

MERLIN: A LoRa-Based Infrastructure for Bidirectional Crisis Communication Between Civil and Public Authorities

Laura Stojko  · RI CODE, University of the Bundeswehr Munich, Germany · laura.stojko@unibw.de

Mario Silaci · RI CODE, University of the Bundeswehr Munich, Germany · mario.silaci@unibw.de

Michael Grabatin · RI CODE, University of the Bundeswehr Munich, Germany · michael.grabatin@unibw.de

Johann Altgenug  · RI CODE, University of the Bundeswehr Munich, Germany · johann.altgenug@unibw.de

Wolfgang Hommel  · RI CODE, University of the Bundeswehr Munich, Germany · wolfgang.hommel@unibw.de

Abstract. During large-scale blackouts, mobile communication infrastructures often fail, limiting coordination and information exchange. This problem is particularly critical in rural areas with a dispersed population, where communication between citizens, authorities, and emergency services becomes difficult. This paper presents MERLIN, a LoRa-based communication infrastructure designed to enable bidirectional crisis communication during blackouts. Drawing on crisis informatics, the system's potential to support collaboration among stakeholders is examined using a classification matrix for social software, focusing on coordination among citizens, public authorities, and emergency services during blackouts. Specifically, the system is designed to allow authorities to receive emergency alerts, coordinate response activities, support emergency planning, and disseminate critical information to citizens. The paper presents an example of bidirectional crisis communication operating over a purpose-built LoRa-based wireless mesh network. It discusses its implications for crisis informatics research and illustrates how decentralized communication infrastructures can support coordination and information exchange during blackouts.

Keywords. crisis communication, collaboration, civil, state authorities, lora, lorawan, resilient

1 Introduction

Extreme weather events can damage critical infrastructure (Council of European Union, 2022), e.g., broken landlines, and lead to power outages or the collapse of communication networks. Such large-scale outages are referred to as blackouts. Managing crises during a blackout, rarely an isolated event, requires alternative communication methods to organize task forces, technical personnel, or affected citizens. Common alternatives such as two-way radio systems, satellite communications, mobile ad hoc networks, and amateur radio rely on independent or battery-powered infrastructure. While they can temporarily bridge communication gaps, their dependence on power availability or specific infrastructure limits their

Laura Stojko, Mario Silaci, Michael Grabatin, Johann Altgenug, Wolfgang Hommel. 2026. MERLIN: A LoRa-Based Infrastructure for Bidirectional Crisis Communication Between Civil and Public Authorities. In: *Proceedings of the 24th EUSSET Conference on Computer-Supported Cooperative Work (ECSCW) – Posters and Demos*, Reports of the European Society for Socially Embedded Technologies. ISSN: 2510-2591 https://doi.org/10.48340/ecscw2026_131

This article is released to the public under the Creative Commons Attribution 4.0 license. You are free to share and adapt this work as long as the attribution to the authors is preserved. For details, see: <https://creativecommons.org/licenses/by/4.0/>



Find the latest version of this document in the EUSSET Digital Library: <https://dl.eusset.eu/>

effectiveness in prolonged blackouts, highlighting the need for a reliable, energy self-sufficient, wide-ranging crisis communication infrastructure.

Hence, we demonstrate MERLIN (Messaging with regional LoRa infrastructure) as a resilient backup communication solution based on LoRa, a low-power wide-area (LPWAN) radio technology (Farrell, 2018) known for long range, energy efficiency, and low operating costs, widely used in industrial Internet-of-Things (IoT) and smart city applications (Jeong et al., 2018; Mekki et al., 2019; Prado et al., 2025). This solution contributes to Crisis Informatics, which “is a multidisciplinary field combining computing and social science knowledge of disasters; its central tenet is that people use personal information and communication technology to respond to disasters in creative ways to cope with uncertainty” (Palen and Anderson, 2016), whereas the term was first coined by Hagar (2006). This field of interest “views emergency response as an expanded social system where information is disseminated within and between official and public channels and entities.” (Palen et al., 2009)

Since September 2024, MERLIN has been operated as a field deployment in the Austrian municipality of Neuhaus in Carinthia, near the Slovenian border, a rural region with limited mobile network coverage due to the topology and border regulations. Limited communication capabilities hinder collaboration within the community, particularly crucial in crisis situations. By collaborating with the EU-funded dtec.bw project ROLORAN (Resilient Operation of LoRa Networks)¹, the MERLIN system has been developed in order to overcome communication issues between local authorities, emergency services, and citizens. This work presents a real-world case of infrastructure-supported crisis collaboration enabled by MERLIN, highlighting how decentralized communication systems can facilitate coordination among citizens, authorities, and emergency services under extreme conditions.

To better contextualize this work’s contribution, related literature is discussed in the next section. Subsequently, the MERLIN system, its components, stakeholders, and potential for collaboration are summarized. Finally, a discussion of the current system, a conclusion, and an outlook summarize the contribution of this work.

2 Related Work

While Munkvold (2023) summarizes the challenges in emergency responses, particularly interesting for Computer-Supported Cooperative Work (CSCW), is research on collaboration in crisis informatics as displayed by a special issue of Pipek et al. (2014). Overall, this field has a strong focus on social media use, e.g., Reuter et al. (2018). While these studies show the need to investigate collaboration during crises, they offer no alternatives to blackouts, since social media relies on mobile networks. In the event of a blackout, these mobile networks are unavailable, and social media use is impossible. Our solution focuses on contributing to the phase of managing the crisis during the event, especially responses to a crisis event, which can be described as follows according to Pearson and Clair (1998): The coordination of stakeholders and information dissemination that can impact individual and collective reactions, including shattered assumptions, impaired cognitive, emotional, and behavioral responses, and eroded social structure.

¹ <https://go.unibw.de/roloran>

Currently, technological communication solutions for blackout crises rely on satellite-based systems to establish communication channels with crisis emergency teams, as demonstrated by Igarashi et al. (2016) for emergencies in Antarctica. However, they require a reliable power supply for long-term use, which becomes critical during prolonged power outages. In comparison, LoRa-based solutions are much more energy-efficient due to their use in IoT systems, thereby offering a more sustainable communication technology. Additionally, LoRa networks for such communication purposes are less costly and easier to deploy as discussed in Schmidt et al. (2023). While their approach focuses on technological advances and the use of LoRa in disasters, they do not provide details on the potential for communication or collaboration. LoRa-enabled devices have also been applied, for instance, by Donavalli et al. (2024) to track and monitor alpine climbers’ health, ensuring their safety in such high-risk activities. While their approach focused on tracking climbers’ locations and monitoring their physical state by transmitting physical information such as pulse rate and temperature, the project’s objective was not to establish communication with them.

While prior work has explored communication infrastructures in disaster scenarios, most solutions either rely on centralized systems or focus on technological aspects of LoRa-networks, e.g., Centelles et al. (2019); Liao et al. (2017); Prade et al. (2022); Sciullo et al. (2020), without addressing collaboration among stakeholders.

3 MERLIN: A Resilient Blackout-Communication System

3.1 System Components and Setup

The MERLIN infrastructure provides a reliable communication system during blackout scenarios. It comprises crisis management software, multiple MERLIN bases, and MERLIN messengers, along with the custom-made “Roloran Disaster Communication Protocol” (RDCP) protocol to connect all components and enable data exchange, as shown in Figure 1.

The custom-made RDCP enables a text-message-based, bidirectional crisis communication system. The protocol is open-source², actively developed by the ROLORAN project, and incorporates security features to enable confidential and trustworthy message exchange in critical situations, using AES-256-based encryption and Schnorr signatures. The RDCP supports various message types, including private and official announcements, and device-specific status updates. In contrast to other LPWAN solutions (such as Meshtastic or Meshcore), RDCP uses multiple radio channels and combines mesh-based routing with star network topologies to reduce collisions. Acknowledgment-based retransmission ensures reliable delivery of messages, even for newly connected devices. The system prioritizes reliability over transmission speed and supports communication with individuals, groups, or the entire network.

The backbone of the MERLIN infrastructure is formed by ten stationary and mobile MERLIN bases (Figure 2c). MERLIN bases interconnect within radio range, creating redundant radio links. All messages sent by the crisis management software, MERLIN

² <https://github.com/roloran/RDCP-Specs>

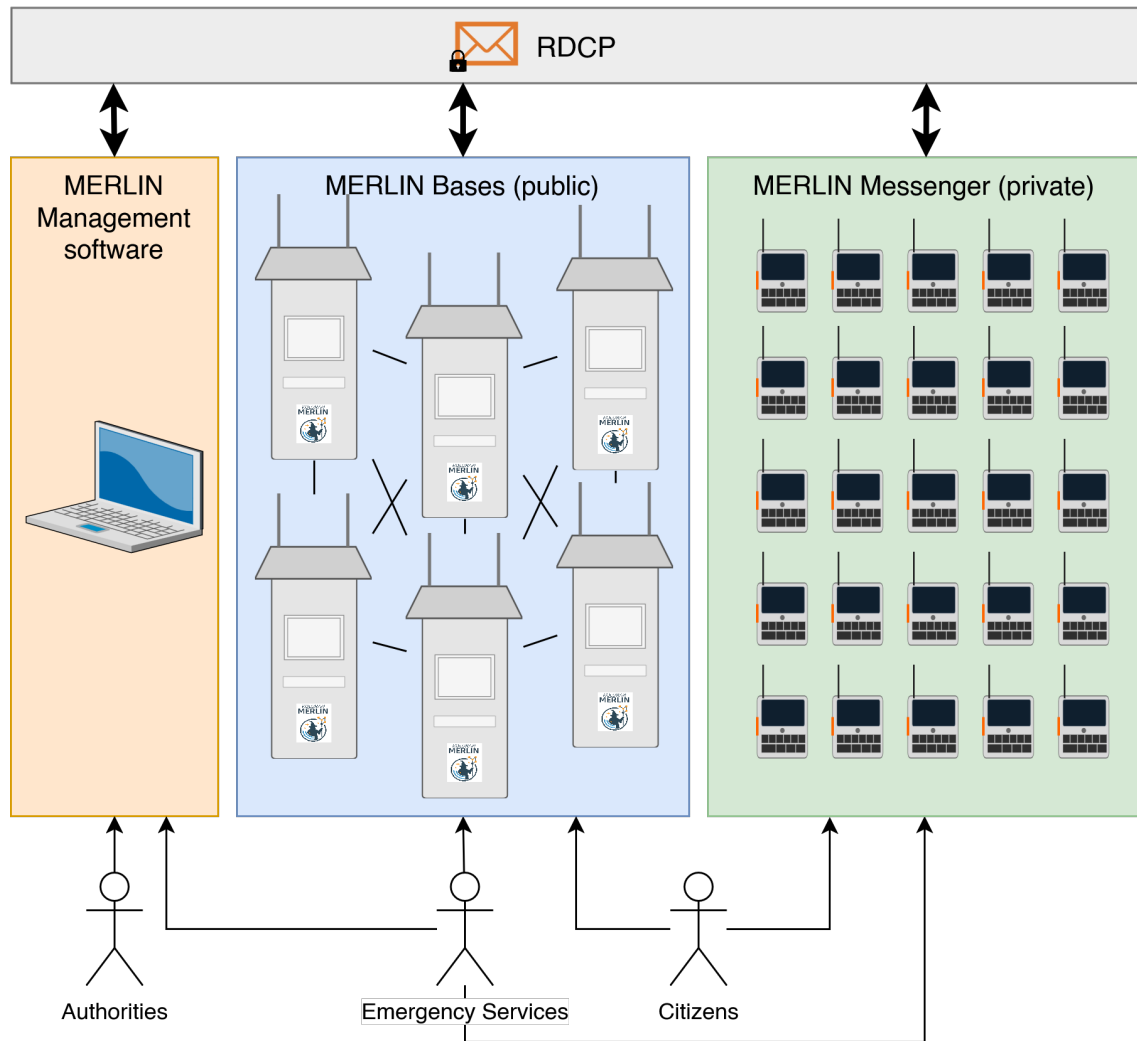


Figure 1: Overview of the MERLIN system and its role in enabling communication between citizens, authorities, and emergency services.

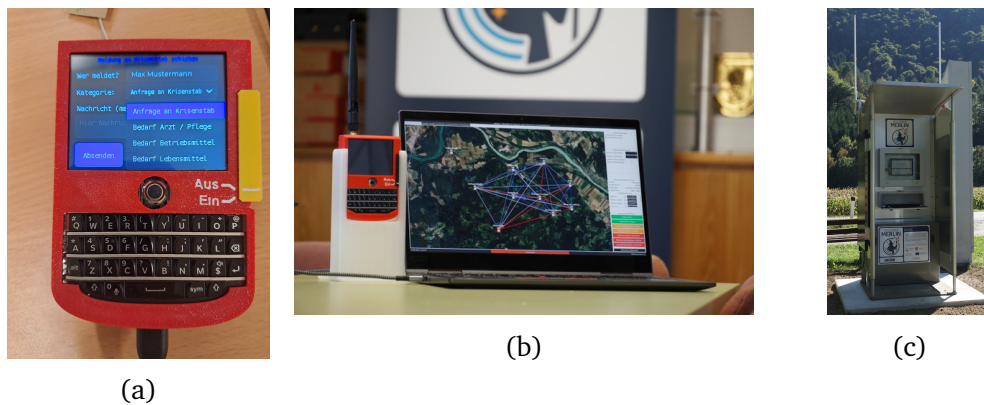


Figure 2: MERLIN components in use: (a) user interface of messengers (based on LILYGO T-Deck), (b) management notebook, and (c) a stationary base.

bases, and MERLIN messengers are relayed through the network to their destination. Furthermore, MERLIN bases serve as public emergency stations: they display received messages on attached e-ink displays and allow user interaction via keyboard. A guided process for emergency reports supports users in critical situations by providing a step-by-step workflow for submitting relevant information. For resilience, MERLIN bases are battery-powered and solar-charged, enabling long-term operation during power outages. Suitable locations were selected to maximize network coverage (Silaci et al., 2025), accessibility, and sunlight exposure.

MERLIN messengers (Figure 2a) are private, mobile handheld devices with an external power source that enable citizens to send and receive messages within the MERLIN infrastructure's range. In our real-world deployment, approximately 100 devices have been distributed among citizens and emergency personnel. They use a touchscreen and an on-board keyboard to display and navigate messages and guide users through the creation of emergency reports. The current crisis state is indicated by expressive colors and the available interaction options. In crisis mode, emergency reports can always be sent and are acknowledged with information about the current system state. Feedback allows users to assess whether message transmission was successful. All official broadcast messages are signed using public-key signatures to prevent impersonation. Messages between device pairs are encrypted to ensure confidentiality. Messages are stored locally and synchronized via nearby MERLIN bases, allowing energy-efficient operation and continued use during inactive periods. Due to roaming capabilities, MERLIN messengers can be used throughout the infrastructure deployment and connect via the best entry point based on the received signal quality.

The crisis management software (Figure 2b) serves as a communication interface for authorities and task forces within the MERLIN infrastructure. It can be deployed on common operating systems and used at any location within the network's reach, supporting multiple instances in different operating modes. The software enables the reception and transmission of messages distributed via the RDCP, enabling bi-directional communication with MERLIN messengers and bases, used by emergency services and citizens, either individually or in groups. To support crisis management, messages can be filtered, annotated, categorized, or invalidated, facilitating the handling of emergency reports. In addition, the software collects telemetry data to visualize the system state on a map, including MERLIN base locations, link quality, and base battery status. Also, the system supports provisioning of new MERLIN messengers, with automated configuration scripts for cryptographic material and personal data that integrate these devices into the network, thereby supporting the system's scalability.

3.2 Stakeholders and Collaboration Potentials

In crisis situations, it is vital to reduce uncertainties and grasp issues and needs as quickly and reliably as possible to ensure everyone's safety. According to the classification matrix for social software in crisis management by Reuter et al. (2012), MERLIN is designed to enable bidirectional crisis communication among authorities and citizens (crisis communication), among authorities (inter-organizational crisis management), and between citizens and authorities (integration of citizen-generated content). While the direct link between citizens is not the focus of the MERLIN

system, it strongly supports the other areas and enables collaboration among crisis stakeholders.

- **Authorities**, who communicate and collaborate with other authorities (to organize supportive measures), share situational information with citizens, manage the response to the crisis by maintaining an overview of the extent of the crisis, and conduct situation assessment based on available information from other authorities and citizens, and emergency response planning.
- **Citizens**, who receive information about the crisis situation, respond to situation assessment questions, report emergency needs and immediate help that directly affect them, as well as provide information about their potential to support other affected citizens or contribute to resolving the crisis.
- **Emergency services**, who receive prioritized information on emergency needs, critical situations, available resources, and request support from other emergency services and provide situation assessments.

The collaboration potential among these stakeholders, together with a depiction of the appropriate MERLIN system components, is shown in Figure 1. This demonstrates the various devices required and their useful application in blackout scenarios. To illustrate how such interactions may unfold in practice, consider the following examples: A citizen can submit an urgent need for water as an emergency report via a MERLIN messenger or base, which is propagated through the network and becomes available to authorities for coordination and response planning. Conversely, authorities can, for example, broadcast critical information, such as evacuation instructions, which are received and displayed on both public MERLIN bases and personal messenger devices.

4 Discussion and Conclusion

As a LoRa-based system for emergency communication during prolonged blackouts, MERLIN introduces specific challenges for collaboration under constrained conditions, given the high-stress environment and unfamiliar technology. Effective collaboration requires an intuitive user interface design with high informative value. This challenge is amplified by the dedicated hardware necessary. The low-power design of MERLIN bases and MERLIN messengers operates for a month on battery power, with a low-resolution, low-color display. The system is designed for two-way communication, but RDCP, ensuring reliable wireless transport of messages over an unlicensed frequency spectrum, has low bandwidth and high latency. As a result, the user experience differs markedly from texting via SMS or messaging apps, which provide near-instant message delivery notifications and quick replies, to which most users are accustomed. With MERLIN, those operations can take up to several minutes. Those limitations that might frustrate users also affect how mission control can interact with the system. The MERLIN bases are accessible to anyone and located primarily in public, well-accessible areas. Detecting misuse, e.g., through follow-up questions, requires more attention and time than during a phone call. The personalized MERLIN messenger devices are less likely to be misused deliberately.

Collaboration under the outlined constraints resurfaces challenges thought to have been resolved by modern telephony and instant messaging. From a CSCW

perspective, MERLIN shows how decentralized, low-bandwidth infrastructure can mediate coordination between citizens and authorities when conventional communication breaks down, highlighting the need to balance reach, reliability, feedback, trust, and accountability in the design of such systems.

5 Future Work

Our projects' next steps includes adding an emergency button for citizens to alert authorities and request emergency services. While its implementation and a clear, citizen-relevant use-case description still need to be aligned, it holds strong potential to complement the current deployment in such crisis scenarios. In the long term, we aim to investigate how regional authorities and citizens can leverage LoRa-based communication in their homes using existing devices, such as smartphones, and how these devices can be easily adapted to support LoRa communication.

Acknowledgments

This work originates from the ROLORAN research project. ROLORAN is funded by dtec.bw — Digitization and Technology Research Center of the Bundeswehr, which we gratefully acknowledge. dtec.bw is funded by the European Union — NextGenerationEU.

References

- Centelles, Roger Pueyo, Felix Freitag, Roc Meseguer, Leandro Navarro, Sergio F. Ochoa, and Rodrigo M. Santos. 2019. A LoRa-Based Communication System for Coordinated Response in an Earthquake Aftermath. *Proceedings*, 31 (1). <https://www.mdpi.com/2504-3900/31/1/73> · <https://doi.org/10.3390/proceedings2019031073>
- Council of European Union. 2022. *Council regulation (EU) no 2022/2557*. <https://eur-lex.europa.eu/eli/dir/2022/2557/oj>.
- Donavalli, Sashank, Harshitha Kambham, and B. Pitchaimanickam. 2024. Monitoring Systems for Mountain Climbers using IoT. In: *10th International Conference on Communication and Signal Processing (ICCSP)*, pp. 1315–1320. <https://doi.org/10.1109/ICCSP60870.2024.10544272>
- Farrell, Stephen. 2018. *Low-Power Wide Area Network (LPWAN) Overview*. RFC 8376. <https://www.rfc-editor.org/info/rfc8376> · <https://doi.org/10.17487/RFC8376>
- Hagar, Christine. 2006. Using research to aid the design of a crisis information management course. In: *ALISE Annual Conference SIG Multicultural, Ethnic & Humanistic Concerns (MEH). Information Seeking and Service Delivery for Communities in Disaster/Crisis*.
- Igarashi, Kiyoshi, Ken Umeno, Masaki Okada, and Masayuki Kikuchi. 2016. Study on emergency message communication system for ensuring safety in Antarctica under extremely severe environments. In: *International Conference on Smart Green Technology in Electrical and Information Systems (ICS-GTEIS)*, pp. 116–119. <https://doi.org/10.1109/ICSGTEIS.2016.7885776>
- Jeong, Jin-Doo, Youngmee Shin, and Il-Woo Lee. 2018. Long-Range Transmission of Photovoltaic Climate Information through the LoRa Radio. In: *2018 International Conference on Information and Communication Technology Convergence (ICTC)*, pp. 956–959. IEEE. <https://doi.org/10.1109/ICTC.2018.8539429>
- Liao, Chun-Hao, Guibing Zhu, Daiki Kuwabara, Makoto Suzuki, and Hiroyuki Morikawa. 2017. Multi-Hop LoRa Networks Enabled by Concurrent Transmission. *IEEE Access*, 5: 21430–21446. <https://doi.org/10.1109/ACCESS.2017.2755858>

- Mekki, Kais, Eddy Bajic, Frederic Chaxel, and Fernand Meyer. 2019. A comparative study of LPWAN technologies for large-scale IoT deployment. *ICT Express*, 5 (1): 1–7. <https://www.sciencedirect.com/science/article/pii/S2405959517302953> · <https://doi.org/10.1016/j.icte.2017.12.005>
- Munkvold, Bjørn E. 2023. Supporting Inter-Agency Collaboration in Emergency Management: Recurring Challenges Relevant for CSCW. In: *Proceedings of 21st European Conference on Computer-Supported Cooperative Work*. European Society for Socially Embedded Technologies (EUSSET). https://doi.org/10.48340/ecscw2023_n01
- Palen, Leysia and Kenneth M. Anderson. 2016. Crisis informatics-new data for extraordinary times: Focus on behaviors, not on fetishizing social media tools. *Science*, 353: 224–225. <https://www.science.org/doi/10.1126/science.aag2579> · https://doi.org/10.1126/SCIENCE.AAG2579/ASSET/17FA270B-AE2C-41A0-9609-C01517DA9A0C/ASSETS/GRAPHIC/353_224_F1.JPEG
- Palen, Leysia, Sarah Vieweg, Sophia B. Liu, and Amanda Lee Hughes. 2009. Crisis in a Networked World: Features of Computer-Mediated Communication in the April 16, 2007, Virginia Tech Event. *Social Science Computer Review*, 27 (4): 467–480. <https://doi.org/10.1177/0894439309332302>
- Pearson, Christine M. and Judith A. Clair. 1998. Reframing Crisis Management. *The Academy of Management Review*, 23: 59–76. <https://journals.aom.org/doi/abs/10.5465/AMR.1998.192960> · <https://doi.org/10.5465/AMR.1998.192960>
- Pipek, Volkmar, Sophia B. Liu, and Andrius Kerne. 2014. Crisis Informatics and Collaboration: A Brief Introduction. *Computer Supported Cooperative Work: CSCW: An International Journal*, 23: 339–345. <https://link.springer.com/article/10.1007/s10606-014-9211-4> · <https://doi.org/10.1007/S10606-014-9211-4/METRICS>
- Prade, Lucio, Jean Moraes, Eliel de Albuquerque, Denis Rosário, and Cristiano Bonato Both. 2022. Multi-radio and multi-hop LoRa communication architecture for large scale IoT deployment. *Computers and Electrical Engineering*, 102: 108242. <https://www.sciencedirect.com/science/article/pii/S0045790622004773> · <https://doi.org/10.1016/j.compeleceng.2022.108242>
- Prado, Fabrizio André Farfán, William César Pérez Campos, Steisy Anahi Carreño Tacuri, Favio David Cabrera Alva, and Harold Jacobed Carhuas Lizarbe. 2025. Design Of A Communication System To Send Text Using Lora At 400 MHz. *arXiv preprint arXiv:2511.21434*.
- Reuter, Christian, Amanda Lee Hughes, and Marc André Kaufhold. 2018. Social Media in Crisis Management: An Evaluation and Analysis of Crisis Informatics Research. *International Journal of Human-Computer Interaction*, 34: 280–294. <https://www.tandfonline.com/doi/abs/10.1080/10447318.2018.1427832> · <https://doi.org/10.1080/10447318.2018.1427832>
- Reuter, Christian, Alexandra Marx, and Volkmar Pipek. 2012. Crisis Management 2.0: Towards a Systematization of Social Software Use in Crisis Situations. *International Journal of Information Systems for Crisis Response and Management (IJISCRAM)*, 4: 1–16. <https://www.igi-global.com/article/crisis-management-towards-systematization-social/66344www.igi-global.com/article/content/66344> · <https://doi.org/10.4018/JISCRM.2012010101>
- Schmidt, Daniel, Franz Kuntke, Maximilian Bauer, and Lars Baumgärtner. 2023. BPoL: A Disruption-Tolerant LoRa Network for Disaster Communication. In: *IEEE Global Humanitarian Technology Conference (GHTC)*, pp. 440–447. IEEE. ISBN: 979-8-3503-2132-6 <https://ieeexplore.ieee.org/document/10354717/> · <https://doi.org/10.1109/GHTC56179.2023.10354717>
- Sciullo, Luca, Angelo Trotta, and Marco Di Felice. 2020. Design and performance evaluation of a LoRa-based mobile emergency management system (LOCATE). *Ad Hoc Networks*, 96: 101993. <https://www.sciencedirect.com/science/article/pii/S1570870518309004> · <https://doi.org/10.1016/j.adhoc.2019.101993>
- Silaci, Mario, Daniela Pöhn, and Wolfgang Hommel. 2025. Method for Systematic LoRa Measurements in Outdoor Scenarios. In: *2025 12th International Conference on Future Internet of Things and Cloud (FiCloud)*, pp. 281–288. IEEE. <https://doi.org/10.1109/FiCloud66139.2025.00045>