Disaster-Resilient Information Communication Technologies for Disaster Management: A Literature Review

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Abstract: The goal behind this research is to approach the complex issue of resiliency and communication infrastructure failures in disasters through an interdisciplinary perspective. This study looks at society and disaster management professional's dependence on technology, specifically the information communications technology infrastructure during the emergency management phases: disaster prevention, mitigation response, and recovery. After disasters, communication technologies such as cellular, radio, and internet networks are affected, greatly limiting the quality of service of these critical services. Major issues start to rise, such as sharing real-time information and communicating amongst agencies, making adequate disaster mitigation, response, and recovery difficult. My research and prototype technology will look towards disaster resilient technology such as Device to Device Mesh Networking to solve this complex issue.

Introduction: Resiliency has become quite a fashionable buzzword over the past years as the world faces an increasing risk of both natural and human-made disasters. This literature review is set up into various sections to examine the interdependence of information communication technologies and disaster management and what happens when these technologies fail. Section (1) *The Complexity of Defining Resilience* finds that "resilience" is too complex to define with one disciplinary perspective and must be examined as an inter- or multi-disciplinary perspective. Section (2) *ICT usage in Disaster Management* examines cases in which emergency management professionals rely on technology in all phases of disaster management. Section (3) *Failures in Information Communication Technologies* looks into how ICT's fail during and after disasters and the consequences of these failures. Lastly, Section (4) *Information Communication Technologies* tools will examine how innovative Internet of Things LoRa Technology can be used as a device to device mesh communications network to help disaster management and people in need.

The Complexity of Defining Resilience

There are three conceptual continuums: the tension between a *speedy recovery and timely adaptation*, the *severity* of the disturbance, and the *state of return* that resilience would need to accomplish or aspire to (Comfort et al., 2010a). By staking out an integrative and middle ground along the three conceptual continuums, we can then formulate the first definition of resilience which takes more of an approach to social science theory: Resilience is the capacity of a social system (e.g., an organization, city, or society) to proactively adapt to and recover from disturbances that are perceived within the system to fall outside the range of standard and expected disturbances (Comfort et al., 2010a). The National Research Council defines resilience similarly in their committee report Disaster Resilience a National Imperative "as the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" (NRC, 2012). While these are vast definitions for resilience, they do not focus on the critical infrastructure aspect of creating resilient systems. Research on resilience in critical infrastructure such as ICT defines it as a network's ability to provide and maintain an acceptable level of service in the face of various faults or challenges that can affect normal operations (Sterbenz et al., 2010). While many of the underlying definitions are similar, there seems to be limited research of an integrated definition of resilience that incorporates these multiple perspectives. I intend for the outcome of my research to create this multiperspective definition of resilience.

Operational Approach

Resilience can not be measured or engineered (Boin et al., 2010b). It cannot be remedied simply by adding new policies, advanced technologies and implementing a new practice to a vulnerable community. Resilience should rest on the community's physical infrastructure, socioeconomic health, the health and education of its citizens, and its natural environment (NRC, 2012). These insights form what the researchers call a socio-technical approach toward resilience (Boin et al., 2010b).

Services such as the power grid, water, and telecommunications are considered critical services to human well-being and society's functioning. These services are defined as complex systems due to the interdependent nature of one another. If the grid goes down, water plants and telecommunications infrastructure are also going to go down. In a complex socio-technical approach, resilience needs to be built into the human and institutional processes within which these technical systems are embedded (Van der et al.,2018). We need a change in telecommunications regulatory and policy frameworks that affect the overall deployment and use of ICTs especially in disaster events (ITU 2017). These changes and policies should help guide activities, roles, and responsibilities throughout an event and help ensure continuity of ICT operations following a disaster, not hamper the process (ITU 2017). There is also much need for collaboration outside of "silos" and not be one discipline or perspective that takes precedence over another. Good policies and frameworks can not happen if policymakers do not know the barriers on the tech industry side, and tech can not be created if there are too many barriers. In disaster management, a wide range of players and stakeholders are impacted by disasters and are brought into the disaster management process. Whether human-made or natural, any given disaster event may involve several different government departments at the national, state, and local levels, foreign aid and relief organizations, NGOs, private sector entities, and volunteer groups (ITU 2017). It is crucial that all stakeholders and players collaborate and work effectively with one another and share ideas of building ICTs to enable easy information sharing and interoperability.

ICT Usage in Disaster Management

whether a natural or human-made disaster, it requires partner organizations to communicate with one another effectively, make informed decisions under conditions of uncertainty, and effectively engage with individuals and local communities in collaborative efforts (Qian Hu & Naim Kapucu 2016). To have effective management, organizations rely on information communication technologies (ICTs) to help share and process real-time information, establish diverse communication channels, engage a broad spectrum of stakeholders, and coordinate efforts among a large number of partner agencies (Qian Hu & Naim Kapucu 2016).

Two-way radio technologies have been an essential tool for first responders, emergency management professionals, NGO relief organizations, private sector entities, and volunteer groups for a while. Due to interoperability and the barrier of the expense of these devices, agencies, organizations, and disaster management professionals look towards Amateur radio. Radio hobbyists known as ham operators worldwide provide critical voice and data communications for FEMA, local emergency response agencies, and the Redcross for decades. The National Library of Medicine (NLM) created a program in 2008 leveraging Amateur radio hobbyists to provide resilient email service to local users, other hospitals outside the disaster zone (NLM 2008). In 2012 during Hurricane Sandy, radio operators staffed emergency management facilities and shelters around the NY and NJ area to help with emergency communications and help keep everyone connected.[1] Amateur radio has a hard time keeping up with the increased demand for broadband data communications by emergency responders, rendering amateur radio obsolete in all but the most basic survival situations (Townsend, 2005).

With the advent of social media and the ability to share information globally and in real-time, disaster management, NGO relief organizations, private sector entities, and volunteer groups find it as a useful tool. During Hurricane Harvey, Twitter accounts of regional police departments, local fire departments, municipal offices, and personal accounts of the city's police and fire chiefs were found to be the most influential actors during the disaster, leveraging Twitter to share information during and after the disaster (Yang & Brenton, 2018). During research using Twitter about Hurricane Sandy, researchers were able to pinpoint 52M tweets from 13M users between October 14, 2012, and November 12, 2012 (Sadri et al., 2018). These tweets were people sharing information and looking for information about the storm and storm damage after the disaster. Data Science is becoming a hot topic because with all this data. We can better understand how a disaster affects a particular region or area and could allow disaster management professionals to disperse resources and help more effectively and adequately.

Failures in: Information Communication Technologies

While ICT's are critical to disaster response during a crisis, whether that be human-made or a natural disaster, they could be easily paralyzed. Some of the principal reasons they fail are physical damage, damage of supporting infrastructure, or congestion (EL & Mcheick, 2010). Damage to these infrastructures can be too costly and time-consuming to restore. It may require maintenance or replacement of complex hardware, mainly if essential components such as cell towers or cables are concerned (EL & Mcheick, 2010). Wireless networks are highly variable in

[1] "ARRL." As Hurricane Sandy Wreaks Havoc on East Coast, Hams Heed Call to Help, 2012, www.arrl.org/news/as-hurricane-sandy-wreaks-havoc-on-east-coast-hams-heed-call-to-help.

their vulnerability to physical damage and weather conditions, degrading service quality (EL & Mcheick, 2010). Some if not all of these vulnerabilities are found to hamper public safety land mobile radio systems (LMR). More than fifty percent of the Puerto Rico Police Departments' primary network, the P25 radio system, and most interoperability system equipment for emergency communications throughout Puerto Rico were not operational (Cordova et al., 2020). One of the most prevalent issues and causes of failures are breakdowns by supporting infrastructure. The cellular networks are very dependent on the electrical grid; therefore, if they go down, so do all cell sites. This was also an issue after Hurricane Maria devastated Puerto Rico, where 95 percent of all cell sites were knocked out of service due to physical tower damage, and no electrical grid was functional either ("Communications Crisis in Puerto Rico," 2019).

Issues from Failure: In ICT'S

As mentioned earlier, it is crucial to have effective communications, especially during the response and recovery phase post-disaster. The study of Mortality Reporting and Rumor Generation focused on the Government of Puerto Rico's crisis and emergency risk communications following Hurricane Maria and the post-disaster information environment to help identify factors that may have contributed to the public's negative perceptions of mortality reports. Challenges were faced due to cascading failures to critical infrastructure and key resource sectors during and post-disaster. Maria left millions of residents without electricity, water, and telecommunications for weeks to months following the disaster. Puerto Rico Police Departments' primary P25 system and the interoperability system for emergency communications throughout Puerto Rico were not operational (Cordova et al., 2020). The inadequate crisis communication planning and training, coupled with information gaps and inconsistencies, contributed to rumors around the mortality rates (Andrade et al., 2020). Consequently, the Puerto Rico Government lost credibility, perceived transparency, and public trust.

Information Communication Technologies: IoT as a Relief Tool

Today's smartphones are highly dependent on the availability of telecommunication infrastructures, such as Wi-Fi or cellular technology (Höchstet et al., 2020). Once these systems go down, our cellphones become useless. While technologies do exist that allow you to build rapid cell phone redundant communications, usually via satellite coverage, these types are often only accessible to advanced users due to regulations, high costs, or technical complexity (Höchstet al., 2020). LoRa long-range and low-power network protocol designed for the Internet of Things to support low data rate applications. It also consists of a proprietary physical layer, using the Chirp Spread Spectrum (CSS)[2] in the freely usable unlicensed industrial, scientific,

[2] "A spread spectrum technique uses wideband linear frequency modulated chirp pulses to encode information. A chirp is a sinusoidal signal whose frequency increases or decreases over time" "Chirp Spread Spectrum Definition: IoT ONE Digital Transformation Advisors." *IoT ONE*, www.iotone.com/term/chirp-spread-spectrum/t110.

medical (ISM) bands at 433, 868, or 915 MHz, depending on the global region (Höchstet et al., 2020). You can use affordable, off-shelf, twenty-dollar boards to build a mesh of these devices and make a rapidly deployable infrastructure-less communication network (Sciullo, Luca, et al., 2020). Reducing the complexity issues of cost and technical complexity.

The ClusterDuck Protocol (CDP) created by Project OWL currently runs on off-the-shelve Internet of Things (IoT) boards leveraging LoRa technology. This long-range and low-power network protocol supports low data rate applications. It consists of a proprietary physical layer that uses (CSS) In the freely usable unlicensed industrial, scientific and medical bands at 433, 868, or 915 MHz, it depends on the given global region operating in. The CDP Network currently has four components: a DuckLink IoT Device, MamaDuck IoT Device, PapaDuck IoT Device, and the OWL Data Management System (DMS). These devices are flashed with a custom operating system that instructs the devices how to create data and handle incoming and outgoing messages and how to control the onboard radio chips. The Duck devices broadcast a WiFi access point to which an end-user can connect to. There is also the option to connect to the devices over low-power Bluetooth. Once a user connects, they can use the Duck portal page to submit emergency messages or any 256 character text message. Once the message is sent, The Duck communicates that message using Device to Device (D2D) communication to the MamaDuck over LoRa. The MamaDuck communicates that message with the PapaDuck over LoRa. Then the PapaDuck pushes the message up to the cloud platform, the DMS. The Duck devices are remarkably customizable. Besides using the devices for sending emergency messages, you can also attach sensors such as temperature and pressure, air quality, gas detection, and many others to collect data in austere off-grid environments.

Conclusion:

This paper has reviewed the literature on Disaster-Resilient ICTs for Disaster Management around four main areas: (1) *The Complexity of Defining Resilience* found that "Resilience" is too complex to define with one disciplinary perspective and must be examined as an inter- or multi-disciplinary perspective. While each discipline has varying language on how they describe resilience, there was an interlinking issue of physical and technological systems' ability to balance back. (2) *ICT usage in Disaster Management* examined cases in which emergency management professionals rely on technology in all phases of disaster management. (3) *Failures in Information Communication Technologies* looked into how ICT's fail during and after disasters and the consequences of these failures. The literature found our communications infrastructure to not be resilient by nature with similar common failures through disasters. (4) *Information Communication Technologies* tools looked into the innovative Internet of Things LoRa Technology mesh communications network CDP, which can be used as a device to device mesh communications network to help disaster management and people in need. This research did not focus on other mesh communication technologies and make a comparison between each solution. In the future and continuation of this research, it is in my interest to make this comparison and make this technology even more robust than it currently is.

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