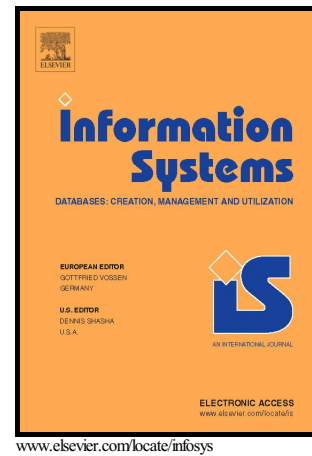


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# Crowdsourcing Emergency Data in Non-Operational Cellular Networks

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## Abstract

In overloaded or partially broken (i.e., non-operational) cellular networks, it is imperative to enable communication within the crowd to allow the management of emergency and crisis situations. To this end, a variety of emerging short-range communication technologies available on smartphones, such as, Wi-Fi Direct, 3G/LTE direct or Bluetooth/BLE, are able to enable users nowadays to shape point-to-point communication among them. These technologies, however, do not support the formation of overlay networks that can be used to gather and transmit emergency response state (e.g., transfer the location of trapped people to nearby people or the emergency response guard.) In this paper, we develop techniques that generate the  $k$ -Nearest-Neighbor ( $kNN$ ) overlay graph of an arbitrary crowd that interconnects over some short-range communication technology. Enabling a  $kNN$  overlay graph allows the crowd to connect to its geographically closest peers, those that can physically interact with the user and respond to an emergency crowdsourcing task, such as seeing/sensing similar things as the user (e.g., collect videos and photos). It further allows for intelligent synthesis and mining of heterogeneous data based on the computed  $kNN$  graph of the crowd to extract valuable real-time information. We particularly present two efficient algorithms, namely *Akin+* and *Prox+*, which are optimized to work on a resource-limited mobile device. We use Rayzit, a real-world crowd messaging framework we develop, as an example that operates on a  $kNN$  graph to motivate and evaluate our work. We use mobility traces collected from three sources for evaluation. The results show that *Akin+* and *Prox+* significantly outperform existing algorithms in efficiency, even under a skewed distribution of users.

## 1. Introduction

In the age of smart urban and mobile environments, the mobile crowd generates and consumes massive amounts of heterogeneous data [27, 34]. Such streaming data offer the potential of enhanced science and services, such as emergency and crisis management services, among others. The availability of such services is specifically important in scenarios where a *cellular network becomes non-operational*.

A cellular network is deemed *non-operational* when there is no (sufficient) network connectivity. This might happen due to damage caused by a disaster (e.g., major flooding), or due to overloading caused by an unexpectedly large crowd trying to access telecommunication services simultaneously, e.g., consider the connection problems mobile users have faced during public celebrations of New Year's Eve.

Each cellular tower has a limited capacity of users it can service simultaneously. Specifically, each cellular tower has a limitation on its communication bandwidth to the carrier (back-haul bandwidth), a limitation on the aggregate bandwidth capacity offered by the spectrum and protocol used for wireless communication, and a limitation on the capacity of the network gears [24].



Figure 1: (left) Large crowd protesting in Syria (Reuters 2014), (right) Woman using her mobile while waiting for help in China floods (Reuters 2012).

The following are some real-world scenarios making a network non-operational. These are cases where emergency and crisis management services are needed the most.

*Ad-Hoc Event Services.* Large ad-hoc events can be cultural festivals (e.g., Woodstock, Old Car enthusiast gatherings), sporting events, conventions and fairs, ad-hoc demonstrations (e.g., Occupy Wall Street 2011) and ad-hoc protests (e.g., Egypt 2013, Syria 2014, Romania 2014, Hong Kong 2014) as seen in Figure 1 (left). *In such scenarios, being able to monitor and provide communication within the crowd can aid organizing authorities to better manage the crowd<sup>1</sup> and prevent lethal crowd disasters<sup>2,3</sup>.* Additional services can also be applied, like new entertainment services<sup>4</sup> and crowd-games<sup>5</sup>.

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<sup>1</sup>WorkingWithCrowds, Online: <http://www.workingwithcrowds.com/>

<sup>2</sup>Love Parade disaster, Online: <http://goo.gl/2FpIbm>

<sup>3</sup>Hillsborough disaster, Online: <http://goo.gl/xvLRlc>

<sup>4</sup>Opphos, Online: <https://www.sics.se/projects/opphos>

<sup>5</sup>CrowdControlGames, Online: <http://crowdcontrolgames.com/>

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