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Movable Base Stations in Mobile Networks for Emergency Communications

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Abstract—An emergency communication system is necessary for first responders, who need to enter areas with no network coverage or damaged network infrastructure due to natural or man-made disasters to perform emergency tasks. The first responders usually rely on fixed base stations deployed according to the needs of the mission, to meet the communication needs. However, fixed base stations can pose several limitations, typically for supporting the mobility of groups of users. Thanks to the development of software defined radio and software defined networks, embedding the functions of a base station on a movable platform, such as a vehicle or a drone, is now a possible alternative. The base station carried by the movable platform can react to changes in the network in real time, allowing more flexibility and introducing a new degree of freedom for the emergency communication network. In this work, we present a quantitative network performance comparison between a fixed base station and a movable base station, when a group of first responders is moving in a geographical area for an emergency rescue mission. We show that a movable base station provides up to 4 times the throughput of a fixed base station.

I. INTRODUCTION

Emergency mobile networks are critical for first responders, who need to communicate with each other and possibly with a remote control center during their operations. Communication needs do not consist only in voice communication services, but also in large bandwidth requirements such as real-time video transmission. However, geographical areas requiring first responder intervention are often without network coverage, either because they are situated in remote regions, or because the existing network infrastructure has been damaged by the natural or man-made disasters that require the operations in the first place. In these cases, when an existing network is not available, the emergency network is transported and deployed by the first responders themselves.

There are two possible solutions for a rapid deployment of a mobile network in such scenarios. The first one is to install fixed base stations (FBS), as it is common in commercial mobile networks. In this case, no matter how the users move in the area, and regardless of their traffic demand, the FBS will provide wireless coverage in the considered area. The second solution is to use movable base stations (MBS), which change their position as the users move, following the first responder team, to optimize the performance of the network.

As the location of FBS needs to be predetermined, accounting for obstacles in the field and possible mobility pat-

terns, their deployment requires some significant pre-planning, which is not always possible in emergency situations. In addition, the computing and communication resources of FBS are also preset according to the density of users in the area that needs to be covered, which can be difficult to estimate if the emergency network also needs to be open to civilians present in the area. Therefore, the deployment of FBS requires skilled human personnel to be present on-site for installation and commissioning. This dependence of emergency mobile networks on pre-installed and pre-configured FBS is a prominent problem, since when FBS resources are insufficient, network performance will fluctuate.

In recent years, Network Function Virtualization (NFV) and Software Defined Networking (SDN) developed significantly and offer more and more opportunities in the field of mobile networks. It is today possible to embed all the mobile network functions on a movable platform, such as a vehicle or a drone [1]. Based on these technologies, MBS can be deployed automatically, anytime and anywhere. Moreover, MBS can reposition themselves and increase or reduce the mobile networks capacity in real time, in response to user demand and environment changes [2]. Of course, this requires the control in real-time of MBS configuration and positioning. However, before addressing the challenge of controlling the movement of MBS to achieve the best network performance, we first need to understand and quantify the benefits and limitations of FBS and MBS in an emergency scenario.

Thus, in this paper, we assume that a group of first responders enters a target area that does not yet have mobile network coverage. A FBS or a MBS will be set to serve the group of users. We conduct a thorough comparison of the network performance in these two scenarios, under different radio propagation conditions and user mobility models. The results show that the use of MBS can multiply the network throughput by 4 when compared to a FBS. To reach the same throughput, the required transmit power of the MBS can be 50dBm smaller than that of a FBS. This comes at the expense of a reduced coverage of the area of study, which can reach 50% at equivalent transmission power between MBS and FBS. Additionally, if static and mobile users exist at the same time, the MBS that moves with the mobile users can still provide better network performance for them, while not degrading significantly the performance observed by static users.

The rest of this paper is structured as below. Section II discusses some previous studies on the topic of MBS. Section III

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introduces the system model, the group mobility model, and the setup of our simulation. Section IV presents the simulation results we obtained, and Section V concludes the work.

II. RELATED WORK

Due to the unpredictable situations that it needs to accommodate, an emergency communications network should be considered as an autonomous and resilient system [3]. There are some existing attempts to use MBS in these scenarios. For example, Gomez *et al.* [4] demonstrate a standalone mission-critical communication system consisting of an aerial part and a terrestrial part. The aerial part is a balloon that carries radio equipment providing network coverage, and it connects to the core network on the ground via an optical fiber. Although their objective is to provide a stable and large network coverage, these tethered solutions limit the mobility of the MBS and reduce the flexibility of the movable platforms. With ABSORB, Nakayama *et al.* [5] propose a cellular architecture composed of MBS carried by vehicles, which also includes optical fiber backhaul links. Although the base stations can change their location depending on the user demand, the location and the movement paths of the MBS are limited by the need to connect to this optical fiber backhaul. Besides, service interruption occurs during the MBS movement. In the SkyCore project, Moradi *et al.* [1] not only place the radio access network on a drone, but also embed the core network functions on the same equipment, together with the MBS.

The integration of MBS in mobile networks is also well investigated, especially in terms of optimal base station placement according to diverse objectives. Al-Hourani *et al.* [6] optimize the altitude of the MBS to maximize its coverage. They consider the case of only one static MBS, whereas Mozaffari *et al.* [7] maximize the coverage considering two MBS which interfere with each other. Lyu *et al.* [8] propose a placement algorithm to cover all the users in the target area with a minimum number of MBS. With the same objective, Kalantari *et al.* [9] use particle swarm optimization to minimize the number of required MBS. Adam *et al.* [10] optimize the placement of multiple MBS based on different user Quality of Service (QoS) requirements. Abdalla *et al.* [11] optimize the placement of a MBS for maximizing the secrecy of the communication channel by using a deep Q-network, in order to prevent eavesdroppers from capturing traffic. However, in these works, when the purpose is to optimize the placement of MBS, the users are usually assumed to be static.

Several research works show that the repositioning of MBS can improve the network performance. Fotouhi *et al.* [2] show that moving the MBS towards the target users will improve the spectral efficiency. In [12], the same authors demonstrate that, if the MBS can be dynamically relocated, the MBS can optimize the overall performance in the entire network, because the performance gap between edge users and central users is reduced. Moreover, the fairness is also improved. The authors propose a follow-up study [13], where they highlight that a target network performance can be achieved with the deployment of less MBS, if these are allowed to move freely.

Finally, Andreev *et al.* [14] deploy both terrestrial and aerial MBS, and show that MBS can reduce the outage probability, even if they are randomly moved.

Other results show a certain negative impact of MBS, focusing mostly on the fact that they are energy-constrained, and the mobility of MBS therefore reduces the system lifetime. Kalantari *et al.* [15] underline that, if the initial position of MBS is well studied, the mobility of MBS is not necessarily mandatory, when the user movement range is not large. However, these studies do not conduct a comparison between FBS and MBS. To the best of our knowledge, our work is the first to compare in a quantitative manner the network performance between FBS and MBS, not only in a first responder scenario, but in general.

III. SYSTEM MODEL

Our objective is to evaluate the network performance in a scenario with a group of first responders conducting operations in an area served by only one base station, either FBS or MBS. We suppose that there is a group of N users moving in a target area A . In the group of first responders, we assign one group leader and $N - 1$ group members. The simulation studies this system for a time duration T . At the beginning of the simulation, the group members are randomly placed around the group leader. The maximum initial distance between the group leader and the edge group members is noted as the user dispersion R . The MBS is able to follow the movement of users. In our model, the MBS will follow the group mobility by localizing the group leader. However, we consider there may be an estimation error when localizing the group leader. We denote this error as E_{err} .

As the first responders usually act collectively, we adopt the Reference Point Group Mobility (RPGM) as the mobility model for our group of users [16]. For each time step Δt , the users update their positions according to RPGM. In this model, the movement of the group leader defines the group motion vector \vec{g} . The group motion vector \vec{g} has a random direction within 360° for each time step, and the magnitude of \vec{g} is a random value within $[0, V_{max}]$. All the group members follow the mobility of the group leader, and then they have an individual random motion vector \vec{r}_i . Same as the group motion vector, \vec{r}_i also has a random direction within 360° for each time step for each user, the magnitude of \vec{r}_i is a random value within $[0, v_{max}]$. So, the final motion vector for each group member is the sum of the group motion vector and the individual random motion vector.

The FBS is not able to react to the user mobility, and it is located at the center of the target area A . Instead, the MBS will reposition itself to follow the group mobility by following the group leader with a fixed altitude h . For the convenience of the comparison, we consider the altitude h of the MBS is the same as the height of the FBS.

We suppose that we know the positions of the base station and the users during the observation time T , thus, we can compute the distance between the base station and the users at each Δt . According to the Friis equation, the free-space

path loss (FSPL) for a line-of-sight (LoS) propagation can be calculated as:

$$FSPL_n = 20 \log_{10} d_n + 20 \log_{10} f + 20 \log_{10} \left(\frac{4\pi}{c} \right) \quad (1)$$

where d_n is the distance between the base station and the user n , f is the signal frequency and c is the speed of light.

For a non-line-of-sight (NLoS) propagation, the path loss can be modeled as the sum of the FSPL and an extra attenuation, as below:

$$PL = FSPL + \eta \quad (2)$$

where FSPL represents free-space path loss between the base station and the user, and η represents the excessive path loss, due to reflection, diffraction, fading, *etc.*

We adopt a probabilistic model to estimate the path loss. With this probabilistic model, LoS and NLoS propagation will have different probabilities of occurrence. Then, we can compute the path loss as following:

$$PL = P(LoS) \cdot PL_{LoS} + P(NLoS) \cdot PL_{NLoS} \quad (3)$$

Based on the recommendations of the International Telecommunications Union (ITU), we can class four different radio propagation environments: Suburban, Urban, Dense urban and High-rise urban [17]. For each environment, we have different probabilities of occurrence of LoS and NLoS conditions. The probability of LoS and NLoS can be considered as a continuous function of the elevation angle θ . The trend of this function can be expressed approximately as [6]:

$$P(LoS, \theta) = \frac{1}{1 + ae^{-b(\theta-a)}} \quad (4)$$

where a and b are parameters depending on the environment. As we only have one base station in the target area, no external interference is considered. We simply use a thermal noise model, producing a noise level constant for a given bandwidth.

With known transmit power, the path loss can be computed, and we can calculate the received power for each user at each Δt . We choose the throughput between the user and the base station as the metric of interest for network performance. We consider that the MBS (similarly to the FBS) can directly provide some edge services to the users. This is particularly true for first responders scenarios, where a control center can be installed locally. For external services, such as Internet access, we consider a high capacity backhaul link (*e.g.*, millimeter-Wave or satellite) is available. We compute the maximum theoretical throughput for each user (given by the Shannon capacity of the channel) at each Δt :

$$Throughput = B \cdot \log_2(1 + SNR) \quad (5)$$

IV. RESULTS

We conduct an extensive set of simulations, using an in-house simulator, to compare the FBS and MBS scenarios in the first responder context. The default values of simulation parameters are provided in Table I. All the results presented below are based on 100 simulations and the confidence interval is set to 95%.

A	20 km x 20 km
Tx_Power	40 dBm
h	30 m
R	20 m
Bandwidth	5 MHz
T	30 min
Δt	1 s
N	15
V_{max}	2 m/s
v_{max}	0.2 m/s

TABLE I
SIMULATION PARAMETERS

A. LoS environment

First, we evaluate the impact of the number of users on network performance in a LoS environment. In Fig. 1, we show the evolution of the average user throughput when the number of users increases. Because of the lower distance between the MBS and the users, MBS has significantly better performance than FBS. Besides, MBS always follows the group of users, while FBS is fixed at the center of the target area, so the FBS performance depends on the user location. Therefore, the user throughput is more homogeneous in the case of MBS.

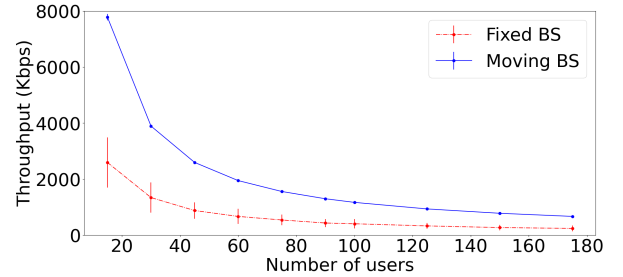


Fig. 1. Average user throughput for different numbers of users (CI=95%).

In Fig. 2, we evaluate the impact of the transmission power on the average user throughput in different radio propagation conditions. For the same transmission power, if we consider only the LoS conditions, the average throughput of MBS is up to 4 times higher than the average throughput given by FBS. In the other sense, to achieve a target throughput, the required transmission power of MBS is much lower than that of FBS, the difference reaching almost 50dBm.

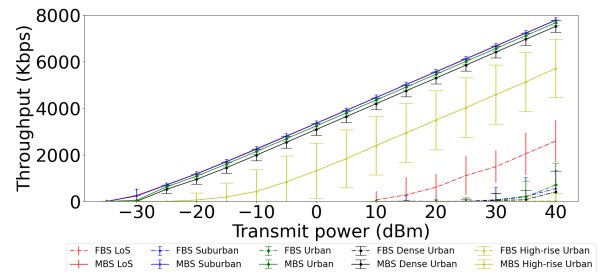


Fig. 2. Average throughput of different radio propagation models (CI=95%).

In Fig. 3, we investigate the impact of user dispersion R on the user throughput. We assume $P_t = 20\text{dBm}$. As already observed, the user throughput of a MBS is higher than the one for FBS. However, as the MBS follows the mobility of the group leader, when the user dispersion increases, the distance between the MBS and the group members also increases. Thus, the performance decreases with the increase of the dispersion for a MBS network. On the other hand, the FBS is fixed at the center of the target area, so its performance only depends on the random position of the users. The median user throughput in FBS network is around 500 Kbps, showing even a slight increase with user dispersion. We remark that, for what we consider a realistic user dispersion in a first responder scenario, *i.e.*, lower than 1 km, the MBS is a much better choice. The user throughput becomes similar for MBS and FBS when the user dispersion reaches values as large as 5 km.

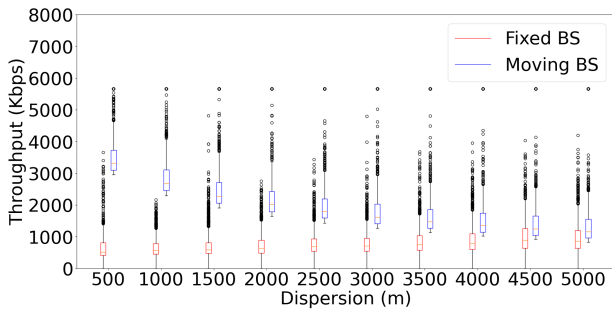


Fig. 3. User throughput for different user dispersion values.

We focus on two specific scenarios in Fig. 4, where we show the distribution of user throughput for a user dispersion of 500 m (Fig. 4a) and for an extreme value of 5 km (Fig. 4b). As seen in Fig. 4a, when the user dispersion is low, even the worst users in the MBS scenario reach a higher throughput than the best users in the FBS case. Comparing the FBS distributions in Fig. 4a and Fig. 4b, we also understand why the FBS performance slightly improves with the increase of user dispersion. This phenomenon happens because, as the user dispersion increases, the impact of the group leader location becomes less important. When the user dispersion is low, if the initial (random) position of the group leader is far away from the FBS, then the throughput of all the users is reduced, since their locations are highly correlated. When the user dispersion becomes larger, the user throughput is less affected by the position of the group leader, and we can notice a slight shift of the distribution. Of course, for MBS, when the dispersion increases, the distance between the users and the MBS becomes larger, and the throughput decreases.

As the user dispersion becomes larger, the difference in the wireless channel quality of each user becomes larger. Therefore, we also study the fairness of the per-user throughput with different user dispersion. Furthermore, we remark that MBS always follows the group leader, so the group leader is particularly close to the base station, and the throughput of the group leader is extraordinarily high and constant, which leads to a lower fairness of the per-user throughput with MBS. For

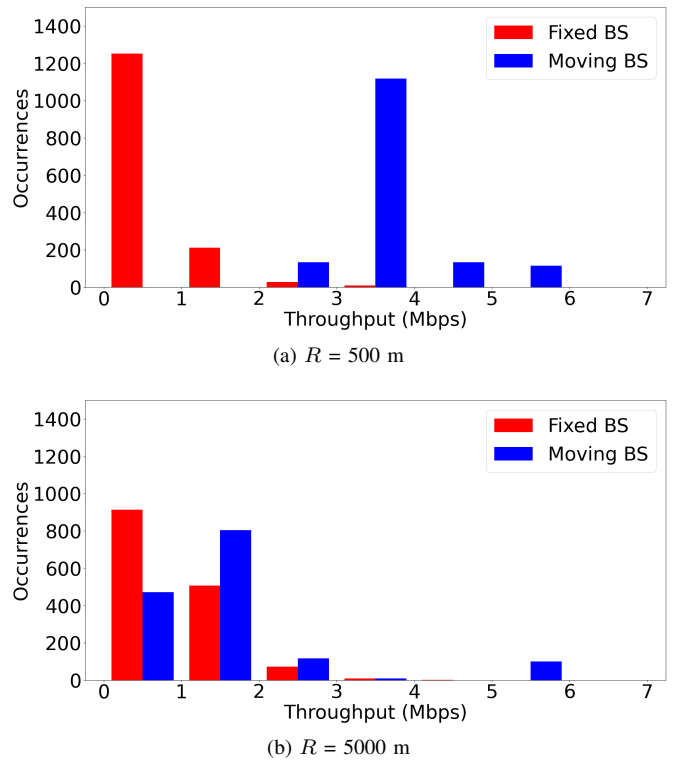


Fig. 4. User throughput distribution for different dispersion values.

this reason, we evaluate the fairness of the per-user throughput by excluding the group leader.

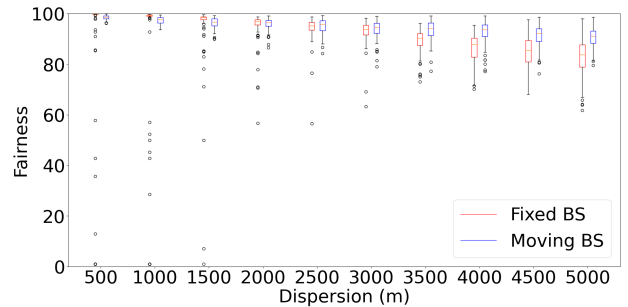


Fig. 5. Fairness of per-user throughput for different dispersion values (without group leader).

We show the evolution of fairness by increasing the user dispersion in Fig. 5. We can see that, overall, the fairness of the per-user throughput decreases with the increase of the user dispersion. This is because, as the user dispersion increases, the difference in distance between different users and the base station becomes larger, and thus, the throughput gap among users becomes larger. With the results in Fig. 5, we observe that MBS also provides a more equitable performance to users than FBS.

B. NLoS environment

To deal with different environments, we implement several NLoS propagation models and measure the average user

throughput in Fig. 2. Similarly to what we observed in a LoS environment, the MBS provides a significantly higher throughput to users. The impact of NLoS on network performance is related to the density and height of buildings in the environment. NLoS conditions have a significant impact on the FBS network, and the network performance is severely degraded. Compared to the user throughput in LoS environment, the throughput with FBS in suburban, urban and dense urban environments has a heavy fluctuation. In the high-rise urban environment, the user throughput is close to zero. In the case of MBS, the suburban, urban and dense urban environments do not have a significant impact on network performance. This is because the base station follows the users, hence reducing the probability of encountering obstacles on the radio propagation path. In the high-rise urban environment, network performance is significantly reduced even for MBS, but remains high compared to FBS. To achieve a comparable performance, the required transmit power of a MBS can be more than 50dBm lower than the one of a FBS.

In the previous results, we consider the MBS can somehow track the leader and follow the group. However, in practice, there might be an error when the moving MBS tries to locate the group leader. Therefore, the accuracy of the group leader localization by the MBS can be an important issue. We evaluate the impact of this parameter on the network performance by varying the localization error, E_{err} , from 20 m to 500 m. Fig. 6 presents the variation of the average user throughput for different localization errors, in different NLoS environments, with $P_t = 10\text{dBm}$. Depending on the radio propagation environment, the MBS system seems to tolerate a localization error between 20 m and 200 m. With larger localization errors, the user throughput degrades considerably. While the impact of this parameter is clearly significant, we believe that realistic localization errors in practice are in the range of tens of meters, a value for which the MBS approach highly outperforms the FBS one.

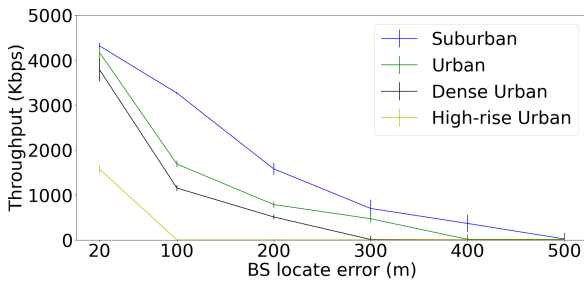


Fig. 6. Average user throughput for different localization errors (CI=95%).

C. MBS Coverage

A possible issue with the MBS approach is that, by moving the base station, the area initially served by the FBS might not be covered entirely during the entire period of operation. To evaluate this, in Fig. 7 we show the average intersection coverage between FBS and MBS in 100 simulations, with two

different transmission powers. With a transmission power of 40dBm, around 60% of the FBS coverage area is still covered by the MBS. Moreover, with a transmission power of 30dBm, the overlap is only minimal. This hints at a potential problem with the MBS approach: a situation where other users, outside the studied group, need to have network coverage is more challenging for a MBS than for a FBS.

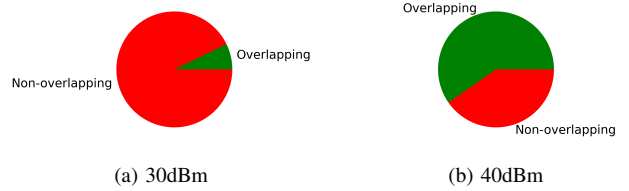


Fig. 7. Average coverage intersection for different transmit powers.

Indeed, sometimes, a part of the first responders may need to stay outside the group and deal with specific issues. Therefore, we evaluate the FBS and MBS performance when there are some static users in the field, together with a group of users moving together. To this end, we keep the original number of users the same and increase the number of static users proportionally. We denote the proportion of static users as α , thus, there are αN static users. We use a default value of 15 total users in our simulation so, for convenience, we choose 20, 40, 60, and 80 percent as the proportion of static users. To deal with the static users, we implement two possible MBS mobility control strategies. The first one consists of the MBS always following the leader of the mobile group, as in the previous results, despite the existence of static users. The second strategy is to place the MBS in the center of mass of all the users. In Fig. 8, we evaluate the network performance for all these scenarios with a varying numbers of static users in a LoS environment.

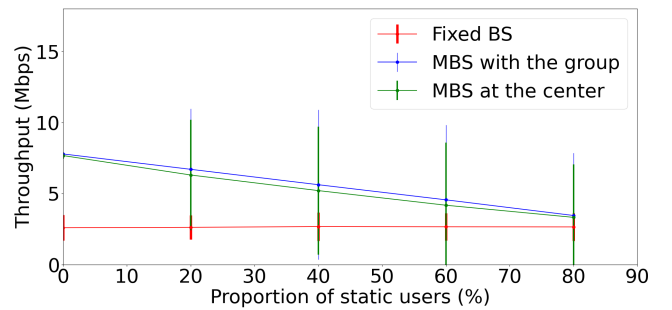


Fig. 8. Average user throughput with different numbers of static users in a LoS environment (CI = 95%).

Overall, the MBS approaches perform better than FBS. However, as the proportion of static users increases, the average user throughput of MBS gradually decreases, no matter which mobile control strategy is used. The strategy where the MBS follows the group leader movement has a slightly better performance than the strategy using the center of mass.

However, for both strategies, the confidence intervals are very large, indicating significant user disparity.

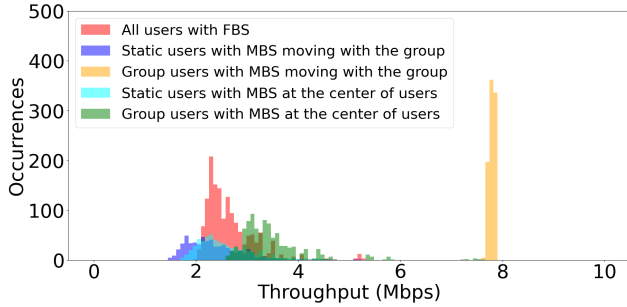


Fig. 9. User throughput distribution in LoS environment when $\alpha=40\%$.

To better understand this phenomenon, we divide MBS users into static users and mobile group users and show the results of these two groups in Fig. 9. The throughput of FBS users is also shown, for comparison, without distinguishing between mobile and static users in this case. When MBS closely follows the group of mobile users, the throughput of these users is guaranteed, and it is close to 8Mbps. The throughput of static users for this MBS scenario is slightly lower than the one of FBS users. When the MBS is placed in the center of mass of the users, as it is quite common in the literature [18], the performance observed by the static users does not actually improve. However, the mobile group users have a noticeable drop in performance in this case.

Overall, our results demonstrate that using MBS can bring significant gains in scenarios where a group of users moves together, such is the case for first responder teams. Under realistic group dispersion and localization error, 4x throughput is obtained by a MBS approach, when compared to a classical FBS solution. If static users are also present in the area, they observe a slight decrease in their performance.

V. CONCLUSION

In this paper, we present a quantified performance comparison between a FBS and a MBS approach in a first responder communication scenario. We observe that a MBS is much more suitable for covering a group of mobile users active in the field. The reason for this is that the MBS can follow the users and reduce the communication distance. This results in a reduction of the transmission power by up to 50dBm to achieve a target throughput in a LoS environment. In a NLoS environment, the advantage of MBS is even more significant, as obstacles can also be avoided by the base station mobility. However, the advantage of MBS depends on the user dispersion. As this parameter increases, the users are spread more evenly in the studied area and the performance of the MBS is gradually approaching that of FBS. The performance of MBS is also impacted by the accuracy of locating the group. When the localization error becomes large, the performance of MBS is highly impacted, especially in environments with high obstacle density. Besides, by using an MBS, a part of

the area originally served by the FBS is no longer covered, meaning that users outside the group followed by the MBS might encounter a lower service availability. Finally, when both static users and mobile group users are present, the use of MBS provides a significantly better performance for group users than the use of FBS, with a slight performance degradation for static users. In the future, we will continue our study by investigating the advantages and disadvantages of using MBS. We will extend our investigation considering, e.g., convergence and separation of multiple groups of users, and a mobile network composed of several FBS and MBS, as well as different MBS mobility control strategies.

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