# DTN MapEx: Disaster Area Mapping through Distributed Computing over a Delay Tolerant Network

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***Abstract*—Disaster area map generation and sharing are critical to disaster response operations. In post-disaster contexts however, cloud-based mapping services and data may be unavailable because of network challenges. Disruption Tolerant Network (DTN) architectures have been proposed for data sharing in challenged networks. However, map generation may be too complex for individual DTN nodes given their limited computing resources. To generate and share maps of disaster areas, we present DTN MapEx, a distributed computing system for mapping that operates over a DTN. DTN MapEx distributes disaster map data and map generation tasks to multiple nodes to minimize individual computational loads. In the system, responders and volunteers act as mobile sensing nodes. They log the GPS traces of their traversed paths and collect disaster area map data such as the coordinates, images, and assessments of points-of-interest. The mobile nodes then route their collected data and a task request through the DTN to pre-deployed, fixed Computing Nodes. The Computing Nodes aggregate the data to generate a map and opportunistically route it back to the network. To reduce complexity, mapping tasks and data are divided amongst Computing Nodes based on their current computational load. Computing Nodes periodically update the DTN about their current loads. Mobile nodes use these updates in deciding where to allocate their task requests and data. In this paper, we present the design of DTN MapEx and perform initial evaluations on its feasibility in disaster scenarios.**

***Keywords—Delay Tolerant Network; Distributed Computing; Disaster Management***

## I. Introduction

In recent years, the number of disasters that have hit urban areas has been increasing, which has led to rising costs of damages and casualty counts [1]. In November 2013, Typhoon Haiyan made landfall in the Philippines and left 6,155 people dead and 1,785 missing while causing 8.28 billion USD in damages [2]. In March 2011, a magnitude 9.0 earthquake occurred off the Pacific coast of Tohoku, Japan, which generated a tsunami that caused 15,641 fatalities [3].

Efficient disaster response is critical to minimizing casualty counts. Disaster response teams are tasked to perform rapid surveys of disaster-struck areas, allocate rescue and evacuation personnel and equipment based on need, and carry out their strategies.

An integral part of response operations is the site triage and assessment process [4]. Urban Search and Rescue (USAR) teams assess the disaster area and generate a priority map based on the collected information. The priority map is reported to the team leaders, who then devise response strategies and make resource allocation decisions based on the reported disaster area map. The triage process is not without its share of difficulties. In post-disaster scenarios, communication networks may be challenged because of damaged infrastructures, congestion, or power shortages. Under such circumstances, access to cloud-based mapping data and services are limited or outright unavailable. Without access to digital mapping, responders resort to pen-and-paper mapping methods, which are error-prone and inefficient. In addition, without communication networks, reports are given through radio and face-to-face meetings that slow down triage [5], [6].

Previous studies have shown the feasibility of Disruption Tolerant Networks (DTNs) during post-disaster situations to address the problem of data transmission and sharing under challenged network scenarios [6]-[11]. In these studies, mobile nodes (e.g., responders, vehicles, and the like) tour the disaster area, collect data, and route information through the DTN to a destination or sink. Their results show that using DTNs can improve information availability in disaster areas. However, the triage and assessment process requires map generation, a task that may be too complex or difficult, computation-wise, for individual DTN nodes.

In this paper, we present the design and initial evaluations of DTN MapEx: a distributed computing system for disaster map generation that operates over a DTN. In DTN MapEx, responders and volunteers carrying mobile devices act as mobile DTN nodes. They move through their assigned areas and collect triage and assessment data. Through opportunistic communication, the mobile nodes transmit their collected data, along with service requests, to pre-deployed, stationary Computing Nodes. The Computing Nodes, upon receiving a service request, aggregate the data to generate a digital map, which is then opportunistically routed back through the network to requesting client nodes. A novel feature of DTN MapEx is that it reduces computational complexity. DTN MapEx distributes mapping tasks to Computing Nodes based on their computational load. Computing Nodes periodically send updates through the DTN about their current load. Mobile nodes use these updates to decide where they will send their data and next service request.

DTN MapEx addresses the following challenges. First, it aims to improve information availability during disaster response scenarios. The DTN backbone of the system allows disaster map information sharing amongst mobile nodes even under challenged network situations. Second, it aims to facilitate efficient disaster map generation by distributing computing tasks such as image and video processing and data aggregation to dedicated Computing Nodes. This alleviates load from mobile nodes that have limited resources. In this study, we initially evaluate the performance of DTN MapEx in terms of data transfer speed. We show that large file sizes cause noticeable delays in transmission, justifying the need for a distributed approach to computing.

## II. Related Works and our Contribution

### A. Disruption Tolerant Networks

DTNs have been leveraged as means to improve information availability under challenged network scenarios [12]. From the original purpose of providing deep-space communications, DTNs have been applied to disaster response scenarios. [6] presents the design of a human-centric wireless sensor network that consists of responders and stationary sensors. The proposed network uses the responders and their movements around the disaster site as means for opportunistic information transfer.

In [8], a data-collection infrastructure is proposed based on mobile nodes (i.e. people with mobile devices) acting as sensor nodes. The sensor nodes move around the disaster area, collect information about encountered points-of-interest, and transmit the data opportunistically. They also propose aggregating the collected data to reduce data size and minimize delays.

[9] presents the design for DistressNet, a sensor network architecture to support disaster response. DistressNet uses ad hoc communication to route sensor data to an intended destination and uses distributed sensing to minimize energy-consumption, noting that battery life is a limited resource.

[7] evaluates the performance of various opportunistic routing protocols in disaster scenarios. Through simulations, they show how parameters such as the number of mobile nodes, transmitted data size, and data generation rate affect the efficiency of four DTN routing protocols. Similarly, [10] reports on the “fairness” of the message delivery ratios of various routing algorithms and notes that ensuring fair message delivery is a topic that is still open for further study.

The aforementioned studies evaluate DTNs based on how information availability is improved. They use parameters such as data size, node counts, data generation rate, and delay as performance metrics. The contribution of DTN MapEx is that it aims to improve both information availability and generation by considering the computational complexity of required tasks.

### B. Distributed Computing

Distributed computing was developed to improve the overall performance of a system. In a distributed computing system, multiple machines work with together to complete a single complex task. Task allocation is critical to the overall improvement, which can be seen in faster computation time or less computational loads in individual machines. The system must decide to which machine a task will be assigned given that machine’s available resources and those of others [13].

[14], [15], and [16] survey various distributed (e.g., cloud-based) architectures in the mobile environment and evaluate how these improve the overall computation performance of the system. However, the systems and architectures in these surveys assume access to cloud-based services through the Internet, which may be unavailable during disaster scenarios. DTN MapEx differs because it functions over a DTN where data and service availability is dictated by opportunistic contacts between nodes rather than relying on direct routes.

A similar work to ours is Serendipity: a platform for distributed computing over a DTN [13]. They model computational tasks and propose task allocation algorithms based on different connectivity scenarios. When contacts are predictable and a control channel is available, a greedy algorithm assigns tasks based on minimum completion time. When a control channel is unavailable, tasks are allocated opportunistically (i.e. nodes exchange tasks during encounters with other nodes). Serendipity proposes dividing inputs to simpler, similar segments and assigning them to nodes. Our approach differs in that we assign tasks based on category. In the future, our design will consider mobility models that specifically represent node movement during disaster response.

## III. The Disaster Response Methodology

The typical disaster response methodology is described in [4] and [5]. Urban Search and Rescue (USAR) teams arrive at the disaster site and report to the On Site Operation Coordination Centre (OSOCC) and the Local Emergency Management Agency (LEMA). Each USAR team is assigned a subsection of the disaster area as a work-site. A work-site’s size ranges from $2 \times 2$ to $3 \times 3$ city blocks. The USAR team then mobilizes to their assigned section. Upon arrival at their assigned work-site, a USAR team establishes a Base of Operations (BoO): a 50 $m^2$ area that serves as the team’s headquarters, a communications hub, and a treatment site.

After establishing a BoO, a USAR team then divides into smaller teams [5], the Management Team, Assessment Teams, and Rescue Teams. Assessment Teams move through areas of the work-site, search for victims that need to be rescued, and generate maps of the assessed areas. Assessment Teams periodically return to the BoO and report their findings. The Management Team, which remains at the BoO, generates a plan of action based on the reports of the Assessment Teams and relays the plan to Rescue Teams. The Rescue Teams then execute the plan and extract victims from the work-site and bring them to the BoO for treatment. USAR teams periodically coordinate with each other through face-to-face meetings.

### A. *Disaster Area Mapping*

Work-site triage and mapping critical to USAR team operations, the purpose of which is to assess the work-site and assign priorities to areas in order to save as many lives as possible [4]. The process is as follows. First, responders determine the zones or areas to be covered by the triage, taking into consideration the mobility of response teams. Next, all partially- and fully-collapsed structures are marked for assessment. Third, the zone or work-site is assessed. Information such as the number of reported missing and structural assessments of buildings are collected. Fourth, each area is categorized based on standards in [4]. Finally, the areas are prioritized, on which the response strategy is based.

The end goal of the triage process is to generate a map that contains the addresses, landmarks, and/or GPS coordinates of the coverage areas. The areas are marked on the map based on the standards in [4]. Mapping during response operations are typically done through pen-and-paper methods. Responders mark the locations of coverage areas on paper maps. If paper maps are unavailable, responders resort to sketching the areas.

The physical areas (e.g. structures) are also marked based on the assessments of USAR teams. Marking symbols and numbers are spray-painted in the main point-of-entry of a structure to provide maximum visibility. Markings contain information about the area such as the number of live and dead victims, any hazards, and whether or not it is safe to enter the structure. The generated maps and assessment data are reported to the Management Team in the BoO. The Management Team creates a plan of action based on the collected information.

### B. *Communication Methods*

Having reliable forms of communication is important during response operations. Individual USAR teams must be able to coordinate and share information within itself, with other USAR teams, and the OSOCC and LEMA. Common communication equipment includes satellite phones, VHF/UHF radios, the Internet, and cellular networks. Information transfer is also done during face-to-face meetings.

### C. *Challenges*

In disaster response, the quality of information sharing can have a positive or negative effect to coordination, decision-making, and actions. Inefficient information sharing causes delays: responders may be assigned to low-priority areas, actions become redundant, and evacuation slows down [5].

The medium of communication significantly affects the quality of information sharing. The previous subsection lists the common communication methods during disaster response, from which the Internet and cellular networks may be the most efficient. These networks give responders access to cloud-based services through which they can quickly share information about the disaster site with multiple peers.

In disaster scenarios however, the Internet and cellular networks may be unavailable because of damaged network infrastructures, congestion, and lack of power. Without these networks, responders use satellite phones, VHF/UHF radios, or hold face-to-face meetings.

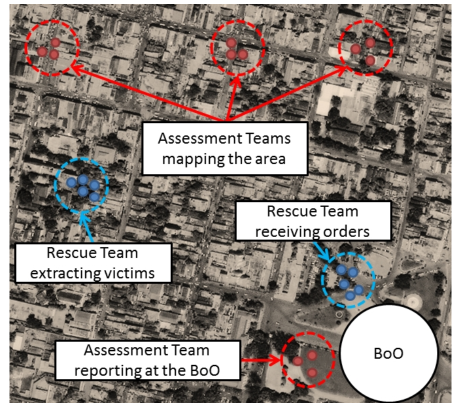



Fig. 1. USAR team operation diagram. Assessment and Rescue Teams deploy from the BoO. Assessment teams make map the work-site and report their findings to the Management Team at the BoO. Rescue teams receive orders from the BoO and exctract located victims.

These alternatives have limited channels of communication and are prone to interference, thus information can only be shared to a few recipients at a time and the integrity of the shared information can be at risk. Similarly, face-to-face meetings can cause delays. Meetings require responders to allot time to physically return to the BoO and possibly wait for other team members to return. Generating information during disaster response operations is also susceptible to inefficiencies. Without access to the Internet and cellular networks, cloud-based mapping services and data cannot be leveraged. Responders resort to using hand-drawn maps, which are error-prone and are difficult to aggregate and disseminate.

### D. *Problem Statement*

Given the aforementioned challenges, the purpose of this work is to develop a system that supports USAR processes and improves information availability and generation in post-disaster scenarios.

Improving information availability means enabling responders to broadcast their findings about work-sites. DTN MapEx must be able to provide a means of disseminating information to multiple recipients even under challenged networks. Assessment Teams must be able to share their collected information to Rescue and Management teams with minimal delay. For information generation, our study focuses on disaster area mapping. Making maps that follow USAR standard markings and aggregating data such as images of the disaster area and text-based evaluations can be complex tasks. Given the limited computing resources available during disaster response scenarios, DTN MapEx must have a means of handling mapping service requests from responders. The system must be able to generate a map of the disaster area from the collected information from all the teams.

## IV. DTN MAPEX: DTN-BASED DISASTER ASSESSMENT MAP GENERATION SYSTEM

### A. *Disaster Map Information and Tasks*

We begin this section by providing a working definition of *Information*. DTN MapEx is a mapping system that supports response teams by generating a digital map of the disaster area. The map is based on collected information, including:

- GPS traces of traversed paths: DTN MapEx logs the GPS location of the node (i.e. responders). The traces are used to create a map of traversed paths that show which sections of the disaster site have or have not been explored or assessed.
- GPS coordinates of work-sites/points-of-interest (PoIs): USAR teams locate work-sites and other PoIs. DTN MapEx records the locations of these work-sites and PoIs and shows them on the map. The work-sites and PoIs are identified based on the INSARAG mapping guidelines.
- Triage and assessments of work-sites/PoIs: Triage and assessment are critical to prioritizing rescue. DTN MapEx allows responders to record their assessments of work-sites and PoIs. The assessments correspond to the markers on the map. Responders can create, view or edit assessments by clicking on a corresponding marker.
- Digital images and videos of work-sites/PoIs: DTN MapEx enables responders to capture images of work-sites and PoIs. A marker's corresponding images and videos can be viewed along with its assessment.

To generate a map, Computing Nodes must perform the following tasks:

- Eliminate noise from the GPS traces.
- Processing images and videos taken from work-sites. Images and videos can be aggregated to give a wider view of the disaster site. Detection algorithms can also be implemented to find victims.
- Aggregate the processed GPS traces, images, and videos to generate an assessment map.
- Render the map, either by showing OSM tiles or plotting the GPS traces.

### B. System Design

DTN MapEx is designed to support disaster response operations. During disaster response operations, USAR team members carry mobile devices with the DTN MapEx application. The USAR team members act as mobile sensor nodes. Using their mobile devices, the nodes gather information about the disaster area, which will be used by the system to generate a map. The system has two main components: the DTN MapEx Activity component and the DTN MapEx Service component. Fig. 2 shows the interaction of components within a single DTN MapEx node.

DTN MapEx activity handles information gathering and visualization. It is composed of the Image Map and GPS Plot modules. The Image Map module enables online and offline mapping and work-site/PoI assessment. As responders explore the disaster area, they can use Image Map to capture images of work-sites and PoIs. The captured images can be annotated with assessments, are geotagged, and stored in the device as map markers. The markers are then overlaid on a map of the disaster area for review. DTN MapEx uses the OSMDroid library to download OpenStreetMap (OSM) tiles of disaster area map, store them on the device, and render them [17]. If the device is online, it downloads OSM tiles of the area as the responder traverses them. If challenged networks are expected in the area, OSM tiles of the disaster area can be pre-downloaded. Fig. 3(a) shows the Image Map module.

The GPS Plot module is an offline means of mapping in case OpenStreetMap tiles are unavailable (e.g., the tiles were not pre-downloaded or internet). The GPS Plot module periodically logs the GPS coordinates of the device. These coordinates are used to dynamically generate a plot of the paths traversed by and trajectories of the mobile nodes, even while offline. As with the Image Map module, responders can capture annotated, geotagged images of PoIs. Fig. 3(b) shows the GPS Plot module. The DTN MapEx Activity component enables responders to assess work-sites and PoIs.

The main goal of DTN MapEx is to improve performance by minimizing the overall delay of information sharing and generation during disaster scenarios. The routing of data and tasks and the deployment locations of Computing Nodes must be considered, and we leave these for future work.

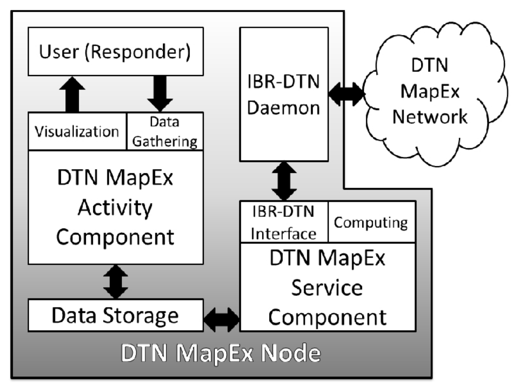
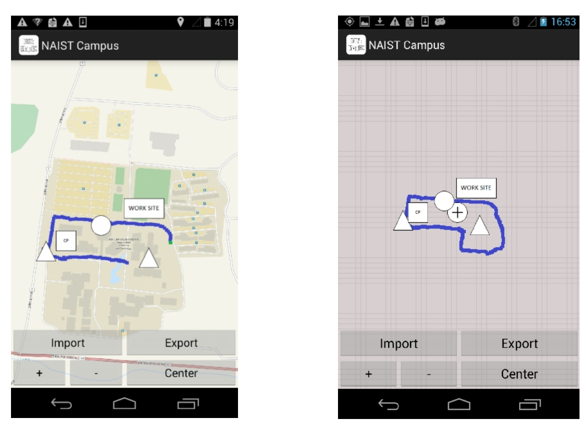



Fig. 2. The components of the DTN MapEx application. Responders gather information thorugh the DTN MapEx Activity component.




(a) (b)

Fig. 3. (a) The Image Map module displays traversed paths over OSMDroid tiles. (b) The GPS Plot module maps paths even while offline. The red traces show the traversed paths and markers show the locations of work-sites/PoIs.

### 1) *Information Sharing through DTN Routing*

The DTN MapEx Service component runs in the background and sends and receives the disaster map information to and from the device to other nodes in the network. Information is sent and received using the Android implementation of IBR-DTN [18], a lightweight, modular, and portable Bundle Protocol implementation. The routing algorithm can be selected through the IBR-DTN daemon. DTN MapEx can use PRoPHET or Epidemic routing [7].

### 2) *Generating Aggregated Maps by Distributed Computing*

Mobile devices typically rely on cloud-based data and services such as the Google Maps API. In disaster settings however, these data and services may be unavailable or difficult to access. When cloud-based mapping services and data are unavailable, DTN MapEx generates its own map by aggregating the information collected by responders. However, aggregating all gathered information to generate a single map with annotations can be a complex task. For example, images taken from a single work-site may need to be stitched together to provide team managers with ground-truth. Images also need to be checked for similarities (i.e. some images may be of the same subject) to reduce the number of redundant files. Individual nodes may not be able to handle heavy processing tasks given their limited battery life and computing resources.

To address this, DTN MapEx distributes aggregation tasks to pre-deployed stationary Computing Nodes. These nodes can be machines with more computing resources and access to a power source, for instance, a laptop powered by a solar panel. Computing Nodes are akin to the “Throwboxes” proposed in [11], but instead of acting as next-hop nodes or improving neighbor discovery rates, Computing Nodes act as field-servers. They provide mapping services to requesting nodes by aggregating the gathered information. Tasks are assigned to Computing Nodes based on the MapReduce model [19]. Some Computing Nodes will be assigned to specific tasks (i.e. to Image processing, to video processing, or to text and GPS trace data processing) and some will be assigned to the reduce operation, and will aggregate the processed data.

## V. Initial Evaluations

We conducted a preliminary set of experiments to test the feasibility of DTN MapEx in disaster response scenarios. For this study, we first evaluated the Transfer Times for different types of data (images, videos, and GPS trace logs).

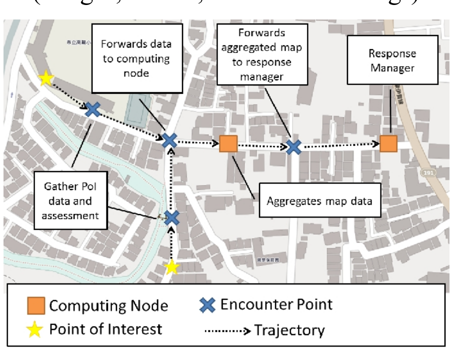



Fig. 4. DTN MapEx routing from encounter points to the response manager.

TABLE I. Test Device Secifications

| Device | Android Ver. | Internal Storage | System Memory | Processor |
|---|---|---|---|---|
| LG Nexus 4 | 4.2.2 | 12.92 GB | 2048 MB | Quad, 1500 MHz |
| LG Nexus 5 | 4.4.1 | 12.55 GB | 2048 MB | Quad, 2260 MHz |

TABLE II. IBR-DTN Daemon Settings

| Parameter | Value |
|---|---|
| Routing | PRoPHET |
| Discovery Policy | Always On |
| Wi-Fi Direct[a] | On |

[a] During actual disaster scenarios, wireless access points are likely to be unavailable. Wi-Fi Direct was turned on to enable peer-to-peer contact.

Data transfer time is crucial to response efforts. If data transfer rates are slow, relevant information cannot reach response managers quickly. For DTN MapEx, the contact time of nodes must be considered. Slow data transfer rates require longer contact windows, which cannot be expected during response scenarios (i.e. response teams move quickly).

To measure transfer time, three types of data files, images (JPEG), videos (MP4), and GPS trace logs (CSV), were routed using the IBR-DTN from the Nexus 5 device to the Nexus 4. DTN MapEx logs the timestamps of the transfer actions to measure the delay. *Send Time* is the upload time from the sender (Nexus 5) to the receiver (Nexus 4). *Send Time* includes the contact initiation, grouping files into batches, and uploading the batch. *Receive Time* is the download time after the transmission from the sender is received. *Receive Time* includes the acceptance of the transmission, downloading the batch, separating the files in the batch, and writing the files in device storage. *Send* and *Receive* times were summed. Tables 1 and 2 show the specifications of the devices and the settings used for the IBR-DTN daemon. Five GPS trace logs of different sizes, containing 1, 3, 5, 10, and 20 km worth of traversed paths (51.2, 153.6, 256.0, 512.0, and 984.0 kB, respectively), were transmitted. Images were transmitted in 5 batches. Each batch contained 1, 2, 5, 10, and 20 images and sizes ranged from 757.8 kB to 2650.6 kB. Three videos, 42.53, 81.40, and 122.20 MB, were transmitted.

The results show that transfer times increase with the file size. For all three file types, delays are evident for larger files. Fig. 5 shows that 15 km worth of traversed path data can be transferred within 3 s. During disaster response, most opportunistic contacts provide a window of a few seconds for data to be transferred before the nodes go out of contact range (i.e. responders pass each other in the field). Longer contact periods (i.e. face-to-face meetings) provide a wider contact window during which, larger files can be transferred. Given that large-sized GPS logs can be transmitted within 3 seconds, transmitting them during short contact windows is feasible. The noticeable delays occur for larger file sizes (i.e. images and videos). Figs. 6 and 7 show that a batch of 20 image files takes 30 seconds to transmit and that a 2-minute video, with a file size of 129.1 MB requires more than 2 minutes to transmit. A contact window that that long might not be realistic in response situations. A possible solution would be to split larger files, and transmit the smaller files to the dedicated Computing Nodes for aggregation. By distributing the load to multiple nodes, the transmission time delay of assessment map data can be reduced. This will be the main benefit of DTN MapEx.

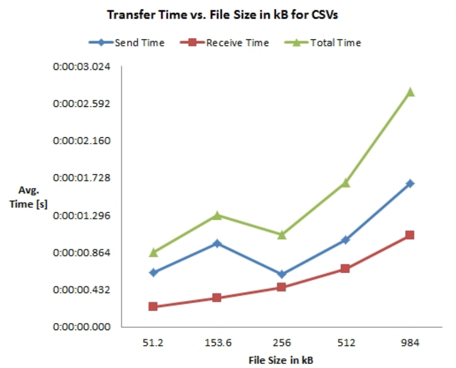



Fig. 5. Transfer times for GPS trace logs (CSV) of varying sizes.

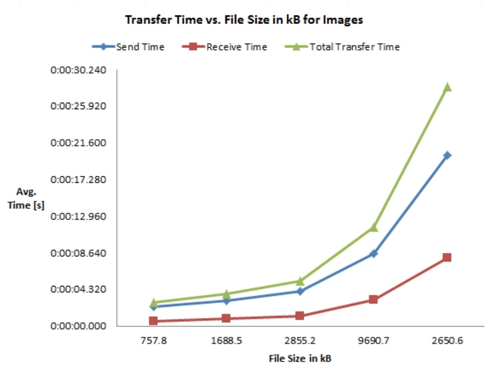



Fig. 6. Transfer times for images (JPEG) of varying sizes.

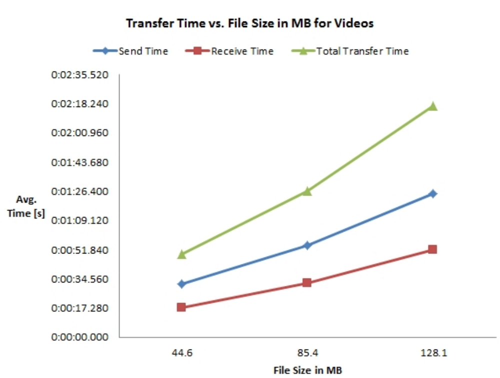



Fig. 7. Transfer times for videos (MP4) of varying sizes.

## VI. Conclusions and Future Work

In this study, we presented the design and initial evaluations of DTN MapEx, a DTN-based disaster map exploration system for Android devices. DTN MapEx integrates DTN and distributed computing to support decision-making by generating and sharing assessment maps of disaster areas, even during challenged network scenarios. In future works, we will present algorithms for data and task distribution, image and video processing, and data aggregation. The performance of DTN MapEx will be further evaluated through experiments and simulations. We will also formulate a routing protocol and a mobility model for disasters.

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## References

[1] R. Pielke, Jr. “Disasters, Death, and Destruction Making Sense of it All,” *Oceanography*, vol. 19, no. 2, pp. 138-147, Jun. 2006.

[2] A. L. Holmes. “The Dynamics of Disaster Economics: The Philippines’ Recovery and Response to Typhoon Haiyan (Yolanda),” in *the 2014 Asia-Pacific System Dynamics Conference*, Tokyo, Japan, 2014.

[3] N. Mori, T. Takahashi, T. Yasuda, and H. Yanagisawa. “Survey of 2011 Tohoku earthquake tsunami inundation and run-up,” *Geophysical Research Letters*, vol. 38, no. 7, Sep. 2011.

[4] *INSARAG Guidelines and Methodology*, The International Search and Rescue Advisory Group, United Nations, 2012.

[5] N. Bharosa, J. Lee, and M. Janssen. “Challenges and obstacles in sharing and coordinating information during multi-agency disaster response: Propositions from field exercises,” *Information Systems Frontier*, vol. 12, no. 1, Mar. 2010.

[6] S. Ochoa and R. Santos. “Human-centric wireless sensor networks to improve information availability during search and rescue activities”. *Information Fusion*, to be published.

[7] A. Martín-Campillo, J. Crowcroft, E. Yoneki, and R. Marti. “Evaluating opportunistic networks in disaster scenarios,” *Journal of Network and Computer Applications*, vol. 36, no. 2, pp. 870-880, Mar. 2013.

[8] J. T. Fajardo et al. “Disaster Information Collection with Opportunistic Communication and Message Aggregation,” *Journal of Information Processing*, vol. 22, no. 2, pp. 1-12, Apr. 2014.

[9] S. George, W. Zhou, H. Chenji, M. Won, Y. O. Lee, A. Pazarloglou, R. Stoleru, and P. Barooah. “DistressNet: A Wireless Ad Hoc and Sensor Network Architecture for Situation Management in Disaster Response,” *IEEE Communications Magazine*, vol. 48, no. 3, pp. 128-136, Mar. 2010.

[10] A. Takahashi. “Fairness Issue in Message Delivery in Delay- and Disruption Tolerant Networks for Disaster Areas,” in the *International Conference on Computing, Networking and Communications*, San Diego, CA, Jan. 2013.

[11] N. Banerjee, M. D. Corner, and B. N. Levine. “An Energy-Efficient Architecture for DTN Throwboxes,” in *INFOCOM 2007*, Anchorage, AK, pp. 776-784, May 2007.

[12] K. Fall. “A Delay-Tolerant Network Architecture for Challenged Internets,” in *SIGCOMM ’03*, New York, NY, USA, pp. 27-34, 2003.

[13] C. Shi, V. Lakafosis, M. Ammar, and E. Zegura. “Serendipity: Enabling Remote Computing Among Intermittently Connected Mobile Devices,” in *MobiHoc 2012*, Hilton Head Island, SC, USA, 2012, pp. 145-154.

[14] M. Shiraz, R. H. Khokhar, and R. Buyya. “A Review on Distributed Application Processing Frameworks in Smart Mobile Devices for Mobile Cloud Computing,” *IEEE Communications Surveys & Tutorials*, vol. 15, no. 3, pp 1294-1313, Jul. 2013.

[15] H. Dinh, C. Lee, D. Niyato, and P. Wang. “A survey of mobile cloud computing: architecture, applications, and approaches,” *Wireless Communications and Mobile Computing*, vol. 13, no. 18, pp. 1587-1611, Dec. 2013.

[16] N. Fernando, S. Loke, and W. Rahayu. “Mobile cloud computing: a survey,” *Future Generation Computer Systems*, vol. 29, no. 1, pp. 84-106, Jan. 2013.

[17] N. Gramlich and N. Boyd. *OpenStreetMap Tools for Android*. [Online]. Available: https://github.com/osmdroid/osmdroid

[18] M. Doering, S. Lahde, J. Morgenroth, and L. Wolf. “IBR-DTN: an efficient implementation for embedded systems,” in the 3rd Workshop on Challenged Networks, CHANTS, San Fransico, CA, USA, pp. 117-120, Sep. 2008.

[19] J. Dean and S. Ghemawatt. “MapReduce: simplified data processing on large clusters.” *Communications of the ACM*, vol. 51, no. 1, pp. 107-113, Jan. 2008.