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Multi-Strategy Simulation of Aerial Post-Disaster Ad Hoc Communication Support Systems

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***Abstract*—In case of destroyed or impaired infrastructure due to natural catastrophes, mobile devices such as smartphones can be used to create civilian ad hoc networks to provide basic means of communication. Due to the human behavior to form groups and cluster around significant locations in such situations, however, the network is often heavily intermittent, and thus, communication between clusters is impossible. Aerial Post-Disaster Ad Hoc Communication Support Systems can overcome the gaps between clusters, but the performance is highly dependent on factors like the applied strategy, the amount of UAVs, or their technical specifications. In this demonstration, we present different support strategies in an urban post-disaster scenario. Attendees can interact and select strategies and explore different strategy parameter settings, while observing the effect on the network performance and, additionally, gaining a comprehensive insight into the strategy behavior. The interaction with the demonstration underlines the vast amount of different settings and influence factors, an aerial system operator must take into account when selecting and adapting a strategy suitable for the current situation, as motivated in our accompanying main conference paper [7].**

I. Introduction

The significant increase in occurrences of large-scale extreme weather conditions such as floods and hurricanes in recent years revealed the vulnerability of critical infrastructure for information and communication technologies (ICT), that are often destroyed in such events [4]. Nevertheless, functioning ICT is crucial for an efficient disaster management, and thus, an important factor in reducing disaster-related fatalities [6]. Smart mobile devices, such as smartphones, can be used to create large-scale delay-tolerant mobile ad hoc networks (DTN-MANETs) within the affected areas by utilizing device-to-device communication [1]. The natural behavior of humans to form groups and gather around shelters or resource depots in disaster situations, however, severely limits the communication performance within the affected area as low mobility between those distinct network clusters will lead to poor inter-cluster communication due to the applied store-carry-forward principle [1].

As shown in previous work, Unmanned Aerial Vehicles (UAVs) can be used as highly mobile, controllable data carriers in post-disaster scenarios to establish communication between otherwise fully separated network clusters [3]. Besides sensing capabilities or independence of obstructed roads, especially small autonomous UAVs have the merit of a fast and flexible situation-adapted deployment. However, the performance and utility of such an Aerial Post-Disaster Ad Hoc Communication

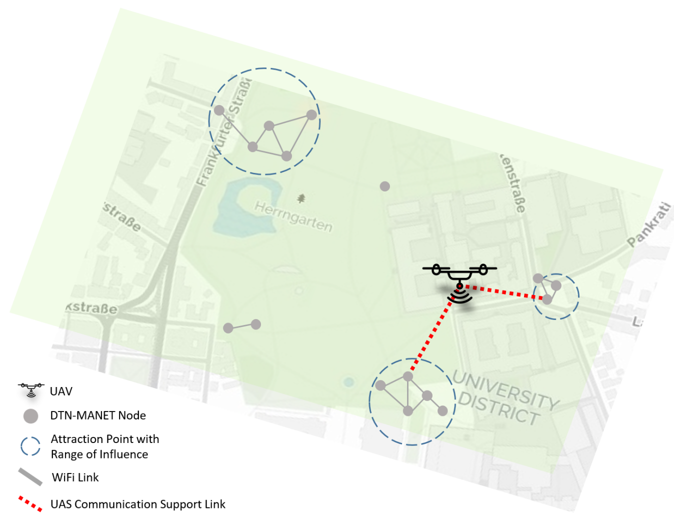
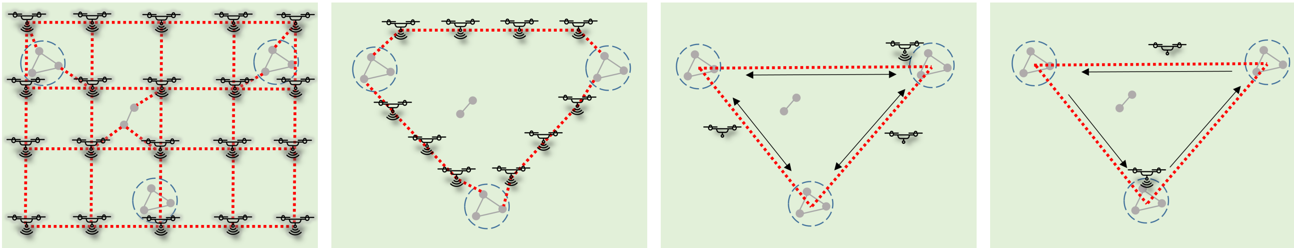


Fig. 1: Mobile devices cluster around points-of-interest in an intermittent urban post-disaster DTN-MANET. With an Aerial Post-Disaster Ad Hoc Communication Support System, message transfer can be re-established between separated clusters.

Support System is strongly dependent on (i) the applied support strategy, (i) the amount of available UAVs, and (iii) the technical specifications of used UAVs and the base station. Due to the amount of possible combinations that arise from those dependencies, experimental evaluation with hardware prototypes in the field is unfeasible and suffers from poor scalability and reproducibility. Therefore, simulations are the preferred method for developing and assessing such complex systems towards an enhanced state, before eventually deploying it in the real world.

We proposed a simulation platform for Unmanned Aerial Systems (UAS) as an extension to the open-source event-based simulation and prototyping platform SIMONSTRATOR.KOM[1] in [3]. It allows for the parallel simulation of Aerial Communication Support Systems and DTN-MANETs using different ad hoc protocols, UAS strategies, UAV specifications, and more. In this demonstration, we enable attendees to interact with the controls of the base station by switching between different communication support strategies and by further influencing

[1] https://dev.kom.e-technik.tu-darmstadt.de/simonstrator/



(a) Relay Mesh (b) Relay Bridge (c) Link Ferry (d) Cyclic Ferry

Fig. 2: Different UAS Communication Support Strategies, sorted from left to right by the number of required UAVs for the strategy operation.

technical specifications of UAVs like battery capacities and flight speeds. Attendees can observe the simulated area from a top-down world view as illustrated in Figure 1, and therein, the impact of their decisions. Furthermore, live plots of network metrics such as the number of clients, the message delivery delay, and the message spread can be viewed during the simulation.

A brief summary of UAS communication support strategies is provided in the following section. Section III provides details of the demonstration scenario and setup, as well as highlighting the possible interaction for attendees.

II. Strategies for Aerial Post-Disaster Communication Support

Figure 1 depicts the urban post-disaster scenario considered for the demonstration. Without a functioning mobile network, affected civilians can only communicate within their devices' WiFi communication range, acting as nodes in a DTN-MANET. However, post-disaster network often become highly intermittent. While intra-cluster communication performs well, inter-cluster communication suffers from very long delays and from message deprecation as the required node movement between clusters happens only occasionally and takes time.

With the deployment of an Aerial Post-Disaster Ad Hoc Communication Support System based on autonomously flying Unmanned Aerial Vehicles (UAVs), message transfer between separated clusters could be re-established. The impact on the overall communication performance, foremost message delivery delay and message spread throughout the network, is however highly dependent on the applied strategy. In turn, which strategy can or should be applied depends on several factors like the network topology and the number as well as the technical specifications of available UAVs. The set of strategies that is available to choose from in the demonstration is illustrated in Figure 2.

The Relay Mesh strategy (cf. Fig. 2a) builds a full-coverage overlay network in the affected network. Messages are exchanged between the DTN-MANET and the overlay network that relays them from UAV to UAV, which results in a quick message delivery. Due to the full coverage, nodes that move in-between clusters are also covered and able to communication with the rest of the DTN-MANET. However, the amount of necessary UAVs to deploy and maintain such a relay network is very high.

With a significantly smaller amount of UAVs, the Relay Bridge strategy (cf. Fig. 2b) is able to reach similar communication performance. In this strategy, UAVs form a straight bridge between network clusters over which messages are relayed and distributed. The drawback, however, is that nodes in-between clusters are not covered unless they move within the communication range of relay UAVs in the bridges. Thus, message deprecation may occur which has a negative impact on message spread, or at least messages will required more time to be fully disseminated in the network.

If the amount of available UAVs is low, *data ferries* can be used to physically transport messages between clusters, instead of building a static relay link. Due to the required movement of the UAVs, however, the message delivery delay is significantly higher than in both of the relay strategies. The Link Ferry strategy requires only as much UAVs as there are communication links between clusters, for example, three UAVs as shown in the illustration (cf. Fig. 2c). Nevertheless, if an additional increase in delivery delay is possible, one of the links can be further dropped in that specific case and the number of UAVs decreases by one. Similarly, UAVs successively visit the clusters in the Cyclic Ferry strategy (cf. Fig. 2d). As shown in [3], the strategy can be operated with only a single UAV, while still having a significant positive impact on communication performance.

III. Demonstration Scenario and Setup

We demonstrate the Aerial Support System in an interactive simulation based on our UAS extension for the Simonstrator.KOM platform [3], [5]. The simulation runs in an urban scenario in Darmstadt, Germany. Mobile nodes move on pedestrian walkways based on OpenStreetMap[2] data and are attracted by points-of-interests, around which they roam or stay for a certain time. The set of points-of-interests is modeled based on real world locations such as public parks, market places, or hospitals. Each node has the ability to communicate with other nodes over WiFi ad hoc links, with which they span a DTN-MANET using the *HyperGossiping* [2] protocol.

[2]https://www.openstreetmap.org/

The movement of mobile nodes and UAVs in the urban environment and around attraction points can be viewed in the *world view panel* as presented in Figure 3. Furthermore, the speed and the current battery level as well as the direction of UAVs can be observed therein. The world view panel gives a visual representation of the different support strategies, and thus, demonstrates strategies and the defined UAV behavior to the attendees in a comprehensible way.

To enable the interaction of attendees with the simulation, we provide an additional *interaction and metrics panel* as shown in Figure 4. On that panel, support strategies and their strategy properties can be set. For example, one can select the RELAY MESH and then choose the number of as well as the distance between relay UAVs. In addition, technical properties of UAVs such as the size of their battery or their speed can be selected.

The panel also provides graphs of aggregated network metrics such as the average message dissemination delay and the average message spread in the network. With that information, attendees can directly explore the possible benefits or drawbacks of different support strategies, or their choices regarding strategy parameters of technical specifications of UAVs.

IV. CONCLUSION

The proposed demonstration gives an interactive graphical representation of Aerial Post-Disaster Ad Hoc Communication Support Systems and, thereby, enables the exploration of different support strategy characteristics, their benefits, as well as their drawbacks for urban civilian post-disaster ad hoc communication. This interaction in combination with direct feedback is a valuable addition to understand the applications for and implications of our main conference paper [7].

V. TECHNICAL REQUIREMENTS

The required equipment for the demonstration contains a laptop and a computer monitor. The laptop is used to allow attendees the interaction with the demonstration over the *interaction and metrics panel*. Additionally, users can interact with basic simulation configurations to switch, e.g., communication protocols or WiFi ranges. On the additional monitor we present the *world view panel*, demonstrating the scenario, the DTN-MANET topology, as well as node and UAV movement. The overall demonstration setup will required 20 minutes. We would kindly as the conference organizers to provide us with an HDMI-capable computer monitor and two power outlets.

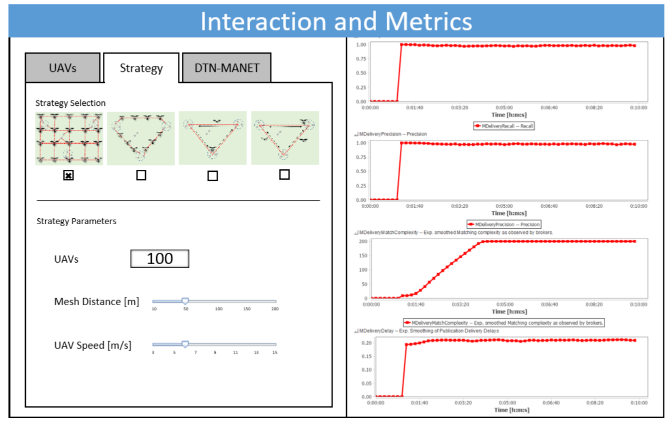


Fig. 4: The *interaction and metrics panel* shows possible interactions, such as strategy selection and parameter settings, and live plotted network metrics.

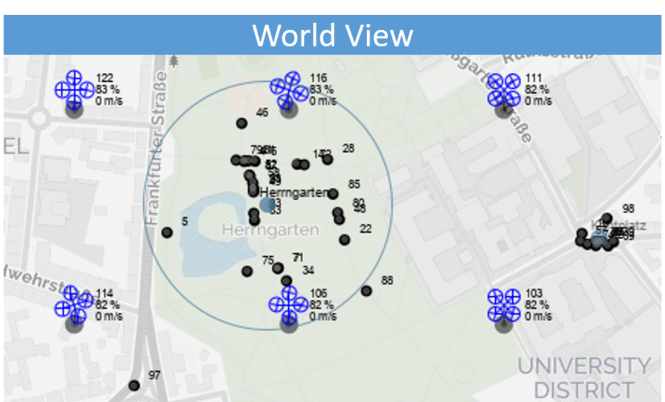


Fig. 3: The *world view panel* visualizes the simulated urban environment including nodes and UAVs.

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