Maintaining both availability and integrity of communications: challenges and guidelines for data security and privacy during disasters and crises

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Abstract—Communications play a vital role in the response to disasters and crises. However, existing communications infrastructure is often impaired, destroyed, or overwhelmed during such events. This leads to the use of substitute communications solutions including analog two-way radio or unsecured Internet access. Often provided by unknown third parties, these solutions may have less sophisticated security characteristics than is desirable. While substitute communications are often invaluable, care is required to minimize the risk to NGOs and individuals stemming from the use of communications channels with reduced or unknown security properties. This is particularly true if private information is involved, including the location and disposition of individuals and first responders. In this work we enumerate the principal risks and challenges that may arise, and provide practical guidelines for mitigating them during crises. We take plausible threats from contemporary disaster and crisis events into account and discuss the security and privacy features of state-of-the-art communications mechanisms.

I. INTRODUCTION

A. Motivation

Communications is an important “force-multiplier” during disasters and crises [1]. The challenge, of course, is that during such events communications capability is typically reduced, while, conversely, demand for communications increases. This often creates, or broadens, the gap between what the indigenous communications capacity can provide, and the demands placed upon it. As a result supplementary communications capabilities are often bought into disaster and crisis zones in an attempt to bridge this gap. A problem arises, however, in that the security properties of the collection of communications options available in a disaster zone may not be immediately apparent, and as adversaries become more and more active during disaster response activities [2], there is a compelling need to provide responders with practical evidence-based information that will allow them to make informed decisions about their use of the available resources, so as to maximize their mission effectiveness, while minimizing the risk for harm.

B. Contribution

The primary contribution of this paper is to translate understanding generated through recent information security research into a form where it can be of direct use by those engaged in providing and using communications technologies during disasters and crises. To address this goal, we analyze and identify the most significant security requirements, possible threats and challenges for communications technologies used during disasters and crises. We also summarize several existing technologies utilized by responders as communication channels during disaster, their assumptions as well as security features they offer. Finally, we provide, using a flow chart, a useful guideline to select a suitable technology, which takes into account possible attacks that could arise during disaster scenarios.

C. Outline

This paper is structured as follows: first, representative communication scenarios in a disaster situation are presented. Next, adversary and threat models are discussed. Subsequently, the main security features considered in this paper are analyzed, followed by a description of the communication technologies used in emergency scenarios and their security weaknesses. Finally, practical guidelines for mitigating the risks and challenges from the use of different communication channels during crises are discussed. We conclude the paper providing potential future research directions.

D. First of a series

In recognition that this is a constantly evolving situation, and that it is impossible for any one paper to exhaustively explore this space, it is our intention that this guidelines paper is the first in a series. Successors will attempt to include further technologies and responses to the predominant prevailing threats and explore mitigation strategies as they evolve.

II. SCENARIOS

There is naturally partial commonality between information security scenarios between crisis and non-crisis contexts. The purpose of this paper is, however, to address the particular needs of crisis responders. In this section we define what we mean by crisis, and enumerate scenarios that are known to occur in crisis situations.
A. Definition of a disaster or crisis

There is considerable variation in the definition of a disaster, both in terms of the scope of the kind of events included, as well in the nomenclature used [3]. Authors in [3] explored the existing literature covering the definition of the term disaster, discovering hundreds of variant definitions. From those, they proposed the following as the most consistent definition of a disaster, a definition which shall be assumed throughout this paper to cover the events of interest. In this paper, a crisis is considered to be a variant descriptor for a disaster.

‘...the widespread disruption and damage to a community that exceeds its ability to cope and overwhelms its resources.’ [3]

This procedurally generated consensus definition is in strong agreement with the definition produced by the United Nations for disaster:

‘...A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.’ [4]

That is, the overarching defining characteristic of a disaster, as compared to, for example, an accident or other non-disastrous undesirable event, is that in a disaster, there is a need for external support. In the case where a disaster involves communications, this implies that additional communications capability or capacity is required to be introduced to the disaster zone. This may then require that responders, residents, existing services and authorities, and any other parties active in the disaster zone, resort to communications tools, technologies, suppliers and/or media that they would not normally use. As a result, the resulting communications may have drastically different security properties compared with the regular use. It is from this context that the following scenarios are derived.

B. Use of unknown or insecure internet connectivity

Perhaps the simplest scenario is using internet connectivity, possibly provided by unknown parties, for whatever purposes are necessary. Here the scenario is simply that the security properties of the internet connectivity are unknown. It may also be that existing internet connectivity is being used, but which is not adequately secured. For example, disaster responders may come into a disaster zone, and make use of existing indigenous internet connectivity, that may not be as secure as they are normally accustomed to. Possible risks include that the connectivity may be surveilled, censored, inter-mediated or otherwise interfered with by some party, whether or not they are the supplier of the internet connectivity. For example, a militia or other informal power-block may monitor internet communications in order to gain advantage or further their victimization of others. In some locations it is also possible that surveillance may be used to gather material in order to seek expulsion or incite or commit extra-judicial violence or other actions against disaster responders, e.g., in areas where religious or other extremist activity is present.

C. Communications between personnel within organizations

Where conventional communications are disrupted, it may be necessary to use personal communications media that are less secure than those ordinarily used. For example, analog or digital radios may be used in place of cellular mobile telephony. Or alternatively, mobile telephony standards may be used that offer inferior security properties, such as 2G (and some 3G) GSM networks. In such cases, many of the same risks can arise as when using internet connectivity. That is, communications may be eavesdropped, falsified, or otherwise interfered with. Eavesdropping alone can pose a significant risk to personnel, when it allows hostile actors to anticipate their movements and disposition. A complication that can arise is that in some locations it may be desirable for an organization to communicate in the clear, so as to avoid causing anxiety for the government in the disaster zone.

D. Communications between organizations

Communications between organizations is in many regards isomeric to communications within organization, but with any negative impacts being able to affect more than a single organization.

E. Dissemination of public safety or similar information

Public dissemination of information differs strongly from the above scenarios, where confidentiality is a prominent requirement. Instead, for public dissemination of information it must be readable by all parties, and thus sent in the clear, but it must also be authentic, that is not impersonable, and it must not be able to be modified, which could lead to dangerous mis-informing of recipients. A further issue is timeliness of the information, so that only information that is still correct and useful is received, and cannot be replayed at a later time by a hostile party.

III. Adversary and threat models

A user in a communication network during a disaster can act in any of the following roles: (1) an honest user, who contributes to the communication, cooperates with neighbors, acts according to the specified protocols, rules, etc, or, (2) a malicious user, who tries to manipulate or subvert the normal communications. An adversary’s behavior and the impact of an attack can vary according to the capabilities of the adversary as well as the scenario or situation in which an attack occurs. Whether an adversary works alone and independently (single attacker), as compared to whether they collaborate with other malicious users (colluding attacker), this will depend on the goals of an attack, but also on the motivation of these attacks. On the one hand colluding attackers can be desperate people, who try to take advantage of available resources without regard for others, for example, to meet their basic needs for food, shelter and other materials. For these actors, they can perhaps be modeled from a game theory perspective as seeing the situation as a zero-sum game, and they are seeking to maximize their gain, without being arrested by the fact that it necessarily increases the loss of other parties. That is, their
objective is their gain, rather than the loss of others. On the other hand, there can be actors such as terrorists, who can also be colluding attackers, but who are actively trying to exploit destruction and chaos in the civilian communication causing panic and confusion, and can perhaps be modeled from a game-theory perspective as seeking to minimize the sum of the game from the perspective of other parties. That is, rather than failing to be arrested by the presence of a zero-sum game, they are actively motivated by this. As this analysis reveals, while their motivations, and thus modes of operation may differ, they have the same final effect of undertaking actions that induces losses upon other parties. In this subsection we are going to give a high level overview of possible adversaries that can be considered during a disaster scenario:

- Non-cooperative user’s behavior: In some situations when normal users (civilian or organization) compete to gain some limited resources, they may cease cooperative actions, as they actively seek to optimize their own resources. Their behavior can affect the entire communications channel as a whole.

- Militias: Haiti Earthquake of 2011 saw many examples of this kind of adversary [5]. Militias broke into stores and induced a state of violence and anarchy. Without a security mechanism for communication channels, the militias are able to listen to the communications of others, and use this intelligence to their advantage, and therefore the disadvantage of others [6].

- Terrorists: A terrorist has different purpose that vary according to the situation: creating fear in the population, gaining international publicity for a terror group, but also supporting political or religious ideology, perceived or actual inequitable treatment, among other factors [7], [8].

- Looter: During the Katrina Hurricane of 2005, fabricated reports of the shooting of rescuers and civilians, act of violence, etc., were reported [9]. The spread of rumors about looting and the lack of authority’s presence contributed to a general rise in panic and wide distribution of inaccurate information to citizens. Attackers used this information and looted abandoned properties or tried to take the resources of isolated community residents.

- Political motivated organizations: In the Russian - Georgia conflict of 2008, governmental and civilian infrastructure was the victim of cyber attacks, whose main purposes was to disrupt and to compromise the communication within Georgia, as well as to gather intelligence from and about military and political groups [10].

In this section, we describe possible mechanisms that can be used by an adversary in order to achieve an attack:

1) Eavesdropping: Passive eavesdroppers will attempt to intercept the location information or movement patterns of users, e.g., to collect social graphs of participants. A malicious user can use this information for subsequent attacks.

2) Message tampering: Attackers can inject false location information or modify legitimate information affecting the reliability or truth in such networks. For example, an adversary may distribute fabricated information about available local infrastructure (e.g., hospitals or shelters locations) to overload them.

3) Identity theft: Adversaries may pretend to be valid users, or other legitimate identities. For example, they could pretend to be a trusted authority, such as the government or a well-known NGO, and send false information about a disaster which does not exist, causing panic among the populace.

4) Jamming: Attackers may block future packets or the communication channels between normal users. By deliberately interfering in this way, users can be prevented from communicating with other devices, and produce a lack of availability. Single or colluding attackers may try to interfere with data sent by authorities, e.g., warnings or announcements about potential hazards, to further amplify the effect of their attack. For example, by maintaining the impression that the communications channels are operative, e.g., by allowing all other communications to continue unimpaired, thus reinforcing the implicit belief among other parties that there are no suppressed communications.

IV. INFORMATION SECURITY MODEL

We identify the main security properties considered in this paper when choosing a specific system for a crisis.

A. Confidentiality (that no one else can listen in)

There are scenarios, where it is important to ensure that only the specified person can read the exchanged information [5]. [10]. Attacks to this property attempt to get access to sensitive information without accurate authorization. Hence, different methods and mechanisms are necessary to keep the content of a message secret from unauthorized users. In certain scenarios, however, where the data is public by itself, this property may be not mandatory, or even desirable.

B. Integrity (that communications cannot be modified)

Attacks to the integrity of communications attempt to modify legitimate information, for example replacing the text of a communications with text of the attackers choosing. In this context it is necessary to verify if the exchanged information between two parties was altered during transmission, as well as to protect the content of a message against any alteration. In most cases, this is a mandatory property, as otherwise an attacker could maliciously cause arbitrary misinformation.

C. Authenticity (that no one can impersonate another)

The receiver of a message should be able to corroborate that the purported sender is in fact the authentic author of the communication [9], e.g., for public alerts or warnings from rescuers. Without such an authentication mechanism, users could impersonate one another, with considerable scope for disseminating mis-information with malicious intent.
D. Validity (that a communication is fresh, and has not been superseded by another)

In some scenarios it is important to verify if the exchanged data is still valid data [9]. Without a mechanism to verify the freshness of the information, an adversary can replay old messages without being detected, and the old data may not merely be of reduced value, but may in fact be harmful. For example, an attacker could re-play messages indicating that particular places are safe (or unsafe) to influence the activities of people and/or agencies to their advantage.

E. Anonymity, Privacy, Social Accountability and Non-Repudiability

Anonymity, privacy, social accountability and non-repudiability represent an additional set of security properties that are particularly important when private persons communicate with one another, with the public at large, and in some cases, with government and authorities. Together, they allow users to interact without excessive fear of the consequences of their communications, or of the consequences of the communications activities of others (including passive collection of communications). However, the focus of this paper is on communications among persons and organizations where the opposite is the case: where it is highly desirable for the authenticity of persons and their actions to be sustained. Therefore these topics are not within the scope of this paper. However, they are not necessarily irrelevant to all disaster scenarios; their importance can differ according to the nature of the emergency scenario. For example, anonymity can be of significant importance in scenarios where a government controls communication channels. In such cases, it is important that the opposition or other people with differing opinions or anti-government positions cannot be identified, or at least cannot be distinguished among a group of senders. An example of this is following the 2008 Sichuan Earthquake in China, where a teacher was sentenced to one year of prison, because he posted photos about the damage occasioned by the earthquake on schools [11].

V. COMMUNICATION TECHNOLOGIES

Different technologies can be used in the communication between organizations and civilians after disaster scenarios. These systems, however, may suffer a lack of security, providing either none or weakened security feature(s). This is particularly the case for security features that depend on some kind of centralized infrastructure. For example, many communications systems offer security features that depend on the availability of centralized infrastructure, e.g., internet access is often required to check the validity of digital certificates. The following text describes a number of the communications technologies that are often provided post-disaster, and explores their security properties.

A. Infrastructure-less technologies

1) Analog Radio: Analog radio has played a prominent role in disaster communications for many decades, and as our private correspondence with New Zealand Red Cross confirms, this role continues to the present. In particular, Ultra High Frequency (UHF) and Very High Frequency (VHF) hand-held radios are frequently used to provide communications among personnel deployed during and following disasters. High Frequency (HF) radio is still present in many situations, however NZ Red Cross informs us that its role is diminishing, and is increasingly being replaced in the field by lower-cost satellite based-solutions, such as the deLorme inReach [12], that allows global communications reach, without the complications of maintaining and operating an HF radio installation, including ensuring that trained personnel are available.

Analog radio is also an unsecured broadcast medium. That is, any party with a suitable radio is able to listen to all communications. Indeed, all parties must listen to all communications if they are to hear communications that are intended for them. In some situations this broadcast nature is helpful, for example, when information is non-confidential, and desirable for multiple parties to receive, e.g., the disposition of members of a team as they carry out their activities. However, even in such cases, adversaries are able to easily listen to communications, replay recorded communications (simply by recording the transmissions of others on a channel, and then replaying them into the microphone of a radio at a later time), or to more actively participate in communications in a variety of subversive, or even merely disruptive manners. This is because analog radio is lacks confidentiality, authenticity and integrity.

2) Digital Radio: The arch-typical example of this technology in Europe is Terrestrial Trunked Radio (TETRA), which allows the exchange of speech and status messaging with a limited data rate. Digital radio systems offer some improvements over analog radio, in that communications often supports confidentiality, and some digital radio systems can authenticate communications, and ensure their integrity. However, this is not the case for all digital radio systems, and care must be taken to gain an adequate understanding of how confidentiality, authentication and integrity are provided by the radio system, and how they can be protected against common attack paths, such as theft, loss of a radio handset or traffic analysis, which imply a significant threat in some environments, e.g., in presence of militias. Also, some digital radio systems require supporting infrastructure, such as a base station or central repeater.

3) Off-grid ad-hoc networks: In addition to the traditional analog and digital radio communications system, distributed mobile ad hoc networks (MANET) have been developed over the past twenty years or so, primarily enabled by the development of 802.11 Wi-Fi [13], [14]. The general intent of such networks can be summarized as facilitating the creation of networks, without reliance on conventional fixed infrastructure. Within the humanitarian space, projects of potential interest include, without limitation, the FreiFunk and associated projects in Europe [15], [16], the Commotion Wireless project from the USA [17], [18], and the Serval Project from Australia [19]–[22].

Each of these projects has a particular focus, for example,
FreiFunk and the related movement can be perhaps simply summarized as facilitating the provision of (typically wireless) internet access, independent of existing infrastructure. The Commotion Wireless project is primarily interested in providing secured internet and intranet access in difficult environments, such as providing communications for dissidents under oppressive regimes. The Serval Project is primarily focused on providing secured mobile telecommunications, without dependence on existing infrastructure, with an emphasis on disaster response and isolated communities. The differing approaches and intentions of each projects results in a diversity of security properties of these networks. However, many modern incarnations pay particular attention to the issues of confidentiality, authenticity and integrity of communications—including the difficult matter of managing the routing of communications among the devices in a MANET [23], [24]. When contemplating using such systems, particular emphasis should be placed on ensuring an appropriate fit for the security requirements at hand.

B. Infrastructure-based technologies

1) Cellular Networks: Cellular networks were designed to provide voice applications based on digital technology, and offer improved confidentiality, authentication and integrity compared with the first generation analog cellular networks. While the situation has improved with each successive generation of cellular technology, significant security issues remain and are constantly uncovered. Different studies and important examples [25]–[27] have demonstrated the feasibility of some attacks exploiting successfully the existing vulnerabilities and weaknesses of the underlying standards or poor operational practice by operators, e.g., by redirecting user traffic or theft of valid user identities, particularly in the face of a determined adversary who has the means to obtain specialized hardware that allows interception of 2G and 3G communications with relative ease. Such hardware is available for less than US$1,000, placing such attacks well within the reach of many adversaries.

Also, cellular networks are designed with “lawful intercept” capability included, and therefore any use of such networks must take into account that not only the local government, but also potential adversaries with sympathizers within cellular carriers, may be able to intercept all communications, and use the advanced location capabilities of modern cellular base-stations to obtain pervasive location data on users, including reliable predictions of where users are likely to be at a future time and date. This can be particularly hazardous in civil unrest situations, where one or more of the belligerents have reason to be opposed to the delivery of humanitarian relief in an area. For example, the authors are aware through private correspondence of situations where the resources of cellular networks and/or ISPs are alleged to be made available to such parties, and where that information has apparently been used to target relief workers.

2) Satellite Radio: Satellite communication can offer high-speed data and video transmission in crisis. Many systems, however, suffer problems such as weak security properties, problems with synchronization, and in some countries, their use during disasters may not be allowed. Notwithstanding the above difficulties, newer satellite communications tools, such as short-burst-data (SBD) modules connected to the Iridium constellation offer the ability to communicate from most locations on the surface of the earth using an SMS-like interface, and only a small battery powered satellite terminal that can be carried in a pocket, and can pair with a smartphone. However, the security on the Iridium SBD service has to be described by ‘security by obscurity’.

There is sound reason to believe why a determined attacker could listen to all Iridium SBD data directed to a given locale, by demodulating the broadcast signal from each satellite as it passes overhead, using only a few hundred dollars of equipment [28]. This attack is particularly concerning, because it would seem that the SMS-like service is unencrypted, and could be relatively easily spoofed. That is, a determined adversary could potentially transmit signals that an Iridium SBD would interpret as having come from a satellite, thus allowing an adversary to inject themselves arbitrarily into conversations. Because the transmissions from the satellites are unencrypted, this could be implemented in a manner that uses intelligence gathered from the transmissions to allow the mounting of sophisticated attacks that would be difficult for an end-user to detect.

3) Social media: In recent years, different disaster scenarios have widely shown the importance and benefits of social media (e.g., twitter, facebook, webblogs, wikis and other web-based resources) in such situations [5], [6], [29], [30]. These media enable a communication channel between the different actors in the disaster area, but also facilitate the coordination, organization and involve spontaneous volunteers and civilians in the rescue efforts. Platforms such as crowd-sourcing and related mapping tools have begun to play prominent roles following disasters, allowing important information to be collected, classified and organized, greatly increasing its value and utility in the response effort.

These communications channels, however, build on existing communications infrastructures—mainly the internet—with a central infrastructure, which itself may be affected after a disaster. Due to the huge volumes of data and redundant information generated by such media, the identification of relevant messages without an appropriate prioritization of the information can be difficult, affecting the ability for a prompt and efficient response by rescuers organizations. An interesting example was Hurricane Sandy in 2012, where more than 20 million tweets about the disaster were generated [31]. Furthermore, the open nature of social media (every person can publish new information, or repeat existing information) complicates the validation of the data being spread, making it easier for malicious users to manipulate data, or in some cases, cause the spread of false information. The Safety Check feature activated by Facebook after the Nepal earthquake in 2015, was a good example of the misuse of social media during disaster scenarios [32].
TABLE I
SUMMARY OF COMMUNICATION TECHNOLOGIES AND THEIR SECURITY FEATURES IN DISASTER SCENARIOS

| Technology                  | Examples             | Security Features | Comments                                                                |
|-----------------------------|----------------------|-------------------|--------------------------------------------------------------------------|
| **Infrastructure-less**     | HF radio             | 0                 | n.a.                                                                     |
| **Technologies**            |                      |                   | In situations where it is desirable to send non-confidential information and to reach multiple parties, the broadcast property of analog radio is very helpful. Due to the broadcast nature of this medium, however, any party with a suitable radio is able to listen to all communications, or replay old recorded communications. This is, confidentiality, integrity, authenticity and validity are not provided by analog radio. |
| Analog Radio                | TETRA, Satellite     | C*, I*, A*        | Digital radio provides several improvements over analog radio. Some level of security such as confidentiality, authentication, etc., can be provided by these radio systems. Nevertheless, different analyses [33], [34] have identified significant security weaknesses of these systems, which lead to potential attacks that could affect the provided security features such as confidentiality, etc. For example, an adversary can get access to sensitive data, track devices or analyse exchanged traffic. Furthermore some digital radio systems still require some form of supporting central infrastructure. |
| Digital Radio               | Project VSAT         | C*, I*, A*        | MANETs have emerged over the past twenty years to enable a communication without reliance on traditional fixed infrastructure. Different projects focused on MANETs as a viable solution to implement multi-hop communication in emergency scenarios [23], [24]. These technologies have the potential to provide advanced security properties, e.g., confidentiality and authentication, without recourse to any centralized or fixed infrastructure [35], however care should be taken to verify that the desired properties are provided by the particular system being considered. |
| Off-grid ad-hoc networks    |                      |                   |                                                                          |
| **Infrastructure-based**    | Iridium, VSAT,       | C*, I*, A*        | Satellite communications are widely used in different scenarios, including in emergency communications. In 2014 IOActive [36] evaluated several satellite communication systems and identified numerous vulnerabilities that attackers could exploit. For example, attackers can disrupt all communications on some satellite systems by compromising just a few devices. |
| **Technologies**            |                      |                   |                                                                          |
| Satellite Radio             |                      |                   |                                                                          |
| Cellular Networks           | 2G                   | 0                 | 2G Cellular networks suffer from inherent security weaknesses. These weaknesses arose during the rapidly growth of cellular networks, particularly as they began to carry data as well as voice. Existing vulnerabilities such as targeting the availability, redirecting user traffic or cloning valid user identities, represent several of the readily exploitable security flaws of 2G networks. Although 2G networks use different encryption methods, some of the mandatory mechanisms do not provide any security and are vulnerable to some attacks. Sound operational security is of utmost importance in 2G networks. |
| 3G                          | C*, I*, A*           |                   | 3G Cellular networks provide improvements, new functionality and security features over 2G networks. These networks, however, also inherit some vulnerabilities and threats from 2G, e.g., flooding attacks, which exploit paging vulnerabilities in both cellular network generations. 3G cellular networks implement different countermeasures to avoid many of the 2G vulnerabilities. These countermeasures, however, have no effect in dual operation mode, that is when 2G and 3G networks employ the base stations simultaneously (inter-operation between 2G/3G networks), which is still common in many countries [35]. |
| 4G                          | C*, I*, A*           |                   | The security measures of 4G networks are very similar to those of the 3G Cellular networks. The main additional security improvements of 4G networks are focused on key management and protection against physical attacks against base stations. Nonetheless, some security issues still remain a problem in the 4G networks. Some studies have already identified security vulnerabilities in the architecture of 4G networks [37], [39]. |
| Online Social Networks      |                      |                   |                                                                          |
| Email service               |                      |                   |                                                                          |
| Chat, VoIP systems          | Skype, Whatsapp      | C*, I*, A*        | Alternative systems such as VoIP or chat applications are very helpful during emergency scenarios. They do not only offer the same features from traditional communication channels, e.g., PSTN, but can also provide additional capabilities, e.g., video and large scale calling. Nevertheless, many of these implement proprietary protocols and security countermeasures, which imply interactions between different technologies that can also lead to unexpected results which may in turn result in security issues [32], [33]. |

**Legend:** 0 = considered insecure; n.a. = not applicable; C = Confidentiality of data; I = Integrity of data; A = Authenticity of sender; * = known issues

VI. GUIDELINES

In this section, we summarize the main communication technologies utilized during disaster scenarios and known security threats found in the literature.

Table I compares communication technologies discussed in Section V. It provides selected references to relevant information security surveys or known vulnerabilities, as well as security features offered by each technology (depending on configuration). We were only able to find relatively few studies or related work that supply directly helpful information about possible issues, and security requirements for such technologies in disaster scenarios. The summarized technologies are
not necessarily applicable to all disaster scenarios, their importance and requirements can differ according to the features of the emergency scenario, as well as by the communication mode(s) required. Overall, the results in Table I indicate the lack of security for several communication technologies, e.g., on analog radio communication, 2G cellular networks, etc., which nonetheless continue to be major communications channels used during disasters.

Due to the wide range of scenarios and their specific characteristics, it is difficult to generalize and mandate specific technology choices and security settings. Likewise, it is impractical to specify requirements for all imaginable disaster scenarios in detail. We simply encourage practitioners to educate themselves of these issues, so that they can make informed decisions relevant for their situation.

**Fig. 1.** Flow chart for the selection of appropriate communications technologies for use during disaster scenarios

In support of this, we have attempted to identify the minimal steps necessary to rationally select an appropriate technology during crisis (Fig. 1).

First of all, it is important to identify possible security threats that can arise in the crisis. Then, one can define which communication modes are required (e.g., to transmit voice, etc). Following this, one can also consider and specify the minimal security requirements that a communication technology should provide in order to minimize the impact of possible adversaries identified in the first phase. Finally, one can select a technology or technologies from all available technologies and verify if the technology complies with the identified requirements.

**VII. Conclusion**

Communications technologies for emergency response predominantly focus on the establishment of communications after a disaster. Security is often completely ignored due to missing knowledge on security mechanisms and the complexity to implement secure communications. Nevertheless, foundational security features, like authentication, confidentiality and integrity become mandatory, as without those features significant risks result, e.g. false information can be distributed during crisis situations, resulting in confusion or a loss of trust amongst recipients.

To address these issues, this paper has presented an overview of some scenarios that occur in crisis situations, where crisis responders use insecure channels. Furthermore, we have provided an analysis of possible threats that may appear during a disaster, defining an adversary model. Hence, we have described the most significant security requirements to achieve a practicable and secure communication after a disaster scenario.

Finally, we propose a flow chart (see Figure 1) which summarizes the different steps considered necessary for choosing an appropriate technology to communicate during a disaster (see technology overview in Table I). It is our hope that these contributions may be of practical assistance to emergency and disaster responders.

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