Ad Hoc communication topology switching during disasters from altruistic to individualistic and Back

Banerjee, Indushree; Warnier, Martijn; Brazier, Frances

DOI
10.5220/0009434201030107

Publication date
2020

Document Version
Final published version

Published in
COMPLEXIS 2020 - Proceedings of the 5th International Conference on Complexity, Future Information Systems and Risk

Ad Hoc Communication Topology Switching during Disasters from Altruistic to Individualistic and Back

Indushree Banerjee, Martijn Warnier and Frances Brazier

Faculty of Technology Policy and Management, Systems Engineering and Simulations, Delft University of Technology, Delft, The Netherlands

Keywords: Ad Hoc Communication Networks, Disaster Management, Topology Switching, Autonomous Computing.

Abstract: Disaster communication has made immense progress in the last thirty years. At present, disaster research focuses on bottom-up approaches such as civilian inclusion in disaster response. With the advent of smartphones, citizen-based emergency communication has become possible. Present ad hoc communication technologies typically form a fully connected mesh network, which connects all phones that are within each other's transmission range. This facilitates low-latency direct communication between citizens, but it quickly drains the battery of phones. Alternative ad hoc communication networks form an adaptive energy-efficient network topology, that is most draining to batteries of phones that have a higher charge, while low-energy phones are spared from relaying messages, thereby preserving battery and thus maintaining their connection with the rescue communication network. Both of these approaches have their own advantages. Which one is best for communication needs depends on the context. This position paper discusses the possibility of a decision model as an approach to automatically switch between the two alternative ad hoc communication networks. This ensures that citizens in disasters can make use of the optimal communication system at all times.

1 INTRODUCTION

To enhance societal resilience against disasters, collective participation of citizens in a timely and informed manner must be incorporated (Comfort and Haase, 2006; Comfort et al., 2010). One way of facilitating citizen autonomy is to design emergency communication services with existing tools such as smartphones that can provide continuous access to information (Maryam et al., 2016; Kumbhar et al., 2016).

To form a mobile ad hoc communication network (MANET) smartphones use their inbuilt WiFi or Bluetooth to connect with other devices in their proximity or transmission range to exchange messages in a peer-to-peer mode, forming communication networks on-the-fly (Wang et al., 2017; Raffelsberger and Hellwagner, 2013). Ad hoc networks such as MANETs (Mobile Ad Hoc Networks) have two main topologies for their underlying connectivity: full mesh or scale-free.

The topology of a network determines the pattern of connectivity between nodes to form connections. In a full mesh topology, nodes within transmission range of each other form a direct point-to-point connection. This leads to a fully connected network such that every node in the transmission range gets connected and as they move around they make more connections dynamically. If the sender and the receiver are not in direct contact, there are always relaying nodes that can pass the message to the intended destination. Applications such as Firechat (Lin et al., 2015), ServalMesh (Lieser et al., 2017), HelpMe (Mokryn et al., 2012) follow this topology and are promoted as solutions to disaster emergency communications.

The performance of the network depends on the chosen topology, and each topology has its own benefit. A full mesh topology provides more connectivity and reliability due to redundant routes. However, scaling a full mesh topology is a challenge. Additionally, a full mesh topology can lead to extreme battery drainage of participating nodes due to high connection costs.

Alternatively in a scale-free network topology, like the recently developed SOS (Banerjee et al., 2020), delay and latency can be very high. Therefore, to cater to a specific requirement, the topology is predetermined for a specific application.

For example, for a sparsely populated area, a scale-free network topology is preferred. However,

Banerjee, I., Warnier, M. and Brazier, F.
Ad Hoc Communication Topology Switching during Disasters from Altruistic to Individualistic and Back.
DOI: 10.5220/0009434201030107
In *Proceedings of the 5th International Conference on Complexity, Future Information Systems and Risk (COMPLEXIS 2020)*, pages 103-107
ISBN: 978-989-758-427-5

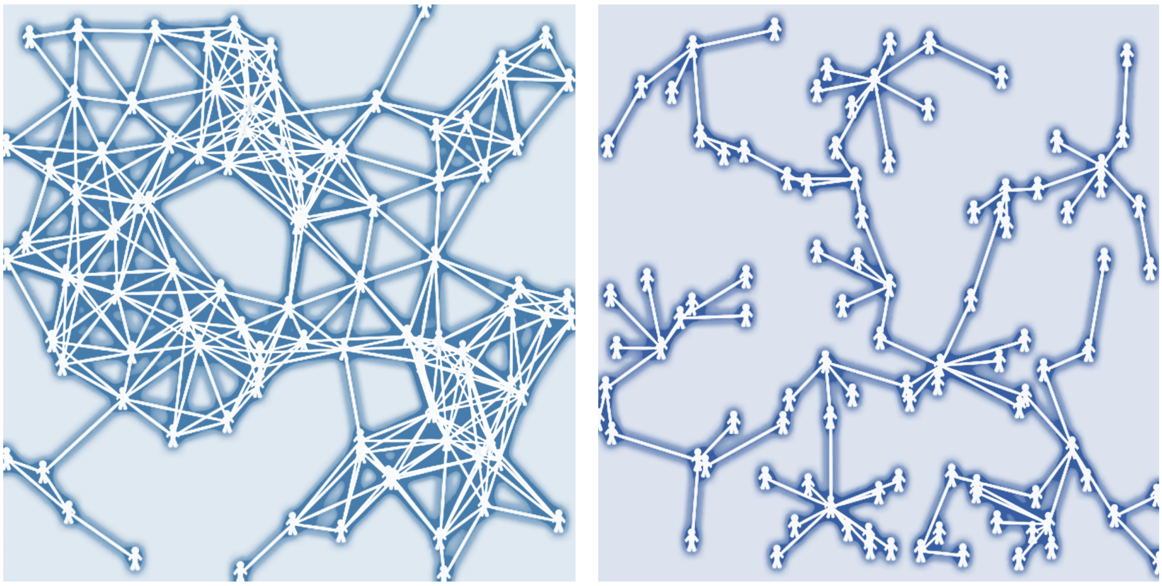

Figure 1: This figure represents two different topologies. On the left a full mesh topology is represented (individualistic topology) and on the right a scale-free network topology is illustrated (altruistic).

for a densely populated area a full mesh topology is chosen.

In addition to density and mobility, there are many other factors that play a role in maintaining connectivity, such as available resources, whether charging facilities are available, context and social information or relationships (Jedari et al., 2018). This can lead to non-cooperative behaviour among relaying nodes. Based on the behaviour of nodes, literature (Jedari et al., 2018) classifies mobile nodes in three main categories,

- selfish
- cooperative, and
- malicious nodes.

Malicious nodes are out of the scope of this paper. This paper mainly focuses on selfish node behaviour and cooperative node behaviour.

A selfish node can on purpose drop messages either to save resources, decline to connect due to privacy issues and may have social biases before joining an ad hoc network in a community. This can limit the coverage area and scaling of the network, while lowering reliability of message delivery due to network segmentation.

Therefore, there is a need for networks to be able to switch between topologies depending on the spatial-temporal-resource context.

This paper addresses these criteria required for a decision model that generates a self-organised topology with respect to spatial-temporal-resource context. The purpose is to switch between two main topologies, namely individualistic and altruistic.

In this paper a full mesh topology is called an individualistic topology since it forms connections and routes data without consideration for other nodes in the network. As represented on the left panel of figure 1, each node connects with every other node in its proximity or transmission range and communicates without any consideration of relaying nodes.

During disaster where there is continued uncertainty of available resources and need of continued access, it is very possible that nodes demonstrate selfish behaviour and behave more individualistically.

At present three main categories of incentive mechanisms are present that promote co-operative behaviour. Specific to disaster scenarios are reputation-based, credit-based and tit-for-tat-based (Gupta et al., 2014; Radenkovic et al., 2018; Asuquo et al., 2016). However, these mechanisms mainly focus on data routing and not topology creation.

Therefore, this paper defines a scale-free network as an altruistic topology that forms an ad hoc network while considering node limitations in terms of resources. The right panel of Figure 1 shows the formation of an altruistic network that promotes equal participation of nodes to avoid low-energy nodes for relaying, thus preventing selfish behaviour.

During disasters, an effective response is highly dependent upon the ability of a system to sustain dynamic changes. Systems must be modeled with the consideration of dynamic context, while updating information and a continued access to information,

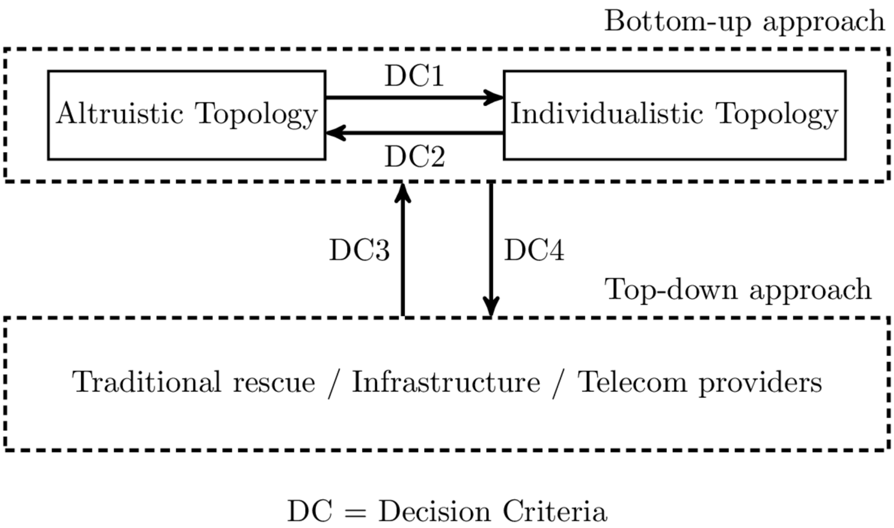

Figure 2: Decision model framework.

therefore, the decision model must allow switching between these two connection topologies.

2 DECISION MODEL AND DECISION CRITERIA

The switching can be determined by various factors such as the density of nodes, mobility of nodes, availability of resources such as charging facilities, social participation, inclusion of traditional rescue among others.

Access to updated information needs to be continuous and thus a smooth automatic transition that avoids discontinued communication service is very necessary.

The first transition takes place in the immediate aftermath of a disaster, i.e. when infrastructures are unavailable, services switch to a bottom-up approach. This transition is reversed when infrastructure is either restored or traditional rescue brings equipment such as unmanned aerial vehicles or WiFi access points to re-establish communication and install a top-down approach.

The second transition takes place between topologies catering to bottom-up approaches, between altruistic and individualistic topologies. This framework is represented in figure 2.

2.1 The Decision Tree

This section presents an example of decision trees that determine when to switch between the two types of topologies in the bottom-up approach. The decision is based on three factors:

1. charge of the participating nodes,
2. node density, and
3. number of messages being exchanged.

First, charge of the participating nodes is central in deciding which topology to use, since node participation is a top priority. If the charge of participating nodes is low, low energy nodes start running out of battery, and stop participating.

Second, node density determines how many nodes are in transmission range, and therefore determines how many connections need to be made. Getting connected is an expensive process. If there are many nodes in range, and every node connects to all nodes in range, this drains the battery quickly, and will in the end not be efficient.

Third, if the number of messages being sent is high, then a topology that relies on nodes relaying messages via many intermediate nodes will drain battery quickly, and will not be efficient.

In the proposed decision models, this last factor is not included, because it is not a top priority and the decision model should be simple to conserve energy in computation.

In the decision model, a number of criteria are formulated for evaluating whether a node can best switch to a different type of topology, or best stays with the present topology in use. These decision models are not mirror images: Once an altruistic topology is in place, the threshold should be high to switch to an individualistic topology.

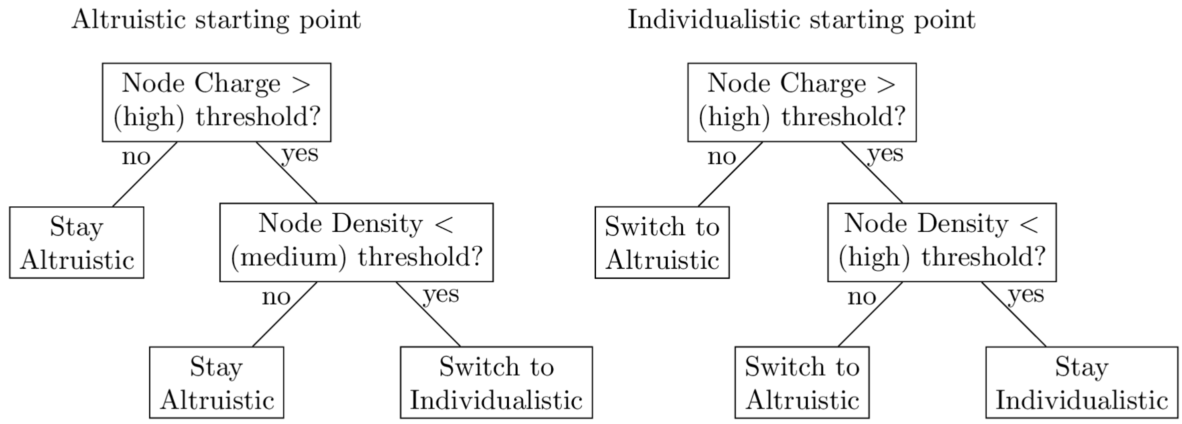

Figure 3: Decision tree for switching between altruistic to individualistic and back.

The decisions as represented in figure 3 are followed at the level of individual nodes: Every node decides for itself whether it will switch to the different topology, and although this decision is shared with the surrounding nodes, it will only affect the connections of this node.

Therefore, the topology of the whole network can be a hybrid between the two types of topologies, with some areas or some subsets of nodes following the individualistic topology, and other areas or subsets of nodes following the altruistic topology. The decisions are all dichotomized using thresholds, to keep computations simple and low in energy consumption, as they need to be performed by each individual phone at regular intervals.

The switching is performed by adaptive self-organisation that follows the principles of Autonomic computing (Brazier et al., 2009). Autonomic computing has been used for designing complex system through self-organisation and self-management of individual entities participating in forming the system without human intervention.

The process involves each entity monitoring the environment to acquire context information, analyzing the information to gather perspective, planning based on the analyses and finally executing the decision. The same decision criteria will be followed by each node.

In the ad hoc networks, participating nodes are not aware of the context and their own limitations at the beginning as they join the network. As the network formation begins and the number of nodes participating increases, the context changes and thus they need to change their connectivity pattern to maintain communication and coverage.

The approach includes setting thresholds for various decision criteria. In the extended version of this paper, the algorithms for switching will be extended.

3 CONCLUSION

In conclusion this paper presents the conceptual framework of a decision model that allows topology switching using autonomic computing and self-organisation for emergency communications in the aftermath of a disaster.

The purpose is to allow smooth transition of different connectivity patterns that allows human collective intelligence to be utilized via technical means to support its society in complex, dynamic environments. An adaptive system capable of facilitating communication between affected citizens provides citizens the autonomy to help themselves.

REFERENCES

Asuquo, P., Cruickshank, H., Ogah, C. P. A., Lei, A., and Sun, Z. (2016). A collaborative trust management scheme for emergency communication using delay tolerant networks. In *2016 8th Advanced Satellite Multimedia Systems Conference and the 14th Signal Processing for Space Communications Workshop (ASMS/SPSC)*, pages 1–6. IEEE.

Banerjee, I., Warnier, M., and Brazier, F. M. T. (2020). Self-organizing topology for energy-efficient ad-hoc communication networks of mobile devices. *Complex Adaptive Systems Modeling*. Journal article under review (preprint available online).

Brazier, F. M., Kephart, J. O., Parunak, H. V. D., and Huhns, M. N. (2009). Agents and service-oriented computing for autonomic computing: A research agenda. *IEEE Internet Computing*, 13(3):82–87.

Comfort, L. K. and Haase, T. W. (2006). Communication, coherence, and collective action: The impact of hurricane katrina on communications infrastructure. *Public Works Management & Policy*, 10(4):328–343.

Comfort, L. K., Oh, N., Ertan, G., and Scheinert, S. (2010). Designing adaptive systems for disaster mitigation and response. *Designing resilience: Preparing for extreme events*, pages 33–62.

Gupta, A. K., Bhattacharya, I., Banerjee, P. S., and Mandal, J. K. (2014). A co-operative approach to thwart selfish and black-hole attacks in dtn for post disaster scenario. In *2014 Fourth International Conference of Emerging Applications of Information Technology*, pages 113–118. IEEE.

Jedari, B., Xia, F., and Ning, Z. (2018). A survey on human-centric communications in non-cooperative wireless relay networks. *IEEE Communications Surveys & Tutorials*, 20(2):914–944.

Kumbhar, A., Koohifar, F., Güvenç, I., and Mueller, B. (2016). A survey on legacy and emerging technologies for public safety communications. *IEEE Communications Surveys & Tutorials*, 19(1):97–124.

Lieser, P., Alvarez, F., Gardner-Stephen, P., Hollick, M., and Boehnstedt, D. (2017). Architecture for responsive emergency communications networks. In *2017 IEEE Global Humanitarian Technology Conference (GHTC)*, pages 1–9. IEEE.

Lin, W. Y., Hsueh, K.-P., and Pa, P.-S. (2015). The development of emergency communication app using ad hoc network with ipv6. In *2015 International Conference on Intelligent Information Hiding and Multimedia Signal Processing (IIH-MSP)*, pages 41–44. IEEE.

Maryam, H., Shah, M. A., Javaid, Q., and Kamran, M. (2016). A survey on smartphones systems for emergency management (spsem). *International Journal of Advanced Computer Science and Applications*, 7(6):301–311.

Mokryn, O., Karmi, D., Elkayam, A., and Teller, T. (2012). Help me: Opportunistic smart rescue application and system. In *2012 The 11th Annual Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net)*, pages 98–105. IEEE.

Radenkovic, M., Walker, A., and Bai, L. (2018). Towards better understanding the challenges of reliable and trust-aware critical communications in the aftermath of disaster. In *2018 14th International Wireless Communications & Mobile Computing Conference (IWCMC)*, pages 648–653. IEEE.

Raffelsberger, C. and Hellwagner, H. (2013). A hybrid manet-dtn routing scheme for emergency response scenarios. In *2013 IEEE international conference on pervasive computing and communications workshops (PERCOM workshops)*, pages 505–510. IEEE.

Wang, Y., Wei, L., Vasilakos, A. V., and Jin, Q. (2017). Device-to-device based mobile social networking in proximity (msnp) on smartphones: Framework, challenges and prototype. *Future Generation Computer Systems*, 74:241–253.