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Article

Co-channel Interference Evaluation for Coexisting Public-Safety Networks and 5G Commercial Network

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Abstract: In this paper, we deploy the public-safety network which is overlapped with 5th-gerneration (5G) commercial network. Note that 5G commercial networks is assumed to operate on 700 MHz frequency band to observe the effect on public-safety network. Our main focus is to evaluate the interference on public-safety user equipment (UEs) (which are distributed outside the tunnel) from the 5G base stations (gNBs) (which are deployed inside the tunnel). Considering the aforementioned scenario, we compare it with the coexisting scenario of public-safety, and railway networks. In second scenario, we deploy the railway eNBs without tunnel and evaluate the co-channel interference on public-safety UEs. Radio access network sharing is an important candidate to consider for coexisting next-generation wireless communication networks. For the coexisting LTE networks (public safety verses railway) and 5G commercial network, which are assumed to utilize the same spectrum, active radio access network sharing should be considered. In this chapter, we evaluate the co-channel interference on two types of scenarios, i.e., (i) coexisting public-safety and railway networks, (ii) coexisting public-safety and 5G commercial networks. Moreover, we compare these scenarios by considering the radio access network sharing and non-radio access network sharing by public-safety UEs to evaluate the co-channel interference. The system-level simulations are performed to evaluate the UE average throughput, UE received interference, and UE outage probability. By activating the radio access network sharing, some improvement in throughput, and reduction in interference and outage performances, can be achieved. Simulation results validates the effectiveness of radio access network sharing for coexisting public-safety networks and 5G commercial networks.

Keywords: 5G, public-safety network, railway network, 5G commercial network.

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1. Introduction

Governmental authorities have committed to using LTE as the foundational technology for the next-generation of public safety networks as a result of the great success of LTE/LTE-Advanced to become wireless communications standards for the delivery of broadband internet data and high definition speech. Relying on mission-critical push-to-talk services, public-safety applications and conventional commercial applications (for utility companies and railroads, for example) can both be used [1-5]. Instead of using several devices, first responders can easily combine all mobile voice and internet data applications with mission-critical push-to-talk. It is also possible to implement public-safety elements (such as situational awareness in intelligent operating systems or video connections like remote monitoring). Railway, or mission-critical communications for trains, is already implemented, albeit on a small scale.

With new mission-critical railway terminals installed on its high-speed railway network, various countries leading in the railway industry. The railway network supports maintenance and operational services on a high-speed, commercial railroad line that travels at up to 250 km/h and satisfies the mission-critical needs of the rail network. Utilizing an LTE router (which gathers signals sent from multiple devices implemented on a ship to safety centers on soil) and radio access network sharing (which enables two or maybe more network carriers to communicate with their wireless infrastructure), maritime communication technology makes it possible for video communication to occur among ships at ocean and land-based safety centers [6-10].

In order for vital communication to evolve globally and for next-generation public safety systems to exist. The public safety network gains notoriety as a result of the rapid advancement of broadband technology and the use of LTE solutions in the vital communications. Therefore, the goal is to come up with solutions to meet the rising need for data-rich services (e.g., multimedia connections, live video streaming, and data collection). The third-generation partnership technology is supported by the public-safety solution, which consists of a multi-mode advanced radio, recording device, remote radio unit, as well as other broadband devices and offers cutting-edge data and video services for crucial operations. It can give the extensive network coverage and satisfies the public safety minimum standards for a variety of situations (such as mega events, city accidents, city patrol, mobile offices, etc.) [11-13].

The railway solutions of the new generations include a control panel, servers, an LTE network, a train's on-board communication system, and a multi-mode advanced radio that supports voice, data, and video communication between trains and with other entities like operation control centers and waysides. Numerous published research publications and active initiatives have concentrated on managing interference on a single network while offering effective radio resource management algorithms, but without taking into account more complex scenarios like the coexisting two or three networks. Since the current mobile communication systems are transitioning to 5th-generation (5G) systems, which emphasize and demand the same user experience anywhere, anytime, this is a must [14-17].

Considering the abovementioned cases, this paper focuses on the coexisting of two LTE networks (such as coexisting public-safety and railway networks, and co-existence of public-safety and 5G major networks) and three networks (public safety, and railway networks), and employs the effective mission critical user priority-based resource scheduling schemes. However, there are a number of problems that need to be resolved as a result of the coexistence of public safety networks, including co-channel interference, mission-critical user needs, quality-of-service (QoS) priority, etc. Therefore, co-channel interference management and user priority-based resource allocation for mission-critical applications both demand serious consideration and insightful research [17-20]. Many contributions in the literature have been made to interference management and resource allocation [21 – 38]. The user-service priority for the following public-safety, and railway networks is defined. The mission critical and non-MC operation priorities, as well as the guarantee bit-rate (GBR) / non-GBR capacity are categories.

The main contribution of this paper is given below:

• We evaluate the co-channel interference for coexisting public-safety, and railway networks;

• We also investigate the performance of coexisting public-safety and 5G commercial networks;

• We compare these scenarios by considering the radio access network sharing and non-radio access network sharing by public-safety users to evaluate the co-channel interference.

The rest of this article is structured as follows: The system model for co-existing public-safety, and railway network in detail in Section 2. In Section 3, we present analysis on co-channel interference for coexisting LTE networks. Then, we describe the simulation findings in Section 4 and we conclude this paper in Section 5.

2. System model for coexisting public safety (public-safety verses railway) and 5G commercial network

a) Network layout

We consider 1-tier of coexisting public-safety and 5G commercial networks in which center cell is the region of interest. The 5G gNBs are deployed inside the tunnel within the center cell. The tunnel is lied at the edge of the two sectors of the center cell. The public-safety user equipment (UEs) are distributed randomly within the center cell except the area covered by the tunnel. The public-safety eNB is based on three sectors and deploy forty UEs in each sector of the center cell. We assume that no user is deployed in the 1-tier as well as inside the tunnel, as shown in Figure. 1. It means that 1-tier eNBs are generating the interference to the center cell users. Hence, center cell is considered as the region of interest for the coexisting public-safety and 5G commercial networks. Typically, the 5G gNBs are based on tri-sectors but we assume two sectors for each 5G gNB site to support the coverage over the tunnel.

b) Channel model

Typically, channel model is based on the following prominent parameters, i.e., pathloss, shadowing, and fast fading. In this chapter, rural macro pathloss model is considered for both public-safety eNBs and 5G commercial gNBs [44]. Note that 20 dB extra penetration loss is added for the 5G gNBs due to tunnel loss. The rural path loss model is written as follows:

$$\begin{aligned} Pathloss(L) = {} & 69.55 + 26.16\log_{10}(F) - 13.82\log_{10}(S_h) \\ & + \left[44.9 - 6.55\log_{10}(S_h)\right]\log_{10}(L) - 4.78\left(\log_{10}(F)\right)^2 \\ & + 18.33\log_{10}(F) \; - \; 40.94 \end{aligned} \tag{1}$$

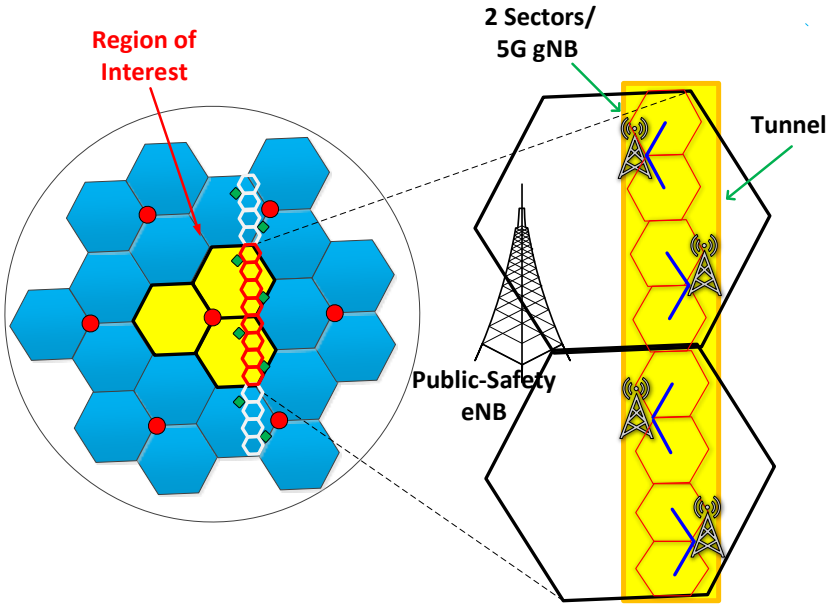


Figure. 1 Network deployment of coexisting public-safety and 5G commercial networks.

where L, S_h, and F represent the distance between eNB and UE, antenna height of eNB, and carrier frequency, respectively.

We consider the log-normal shadowing model with 0 dB mean and 6 dB standard deviation [45]. We utilized the D1 and A2 scenarios of Winner II channel model to produce the fast fading for public-safety network and 5G commercial network, respectively [25]. 3-dimention antenna pattern consists horizontal and vertical cuts of antenna gain [24], which is written as:

$$\begin{cases} \mathrm{A_V}\left(\theta_V\right) = \min\left[12\left(\dfrac{\theta_V - \theta_{etilt}}{\theta_{3dB}}\right)^2, \mathrm{SLA}_v\right] \\ \mathrm{A_H}\left(\varphi_H\right) = \min\left[12\left(\dfrac{\varphi_H}{\varphi_{3dB}}\right)^2, \mathrm{A_m}\right] \end{cases} \tag{2}$$

where $\mathrm{A_V}$, $\mathrm{A_H}$, θ_V, and φ_H represent the vertical cut, horizontal cut, angles between the sector antenna direction, base station to user transmission path direction along the vertical and horizontal planes, respectively. θ_{3dB}, φ_{3dB}, SLA_v, and $\mathrm{A_m}$ are the 3 dB vertical and vertical beam widths, side lobe vertical attenuation, backward attenuation, respectively. The following equation is used to compute the antenna gain:

$$AntennaGain = \max_AntennaGain - \min\left[\mathrm{A_V}\left(\theta_V\right) + \mathrm{A_H}\left(\varphi_H\right), A_m\right] \tag{3}$$

Typical values for these parameters are: $\varphi_{3dB} = 70^\circ$, $A_m = 20dB$, $\theta_{3dB} = 10^\circ$ $\mathrm{SLA_V} = 20\mathrm{dB}$, and $\theta_{\mathrm{etilt}} = \left(0^\circ, 15^\circ\right)$.

3. Analysis on co-channel interference for coexisting LTE networks (public safety verses

railway) and 5G commercial network

a. Non- radio access network sharing scenario

According to Fig. 2, the coexisting scenario elaborates that public-safety UE are unable to get the networks access from the 5G gNBs due to non- radio access network sharing. Though 5G gNBs are lied inside the tunnel and covering the small area which is overlapped with public-safety network, but still they can provide strong enough signal power to the outside surrounding public-safety UEs which are deployed very close to the tunnel. The aforementioned scenario is slightly similar to the coexisting macro cells and closed subscriber group femto cells, where femto cells provide the network access to specific number of users. However, both public-safety and 5G gNBs are high power nodes but with limited coverage of 5G gNB along the tunnel causes a sever co-channel interference to the public-safety UEs, especially when they are very close to the tunnel. From the Figure. 2, the public-safety UEs (B and C) are receiving very low desired signal power because they are positioned at the edge of public-safety coverage and due to very close to the tunnel, they are getting strong enough interfering signal from the 5G gNBs.

b. Radio access network sharing scenario

In this case, 5G gNBs enhance the cell edge coverage of public-safety network by active radio access network sharing. The 5G gNBs allow the network access to the public-safety users instead of giving the high interference. This accomplishes will reduce co-channel interference for the coexisting public-safety and 5G commercial networks. Moreover, the resource utilization of 5G gNBs is boosted under the radio access network sharing environment, which impacts the improvement in overall system performance.

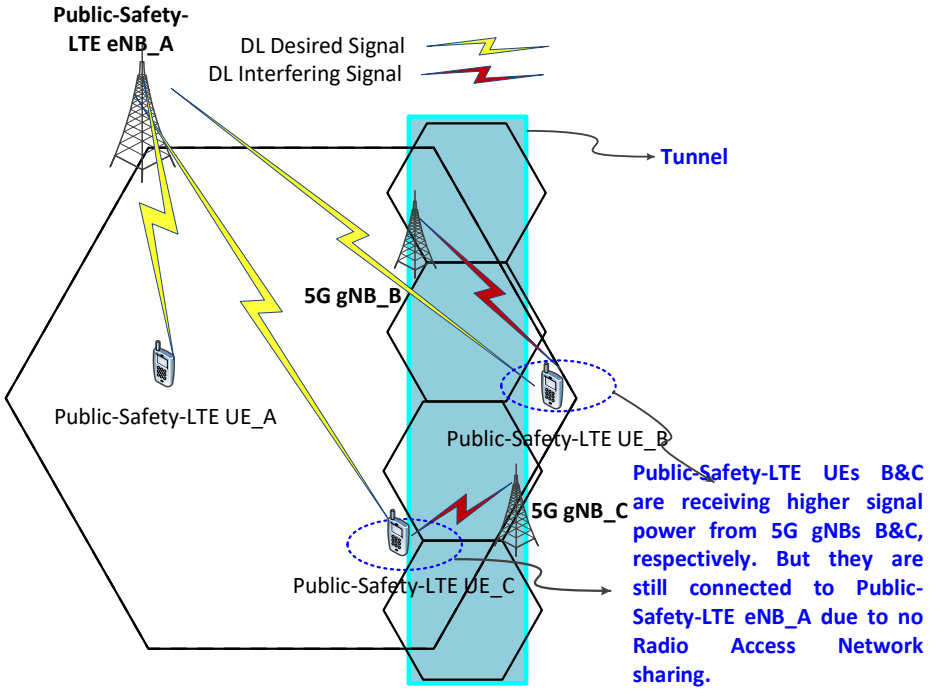


Figure. 2 Coexisting deployment for Public-Safety-LTE and 5G commercial networks without radio access network sharing.

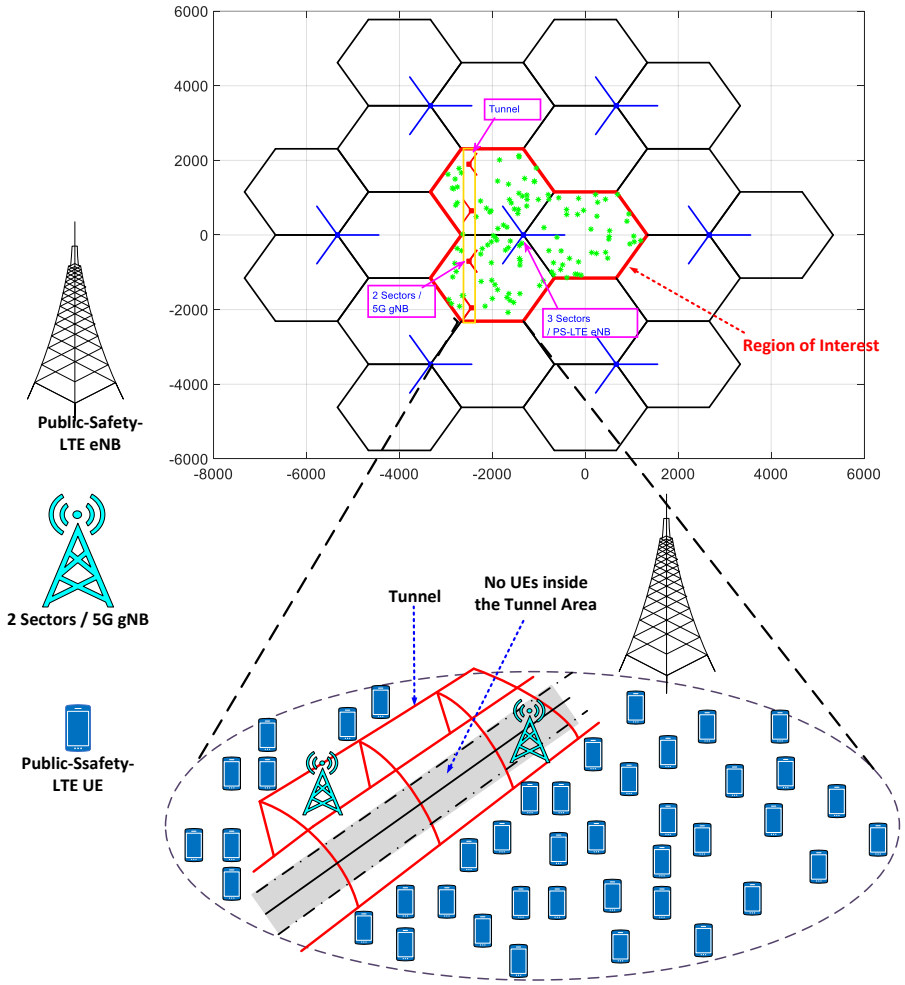


Figure. 3 Coexisting deployment of public-safety-LTE and 5G commercial networks under the radio access network sharing scenario.

However, we deploy the 5G gNBs inside the tunnel and no UEs are considered as well, but still the signal power of 5G gNBs is strong enough after the tunnel wall loss for the surrounding public-safety-LTE users which exist close to the tunnel and edge of the public-safety-LTE network. Fig. 3 shows the network deployment of coexisting public-safety-LTE and 5G commercial networks under the radio access network sharing scenario. From the Figure. 3, it can be clearly seen that no public-safety-LTE UEs are existed within the tunnel area.

4. Simulation Results and Discussions

The system-level simulations are performed to evaluate the performance of coexisting LTE networks (public safety verses railway) and 5G commercial network by comparing the non- radio access network sharing and active radio access network sharing scenarios. Our main concern is to prove that public-safety-LTE users can get some benefit of active radio access network sharing even 5G gNBs are lied inside the tunnel. The downlink system is considered, and simulations are performed under 1-tier cellular layout. Instead of using full buffer, we consider the practical traffic models such voice over IP (VoIP) and Video in our scenario. The prominent simulation parameters for the coexisting public-safety-LTE and 5G commercial networks are listed in Table 1. We evaluate the performance of coexisting LTE networks (public safety verses railway) and 5G commercial network by considering the important

performance indexes such as UE average throughput, UE received interference, and UE outage probability. We activate the 5G gNBs radio access network sharing for public-safety-LTE UEs and check that how much public-safety-LTE UEs can get the benefit of radio access network sharing. We compare the performances by employing the radio access network sharing and non- radio access network sharing for the overlapped LTE networks (public safety verses railway) and 5G commercial network.

Table 1: System-level simulation parameters for the Public-Safety-LTE and 5G network.

Parameters	Values
Carrier Frequency	778 MHz
Bandwidth	10 MHz
No. of Public-Safety-LTE eNBs	21 Sectors (1-tier, 7 Sites) [Only 3 Inner Sectors in the ROI.]
No. of 5G gNBs	Maximum 2 gNBs/Sector
Inter-eNB Distance	Public-Safety-LTE eNBs : 4 km, 5G gNBs : 1 km
No. of Public-Safety -LTE UEs	40 UEs / Sector Total : 120 UEs
Transmission Power	Public-Safety-LTE : 46 dBm, 5G : 43 dBm
Path Loss Model	Public-Safety-LTE : Rural Macro 5G : Rural Macro + 20 dB (Tunnel Loss)
Shadowing	Log-normal Distribution
Fast Fading	Public-Safety-LTE : Winner II (D1-Rural Macro) 5G : Winner II (A2- Indoor to Outdoor)
UE Mobility	Public-Safety-LTE UE : 3 Km/h
Transmission Modes	SISO (1x1)
Traffic Models	Public-Safety-LTE : VoIP (80 %), Video (20 %)
Scheduling	Proportional Fair Traffic

UE average throughput: The throughput equation is as follows:

$$UE_j_Average\ Throughput = \frac{TB}{Accounted_TTIs * TTI_Time}\ Mbps \quad (4)$$

where TB is the total bits for UE_j, Accounted_TTIs are the maximum number of TTIs in which

RBs assigned to UE_j, and $\mathrm{TTI_Time}$ is 10 msec. In this chapter, UE average throughput performance is compared at 50 % of CDF. From the Figure. 4(a), at 50 % of CDF, the numbers for UE average throughput are 0.81 Mbps, 0.38 Mbps, 1.18 Mbps, and 1.34 Mbps for the cases (Public-Safety -LTE + LTE-railway) without radio access network sharing, (Public-Safety-LTE + 5G) without radio access network sharing, (Public-Safety-LTE + LTE-railway) with radio access network sharing, and (Public-Safety-LTE + 5G) with radio access network sharing, respectively. Hence, there is significant throughput improvement in radio access network sharing cases than without radio access network sharing cases. Moreover, it can be observed that (Public-Safety-LTE + 5G) cases has better throughput at some points due to less interfering power (wall penetration) from the 5G gNBs, but the maximum throughput is less than (Public-Safety-LTE + LTE-railway) cases because LTE-railway cases have one more user. In (Public-Safety-LTE + 5G) cases, there is very small performance difference between radio access network sharing and without radio access network sharing scenarios because Public-Safety-LTE UEs cannot achieve much benefit of radio access network sharing due to tunnel wall loss.

UE received interference: the equation for UE received interference can be written as:

$$I_i = \sum_{j \neq i,\ k \neq i} G_{j,k}^{N} P_{j,k}^{N} + \eta \tag{5}$$

where I_i is aggregate interference received from all neighbor public-safety-LTE eNB and 5G gNBs except the serving base station. $G_{j,k}^{N}$ is the channel gain between the surrounding public-safety-LTE eNBs and 5G gNBs to their users *j* and *k* on PRBs, respectively, $P_{j,k}^{N}$ is the transmit power from the surrounding public-safety-LTE eNBs and 5G gNBs to their *j* and *k* on PRBs, respectively, and η is thermal noise per PRB. From the Figure. 4(b), it can be clearly seen that radio access network sharing cases has less interference than without radio access network sharing cases. In (public-safety-LTE + 5G) cases, public-safety-LTE users are receiving less interference from the 5G gNBs (due to less interfering power because of wall penetration). In (public-safety-LTE + 5G) cases, there is very small performance difference between radio access network sharing and without radio access network sharing scenarios because public-safety-LTE UEs cannot achieve much benefit of radio access network sharing due to tunnel wall loss.

UE outage probability: the UE outage probability equation is:

$$P(\text{outage}) = 1 - P(SINR > SINR_Threshold) \tag{6}$$

where $P(SINR > SINR_Threshold)$ is the probability when UE received SINR is higher than the SINR threshold, then UEs are not in outage.

Figure. 4(c) illustrated that radio access network sharing cases has less outage than without radio access network sharing cases. In (Public-Safety-LTE + 5G) cases, public-safety-LTE UEs has less outage because 5G gNBs are providing less interference due to less interfering power (wall penetration loss). In (public-safety-LTE + 5G) cases, there is very small performance difference between radio access network sharing and without radio access network sharing because public-safety-LTE users cannot achieve much benefit of radio access network sharing due to tunnel wall loss. Hence, it can be concluded from the figures 4(a), 4(b), and 4(c) that active radio access network sharing is more effective and boost the system overall performance for the coexisting public-safety-LTE and LTE-railway networks, because

LTE-railway eNBs can directly serve the public-safety-LTE UEs without tunnel wall loss. Though, the performance of active radio access network sharing is not so good but still cell edge users can get meaningful benefit in case of coexisting public-safety-LTE and 5G commercial, because we deploy the 5G gNBs inside the tunnel in which signal power is become weaker due to tunnel wall loss.

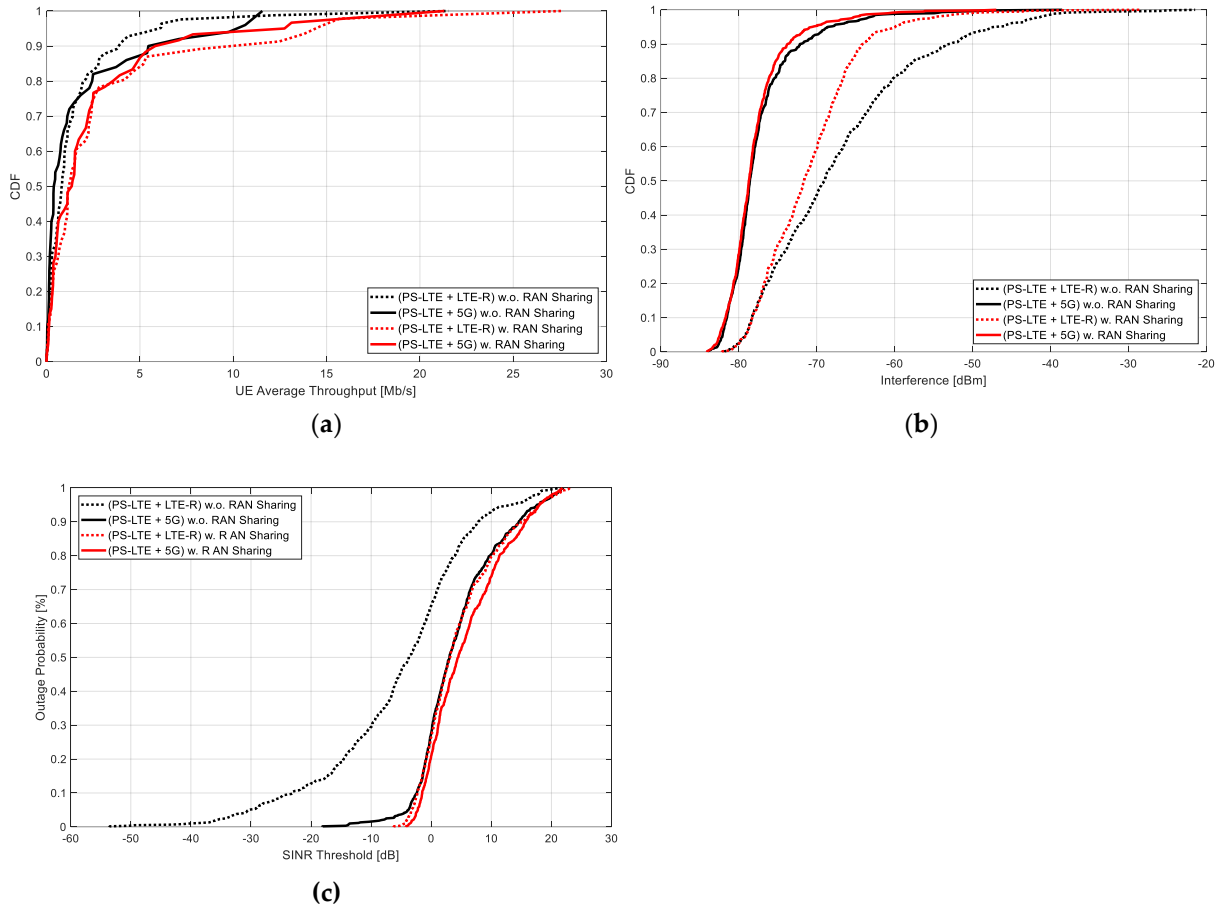


Figure 4 Performance comparison: (a) UE average throughput comparison for coexisting LTE networks (public safety verses railway) and 5G commercial network; (b) UE received interference comparison for coexisting LTE networks (public safety verses railway) and 5G commercial network, (c) UE outage probability comparison for coexisting LTE networks (public safety verses railway) and 5G commercial network.

5. Conclusion

We contrast it with the situation in which railroad networks and public safety coexist. In the second scenario, we place railway eNBs outside of tunnels and assess the co-channel effect on user equipment (UE) for public safety. A key possibility for the coexistence of next-generation cellular communication networks is radio access network sharing. Active radio access network sharing should be taken into account for the coexisting cellular networks (public safety versus railroad vs. commercial), which are assumed to use the same spectrum. In this chapter, we assess the co-channel interference in two different scenarios, namely I public safety and rail networks operating simultaneously, and (ii) public safety and 5G major networks operating simultaneously. To assess UE average throughput, UE received interference, and UE outage probability, system-level simulations are run. Throughput can be improved, interference and outages can be decreased, and radio access network sharing can be turned on. The efficiency of radio access network sharing for coexisting public-safety networks and 5G commercial networks has been validated by simulation

results.

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