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# Arguments for One Radio Access Network (OneRAN) mobile infrastructure

Muhammad Usman Sheikh<sup>1</sup> · Jukka Lempiäinen<sup>2</sup> · Riku Jäntti<sup>1</sup>

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## Abstract

The frequency spectrum is a scarce resource, and is owned and regulated by the state to ensure its efficient and fair utilization. All over the world, a large number of Mobile Network Operators (MNOs) are already involved in either active or passive Radio Access Network (RAN) sharing to maximize cost savings. The aim of this article is to challenge the ownership of individual operator's infrastructure and present technical arguments for One Radio Access Network (OneRAN) approach for deploying a cellular network. The enormous increase in data traffic and regulatory requirements concerning public safety communications provide the basis for migrating to OneRAN infrastructure. The OneRAN approach provides an opportunity to gain technological benefits and helps in meeting the requirements of critical communication. OneRAN targets to maximize the savings on capital and operational expenses. The main focus of this work is outdoor wide-area coverage i.e., outdoor users in rural areas and on highways, as it is assumed that indoor service provision in the future requires a dedicated indoor solution. For the research work of this article, a measurement campaign was launched and different Key Performance Indicators (KPIs) of Long Term Evolution (LTE) technology for three commercial MNOs of Finland were measured over a 52 km highway from Iittala to Tampere city. The acquired results highlight the gain of OneRAN infrastructure as it enhanced the user quality of experience i.e., user throughput, especially of the critical cell border users, and improved the overall system performance economically. Finally, supportive arguments are presented for having a OneRAN infrastructure specifically over the highways.

**Keywords** Mobile network · Wide area coverage · RAN sharing · Spectrum efficiency · trunking gain · OneRAN

## 1 Introduction

In recent 25 years, we have seen the deployment of cellular networks across the globe with different generations of communication systems i.e., from the first digital Global System for Mobile (GSM) network to the latest Sixth Generation (6G) New Radio (NR) system [1]. The history and the development of GSM evolution-based mobile services started from state-owned activities of Postal Telegraph and

Telephone (PTT) companies in the late 1980s and early 1990s. By the mid-1990s, private companies started to show their interest in applying for frequency licenses and started deploying privately owned mobile networks. This development can be considered as a basis for the mobile network evolution during the late 1990s and throughout the 2000's, resulting in multiple i.e., 3–5, mobile networks in most countries.

In the beginning, the size of the coverage or the service area was considered a competitive edge for mobile operators, and typically the service provider with the widest coverage was also economically the biggest operator in a country. However, it was observed that people mostly live in cities, and data services are mainly used in indoor locations. In cities and proximity, mobile networks are efficiently utilized as the population is mainly concentrated in a small geographical area. Thus, for the rest of the nationwide coverage, the radio networks or the radio resources are not efficiently utilized, and the GSM Association (GSMA) reports that remote deployment and rural deployment cost 35% and 18% more

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✉ Muhammad Usman Sheikh  
muhammad.sheikh@aalto.fi

Jukka Lempiäinen  
jukka.lempiainen@tuni.fi

Riku Jäntti  
riku.jantti@aalto.fi

<sup>1</sup> Department of Communications and Networking, Aalto University, 02150 Espoo, Finland

<sup>2</sup> Department of Communications Engineering, Tampere University, 33720 Tampere, Finland

compared with the urban deployment of the mobile network, respectively [2].

Generally, after initial network deployment, all the Mobile Network Operators (MNOs) gradually start to achieve nationwide coverage, and thus the coverage provided by the MNO is not considered anymore a competitive edge. Mobile operators realized the in-efficiency of network deployment in rural areas, and by the end of the last century, the mobile operators started to share their Radio Access Network (RAN) i.e., commonly known as RAN sharing [3]. The target of RAN sharing is to squeeze the infrastructure cost while keeping a certain level of Quality of Service (QoS) [4,5]. 3rd Generation Partnership Project (3GPP) provides details related to network sharing, architecture, and functional description in Technical Specification (TS) 23.251 [6]. The concept of RAN sharing was heartily welcome by the MNOs and was adopted at a large scale for Third Generation (3G) Universal Mobile Telecommunications System (UMTS) and Fourth Generation (4G) Long Term Evolution (LTE) system. The concept of Network Slicing (NS) for the 5G system was brought into discussion among the MNOs within Next Generation Mobile Network (NGMN) alliance. Network slicing enables the shared usage of the physical infrastructures of several MNOs for different types of services [7], whereas the physical infrastructure includes radio access network, edge computing servers, cloud computing resources, Unmanned Aerial Vehicle (UAV) infrastructures, etc. However, different challenges like interoperability, mobility awareness, and end-to-end orchestration are associated with network slicing and need to be resolved for efficient operation [7].

Currently, there are several frequency bands available for 5G between 3–30 GHz, and in the future higher Millimeter Wave (mmWave) frequencies will also be available for 5G deployment [8]. Due to bad radio propagation properties at mmWave frequencies [9], operators are also discussing possibilities to deploy 5G base stations using RAN sharing to reduce both Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) [5]. A higher number of BSs will be required to provide an adequate level of coverage at the higher frequency of operation i.e., mmWave frequencies compared with sub-6 GHz frequencies. The density of the human population and the higher frequency bands of operation encourage the MNOs to deploy shared networks, especially on the highways and in rural areas or cities with sparse populations. In rural areas, operators have continued to deploy their networks partially for targeting better QoS and Quality of Experience (QoE) and partially due to regulatory requirements i.e., mandatory coverage requirement from the regulatory authority [10]. Despite the dense and ultra-dense deployment of outdoor base stations, the provision of high QoS is limited in an indoor environment i.e., private apartments [11]. Moreover, the use of high frequencies will make

it more difficult to provide homogeneous coverage in indoor locations due to heavy Outdoor to Indoor (O2I) building penetration loss [12], and it highlights the issue of having indoor coverage using an outdoor base station, especially at higher frequencies.

We have witnessed the deployment of different generations of cellular networks i.e., GSM, UMTS, LTE, and 5G-NR at different frequency bands, and each system utilizes a different system bandwidth [1]. Without a doubt, it can be said that the maintenance of multi-vendor systems using several frequency bands is a challenging and expensive task. Thus, operators are aiming to shut down the operation of some of those older systems such as GSM or UMTS [13,14]. The future target of MNOs is to concentrate on fewer systems/technologies and achieve maximum cost and spectrum efficiency. In practice, the coverage and service area of different MNOs overlap with each other, especially in densely populated areas. Yet, there is a bottleneck in providing nationwide homogeneous coverage for the outdoor user. Moreover, the provision of indoor service from an outdoor base station is critically challenging [11]. In rural areas, to maximize cost-saving the MNOs have already started sharing their RAN and Core Network (CN), and utilizing fewer technologies [15]. In the case of One Radio Access Network (OneRAN) infrastructure approach, the resources from multiple operators are pooled together, and instead of utilizing separate infrastructures for different operators, a single mast/tower is used, hence helping in cost-saving and better utilization of resources. Whereas in the case of multiple MNOs, each operator has its own mast or in the case of passive RAN sharing i.e., mast sharing, every operator tries to occupy the highest antenna position for better signal propagation, and it is required to keep a safe vertical distance of 3–5 m between the antennas of different MNOs.

In this article, the target is to provide arguments for utilizing OneRAN on highways and in rural areas based on acquired measurement results from the practical networks of three different MNOs. It is assumed that the indoor service is provided with separate indoor solutions i.e., indoor Distributed Antenna System (DAS) or with other short-range radio technologies such as WiFi. The measurement data is processed and analyzed, and the acquired results highlight that the oneRAN infrastructure is technically a better solution for improving the user QoE i.e., user throughput, and the overall system performance while maximizing the cost-saving, especially on highways. The rest of the article is organized as follows. Section 2 presents background theory related to capacity, trunking efficiency and traffic flow. Section 3 explains the measurement setup and gives detail about the scenario and measurement configuration. In Sect. 4 the discussion and the analysis of the measurement results are given. Finally, Sect. 5 presents the concluding remarks.

## 2 Background theory

Mobile networks are based on the cellular concept that defines the basic architecture and layout of the mobile networks. Generally, the mobile networks are deployed with sectorized sites i.e., each base station site has  $N_r$  number of cells/sectors, where each cell has its own Transmitter (Tx) and Receiver (Rx) antenna [16]. Every cell is equipped with single or more RAN technologies such as GSM, UMTS, LTE, or 5G-NR, where each RAN technology has a different frequency of operation. The coverage or the service area of each radio access technology can be different, depending upon the link budget and the system configuration. Figure 1 illustrates the coverage of a heterogeneous network with a macro layer, micro layer, and femto layer.

### 2.1 Cell capacity and trunking gain concept

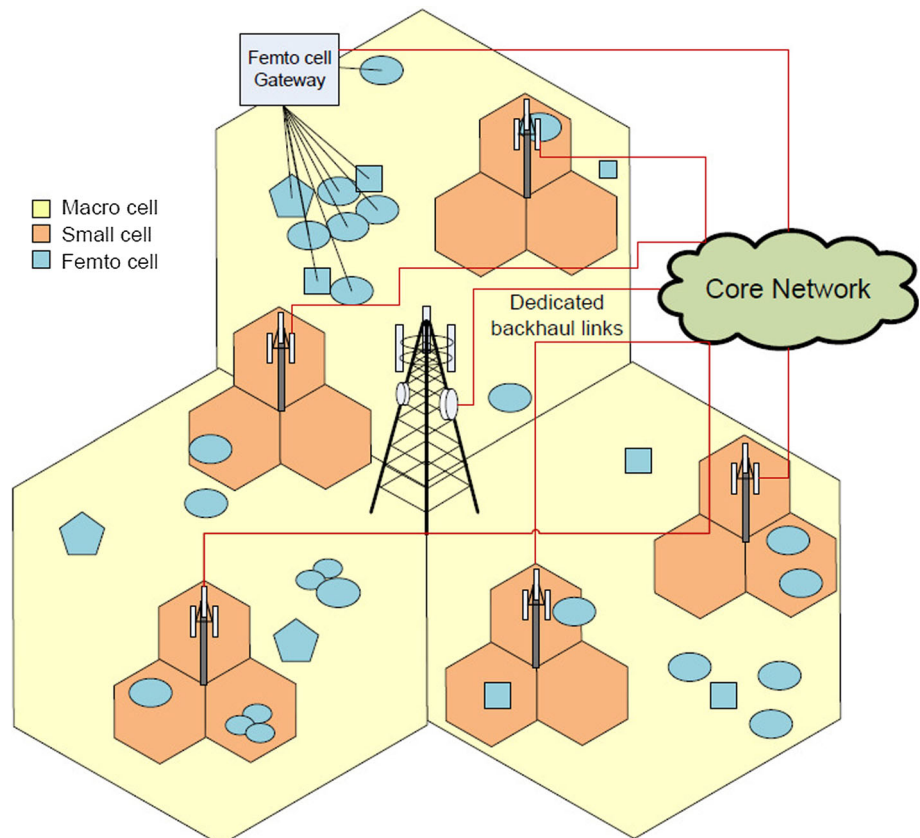
The amount of data is generally expressed in megabytes (*MBs*) or gigabytes (*GBs*), whereas the rate of data transfer is expressed in megabits per second (*Mbps*) or gigabits per second (*Gbps*). The data rate or the channel capacity relies on multiple factors e.g., multiple access schemes i.e., time, frequency, orthogonal frequency, and code division multiple access, utilization of Modulation and Coding Scheme

(MCS) i.e., On-Off keying, BPSK, QPSK, N-QAM, available system bandwidth, Signal to Interference Plus Noise Ratio (SINR), the number of antennas and the number of parallel bit streams, etc.

$$C_M = N_B B \log_2 \left( 1 + \frac{S}{I + N} \right) \quad (1)$$

Equation 1 shows the simple Shannon capacity formula, where  $C_M$  is the maximum achievable capacity expressed in *bps*,  $B$  is the system bandwidth expressed in hertz,  $N_B$  is the number of parallel bit streams,  $S$ ,  $I$ , and  $N$  are the received signal, interference and noise power, respectively [17]. It can be seen in Eq. (1) that the system capacity is directly proportional to the system bandwidth i.e., the larger the  $B$ , the higher will be the capacity. The frequency spectrum is a scarce and shared resource, and the frequency resource is shared at different levels. First, the frequency spectrum is shared among the operators, and in the case of frequency reuse factor  $1/k$ , the allocated band for each operator is divided among  $k$  cells [18]. In the case of Frequency Division Duplex (FDD) systems the frequency resources are further split among the active users. A portion of the frequency spectrum is reserved for guard bands, as guard bands are used for avoiding the intra-, and inter-system technology interference [18]. These guard bands may occupy tens of the percentage of

**Fig. 1** Illustration of heterogeneous network



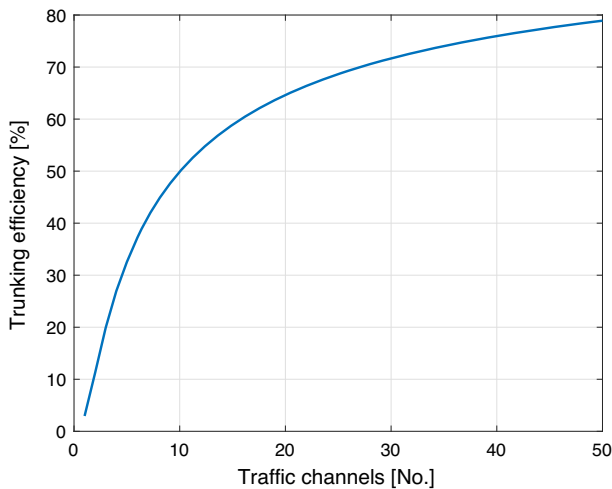


Fig. 2 Trunking efficiency

the total allocated spectrum given multiple mobile operators utilizing several technologies (3–4), and utilizing different bandwidths.

For efficient utilization of the resources the available capacity i.e., the frequency spectrum is shared among several users in a cell. In the case of a circuit-switched network, the Grade of Service (GoS) or the blocking probability for the given number of trunking channels and Erlangs of traffic is estimated through the Erlang-B equation [18]:

$$P_B = \frac{\frac{A^C}{C!}}{\sum_{k=0}^C \frac{A^k}{k!}}, \quad (2)$$

where  $P_B$  is the blocking probability,  $A$  is the traffic in Erlangs, and  $C$  is the number of trunking channels. The total traffic  $A$  equals  $\lambda T$ , where  $\lambda$  is the arrival rate of incoming calls and  $T$  is the average duration of each call [18]. The useful carried traffic is  $A(1 - P_B)$ , and that is always less than the total traffic  $A$ . The trunking efficiency of the carried traffic in percentage is given as:

$$\eta = \frac{A(1 - P_B)}{C} * 100 \quad (3)$$

Figure 2 shows the trunking efficiency of circuit-switched traffic as a function of available traffic channels assuming 2% of blocking probability. It can be seen in Fig. 2 that trunking efficiency increases with the increase in the number of available traffic channels in a resource pool.

Erlang-B formula assumes a Poisson arrival process with exponentially distributed call lengths. For a given  $C$  number of channels, the blocking probability  $P_B$  i.e., the probability that an arriving call finds all the channels occupied is given by the Erlang-B equation. It should be noted that Erlang-B formula is not valid if the calls arrive in bursts or the call

attempts are kept in the queue. Both of these happen in an emergency scenario, where many people try to place their call at the same time, and in case the line is busy they try again immediately. However, Erlang-B formula is a reasonable metric for analyzing circuit-switched telephony systems in regular conditions. Erlang-B does not provide any insight into the performance of data traffic. We will discuss that in more detail in Sect. 2B.

## 2.2 Traffic flow model

Let us consider the traffic seen by mobile operators at flow level in order to avoid the modeling of the complex interaction of packet-level mechanisms at short-time scales. Our focus is on long-term resource allocation while the short-term resource allocation processes are realized. The flow of the content is then viewed as a fluid that is transmitted as a continuous stream through the network. The transmission rate changes at flow arrivals and flow departures only. Flow arrivals happen when a new session starts. Hence, the flow arrivals can be modeled with Poisson arrivals even if the individual packet level arrivals are known not to follow that distribution. The flow level throughput has been derived for wireless networks in [19]:

$$\gamma_u = r_u(1 - \rho_m) \quad u \in \mathcal{U}_m \quad (4)$$

where  $\rho_m = \sum_{u \in \mathcal{U}_m} \frac{\lambda_u}{\sigma_u} r_u$  is the channel occupancy of load of the base station,  $\lambda_u$ ,  $\sigma_u$  and  $r_u$  are the arrival rate (flows/s), mean flow size (bits), and data rate of class  $u$  flows, and  $\mathcal{U}_m$  denotes the set of flows served by  $m^{th}$  operator. Let  $R_m = \sum_{u \in \mathcal{U}_m} r_u$  denote the peak maximum throughput of operator  $m$ . The total flow level throughput seen by the operator  $m$  is denoted by  $\Gamma_m$  and is given as:

$$\Gamma_m = \sum_{u \in \mathcal{U}_m} \gamma_u = R_m(1 - \rho_m) \quad (5)$$

We note that the data rate  $r_u \propto B$  and scales linearly with the bandwidth  $B$ , whereas, the load  $\rho \propto B^{-1}$  and scales inversely to the system bandwidth  $B$ . Hence, the flow level throughput seen by OneRAN system aggregating the resources of  $M$  MNOs with identical deployments is given as:

$$\Gamma = \sum_{m=1}^M M R_m \left( 1 - \frac{1}{M} \sum_m \rho_m \right) \quad (6)$$

or

$$\Gamma = M^2 \bar{R} (1 - \bar{\rho}) \quad (7)$$



where  $\bar{R}$  and  $\bar{\rho}$  denote the mean peak throughput and load across the operators. At the flow level, the aggregation of bandwidth over  $M$  operators with identical system bandwidth would yield a factor of  $M$  increase in the peak data rate, and a factor of  $M^2$  increase in the flow level throughput.

### 2.3 Cell border area performance criteria

In the case of mobility, the user moves across the coverage area of multiple cells, and while moving from one cell to another cell the handover procedure is performed so that there is no interruption in the usage of mobile service. The quality of the cell border area is of significant importance as it defines the performance of users with low throughput and QoS, and the signal quality at the cell border is also used as an input for the coverage planning of the mobile network [20]. The higher QoS requirement limits the coverage area of the cell, and thus more cells are required to cover the given area.

In cities, the users are non-homogeneously distributed, as most of the users are found in an indoor environment, hot spot areas, and mobile radio networks are generally capacity-limited in densely populated areas. Therefore, the required number of base stations mainly depends upon the capacity requirements of the network. However, in an indoor environment, the signal coverage is limited even after over 20 years of deployments. In densely populated city areas, there still exists the challenge of providing indoor coverage in old and new building types with outdoor BS. Due to Building Penetration Loss (BPL), the received signal level from outdoor BS is further attenuated in an indoor environment, especially, at higher frequencies and in new building types [21]. High O2I BPL results in lower signal strength, signal quality, and lower data rates. Therefore, it is foreseen that indoor service provision may require separate indoor solutions, or small base stations with a low transmit power, and antenna at a low height. Adding more base stations may not be a viable solution due to additional OPEX and CAPEX, and also the capacity gain of site densification decreases with the increase in the number of sites [22]. Closely placed base stations interfere with each other in dense urban areas, and the relative area spectral efficiency for outdoor users decreases with the increase in relative cell density [22].

Due to sparse population density in rural areas and around the highways, the coverage aspect appears as the limiting factor during the planning phase of the network. During normal days, the density of the users stays at an adequate level in rural areas and on highways. Whereas, in the case of mid or large-scale emergency scenarios, the need of using critical mobile communication arises. In emergency scenarios, a comparatively large number of users e.g., victims present in the vicinity of the affected area, police, fire brigades, and ambulances need to access mobile services. Hence, the need for critical communication should be considered while plan-

ning the minimum performance criteria of the commercial mobile networks, as authorities may need to use the commercial mobile networks for critical communications [23]. One of the targets of this study is to show that with the help of OneRAN solution, higher capacity can be conveniently provided for critical communication, specifically on highways.

### 3 Measurement setup and scenario

The measurement campaign for this research work was carried out in Finland, and different Key Performance Indicators (KPIs) of LTE i.e., Reference Signal Received Power (RSRP), RS Signal to Noise Ratio (RS-SNR), and application layer throughput in Downlink (DL) and Uplink (UL) direction were measured. The study of the network deployment on highways is the main focus of this work. Therefore, a measurement was performed on a highway from Iittala city to the entrance of Tampere city, and the measurement route is shown by the blue line in Fig. 3. It should be noted that the highway is mainly dominated by open fields. The performance of three commercial MNOs of Finland, those are named MNO-A, MNO-B, and MNO-C is measured and compared in this article. It was found that each operator has 20MHz and 10MHz bandwidth at LTE1800 and LTE800 bands, respectively. All MNOs were operating in LTE FDD mode i.e., a separate band for UL and DL. The measurement data is acquired by using a commercial NEMO outdoor measurement tool installed on the laptop. Three LTE HUAWEI modems equipped with the SIM card of each MNO are connected to the laptop, and the GPS device is used to acquire the position data. It is important to highlight here that there were no peak throughput or data usage restrictions i.e., unlimited data usage was allowed on the SIM cards used in this mea-

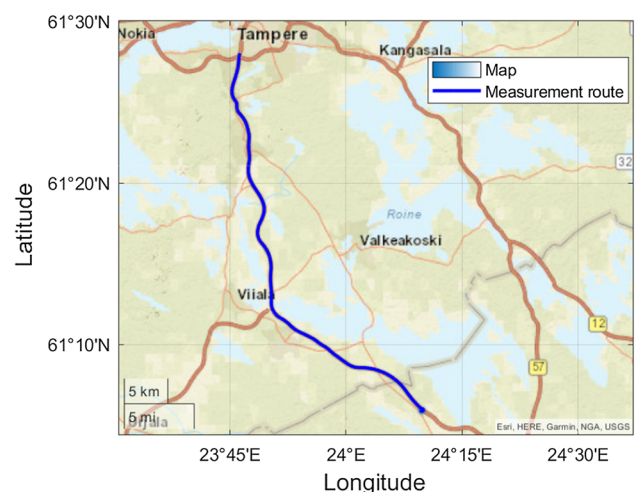


Fig. 3 Measurement route

surement. Three bands of LTE i.e., LTE800, LTE1800, and LTE2600 were supported by LTE modems, and they were locked to the LTE system only i.e., they are not allowed to camp on any other available cellular technology. The LTE modems used in this measurement campaign were capable of supporting maximum 64QAM Modulation and Coding Scheme (MCS) in both UL and DL directions. During the measurement, LTE modems were continuously measuring the RSRP and RS-SNR and were sending the measurement reports to the serving base station. It is important to mention here that during the measurement, LTE modems were downloading and uploading the data mutually exclusively i.e., modems were actively downloading the data from the server for 60 sec, and then uploading the data for 20 sec on repeat. Later, NEMO analyze tool and MATLAB tool are used to extract and process the measurement data.

## 4 Results and discussion

This section presents the measurement results and discusses the arguments for OneRAN infrastructure deployment over the highways. The first metric considered for the analysis is the reference signal received power, and Figure 4 shows the Cumulative Distribution Functions (CDFs) of measured RSRP over the measurement route for three different MNOs. The RSRP of a LTE cell is generally used as a coverage metric. It is important to mention here that all three MNOs had continuous LTE connectivity over the measurement route shown in Fig. 3, and therefore the CDFs of RSRP for different MNOs shown in Fig. 4 can be directly compared. The exact information about the location of the BS is not known to us, as we were only measuring few performance metrics along the measurement route without prior knowledge about the radio parameters used at the BS. It can be seen in Fig. 4, that the best mean RSRP level of around  $-88$  dBm is provided by MNO-B, whereas the mean RSRP level of around  $-91$  dBm and  $-99$  dBm is obtained for MNO-A and MNO-C, respectively. The cell border areas are critical and should be minimized. In the case of target RSRP of  $-105$  dBm as a coverage threshold for network planning, it can be seen that around 15%, 12%, and 32% of the measurement samples of MNO-A, MNO-B, and MNO-C, respectively, are below the coverage threshold i.e., they are in coverage outage.

Figure 5 shows the utilization of LTE800 and LTE1800 band, and Figure 6 shows the number of primary serving LTE cells for three considered MNOs over the measurement route. It is interesting to find that different MNOs have different strategies for providing LTE coverage over the highway, and a direct relationship is found between the utilization of the LTE band and the number of LTE cells. Interestingly, it is found that MNO-B provided the LTE coverage over the whole measurement route through the LTE800 layer only, and deployed

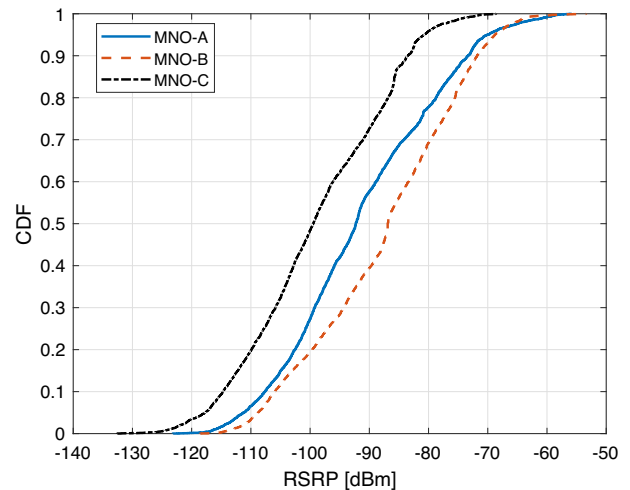


Fig. 4 CDF of LTE reference signal received power of different MNOs

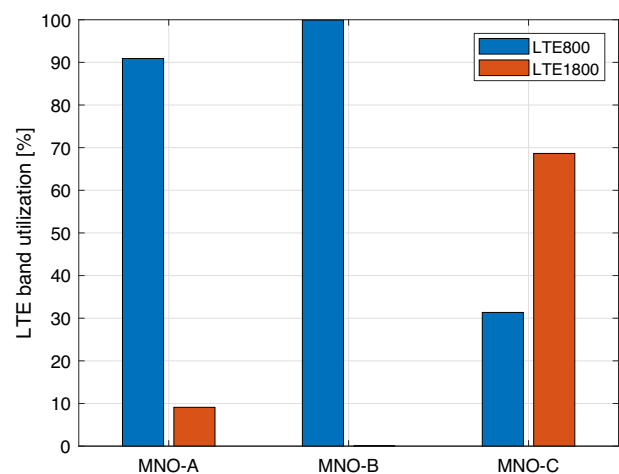
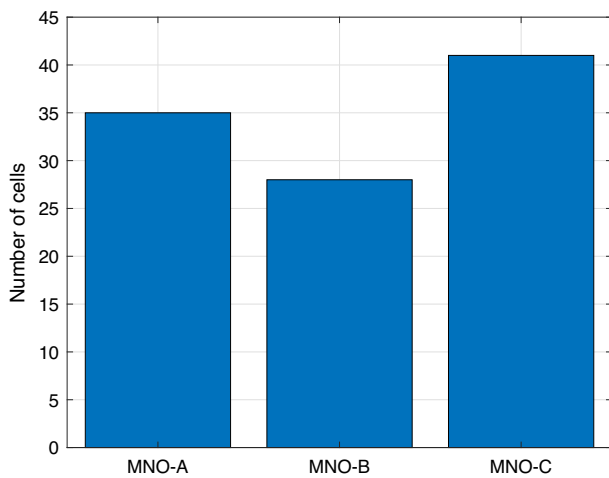


Fig. 5 LTE serving band utilization for different MNOs

the least number of LTE cells i.e., 28, and yet provides the best mean RSRP level among all three MNOs. Whereas, MNO-C mainly utilizes the LTE1800 layer i.e., almost 69% of the measurement route is covered with LTE1800 as the primary layer over the highway while using 41 primary LTE cells i.e., around 46% more number of cells compared with MNO-B. It should be noted that although MNO-C has deployed 46% more number of cells compared with MNO-B, however, due to the 69% usage of LTE1800 layer the mean RSRP of MNO-C is almost 11 dB lower as compared with MNO-B. Whereas, MNO-A has 91% LTE800 utilization and has deployed 35 cells to cover the measurement route. These results clearly show that LTE800 is mainly utilized by two of the MNOs, and is a good choice in terms of CAPEX and OPEX saving, and for providing better coverage with a lesser amount of cells. It is interesting to find that MNO-C has deployed almost the double number of LTE1800 cells to match the

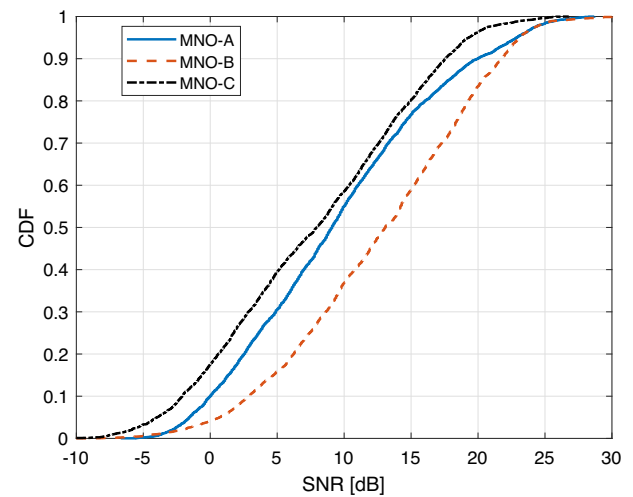


**Fig. 6** Number of serving LTE cells across the measurement route for different MNO

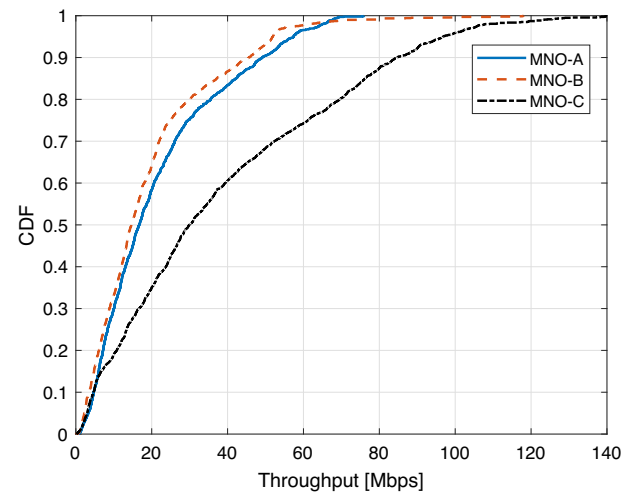
coverage of the LTE800 cell, and still MNO-C is not able to attain the coverage equivalent to the MNO-B. Moreover, in the case of OneRAN approach, the site grid of the best performing operator can be used i.e., MNO-B site grid with LTE800 deployment, and the frequency resources from multiple MNOs are pooled together at a single mast. In this way, the same level of coverage can be achieved as the best performing operator, while it efficiently utilizes the resources and helps in saving the cost.

Now, we are discussing the quality-related performance metric i.e., downlink RS-SNR. Figure 7 shows the CDFs of measured downlink RS-SNR over the measurement route for three different MNOs. The RS-SNR is directly proportional to RSRP, and it can be seen in Fig. 7 that MNO-B provides the best mean RS-SNR of around 12.6 dB among all three MNOs, whereas, the mean RS-SNR of around 9.5 dB and 7.8 dB is obtained for MNO-A and MNO-C, respectively. Earlier, we found the coverage outage with respect to the RSRP threshold, similarly, we can also define the service outage with respect to the downlink RS-SNR target threshold. The obtained measurement results show that for the RS-SNR threshold of 5 dB, there are around 30%, 16%, and 39% of the measurement samples below the service outage threshold i.e., they are in service outage, for MNO-A, MNO-B, and MNO-C, respectively. These results reveal the fact that there are large areas over the highways which are not fulfilling the coverage and service requirements. It also highlights that even the MNO with the highest mean SNR value i.e., MNO-B is not completely meeting the coverage and service requirements and yet requires more number of cells, though MNO-B utilized only LTE800 layer over the whole measurement route on the highway.

Figures 8 and 9 show the CDFs of measured downlink and uplink application layer throughput over the measurement route, respectively. Throughput of LTE system depends



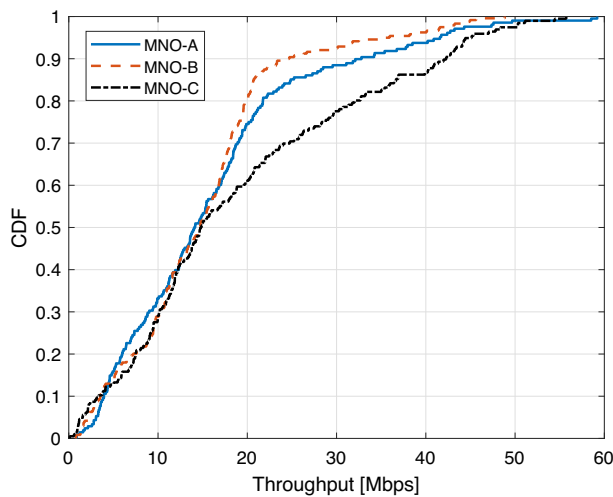
**Fig. 7** CDF of LTE reference signal SNR of different MNOs



**Fig. 8** CDF of downlink application layer throughput of different MNOs

upon numerous factors and variables e.g., the bandwidth of the system, SINR, MCS utilization, Physical Resource Block (PRB) utilization, MCS utilization, Physical Resource Block (PRB) utilization, number of users per Transmission Time Interval (TTI), number of transmit bitstreams, number of cells in a system, number of active users in a cell, and Carrier Aggregation (CA), etc. Therefore, it can be seen in Figs. 8 and 9 that even though the MNO-C had the lowest value of mean RSRP and mean RS-SNR, yet the MNO-C provides the highest mean DL and UL application layer throughput of around 38.9 Mbps and 19.2 Mbps, respectively, due to the heavy utilization of LTE1800 band over the measurement route. It is good to remind here that the LTE modems used in this measurement support 64QAM as the highest MCS. It should be noted here that LTE800 has 10 MHz bandwidth, whereas LTE1800 has 20 MHz bandwidth. Similarly, MNO-A and MNO-B offer the mean application layer throughput of



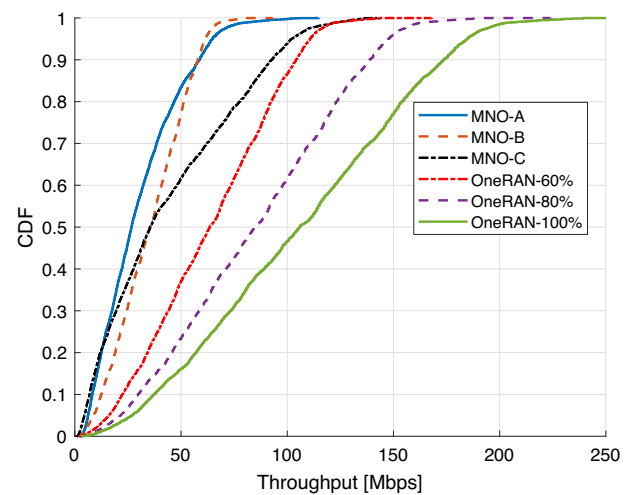


**Fig. 9** CDF of uplink application layer throughput of different MNOs

around 21.7 Mbps and 19.4 Mbps, respectively. The detailed analysis of the measurement data showed that the PRB utilization was not 100% during the whole measurement route, and was found different for three MNOs, and was changing randomly throughout the measurement route. The main difference in UL and DL throughput is due to the utilization of Rank 2 in DL, whereas UL was limited to Rank 1 only, as Rank defines the number of parallel bitstreams. The measurement data also revealed that MCS with an index 28 was used as the highest MCS in the DL direction, whereas in UL the highest MCS was limited to MCS index 24 for all MNOs. Therefore, higher throughput values are achieved in DL as compared with UL in the case of all MNOs.

In order to solely highlight the gain of OneRAN approach, we have computed the application layer throughput for three mobile operators using a modified form of Shannon capacity formula given as  $T = N_B B \log_2(1 + SNR)(1 - \alpha)\zeta$ , where  $N_B$  is the number of bitstreams,  $B$  is the bandwidth,  $\alpha$  is the control channel overhead, and  $\zeta$  is the spectrum utilization or in case of LTE it is PRB utilization. We have assumed a single bitstream  $N_B = 1$ , and  $\alpha = 0.2$  i.e., 20% control channel overhead, and  $B = 10$  MHz and  $B = 20$  MHz for LTE800 and LTE1800 samples, respectively, and  $\zeta = 1$  i.e., all PRBs are allocated/utilized. We have considered the RS-SNR of MNO-B as a basis for OneRAN, as MNO-B has utilized the LTE800 band only for providing coverage over the highway, and provides the best RS-SNR results among all considered MNOs. In addition, in the case of OneRAN the available bandwidth is  $B = 30$  MHz i.e., the sum of 10 MHz from each operator.

Figure 10 shows the CDF of maximum achievable application layer throughput for three considered MNOs along with OneRAN considering 60%, 80%, and 100% PRBs utilization. It can be clearly seen in Fig. 10 that the throughput is significantly improved by pooling the spectrum of



**Fig. 10** CDF of max theoretical application layer throughput in DL direction

different operators and utilizing it via centralized operation. It is evident in Fig. 10 that with 100% spectrum utilization the mean throughput of OneRAN network is remarkably higher compared with the mean throughput of any of the individual MNO, even 60% spectrum utilization provides a much higher mean throughput values compared with the individual MNO performance. It can be seen in Fig. 10 that with OneRAN the peak throughput or system throughput is increased by the factor  $M=3$  in our case, as we have considered three MNOs with equal spectrum, however, the flow level throughput is expected to increase by 9 times as shown by flow level throughput model given in Eq. (7).

It is highlighted and discussed earlier that the cell border areas i.e., low throughput and RS-SNR regions are critical, and we have found from the results presented in Fig. 10 that OneRAN approach not only improves the maximum achievable user/system throughput or mean throughput values rather it also improves the user experience i.e., user throughput, in bad areas. Earlier in this article, the coverage and service threshold is defined with respect to RSRP and RS-SNR, respectively. Here, the minimum application layer throughput required at the cell border area is set to 20 Mbps for smooth provision of services, especially critical mission services. With respect to the given application layer throughput threshold, Figure 10 shows that 36%, 22%, and 31% of the throughput samples are below the targeted throughput threshold for MNO-A, MNO-B, and MNO-C, respectively. It shows that fairly a large area over the highway is not fulfilling the targeted data rate requirement. Whereas OneRAN improves the throughput of the users with low RS-SNR, the percentage of samples not meeting the throughput requirement is brought down to 8%, 4.5%, and 3% with 60%, 80%, and 100% spectrum utilization, respectively. These results highlight that in a commercial cellular network, it is imprac-

tical to completely get rid of RS-SNR regions, however, the approach of OneRAN is found considerably helpful for the case of critical mission type communication in bad quality areas. Therefore, OneRAN approach can be considered as one effective solution for efficiently fulfilling the requirement of critical communication in commercial mobile networks.

## 5 Conclusion

Cellular networks are drifting towards data-dominated traffic from circuit-switched traffic, and in the future, it is expected to support a different variety of public safety communication services. The economical aspects of commercial cellular networks advocate the sharing of radio and infrastructure resources among the MNOs at various levels. It is already established fact and was supported by Erlang based traffic model and flow traffic model that the frequency resources in the same pool give better spectrum efficiency than having those resources in separate pools. In this paper, technical arguments are presented for the deployment of OneRAN infrastructure in rural areas or over the highway areas, as the focus of this work was outdoor wide area coverage on highways. The measurement data from three commercial MNOs using LTE technology was collected over a highway from Iittala to Tampere city in Finland, and several KPIs were measured. The measurement data revealed that different strategies were adopted by considered MNOs for providing coverage along the measurement route. MNO-B solely used LTE1800 for providing coverage. The analysis of coverage-related KPIs highlighted the importance of using a lower frequency band for coverage. It was found that although MNO-C has deployed 46% more number of LTE cells compared with MNO-B, however, due to the 69% usage of LTE1800 layer the mean RSRP of MNO-C is almost 11 dB lower as compared with MNO-B. Considering the RS-SNR, a theoretical application layer throughput for three considered MNOs was computed along the measurement route. For the target application-layer throughput of 20 Mbps, 36%, 22%, and 31% of the samples were found below the target for MNO-A, MNO-B, and MNO-C, respectively. In the case of OneRAN infrastructure, the overall system/user throughput, especially the critical cell edge user throughput is improved by pooling and utilizing the spectrum of different MNOs via a centralized approach in an economical way. Interestingly, it was found that the percentage of samples not meeting the throughput requirement is brought down to 8%, 4.5%, and 3% with OneRAN approach considering 60%, 80%, and 100% spectrum utilization, respectively. With OneRAN, a chunk of the spectrum that was used as a guard band between multiple MNOs was made available for data users. It was found that OneRAN infrastructure is a technically easy solution to cut operational and capital costs, and a

positive step towards critical communication to support public safety needs over a commercial cellular network.

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**Data Availability** The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Conflict of interest** The authors have not disclosed any competing interest.

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**Muhammad Usman Sheikh** was born in Rawalpindi, Pakistan, in 1983. He received his B.Sc. degree in Electrical Engineering from CIIT Islamabad, Pakistan in 2006. He received his M.Sc. and D.Sc. (Tech) degrees from Tampere University of Technology (TUT), Finland in 2009 and 2014, respectively. Currently, he is working as a post doctoral researcher at Aalto University, Finland where he is focusing on the future generations of cellular networks. He is actively involved in numerous research and development projects. He has more than 8 years of experience from different radio network planning and optimization projects. His general interests include network planning and optimization, future mobile technologies, 3D ray tracing, advanced antennas and novel and innovative cellular concepts. He is the author of several international journal articles, conference papers, and book chapters and he is a senior IEEE member.



**Jukka Lempiäinen** was born in Helsinki, Finland, in 1968. He received his M.Sc., Lic. Tech, D.Sc.(Tech) all in Electrical Engineering, from Helsinki University of Technology, Espoo, Finland, in 1993, 1998 and 1999, respectively. He is a Senior Partner and the President of European Communications Engineering Ltd. He has altogether more than twenty years’ experience in GSM based mobile network planning and consulting. For his entire industrial career, he has been concentrating on the radio planning of cellular networks. He has been also a full Professor since 2001 at Tampere University, Finland, where he is Head of Laboratory of Radio Network Planning (RNP) at Department of Communications Engineering. He is the author of two international books, three book chapters, several tens of journals and conference papers, and he holds four patents. He is a senior IEEE member and a URSI national board member, Finland.



**Riku Jäntti** is a Full Professor of Communications Engineering and the head of the department of Communications and Networking at Aalto University School of Electrical Engineering, Finland. He received his M.Sc (with distinction) in Electrical Engineering in 1997 and D.Sc (with distinction) in Automation and Systems Technology in 2001, both from Helsinki University of Technology (TKK). Prior to joining Aalto (formerly known as TKK) in August 2006, he was professor

pro tem at the Department of Computer Science, University of Vaasa. Prof. Jäntti is a senior member of IEEE and associate editor of IEEE Transactions on Vehicular Technology. The research interests of Prof. Jäntti include radio resource control and optimization for machine type communications, Cloud based radio access networks, RF Inference, and quantum communications.