

Performance of Mobile Networks with UAVs

Can Flying Base Stations Substitute Ultra-Dense Small Cells?

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Abstract— A crucial challenge for future mobile networks is to enable wide range of scenarios and use cases for different devices spanning from simple sensors to advanced machines or users' devices. Such requirements call for highly flexible and scalable radio access network (RAN). To provide high flexibility and scalability in dynamic scenarios, flying base stations (FlyBSs), i.e., base stations mounted on general unmanned aerial vehicles, can be integrated into RAN. In this paper, implementation and operational issues related to the FlyBSs are discussed. Additionally scenarios where the FlyBS can be profitable are outlined. Furthermore, we define the architecture of a flying RAN (FlyRAN) encompassing the FlyBSs and enabling real-time control of whole RAN so that it can dynamically adapt to users' movement and changes in their communication activity. Our results show the superior efficiency of FlyBSs comparing to an ultra-dense deployment of static base stations (BSs) for a realistic scenario with moving users. Our simulations suggest that one FlyBS can provide throughput comparable to static BSs deployed with density corresponding to inter-site distance of 45 meters. At the same time, energy efficiency of the communication for the user equipment can be improved more than 5-times. This indicates that integration of the FlyBSs into mobile networks can be an efficient alternative to ultra-dense small cell deployment, especially in scenarios with users moving in crowds.

Keywords— Mobile networks, Unmanned Aerial Vehicle, Flying base station, Network Throughput, Energy efficiency, Architecture

I. INTRODUCTION

Future mobile networks assume ultra-dense deployments of mostly static base stations (BSs), represented typically by small cells, to meet future communication demands by a soaring number and diversity of user equipments. It is expected that tens of small cell BSs will be deployed per square kilometer [1] in areas with dense traffic. Moreover, the data will be generated not only by humans, but also by massive amounts of various machines, sensors and vehicles. Such trends are anticipated to continue beyond the 5G transition. The dynamic mix of human and machine type communication implies strong requirements on the network's dynamicity, which should be able to cater to traffic with different priorities generated by heterogeneous devices with highly fluctuating spatio-temporal traffic patterns. Ultra-dense deployments of the static small cells aiming to meet such requirements is likely to be expensive and cost-inefficient

as many of these newly built BSs will be underutilized (in terms of communication load) most of the time.

In parallel to the evolution of mobile networks, Unmanned Aerial Vehicles (UAVs), represented by drones, balloons, or airships, are increasingly exploited in different domains as monitoring of hardly accessible areas, delivery of mails or drugs, agriculture monitoring, or for rescue purposes. The UAVs can be integrated also into communication systems [2] for provisioning of wireless connectivity in sparsely populated areas, or where building entirely new mobile network infrastructure is complicated or commercially ineffective (e.g., projects Loon by Google and Internet.org by Facebook). Furthermore, the UAVs are often considered as a back-up solution providing temporary coverage in emergency situations or temporary hot-spots scenarios (concerts, sport events) [3]. However, in all these cases, the UAVs are supposed to be nearly static and activation of such network requires relatively long time and involvement of humans. Some flexibility and adaptability with respect to the fluctuating spatio-temporal traffic patterns is to be expected, but it has not been explicitly considered or analyzed.

The possibility to integrate the UAVs into mobile networks, offering communication services in common non-emergency situations, has been addressed in several recent works, e.g., in [4]-[17]. An architecture for wireless networks with the UAVs is outlined in [4] and [5]. These papers, however, define only very high level architecture based on 4G cellular networks. An extension towards 5G including a control of UAV-based flying base stations (FlyBSs) based on centralized SDN/NFV is outlined in [6].

An efficiency of the FlyBSs for balancing the load of neighboring static base stations is demonstrated in [7] by a field test with the FlyBSs positioned by a human operator. A similar scenario is considered in [8], where the authors investigate a possibility to offload the traffic in heavily loaded cells over to less congested ones using the FlyBSs to relaying users' communications. Analytical evaluations show that the FlyBSs can significantly increase throughput of the users in the overloaded cells. Design and implementation aspects of an aerial network based on LTE-A is analyzed in [5]. The authors provide an overview of possible platforms for the FlyBSs and outline their developed and tested solution for a large airship (34m²) serving as the FlyBS assuming low operational altitude in range

of hundreds of meters. The authors assume fiber optic link between the FlyBS and a core of the cellular network.

The impact of the FlyBS's altitude on the coverage and cell radius is analyzed in [9]. The authors provide mathematical model for optimization of the FlyBS's altitude in order to maximize radio coverage while satisfying maximum allowed path loss. The paper assumes FlyBSs flying at low altitudes spanning from hundreds to thousands of meters. The analysis of a possible placement of the FlyBSs according to the users' distribution in the area is considered in [10][11]. In [12], the authors propose a machine learning-based approach to derive radio maps, which are then exploited for the FlyBS positioning in [13]. Furthermore, in [14] and [15], the authors identify an optimal position of multiple FlyBSs to maximize coverage and reduce transmission power. In [16], the authors investigate the impact of the FlyBSs on the interference level in the network and observe that the FlyBSs increases an average level of interference. Moreover, the authors also show that this interference is becoming more significant with increasing altitude of the FlyBSs as these have to transmit with higher power. This gives motivation for us to focus on an ultra-low altitude FlyBS, operating few meters above users, in order to improve throughput and reduce energy consumption of user equipments (UEs).

All above-mentioned papers support exploitation of the FlyBSs as a part of RAN in cellular networks. The FlyBSs are seen as an enabler for communication in high frequency bands, which are proven to be efficient for UAV-based mobile networks as shown in [17]. However, the research papers address only scenarios with static users and do not target the possibility of a real-time self-optimization of the FlyBSs' positions with respect to a dynamicity of the users in terms of throughput requirements and mobility.

Thus, in this paper, we introduce a framework for self-organizing Flying RAN (FlyRAN) with ultra-low altitude FlyBSs that are automatically positioned in real-time according to the users' requirements and mobility. First, we discuss implementation issues/challenges and flying regulation aspects related to the integration of the ultra-low altitude FlyBSs mounted on small drones into mobile networks. Second, we define scenarios where we foresee notable gain in performance justifying a use of the FlyBSs instead of the static network densification. Third, we outline an architecture exploiting computing resources distributed at the edge of the network to control the FlyBS and we investigate communication and control aspects related to the positioning of the FlyBS according to the users' behavior. As the major finding, we demonstrate that the FlyBSs can be seen as an efficient alternative to the small cell densification paradigm since the FlyBSs introduce a significant gain in channel quality, throughput, and UEs' energy efficiency for users moving in a crowd.

The rest of the paper is organized as follows. Next section discusses implementation and flying constraints for the FlyBS; justifies scenarios and use-cases suitable for the FlyRAN; and then outlines architecture and communication/control aspects for real-time control of the FlyRAN. Then, Section III provides performance analysis by means of simulations. The last section summarizes major findings and outline potential future work.

II. FLYRAN WITH ULTRA-LOW ALTITUDE UAVS

In this section, we discuss key implementation aspects and limitations for the ultra-low altitude FlyBS. Subsequently, scenarios envisioned as beneficial for deployment of the FlyRAN are outlined. Furthermore, we describe an architecture integrating the FlyBSs into mobile networks and we suggest solutions for the communication and control of the FlyRAN.

A. Flying base station – implementation and operation constraints

The FlyBS is represented by a communication hardware mounted on a small drone (e.g., quad-copter). The small drone should be able to carry communication hardware including: antennas, interfaces for radio communication, processor and supporting circuits for communication control and processing, and also an additional power source for communication. Even if we assume emulation of this payload with general purpose hardware, such as Universal Software Radio Peripheral (USRP), the weight of payload can be estimated to be about one kilogram. This includes one radio interface for communication with the UEs and one for communication towards core network. The weight of these communication interfaces for software defined radio is tens of grams each. Then, antennas for high frequency bands, even with massive MIMO, can weigh up to around 100g if based on silicon phased-array chips, as indicated, e.g., in [18]. Another hardware mounted on the drone is a CPU and supporting circuits for communication control. This can be realized by a common embedded PC with weight of 300–400g. Last, batteries are needed to supply the communication part with power, although it might be envisioned to share propeller engine power with the power needed for communication purposes from a single common battery. Even for general batteries with very high capacity, the weight is about 300–400g. Note that our example of the payload is rather pessimistic in terms of the weight as it does not assume any hardware developed specifically for the FlyBSs. Once manufacturers focus on development of a light-weighted hardware for the FlyBSs, it is very likely that they find a way how to significantly reduce the payload weight. Anyway, the payload of one kilogram can be carried by common drones available nowadays on the market.

The payload influences flying and operational time of the UAV. Conventional UAVs can fly typically a only tens of minutes [5], which seems to be limiting. However, the UAVs with a hydrogen cell, which are already available at the market, can fly for 2.5 hour with a payload of one kilogram [19]. Such flying time is sufficient for scenarios where dynamic operation of the FlyBSs is supposed to cover peak traffic hours. Additionally, future evolution of the power sources in a combination with energy harvesting and efficient design of the UAVs for purposes of the FlyBSs can further prolong the flying time and enable exploitation of the FlyBSs in scenarios requiring longer operational time. Note that the FlyBS can charge their batteries if their service is not required or if battery level is low. The charging can be done at static BSs or specifically deployed charging stations via lasers as proposed in [4].

The operation of the FlyBSs in commercial scenarios still has to comply with safety regulations and the FlyBSs should not endanger people. Regulations in their current state could represent a major obstacle in the way of a successful deployment

of FlyRAN. Current limitations for flying of the commercial UAVs vary among countries. A minimum distance of the UAVs from people is typically in dozens of meters.

However, as can be seen from recent favorable evolutions in the area of autonomous driving, FlyRANs regulatory aspects are expected to evolve rather quickly, and generally in the direction of a relaxation of these limitations, pushed by market pressure in other domains of application of drones, and by increasing familiarity by the general public. For example, in the US, small drones shall be allowed to fly above people and larger drones shall be limited to 3m vertically and 6m horizontally from people [20]. The relaxation of flying restrictions is strongly supported by many industries including cellular network operators. Also Europe is going through discussions on a general framework for regulation of the commercial UAVs [21]. At the same time, a majority of recent studies on the UAVs in mobile networks assumes the UAVs flying directly above people (see e.g., [4][5], [9]-[17]). As the proposed FlyRAN concept targets future generation of mobile networks, it is reasonably likely that the small commercial drones will be allowed to fly only few meters above people when enough security will be guaranteed by vendors and operators.

B. Scenarios and use cases for FlyRAN

An open question, so far not answered in literature, is: what is the suitable and cost efficient scenario for drones in mobile networks? Thus far, the drones are mostly exploited in emergency situations and public safety scenarios. Nevertheless, such scenarios are rather exceptional, do not impact significantly on the cost of network operation, and do not introduce any profit to the operators and the users. Hence, we focus on a conventional operation of the network. Recent works assume static scenarios (fixed position of users), where the FlyBSs can be beneficial from CAPEX and/or OPEX reduction on the operator's side in some specific cases. However, an impact on the users' quality of service is not that significant in these scenarios. The reason is that the FlyBS remains at almost the same position if the users stay static. Consequently, the static BS deployed in a suitable position provides similar performance as the FlyBS.

We foresee the FlyRAN to be beneficial mainly in scenarios where the moving users require a temporal connectivity and their requirements fluctuate over time. Typical situation showing significant efficiency of the FlyRAN is represented by pedestrians or vehicular users moving in crowds. This is emphasized if the crowd is in an area with limited availability of radio channels or with poor channel conditions where dense deployment of the static BSs would be needed only to cover peak traffic hours. A more concrete example of the scenario suitable for consideration of FlyBSs is a stadium, university, industrial area, or parade where the users are coming to a specific area in similar time (visitors going to a match or performance, students going to lectures, employees going to work, etc.), then stay during the event, and finally leave in crowds. In such scenarios, it is not economical to deploy small cells densely as these are exploited only small fraction of time while costs (maintenance, site renting, energy, etc.) are accounted all the time.

The FlyRAN is suitable also for scenarios with heavy vehicular traffic (e.g., traffic jam) as it is uneconomical to deploy a high number of the static BSs along each highway. However,

if there is a traffic jam, all the users start searching for information related to the situation and an alternative route, which generates localized surge of data traffic. In this case, the FlyBSs can literally follow the vehicles in the traffic jam and improve connectivity to the users.

C. Flying radio access network – communication and control

The scenarios suggested in the previous subsections require real-time control of the FlyBSs' position. In the proposed concept, we consider cloud computing resources distributed close to the edge of mobile networks to control the FlyBSs in real-time (see Fig. 1). In addition, we assume ultra-low altitude FlyBS (from meters to tens of meters) operation to ensure proximity of the FlyBS to the UEs allowing efficient communication and, at the same time, reducing energy consumption on the side of the UEs. Moreover, the proximity between the UEs and the FlyBS also reduces interference, as lower transmitting power is required also on the side of the FlyBS [16]. Communication at short distances can also be seen as an enabler for massive exploitation of communication in higher frequency bands (e.g., mm-waves or visible light communication), since these bands are efficient particularly for short distance communication with line-of-sight (LOS) [22].

The FlyBS can be connected to the core network via either a conventional static BS or a baseband unit (BBU) (see Fig. 1). In the former case, the FlyBS is denoted as FlyRS, as it relays communication between the UEs and the static BSs. In the latter case, the FlyBS acts as a flying remote radio head (FlyRRH) in similar fashion as a conventional RRH in Cloud-RAN. For the sake of simplicity, the term FlyBS denotes both FlyRS and FlyRRH in this paper if both can be applied.

The FlyBSs are expected to serve a lot of UEs resulting in high requirements on radio communication. Thus, wireless fronthaul and relaying should exploit wide bandwidth in higher frequency bands and directional antennas. To that end, a challenge for future research is to ensure LOS communication between the FlyBS and the static BS/BBU to deliver benefits related to proximity between the transmitter and the receiver. Huge load of data can be imposed at the fronthaul if most of the control functions are kept at the BBU [23]. To alleviate the fronthaul load, various signal compression techniques can be exploited [24]. Since there is a trade-off between complexity, energy consumption, and fronthaul load, finding optimal functional splitting remains a future research challenge.

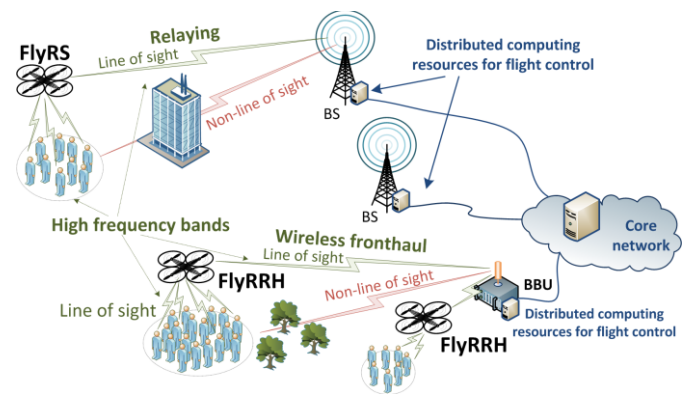


Fig. 1. Architecture of mobile network supporting FlyRAN with real-time flight control.

To determine the optimum position of the FlyBS over time, the position of the users served by the FlyBS should be known. As the FlyBSs are expected to serve outdoor users where GPS is typically available, we can assume position of the users are known in real networks. The positions of the UEs are collected by the serving BSs (either static BS or FlyBS) and delivered to a control unit, implemented as a logical function by means of computing resources distributed over the edge of mobile network. Once the new coordinates of the FlyBS are determined, these are fed back to the FlyBS, which autonomously moves to these coordinates. Due to computation at the edge of mobile network, the delay in determination of the new position for the FlyBS is negligible. Note that in this paper, we investigate maximum network throughput, thus we assume the FlyBS is positioned in the center of gravity of the user's locations.

III. PERFORMANCE EVALUATION AND KEY FINDINGS

For comparison of the FlyBS's efficiency with respect to the ultra-dense small cell deployment, we analyze a scenario where people move in a crowd along a street, for example, as if they would be leaving a stadium after a match. In this section, we first define evaluation scenario and models and, then, we discuss simulation results.

A. Scenarios and models for performance evaluation

In order to estimate the system gains of the FlyBS in the scenario of interest, we consider a throughput analysis in a so-called "linear crowd" scenario with users moving along a street. The considered scenario and deployment is depicted in Fig. 2. We compare two competitive cases: 1) conventional scenario with (ultra)-dense deployment of small cells (Figure 2a) and 2) scenario with the FlyBS (Figure 2b).

In both scenarios, the users move linearly as a crowd on a street with a length of 500m. The number of active users varies between 10 and 1000. The users entering the street are spread over time following real movement of users modeled according to "bottleneck scenario" described in [25]. The users stay in the simulation area until they reach the end of the street (in real scenario represented, e.g., by entrance to an underground station). We assume full buffer traffic model and fair distribution of capacity among UEs. Furthermore, in both scenarios, a single Background BS is deployed 200m from the center of the street and its height is 5m. This BS introduces interference into the system and it also can serve background users, not served by the FlyBS.

In the ultra-dense small cell scenario, the Small cell BSs are distributed uniformly at fixed positions along the street in a distance of 10m. To reflect advanced radio access technologies, we adopt coordinated multipoint (CoMP) with dynamic cell selection and interference mitigation of the Small cell BSs according to [26].

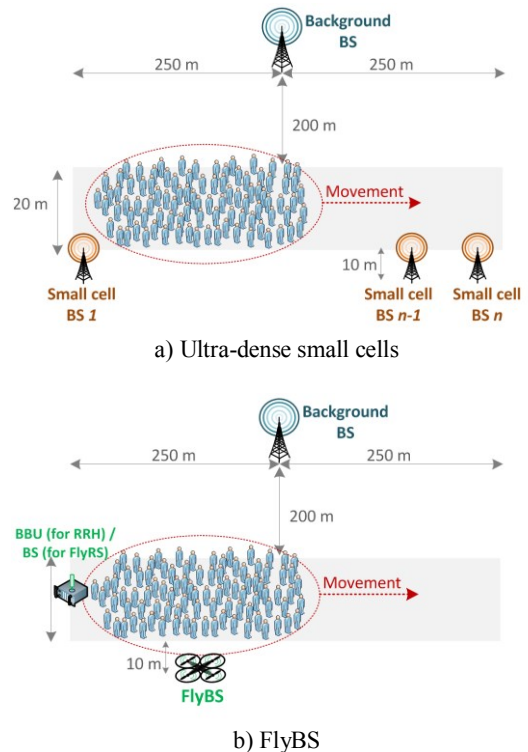


Fig. 2. Simulation scenario and deployment of base stations for the conventional ultra-dense deployment of small cells (a), and for FlyBS (b).

In this paper, we investigate efficiency of the FlyBS in terms of network capacity. From the capacity perspective, the optimum position of the FlyBS corresponds to a center of gravity of the communication requirements of the UEs served by the FlyBS at each time instant. Thus, in the second scenario, the FlyBS follows the center of gravity of the crowd served by the FlyBS considering a safety margin for the FlyBS set to 10m from the street. To determine the center of gravity of the UE's requirements, the current positions of the UEs defined by coordinates $[x_i, y_i]$ for the i -th UE are exploited. The coordinates are weighted with the UEs' relative required throughput α_i . Consequently, in each time instant, the FlyBS is navigated to coordinates $[x_d, y_d]$ derived as follows:

$$x_d = \frac{1}{n_u} \sum_i \alpha_i x_i ; \quad (1)$$

$$y_d = \frac{1}{n_u} \sum_i \alpha_i y_i ; \quad (2)$$

where n_u is the number of the UEs served by the FlyBS and $\alpha_i \in <0, 1>$ is the relative throughput requirement of the UE_i .

The FlyBS operates at a fix altitude of 10m above users for security reasons. Note that the UAVs are supposed to be allowed flying even closer to the users when the FlyBS will be commercially deployed as explained in Section 2, but we target to show rather more pessimistic case as these relaxations are not confirmed yet.

We model radio channels between the UEs and all types of BSs and for the wireless fronthaul and relaying according to [27] for 38 GHz band. We assume bandwidth of 500 MHz and transmit power of all BSs equals to 32 dBm. According to [27], we further assume partially obstructed link without clear LOS (Path Loss exponent = 2.21) and no gain omnidirectional antennas between the UEs and all BSs (both FlyBS and static small cell BSs). For wireless fronthaul and relay, we assume clear LOS (Path Loss exponent = 1.92) and directional antennas with a gain of 20 dBi [27]. For the FlyRS, the bandwidth is shared between the UE-FlyRS and the FlyRS-BS links so that overall throughput is maximized. Furthermore, we assume adaptive modulations and coding according to recent 3GPP standards for cellular networks (modulations ranging from QPSK to 256 QAM and code rates from 78/1024 to 948/1024). For analysis of the energy efficiency of the UEs, we exploit energy consumption models defined in [28]. All results are averaged-out over 50 drops with random movement of users.

B. Results and discussion

The performance in both scenarios is analyzed in terms of SINR experienced by the UEs, UEs' throughput, and energy efficiency of the UEs' communication for the FlyBS and ultra-dense small cell base stations (denoted in figures as SCBSs).

Fig. 3 shows cumulative distribution function of SINR experienced by 10 active UEs (solid lines) and 1000 active UEs (dashed lines). Note that SINR for the UEs is the same for the FlyRS and FlyRRH, thus, we denote it as FlyBS. As the figure depicts, the highest SINR is reached by the FlyBS. For the FlyBS, SINR slightly decreases (roughly by 1-4 dB), if the number of UEs rises from 10 to 1000. This is caused by the fact that a higher number of UEs leads to a larger crowd covering bigger area. Fig. 3 also demonstrates that the SINR in scenario with the Small cell BSs increases and converges to the one of the FlyBS with rising number of Small cell BSs. Nevertheless, even for 10 Small cell BSs deployed regularly along the street with inter-site distance of 45 meters, the SINR is still 2 and 5 dB below the FlyBS most of the time for 1000 and 10 UEs, respectively. The reason is that the FlyBS can find the most suitable position to serve the UEs.

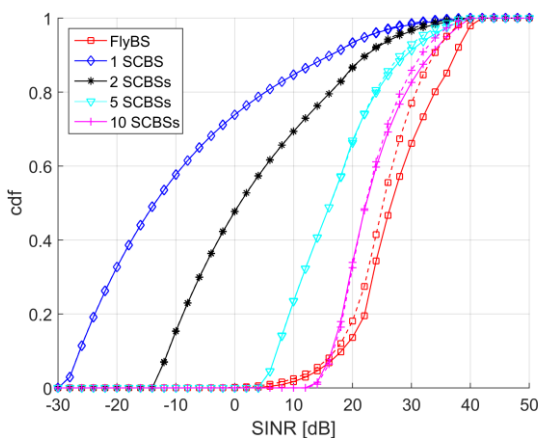


Fig. 3. Cumulative distribution function of SINR experienced by UEs for 10 UEs (solid lines) and 1000 UEs (dashed lines).

Fig. 4 illustrates a relative throughput over different amount of the UEs and for various types of BSs. The throughput of the UEs is averaged out over whole simulation time and over all UEs. In this case, we distinguish FlyRS and FlyRRH. As Fig. 4 shows, the FlyRRH offers more than twice higher throughput comparing to the FlyRS. The lower throughput of the FlyRS is caused by sharing resources between communication with the UEs and relaying to the static BS.

The network throughput for both the FlyRRH and the FlyRS decreases if the number of active UEs increases. This is caused by enlarging the area occupied by the crowd of users. Consequently, the edge users cannot fully exploit the highest channel quality and, at the same time, the scenario becomes more static (users cover almost whole area for majority of simulation time and, thus, the FlyBS moves only slightly). This confirms our proposition related to suitable scenarios for FlyRS given in Section II. Both types of the FlyBSs significantly outperform single Small cell BS. We can also see that almost 5 Small cell BSs (inter-site distance of 83 meters) are needed to achieve the throughput equal to the FlyRS independently on the number of the UEs. Fig. 4 further shows that the FlyRRH can introduce notable gain even comparing to the ultra-dense Small cell BSs scenario with 10 Small cell BSs (inter-site distance of 45 meters).

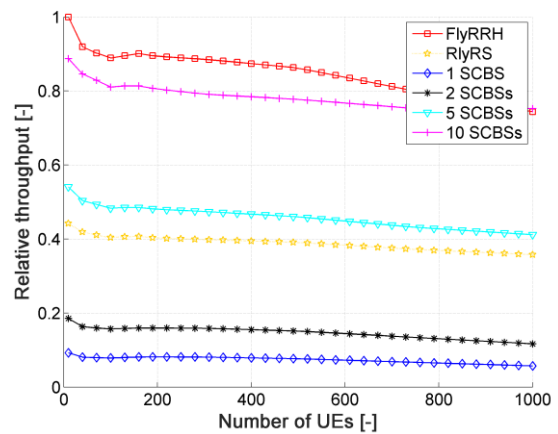


Fig. 4. Overall network throughput over amount of the users achieved by FlyBS and static small cell BSs.

Fig. 5 demonstrates how many Small cell BSs are needed to offer the same throughput as one FlyBS. Note that we consider only the FlyRRH to show maximal potential of the proposed concept. If only one Small cell BS is deployed, the FlyRRH can offer more than 11 times higher throughput. To reach the same throughput as the FlyRRH for very large crowd (1000 UEs), at least 10 Small cell BSs uniformly deployed along the street with density of one Small cell BS every 45 meters and exploiting CoMP are needed. For smaller crowds the required Small cell BS density is even higher (one Small cell BS every 30 m for 10 UEs). These results confirm that the FlyRRH can be seen as an alternative to deploying ultra-dense network as well as a solution to further improve network throughput even in areas with relatively dense deployment of small cells.

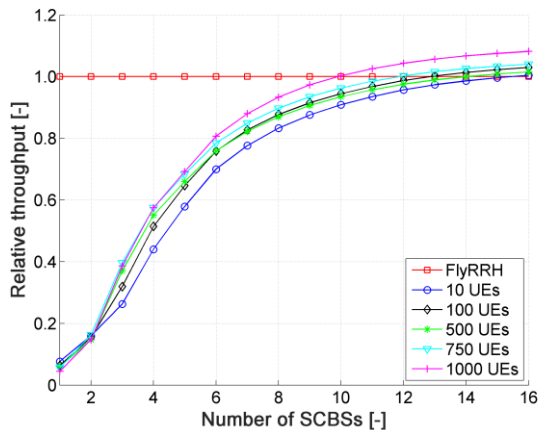


Fig. 5. Ratio of throughput of FlyRRH and number of Small cell BSs deployed along the street (b).

In Fig. 6, we analyze relative energy efficiency of the UEs' communication (jointly in downlink and uplink), i.e., the number of bits transferred and received by the active UEs per joule consumed by the UEs. As the figure shows, the energy efficiency decreases with the number of UEs. This is caused by lowering channel quality as the crowd of active UEs is spread over a larger area. Comparing to a single Small cell BS, the energy efficiency is improved more than 5.3x and 2.4x by the FlyRRH and FlyRS, respectively. If the number of Small cell BSs is increased to 10, the FlyRRH still improves the energy efficiency by approximately 6%. The energy efficiency of the FlyRS is in range of the efficiency of 2 and 5 Small cell BSs. The superior performance of the FlyBSs comparing to the Small cell BSs is because of increased throughput and shortening distance between the UEs and the FlyBS.

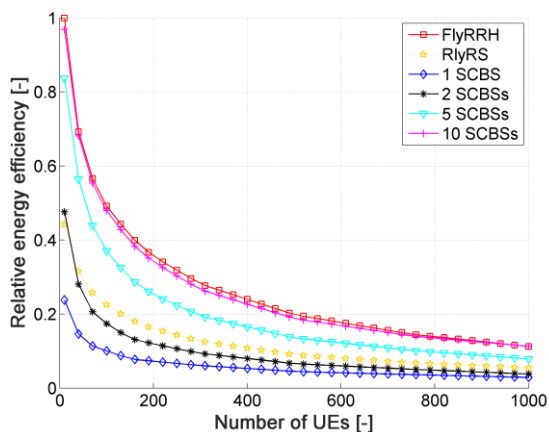


Fig. 6. Energy efficiency of the UE's communication (as the number of bits transferred and received by the UEs per joule). We assume a half of the time the UEs are transmitting and a half of the time are receiving data.

Having in mind that one FlyBS can replace more than 10 static BSs deployed with inter-site distance of 45m in terms of throughput and, at the same time, increase energy efficiency for the UEs more than 5x, Capital Expenditures (CAPEX) and Operational Expenditure (OPEX) of the FlyBSs are relaxed. Of course, a cost efficiency of the proposed solution requires a deeper analysis, which is left for further investigation. Also the

UEs battery life-time is prolonged significantly. This underpin high potential of the FlyRAN for future mobile networks for users as well as operators perspective in scenario with users moving in crowds.

IV. CONCLUSIONS

In this paper, we have presented a framework and an architecture of future radio access network enhanced with the FlyBSs serving moving users. The proposed concept enables to optimize the network in real-time according to the users' throughput requirements and movement. Furthermore, due to proximity between the FlyBS and the UEs, the proposed concept enables massive exploitation of higher frequency bands for communication. As shown by simulations, the FlyBS introduces a significant gain in channel quality for users moving in crowd and has a potential to replace many static BSs in terms of throughput. We have shown that more than 10 BSs deployed along the street in the scenario with inter-site distance of 45 meters can be replaced with a single FlyBS while throughput is kept the same. Moreover, the energy efficiency on the UE side can be increased more than 5x, if the static BSs deployment is substituted by the FlyBS. This proves high potential of the FlyBSs for integration and implementation in future mobile networks instead of wide ultra-dense deployment of small cells.

In the future, this work should be complemented with a deep cost analysis of the proposed solution considering both CAPEX and OPEX. Then, the positioning of the FlyBSs should be extended towards consideration also energy aspects related to communication and flying and evaluated in more generous scenario with a variety of mobility patterns. Moreover, additional significant challenges are to associate the users to the FlyBS if the users are moving with different speeds or some of them are even static and positioning of the multiple FlyBSs.

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