Drone assisted multi-technology rescue operations

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Opérations de secours multi-technologies assistées par les drones
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Les communications opportunistes offrent une alternative intéressante pendant les scenarios de catastrophe, où l'infrastructure de communication peut être endommagée, permettant de faciliter et d'accelérer les opérations de secours. Notre solution se base sur une communication collaborative entre des appareils mobiles utilisés quotidiennement (e.g. smartphones) pour assister les opérations de secours et de recherche de survivants en exploitant les différentes technologies de communication disponibles sur ces appareils. Par ailleurs, ce travail utilise des drones pour relayer les informations entre les équipes de secours et les survivants. Les résultats montrent que cette solution permet de maintenir une large couverture réseau tout en réduisant la consommation d'énergie.

Mots-clefs : disaster recovery, multi-technology communication, energy efficient communication, drone

1 Introduction

The first 72 hours after a disaster are particularly critical: they are referred to as the *golden relief time* and they are exactly when exhaustive research and rescue activities are taking place. Unfortunately, communication networks (e.g., cellular base stations) could be completely destroyed or damaged; and even when they continue working, they suffer from high access demand to their (limited) resources within a short period of time. This, in turn, exposes both people and rescue teams to the denial of communication services.

In this respect, this work leverages smart devices owned by the survivors and uses UAVs (Unmanned Aerial Vehicles) such as drones to provide an on-demand communication infrastructure for disaster scenarios [GJV16, ZZL16]. Drones are particularly suitable as they can quickly and easily cover affected areas. Our work proposes a collaborative protocol that exploits devices' various network technologies and organizes wireless autonomous devices such as smartphones in a multiple-tier architecture by targeting a balanced energy consumption in the whole network. Furthermore, it introduces a data collection scheme that relies on drones to visit wireless devices and collect their data in a short time.

Extensive simulations in realistic settings demonstrate that the proposed solution balances the energy consumption by means of efficient drone routes, thereby effectively assisting search and rescue operations.

2 Related Works

Data dissemination under missing or damaged communication infrastructure has received increasing attention in the last few years [YFLT16, LCLP17]. However, most of these solutions are based upon a single communication interface (e.g., WiFi) and assume the rescue teams can complement (instead of replace) the existing communication services. Exploring and extending the coverage of wireless communications with UAVs has also been widely investigated, especially in situations where people could not be physically reached [GJV16, ZZL16]. However, even some recent solutions [LZZL17, LZZ16] solely address placement and optimization of UAVs to offer wireless communication in specific areas. As a consequence, they do not consider the communication aspects related to the end-devices such as energy efficiency, which is a key issue to allow rescuers to locate and offer first aid to victims.

3 Multi-technology communication

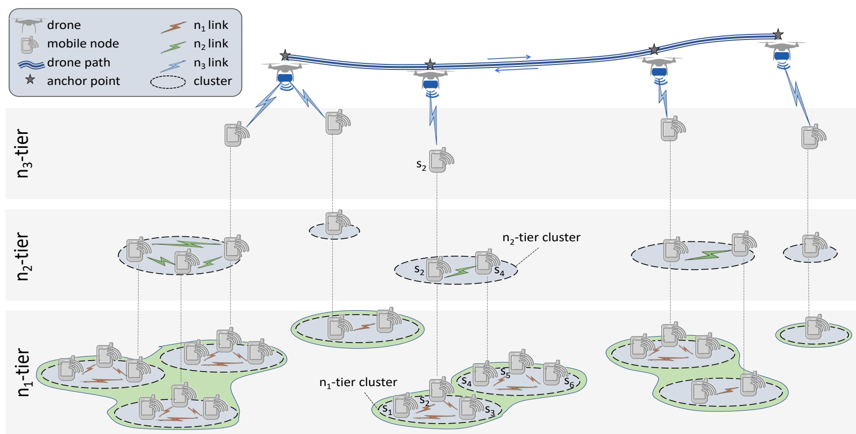


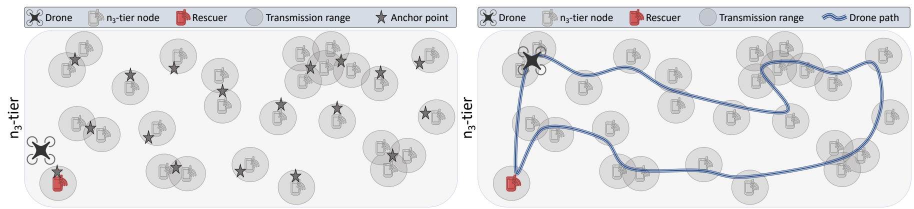
Fig. 1: A three-tier communication architecture

The considered network environment consists of mobile devices equipped with multiple network technologies, such as those available in off-the-shelf smartphones (e.g., Bluetooth, WiFi, and cellular). These technologies are characterized by different transmission ranges and energy consumption characteristics [MM17]. Accordingly, a multiple-tier architecture is created by grouping devices capable of reaching each other directly (i.e., in a single hop) with a given technology into clusters, as illustrated in Fig. 1. Tiers are layered depending on their features: the lowest tier is composed with the most energy-efficient communication technology, and the shortest communication range. The highest tier is made with the most energy-hungry technology and highest range. Intermediate tiers are made by increasing levels of energy efficiency and decreasing transmission ranges. The number of tiers depends of available technologies. Figure 1 shows a realistic network composed of three tiers as could be done with current smartphones where tiers are made with Bluetooth (n_1), WiFi (n_2) and cellular (n_3) communication technologies.

One node in each cluster is designated as cluster head (CH). The CH collects data from one tier and relays them to the upper tier. The CHs in the highest tier communicate directly with a drone that hovers over them. For example, node s_4 in Figure 1 is a CH for the cluster that includes nodes s_5 and s_6 in the n_1 tier. Instead, node s_2 is a CH in two levels: CH of the n_1 cluster that includes nodes s_1 and s_3, and CH of the n_2 cluster that contains node n_4. In addition to the mobile devices, the network also includes drones sent on-demand. Drones are equipped with the highest tier technology (e.g. on-board femto-cells) [Nam17, STM+17]. In particular, a drone makes a tour of the network by reaching certain designated locations where it collects data from one or more nodes, depending on the specific path planning algorithm employed. In Figure 1, node s_2 is the only one able to communicate with the drone among all nodes in the n_3 cluster it belongs to.

The adopted architecture supports energy-efficient operations for both mobile devices and the drone. On the one hand, it allows the preservation of mobile devices' battery power by making them cooperate and elect CHs as intermediate relays responsible for upper layers communications. On the other hand, it simplifies path planning of the drone – consequently its energy consumption – by reducing the number of nodes in the highest tier with which the drone exchanges data.

The follows discusses how to decide the path of the drone to visit the nodes in the highest tier of the network. As already mentioned, data collection as well as reporting to rescue teams leverages drones equipped with femto-cells as an on-demand communication infrastructure [LZZL17]. To fully cover the area affected by the disaster and effectively provide wireless communication capability, the drone must visit all the nodes which have switched on the highest tiers interface. The solution proposed in this work operates as follows. Once the nodes are discovered by initially covering the whole target area [Câm14], anchor points are then derived. Anchor points can be either *(i)* highest tier nodes or *(ii)* locations from which a drone can reach multiple highest tier nodes. That is, an anchor point can be anywhere in between



a

b

Fig. 2: a) Drone *anchor* points (stars). b) the shortest path for a drone to visit all the anchor points.

the highest tier nodes it serves, as shown in Fig. 2a. Hence, there is no need for the drone to hover above every node since hovering above the (fewer) anchor points suffices to serve all nodes. Consequently, given such anchor points as an input to a path planning algorithm, the drone follows the shortest path that visits all these points and collects data, shown in Figure 2b.

Several schemes to plan the drone's path are considered to derive the order of visit of the anchor points. Such schemes aim at finding the shortest path that visits all anchor points (TSP), with the drone returning to its initial location at the end of a tour (to recharge, for instance). Other try to visit a minimum number of positions from which several nodes can be reached (CETSP).

4 Performance Evaluation

A performance evaluation of the proposed multi-tier data relaying scheme is conducted next, with focus on two key aspects: efficiency of relaying data through the tiers in terms of low energy expenditure, and efficiency of deploying an UAV to provide on-demand wireless communication in disaster scenarios. The average values along with the related standard deviations are then reported. For comparison purposes, we present the performance of other two schemes namely baseline and static, along with our proposed solution. The Baseline approach considers every node as a cluster (each single node is present at every tiers) while in the static approach, nodes collaborate among each other to relay their data through the tiers (designed as COPE). The hovering time at a given position depends of the number of nodes to offload from this position.

The disaster scenario consists of a varying number of nodes (survivors) randomly distributed over an urban area of 10 by 5 km. Each survivor is equipped with a mobile device (e.g. smartphone) provided with three network interfaces: Bluetooth, WiFi and cellular, with transmission ranges and energy consumption of 100 m/50 mW, 200 m/70 mW, and 500 m/120 mW resp. [PPLA17]. Finally, each node is assigned a random initial energy level in [10 kJ,20 kJ]. Without loss of generality, CHs are selected every $\delta t = 15$min.

Figure 3 depicts the number of alive nodes over time. More specifically, 400 initial nodes randomly distributed in an urban area disseminate their data in accordance with the three schemes: baseline, static, and the dynamic one. The baseline scheme, in fact, performs poorly in terms of number of alive nodes over time and energy fairness among them: all the nodes leave the network (due to no energy left) within a relatively short period of time with respect to the golden relief time, and such a trend is almost linear on time. By contrast, the static scheme outperforms the baseline, leading to at least 50 alive nodes more than the baseline scheme and such a gap increases over time. Furthermore, it offers a smoother dynamic of nodes leaving the network, i.e., fewer nodes run out of battery at the same time instant. Our proposed dynamic scheme of clustering and CH selection outperforms the baseline and the static schemes. As it introduces energy expenditure fairness among nodes, it increases the number of alive nodes at a given time instant compared to the other two schemes. Moreover, most of the nodes run out of battery alone, or in smaller groups. In other words, nodes have comparable energy levels in the network over a longer time. This explains the fact that the static scheme slightly outperforms the dynamic one in the last two hours, approximately in the period from hours 6 to 8.

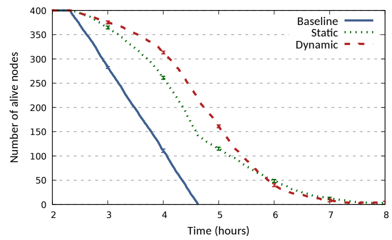
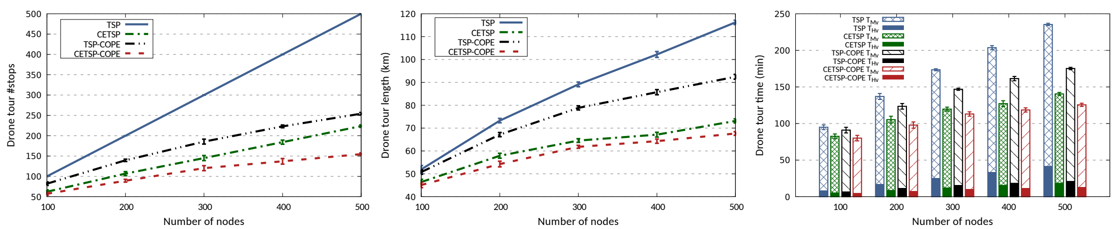


Fig. 3: Number of alive nodes over time



a) number of stops b) tour length c) hovering/flying time

Fig. 4: Comparison of various algorithms as a function of the node density in the network.

5 Conclusion

This work proposes a dynamic scheme for drone-assisted communication for disaster recovery scenarios leveraging multiple network technologies. Results have shown the benefits of the proposed scheme from both, the drone and the survivors perspectives, allowing a a longer and maximum network coverage.

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