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Decentralized Disaster Area Detection in Mobile Networks

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***Abstract*—In highly developed countries information and communication technology is considered a critical infrastructure alongside other infrastructures like power and water supply or the health care system, whose absence or failure increasingly impairs the life of the affected population. Due to high interdependencies between those critical infrastructures, cascading effects occur when one of them becomes unavailable. Unresolved power blackouts, in particular, can lead to the shutdown of other infrastructures with passing time. In such situations, it is crucial to quickly determine the area affected by a blackout in order to coordinate mitigation efforts.**

In this work, we present algorithms that enable an autonomous analysis of the area affected by the failure of the aforementioned power supply and information and communication technologies and for spreading that information about the disaster area among the affected population. To achieve this, mobile ad hoc networks can be utilized using the mobile devices of the affected population.

In this demonstration, attendees can observe the behavior of mobile nodes entering and exiting the simulated disaster area while sharing their movement history to estimate the area that is affected by the infrastructure blackout. The continuous area estimation of each node can be observed via live visualizations while the area of the blackout can dynamically increase or decrease. Additionally, the quality of the disaster area detection is shown through live plots of relevant metrics.

I. INTRODUCTION

Disasters such as the hurricane Sandy in 2012 or hurricane Maria, Jose, and Harvey in 2017 have demonstrated destructive impact on critical infrastructures and the corresponding challenges to disaster relief efforts. Especially when disasters strike in urban environments, a functioning information and communication infrastructure is key for emergency response but in the example of the aftermath of a hurricane is often not available [1]. Also, the threat of cyber attacks on critical infrastructure becomes more and more prominent [2]. Utilizing the smartphones of citizens and responders affected by the infrastructure blackout, resilient infrastructure independent ad-hoc communication networks can be established [3]. While there exists a variety of emergency services based on smartphone-based ad hoc networks [4], the affected area of the blackout is often unknown to the infrastructure provider and the citizens [5]. Therefore, we propose a decentralized disaster area detection in mobile ad hoc networks, enabling mobile devices to share their location history with neighboring nodes to construct the affected area of the blackout. We contribute different algorithms to calculate the area based on the shared locations and present mechanisms for an adaptive and resource efficient area detection.

In this demonstration, we enable attendees to interact with the proposed service by changing the blackout area dynamically and by further influencing the mobile nodes disaster area calculations. Attendees can observe the resulting behavior from three different views through our node-, world- and statistics-view showing the simulated area, the nodes view on the area and different metrics. This metrics contain, among others, the precision, recall and f1-score and can be observed as live plots during the demonstration. Section III details the demonstration scenario and setup, highlighting the interaction possibilities.

II. DECENTRALIZED DISASTER REGION DETECTION

Source: Openstreetmap, Flaticon

Figure 1. Scenario: Unknown blackout area with no available communication infrastructure.

Figure 1 shows the infrastructure blackout scenario for the demonstration. An unknown area is affected by the blackout. Nodes inside that area will detect that there is no cellular connection anymore and will switch to ad hoc communication mode. All these nodes start tracking their movement while sharing their location history with neighboring nodes in communication range. Because nodes can exit and reenter the blackout area, the location history can store two types of locations; infrastructure available or infrastructure unavailable. Figure 2 sketches the temporal sequence of the knowledge about the blackout area for a specific node in this area. Black dots represent locations where the central communication infrastructure is not available, and red dots represents the location where the communication infrastructure is still intact.

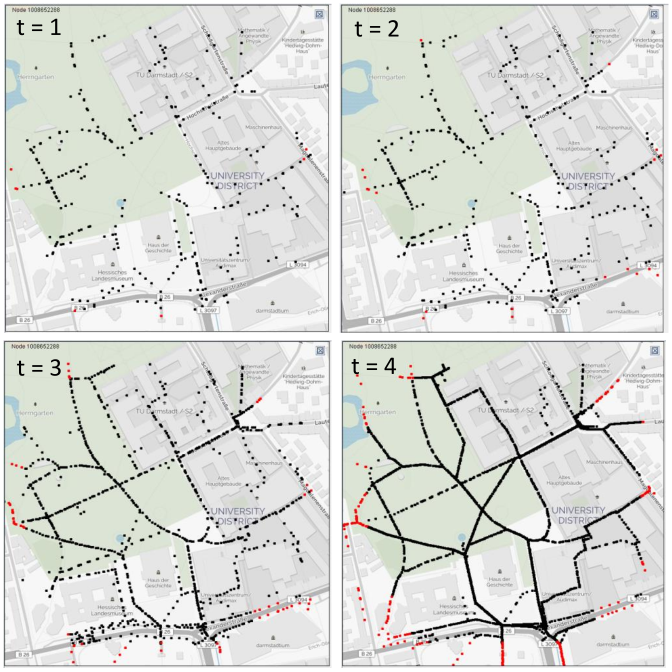

Figure 2. Temporal sequence of the a nodes knowledge of the disaster area. Black dots represent locations inside the blackout area with no intact infrastructure, and red dots outside the area.

A. Disaster Region Recognition/Calculation

To calculate the disaster Region from the logged and exchanged locations, three different algorithms have been implemented. The calculation of the disaster area is done by each node individually with the locations known to that particular node.

- The *Corners* algorithm determines the northern-, southern-, western- and easternmost location and constructs a quadrilateral with those locations as its vertices.
- The *Bounding Box* algorithm extends the *Corners* algorithm. It takes the quadrilateral and draws the smallest, non-rotated rectangle around it.
- *Andrew's Monotone Chain Convex Hull* algorithm [6] constructs the convex hull of a set of 2-dimensional points. The *Andrew's Monotone Chain* algorithm computes the upper and lower hulls of a monotone chain of points. Like the *Graham Scan* [7], it runs in $O(nlog-n)$ time due to the sort time. After that, it only takes $O(n)$ time to compute the hull [8].

Depending on the size of the blackout area and the number of the affected nodes, the number of stored locations on each node can get very large. Therefore nodes only exchange unknown positions after broadcasting their knowledge in a three handshake manner. Additionally, to reduce the amount of exchanged data, we provide the option to broadcast only the locations which are relevant for the disaster area calculation. For *Andrew's Monotone Chain* this results in only broadcasting the hull and for the *Bounding Box* and *Corners* algorithm only the corners of the rectangle.

Because the size and the shape of the blackout area can change dynamically and the storage on the devices is limited, nodes also need to decide when stored location should not be considered for the disaster area calculation anymore. This can be achieved by simply defining a maximum *time to live* (TTL) after that locations will not be considered anymore and removed from the location storage on any node that either generated this specific location or received it through a broadcast. For this purpose, each location is logged and broadcasted together with origin timestamp and the TTL. If the TTL is set too low, information might expire before it has the chance to be spread in the disaster area. If the TTL is set too high, the lists of location will grow and more outdated locations will continue to be stored. This leads to increased computational cost, redundancy in high traffic areas and possibly wrong results in low traffic areas.

To handle dynamic error corrections additionally to the TTL based location timeouts we introduce so-called *location consistency checks*. During this check, each node iterates its stored locations and checks them for contradictions like an infrastructure available location in the middle of a group of no infrastructure available locations. In such a case, it is assumed that the freshest location (based on the TTL) is the updated one and all locations of the opposite type in a defined radius around the freshest location are removed. An example of the dynamic change of the simulated disaster area is displayed in Figure 3.

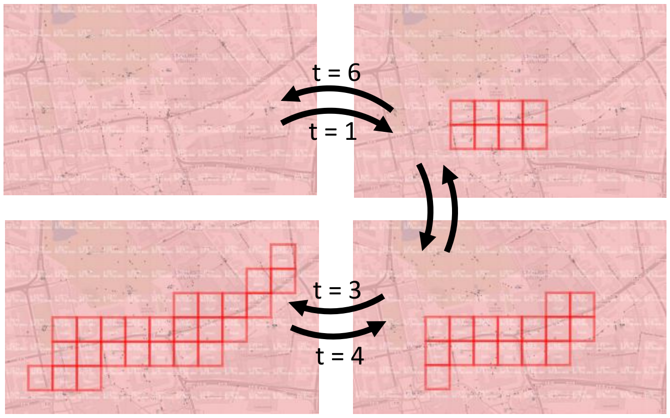

Figure 3. Dynamic change of the simulated disaster area.

III. DEMONSTRATION SCENARIO AND SETUP

We demonstrate the aforementioned decentralized disaster area detection in an interactive simulation relying on the SIMONSTRATOR platform [9]. The simulation is based on the model of social mobility proposed in [10], with mobile nodes following pedestrian routes in an urban scenario based on OpenStreetMap data. Nodes select potential destinations from a series of attraction points that model interesting points in the real world. Such sights are public parks, market places and other interesting places in an urban environment. Each mobile node can communicate via Wi-Fi ad hoc with neighboring nodes to spread the individual location history.

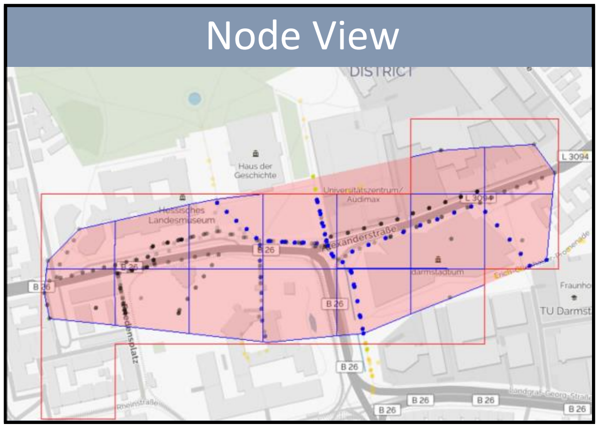

Figure 4. Nodeview: Calculated disaster area, based on shared location histories of mobile nodes.

The demonstration has three different layers of visualization: the *world*, *node* and *statistics views*. The behavior of the nodes and the area of the infrastructure blackout is visualized in the *world view*, the individual perspective of a node and the calculated disaster area is illustrated in the *node view* and the *statistics view* shows a variety of live metrics. Figure 4 shows one example for an individual *node view*. The red lines represent the affected area and the red polygon shows the calculated area by the selected node. This calculation is based on the node's own location history (blue dots) and locations received by other nodes (black dots).

A. Interaction with the Demonstration

Attendees can interact with the demonstration by using the *world view* to change the area that is affected by the blackout dynamically. Via the *world view* they select individual nodes or groups of nodes that will be displayed on the *node view*. Additionally, attendees can switch between different simulation setting to change the proposed calculation algorithms explained in Section II-A or switch on and off the mentioned *consistency check* to directly observe their influence on the decentralized disaster area detection. With the enabled *consistency check* attendees can see that dynamic changes of the area, no matter if the area will increase or decrease, will be detected and updated much faster and accurate by the nodes.

IV. CONCLUSION

Our demonstration shows an example of the meaningful use of smartphone-based ad hoc networks during an infrastructure blackout caused by e.g. disasters or cyber attacks. Knowing the affected area of the blackout can be useful in many ways, the information can be used to support the affected civilians and navigate them to the nearest location with intact infrastructure, or the area detection can be used by emergency operations to plan emergency response actions.

V. TECHNICAL REQUIREMENTS

The necessary equipment for the demonstration includes a laptop and a monitor. The displays are used to show attendees the world, node and statistics views of the simulated blackout, demonstrating the node behavior and the disaster area calculation based on the nodes locations histories. In addition, the user can interact with the simulation configuration and switch between these algorithms and simulation options to explore the benefits of accurate and adaptive range detection. We ask the conference organizers to provide us with a computer monitor (22-24" with HDMI connection) and two sockets. The demonstration takes 20 minutes to set up.

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