5G-Enabled Healthcare in Mobile Scenarios: Challenges and Implementation Considerations

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ABSTRACT

Wireless connectivity delay, disruption, or failure can significantly affect the performance of wireless-enabled medical devices, which in turn causes potential risks to the patient. Notably, the challenges related to connectivity provisioning are exacerbated in the fifth-generation (5G)-enabled healthcare use cases where mobility is utilized. In this article, we describe relevant 5G-enabled healthcare use cases involving mobility and identify the connectivity challenges that they face. We then illustrate practical implementation considerations, tradeoffs, and future research directions for enabling reliable 5G healthcare transmissions. This is done through simulation of connected ambulances as an example use-case.

I. INTRODUCTION

Existing healthcare systems have several limitations including lack of an individualized diagnosis and treatment model, lack of a holistic data-driven healthcare practice model and inconvenience of transportation to access healthcare services in rural areas. Additionally, medical devices commonly integrate sensors to be used in a single location, which limits the possibility for data reuse and efficient deployment of software updates [1]. Moreover, with the growth of bandwidth hungry applications such as video streaming and multimedia file sharing, and proliferation of smart healthcare devices, the demand for broadband on the move is rising, highlighting the opportunity for using improved wireless communication infrastructure.

The fifth-generation (5G) mobile network technology can help create an opportunity for augmenting current medical practices with improved connectivity to create novel use-cases, such as in-ambulance treatment by remote physician. Compared to 4G, 5G performance targets includes higher multi-Gbps peak data speeds, 10 times decrease in latency, 10 times increase in connection density and throughput, 3 times increase in spectrum efficiency, and 100 times increase in traffic capacity and network efficiency[1]. With such advancements in wireless technology, healthcare-related use cases and applications are being explored. These include use cases such as connected ambulance, remote robotic-assisted surgery, service robotics, teleconsultation (remote monitoring, diagnosis, and treatment), and wearable/implantable medical devices. These applications rely on robust, reliable, and seamless wireless connectivity across the continuum of connected care.

However, 5G-enabled medical applications and use cases can incur challenges stemming from the evolving characteristics of wireless cellular networks, such as cell densification, simultaneous operation at multiple frequency brands, control-data plane split, network virtualization, an amalgam of new technologies, flexible infrastructure, and spectrum allocations that lead to a growing complexity. Examples of the tradeoffs and practical implementation considerations in 5G network resource allocation include new resource allocation considerations in 5G due to adaptive numerology and mini-slots, the tradeoff between quality of service and handover latency in small cells, tradeoff between coverage, capacity and load balancing in medical IoT. Developing adaptive, automated and scalable algorithms for service monitoring and assurance solutions to address the large number of serviceable base stations and the growth in medical IoT is another challenge. Also challenging is the development of novel algorithms that can dynamically optimize network configuration parameters. For example, changing traffic density and high mobility in a connected ambulance scenario resulting in dynamic adjustment of network parameters to meet service demands [1].

When contrasted with fixed wireless deployments, provisioning high-quality wireless connectivity becomes more complicated when mobility is involved since additional factors need to be considered. For instance, mobile users perform handover (HO) from one base station to another to maintain connectivity to the network. Moreover, mobile users also often encounter problems such as frequent handovers and poor coverage that can lead to poor signal quality and ultimately result in low throughput or connection failure. Considering the risks associated with the connection delay, disruption, or failure in wireless enabled healthcare applications, the challenges brought by mobility in 5G-enabled healthcare should be studied and addressed to promote patient safety and successful application deployment. This is especially relevant with the advent of cellular connectivity facilitating emergency healthcare management services where high mobility might be present.

In this article, we consider relevant 5G-enabled healthcare use cases that involve mobility in Section II. The connectivity challenges relevant to those applications are identified and discussed in Section III. We then present a connected ambulance case study in Section IV based on simulating a dense network deployment in an urban environment where connected ambulance services are used. Section V concludes the article.

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[1] *Barb, Gordana, and Marius Otesteanu. "4G/5G: A comparative study and overview on what to expect from 5G." In 2020 43rd International Conference on Telecommunications and Signal Processing (TSP), pp. 37-40. IEEE, 2020.*

II. USE CASES FOR 5G-ENABLED HEALTHCARE IN MOBILE SCENARIOS

5G-enabled healthcare applications are diverse and thus have diverse connectivity requirements. In this section, we focus on applications where mobility is relevant. Readers interested in a detailed analysis of connectivity key performance indicators for 5G-enabled healthcare applications may refer to [2].

A. *Connected ambulances*

An example of healthcare use cases where mobility is a key consideration is the in-ambulance treatment by a remote physician, which is also referred to as *connected ambulance* [3]. In this use case, data collected in the ambulance, e.g., medical imaging and live video streaming from the onboard medical equipment such as sonograph, imaging devices, electrocardiogram (ECG), and other patient monitors, is transmitted to the remote physician for prehospital diagnosis. By acquiring the latest status of the incoming patient, the remote physician can assemble the treatment team in the hospital and arrange necessary facility resources in advance to avoid treatment delays. Physicians can also guide the onboard paramedic staff while the patient is en route to the hospital.

Although earlier works, especially trials using the 4G networks, showed the opportunities in this type of application, it was reported that adequate and resilient mobile coverage for broadband services was still limited. Notable factors impacting the connected ambulance service includes the unstable bandwidth available in the 3G/4G mobile networks, the lack of prioritized access to the high-speed broadband connections for medical service users, rapid explosion of wearable medical devices, competition with other users especially during rush hours in the densely populated urban areas, and high demand of ubiquitous coverage [3]. Approaches to address these limitations were also reported in the literature. For example, a trial of the connected ambulance use case was conducted using satellite communications in the absence of mobile broadband coverage [4]. Additionally, a small cell study was conducted to help alleviate mobility-related challenges encountered by connected ambulances in [5]. A small cell base station was installed inside the ambulance to network the onboard paramedics and provide them with access to remote medical application servers. The results in the study showed that users inside the ambulance served by the mobile small cell achieved higher throughput, lower packet loss rate, and lower delay as compared to users with microcell links who were experiencing a higher handover latency. Other experiments using 5G mobile networks for the connected ambulance use case are also reported in literature, such as the work in [6] which evaluated live video streaming performance.

B. *Wearable and implantable medical devices for moving users*

The Internet of Things (IoT) is another use case that can benefit from the capabilities of 5G wireless communication. While medical IoT devices such as wearable healthcare monitoring devices are commonly used at fixed locations, it is worth noting that they can be mobile. For example, a patient who is in a moving vehicle and needs continuous monitoring through wearable medical devices such as body-worn sensors and vital signs monitors. The monitored signals are then transmitted wirelessly in real-time to the healthcare provider network where a clinical decision support system can help detect critical signs of patient deterioration and alert the relevant parties to act [7].

C. *Healthcare monitoring systems in autonomous vehicles*

Use cases are also emerging where healthcare monitoring systems are integrated into autonomous vehicles. Sensors that collect the patient and environmental data such as blood pressure, pulse rate, body temperature, airflow, humidity, and movement sensors can be integrated into the car's informatics system along with image, speech, and video capturing devices. Alarms raised for the driver or passengers by combining information from these sensors can be used to communicate with surrounding autonomous vehicles and connected vehicle roadside unit (RSU) for help. Upon receiving responses, the autonomous vehicle can re-route to the nearest emergency treatment center according to the distance, instead of proceeding with the original navigation [8]. In addition, staff in the destination hospital and other passengers can also be alerted to further increase the utility of such system.

III. CHALLENGES IN 5G-ENABLED HEALTHCARE IN MOBILE SCENARIOS

Unlike static healthcare applications, mobile healthcare scenarios involve additional challenges. Some of these stem from the current state of 5G deployments which can impede the full realization of mobile 5G-enabled healthcare. For example, the current availability of 5G networks is sporadic with the 5G deployments concentrated in densely urbanized areas. The carriers largely rely on their legacy infrastructure investments, i.e., 4G networks, to supplement 5G network coverage. However, pre-5G networks can only provide limited capacity without the native support for quality of service (QoS) in the end-to-end data path. Moreover, network outages and congestions continue to be causes for degraded connectivity.

Beyond the limited 5G coverage in the early adoption stage, 5G-enabled mobile healthcare can be restrained by challenges that are rooted in 5G nuances and peculiarities. The survey published in [9] presents a vast array of mobility management challenges in emerging ultra-dense networks. The discussion was on a high level without addressing the considerations of any specific application. Hereafter, we highlight some of the challenges from the perspective of 5G-enabled mobile healthcare scenarios.

- *Increase in the frequency of handovers and signaling overhead due to dense network deployment:* Aside from utilization of higher frequency bands, another approach to provide augmented capacity and ubiquitous coverage in 5G is the ultra-dense network (UDN) deployment. With UDN, base stations (BS) are placed in a tightly packed manner. The expected 5G base station density is between 40 to 50 BS per km^2, compared to 8 to 10 BS per km^2 in 4G [10]. As a result, UDN significantly increases the frequency of handovers the user would experience. Accordingly, the chances of handover failures are also increasing, which can be further aggravated due to the limited time allowed to complete the handover execution. Such handover failures can affect the performance of 5G-enabled healthcare in mobile scenarios, where a stable wireless connection is needed to achieve a desired QoS. Additionally, the inherent increase in the signaling overhead during handovers can potentially reduce the network resources available for data transmission.

- *Data interruption during handover execution:* The current 5G handover process relies on legacy 4G technology, i.e., the handover is performed in a break-before-make manner. In such a handover style, the user's connection with the serving base station is interrupted before a new connection with the target base station is established. The interruption causes a delay that the user can perceive during the handover execution. In most cases, this short interruption has a negligible impact on the carried service. However, the interruption might negatively impact 5G-healthcare applications with tight delay tolerance.

- *Unbalanced load in heterogeneous network deployments:* 5G deployments are heterogenous in nature with a multitude of base station types in the network. Macrocells and small cells are commonly used to meet diverse coverage needs. An unbalanced load can occur in a network with users unevenly distributed in the serving cells across different layers. Although the imbalance in the utilization affects both static and mobile users, the impact is more pronounced in mobile applications with strict requirements for QoS. Mobility load balancing (MLB) is a technique to induce utilization fairness between different layers in the network [9]. When MLB is activated, moving users might suddenly be offloaded to a layer with low utilization causing connection interruptions, which can be unfavorable to delay sensitive healthcare applications.

- *Lack of intelligent handover decision mechanism:* The 5G HO process solely depends on the signal strength and quality. That is, handover commences once the signal strength or quality of the target base station becomes better than the source base station. Although the point of handover can be controlled by several handover-related parameters [11], minimal intelligence is currently involved in the process where several issues can occur such as ping-pong handover, delayed handover, too early handover, and unwanted handover to overshooting cell, all of which can result in radio link failures (RLF). RLF is a complete loss of connection between the network and the user. RLF might then lead to a complete loss of functionality in a 5G-enabled healthcare application.

- *Challenges due to dual connectivity:* Dual connectivity in the 5G non-standalone (NSA) mode allows users to connect at the same time to a 4G BS that serves as a master access point and a 5G BS that serves as a secondary node. This type of deployment can accelerate the activation of 5G services when the 5G standalone (SA) operation is not yet available. However, dual connectivity introduces additional challenges. For instance, the timing of dual connectivity activation can cause service interruption when triggered in areas where either 4G or 5G coverage is poor [12]. It also introduces a longer interruption during the handover due to extra procedures such as adding/remove the secondary nodes.

The aforementioned challenges might be aggravated in scenarios with elevated user speeds (e.g., connected ambulance on the highway), elevated user density (e.g., several connected ambulances rushing to the same location in a disaster), the presence of outages occurring due to software or hardware failures, and the presence of multiple critical traffic streams in the network (e.g., telesurgery and connected ambulance operating at the same time in the same location). In the next section, we use simulation to focus on the connected ambulance as an example of 5G-enabled mobile scenarios to discuss specific challenges, implementation considerations, and trade-offs between different parameters.

IV. CASE STUDY: CONNECTED AMBULANCE

A. System Model

We consider the connected ambulance use case in an urban environment. The destination of a healthcare facility (shown in Fig. 1) in the New York city is considered and the traces for ambulance users to the healthcare facility and non-ambulance users in the network are pre-generated from random starting points in the simulation area according to a fixed average speed using Google Street maps and global coordinates information. In addition, other non-ambulance users with varying speeds also move on the streets within the considered area. Table 1 lists the system parameters unless specified in individual experiments.

The ambulances and non-ambulance users perform handovers as they move between the base stations. To initiate the handovers, we utilize the 3GPP standard handover event *A3* (defined in 3GPP TS 38.331), which triggers the handover once the reference signal received power (RSRP) level of the target base station becomes better than the serving base station by a value set by the parameter *A3-offset* over a period set by the parameter *time-to-trigger (TTT)*. Future works will investigate handover triggering by other events too, such as event A5. While most of the handovers are successful, there are instance wherein proper handovers cannot be performed between base stations due to reasons such as poor signal conditions. If a user stays under a poor condition longer than a time threshold set by the parameter *T310*, RLF is declared that allows the user to search for a better base station. In this paper, we use the mobility parameter values shown in Table 1 to maximize the success rate of handovers while minimizing the occurrence of RLF.

For non-ambulance users, we implement a first-come, first-serve scheduling mechanism. However, a higher priority is assigned to ambulance users in each Transmission Time Interval (TTI) scheduling to promote the ambulance connectivity services. In addition, we assume that each ambulance user requires 10 physical resource blocks (PRBs) to account for the diverse communication needs of in-ambulance services. The PRB requirements of non-ambulance users are randomly chosen from 1, 3 and 10 PRBs to emulate different types of users and connectivity demands in the network.

B. Simulation Setup

We simulate the scenario using a ray tracing commercial planning tool, Atoll [2] , to plan, simulate, and optimize the assumed 5G network in the connected ambulance use case. First, the network topology of 5G New Radio macro and small cells is modeled and created in simulation as shown in Fig. 1 to represent a deployment in New York City, NY. To improve the practicality of the simulation environment, we use Digital Terrain Model (DTM) raster files representing the elevation of the ground over sea level. DTM contains the altitude value (in meters) on evenly spaced points, along with features of the bare-earth terrain, such as rivers and ridges**.** Using the altitudes at the vertices of the grids from DTM, a series of linear interpolations is performed to

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[2] https://www.forsk.com/

[3] Forsk. Atoll. "Technical Reference Guide for Radio Networks", Version 3.4.0., June 2018.

determine the altitude of a point located inside a bin[3]. We use clutter classes representing the type of terrain (land cover or land use). The clutter classes map is a grid representing the ground with each grid assigned a clutter class code corresponding to its clutter type. Clutter types include surface street, open bare ground, grassland, low vegetation, forest, and buildings of various height ranges. Clutter heights map is also used for representing individual heights of clutter. Clutter height of a point is the height of the nearest point in the clutter heights file which stores the height corresponding to each clutter type on evenly spaced points.

We then incorporate the shadowing effect modelled by a log-normal (Gaussian) distribution. Instead of using a distribution with a fixed standard deviation, we vary the standard deviation according to the clutter type as different clutter types have different shadowing effects. The path loss model is chosen to be the aster propagation model, rather than any empirical or semi-empirical path loss models that are based on measurements in a specific environment and limited in their ability to capture idiosyncrasies of various propagation environments. In contrast, the aster propagation model is based on ray tracing propagation techniques and incorporates vertical diffraction over roof-tops, horizontal diffraction/reflection based on ray-launching and ray tracing calculation on raster data as well as on vector building data. We use a practical 3-D antenna model composed of horizontal and vertical antenna patterns as opposed to a theoretical antenna pattern equation based on analytical assumptions and simplifications.

The network scenario settings are reported in Table 1. The carrier frequency, channel bandwidth, duplexing mode, transmission time interval, and handover event parameters are based on 3GPP specifications. The maximum transmit power, A3-offset, A3-TTT, and T310 parameters are based on industry gold standards. Other parameters are set after analyzing the case study and doing cell planning. For the initial planning stage of the network, Atoll's automatic cell planning (ACP) tool combined with the industrial domain knowledge of the authors are used for site placement, antenna selection, and azimuth and tilt settings based on > 99% area coverage objective, i.e., RSRP > -105 dBm and Signal to Interference and Noise Ratio (SINR) > 10 dB.

While Atoll offers a realistic model of the 5G network, it does not support handover. This motivated the use of a 3GPP-compliant simulator to implement a detailed 3GPP-based handover process and incorporate mobility-related configuration and optimization parameters, i.e., SyntheticNET [13]. After the network planning and optimization steps in Atoll, site information such as base station location, ambulance, and healthcare facility locations, and RSRP maps of each base stations are then imported to SyntheticNET. Combining the capabilities of the two simulators attempts to address the practicality of modeling the network deployment and mobility evaluation.

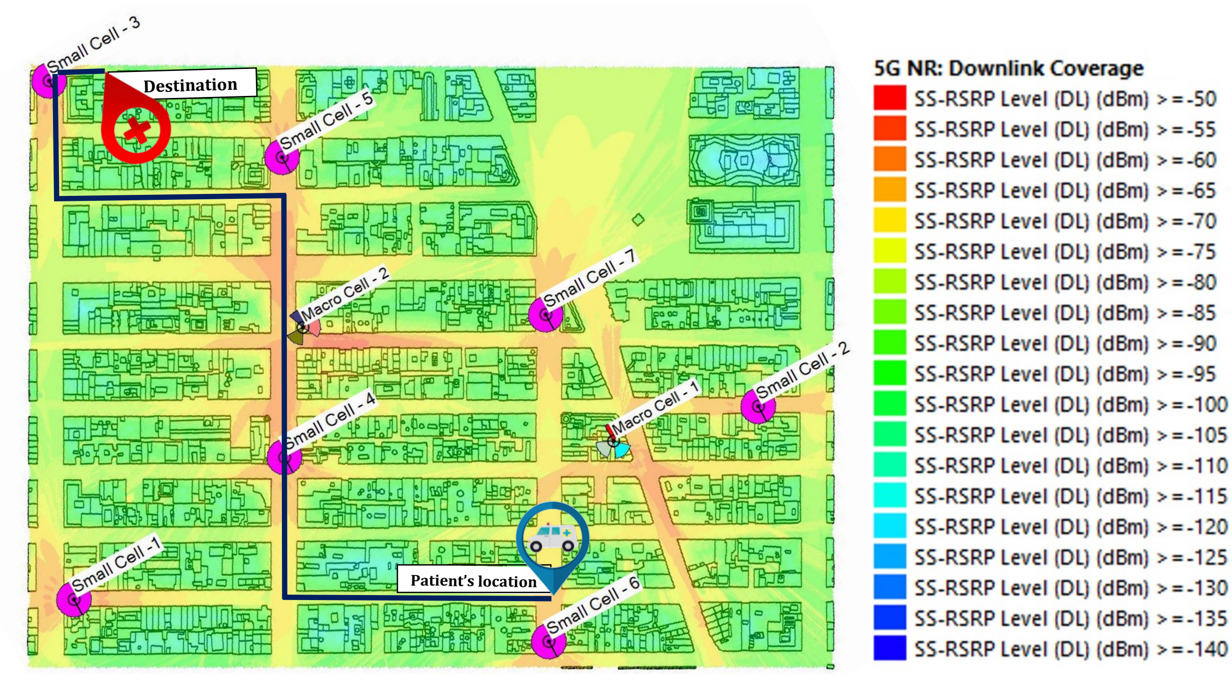


Fig. 1: System model showing the base station deployment, downlink coverage, and an example of ambulance user trajectory in the simulation area.

Table 1: Network scenario settings.

System parameters	Values
Carrier frequency	Small cell: 3.5 GHz Macro cell: 800 MHz
Channel bandwidth	Small cell: 50 MHz Macro cell: 5 MHz
Duplexing mode	Small cell: TDD Macro cell: FDD
Maximum transmit power	Small cell: 10 dBm Macro cell: 36 dBm
Path loss model	Aster propagation (ray tracing)
Cell sectors	Small: Omni-directional Macro: Tri-sectored
Number of sites	Macro:2 Small: 7
Geographical information	Ground heights, building heights, land use map
Ambulance users average speed	60 km/h
Non-ambulance users average speed	3 km/h, 20 km/h, 50 km/h
Beamforming Model	Small cell: Mid-band, 32T32R, 360 deg beam sweeping, 17 dBi composite antenna gain Macro cell: Low & Mid-bands, 64T64R, 90 deg beam sweeping, 24 dBi. composite antenna gain
No. of active non-ambulance users	45
No. of ambulances	1 to 12

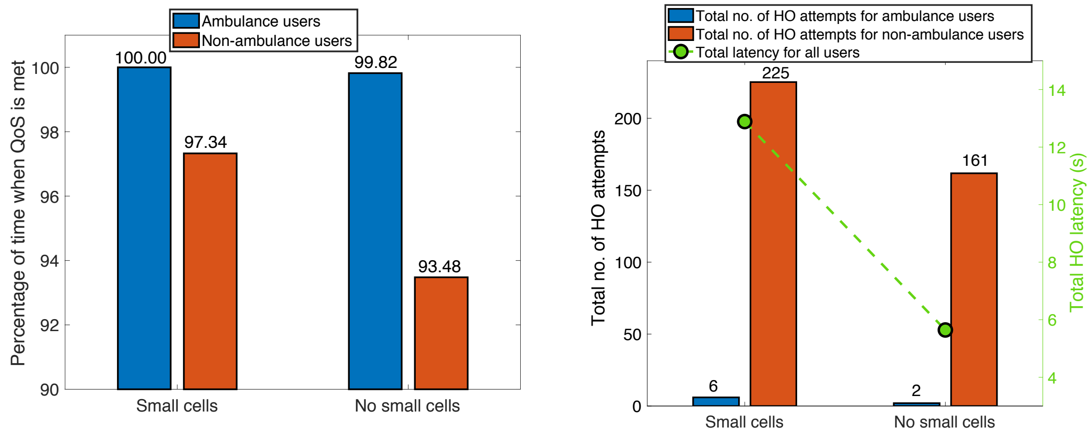
Bin/grid size	1 m
Coverage area size	670000 m^2 (0.67 km^2)
BS height	Small cell: 10 m Macro cell: 30 m
Shadowing	Clutter-dependent shadowing
Sampling frequency	16 ms
Transmission time interval	1 ms
Total simulation time	114000 ms
Handover event	Event A3
A3-offset	2 dB
A3-TTT	256 ms
T310	1000 ms

C. *RESULTS AND DISCUSSION*

In this section, we illustrate some of the challenges highlighted in Section III through numerical results and analysis using the system model and simulation setup in IV-A and IV-B.

- *Challenges due to the increase in the frequency of handovers and signaling:*

A heterogeneous dense network deployment consisting of both macro cells and small cells can be an effective solution to offload traffic to small cells especially in case of high user densities. However, this comes with the cost of increased signaling during handovers. As mentioned in Section III, small cells contribute to increasing the frequency of handovers, which consequently leads to an increase in latency or delay. To investigate this trade-off, we evaluate the number of HOs attempted and the fraction of time when QoS is met. We consider the percentage of time when QoS is met as the percentage of total simulation time when the PRBs allocated to a user are equal to or greater than the PRBs requested by a user. Since we have many users in the network, we average it over all users. For example, assume that a user needs x PRBs, and gets y PRBs out of the fixed total PRBs available (depending on the channel bandwidth and subcarrier spacing). Then, for calculating the fraction of time when QoS is met, we sum the total time duration for which $y \geq x$ for each user, average it over all users and divide it by the simulation time. The trade-off is depicted in Fig. 2 showing the impact of adding small cells to the network in a connected ambulance use case. In Fig. 2 (a), we observe an increase in the percentage of time when QoS is met for both ambulance and non-ambulance users upon the incorporation of small cells in the network. On the other hand, the number of handovers attempted increased from 161 to 255 and 2 to 6 for non-ambulance users and ambulance users, respectively, as shown by the results in Fig. 2 (b), which is also reflected by total HO latency for all users. The difference between the performance metrics in Fig. 2 for small cells vs. no small cells scenario is more significant for non-ambulance users as compared to ambulance users because a scheduling priority is given to ambulance users. It should also be noted that inter-frequency HO (when HO is performed from macro to small cells or vice versa) signaling is more demanding as compared to intra-frequency HO (when HO is performed between macrocells) signaling. This is due to the inter-frequency cell discovery procedure, which would contribute to increasing the latency when small cells are present.



(a) (b)

Fig. 2 Performance comparison between ambulance and non-ambulance users with and without small cells: (a) QoS fulfillment, (b) total number of HO attempted and HO latency .

- *Challenges due to the lack of intelligent handover decision mechanism:*

To illustrate this challenge, we consider two scenarios: 1) variation in the number of ambulances traveling on different routes and 2) variation in the number of ambulances traveling on the same route (e.g., in case of an emergency where multiple ambulances rush to the same location).

To simulate the first scenario, we use five ambulance routes. While these paths have different ambulance starting points, all of them end at the same location (i.e., health center shown in Fig. 1) at the same time. It can be observed from Fig. 3 that as the number of connected ambulances in the network increases, the average scheduled time for non-ambulance users (i.e., the percentage of the time when the average number of PRBs allocated to non-ambulance users is non-zero) decreases, owing to the greater proportion of resources being consumed by the prioritized ambulance network traffic. Consequently, the average time spent per user in RLF (i.e., the time for which the users remain in RLF divided by the total number of users) increases to as high as 70 ms when there are 5 ambulances in the considered network coverage area, leading to 4.5% cumulative time spent in RLF for all users during the total simulation time. The increase in RLF for non-ambulance users can be attributed to the decline in signal quality due to increased interference introduced by elevated base station loads. On the other hand, for connected ambulances, the non-monotonic trend in the average scheduled time per connected ambulance in Fig. 3 can be explained by considering the average time in RLF per ambulance user. When there were one or two ambulances in the simulation, we see that the average scheduled time per ambulance user (which is the percentage of total time during which the required 10 PRBs per ambulance user are allocated) is 100%, owing to the absence of RLFs observed in the traveled routes. However, due to RLFs being observed in one or more connected ambulances when 3, 4, or 5 ambulance users were present, we observe a drop in the average scheduled time per ambulance user. Please note that this trend will likely change when the ambulance routes are changed as RLFs are dependent on several factors along the ambulance routes, including location of the users, propagation characteristics, distribution of other users, positioning of base stations the ambulance connects too. These factors affect the

RSRP and SINR, and consequently, RLFs. In such cases, intelligent handover mechanisms can help avoid RLFs by balancing resources or reallocating them through offloading frameworks.

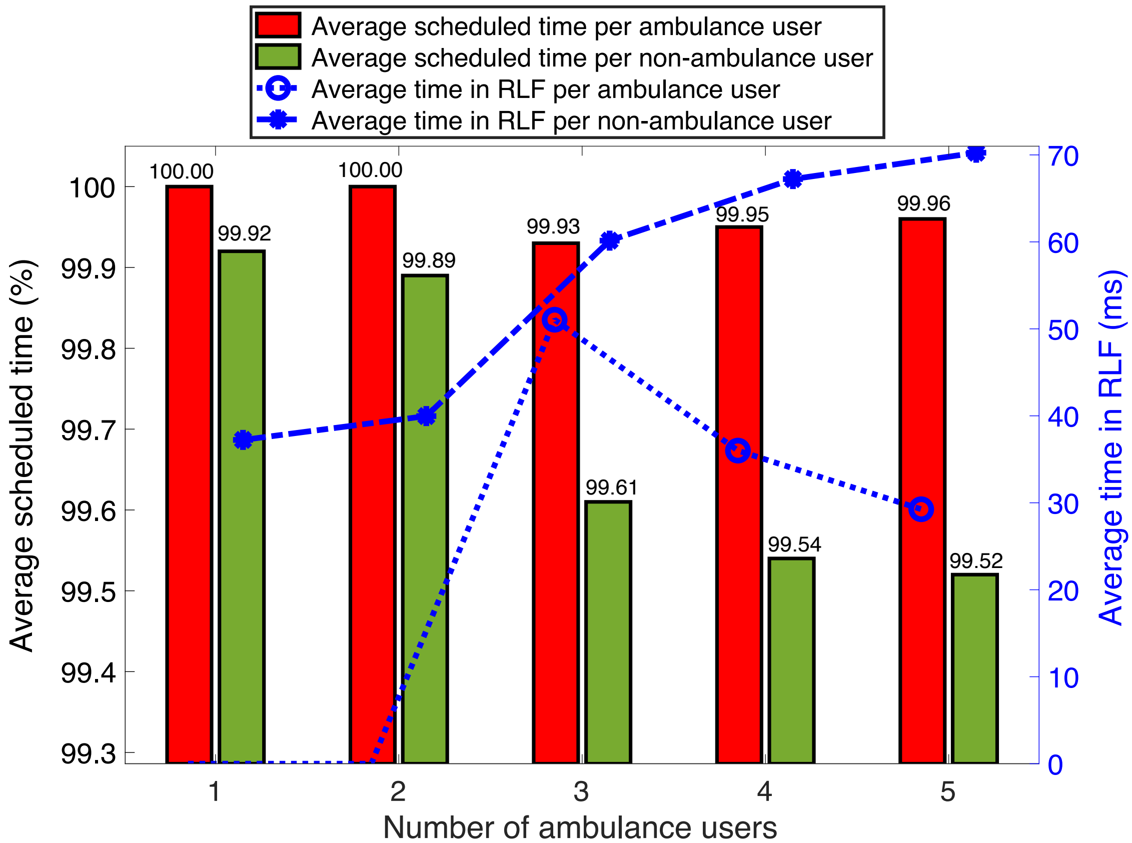


Fig.3. Effect of variation in the number of connected ambulances traveling on different paths on the average scheduled time and average RLF time for connected ambulances and non-ambulance users.

To simulate the second scenario, i.e., an emergency wherein several ambulances rush to the same destination using the same route, we vary the number of connected ambulances to 1, 3, 6, 9, and 12 and investigate the impact of increasing the number of connected ambulances in terms of throughput and resource allocation. From Fig. 4, we see that the mean throughput of non-ambulance users exponentially decreases as the number of connected ambulances increases. In addition, the impact extends beyond the non-ambulance users in this scenario. Specifically, the impact on the connected ambulances on average can be gauged by the resources required by the ambulances minus the resources allocated to them as illustrated in Fig. 4. This difference exponentially increases with the increase in the number of ambulances. Consequently, we note the that intelligent handover mechanisms might help alleviate these connectivity degradations during emergencies through dynamic scheduling, resource allocation, infrastructure, and bandwidth allocation.

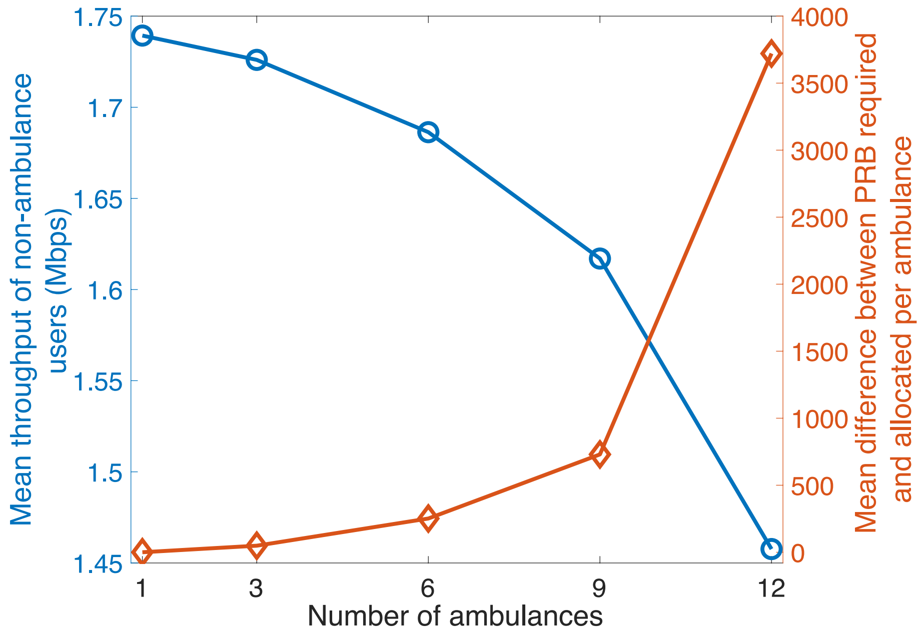


Fig. 4. Impact of increase in the number of connected ambulances in an emergency scenario.

- *Challenges due to increased handovers and signaling with elevated user speed:*

Fig. 5 shows the effect of varying user speeds on the HOs attempted in the presence and absence of small cells. As the user speed increases, the number of HOs attempted also increases both in the presence and absence of small cells. This is attributed to HOs taking place more frequently to maintain user connectivity through the coverage area. Accordingly, user speed should be considered as a design parameter in connected ambulance applications and other wearable and implantable devices intended to maintain connectivity while mobile. This can inform the design and implementation of risk mitigation strategies to ensure patient safety. On the network side, operators can implement mobility prediction schemes, such as predicting future cell loads using past handover traces data, that can enable proactive scheduling and load balancing strategies [14].

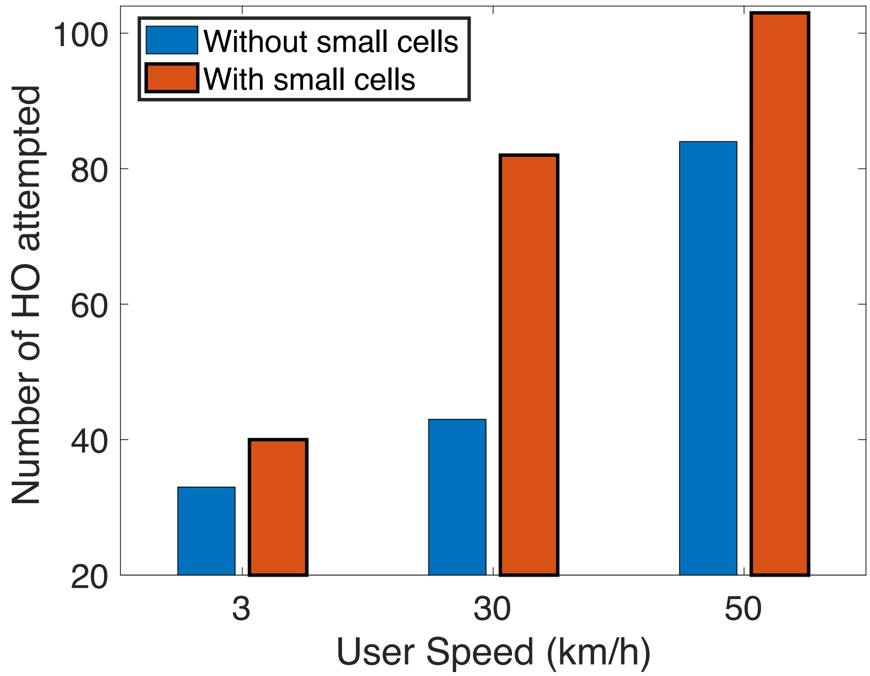


Fig. 5. Effect of varying user speeds on the HO attempts in the presence and absence of small cells.

- *Challenges due to degraded performance caused by network outages*:

Outages in a network are faults that can occur due to hardware, software, or functionality failures (e.g., power supply, radio board, network configurations). Outages are commonly detected through system alarms, performance counters, or by complaints filed by network subscribers. Detecting and resolving these outages can take hours and at times days, which can deprive connected ambulances and other 5G-enabled healthcare applications from the connectivity that enables their functionality. We simulate the outage scenario by powering off one of the macro base stations in Fig. 1, which is the one labeled as Macro Cell-2 (MC-2). Results in Fig. 6(b) show the decline in the RSRP conditions along Route 1 upon inducing outage on MC-2. In the legend, "Route x – no outage" depicts the scenario in which the ambulance is on route No. x when no outages are present in the network. "Route x – outage" indicates the scenario in which the ambulance is on route No. x while an outage is present. The lowest RSRP before outage was -100 dBm. However, the impact of outage is manifested by the RSRP level along Route 1 going below -100 dBm for a considerable fraction of the travel time, which can translate to communication degradation or loss in some cases, e.g., if the user is at cell edge [15]. While this can be mitigated by developing autonomous mechanisms to quickly detect and compensate for outages, another solution can be the implementation of a smart re-routing algorithm. We demonstrate this by re-routing the ambulance to alternative routes 2 or 3 in Fig. 6(c) and 6(d). Although these routes would take longer for the ambulance to reach its destination so that our simulation in this study has to extend to 150 sec to capture the entire data for all routes, they would avoid the effect of MC-2 outage. However, if the alternate route is significantly longer, and in case a patient needs to be transported to the hospital as soon as possible, this might not be a good solution either. This calls for the joint optimization of travel time and coverage conditions along the way from the source to destination. Devising such solutions and assessing potential adverse impact of taking a longer route can be part of future work. Moreover, theoretical analysis of the challenges mentioned in this paper through mathematical forms will be considered as part of our future work.

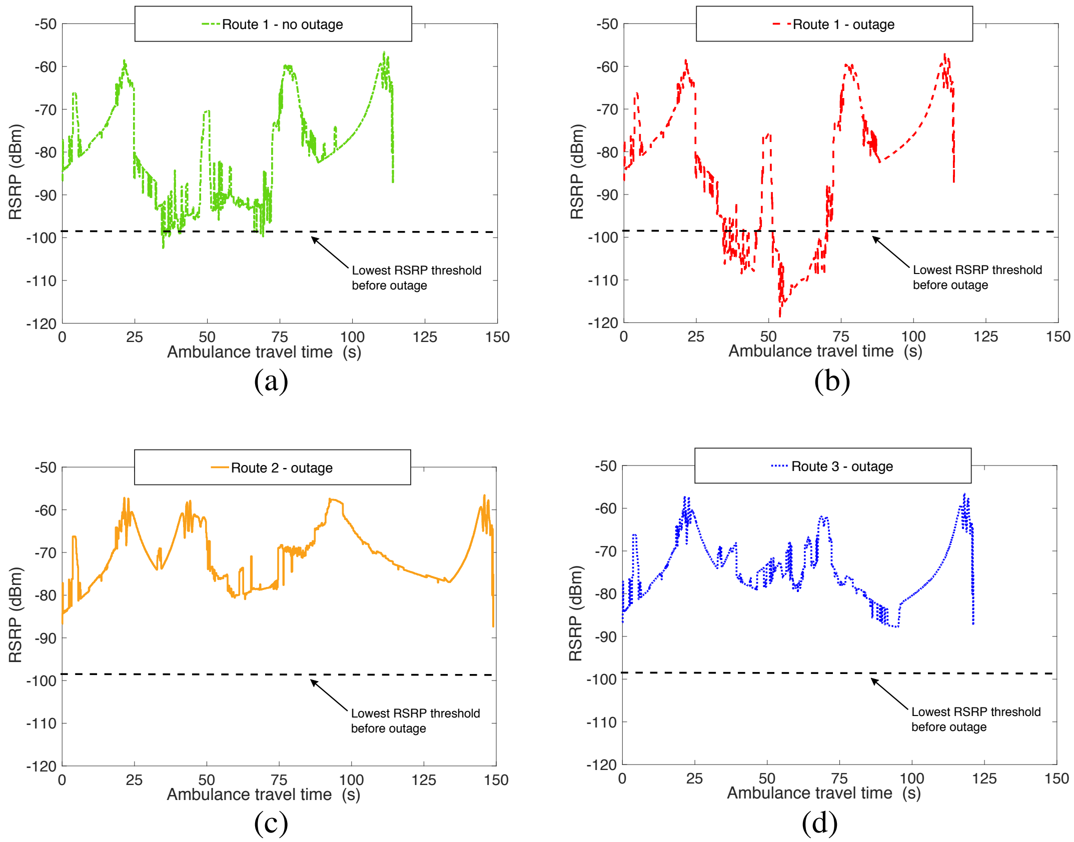


Fig. 6. RSRP on different routes in the presence and absence of outage.

V. CONCLUSION

While 5G promises to create novel use cases and augment connectivity in healthcare, this comes with the responsibility to assure safe and reliable communication performance for wirelessly enabled medical functions and applications. This is relevant in 5G-enabled applications like wearable IoT or connected ambulances, where the failure, disruption, or loss of information via wireless transmissions might lead to patient harm. In this article, we highlighted the challenges and implementation considerations for 5G-enabled healthcare in mobile scenarios using a connected ambulance example. Understanding these challenges is important for developers, network providers, and regulatory authorities in the healthcare sector to facilitate the delivery of 5G-enabled use cases requiring mobility. The discussed challenges and implementation considerations can prompt the exploration and development of innovative solutions on the application and network sides to promote the safety of those applications.

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