIP4D.

A. Validation of the system basic operations

Assuming the situation where the public telecommunications network has been disrupted, data upload tests were operated using three proxy servers and laptop PCs.

1. Data retrieval and download operation from SIP4D

We verify that SIP4D-Xedge can display the list of data archived in SIP4D and the proxy server, identify the data you want by keyword search, download the data, and add the data to the GIS.

2. Data upload operation to SIP4D

Upload information from the disaster response site to SIP4D. As an example, when a layer is added to the map and the area showing the flooded area is drawn with polygons and saved, SIP4D-Xedge periodically tries to upload the saved data to the SIP4D main server. We will verify whether this uploading operation to the proxy server is successful or not. In addition, the photos of the disaster area taken by a drone at the disaster site from the sky are processed into an ortho-image on-site and uploaded using SIP4D-Xedge. The ortho-image is then tiled and displayed as a layer on the map. After that, when the upload operation to SIP4D is performed from the web screen, the data is converted to a dedicated data format (SIP4D-ZIP format) and then uploaded to the proxy server. This upload has also been verified to be normal. Furthermore, we will verify that information is transmitted in a multi-hop manner to another proxy server that has an Internet connection, using direct communication between the proxies and the data synchronization function, and that the proxy server that has an Internet connection automatically uploads the file to the SIP4D main server.

As a result of the operation verification, it was confirmed that the access and operation from the laptop PC to SIP4D-Xedge and the operations (1) and (2) from SIP4D-Xedge to the proxy server functioned without any problem.

B. Performance Evaluation of File Synchlonization

In order to verify the bucket relay transmission by synchronization of files using the wireless LAN on approach communication, we conducted a verification using a configuration with three proxy servers as shown in Figure 4. In this case, all three proxy servers were placed in the same room, and the wireless LAN on the STA side of the proxy servers was stopped to create an environment in which the three servers were not connected to each other wirelessly. Then, the STA-side wireless LAN of proxy server C is activated and connected to the second AP-side wireless LAN of proxy server B to verify the file synchronization function. After the file synchronization is completed, the STA-side wireless LAN of proxy server C is stopped and disconnected, and then the STA-side wireless LAN of proxy server B is activated and connected to the AP-side wireless LAN of proxy A in the same manner to verify the operation of the file synchronization function.

Figure 5 shows a time-series diagram of the operation of each proxy server for each event. The figure shows that service discovery starts 2 to 3 seconds after IP allocation by DHCP is completed after connecting to the wireless LAN, then the neighborhood node is detected within 3 to 6 seconds, and after that, the exchange of the file list of differences and

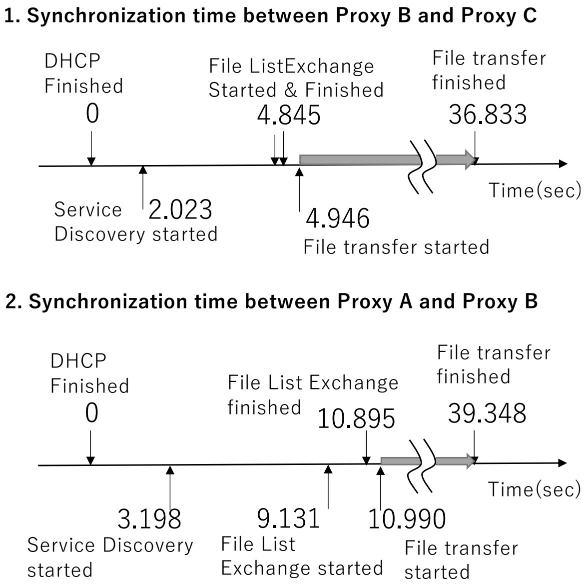

Fig. 5. Elapsed time from IP address allocation by DHCP to completion of file synchronization process.

the transmission of the difference files starts immediately after the detection. The total synchronization time was 36.8 seconds between proxy servers C and B, and 39.3 seconds between proxy servers B and A. The above results indicate that information synchronization between proxy servers can be completed in less than one minute for 100Mbytes of data and demonstrate that this method can significantly reduce human workload and time compared to manual data transfer via USB memory sticks, which could be considered as an alternative.

VI. Conclusion

In this paper, we propose "Portable SIP4D," which enables the collection, viewing, analysis, registration, and sharing of disaster information using the "SIP4D" information pipeline, even in environments where internet connectivity is lost due to damage to communication infrastructure from large-scale natural disasters. We also implemented its functions and validated its operation in experiments. The results showed that data transfers of around 100 MB could be completed in less than a minute, demonstrating the potential to significantly reduce the time and human effort required during disaster response. This data size is equivalent to a single orthophoto image generated from aerial footage taken by drones covering several hundred square meters at a disaster site. In the experiment, we connected a WebGIS server called "SIP4D Xedge," which is used at actual disaster sites, to Portable SIP4D, uploaded data, and verified that data could be transmitted via multiple Portable SIP4D devices. Ultimately, the data was visualized on the main SIP4D server without human intervention.

However, what the current Portable SIP4D has achieved is the transfer of information between the cloud-based SIP4D and the disaster site. There are still some unimplemented parts required for sharing information between different bases at the disaster site, and development on this is currently underway. Moving forward, we plan to continue increasing the capabilities that the SIP4D proxy server can handle and extend the system so that the information registered at disaster sites can be utilized locally within the disaster area before being transmitted to the cloud.

Acknowledgment

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