Feasibility of Using Mobile Base Stations for Improved Resilience and Reduced Energy Footprint

Ahmed Hasan Ansari*, Florian Klingler†, Gianluca Rizzo‡§, and Falko Dressler*
*School of Electrical Engineering and Computer Science, TU Berlin, Germany
†Chair of Computer Networks, University of Bamberg, Germany
‡Institute of Informatics, HES SO Valais, Switzerland
§Dipartimento di Informatica, Universita' di Torino, Italy
{ansari,dressler}@ccs-labs.org, florian.klingler@uni-bamberg.de, gianluca.rizzo@hevs.ch

***Abstract*—Moving Base Stations (MoBSs) provide a flexible approach to dynamically augment cellular infrastructure in response to varying traffic demands and network outages. In this paper, we investigate the feasibility of vehicle mounted MoBSs for improving the capacity, resilience, and energy efficiency of 5G networks. We implement MoBS functionality in OMNeT++ by extending Simu5G gNodeBs with vehicle mobility and Wireless Access and Backhaul (WAB) functionality following the 3GPP Release 19 architecture. The implementation integrates Simu5G, Veins, and SUMO to enable MoBSs to move with simulated vehicles while providing 5G access to user equipment (UE) through a wireless backhaul connection to donor base stations. We evaluate the approach using both a validation scenario and a realistic urban scenario based on the Luxembourg SUMO Traffic (LuST) mobility traces and real base-station locations. Results show that introducing MoBSs reduces access-channel utilization by at least 18% under high traffic load and decreases UE transmit-power requirements, yielding energy savings of at least 11% compared with deployments using only static base stations. In a simulated base-station outage, MoBSs reduce the peak utilization of the remaining donor base station from above 90% to approximately 63%, demonstrating their potential to improve network resilience.**

I. Introduction

The ever-increasing number of traffic users and the growing traffic demand are a major challenge for future cellular networks. This is coupled with the dynamic and heterogeneous nature of traffic due to the very diverse applications and services. However, as the amount of deployed network infrastructure increases, networks become more vulnerable to disruptions such as failures and overload. Network resilience is critical for all future mobile networks and is also part of the ITU's official framework for 6G wireless communications International Mobile Telecommunications (IMT) 2030 [1]. Additionally, the massive deployments of internet of things (IoT) devices as part of various smart city initiatives imply that not only do capacity requirements need to be addressed, but energy efficiency also becomes an integral factor in any planned solutions.

Network densification is an obvious solution to many of these problems. However, network densification will have both positive and negative effects on resilience [2]. In addition to the positive effects on redundancy and capacity increase, negative effects include increased deployment and operational costs.

Another challenge is the lack of efficient resource management. Although an increased presence of cells would handle large traffic demands and increase resiliency, especially during peak hours, traffic trends are very variable. A way to overcome such over-provisioning is to physically move 5G/6G small cells between urban locations based on traffic demands, which is already the case for big events such as sports and concerts. However, these mobile base stations are usually limited in number and cannot be used 'on the move.'

More recently, the mobile base station (MoBS) concept has been proposed [3], [4]. Such moving small cell base stations provide additional capacity, when and where needed, to the end users. MoBS can be realized using driving [3] or flying platforms [5], [6], depending on the specific use case and the corresponding requirements. In addition to capacity requirements, MoBS can be employed to provide local service in areas where the cellular network infrastructure may temporarily not be operational, e.g., after natural disasters.

Realizing such mobile base station brings many challenges, of course. These include advanced distributed resource management, mobility planning, handover decisions, and wireless backhaul solutions. On the wireless backhaul side, 3GPP already defined integrated access and backhaul (IAB) and more recently wireless access and backhaul (WAB) for 5G/6G networks [7], [8]. The idea is to connect a MoBS to a *donor* base station (BS) using a wireless link. The standardized interfaces enable quick integration of new MoBS solutions. Besides densification, of course, resiliency is also increased as failing BSs or insufficient capacity regions can be mitigated. In addition, IoT devices (as well as power-constrained handhelds) also benefit from the close proximity to MoBSs, as they can minimize transmit power and thus increase energy efficiency.

In this paper, we present a feasibility study of using MoBSs for improved resilience and reduced energy footprint of connected devices. To this end, we realized a new simulation framework based on established state-of-the-art tools like Veins [9] and Simu5G [10]. Using a simple validation scenario and a realistic city scenario, we show the benefit of using MoBS to improve capacity and reduce the energy footprint on the end-user side, but most importantly also to help covering outages of the BS. This study is intended to shed light on the general concept, but primarily also possible performance gains and

limitations of the approach.

Our key contributions can be summarized as follows:

- We implemented a complete MoBS scenario using state-of-the-art simulation tools and the most recent 3GPP WAB interfaces;
- We conducted a simulation-based feasibility study, mainly aiming at revealing benefits and limitations of the system;
- We present results suggest clear improvements in terms of capacity, resilience, and energy consumption with respect to fully static deployments.

II. Related Work

Mobile base stations: The moving network concept was originally introduced with the main goal of serving users located inside vehicles such as trains, busses, and cars [4]. More recently, this has been extended to general network densification [3]. 3GPP refers to such nodes as vehicle mounted relays [11]. Unmanned aerial vehicles (UAVs) or drones have also been considered as potential implementations of moving networks [12]. UAVs can potentially be very helpful in dynamic resource management and in increasing energy efficiency [13]. UAVs can also provide better propagation conditions by potentially avoiding obstacles that limit line-of-sight communication [14]. They can also provide assistance in terms of resilience and can be deployed as a temporary on-the-fly relay BSs during post-disaster scenarios [15]. Of course, UAVs also present significant challenges as they can suffer from short flight times due to battery constraints and can require strict regulatory approval for aerial operations. Most relevant also from a resilience perspective are high-altitude platform systems (HAPSs) [16] and satellites. These systems are viewed as key enablers for non-terrestrial networks (NTNs) supporting certain disaster situations and very remote areas.

Wireless backhaul: Wireless backhaul functionality is integral to an effective MoBS deployment. Part of the trend is the potential to reduce CAPEX for BS deployment (BS itself, but also electric power and fiber optics cables). Integrated access and backhaul (IAB) has been seen as one such implementation of wireless backhaul and was also standardized by 3GPP [17]. Using relays, named IAB nodes, this backhaul includes a multi-hop architecture for the future design of the 5G/6G cellular system with wireless backhaul links connecting the IAB nodes to each other and to a donor BS (gNB) [7]. The donor BS provides connectivity to the core network. A possible implementation of such an architecture was presented by Polese et al. [18] and validated in the form of an end-to-end simulation. Here, all IAB nodes were considered static and do not incorporate the mobility aspect of mobile base station. Wireless access and backhaul (WAB) is a more recent development standardized by 3GPP in Release-19 [19] and differs in the architecture of the backhaul nodes. Rubaltelli et al. [8] provided a hardware testbed with an implementation based on WAB. They focus on an out-of-band backhaul scheme to mitigate interference effects. However, the end-user in this work is considered to be onboard user equipments (UEs) inside a vehicle. Both of the mentioned works on IAB and WAB do not deal with the resource allocation problem between the access and backhaul sides of the network, which remains an open problem.

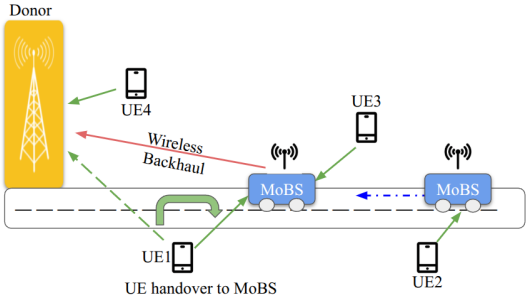


Figure 1. MoBS concept: mobile BS are connected to a donor BS. UEs can connect to both the donor BS as well as to one of the MoBSs. Handovers take place if a UE has a better channel to another BS/MoBS. Green arrows: access links, red arrow: wireless backhaul link, blue arrow: movement of MoBS.

Summary: The concept of moving base stations has evolved from simple in-vehicle relays to a broader vision of mobile infrastructure that dynamically augments 5G/6G networks. Within the moving network paradigm, vehicles can provide a sustainable and cost-effective solution, especially in dense urban environments. When combined with wireless backhaul and multi-access edge computing, vehicles become multi-purpose infrastructure, delivering connectivity, both access and backhaul, and computation where it is most needed. However, challenges remain in mobility management, energy optimization, resource allocation, and coordination among heterogeneous moving nodes.

III. The Mobile Base Station Concept

A. Introduction to MoBS

In the scope of this paper, we focus on vehicle mounted MoBSs, which are designed to be deployed on vehicles, either parked or driving, in order to temporarily improve coverage, in addition to the traditional coverage provided by static macro/micro BSs. The target could be an urban area where demand for content, connectivity, and computing is higher, e.g., due to a higher concentration of broadband mobile users. As such, the main objectives of MoBS deployment can be summarized as follows:

- Dynamic network densification in terms of extending the existing network resources based on coverage and capacity requirements;
- Resilience to outages by providing temporary coverage where existing static network infrastructure may fail.

There is of course a cost to achieve these objectives in the form of network complexity as well as higher delays due to wireless backhaul. But, as will be evidenced by the results of this work, the benefits achieved by using MoBSs can be significant.

The principles of vehicle mounted MoBSs are depicted in Figure 1. The MoBS may move along the road network and support potential UEs in its vicinity. The UE performs handovers between the static donor BS and the MoBSs, and

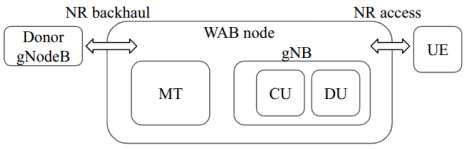


Figure 2. Wireless access and backhaul node. On the backhaul side, the node connects to the donor BS like a UE. In contrast, the WAB node represents itself like a standard gNB to other UEs (figure based on [19]).

among MoBSs based on channel quality. The concept of course helps offloading wireless traffic or providing resilience in case of infrastructure failures. While being served by a MoBS, any down- or uplink traffic is routed through the wireless backhaul link between the MoBS and a nearby donor BS.

B. Wireless Backhaul: Revisiting IAB and WAB

IAB and WAB both rely on donor BSs for wireless backhaul. The donor nodes are directly connected to the core network and so act as a gateway to and from the core network. The architecture of a WAB node is depicted in Figure 2. Within an IAB or WAB node, the gNB provides access functionality to downlink UEs, while the 5G mobile termination (MT) unit acts as a backhaul node towards the uplink donor node. The key difference between IAB and WAB is the implementation of the access part. An IAB node holds partial gNB functionality and only implements the distributed unit (DU) of a 5G gNB and relies on the donor for all centralized unit (CU) functionality. A WAB node, however, contains full gNB function and can therefore handle even more complex functionality such as session creation, resource allocation and mobility management of downlink UEs.

C. Implementation

From an implementation perspective, a MoBS requires two additional crucial elements compared to a static BS: (1) a notion of mobility that extends otherwise static base stations; (2) a system of wireless backhaul. In the following, we describe our implementation of these two aspects in detail.[1] This implementation makes use of the OMNeT++ network simulator and involves different tools and frameworks integrated into a single simulation environment. These tools are (1) Simu5G [10] for 5G New Radio (NR) access functionality. (2) SUMO [20]: to simulate the mobility of vehicle mounted MoBS (3) (Veins) [9]: an OMNeT++ framework to control networking and vehicle interactions.

Extending MoBS with Mobility: The default static 5G gNB modules provided by Simu5G were modified by defining a new custom mobility model. This new mobility module is added to the base gNB module. Another custom module tracks the mobility of SUMO vehicles entering the simulation and binds the MoBS to their movement. It unbinds this mobility when the vehicle exits the simulation. Thus, the MoBS move according to SUMO simulated vehicles and provide 5G gNB functionality.

[1]The code will be made available with the final version of the paper

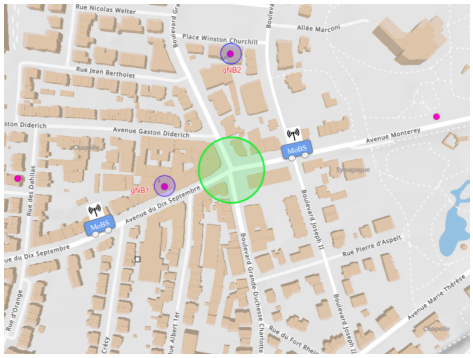


Figure 3. Intersection in Luxembourg geoportal map; base stations encircled in blue (49.6094°N, 6.1181°E and 49.6111°N, 6.1194°E) and the intersection encircled in green (49.609755°N, 6.11935°E).

Implementing WAB: WAB functionality was added to the default gNB node. This implementation follows the work by Rubaltelli et al. [8] and the 3GPP specification of WAB in Release 19 [19]. Essentially, a WAB node consists of a 5G gNB connected to a 5G MT unit. The gNB inside the WAB node provides access to other downlink UEs and the MT provides wireless backhaul towards the uplink donor node.

IV. Evaluation

In the following, we present first a validation using a rather simple scenario consisting of a single street and a single donor BS. This is followed by a detailed feasibility study to learn more about the advantages of vehicle mounted MoBSs for network densification, improved network capacity, resilience, and reduced energy footprint for the connected UEs.

A. Simulation Scenario and Parameters

For the validation study, we rely on the simple single street scenario shown in Figure 1. For the more comprehensive feasibility study, we shifted focus to an actual intersection of Luxembourg (using the Luxembourg SUMO Traffic (LuST) scenario [21]). The mobility patterns of vehicles found in LuST allows for a more realistic simulation of MoBS. Moreover, actual base station positions around the intersection are used based on the Luxembourg Geoportal Map[2] to investigate the efficacy of MoBS in conjunction with static base stations. The chosen intersection along with positions of the base stations is shown in Figure 3. To reflect peak hour of vehicular traffic, the time of 8am-9am in the morning was chosen.

The most relevant simulation parameters are summarized in Table I. We allowed a warm-up period of 60 s in addition to a simulation time of 3600 s to cover an initial transient period. This ensures a significant presence of vehicles that can act as MoBS and allows for steady-state results. UEs are modeled as pedestrians randomly distributed throughout the area in and around the intersection in both experiments and send Poisson-distributed uplink traffic to a server. They also perform handovers where necessary based on the strongest

[2]https://data.public.lu/en/datasets/inspire-annex-iii-utility-and-governmental-services-gsm-antennas-cadastre/

Table I
SIMULATION PARAMETERS

Parameter	Value
UE packet size	1000 Byte
Packet interval	Poisson $\lambda = 50$ ms
Channel frequency access	3.6 GHz
Channel frequency backhaul	2.1 GHz
Resource blocks	6
Simulation time	3600 s
Initial transient	60 s
Number of UE	10, 20 and 50

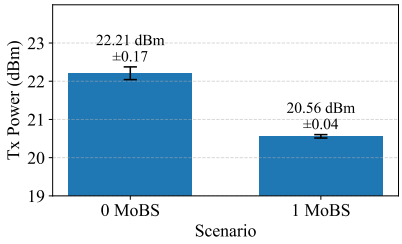


Figure 4. Validation scenario: Average TX power per UE.

signal to noise ratio (SNR). The average packet interval time of 50 ms and the provided 6 resource blocks (RBs) allow for saturated (high load) or unsaturated (low load) scenarios while varying the number of UEs between 10, 20 and 50.

To estimate potential energy savings that can be achieved through the use of MoBS, a simple uplink transmit power control mechanism was implemented. UEs try to reduce the TX power they use based on their proximity to their serving base station by using their downlink SNR as a reference point. If their SNR is higher than a specific threshold, they reduce their TX power in steps of 1 dBm until a minimum value is reached and increase their TX power the same way if their SNR is lower than the threshold. The UE TX power was set to a custom range between 20–26 dBm. For simplicity and validation purposes of the feasibility study, we ignore fading, shadowing and the impact of interference for the following experiments. Additionally, for all simulations the access and backhaul channels of MoBS were chosen to operate in different frequency bands.

B. Validation and Conceptual Feasibility

For the initial validation and feasibility study of our implementation, an initial simulation study based on a single lane scenario (cf. Figure 1 was performed. On the left side, there is a static base station which also acts as a donor node. The car represents a MoBS moving from the right hand side to the left. It loops back around to its original starting point when it reaches the end of the lane and continues this movement to the end of the simulation.

Figure 4 shows the average TX power per UE. There are clear energy savings per UE with the use of the MoBS due to the fact that there is a higher probability that the serving base station is closer to a UE when the base station is mobile. Overall, this represents an approximate energy savings of 36 % for UEs, which is quite significant. This also indicates the availability of a MoBS close to the user despite the fact

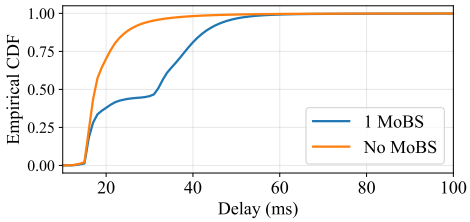


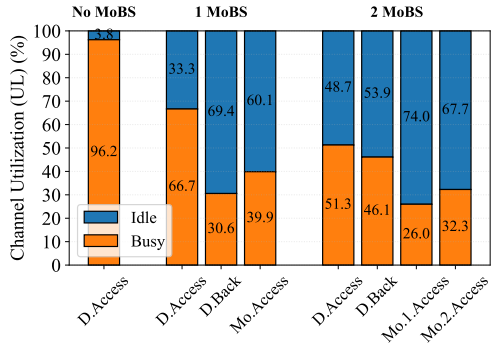
Figure 5. Validation scenario: End-to-end delay per packet received.

that we only use a single MoBS in this validation scenario. The end-to-end delay for uplink transmissions is plotted in Figure 5. Wireless backhaul accounts for a higher delay if the MoBS is used by the UE. This is due to an additional hop that packets have to take from the MoBS to the donor via wireless backhaul.

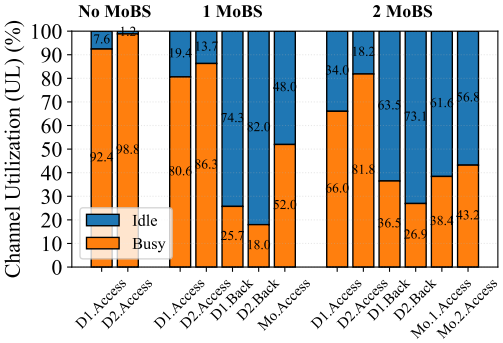
C. Reality Check and Feasibility Study

Following this initial validation, a more detailed simulation study was conducted in which additional metrics such as channel utilization were also investigated under different traffic load conditions. We study different numbers of MoBS, UEs, and donor BSs.

To assess the impact of MoBS on capacity, channel utilization was measured; see Figure 6. Utilization was measured on the basis of the resource blocks allocated at each scheduling interval. If no resource block was allocated, that time slot was designated as idle; otherwise, it was busy. These data were aggregated for all time slots for each node, and the



(a) One donor BS, 20 UE



(b) Two donor BS, 50 UE

Figure 6. Utilization of access and backhaul links (D.Access refers to donor access channel, D.Back refers to donor backhaul channel)

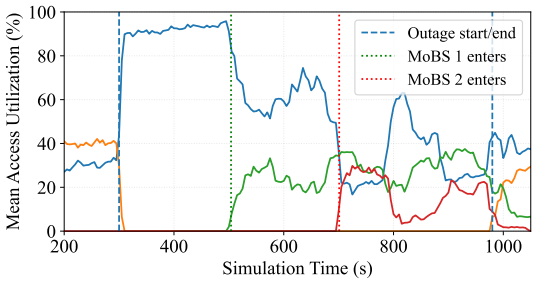
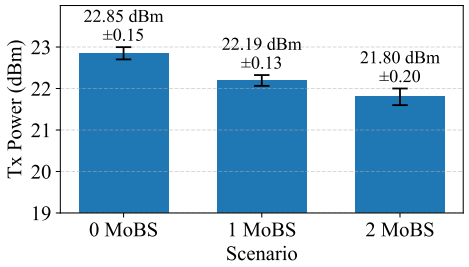
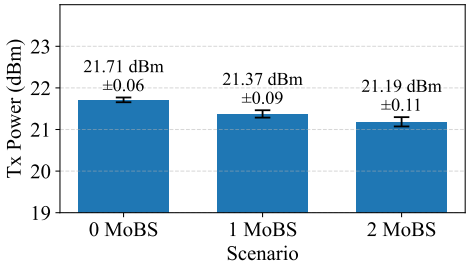


Figure 7. Access channel utilization (Solid lines represent BS utilization. Orange = D1, Blue = D2, Green = MoBS1, Red = MoBS2



(a) One donor BS, 20 UE

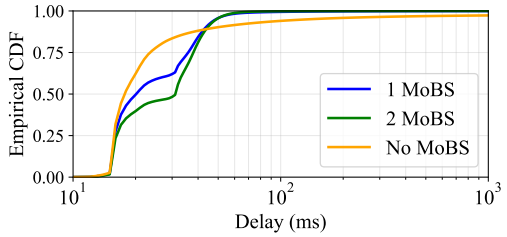


(b) Two donor BS, 50 UE

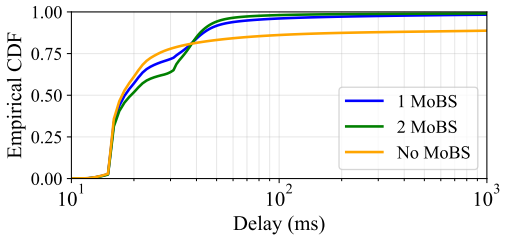
Figure 8. Average TX power per UE.

resulting ratios were calculated. It is evident to see that the high utilization of the access channel for all donors BSs decreases with the introduction of MoBS incrementally. In the single donor scenario, it reduces from 96.2% to 50.5%, a decrease of almost 46%. When two MoBSs are active, we observe a reduction of approximately 18%. More UE traffic is handled by the MoBSs as they dynamically serve UEs. However, the respective backhaul channel utilization also starts to increase as more traffic is routed via the MoBS backhaul towards the donor BS. This provides an interesting observation: Adding more MoBSs can result in saturation of the backhaul channel, which could degrade overall network performance. Consequently, this highlights the need to optimize available resources, perhaps even MoBSs association policies. However, these remain out of the scope of this paper and could be part of future work.

To further investigate the gain in resilience due to the addition of MoBSs, an additional scenario was simulated. The donor to the north-east of the intersection was simulated to suffer an outage or failure during simulation. Then, MoBSs were introduced after the outage had occurred to see their impact, similar to what could happen in a disaster or blackout situation. There were 20 UEs in this experiment and all



(a) One donor BS, 20 UE



(b) Two donor BS, 50 UE

Figure 9. End-to-end delay (log scale).

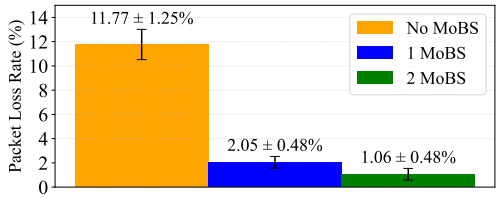


Figure 10. Packet Loss rate - Two donor BS, 50 UE.

other parameters were the same. Figure 7 shows the channel utilization of all base stations. When an outage occurs at $t = 300\,\mathrm{s}$, the remaining active donor has to take over the load of all remaining UEs and its utilization goes beyond 90 %. However, when the first MoBS is introduced at $t = 500\,\mathrm{s}$, it provides support to the donor and is able to serve some of the UEs. The same happens when the next MoBS is added. The peak utilization goes down to around 63 %. This underlines the benefit of MoBSs in terms of resilience.

The energy savings due to MoBS can again be observed in Figure 8. With the introduction of MoBSs, UEs have a higher chance of being closer to their serving base station and, therefore, can reduce their transmit power, resulting in lower average transmission power per UE. Compared with the baseline case of stationary BS only, this represents total energy savings of approximately 21.5% and 11%. The savings are a little lower with two donor BSs, since there is already another stationary base station present, which can serve more UEs than in the single base station case. However, we see a significant reduction in the average energy consumption per UE.

The trend of end-to-end delay is similar to the single lane scenario for the low load case (10 UEs). But for high load cases (one donor BS, 20 UE and two donor BS, 50 UE), the worst case delays are less significant (Figure 9). The addition of MoBS reduces the worst case delay as seen in Figure 9b. This is due to the fact that UEs further away from the donor base station suffer even higher delays due to high channel saturation

and poor SNR. The default Max C/I scheduler assigns resources based on SNR and the UEs closer to the donor BS will have a higher probability of getting more resources. With the addition of the MoBS, the previously poor SNR UEs have a better chance of being served, especially when the MoBS is in their vicinity. This shows an unexpected additional benefit of MoBS on the delay performance in high traffic load scenarios. This is further highlighted in Figure 10. The packet loss here refers to all packets that experienced a delay greater than 500 ms. Such late packets can be considered lost in most applications, such as video streaming, because they have violated their deadline or latency requirement. Here again, the benefit of MoBSs is evident with a 10 % reduction in packet loss with the addition of 2 MoBS compared to the baseline case.

V. Conclusion

In this work, we present an implementation of mobile base station (MoBS) integrated with wireless access and backhaul (WAB) functionality. In both a validation and a larger-scale feasibility study, we demonstrated the gain that MoBS can bring, especially in terms of channel utilization and energy savings. A minimum decrease of 18% in access channel utilization was achieved under high traffic load. However, this coincided with an increase in backhaul utilization, highlighting the need for more efficient resource allocation while using MoBSs. Under outage conditions, the increase in resilience and robustness that MoBSs can provide was also observed Furthermore, energy savings of at least 11% were achieved. Interestingly, the feasibility study focusing on a realistic traffic and mobile communication scenario in the city of Luxembourg also revealed a reduction in worst case end-to-end delays and packet loss under high traffic load. In addition to the capacity increase, this also contributes to the overall improved resilience of the MoBS supported wireless network.

As part of future work, more effective resource allocation mechanisms will be investigated to ensure optimized resource allocation of both access and backhaul resources. We also plan to extend the simulation to cover channel propagation effects such as radio signal shadowing by vehicles and buildings. Another promising area is the use of agentic AI to influence the routes of the vehicles based on reward functions such as traffic load and static base station failures.

Acknowledgments

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