Hierarchical Cloud-Fog Platform for Communication in Disaster Incident Coordination

Duo Jiang, Rui Huang, Prasad Calyam, John Gillis, Olivia Apperson,
Dmitrii Chemodanov, Fatih Demir, Salman Ahmad
University of Missouri-Columbia, Northern Illinois University; USA
{calyamp, gillisj}@missouri.edu; {dj963, rh4m8, oamr6, dycbt4}@mail.missouri.edu; fdemir@niu.edu; ahmadsa@health.missouri.edu

***Abstract*—Communication and coordination in a mass casualty disaster scenario is limited and difficult for medical personnel in the absence of necessary communication infrastructure and technologies that enable situation awareness. This leads to misdirected and delayed triage of scene-wide critically injured patients, especially when there are large numbers of patients needing diverse care levels. A hierarchical cloud-fog setup involving a core cloud and edge clouds (i.e., fogs) can help the patient triage related real-time data movement challenges. It can create visual situational awareness and overcome infrastructure limitations at the wireless network edge. In this paper, we describe our "Panacea's Cloud", a hierarchical cloud-fog platform that provides augmented reality benefits with real-time human communication and geolocation services through the integration of a standardized Incident Command System (ICS) with smart devices such as heads-up displays, virtual beacons, and wireless mesh network elements. We show how the ICS can run using a core cloud as an intelligent dashboard that leverages fog resources and data collection close to the incident scenes. In addition, we describe experiment results from evaluations of Panacea's Cloud dashboard usability and platform performance that show benefits and issues in hierarchical cloud-fog service management in support of ICS communication during disaster incident coordination.**

***Index Terms*—hierarchical cloud-fog platform, fog benefits in health care, disaster medical triage, smart geolocation tracking**

I. Introduction

Disaster incident response is a complex task due to traditional infrastructure assumptions that may fail given the damage made by man or natural causes. Additionally, there is a need to handle large amounts of data from multiple incident scenes and from disaster relief co-ordination efforts between first responder agencies such as fire, police, hospitals [1].

In our previous work [2], [3], we have shown the need for a mobile ad-hoc wireless network (MANET) that needs to be operational for quickly transferring media-rich data from the disaster scene to enable communication in disaster incident coordination. Data in a disaster incident response application context corresponds to the transfer of real-time high-definition video streams generated by paramedics' wearable heads-up displays (HUDs) and other video devices from the disaster triage scene to an intelligent dashboard. We have also found in our prior work that incident response and resource allocation decision making (e.g., ambulance routing to scene, medical supply replenishment) requires significant computational resources, particularly for multiple simultaneous incident cases with a large numbers of patients. The main hypothesis of the research in this paper is that a hierarchical cloud-fog setup involving a core cloud and edge clouds (i.e., "fogs") can help the patient triage related real-time data movement challenges for creating visual situational awareness and overcome infrastructure limitations at the wireless network edge.

This material is based upon work supported by the National Science Foundation under Award Number CNS-1647182 and the Coulter Foundation. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation or Coulter Foundation.

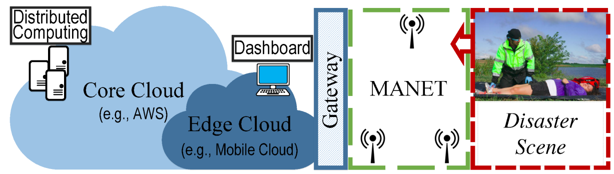

Fig. 1: Illustration to show how during disaster-incidents, data is typically generated at sites where there is not abundant computation/storage resources available. Consequently, data needs to be transferred to an edge cloud or fog, and to a core cloud for pertinent decision making computations.

In this paper, we present our investigations for building a hierarchical cloud-fog platform viz., "Panacea's Cloud" that supports an Incident Command System (ICS) application. Figure 1 illustrates our hierarchical cloud-fog setup for a disaster incident-supporting application we are developing for medical triage communications between paramedics and other first responders. We address the design challenges of the hierarchical cloud-fog setup for the analytics and dissemination of application's real-time data with location-awareness and its usability in austere edge network health conditions. Specifically, we describe a novel geotracking service and our new Panacea's Dashboard features that use core cloud capabilities to integrate smart devices (heads-up displays, virtual beacons and wireless mesh network elements) and their data collection in the fogs. Our approach is innovative because it transforms an ICS application setup and enables real-time triage coordination between incident commanders and first responders simultaneously *across multiple incident scenes*.

In addition, we present our usability evaluation and platform experiments of our Panacea's Cloud in terms of communication and situational awareness (i.e., patient, responder and supply status). Our usability evaluation experiments consider a realistic Tornado disaster incident scenario, and characterize the task completion success rate (effectiveness) and time (efficiency) with human subjects. Our platform experiments highlight the issues in hierarchical cloud-fog service management in terms of HUD heating during ICS communications, and communication quality in HUD-to-device, HUD-to-router and router-to-router communication cases. Thus, our work on Panacea's Cloud as well as its realistic evaluation engenders new possibilities for next-generation ICS systems that outperform existing industry offerings such as Intermedix [4].

The rest of the paper is organized as follows: In Section II, we discuss related work. Section III describes next-generation ICS requirements, and our Panacea's Cloud solution components that utilize hierarchical cloud-fog platform capabilities for communication in disaster incident coordination. Section IV presents our experimental evaluation results that show benefits and issues of our solution approach. Section V concludes the paper.

II. Related Work

Earlier works such as WIISARD [5] proposed a system for response units to improve medical care of victims in disasters scenarios. Personal digital assistants that have wireless capability are integrated with electronic medical record software to replace paper triage tags to log patient information. An Intelligent Transportation System that includes Vehicular Ad hoc Networks (VANETs), and mobile cloud computing resources is presented in [6]. This intelligent system is able to gather information from multiple sources and locations, including the scene of an incident, and to suggest effective strategies and decisions that can be propagated to vehicles (such as ambulances) and other entities in real-time. The systems in these works are comparable to Panacea's Cloud with regards to their intelligent dashboards located in the edge cloud. Our Panacea's Dashboard design is novel in the sense that it enables real-time communication using a hierarchical cloud-fog platform, and orchestrates core cloud resources to execute optimization algorithms for incident response resource allocation, and decision making (e.g., ambulance routing to scene, medical supply replenishment). Moreover, our Panacea's Cloud addresses some of the key drawbacks for information aggregation in disaster networks identified by authors in recent works such as [7] and [8], where they provide a comprehensive analysis of contemporary efforts to address mobile cloud management of disasters.

Recent works such as DIORAMA [9] have similar aims as our Panacea's Cloud work to solve problems of medical triage during mass casualty incidents. The DIORAMA system collects spatiotemporal data to create visual analytics of patient and resource locations and their status, and also features a map interface that supports a set of tools for incident commander communications. Unlike our work, the DIORAMA does not reap the benefits of using an ad hoc wireless network and a cloud-fog platform when traditional infrastructure is affected during a disaster occurrence. Instead, it relies on an intact traditional infrastructure of cell and radio towers for its Android smartphone and tablet applications to interact with active RFID readers and tags to transmit information.

Our work is also closely related to the AID-N effort [10] conducted in 2008, where technologies such as electronic triage tags, web-portals, wearable vital sign sensors, legacy hand-held interface devices, and regular teleconferencing were used to enable collaboration between emergency response personnel. However, the data collection was conducted in an offline manner through physical device synchronization. In contrast to this and other common ICS systems such as Intermedix [4], our Panacea's Cloud can help responders communicate with networked wearable HUDs and to view patient and supply status using virtual beacons at the disaster scene in real-time using a hierarchical cloud-fog platform. Further, our work also addresses another important issue identified in [11] that poorly designed user interfaces to provide situation awareness may cause obstacles for incident commanders tracking first responders across geographic locations with an ICS. Our data collection and analysis methods allows for creation of interactive maps within familiar ICS layouts that have been shown to help ICs to make quick decisions [12].

III. Panacea's Cloud Solution

In this section, we first describe the requirements for effective coordination between the incident commander and responders at a disaster scene. Following this, we describe the system architecture and software design, along with the developed components in our hierarchical cloud-fog solution, including a wireless mesh network communication protocol, use of HUDs, virtual beacons, and Panacea's Dashboard. These components create the fog infrastructure at the edge network, and are integrated with the core cloud computation resources to run complex optimization algorithms to effectively meet the ICS needs of disaster medical triage and resource allocation decision making.

A. Disaster Scene Response Requirements

A typical ICS structure is mainly comprised of the Incident Commander who instructs three subgroups: the Logistics Section Chief, the Planning Section Chief, and the Medical Branch Director. These staff also have authority over various other support personnel that are allocated to particular incidents initiated within the ICS. When an incident occurs, a prior template is used to register the incident, and appropriate staff personnel associated with the template are automatically notified to respond. As responders arrive at the scenes and conduct relief activities, information is passed from these scenes to the heads of the subgroups, and then up to the Incident Commander to interpret and provide more instruction and deploy additional resources (e.g., ambulances, medical supplies, domain experts). Such a personnel organization ensures that the Incident Commander receives all necessary information and has situational awareness to appropriately respond to the various events at the incident scenes at all times.

We recently conducted an online survey in collaboration with EMS1 media website [14] to: (a) obtain a general sense of the scale of disaster incidents in recent times to guide the work of this paper, and (b) gauge the pain points in technology requirements for effective disaster response. The survey attracted 1,746 responses from a population that included a majority of first responders. Survey summary indicated that 60% of disaster incidents range from 5-to-30 triage patients. In addition, 35% of the responders viewed communication in general (including communication with Incident Commander) as the major pain point in the response during a mass casualty incident; 46% of the responders expressed the lack of information or necessary resources (again can be attributed to communication challenges) as the other major pain point. Further, 70% admitted that handheld radio communication was the most frequently used technology to track patients and care for patients during a mass casualty incident, and only 15% had the capability for live tracking of care status.

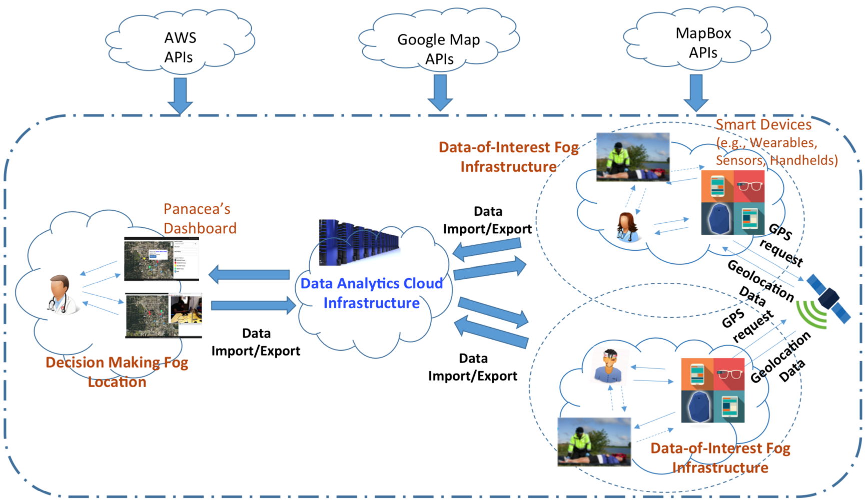

Fig. 2: Panacea's Cloud communication workflow to integrate the core cloud with data-of-interest fog in order to aid ICS decision making.

Thus, a solution such as our Panacea's Cloud has the potential to have a transformative effect on the state-of-the-art in terms of meeting ICS application requirements. It can be a significant capability for disaster relief coordination owing to its features of: (i) live tracking of multiple events' status based on data collection with smart devices at incident locations, and (ii) advanced communication and computation platforms for fostering real-time mission-oriented situational awareness through data integration and dissemination between the incident commander and first responders.

B. Fog Infrastructure of Smart Devices

As the Figure 2 illustrates, there are a sequence of basic workflow events between the disaster incident scenes (data-of-interest fog infrastructure) and the incident command center (decision making fog location). Natural or human-made mass casualty disasters generally encompass a large geographic region as well as result in disrupted infrastructure, such as broken-down networks, uneven terrain, collapsed buildings, and other limitations. Panacea's Cloud provides a fog computing component to this situation through a compact custom enclosure (i.e., a Pelican Case) that is rugged and weather-proof to protect the devices. The fog computing component includes a combination of a mobile RouterBOARD router, Raspberry Pi server with the corresponding database, battery to provide power for several hours, and a touchscreen for configuration. Multiple enclosures or fog computing components can be distributed throughout the geographic region in order to provide the adequate wireless and fog computing coverage for the entire area depending upon the scale of the disaster response, and edge network constraints such as e.g., energy.

The communication component in Panacea's Cloud fog infrastructure is comprised of two smart devices, Heads-up Displays (HUDs) and virtual beacons (i.e., Estimote Beacons). Paramedics wearing a HUD (i.e., Recon Jet) can use virtual beacons to mark location/status of nearby patients. Each HUD determines its current location via GPS and the signal strengths of nearby virtual beacons. This raw data made up of the patient and paramedic locations is sent to the Raspberry Pi server i.e., the fog computing component. Then the gathered data on the Raspberry Pi server is sent to the core cloud infrastructure, if and when available through cellular, wi-fi or satellite connections. The Incident Commander can observe the locations of every paramedic wearing a HUD and every patient marked by a virtual beacon through markers on a real-time map that provides visual situational awareness of the triage care status. Geolocation awareness of various scene locations can also be obtained using not only the HUDs but through any other Global Positioning System (GPS) equipped mobile devices (e.g., phones or tablets).

C. Computing in the Core Cloud

The core cloud resources can be rented from public clouds such as Amazon Web Services (AWS), and associated geolocation assistance services such as Google Maps and MapBox Application Programming Interfaces (APIs) can be leveraged through core cloud access. According to the solution functions necessary in disaster scenarios outlined earlier in Section III-A, it is necessary to migrate parts of system to the core cloud (considering real-time constraints in the ICS application use cases) to adequately process, store and protect the data. In addition, if the scale of number of simultaneous incidents or number of triage patients are large in number, the data handling, data fusion analysis and visualization have to be performed using core cloud resources.

We have designed the Panacea's Dashboard (whose screenshot is shown in Figure 3) to be portable, and can be made to seamlessly be located either in the fog infrastructure or cloud infrastructure depending upon the incident scale and Incident Commander preference. The Panacea's Dashboard front-end is compliant with ICS interfaces in the industry for the functionality expected, and is created using the Twitter Bootstrap framework and HTML 5. The back-end of the dashboard connects to a MySQL database with the use of JavaScript, AJAX, PHP, and jQuery working in unison. The smart devices integration, specifically HUD integration is made possible with the use of the WebRTC framework. The back-end is decoupled from the front-end, which allows custom user interfaces to be developed to suit ICS user needs for disaster response.

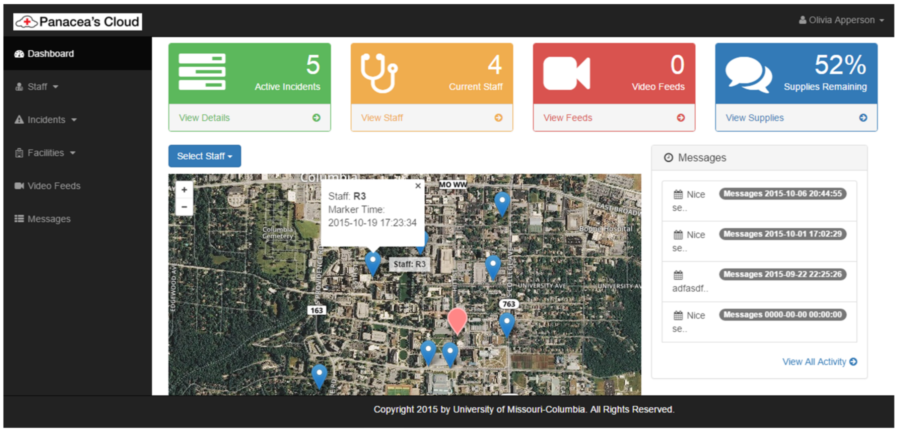

Fig. 3: Panacea's Dashboard layout that creates visual situational awareness of the overall medical triage care status across multiple incident scenes.

A custom chat application that we have developed handles all video streaming data between users and works with a server acting like a directory (or phone book) of every available paramedic. It uses the WebRTC framework, HUD device (i.e., Google Glass or Recon Jet) programming APIs in order to enable live video feeds. The chat application also handles device abstractions by detecting supported HUD hardware (Recon Jet or Google Glass) and maps the controls via the appropriate API for the device. Furthermore, the chat application also handles interacting with the Estimote Beacons to realize the virtual beacon functionality. The Panacea's Dashboard enables Incident commanders to manage the staff directory, active incidents, and helps organize auto-generated notifications of important status items. We can see that the 'Dashboard' page displays the entire real-time visual situational awareness of multiple incidents and the latest status of the patients, responders and the supply at the incident scenes. Contextual markers on the map provide additional communication capabilities such as for e.g., upon clicking a specific paramedic identifying marker on the map, the Incident Commander will have the option to call and interact with the paramedic to provide guidance and instruction as well as to provide patient tagging options. We also have developed symbol sets that can be customized for different public safety stakeholder missions such as e.g., search and rescue.

The computationally-intensive tasks that need to be orchestrated between the fog infrastructure and the core cloud correspond to the Panacea's Cloud Analytical Engine, whose block diagram is shown in Figure 4. Our implementation of the analytical engine within the Panacea's Dashboard has two modes of operation viz., 'Active' and 'Passive' in order to help Incident Commanders analyze vast amounts of information and make strategic decisions in allocating resources at the various disaster scenes. It also enables long-term data logging and archive capabilities that are critical for training and other disaster incident relief analytics purposes.

The active mode refers to the operational aspect that involves synchronous video communication and analysis of scene information. The scene status analysis is presented in the form of prioritized events and graph plots are generated and viewed via the Dashboard page. Thus, the active mode can help the Incident Commander to co-ordinate the handling of multiple incidents occurring simultaneously. The genesis of this occurs with an incident triggering staff assignment to various scenes. The Incident Commander thereafter can use the output of the Analytical Engine to assist the highest prioritized staff/needs. The incident is assumed to be resolved at the scene when e.g., an ambulance takes the patient away from the scene for in-hospital care. As seen in the active mode operation, the status of the responders, patients, and supplies needs to be tracked and analyzed for the Incident Commander asynchronously through a passive mode of operation, which supports visualization tools and notification functionalities.

Our design of the Analytical Engine requires a close interaction between the active and passive modes for effective coordination between the Incident Commander the Responders. The Data Logger module stores information involved with the incidents, such as video feeds, patient logs, and supplies tracking information either in the fog infrastructure or in a core cloud. Thresholds can be set for the generation of prioritized notification importance thus influencing active mode actions e.g., ambulance routing or supply restocking. Therefore, the Analytical Engine's outputs will affect the overall resource allocation, ambulance routing, and supply restoration not only at the scene, but also across the disaster responder eco-system. It does so by catering to the need of first responder groups such as Fire, Police, EMS, and health services to coordinate closely rather than act as isolated units, and thus Federal Agencies such as DoD and FEMA are developing new standards for such data sharing.

D. Geolocation Service

The geolocation service we have developed in Panacea's Cloud possesses the ability to update patient information and GPS locations automatically. In order to track all patient locations, virtual beacons are utilized to digitally label patients versus using traditional cumbersome paper triage tags. Patient movement is determined through the triangularization of paramedic HUDs and virtual beacons. The workflow shown in Figure 5 allows the system to differentiate each virtual beacon and its status. Each virtual beacon possesses a unique Media Access Control (MAC) address that is associated with its unique human-readable identifier. Once patients arrive at a hospital or when an incident is closed, the corresponding virtual beacons are reset in preparation for the next set of patients. The virtual beacon information can also be used to automatically update first responder status events (e.g., inactive, responding) or medical supply depletion rate events.

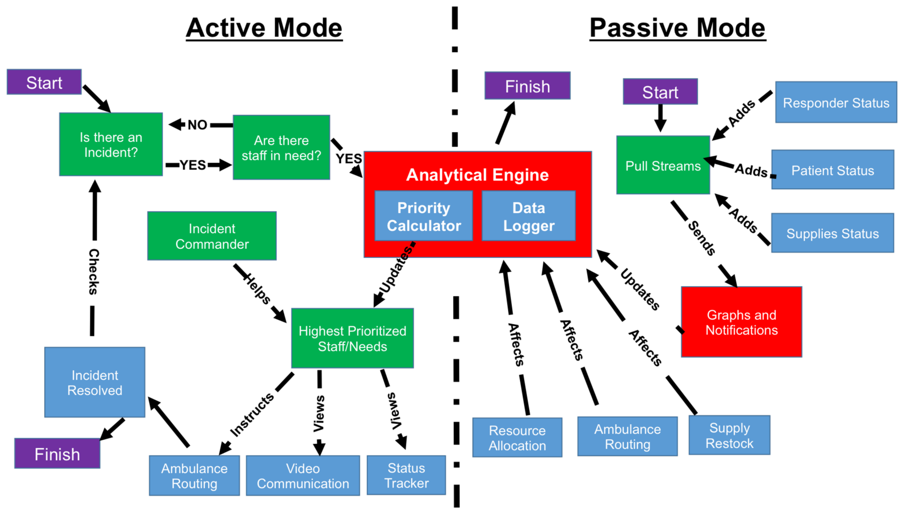

Fig. 4: Analytical Engine for Panacea's Cloud showing Active and Passive Modes for incident scene handling and care co-ordination.

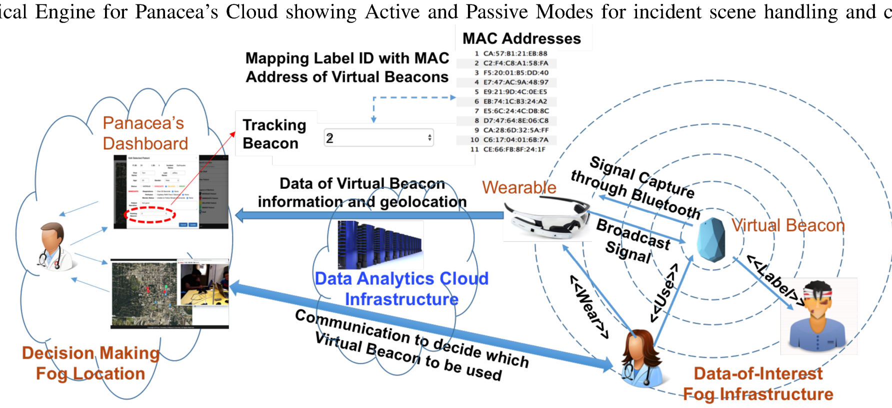

Fig. 5: Geolocation Service for Virtual Beacons Tracking using Wearable Devices in the Data-of-Interest Fog Infrastructure.

As the left side of Figure 5 shows, all virtual beacon MAC addresses and the corresponding unique identifiers are stored into a database setup either in the fog infrastructure or in a core cloud. To avoid duplicity in virtual beacon usage, each virtual beacon has an attribute identifying whether the virtual beacon is currently being used or is available for use. The status/availability of each virtual beacon on the dashboard is dependent on this attribute. The virtual beacons continually broadcast allowing paramedics to locate them with their HUDs via Bluetooth Low Energy (BLE). When a currently being used virtual beacon is found by any one of the active HUD users, the patient location is automatically updated on the map.

The virtual beacons in Panacea's Cloud are Estimote Beacons that are a commonly used hardware for micro-location status tracking and for collecting contextually relevant information about a region of interest in a mobile setting. The virtual beacon information, when used on a map, can be valuable to quickly assess the scene context and visualize important places/objects allowing for the initiation of appropriate coordination measures. To have positional accuracy and energy efficiency in an urban environment, we found that the BLE variety of Estimote Beacons are the most suitable technology due to their low consumption of power, both on the virtual beacon hardware and on the HUDs of paramedics that receive the signals. In our current implementation with virtual beacons, we use the Recon Jet heads-up display's capability to dynamically detect Estimote Beacons via BLE.

Lastly, the geolocation service reduces the amount of manual labor required from responders when communicating visual situational awareness to the Incident Commander. Moreover, Incident Commanders can also send notifications to a responder's hands-free HUD with new information and data through the service. Thus, the geolocation service helps increase the scale of patients being cared and tracked, an improvement to current practice of using onerous traditional triage tags and verbal communication via radio handsets for the difficult task of coordination of status across multiple disaster incident scenes.

IV. Experiments and Results

In this section, we first evaluate the Panacea's Cloud Dashboard usability and feature set compared to readily available solutions demonstrating the need for the dashboard. Next, we describe a set of performance tests which measured the infrastructure hardware and provide use considerations from smart device communications and cloud-fog computing context in the incident scene status analysis. Web resources for Panacea's Cloud features used in the experiments can be publicly accessed at [13] by readers to obtain latest information.

A. Usability Evaluation of Panacea's Cloud Dashboard

The usability evaluation was aimed to analyze and improve user experience of Panacea's Cloud Dashboard. The study included a design review by the research team, task-based eye-tracking data collection, and post-task surveys and interviews with over 10 participants who could serve as Incident Commanders in a real disaster incident event case. Participant inclusion criteria were: range of job experiences, specialization, experience in using digital systems, and experience in handling mass emergency situations. In the following, we discuss the results obtained from user studies and controlled experiments with the Panacea's Cloud hardware/software components, and point out the benefits of our Panacea's Cloud platform.

1) Dashboard Cloud-Fog Placement Evaluation: Our first set of experiments compared different architectures for the Dashboard placement in the hierarchical cloud-fog setup. We evaluated the usability when the Dashboard was placed in either the edge or cloud and studied issues that affect end-users' perception of the system and their decision whether to use the system or not. When the Dashboard was placed in a remote core cloud server instance in Amazon Web Services, human subject participants experienced intermittent difficulties in accessing the various Dashboard features during the testing in cases where the network connection between the core cloud and the fog infrastructure was emulated to be not resilient and adequately provisioned in terms of end-to-end available bandwidth. However, the participants experienced increased accessibility and unanimously preferred a hierarchical cloud-fog setup where the Panacea's Cloud Dashboard functionality is located in the fog infrastructure. Although there is improved accessibility and preference in the fog placement case owing to the benefits of reduced latency than a cloud placement case, the participants noted that energy sources and computation resource capacity at the edge may be limited. Moreover, they expressed a preference of a hierarchical cloud-fog setup when a high scale of data handling is needed. Specifically, they noted the importance of cloud-fog resource orchestration and traffic prioritization in a disaster network for delegation of data analytics tasks arising from geographically-distributed fogs in simultaneously occurring multiple incident response scenarios (as illustrated in Figure 2).

2) Dashboard Usability Evaluation: To analyze the Panacea's Dashboard related: (a) task completion success (effectiveness), and (b) task completion times (efficiency), we conducted an extensive eye tracking study with the 10 participants mentioned above. The usability evaluation scenario focused on a Tornado disaster incident. Task 1 required participants to become familiar with Panacea's Cloud features and share their initial impressions. Task 2 focused on the role of the physician at the University Hospital. The scenario presented a situation in which a tornado caused the roof to collapse in a nearby area. The instruction was "You want to communicate with paramedics in the field and survey the emergency situation. Please check the current status of the incident". Then, users needed to find the paramedics at a specific location (Task 3) and coordinate with them to answer the following questions (Task 4) "How many injured are at the Hall?" and "Who needs immediate treatment?" They were asked to add patient information into the system. Task 5 informed the paramedics that one patient had a change in her health condition, and users were asked to make changes (such as change the patient's condition from 'delayed' to 'immediate'). Task 6 focused on the report to the Director of the hospital (e.g., the number of patients that needed immediate attention in the nearby area).

Our results from the data analysis showed that the participants hit a 90% effectiveness rate in completing the tasks successfully with a hierarchical cloud-fog platform. The average time to complete pre-defined tasks was 24:03 minutes including 5:55 minutes to get familiar with the system as first time users. Participants stayed mostly on the index page and focused mainly on the interactive map followed by video feed page to communicate with the paramedic. Specifically, the interactive map was the feature on which users focused the most, and their focus levels were followed by the legend of markers and the left menu bar.

B. Performance Evaluation of Panacea's Cloud Platform

1) Heads-Up Display Heat Evaluation: One of the challenges of wearable technologies has long been recognized as heating issues that may affect user experience and could cause harm due to skin burns. Hence, we evaluated the Recon Jet used as the HUD by the paramedics, and we measured the temperature differences of this device activity at the beginning for the next half an hour sampled after each 5 minutes as shown in Figure 6a. We observed that the Recon Jet starts with 75 degrees Fahrenheit initially and escalated to 102 degrees Fahrenheit after 25 minutes. Note that we are using the Recon Jet released to consumers early in summer of 2015. Nevertheless, our results demonstrate that heating issues are the major challenge when used for audio and video communications, and that requires developing suitable engineering solutions that help in countering the undesired effects on users through heat management schemes, e.g., in the communication protocols and computation orchestration with cloud-fog resources.

2) HUD-to-VirtualBeacon Communication Evaluation: Making sure the HUDs can find the virtual beacons in the disaster scene is important to satisfactorily track status of patients, paramedics and medical supplies. Hence, we measured the connectivity between Recon Jet (HUD) and the virtual beacons. We found that the maximum distance from the virtual beacons to the HUD is 11.38 ± 0.48 meters. Hence, if we put the virtual beacons closer to the HUD, it is easier for the HUDs to find the virtual beacons. If the distance between the HUDs and the virtual beacons is closer to the maximum, it will take more time for the HUDs to find these virtual beacons due to a higher probability of a disconnection. Such an observed virtual beacons detection behavior of the HUD are due to the following trade-off: the shorter the distance between the HUD and virtual beacons, the stronger is the signal of these virtual beacons. For example, if we put virtual beacons within 10% of the maximum distance from the HUD, the virtual beacon's signal strength is -81.51 ± 1.17 dB. However, if we put virtual beacons within 50% of the maximum distance from the HUD, the beacons signal strength is now -95.1 ± 0.9 dB. Finally, if we put virtual beacons within 90% of the maximum distance from the HUD, the virtual beacons signal strength is -102.1 ± 0.5 dB.

3) HUD-to-Router Communication Evaluation: Having a stable audio and video session connection between the Incident Commander and Responders' HUD is crucial during triage coordination in the fog infrastructure. To this end, we measured the connectivity between Recon Jet (HUD) and wireless routers in a wide open area hosting a fog infrastructure. The

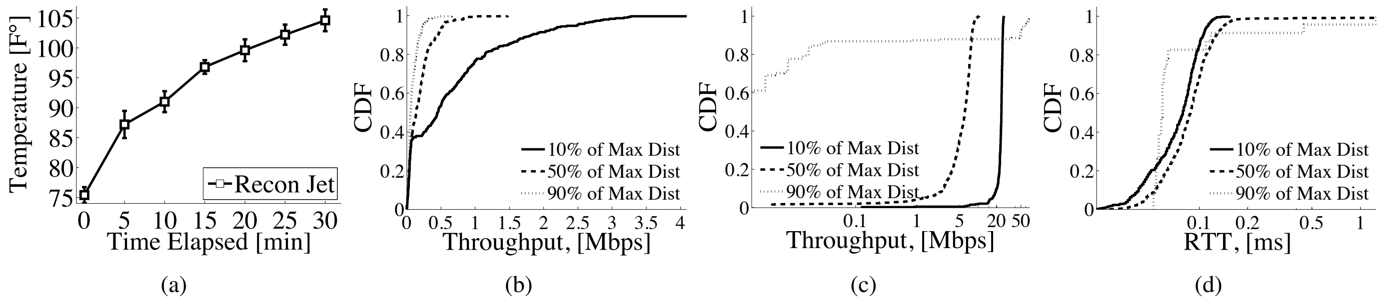

Fig. 6: (a) Recon Jet heat experiment results. The cumulative distribution function (CDF) of: (b) the HUD-to-router connection throughput; the router-to-router connection throughput, i.e., TCP (c) throughput and (d) Round-Trip Time (RTT).

results obtained from our connectivity experiments are shown in Figure 6b. We found that the maximum distance for the communication between a router and the HUD is 145 ± 29 meters. We then performed a video streaming experiment from the 10%, 50% and 90% of the maximum distance between the HUD and the router. Based on our experiment results (see Figure 6b), we can see how the connection throughput degrades with the distance increase. That translates in a low quality video communication between the HUD and the Panacea's Dashboard. Thus, the effectiveness of patients triage can also decrease.

4) Router-to-Router Communication Evaluation: For reasons similar to the previous experiment scenario, we conducted a router-to-router communication evaluation. Based on our result, the maximum distance for the router-to-router communication is 674 ± 38 meters, which means that our wireless mesh network is a scalable solution, e.g., we can cover several city blocks with a few routers. In the router-to-router experiment scenario, we perform the 100 MB file transferring over TCP protocol using Linux SCP tool from the 10%, 50% and 90% of the maximum distance between the routers. Figures 6c and 6d illustrate obtained results: we again see how the connection throughput, i.e., TCP throughput and Round-Trip Time (RTT), degrades with the increased distance factor. Moreover, it can even lead to disconnections, e.g., 60% of the time the routers were disconnected when transferring data from a location that was 90% of the maximum distance. Based on our experiment results, besides scalability we conclude that lower throughput leads to a lower quality of the video communication, and higher RTT leads to a higher command response time.

V. Conclusion

In this paper, we described our hierarchical cloud based real-time Panacea's Cloud platform that provides augmented reality benefits regardless of any physical network infrastructure available in the surrounding environment. We described how our solution can operate with minimal human interaction through integration of a standardized Incident Command System (ICS) with smart devices such as heads-up displays, virtual beacons, and wireless mesh network elements. Our solution adopts a hierarchical cloud-fog paradigm that allows for: (a) orchestration of real-time video feeds between the Incident Commander and Responders wearing HUDs, (b) dynamic real-time tracking and replenishment of medical supply levels, patient as well as responder status, paramedic and patient locations and (c) highly-integrated intelligent dashboard providing visual situational awareness. Research questions addressed in this work relate to the design consideration of a next-generation ICS that can be used for responding to simultaneously occurring multiple incidents via a synchronous geolocation service, and a map interface with intuitive symbols and analytics of large data sets of incident scenes.

Through an extensive usability evaluation and controlled platform experiments, we showed the benefits of the hierarchical cloud-fog platform in terms of ease-of-use and effectiveness for an Incident Commander. Future work is to integrate software-defined networking principles for disaster-incident response scenarios in the hierarchical cloud-fog platform communications to handle media-rich datasets.

References

[1] F. Demir, S. Ahmad, P. Calyam, D. Jiang, R. Huang, I. Jahnke, "A Next-Generation Augmented Reality Platform for Mass Casualty Incidents", *Journal of Usability Studies*, 2017.

[2] J. Gillis, P. Calyam, A. Bartels, M. Popescu, S. Barnes, J. Doty, D. Higbee, S. Ahmad, "Panacea's Glass: Mobile Cloud Framework for communication in Mass Casualty Disaster Triage", *Proc. of IEEE MobileCloud*, 2015.

[3] M. Vassell, O. Apperson, P. Calyam, J. Gillis, S. Ahmad, "Intelligent Dashboard for Augmented Reality based Incident Command Response Co-ordination", *Proc. of IEEE CCNC*, 2016.

[4] "Intermedix Solutions for Health Care" - http://www.intermedix.com; Accessed June 2018.

[5] J. Killeen, T. Chan, C. Buono, W. Griswold, L. Lenert, "A Wireless First Responder Handheld Device for Rapid Triage, Patient Assessment and Documentation during Mass Casualty Incidents", *Proc. of AMIA Annual Symposium*, 2006.

[6] Z.Alazawi, S.Altowaijri, R.Mehmood, M. Abdljabar, "Intelligent Disaster Management System based on Cloud-enabled Vehicular Networks", *Proc. of IEEE ITS Telecommunications*, 2011.

[7] E. Trono, Y. Arakawa, M. Tamai, K. Yasumoto, "DTN MapEx: Disaster area mapping through distributed computing over a Delay Tolerant Network", *Mobile Computing and Ubiquitous Networking*, 2015.

[8] T. Geumpana, F. Rabhi, J. Lewis, P. Ray, L. Zhu, "Mobile cloud computing for disaster emergency operation: A systematic review", *Technology and Society (ISTAS)*, 2015.

[9] A. Ganz, J. Schafer, Z. Yang, J. Yi, G. Lord, G. Ciottone, "Mobile DIORAMA-II: Infrastructure less Information Collection System for Mass Casualty Incidents", *Proc. of IEEE Engineering in Medicine and Biology Society*, 2014.

[10] L. Hauenstein, T. Gao, D. White, "A Cross-Functional Service Oriented Architecture to Support Real-Time Information Exchange during Mass Casualty Events", *Proc. of IEEE Engineering in Medicine and Biology Society*, 2006.

[11] V. Paelke, K. Nebe, C. Geiger, F. Klompmaker, H. Fischer, "Designing Multi-Modal Map-Based Interfaces for Disaster Management", *International Conference on Advances in Computer-Human Interactions*, 2012.

[12] S. Doeweling, T. Tahiri, P. Sowinski, B. Schmidt, M. Khalilbeigi, "Support for Collaborative Situation Analysis and Planning in Crisis Management Teams Using Interactive Tabletops", *Proc. of the ACM International Conference on Interactive Tabletops and Surfaces*, 2013.

[13] "Panacea's Cloud web resources" - https://panaceascloud.wordpress.com; Accessed November 2018.

[14] "EMS1 Media Website for Emergency Medical Service Professionals" - http://www.ems1.com; Accessed November 2018.