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Abstract: In the aftermath of a disaster, information about the location of affected civilians is very important for an efficient disaster relief. A continuously operating autonomous *Aerial Monitoring System* with *Unmanned Aerial Vehicles* (UAVs) can provide an up-to-date overview of the disaster area by tracking wireless signals from carried or worn smart devices on the ground. This work highlights that dynamic allocation of monitoring areas facilitates a continuous deployment of a resilient *Aerial Monitoring System* with heterogeneous UAVs.

Keywords: Unmanned Aerial Vehicles, Situational Awareness, Aerial Monitoring, Disaster Relief

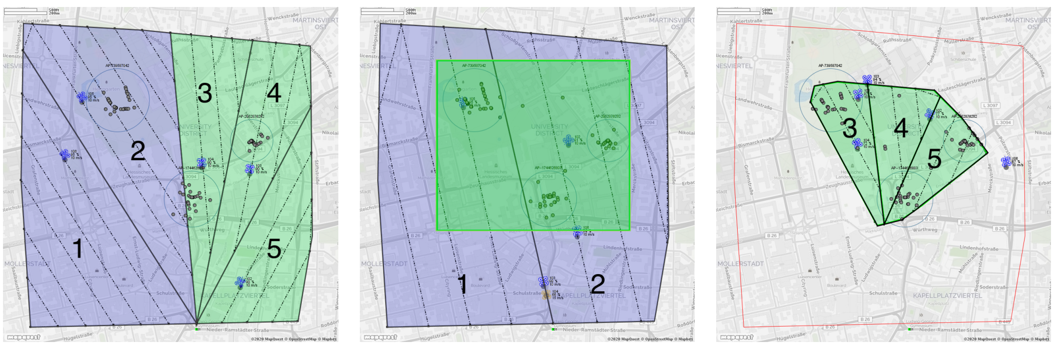
Extreme weather conditions causing large-scale disasters increased in frequency and devastation in recent years and are expected to increase even more in the future [EKN17]. An efficient disaster relief is crucial to limit fatalities and help affected civilians, but requires situational awareness such as knowledge about the location of affected civilians. Approaches for disaster relief usually assume to have this knowledge of the situation in the disaster area [LZRS19, KBR+14]. However, we must expect to have no a priori information in the aftermath of a disaster, and furthermore, that this situation is subject to constant change. Thus, the information on the situation must initially be obtained and then kept up-to-date [EKN17]. Small *Unmanned Aerial Vehicles* (UAVs) can be deployed in the disaster area to gather location information quickly, for example by visually mapping the area or detecting smart devices, as usually carried or worn by civilians, by their wireless signal even within buildings [RAM19]. When operating as part of a continuously operating autonomous *Aerial Monitoring System*, these UAVs can be permanently coordinated to monitor the disaster area, providing an up-to-date view of the situation.

However, the monitoring efficiency depends on several factors such as the number of available UAVs and the size of the monitoring area. As small UAVs are heavily restricted in their flight range due to a limited battery size, one UAV may not be able to cover the whole monitoring area by itself. Thus, the area must be divided and allocated to multiple UAVs, which initially depends on the number of available UAVs and their capabilities. In case of heterogeneous UAVs, possible flight speeds or maximum flight ranges may vary, and higher flight speeds will result in shorter flight ranges in general due to higher power consumption [ZLD+19]. Furthermore, more UAVs may become available during the operation or UAVs fail due to technical or environmental reasons, altering the number of available UAVs over time. The disaster situation may also change over time due to movement of civilians carrying smart devices. These changes require an autonomous *Aerial Monitoring Systems* to be resilient, and thus, to permanently monitor the operation area and adapt itself to changes within. Therefore, we propose *Dynamic Monitoring Area Allocation* (DMAA), combining situational awareness from gathered location information and technical restrictions on available UAVs. By dynamically allocating monitoring areas it contributes to improve (i) resilience against changes in the disaster area, (ii) resilience against UAV failures, and (iii) to adapt the area allocation to technical restrictions of heterogeneous UAVs.

For the design of *DMAA*, we assume to have a predefined monitoring area of the aerial system given as a convex polygon, e.g., a city district that was struck by a disaster. Furthermore, we assume that UAVs are capable of detecting smart devices on the ground within a certain range around them. Completely covering an area requires to pass over every point in an area with this detection footprint. In our case, UAVs fly a back-and-forth sweep—also known as *lawnmower* path—with minimal turns, a well-known approach from the field of Coverage Path Planning (CPP). The distance between lines in the sweep path can be adapted, but must be equal or smaller than the diameter of a UAV's detection footprint to achieve full area coverage.

Due to the limited flight range of UAVs, however, a large monitoring area must be divided into smaller areas. For example, the area could be divided equally between all UAVs. However, the subdivision can also be optimized depending on performance requirements, like shortest area traversal time, or include technical requirements of UAVs. This optimization towards specific requirements and goals requires more extensive treatment and is left open for future work. For simplification in this work, the operation area is subdivided based on the number of available UAVs and their relative flight ranges. By that, UAVs with longer flight ranges are assigned larger areas relative to UAVs with shorter flight range.

Preliminary simulations of the proposed approach were conducted with the SIMONSTRATOR simulation platform [RSRS15] extended for smart devices and UAVs [LZRS19]. The simulated *Aerial Monitoring System* with *DMAA* has two long-range UAVs 1 and 2 and three short-range UAVs 3, 4, and 5 at its disposal. Figure 1a shows a generic convex operation area divided into five monitoring areas. As expected, the two long-range UAVs are assigned to larger areas than the



(a) Long-range UAVs 1 and 2 are assigned larger areas than short-range UAVs 3 to 5.

(b) Long-range UAVs 1 and 2 are assigned to coarse background monitoring.

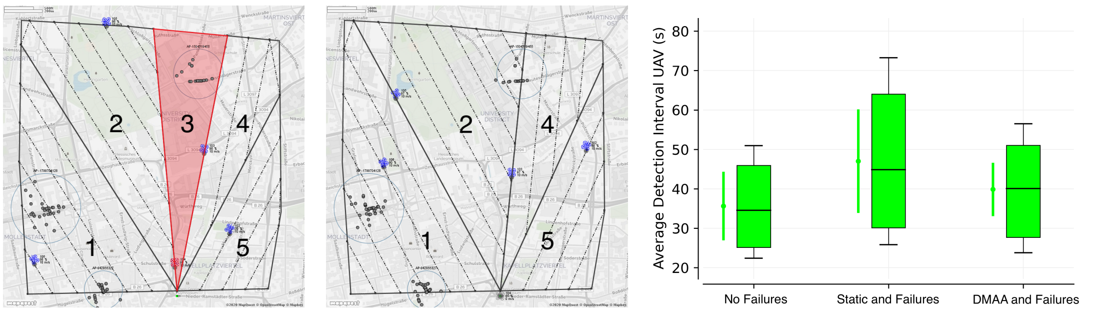
(c) A convex hull determining the detail monitoring areas for UAVs 3 to 5.

Figure 1: *DMAA* with adaptation to the encountered node topology. UAVs are represented by blue symbols, smart devices by grey dots, lines represent UAV flight paths.

three short-range UAVs. Smart devices are represented by grey dots, mostly clustering around three points of interest. After this initial monitoring phase, the system has gained an overview of the operation area, that is held up-to-date by continuously repeating the monitoring flights.

However, the gathered information can be used to further adapt *DMAA*. Since most of the area is sparsely populated, the system separates dense and sparse parts of the monitoring area, as depicted in Figure 1b, into the blue background and the green detail monitoring areas. Background monitoring areas are only traversed by the long-range UAVs 1 and 2. The distance between the back-and-forth sweeps is increased such that the flight range of the UAVs is sufficient to traverse the areas. But this also decreases information quality because not every point of the area is covered. The trade-off is to reduce information quality in sparse areas while also reducing the number of required UAVs, without fully neglecting the area. Therefore, the short-range UAVs 3 to 5 are free to perform a detail monitoring within the smaller green area, where most of the smart devices are located. Densely-populated areas are monitored closely for more up-to-date information and increased detail. Figure 1b shows a bounding box circumventing all detected smart devices to determine the foreground monitoring area. With that, nodes and also their mobility within the bounding box can be monitored. To determine the detail monitoring area, however, a convex hull around node positions could also be used as depicted in Figure 1c. Depending on the underlying topology, this may increase the detail of the monitoring due to a possibly smaller monitoring area than the bounding box. Other approaches like detecting individual clusters and monitor them specifically could have an additional positive impact on monitoring detail.

As UAVs may fail due to technical or environmental reasons, *Aerial Monitoring Systems* must be resilient for a permanent autonomous deployment. Figure 2a shows the same monitoring area allocation as Figure 1a, but UAV 3 fails and requires maintenance. *DMAA* reacts to the deficiency, as shown in Figure 2b. Already allocated areas are increased and re-arranged to cover the deficit, and the assigned UAVs change their path accordingly. In case that the remaining UAVs cannot cover the full operation area, the sweep distance has to be adapted with the penalty of a decrease in monitoring detail. If this would still not be possible, the overall operation area could also be temporarily reduced in size.



(a) A failure of UAV 3 results in the red area being uncovered.

(b) Dynamic adaptation of areas 1, 2, 4, and 5 restores monitoring coverage.

(c) Average node detection interval without failures and with failures for static and *DMAA*, respectively.

Figure 2: *Dynamic Monitoring Area Allocation* improves resilience against UAV failures.

Figure 2c shows initial evaluation results observing the impact of failures on the average detection interval of nodes on UAVs, with and without system adaptation. The first boxplot depicts the interval when no UAV fails. The second one is with UAV failures and no adaptations of the monitoring area allocation, resulting in a significant increase of the interval. Note that this may also result in several nodes not being covered at all. The third plot highlights that an adaptive area allocation approach can compensate for UAV failures. But naturally, as the other UAVs must cover additional space, the interval still increases compared to a system without failures.

Concluding, *Dynamic Monitoring Area Allocation* (DMAA) is a necessary requirement for a resilient *Aerial Monitoring Systems* utilizing heterogeneous UAVs. On the one hand, such a system can autonomously subdivide monitoring areas based on technical restrictions of different UAVs and several optimization goals. On the other hand, such a system can adapt itself after obtaining an overview of the topology to further increase efficiency, for example by monitoring densely-populated areas more closely. Additionally, *DMAA* improves resilience against UAV failures and facilitates an *Aerial Monitoring Systems* to permanently monitor a post-disaster operation area, providing highly valuable situational awareness for disaster relief.

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Bibliography

[EKN17] M. Erdelj, M. Król, E. Natalizio. Wireless sensor networks and multi-UAV systems for natural disaster management. *Computer Networks* 124:72–86, 2017.

[KBR+14] S. Krug, P. Begerow, A. A. Rubaye, S. Schellenberg, J. Seitz. A Realistic Underlay Concept for Delay Tolerant Networks in Disaster Scenarios. In *10th International Conference on Mobile Ad-hoc and Sensor Networks (MSN)*. IEEE, 2014.

[LZRS19] P. Lieser, J. Zobel, B. Richerzhagen, R. Steinmetz. Simulation Platform for Unmanned Aerial Systems in Emergency Ad Hoc Networks. In *16th Intl. Conference on Information Systems for Crisis Response and Management (ISCRAM)*. 2019.

[RAM19] A. Rubina, A. Artemenko, A. Mitschele-Thiel. Towards A Realistic Path Planning Evaluation Model for Micro Aerial Vehicle-Assisted Localization of Wi-Fi Nodes. In *44th Conference on Local Computer Networks (LCN)*. IEEE, 2019.

[RSRS15] B. Richerzhagen, D. Stingl, J. Rückert, R. Steinmetz. Simonstrator: Simulation and Prototyping Platform for Distributed Mobile Applications. *EAI International Conference on Simulation Tools and Techniques (SIMUTOOLS)*, pp. 1–6, 2015.

[ZLD+19] J. Zobel, P. Lieser, B. Drescher, B. Freisleben, R. Steinmetz. Optimizing Inter-Cluster Flights of Post-Disaster Communication Support UAVs. In *44th Conference on Local Computer Networks (LCN)*. 2019.