A systematic review of how wireless communications work and interact in a natural disaster situation in Iquique city

Una revisión sistemática de cómo funcionan e interactúan las comunicaciones inalámbricas en una situación de desastre natural en la ciudad de Iquique

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ABSTRACT

This work applies a Systematic Literature Review (SLR) based on the "Systematic Review Process to Software Engineering" methodology to determine if, in a natural disaster situation in the coastal city of Iquique, there are wireless communication technologies and protocols to permit the connectivity even if the communication is turn off. The SLR defines two questions. The first one aims to identify the most likely natural disaster situation for Iquique. The most common natural disaster situation was determined using information from the literature analyzed, along with its conditions, occurrence, and impact on the city. The second question depends on the answer to the first one and seeks to find the most suitable technology for the natural disaster situation obtained in the first question. The articles were classified based on their indexing and multi-phase review. The results show the most suitable technology available for mobile device communication considering the most frequent scenario of natural disasters in the city of Iquique.

Keywords: Literature systematic review, ad hoc technologies, natural disasters, wireless communication networks.

RESUMEN

Este trabajo presenta una Revisión Sistemática de Literatura (SLR) basada en la metodología "Proceso de Revisión Sistemática para la Ingeniería de Software" para determinar si existen tecnologías y protocolos de comunicación inalámbrica que permitan la conectividad en una situación de desastre natural en la ciudad costera de Iquique, incluso si la comunicación se ve interrumpida. La SLR aborda dos preguntas. La primera tiene como objetivo identificar la situación de desastre natural más probable para Iquique, utilizando información proporcionada por la literatura analizada sobre sus condiciones, ocurrencia e impacto en la ciudad. La segunda pregunta depende de la respuesta a la primera y tiene como objetivo encontrar la tecnología más adecuada para la situación de desastre natural obtenida en la primera pregunta. La clasificación de los artículos se basa en su indexación y revisión en diversas etapas. Los resultados muestran la tecnología más adecuada disponible para la comunicación de dispositivos móviles en el escenario más frecuente de desastres naturales en la ciudad de Iquique.

Palabras clave: Revisión sistemática de literatura, tecnologías ad-hoc, desastres naturales, redes inalámbricas.

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INTRODUCTION

Over the past decade, Iquique has faced numerous natural disasters [7] that have impaired critical services such as internet access, electricity, water, gas, and telephony. These incidents have highlighted the necessity for technology that enables communication among Iquique residents when conventional infrastructure fails. According to SUBTEL, Chile had 24.6 million mobile lines in use in 2020 for a population of 17 million (Chilean Census 2017 [18]), emphasizing the technology's widespread adoption. However, uncertainty remains about whether any technology can facilitate mobile device communication without a centralized communication infrastructure during a natural disaster.

This paper seeks to answer the following question: Are there ad hoc network technologies that facilitate communication and interaction between individuals using their mobile devices that lost internet connection during natural disasters in Iquique? Two main sub-questions guide the study to investigate this general question thoroughly:

- What is the most probable natural disaster scenario for Iquique?
- Given the natural disaster scenario identified in question 1, what is the optimal wireless transmission and communication technology for mobile devices in wireless networks?

A systematic literature review (SLR) is conducted based on the "Systematic Review Process to Software Engineering" methodology to explore these research questions and address the research in general. The paper is organized as follows: Definitions and Classification of Natural Disasters in Chile and Technology Classification; Methodological Selection, which details the SLR methodology; Application of the Selected Methodology, which presents the SLR results and discussion; and finally, a conclusion discussing the study's SRL results and limitations.

Definition and classification of natural disasters in Chile

A natural disaster is an event that generates great damage or destruction over a vulnerable geographical area [8], [9], [10]. Events like these have a direct impact on the normal functioning of the compromised area. In Chile, natural disasters are classified according to the "natural hazard or risk that originated them" [4], being a natural or man-made disaster. Risks or natural hazards correspond to the probability of a specific natural phenomenon with a defined duration and intensity, which may potentially cause damage. There are five types of natural hazards or risks: Geological, Meteorological and Hydrological, Climatological, Biological, and Cosmic.

Wireless network technology

The main topic of this review is to find the most suitable wireless technology with prevalent use for general-purpose mobile devices. This wireless technology facilitates data transmission without needing a physical medium with a predefined path [5]. Particular attention is given to ad-hoc networks, which can operate without a centralized network infrastructure [6]. In such networks, nodes can function as data sources and destinations or as routers in a collaborative environment. Examples instances of ad hoc networks include Mobile Ad Hoc Networks (Manet) [12], Vehicular Ad Hoc Networks (VANET) [12], Wireless Mesh Networks [11] (Mesh Networks) [13], [14], and Smartphone Ad Hoc Networks (SPAN) [14], [15], among others.

METHODOLOGICAL SELECTION

The methodological selection was made by comparing three authors related to the software engineering field (Table 1), which proved to be the most suitable for this work. The methodologies considered were Carrizo's (EMRSL) [1], Kitcherman's (SLRSE) [2], and Mian's (SRPSE) [3]. The comparison result showed that the SRPSE Methodology includes improvements that address potential problems in some review phases.

- Includes a well-defined base template for each stage of the work.
- Allows for justifying the planning of the review prior to its execution.
- Incorporates documentation of the entire process.
- Record the results obtained, including the difficulties encountered during each process.

SYSTEMATIC METHODOLOGY APPLICATION

Planning phase

The objective of the planning phase is to identify wireless communication technologies and protocols

Table 1. Comparison between methodologies for RSL.

	EMRSL	SRLSE	SRPSE
Applicable to any RSL job in any area.	✓	×	✓
Methodology with feedback phases.	✓	✓	✓
Originates from reviews conducted for Human Sciences and Medicine.	×	✓	×
Relies on other RSL methodologies.	✓	✓	✓
Execution is carried out in only three fundamental blocks.	✓	✓	×
Includes the other methodologies compared.	×	×	✓
Aggregates and formalizes ideas on SLR protocols developed in the medical area.	×	×	✓
Introduces a description of the process to support the use of the template.	×	×	✓
Allows to have a data backup.	×	×	✓
Templates are available for easy use.	×	×	✓

that could prove beneficial in natural disaster situations in Iquique. The following general research question has been formulated to address the objective of this SLR:

- Are there ad hoc network technologies that ease communication and interaction among individuals using their mobile devices with a turn-off communication infrastructure during natural disasters in Iquique?

This research has been subdivided into two specific questions due to the broad scope of this research:

- **Question 1**: Considering the context of natural disasters, what potential disaster scenarios could transpire in Iquique?
- **Question 2**: In networks, what existing technologies allow communication between mobile devices when there is no Internet access during a natural disaster?

Selection criteria

Under the SRPSE methodology, the execution phase necessitates the establishment of explicit inclusion and exclusion criteria for each research question. These criteria serve as a guideline for determining the relevance of the literature and sources, ensuring that the data gathered is directly related to the SLR objectives. Table 2 provides a detailed illustration of applying these criteria to address Question 1.

Review execution phase

Upon defining the criteria, the execution phase of the systematic review commenced. Papers procured during this phase are evaluated based on predetermined criteria. The chosen articles shall be subjected to further processing to extract pertinent information to address Questions 1 and 2. Table 4 presents the outcomes of the respective execution, wherein T signifies Total Articles and $S.T$ represents Total Articles on the subject matter.

Table 3 delineates the inclusion and exclusion criteria for Question 2. Similarly to the prior Table, the criteria for Question 2 are established.

Extraction of relevant information

Additional inclusion and exclusion criteria were established for information extraction from the articles addressing Question 1 to categorize and contextualize the articles. In the initial assessment of Question 1, 29 articles were excluded due to their failure to comply with the maximum 8-year age limit. Likewise, in the process of extracting information for Question 2, new inclusion and exclusion criteria were instituted. As a result, the preliminary evaluation of Question 2 yielded 36 articles, from which a mere six were selected (Table 5).

The subsequent phase in the research process is the Extraction Run, which requires evaluating the degree of objectivity in the obtained results. An excerpt of the extraction outcome can be found in Table 6, as presented below:

The information extraction process for Question 2 was conducted by considering the inclusion and exclusion criteria related to mobile equipment used in natural disaster scenarios and their ability to operate without centralized connectivity. Table 7 exhibits a segment of the quality assessment results for Question 2.

Table 2. Inclusion and exclusion criteria for Question 1.

Inclusion	Exclusion
• Eligible documents include those addressing natural disasters in the city of Iquique. • Acceptable document types for compilation encompass Books, Articles, Reports, Book Publications, Instructions, Maps, and Records in lists. • Eligible materials involve publications and records of Iquique's most destructive natural disasters. • Suitable materials also cover publications and records of Iquique's most frequently recurring natural disasters. • Publications and records from Chilean government institutions or organizations are eligible. • Publications and records from Chilean public agencies are included. • Government-recognized Chilean academic institutions' publications and records are eligible. • The literature review includes studies in both Spanish and English languages.	• Publications, articles, and records of natural disasters in Iquique that resulted in minimal damage, specifically those that lasted merely one hour, shall be omitted. • Documents in the form of thesis publications are to be excluded from consideration. • Materials not affiliated with or originating from Chilean governmental institutions, organizations, or their associates shall be excluded from the systematic literature review.

Table 3. Inclusion and exclusion criteria for Question 2.

Inclusion	Exclusion
• Scientific publications eligible for inclusion solely focus on ad-hoc network communication technologies and mobile communication devoid of internet connectivity. • The temporal scope of inclusion is confined to scientific publications dating back a maximum of 8 years from the present day. • The systematic literature review will encompass studies conducted in three linguistic mediums: English, Spanish, and Portuguese. • All works, approaches, and methodologies related to wireless cellular phone network communication without internet access shall be included in the review.	• Dissertations shall be omitted from consideration. • Articles originating from workshops that need more publication for a scientific audience shall be excluded. • Surveys or materials devoid of a well-articulated research question shall not be considered. • Works without reference shall be excluded. • Works comprising at most seven references shall be included. • Employment falling outside the temporal range up to 8 years prior shall not be considered. • Documents lacking recognition by the scientific community shall be excluded. • Non-indexed documents shall be omitted from the systematic literature review.

Table 4. Results for the search of Question 1: What are the possible scenarios of natural disasters in the city of Iquique?

	Scopus		Web of Science		Science AAA		Microsoft Academic		Google Scholar		Google	
Search Terms	**T**	**S.T**	**T**	**S.T**	**T**	**S.T**	**T**	**S.T**	**T**	**S.T**	**T**	**S.T**
Possible scenarios of natural disasters to occur in Iquique.	1	1	2	1 + Rep	1	0	91	0	448	0	140	4
Natural disasters in the city of Iquique Chile.	0	0	0	0	1	0	70	0	260	1	156	2 + 2 Rep
The most repeated natural disasters in Iquique.	0	0	0	0	1	0	112	0	75	0	152	0 + 3 Rep
Most common natural disasters in Iquique	1	1 Rep	0	0	2	0	281	0	584	0	275	0 + 3 Rep
Article, book, or document on Natural disaster in Iquique.	0	0	76	0	0	0	300	0	561	0	141	4 Rep
Article, book, or document on Natural disaster in the Tarapacá region Iquique.	0	0	76	0	0	0	168	0	555	0	129	5 Rep
Total	1		1		0		0		1		6	

Table 5. New inclusion and exclusion criteria for Questions 1 and 2.

Criteria	Question 1	Question 2
Nº	Number of Selected Items	Number of Selected Articles
Title	Article Title	Article Title
Author	List of Article Authors	List of Article Authors
Review	Contextual summary of the analyzed article	Contextual summary of the analyzed article
Type	Type of Natural Disaster	Data Network Type
Damages	Scale of 1 to 5	–
Level	Degree of destruction caused by the natural disaster	–
Technology	–	Connection technology
Connectivity	–	Degree of autonomy

Table 6. Excerpt from the study quality assessment of the total results of the 1st, 2nd, and 3rd performance for Question 1.

NO.	Title	Year	Type of Document	Institution	Language	Disaster	Compliance?
1	Major Earthquakes in Chile.	2021	Historical Record	CSN	Spanish	Earthquake	YES
2	Elaboration of a Seismic Scenario in Iquique.	2017	Book	CIGIDEN	Spanish	Earthquake	YES
3	Map 2: Tsunami inundation and landslide hazards.	2013	Map	SERNAGEOMIN	Spanish	Earthquake, Tsunami Flooding Mass removal	YES
4	Past earthquakes in the vicinity of Iquique Province, Tarapacá, Chile 2014-2021.	2021	Historical Record	VOLCANO DISCOVERY	Spanish	Earthquake	YES

Table 7. Excerpt from the study quality assessment of Total Performance Results (Question 2).

N	Title	Language	ID	Year	Doc Type	Type of Tec	Index	Compliance?
1	Autoconfiguration in MANETS	Spanish	ISSN: 17293804	2014	Scientific journal article	Ad Hoc Networks	It does not have	NO
2	Cognitive Radio and its Impact on the Efficient Use of the Radio Spectrum	Spanish	ISSN: 18155928	2015	Scientific journal article	Other Wireless Communication Network Technology	Scielo	YES
3	VoIP Requirements in Wireless Mesh Networks with Relaying	Spanish	ISBN: 978-950-34-1539-9	2017	Conference Object	Mesh Networks	Proceed ings	NO

ANALYSIS OF RESULTS

In this phase, the primary studies for each research question undergo a comprehensive characterization. A schematic representation (Figure 1 and Figure 2) has been developed to illustrate the resulting characterizations from the analyzed studies.

The characterization scheme for Question 1, displayed in Figure 1, reveals that the most frequently occurring

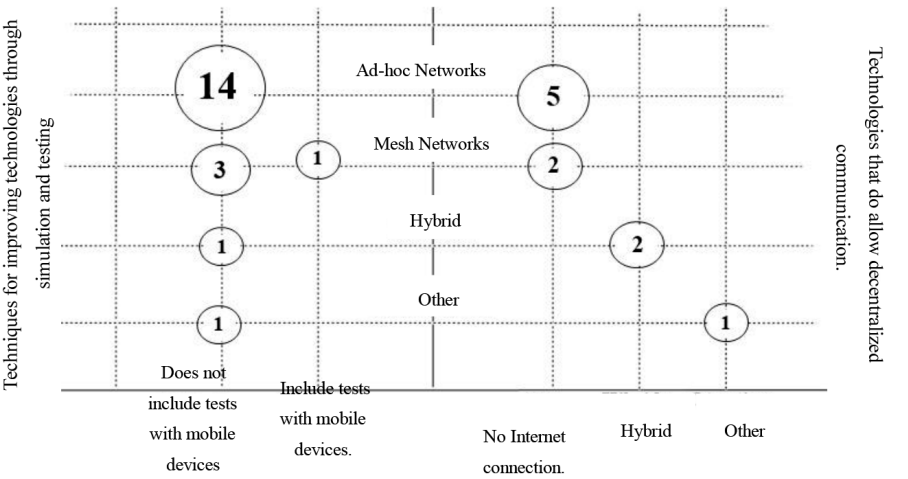

Figure 1. Characterization scheme of the primary studies for Question 2.

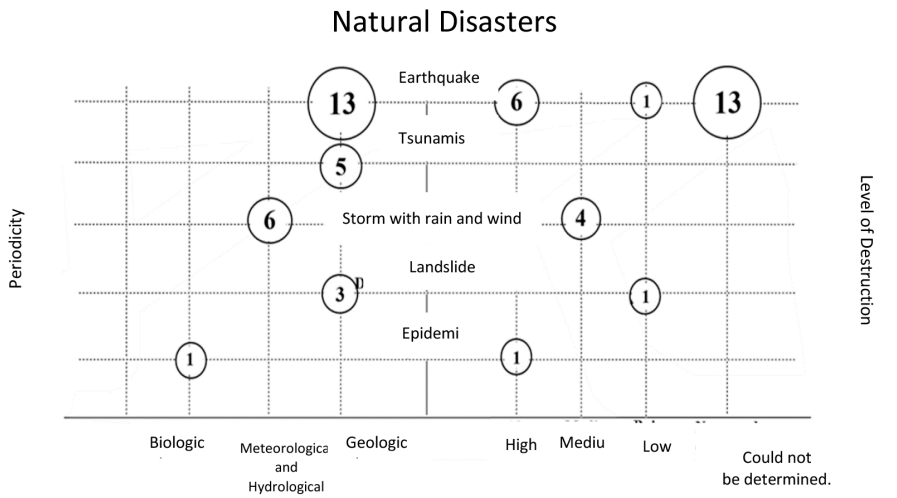

Figure 2. Schematic of primary study characterization for Question 1.

items are related to highly destructive earthquakes. Therefore, the scale defined to classify earthquakes comprises:

- High: High-intensity earthquakes result in the disruption of essential services, roads, critical infrastructure, and loss of life.
- Medium: High-intensity earthquakes that lead to the interruption of essential services, roads, and critical infrastructure.
- Low: High-intensity earthquakes that cause the suspension of essential services.

Based on the analysis of the articles in Question 1, it is evident that the most probable natural disaster scenario is a major earthquake followed by a subsequent tsunami.

Figure 2 presents a quadrant-type scheme for Question 2, where items are characterized based on the type of technology and the number of documents. The documents are further categorized into Ad Hoc Networks, Mesh Networks, Hybrid Networks, and other types of Networks. On the left of Figure 2, articles that do not consider communication between mobile

devices without internet access in a natural disaster scenario are positioned. Of the 14 articles that address Ad Hoc Networks, 3 are related to Mesh Networks, 1 to hybrid technology, and 1 to other technologies.

For Question 2, the most probable disaster scenario derived from the characterization of Question 1 is considered, and the technology described in the articles is evaluated based on the following list of requirements:

1. The technology must enable cell phones to communicate in a natural disaster scenario without an internet connection.
2. It should allow communication between cell phones buried or surrounded by rubble.
3. The technology should facilitate communication between cell phones over short or long distances, accounting for evacuation maps that designate safe zones in the city center-east, i.e., before reaching the "Cerro Dragón" along Route A-16 and at least 30 meters above sea level.
4. It must facilitate communication between people who are isolated on the eighth floor or higher in buildings and who have cell phones.
5. The technology should enable mobile communication despite environmental conditions, including debris, damaged and flooded streets, destroyed buildings, damaged poles, and broken wires.
6. It must allow communication for people with cell phones located in the safe zones established by ONEMI at various beaches and coves along the coastal area of Iquique.

Table 8 presents the outcome of analyzing the attributes associated with the types of technologies for each of the 10 selected items from Research Question 2, then assessing their compliance with the established requirements.

Cross-referencing the items and the requirements yields only 2 items that meet all the requirements:

Table 8. Cross-reference of requirements with selected items.

Title	Method	What is it about	Requirements						
			Re1	Re2	Re3	Re4	Re5	Re6	Re7
Proposing Disaster Management System based on Vehicular Ad hoc Networks	Vanet	Vehicles to create and extend networks	X	X					
Experimentation with MANETs of Smartphones	Manet with Ad hoc Droid	Manet ad hoc with Android package	X	X	X	X	X	X	X
Survey on Simulation for Mobile Ad-Hoc Communication for Disaster Scenarios	Ad Hoc Network	Create a simple Ad Hoc Network	X	X					
Designing delay-constrained hybrid ad hoc network infrastructure for post-disaster communication	Bluetooth and ad hoc networks	Bluetooth, together with an ad-hoc network for communication	X	X					
A Comprehensive Survey in Towards to Future FANETs	Fanet	Drones with ad hoc mesh network	X	X	X	X	X	X	X
Mesh networks, an alternative to network coverage problems: a literature review	Mesh Networks	Create a simple mesh network	X	X					
Efficient and Secured Swarm Pattern Multi-UAV Communication	Red Mesh	Mesh network with WAM network	X		X	X	X	X	X
Bringing Movable and Deployable Networks to Disaster Areas: Development and Field Test of MDRU	MDRU	Van with netting system	X						
Consideration of propagation of disaster information among different types of terminals for Grassroots Information Distribution System Using MANET	Manet and Bluetooth	Manet extended with Bluetooth	X						
Implementation of USRP (Universal Software Peripheral Radio) as OpenBTS for Quadruple Play Services	USRP	Network with radio antennas with PC base	X	X					

- "Experimentation with MANETs of Smartphones"[15]: This item introduces an Android package called AdHocDroid, which allows the creation of a Manet network through cell phones, allowing the cell phone to communicate without an internet connection, regardless of location, distance, height, or obstacles. This network expands according to the number of devices that install the package. This way, they connect automatically, and cell phones become communication nodes despite their distance.
- "A Comprehensive Survey in Towards to Future FANETs."[17] This document proposes using drones as points or nodes to create an ad hoc Mesh type network in a natural disaster scenario, allowing better network coverage independent of location, distance, height, and debris.

CONCLUSIONS

This systematic literature review (SLR) successfully addressed the research objectives by answering the proposed research questions.

Based on data collected from Chilean governmental institutions, the first research question aimed to identify possible natural disaster scenarios in the city of Iquique. The conclusion was that Iquique's most detrimental disaster scenario would be a substantial earthquake followed by a tsunami, which would cause extensive damage to the large esplanade stretching from the city's center to its north center. The review uncovered 12 documents about earthquakes, 5 about tsunamis, 6 about storms accompanied by rain and alluvium, 5 about landslides, and 1 about epidemics. Seismic events of considerable magnitude were determined to be historically responsible for the greatest extent of losses.
The second research question sought to explore the types of technologies currently facilitating communication between cell phones without internet access during natural disaster scenarios. Out of the 10 documents assessed on technologies that enable communication in a natural disaster scenario without internet access, only two satisfied all seven essential technological criteria for a significant earthquake and following tsunami situation:

- Experimentation with MANETs of Smartphones [16].
- A Comprehensive Survey in Towards to Future FANETs [17].

These two papers provided answered the General Research Question: Is there any ad hoc network technology that enables communication and interaction among individuals via their cell phones without internet access in a natural disaster scenario in the city of Iquique? This finding confirms the successful accomplishment of the systematic review in addressing the research objectives.

For future research, the recommendation is to perform field tests to implement the solutions above and extend the investigation to different territorial contexts using the same methodology yet adapting it to the unique characteristics of each area. Furthermore, the proposal includes delving into various multidisciplinary aspects that influence responses to natural disaster scenarios, such as the psychological underpinnings of evacuation models, the need for disaster-specific infrastructure, safe locations for critical infrastructure, and logistical and humanitarian chains for early mitigation. Such research endeavors would contribute to formulating comprehensive public policies to manage diverse disaster scenarios effectively.

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