Social Media Resilience During Infrastructure Breakdowns Using Mobile Ad-Hoc Networks

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Abstract Social media and instant messaging services are nowadays considered as important communication infrastructures on which people rely on. However, the exchange of content during breakdowns of the underlying technical infrastructures, which sometimes happens based on environmental occurrences, is challenging. Hence, with this paper, we examine the resilience of social media during breakdowns. We discuss communication options and examine ad-hoc functionality for the exchange of social media data between different actors in such cases. To address this, we have developed a concept, which makes use of mobile ad-hoc networks (MANETs) for the spontaneous exchange of information with smartphones. We implemented our concept as the mobile application Social Offline Map (SOMAP) and evaluated it within two iterations (1.0 and 2.0). Finally, we discuss our contribution within the context of related work and the limitations of our approach.

Keywords Infrastructure · Resilience · MANET · Social media · Environmental informatics

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1 Introduction

Breakdowns of critical infrastructures—for instance, after an interruption in power supplies based on environmental occurrences—constitute heavy problems. Especially the mental stress within the affected population caused by long-lasting breakdowns can be widely observed (Volgger et al. 2006). Furthermore, the coordination of response actions and the associated communication demand high efforts of the responsible authorities. During a power breakdown, interaction via ICT is only available for a certain period of time. Once the backup power supplies of network providers fail, information cannot be extensively distributed anymore.

Particularly social media have become important communication channels within diverse emergencies (Reuter et al. 2015b): For instance, social media was used during the 2009 Oklahoma Wildfires (Vieweg et al. 2010), 2011 Japanese Earthquake (Wilensky 2014), 2012 Hurricane Sandy (Hughes et al. 2014) or 2013 European floods (Kaufhold and Reuter 2016). These settings have to potential to impair the availability of infrastructure, e.g. during the European floods the local power plant of Magdeburg was threatened by water, or demand other kinds of effective local coordination to fill the gap between the start of an emergency and professional response or to support volunteers in overcoming an emergency. However, when networks fail, ordinary people usually cannot make use of this high amount of information shared in social media anymore. But even during long-lasting power or network breakdowns, mobile devices would still be able to communicate in a decentralized way due to its functionalities, such as Bluetooth or Wi-Fi-Direct in order to support both stability and continuity.

This *design case study* (Wulf et al. 2011)—composed of an empirical pre-study, the development of ICT and its evaluation in two cycles—aims to examine whether social media can remain "social" during breakdowns with the aid of mobile ad-hoc networks (MANETs) to assist direct ways of communication between mobile devices. With the term 'social' we refer to the ability of people to access, post and respond to social media data preferable in real-time, reflecting their use of social media sites in non-impacted times. This is in accordance with the definition of social media as a "group of Internet-based applications that build on the ideological and technological foundations of Web 2.0, and that allow the creation and exchange of user-generated content" (Kaplan and Haenlein 2010).

Based on theoretical concepts, existing applications in this field (Sect. 2) and the evaluation of our offline-map application SOMAP 1.0, which visualizes data from social media (Sect. 3), we present SOMAP 2.0; the enhanced version of SOMAP allows establishing ad-hoc networks by enhancing peer-to-peer (P2P) functions and provides new ways of direct communication (Sect. 4). The integrated network functionality was evaluated by a functional test supplemented by semi-structured interviews. The results of the evaluation are discussed and compared with regard to the current state of the art. The final conclusion comprises limitations and implications for further research in the field of MANETS and infrastructure breakdowns (Sect. 5).

2 Literature Review

When asked about London's power outage in 2003, many people were surprised afterwards that such breakdowns could actually happen (Brayley et al. 2005). According to Lorenz (Lorenz 2010), people have little awareness about power outages until they happen. Thus, ways to distribute relevant information to the people in such cases have to be found. Below, we discuss possibilities for direct communication and present related approaches together with existing applications in that field. Afterwards we outline and discuss the research gap being tackled in this paper.

Communication During Power Outages: The cellular network is a technology that enables people to communicate during power outages, because central stations are usually protected by backup power supplies (Hiete et al. 2010). However, in the course of a power outage this possibility collapses step-by-step or is overloaded after a while (Reuter 2014a). A study on a power outage in the Netherlands in 2007 emphasizes that the direct contact among neighbors is the most common source of information and communication (Helsloot and Beerens 2009). In opposite to the common expectation that people are passive victims in crisis situations (Hunt 2003), citizens often are the first responders on-site (Stallings and Quarantelli 1985) and require certain information (Ludwig et al. 2015). ICT to enable cooperative resilience (Reuter et al. 2016) as the ability to overcome crises of cooperation with the help of adaptability to modified realities by means of cooperation technology.

Depending on the situation, the visualization of information can be essential as Kaufhold and Reuter (Kaufhold and Reuter 2016) outlined with the example of Google Maps in the floods in Germany in 2013. According to Toriumi et al. (2013), social media are used to a greater extent during crisis situations especially via mobile devices. In regions affected by communication failures, information processing via these platforms is temporarily not possible. Even the activities of *digital volunteers* (Starbird and Palen 2011), who process data and information on online social media services, cannot be utilized in such situations. Here, mobile devices can be beneficial due to the availability of the cellular network in power outages. But the challenge of how they can be harnessed after central communication infrastructures collapse still remains. Promising technologies such as Bluetooth or Wi-Fi-Direct enable direct communication among different devices, so that the establishment of ad-hoc networks is conceivable.

Approaches for Ad-Hoc Networking: In their summary "30 years of ad-hoc networking research", Legendre et al. (2011) conclude that "multiple technologies need to be combined to encompass all phases of disaster recovery, while providing differentiated levels of communication services" (p. 7). They elaborated this issue during the initial phase, "delay-tolerant and opportunistic networks have the capacity to provide low-bandwidth data services, while wireless mesh networks have the availability and redundancy to provide limited voice and data services".

Several approaches already deal with information distribution in regions where communication infrastructures fail. Using a *Local Cloud System* (Al-Akkad et al. 2014a), messages can be created and exchanged between mobile devices by creating

Wi-Fi-networks. If a network node provides access to Twitter services, those messages are published and also up-to-date data can be downloaded. The prototype *Twimight* works similarly (Hossmann et al. 2011) and provides a so-called *Disaster Mode,* which gives users the option to publish tweets without requiring Internet connection. Those tweets are uploaded after a successful connection.

The *Help Beacons System* (Al-Akkad et al. 2014b) transfers information directly into the Service Set Identifier (SSID) of a Wi-Fi-network, which then can be found and read by other smartphones. Nishiyama et al. (2014) suggest a concept with permanent Device-to-Device (D2D) communication and present a layer architecture standardizing the use of various devices and radio technologies during communication failures. Furthermore, Reuter (Reuter 2014a) introduces a prototype for displaying crisis-relevant information, which deals with the time period between the cellular network's breakdown and the following overload. Location- and setting-specific information aims to help users getting a better orientation within this timeframe and reducing network load at the same time.

Besides research approaches, applications in the *Google Play Store* support the establishment of ad-hoc networks. Open Garden's *FireChat* enables ad-hoc connections via Bluetooth and Wi-Fi-Direct between various devices, if at least one node has Internet (Shalunov 2013). *Blueeee!* utilizes Bluetooth technology to search for friends online and to chat with them. *The Serval Mesh* is an Android app (Gardner-Stephen 2011) enables ad-hoc connections through Bluetooth and a Wi-Fi ad-hoc mode, which requires rooted devices. Networked people can phone and chat with each other and also up- and download files in a P2P manner.

Research Gap: Our literature study indicates that information from social media is increasingly used for crisis communication (Toriumi et al. 2013). Furthermore, besides the technical possibilities for communicating during power and network breakdowns, direct contact is a highly relevant information source in exceptional situations (Helsloot and Beerens 2009). Kaufhold and Reuter (2016) revealed that location-related data processing with the help of maps can decisively support different actors. A study on Sweden's largest music event outlined the idea for a mobile solution to locate friends without central communication infrastructures (Olofsson et al. 2006).

MANETs can be used in absence of communication infrastructures to establish new and dynamic infrastructures, which offer a certain degree of reliability in the case of multiple connections between different network nodes (Kargl 2003). P2P-systems, which aim to evenly distribute certain tasks in a decentralized manner, can serve as starting point for the design of applications operating in rather inconsistent environments in terms of mobile devices and individuals (Dunkel et al. 2008). Our work aims to combine the areas of (1) ad-hoc networking, (2) provision of social media content, (3) geo-based services respectively map-based representation and (4) direct communication. We are trying to figure out whether and how social media can remain "social" when central communication infrastructures fail. We also tackle technical limitations of existing work by allowing networking and communication over multiple hops (Al-Akkad et al. 2014b; Hossmann et al. 2011) without the need for Internet access (Shalunov 2013) or rooted devices

(Gardner-Stephen 2011). We therefore include further information from our pre-study, serving as a foundation that already addresses certain requirements, to specify an integrated concept.

3 SOMAP 1.0: Social Offline Map Evaluation

SOMAP 1.0, the first version of our mobile Android application, which has already been published (Reuter et al. 2015a), was designed to visualize data from social media on maps. It offers online and offline map functionalities in terms of (a) pro-active loading and storing of potentially needed maps of a respective area as well as (b) the possibility of exchanging information from social media using Bluetooth. Offline maps are downloaded once the application moves to another location, in case an Internet connection is available, and can then be used in areas without network coverage. The application allows adding information from third parties, such as Keyhole Markup Language (KML) layers (Fig. 1). Furthermore, it

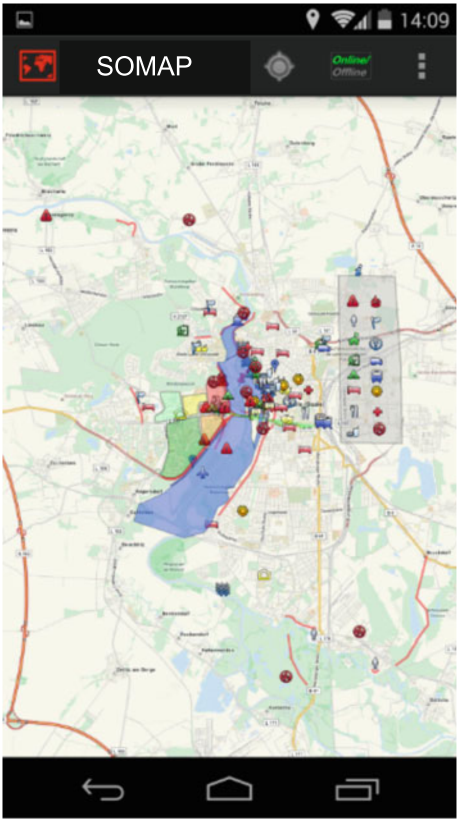

Fig. 1 Additional map layer: KML during the European floods

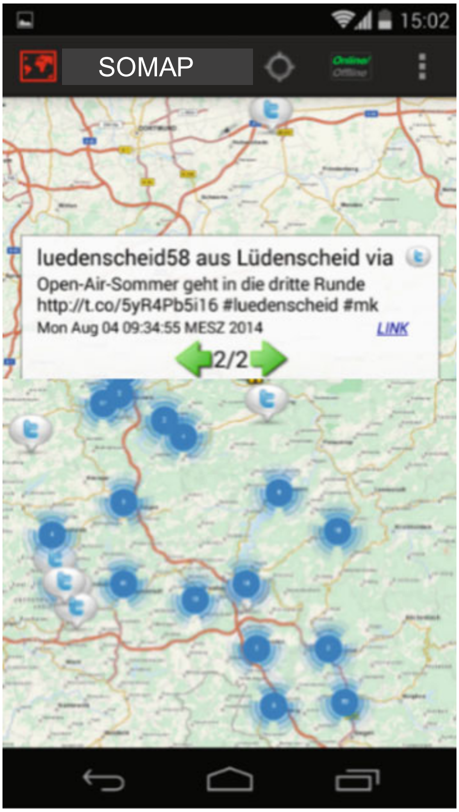

Fig. 2 Integration of social media: information window and cluster marker

provides the option to access Twitter tweets and public Facebook posts via a social media API (Reuter et al. 2015c) and to display them on a map. The user can search for concrete keywords, whereat the search results are filtered by parameters such as location or time (Fig. 2).

The qualitative evaluation of this first version of the application SOMAP aimed to obtain additional information about usability and added value of the application, practical suitability, potentials of enhancement and improvement, and the more specific features of ad-hoc and direct communication. We performed alongside a five-step evaluation guideline to determine the participants' expertise (1) and to introduce a potential scenario of use (2). During the application's general (3) and scenario-specific use test (4), we applied the constructive interaction method (Kahler et al. 2000) and required the users to accomplish both their own and joint tasks; and to maintain a mutual dialogue besides replying to guiding questions.

According to the think-aloud protocol (Nielsen 1993), participants were asked to express frankly their thoughts and their way of proceeding throughout the evaluation. Furthermore, we conducted semi-structured interviews (5) with eight participants of varying age, profession and smartphone experience. The interviews were audio-recorded and transcribed for further analysis according to the categories introduced above.

The evaluation revealed that SOMAP has the potential to support users in emergencies by the combination of an offline map functionality with the opportunity to query and display information from social media. To ensure such support, the application has to be downloaded initially, but it is to be expected that people do not make such provisions before an emergency actually occurs (Lorenz 2010). During the evaluation participants expressed that they would be more likely to download the application if it did not only serve for emergencies, but also had a bearing on everyday life, e.g., for direct communication. Moreover, the handling of the Bluetooth module to exchange social media information was perceived as being complicated.

4 SOMAP 2.0: Mobile Ad-Hoc Networks for Social Media

SOMAP 1.0 facilitates information processing from social media and its geo-based presentation to support during communication infrastructure breakdowns. However, MANET relevant aspects have not been integrated. If users are located in an affected area, new information can only be shared by actors who enter this area from a region with working communication infrastructure. Thus, for direct distribution of information and a more extensive and more user-friendly data exchange, the integrated Bluetooth exchange functionality could be extended by using ad-hoc networking. Direct communication as a further challenge can be derived from certain aspects: On one hand, the subjects asked for the opportunity to create new messages. On the other hand, the literature review shows that direct contact in a region with communication infrastructure breakdowns is a very important source of communication and distribution of information (Helsloot and Beerens 2009). The requirements mentioned above are concretized as derived design challenges, along with further practical requirements, in the following subsections.

R1: **MANET Connection Establishment and Automatized Discovery of Connection Partners**: To enable a direct network, different technologies of radio communication have to be considered: Bluetooth features out with a high degree of platform independence und low energy consumption. It is specified to provide a network range of 50–100 m with up to seven connections to other devices simultaneously. Yet, some devices only provide a range of 1–10 m and the bit rate of 2.1 Mb/s is low compared to Wi-Fi-Direct, which also supports 1:m-connections. It has a high bit rate with 250 Mb/s and a range of 200 m (Wi-Fi Alliance 2014). The connection establishment should be automatized as far as possible and all network participants should get information about entering nodes. During the process of implementation some problems according to Al-Akkad et al. (2014b) occurred when using Wi-Fi-Direct between mobile devices of different manufactures. Thus, merely a Bluetooth service was implemented enabling the operations of accepting, establishing and managing connections, processing data packets and discovering connection partners.

R2: **P2P-Functionality for Social Media Exchange**: Typical P2P-systems as *Gnutella* give notice of themselves with a ping-message to already known network participants when they enter a P2P-network and wait for a pong-message as acknowledgment (Dunkel et al. 2008). This approach is already mapped by entering an ad-hoc network, because the entry is broadcasted to all network participants. The information of social media platforms should directly indicate the clients so that every user has an overview of the existing tweets and posts in an existing ad-hoc network. Additionally, they can be downloaded from the offering clients (Fig. 3).

R3: **Direct Communication and Data Exchange**: The functionality for direct social communication (chat) should incorporate the existing network participants and support interaction besides the exchange of given information. In addition to that, broadcast messages to all clients should be possible. Data exchange formats, respectively a specific protocol, are necessary for the communication over an ad-hoc network. The services communicate with network packets that contain the application data, but do not provide the logical interpretation.

Fig. 3 Download network messages

R4: **Graphical User Interface and Access Control**: Download requests, chat messages and the access control should be illustrated by a graphical user interface (GUI). To split the user interface with regards to content, an Android activity can include fragments that represent different parts of the user interface. Furthermore, break-glass access control was integrated. This kind of access control offers every user access to all information resources. If a resource is requested by a user, it is documented on the providing client revealing who downloaded which information (Stevens and Wulf 2009).

Evaluation Methodology: This iteration (SOMAP 2.0) seeks to evaluate how 'social capabilities', represented with chat and data exchange functions, can be maintained from a rather technical point of view. The philosophy behind the evaluation process was derived from the notion of "situated evaluation" (Twidale et al. 1994) in which qualitative methods are used in order to draw conclusions about real-world use of a technology using domain experts. Furthermore, the evaluation aimed on testing the robustness of the networking functionalities, identifying certain problems and exploring resulting needs for further implementations. The following paragraph describes the setup and conduction of the performance test, concluded with a short interview containing four open-ended questions with eight participants (P1-P8).

The Android application SOMAP 2.0 was deployed on several test devices and was supplied with some social media information. The information (search term *Ukraine*) was gathered within the radius of different and distant towns (*Berlin*, *Hamburg*, *Cologne* and *Munich*), ensuring disjoint datasets on the different devices. After a short introduction of the application (1), the participants performed a connection quality test (2) and were instructed to download the prepared information via P2P (3). Moreover, the participants were asked to send some chat messages over the ad-hoc network (4). Those functional tests were conducted twice, each time with four participants. After this more technical evaluation approach, the evaluation was concluded with four interview questions (5) concerning (a) how participants assess the application's P2P download and chatting functionalities, (b) if they can imagine further applications utilizing ad-hoc networking, (c) their estimation on the limits of the network service and potential enhancements, and (d) whether they want to express other thematic points of interest. The interviews were audio-recorded and transcribed for further analysis in order to enrich the performance test's experiences in a systematic manner. We employed "open" coding (Strauss and Corbin 1998), i.e., gathering data into approximate categories to reflect the issues raised by respondents based on repeated readings of the data and its organization into "similar" statements. These categories reflect the structure of the following results section.

Evaluation Results: The results of the evaluation show that the combination of the four aspects (1) ad-hoc networking, (2) provision of social media information, (3) geo-based services respectively map-based representation and (4) direct communication perform suitable from a technical perspective. The application provides opportunities to download and exchange information from social media via P2P and to discuss certain social media information using the chat component, so that the media is not just exchanged but retains "social" without the need of central communication infrastructure: "I really liked the chat function. Particularly, it is really useful if the Internet breaks down, as you have a connection over such a network, that you can exchange yourself with others over such a chat. The download of messages respectively the tweets, that is certainly nice somehow; the question is what happens, if it is a larger area, if you suddenly find 20000 tweets about one topic" (P2, 30:40).

The participant indicates the requirement to test the application's scalability in greater cases or scenarios. A downside of the current chat implementation is the missing awareness about successful communication: "The problem is if I write a message and wait for a response, I don't know whether the person read the message or has no interest in responding or is involved in a conversation. I cannot check that." (P4, 28:49)

Moreover, participants questioned the suitability of Bluetooth regarding network reach and persistence: "Especially considering emergencies, if we use another technology than Bluetooth that attains a higher network reach, we could deliver the application to a special group of selected users, for instance, emergency services that network among themselves. As an auxiliary network for emergencies services or so" (P5, 27:55).

Therefore, it seems natural to replace Bluetooth with a more modern radio technology, for instance, to offer a reliable auxiliary infrastructure for emergency services in the case of a communication infrastructure breakdown. A higher bandwidth could facilitate the exchange of larger, possibly important data files: "It would be difficult to exchange map data or photos via Bluetooth" (P8, 23:12).

This application aims on providing an auxiliary network infrastructure. Yet, aspects like the P2P-download of social media messages is few mentioned, but the distribution of pictures or additional content is desired. On one hand, this could be the result of the evaluation's focus on the interplay of components; on the other hand, it indicates that further opportunities of improvement have to be considered. To achieve a more concrete assessment of the implemented functionalities and to detect potentials of improvement in different situations of communication infrastructure breakdowns, further appropriate and more comprehensive field research is required.

P8 went about 10 m from the other subjects and left at the same time the space in which the evaluation was conducted. Despite the distance P8 could still successfully download messages. However, the results reveal various connection problems that can be localized in particular on the Samsung Galaxy S devices. When debugging the application, we determined that the application in situations of congestion leads to a CPU overload. Regardless of the crashes during both dates, the download function is largely successfully tested and also most of the chat messages have been sent.

5 Discussion and Conclusion

The aim of our study was to examine whether central characteristics of social media, such as communication and information exchange between different actors, can still be preserved when communication infrastructure fails. Basically we were interested in researching and based on it improving social media resilience during infrastructure breakdowns. These breakdowns might be caused by environmental reasons.

Our literature study has revealed that location-based data and direct communication can play an important role within this context. MANETs are technological concepts to create decentralized and dynamic communication infrastructures. We used it for establishing options of directly downloading the content of Twitter tweets and Facebook posts between individual mobile devices and exchange information from social media.

The evaluation of the extended application SOMAP 2.0 was limited to a small field of participants, but revealed that social media, including the aspects of local reference and direct communication, can remain "social" during communication infrastructure breakdowns, when the above mentioned aspects are considered and state of the art technologies are combined. From a theoretical point of view, the application contributes to resilience by providing an additional layer of communication and collaboration infrastructure for emergent communities during natural or political disasters. Emergent collaboration infrastructures (Reuter 2014b), as a concept to support ad-hoc needs of collaboration, might gain value out of this concept. However, participants questioned the application's performance and its usability in large-scaled scenarios. The evaluation again emphasizes the drawbacks of Bluetooth's low range and low bitrate. Furthermore, because Apple only implements a limited version of the Bluetooth protocol, a native network among Android and iOS devices is not possible. This leads to the requirement of a more suitable network technology like Wi-Fi-Direct to enable a more reliable auxiliary network infrastructure and the exchange of media files. However, technological diversity amongst devices still constitutes a problem here (Al-Akkad et al. 2014b), such as some Wi-Fi-Direct devices only support 1:1-connections.

In comparison to existing approaches, the main advancement of SOMAP 2.0 is the combination of specific aspects, such as the distribution and map-based presentation of geospatial information from social media and the direct communication in combination with MANETs. In particular, compared to Al-Akkad et al. (2014b) or Hossmann et al. (2011), our approach differs in a way that the networking and communication over multiple hops become possible. Our initial approach to consider several radio technologies for networking is in accordance with ideas of Nishiyama et al. (2014). However, the various incompatibilities between individual smartphone manufacturers hampered us implementing Wi-Fi-Direct. In contrast to the application *Open Garden* (Shalunov 2013), within SOMAP 2.0 none of the nodes needs Internet access. Moreover, in contrast to the application *The Serval*

Mesh (Gardner-Stephen 2011), no root access for the use of necessary functions is needed.

Nevertheless, the individual functions should be investigated with regard to usability aspects for improving the links between the map interface and ad-hoc networking interface. Also, the maturity of the approach has to be further examined and improved to provide a robust communication layer during disasters. Thus, a comprehensive functional test is required to gather quantitative and enrich qualitative evaluation results. These are necessary steps to further examine the "social" capabilities of MANET-based applications, like SOMAP 2.0, in large-scale power breakdown scenarios, which—when mature—could (and will) also be integrated in online social networks itself, like Facebook, which are already working in that area (Wiseman et al. 2015).

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