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ESTABLISHING A MESH COMMUNICATION BACKBONE FOR DISASTER MANAGEMENT: PROOF OF CONCEPT

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ABSTRACT
This article addresses the establishment of a mesh communication backbone to facilitate a near real-time and seamless communications channel for disaster data management at its proof of concept stage. A complete function of the data communications is aimed at the input in near real-time of texts, photos, live HD videos of the incident to originate the disaster data management of a military unit responsible for prevention and solving disaster problems and in need of a communication backbone that links data from a Response Unit to an Incident Command Station. The functions of data flow were tested in lab and at fields. Texts encompassing registered name, latitude, longitude, sent time were sent from concurrent 6 responders. Photos and full HD live videos were successfully sent to a laptop Incident Command Station. However, a disaster database management system was needed to store data sent by the Response Unit. Quantitative statistics were suggested for a more substantial proof of concept and subject to further studies.

Keywords: Disaster management**,** proof of concept**,** mesh communication**,** communication backbone

1. INTRODUCTION

Shannon and Weaver (1949) invented the model of communication, known as the “Shannon and Weaver model of communication”, to get a message from one point to another in discovering how communication messages could be converted into electronic signals most efficiently, and how those signals could be transmitted with a minimum of error. A reliable communication backbone is regarded as a crucial infrastructure to the interface and integration of standard electronic devices for the message transmission and to the better situation awareness of the destination. Ran and Nedovic-Budic (2016) reported the integration of spatial planning with flood-risk management to gain prominence as an approach to mitigating the risks of flooding. The approach was reported to be impeded by the absence of easy access to integrated and high-quality information, and the technologies and tools to use information. To facilitate the integration, a Spatially Integrated Policy Infrastructure (SIPI) was conceptualized for an integrated spatial planning with flood-risk management should encompass three elements: (1) data and information, (2) decision support and scientific analysis tools, and (3) access tools and protocols.

Figure 1: An operational view of the mesh communication backbone

Kumsap (2018) proposed the concept of mobile C^{4}ISR (Command, Control, Communication, Computer, Intelligence, Surveillance, Reconnaissance) system for disaster relief. The preparedness could be achieved by UAV terrain modeling over a frequently flooded area in normal situation. The product of image acquisition e.g., orthoimages, digital terrain models and updated ground survey, is integrally developing a platform to host data and information from reconnaissance and emergency response for situation awareness in common operating picture (COP). Activities reported in form of texts, photos, video clips as far away as 150 kilometers from the mobile C^{4}ISR are live broadcast by an Unmanned Aerial Station hovering at 3,000 meters above the Response Unit. Kumsap et al (2017) explained the project in which the mobile C^{4}ISR was implemented in the Defence Technology Institute that implemented the integration of communications, military simulation and training, and unmanned vehicle technologies for the emerging situation awareness to be viewed from the COP.

Back in 2012, the Royal Thai Government, in conjunct-tion with the World Bank and other development partners, undertook the rapid assessment of the impact of the floods in 26 of the 66 affected provinces. It provided recommendations for resilient recovery and reconstruct where the continuation of broadcasting to all communities before, during and after disasters should be ensured. In this respect, it was suggested to improve communication from the National Early Warning Center to the broadcasters and engage broadcasts around disaster risk reduction. Such radio community could provide communications in disaster preparedness, disaster response and relief and post-disaster communications in accordance with their community needs. In Ali et al (2014), they proposed a novel Integer Linear Programming (ILP) optimization model to reconstruct the optimal connected mesh backbone topology with a minimum number of links and relay nodes which satisfies the given end-to-end QoS demands for multimedia traffic and identification of extra resources, while maintaining redundancy. Although the reconstructed optimized backbone mesh topology also maintained the specific level of redundancy, the study only considered single-path routing between source and destination pairs. The work should be further extended to multipath routing between source and destination pairs. Wan and Zlatanova (2016) presented an approach for using a multi-agent system for navigating one or multiple responders to one or multiple destinations in the presence of moving obstacles. A set of software agents was designed and developed to support the spatial data processing and analysis involved in the routing process. There still needed considerations for future developments, one of which was the real time positions of the relief vehicles. Because the communication infrastructure may not be available or work properly during a disaster response, a decentralized method is needed to allow negotiations among different users.

In Khaliq et al (2019), a Vehicular Ad Hoc Network (VANET) was used to carry out the rescue operation, as it did not require any pre-existing infrastructure. The work proposed and validated an effective way to relay the crucial information through the development of an application and the deployment of an experimental TestBed in a vehicular environment. The performance of the system was analyzed in terms of response time, successful data transmission, and delay. The proposed prototype application was examined through experimental validation by fetching the user message from the GPIO pins of the Raspberry Pi through serial communication, and the geographical coordinates of the user from the GPS sensor. This study, along with the implemented TestBed, provided an effective way to exchange crucial information amongst volunteers and staff working in dire situations, such as that of a post-disaster rescue-and-relief operation. Since fast and reliable communication plays a key role in such scenarios, this work offered a viable solution that can be implemented by the concerned authorities at times of catastrophic disaster. Wireless ad hoc networks such as mobile ad hoc networks, wireless sensor networks and wireless mesh networks were the promising alternatives in situations of disaster communication. Channa and Ahmed (2019) presented a survey of the proposed emergency response communication frameworks and the potential security services required by them to provide reliable and secure information exchange during emergency situations. The majority of the proposed schemes lacked the security services required for reliable and secure information exchange. The key security services included privacy, data integrity, authentication, key management and access control.

This article addresses an experimental proof of concept of the establishment of a mesh communication to form a near real-time, crucial and seamless communications channel for disaster data management that may be unavailable of malfunctioned due to disaster incidents for the Mobile Development Unit 31 (MDU 31) located at Northern Nan province. The MDU 31 is one of five Units under the Third Armed Forces Development Command at Chiang Mai province (the 3rd AFDC). Under the supervision of the 3rd AFDC, the MDU 31 is responsible for prevention and solving disaster problems and humanitarian assistance. The MDU 31 response units are dependent upon a commercial and costly network coverage for data communications and in need of the communications backbone that establishes freely accessible yet secure data links from the Response Unit to the Incident Command Station. Therefore, the objective of this current work is to report proof of concept of the establishment of the mesh communication backbone for disaster data management by experiments in laboratory and at field in support of decision making processes upon the disaster management of the MDU 31.

2. SUB-SYUSTEMS OF MESH COMMUNICATION BACKBONE

To closely resemble the theory by Shannon Weaver model and adopt the data flow proposed by Kumsap (2018), the operational view of the mesh communications backbone was initiated to facilitate the injection of disaster data including geo-tagged photos, geo-locations and video clips on the data flow. The Response Unit injects data into the flow to start the mission while management at the Command and Control station receives information to make a decision and feeds the command back to the data communication flow. Each node of operation is functional as follows:

2.1. Response Unit

A response team of 12 military officers is equipped with 6 smartphones to feed in photos, request texts, map locations and video clips to the flow with the man pack as data portal. The 2 Mbps data throughput, 2W Tx power man pack receives GPS signal, sends .txt, .csv log files in real time and accommodates IP camera type video signals. This originates the disaster management with the man pack joining the network to act as the portal of data input.

2.2. Unmanned Aerial Station

Apart from the radio device for flight control, the unmanned vehicle is equipped with a two-way communication, 1.4 – 2.4 GHz, 10W transmission power, 2-8 Mbps receiving radio broadcast device. It is an aerial node to relay the data at approximately 9,000 feet above or away from the Response Unit. The communication is alive at 30 – 150 kilometers from the

Incident Command Station (see Figure 1). The unmanned vehicle is gasoline – fueled and capable of 6 hour endurance.

2.3. Incident Command Station

The mobile command station is now being developed to house high-performance computational work stations and servers. A grid antenna is attached to receive and transmit data into and out of a 10 Mbps bandwidth, 1.4 – 2.4 GHz frequency and 10W Tx/Rx device. The modeling, analysis and simulation of the data received from the Response Unit is performed at this node that is stationed remotely up to 150 kilometers away from the incident area and with easy access to an active communication channel.

2.4. Command and Control Station

This data destination is equipped with capacity where intelligence is produced upon the information visualization and situation awareness of 3D common operating pictures. A decision support system with serious game engine is the back office of this station and planned to take shape in Thailand's 2020 fiscal year. Standard operating procedure (SOP) of damage assessment, forcible entry, victim search, rescue and saving life, and evacuation is product of the *Station*'s disaster management and sent back to the response team in form of optimum routes and SOP.

3. DATA INJECTION AT THE RESPONSE UNIT

Kumsap et al (2018) proposed the enhancement of disaster preparedness and response by setting up the system to support the disaster recovery team in case of wide-area communication blackout caused by flooding, earthquakes or any large-scale accidents. The notion was based on today system communications that are digital and IP-based with a wide variety of data communications such as voice, video or other bandwidth-greedy information, occupying lots of bandwidth ranges while requiring stable transmission. Mesh topology was adopted to relay data between each node, thus improving the system latency. The backbone was regarded as an infrastructure that needs a portal to input disaster data. The data including geo-tagged photos, geo-locations and video clips was used to start the disaster report from an incident site, i.e., being injected to the Response Unit, being relayed at the Unmanned Aerial Station, being analyzed at the Incident Command Station, and being managed under a decision making process at the Command and Control center. This current approach promises integral technologies such as the unmanned aerial station for signal relay, man pack radio networked with smartphones for response unit, mobile incident command for spatial analysis and networking fielded missions with the command and control station. The implementation of the proposed methodology can be seen on Mesh Backbone diagram of Figure 2.

At Network diagram of Figure 2, six smartphones with mobile application for disaster report are to inject data including texted report in .txt or .asci; geo-tagged photos in .jpeg, .tif or .geotif; and video clips in .flv, .avi, .mov, .wmv or .mp4**.** into a rugged notebook for storage via a wireless access point connected with the man pack. Designed and implemented specifically for the military performing task at the Response Unit, this data input portal was exclusive for the military Response Unit. The situation awareness and common views of the command center and the response team demand a closed system of the backbone. However, the Command and Control Station would manage in-coming data from the public and can be reached by the public in general for the purpose of disaster response or public disaster report. The data is transmitted to the Tx/Rx device onboard the aerial station within the 9,000 foot range of the man pack. The data received at the Incident Command station is further analyzed in an image and video processing server environment. The result information is sent to the Command and Control station through an existing communication infrastructure. Decision making upon damage assessment, forcible entry, victim search, rescue and saving life, and evacuation is sent back to command the mission in reverse of the previously explained data flow.

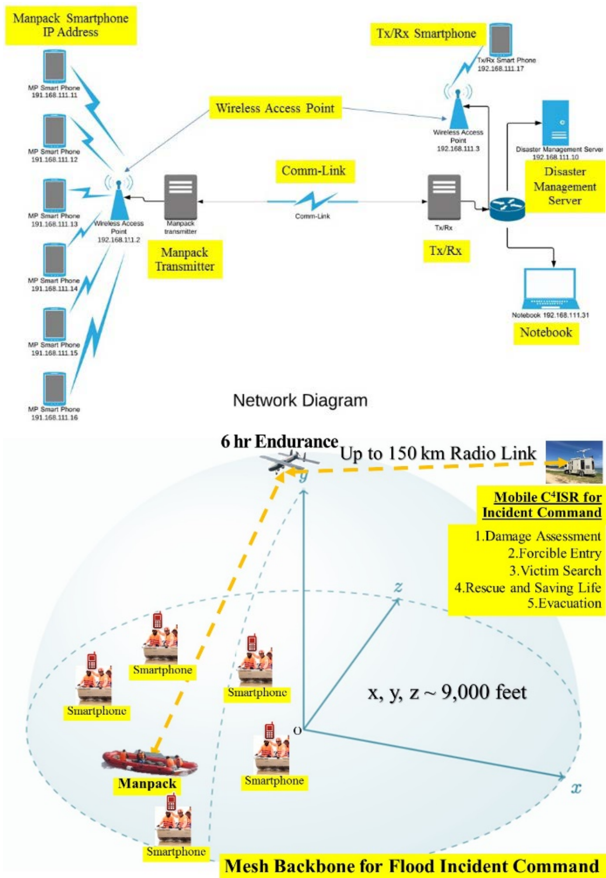

Figure 2: Network diagram for conceptual design and mesh backbone for operational design

4. EXPERIMENT ON DATA INJECTION TO THE BACKBONE

In order to proof the concept, a few experiments were carried out to test a simplified architecture extracted from the data flow diagram in a laboratory and at fields with and without a flood incident. However, the test conducted in the laboratory was with the 6 smart phones and without the unmanned relay station. The field tests were with to send texts of map coordinate, geo-tagged photos, and a live full HD video to the notebook that acted as the Incident Command Station.

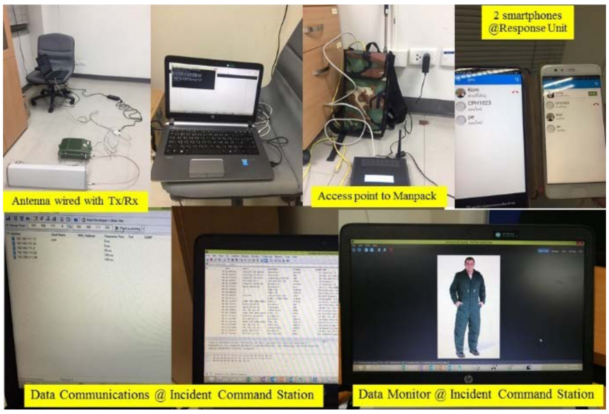

Figure 3: Rough interface of the network backbone

4.1. Laboratory Test

In reference to the Network Diagram of Figure 2, the hardware was networked as illustrated in Figure 3. The smartphones installed with a mobile application were used to send texts, photos and video clips with one another via an access point wired with the man pack through to the notebook as a data monitor at the Incident Command Station. Data communications between the smartphones and the notebook acting as a workstation were tested at as far as 50 meters. All the smartphones were used to concurrently send texts, photos and full live video to proof the 24 Mbps bandwidth handling of the man pack. Live chats were also tried among the smartphones and between each of them and the notebook, see the lower right inset of Figure 3.

4.2. Field Tests

Normal Situation Testbed. The system was setup at various locations in the Northern part of Thailand. A generator (see the upper left inset of Figure 4) was used to produce power for the Tx/Rx device, antenna and the notebook that managed to chat live with the Response Unit. The Incident Command Station was mobile and compact. Map locations of an activity were periodically reported back to the station in 10 second interval with the most recent being plotted on the map (see the lower left inset of Figure 4). Photos were sent at will as far as 2 kilometers between the man pack and the Incident Command (see the lower right inset of Figure 4). Two hundred meters were the distance that the smartphone being used as the video and photo source was visible to the man pack. The communications were active regardless of rough and vegetated terrain provided that the antenna was directed toward the Response Unit in operation. The structured text to send report from the response unit is now being developed in the lab.

In addition, the system was tested for functions of sending texts, photos and video at the MDU 31. The man pack and the Tx/Rx device acted as nodes for the communications backbone to receive and send the communicated data from and to one another, forming a near real-time, crucial and seamless communications channel.

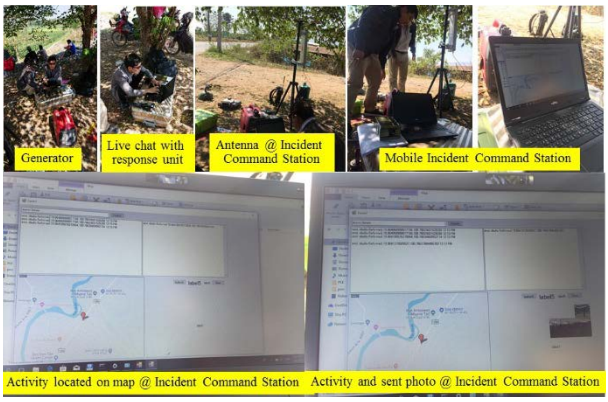

Figure 4: Configuration of the established backbone

Figure 5: Field test results of sending texts, photos and video

Therefore, this is regarded as prime contribution to disaster data management that keeps the Response Unit and the Incident Command Station stay connected due to the unavailability and malfunction of communications due to disaster incidents for the MDU 31. The six smartphones were connected to an access point that was attached to and powered by the man pack. The response team of 6 persons moved as a group in order to stay at least 50 meters away from the access point for data communications. A text formatted in Thai of DTI, registered USER NAME, LATITUDE, LONGI-TUDE, TIME (see the topmost inset of Figure 5) was sent via the access point to the man pack and finally to the antenna connected to the Tx/Rx device where the laptop was used to respond back in text to the response team. Geo-tagged photos were successfully sent (see the middle inset of Figure 5) to the laptop in the same manner as texts but at manual operation. The photos were coded at the smart-phone and decoded at the laptop, easing the need to occupy much of the bandwidth during the data sending. However, the test of live full HD video (see the lower inset of Figure 5) was performed on only one smartphone and successfully attained at the required live operation and seamless data communication.

5. RESULTS AND DISCUSSION

The mesh communication backbone regarded in this work as the channel for the data to flow smoothly from the Response Unit through to the Incident Command Station despite the unavailability or damaged communi-cation channel. The MDU 31 response units previously dependent upon the commercial and network coverage for the data communications was promised with the proposed communications backbone that established free access to the data links and communications back and forth between the Response Unit to the Incident Com-mand Station. Therefore, the objective of this work on proof of concept of the establishment of the mesh communication backbone for disaster data management of the MDU 31 was fully implemented and successfully tested in the lab and at the field. The text formatted in Thai was illustrated to prove the data sending by the response team and from the incident commander. The geo-tagged photos could be successfully sent to the laptop at manual operation without bandwidth occupa-tion at all times by coding and decoding measures. The test of live full HD video was performed by one responder to attain the live operation and seamless data communication. Two hundred meters were the distance that the smartphones being used as the video and photo source were visible to the directed antenna. The ten second interval was followed to update the geo-locations of locations of the response team. However, an automatic storage of data was needed to manage the transmitted data and accumulate the disaster database management system of the MDU 31.

Quantitative statistics were a more substantial proof of concept and subject to further address after the Unmanned Aerial Station and Command and Control are introduced to the system. The generator caused signal fluctuation upon system's power provision in the Normal Situation Testbed, subject to retest in a complete team of the Response Unit for the disaster database management and with the live chat and data communications for system latency and stability. The map previously used to base locations of the activity is subject to replacement with the acquired, geo-referenced images from the used drone to form a common picture for the disaster management. In addition, signal propagation from the directional antenna empirically achieved with manual adjustment of the antenna was reckoned to be more problematic with the Unmanned Aerial Station intro-duced to the system, not yet tested for this proof of concept. With the more stable source of power, the Flooded Situation Testbed results proved viable several aspects of the established mesh communication backbone; the completely versatile source of power to feed the system, the portable man pack requiring only one operator, the almost all obstacle-free propagation of signal transmission and receiving, and the powerful device for up to 2 kilometers of data communications regardless of rough and vegetated terrain. There is room for improvement on stabilized video being fed live to Incident Command Station to avoid dizziness from video watching. Bandwidth occupation for text messages, photos and video clips needs further studies to manage the reserved and available bandwidth with help from mesh networking.

There were limitations hindering the complete proof of concept for the real establishment of the mesh communication backbone. The uninstalled but assumed Unmanned Aerial Station ideally aimed at 9,000 feet was tested only horizontally away from the Response Unit. Another field test with the unmanned equipment hovering above was planned to take place in a few months from this publication, being expected to form another novel publication. Six smartphones being concurrently networked to validate proper commu-nications and bandwidth management, being another limitation of this current work, were scheduled to co-exist in the same field test. The other limitation realized and obvious from this proof of concept was the map for situation awareness and display of tasked activities in the field, which would start and enable disaster management at the Incident Command Station. It was mentioned in the operational design on Figure 3 in include *Damage Assessment, Forcible Entry, Victim Search, Rescue and Saving Life, Evacuation* and subject to further investigation at the final stage of the entire project.

6. CONCLUSION AND RECOMMENDATIONS

This article addresses the proof of concept in establishing the mesh communication backbone for the MDU 31 response units to perform tasks independently of the commercial and network coverage for the data commu-nications. The Shannon Weaver model of communica-tion was followed to formulate the flow of data back and forth between the Response Unit and the Command and Control Station. The communication devices and their capacity were elaborated with the Network diagram for the Response Unit being illustrated and the mesh communication backbone being depicted. The data com-munications between the Response Unit and the Incident Command Station in form of formatted texts, geo-tagged and live full HD video was evidence of successful addresses of the establishment of the communication backbone for the near real-time and seamless communications channel of the MDU 31. The mobile application for the Response Unit is subject to further development since it will input text messages, geo-tagged photos and video clips to the system flow, thus provoking the decision making at the Command and Control station.

The power generation for electronic equipment was problematic and needed careful design and development of the mobile vehicle that will house functions at the Command and Control station. Empirically, up to 2 kilometers of data communications between the man pack and the Incident Command was achieved regardless of rough and vegetated terrain provided that an antenna was directed toward the Response Unit in operation. Mathematical equations to explain the bandwidth occupation are suggested to quantitatively prove the success of the established mesh communication backbone and its kind. Further introduction of Unmanned Aerial and Command and Control station to the data flow and communications has to be addressed to verify the complete mesh communication backbone. Eventually, the decision support system simulated by serious game engine at the Command and Control station is novel and unique to the disaster database management and worth further investigation.

The recommendations will be further studied to complete the DTI's HADR project. Further work includes the installation of the communications equipment on the UAV to fully integrate the Unmanned Aerial Station to the backbone. Investigation on the simulation of the mission according to the data flow. Another room for study is to concurrently manage six smartphones within the 2.4 Mbps bandwidth network with seamless communications and optimized bandwidth management. Last but not least, the military disaster management in form of SOPs encompassing *Damage Assessment, Forcible Entry, Victim Search, Rescue and Saving Life, Evacuation* will be further investigated at the final stage of the project.

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