

Article

# **QoS Priority-Based Mobile Personal Cell Deployment** with Load Balancing for Interference Reduction between Users on Coexisting Public Safety and Railway LTE Networks

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**Abstract:** The Republic of Korea has played a leading role in the development of next-generation long-term evolution (LTE) public safety networks. The LTE-based public safety (PS-LTE) network, the LTE-based high-speed railway (LTE-R) network, and the LTE-based maritime (LTE-M) network use the same 700 MHz frequency band. That results in severe co-channel interference (CCI), so there is a dire need for practical research into resolving the CCI issue. Moreover, unplanned deployment of the mobile personal cell (mPC) generates serious user-association issues owing to its movement, which leads to severe co-channel interference in coexisting PS-LTE and LTE-R networks. Indeed, it is important to satisfy users' quality of service (QoS) requirements during resource allocation in specific public safety situations. Therefore, we address the CCI issues through wise deployment of the mPC for user association and load balancing in overlapping PS-LTE and LTE-R networks. In this paper, we propose a QoS mPC deployment (QoS\_mPCD) scheme for priority-based load balancing and interference reduction in coexisting PS-LTE and LTE-R networks. The proposed scheme efficiently manages the user-association and load-balancing problems, and allocates the best resources to high-priority users based on defined service priority levels. Moreover, we employ an enhanced inter-cell interference coordination (eICIC) scheme that further reduces the interference with the users offloaded onto an mPC. System-level simulations are performed to evaluate the proposed QoS\_mPCD scheme by considering important performance matrices such as user equipment (UE) throughput, UE received interference, and UE outage probabilities.

**Keywords:** public safety network; railway network; coexistence; mobile personal cell; priority gate model

# 1. Introduction

The unification of public safety-long-term evolution (PS-LTE), LTE-based high-speed railway (LTE-R), and LTE-based maritime (LTE-M) networks is today's dire need in order to maintain communications during a large-scale disaster [1,2]. In the Republic of Korea, the same 700 MHz band is allocated to PS-LTE, LTE-R, and LTE-M networks [2–4]. So, a well-defined, centralized operational policy is needed in order to efficiently control resource-management and co-channel interference (CCI) issues [5]. Korea established the world's first public safety network, which leads the world in its vast investment in the evolution of public safety networks [1]. In current scenarios, public safety (PS) users face hurdles in getting a quick response to any PS situation, because they use different networks, and there is too much delay in sharing disaster information between the concerned



authorities. To overcome this issue, a unified disaster management system is required where public safety networks work together. Accomplishing this will result in quick sharing of factual information from a disaster, in order to tackle it with correct safety measures. Moreover, the deployment of the mobile personal cell (mPC) can play a vital role in resolving the user-association problem in complex scenarios like the coexistence of two public safety networks. However, this creates new challenges from an mPC's unplanned deployment and its mobile nature in overlapped networks.

The deployment of an mPC can boost system performance and improve user quality of service (QoS) by deploying the mPC near the desired area, such as high-traffic zones in commercial areas, and in PS situations, etc. Thus, more users can be associated with the mPC in order to achieve an offloading gain in the heterogeneous network (HetNet) environment. Figure 1 shows deployments in PS situations under overlapping PS-LTE and LTE-R networks. However, the unplanned deployment of mPCs generates serious user-association issues due to their mobile nature, which leads to severe co-channel interference for coexisting PS-LTE and LTE-R networks. Conventionally, static user-association schemes are unable to associate users dynamically according to PS situations and network load conditions [6,7]. We investigate the features of our proposed scenario where co-channel interference is the major problem. In this paper, we deploy the mPC wisely in PS situations to reduce the interference and by employing the eICIC scheme is an efficient way to further reduce CCI in overlapped networks.



Figure 1. Mobile personal cell (mPC) deployments based on public safety situations.

# 1.1. Related Work

Studies from the literature can generally be divided into two groups: (1) Strategies based on channel borrowing from cells that are lightly loaded, like load balancing with selective borrowing [8], and QoS priority-based dynamic fractional frequency reuse tapping the resources from lightly loaded cells [9], etc.; and (2) strategies based on traffic transmission to loaded cells, like cell breathing techniques [10], mobility-aware admission control [11], and bias-based offloading in HetNets [12].

We adopt the traffic transmission strategy that is described under the second group. Many contributions exist to address the issue of user association in HetNets with static small cells. These results have restrictions, because they optimize the efficiency of the system or network based on user associations. Therefore, the effect of offloading has not been analyzed or well-studied, because it is more difficult because of the different signal and interference issues [13]. The existing systems do not take into account the different moving patterns and QoS requirements of users and the base station (BS). Nonetheless, effective user associations should be able to decide on public safety scenarios depending on critical requirements. Thus, allocating resources to users has to be considered based on users' priorities and locations in the specific network situations. This kind of user information is referred to as *context information* in the proposed scheme [13].

# 1.2. Motivations

A lot of research has focused on addressing co-channel interference issues in a single network by proposing efficient resource allocation schemes but without considering critical scenarios like the overlapping of two LTE networks [14–18]. Moreover, the concept of the mobile personal cell has been used previously by considering a single network [13,19]. However, deployment of the mPC has not been evaluated in the complex environment of coexisting public safety networks. Mobile communications technology is evolving into 5G systems in which the user needs identical, reliable connectivity everywhere and anytime. Therefore, we focus on the coexistence of next-generation public safety networks, and we employ an efficient QoS priority-based mPC deployment scheme for load balancing and interference reduction. However, the deployment of an mPC in complex scenarios generates new challenges, i.e., user associations, CCI, QoS prioritization, etc. Thus, immense interest and practical research are needed to resolve the aforementioned issues. In the overlapped environment of Korea's PS-LTE and LTE-R networks, where both high-priority users and low-priority users exist in a random fashion, it is very important to deal with users based on their QoS requirements and defined service priority levels during the resource allocation process.

#### 1.3. Main Contributions

Details of this paper's major contributions are as follows:

- We deploy mPCs under coexisting environments of public safety networks (PS-LTE and LTE-R) to assess the proposed scenario's performance.
- We propose a QoS\_mPCD scheme for load balancing and interference reduction that can associate users wisely during a cell range extension (CRE) offset to an mPC according to their connection priority levels, as mentioned in Table 1.
- Since high-priority users can be offloaded to the mPC, we thus employ an eICIC scheme to further decrease interference with the mPC's offloaded users.
- Unlike fixed small cells, the dynamic ratio of the almost blank sub-frame (ABS) muting ratio is considered in this paper [13].
- Sine LTE-R is assumed to be the train control signal, zero error tolerance is needed for reliable communications. Therefore, we provide the best resources to the LTE-R user during the resource allocation process.
- We evaluate important performance indexes (throughput, interference, and outage).

The breakdown of the remaining sections is as follows. Section 2 contains the system methodology, in which we explain the priority gates model, the network layout, and the channel model. Section 3 describes the procedure for the proposed QoS\_mPCD scheme in detail. The conducting of system-level simulations is described in Section 4. Finally, the conclusion is Section 5.

User Priority	User Identification	Traffic Class	Barring (RACH)	Establishment Cause
PS First Responders	PS Emergency: PS1 to PS5	12–14	Barring for Special	High-priority Access
Commercial User Emergency	Commercial User Emergency	10	Barring for Special	Emergency
Commercial User Non-Emergency	Commercial User Non-Emergency	0–9	Low Barring Factor	Mobile originating

Table 1. User priorities in 3GPP ProSe LTE-A.

# 2. System Methodology for Coexisting Public Safety Networks

This section explains the priority gates model of the PS-LTE network. Second, we discuss the network layout, and finally, channel model details are provided.

### 2.1. Priority Gates Model of the PS-LTE Network

The priority gates model for the PS-LTE is the procedure that divides the process required for a user's device to connect to the network into three steps, as shown in Figure 2 [20]. To access and use the network, device users must pass the criteria presented at each step. The priority gates model's first step is the access priority. The user's priority is classified, as shown in Table 1, according to the access class in the device's chip [21].



Figure 2. The priority gates model of the public safety-long-term evolution (PS-LTE) network.

Consequently, the access priority step distinguishes public safety users accessing the PS-LTE network to obtain resources first, according to the access class of the chip embedded in the device. The third-generation partnership project (3GPP) prioritized use of the same frequency band into public and non-public safety users. However, in Korea, the frequency band of public safety networks is the same, so the access priority step has to be changed.

The admission priority step uses allocation and retention priority (ARP) to prioritize resources according to preset pre-emptions. ARP consists of three parameters: ARP priority level, pre-emption capability indicator, and pre-emption vulnerability. ARP is only involved in creating or rejecting a new

EPS bearer. ARP is not involved in the packet forwarding priority in situations in which packet data are sent once an EPS bearer is created [22]. Users can access the PS-LTE network after the last step (scheduling priority). In scheduling priority, the base stations use QoS class identifier (QCI) parameters to control the priority of packet transmissions.

In this paper, Step 1 (access priority) is not considered, because it is used to distinguish between public safety and non-public safety users, and we consider only public safety users. Since we do not consider the other users of commercial networks, Step 2 (admission priority) is not applied. Because we are managing resource allocation using scheduling, we employ Step 3 (scheduling priority) in our simulations to check the feasibility of our proposed scenario.

#### 2.2. Details of the Network Layout

Low-power smalls cells are used in the existing macro-cell infrastructure to achieve a 1000-times data rate for 5G systems [23]. Furthermore, benefits like suitability for less consumption of power and reliability for PS scenarios are driving 5G systems to focus on a user-centric strategy, thus providing an even user experience everywhere and anytime. These objectives can be accomplished by setting up a centrally managed software-defined networking (SDN) architecture-based 5G mobile personal cell that can meet users' needs by giving extensive connectivity, depending on the situation [19].

In this paper, we consider an uplink LTE-A system. We assume a K-tier system (K = 1) in which M macro-cells (eNBs), N mPCs, and L hexagonal sectors (L = 3) are deployed. The N mPCs are randomly deployed. We denote all base stations (BSs) with B (eNBs M + mPCs N), and all users (i.e., LTE-R users, PS-LTE users, and mPC users) with U. We consider base stations and users to be transmitting with power  $P_K^B$  and  $P_K^U$ , resepectively. The user *u* association is done with only one base station at a time. According to the eICIC, the all resource blocks (RBs), R, are allocated to users in such mechanism, i.e., the user can either get blank (b) or non-blank (n) RBs. As we consider the PS priority mechanism, both high-priority and low-priority users exist in the system. In order to facilitate a high-priority user, we reserve the blank RBs, and after that, low-priority users will be served. Moreover, we consider the following two variables: (1)  $\beta_{j,u}^{(n)}$ ,  $\beta_{j,u}^{(b)} \in \{0, 1\}$  means the user is connected to BS *j* using a non-ABS (n) or a blank (b) RB; and (2)  $\delta_u \in \{0, 1\}$  shows the PS priority indicator, i.e.,  $\delta_u = 0$  for non-LTE-R user *u*, and  $\delta_u = 1$  for LTE-R user *u*. Furthermore, users can shift to connect with another BS in order to balance the system load, while the LTE-R user sticks to the attached serving BS. Two factors are involved in the user association with BS *j* [13]:

$$\rho_{eNB_j/mPC_j}^{(n)} = \frac{1}{(1-v)R} \sum_{u \in U} \beta_{j,u}^{(n)} r_{j,u}^{(n)}$$
(1)

$$\rho_{eNB_j}^{(b)} = \frac{1}{vR} \sum_{u \in U} \beta_{j,u}^{(b)} r_{j,u}^{(b)}$$
(2)

where  $r_{j,u}^{(n)}$  and  $r_{j,u}^{(b)}$  present the required RBs for user *u* associated with BS *j* by using (*n*) or (*b*) RBs, respectively. LTE-R users have priority to access the blank RBs of mPC *j* during the ABS period. However, when high-priority users are fewer in number, and enough RBs are available, then the low-priority users can connect with mPC *j*. The normalized load on mPC *j* during RBs is written as follows [13]:

where  $r_{j,u}^{(n)}$  and  $r_{j,u}^{(b)}$  present the required RBs for user *u* associated with BS *j* by using (*n*) or (*b*) RBs, respectively.  $\delta_u \in \{0, 1\}$  shows the PS priority indicator, i.e.,  $\delta_u = 0$  for non-LTE-R user *u*, and  $\delta_u = 1$  for LTE-R user u. Hence, the total of the required RBs for BS *j* is calculated as follows [13]:

$$\rho_{eNB_j/mPC_j} = (1 - v)R\rho_{eNB_j/mPC_j}^{(n)} + vR\rho_{eNB_j/mPC_j}^{(b)}$$
(4)

where  $\rho_i$  represents the load of BS *j* as calculated in Equations (1)–(3).

QoS for users can be potentially improved by deploying the mPC in the targeted deployment area, like PS scenarios. The mPC can try for offloading gain by facilitating more users.

#### 2.3. Details of the Channel Model

The channel model was constructed as seen in Equation (5), calculating path loss, shadowing, and fast-fading from antenna gain:

$$H_{u,j}(dB) = AG_{u,j} - PL_{u,j} - Shd_{u,j} - F_{u,j}$$
(5)

where channel  $H_{u,j}(dB)$  encompasses the effect of pathloss  $PL_{u,j}$ , shadowing  $Shd_{u,j}$ , and antenna gains  $AG_{u,j}$  and it also has a fast fading  $F_{u,j}$  component.

In this paper, the rural macro model is used as a path loss model for eNB-connected users [24] as shown in Equation (6):

$$PL = 69.55 + 26.16log_{10}(f) - 26.16log_{10}(D_b) + [44.9 - 6.55log_{10}(D_b)]log_{10}(L) - 4.78(log_{10}(f))^2 + 18.33log_{10}(f) - 40.94$$
(6)

where *PL* is the distance between the BS and user in km, f is the carrier frequency in MHz, and  $D_b$  is the base station antenna height above ground in meters. The details of (6) are given in [24]. Shadowing and fast fading are considered in this paper [25,26].

The UL per-user signal-to-interference-plus-noise ratio (SINR) of user u associated with BS *j* on a non-blank (n) RB is as follows:

$$SINR_{u,j}^{(n)} = \frac{P_{u,j} |H_{u,j}|^2}{\sum_{l \in B, \ l \neq (M \cup j)} \rho_l^{(b)} P_{u,l} |H_{u,l}|^2 + \sigma^2}, \quad \forall_j \in B$$
(7)

where  $P_{u,j}$  is UL-transmitting power of user *u* associated with BS *j*.

The UL per-user SINR is as follows:

$$SINR_{u,j}^{(n)} = \begin{cases} \frac{P_{u,j}|H_{u,j}|^2}{\sum_{l \in B, \ l \neq (M \cup j)} \rho_l^{(b)} P_{u,l}|H_{u,l}|^2 + \sigma^2}, \ \forall_j \in B, \ j \neq M, \\ 0, \qquad \forall_j \in M, \ \delta_{l,u}^{(b)} = 0 \end{cases}$$
(8)

where  $P_{u,j}$  is the UL-transmitting power of user u associated with BS *j*.  $\delta_{l,u}^{(b)} = \{0, 1\}$  is the priority indicator, and is chosen depending on whether the user is in the CRE to access the blank (b) RB area.

We utilize the minimum path loss-based and PS priority-aware user association using the following [13]:

$$\psi_{u,j}^{k} = \arg\max_{k \in \{1,2,\dots,K\}} \delta_{u,j}^{k} \left( PL_{\min_{u,j}}^{k} + bias_{j} \right)$$
(9)

The details about Equation (9) are given in [13].

# 3. Proposed QoS\_mPCD Scheme Procedure

In this paper, we deploy mPCs to provide the best resources to high-priority users in assumed scenario. According to defined priorities, users can be separated during resource allocation procedures. The unplanned deployment of an mPC causes a severe user-association problem because of the mPC's mobile nature, and it also creates serious CCI [13]. This requires flexibility in the deployment of the mPC in order to overcome the CCI issues and also to ensure high-priority users can be served efficiently. Therefore, the proposed QoS\_mPCD scheme is very suitable for dealing with said issues. The proposed procedure for deploying the mPC based on QoS priority access is shown in Algorithm 1.

Algorithm 1. Proposed QoS priority-based mPC deployment scheme

```
For each BS j \in B
1:
2:
            Initialization x \leftarrow 0
                  Total_RBs = 50 \leftarrow \begin{cases} First Schedule the best RBs, Schedule the remaining RBs, Schedule
                                                                                                                                                                          LTE – R user
3:
                                                                                                                                                              non – LTE – R user
3.
                   BS (K \in 11) \leftarrow (BS[PS =3, R = 8]))
                   parameters (i, SINR_threshold, cellEdgeUE, cellCenterUE,
3.
                      LTE RUE, PS UE, mPC UE, HII).
4:
            Step 1. Context Information Collection
                   Exchange the context information between UE and BS.
5:
                   Count the number of cell-edge users based on SINR threshold.
6:
7:
                   for each UE u \in U do
8:
                             Check SINR_{u,i} < SINR_{threshold_{u,i}}
9:
                             u_{edge} = u_{edge} + 1
10:
                    end for
                    Users (PS-LTE UE, LTE-R UE, mPC UE) are classified based on priority.
11:
              Step 2. User Association and Resource Allocation
12:
13:
                    for each UE u \in U do
                          Estimate PL_{u,j} and select BS j that maximizes and associates user u with it.
14:
15:
                          Allocate maximum transmission power to users.
16:
                          if SINR<sub>LTE-R,j</sub> < SINR_threshold<sub>LTE-R,j</sub>
17:
                                Use distance-based power control scheme for users to meet LTE-R UE SINR.
18:
                          end if
19.
                          Dynamically adjust RBs during the RBs allocation for mPC user.
20:
                     end for
21:
                    Calculate the load on each BS j.
22.
                    Compute Throughput, Received SINR, and Interference on each UE u, respectively.
23:
                    i = i + 1
24:
               Step 3. Application of SDN-based eICIC
25:
                    while HII = 0
26:
                          for each M \in B in 1st-tier do
27:
                                Use optimum ABS ratio to accordingly transmit ABS.
28:
                                Plan offloaded users' u in mPC during ABS.
29:
                          end for
30:
                     end while
```

# 3.1. Step 1: Context-Information Collection

In this step, context information (CI) is gathered based on three important parameters: user location, user connection priority, and user deployment. This will result in efficiently scheduling users according to public safety priorities. The details of CI collection are as follows.

First, the SINR is measured to determine the cell-edge user from the cell-central user. Calculate the location information according to the user's SINR using

$$SINR_{u,j} > SINR\_threshold_{u,j}^{location}$$
(10)

where SINR<sub>u, j</sub> represents the SINR value of user u connected to BS j [13].

Second, collect the number of users who send an emergency connection request to base stations. This helps to differentiate the connection requests belonging to high-priority and low-priority users. Information is collected by classifying users into defined priority levels.

Finally, information is collected to know the high priority users' connection requests.

### 3.2. Step 2: User Association and Resource Allocation

Users can be associated with BS *j* using the user's contextual information. The association based on a minimum path loss is the most optimized approach. The deployment of the mPC is very helpful in supporting the PS user in coexisting networks. Our main objective is to provide the best resources to high-priority users, so it is a very efficient approach, i.e., using the context information of the users, to serve PS users on a priority basis, and it will also boost the performance of the overall network, because the proposed scheme is dealing with users according to priority levels. Moreover, if more PS users lie on the cell edge, they can be offloaded to the mPC, and hence, more users can be associated with the mPC. Equation (9) applies user priority constraints so users can be associated with the nearest BS. The resources are allocated to public safety users in accordance with their service priority levels [13]. After allocating resources to public safety users as a high priority, resources are distributed to these public safety users to enhance the data rate according to proportional fair scheduling. That is, all resources are first secured for public safety users with high-priority access.

#### 3.3. Step 3: Application of SDN-Based eICIC

If interference exceeds the predefined threshold, it can be managed by SDN-based, centrally controlled eICIC. By employing eICIC, the data signal is not transmitted during the ABS. It means transmission of the ABS from the BS can play a vital role in controlling the interference. If there is no ABS transmission, then users offloaded to the mPC will receive high transmission power from the BS. That causes more interference in the CRE. So, when eNBs transmit an ABS, it will be beneficial for low-power mPCs, because they are able to schedule offloaded PS users efficiently. This accomplishes a further reduction in interference, hence, boosting system performance in terms of throughput, interference, and outages. We follow the same procedure mentioned in [13] for the implementation of Step 3 in our proposed scenario.

#### 4. System-Level Simulation

The simulation process takes into account resource allocation according to the LTE prioritization gates model already described. As shown in Table 2, the traffic model assumes train control data for LTE-R and PS-LTE voice calls. Train control data are essential for safe operation and control of trains, and should be guaranteed a higher QCI priority than PS-LTE voice calls. The main simulation parameters are listed in Table 3.

We do not consider applying access class barring, which is the access priority step distinguishing between public safety and non-public safety users, because there are only public safety users, not users of commercial networks. Also, the second admission priority step is not applied, leaving only the third step for scheduling priority to be applied in the simulation process. Our main concern of presenting the priority gates model in order to practically follow the procedures in the proposed work. In our proposed frame work, we practically employed the Step 3 (scheduling priority) according to the assumed scenario because we are managing resource allocation using scheduling. The Step 1 and Step 2 will be considered in our future work. In present work, Step 1 (access priority) is not considered, because it is used to distinguish between public safety and non-public safety users, and we consider only public safety users. Since we do not consider the other users of commercial networks, Step 2 (admission priority) is not applied.

	Treffe Medal	ARP			OCI Priority
Trame Model		Preemption Capability	Preemption Vulnerability	QCI	QCITIONITY
LTE-R	Control Data	Yes	No	0	1
PS-LTE	Voice Call	Yes	Yes	1	2

Table 2. QoS class identifier (QCI) priority under the traffic model.

 Table 3. System-level simulation parameters.

Parameter	Value			
Carrier Frequency	723 MHz			
System Bandwidth, No. of PRBs	10 MHz uplink, 50 PRBs			
No. of PS-LTE eNBs	21 Sectors (1-tier, 7 Sites) [Only 3 Inner Sectors in the ROI]			
No. of LTE-R eNBs	Maximum 2 eNBs/Sector beside the Railway			
Inter-eNB Distance	PS-LTE eNBs: 4 km / LTE-R eNBs: 1 km			
No. of mPCs	21 mPCs/Inner Sector in the ROI			
mPC Mobility Pattern, Speed	mPC Random Walking Model, 3km/h			
No. of UEs/Sector	mPC UEs: 4/mPC / PS-LTE UEs: 8			
NO. OF DES/Sector	LTE-R UEs: 1 (Control Signal)			
UE Mobility	LTE-R UEs: 250 km/h			
UE RF Parameters	Max Tx Power: 23 dBm / Noise Figure: 9 dB			
Path Loss Model	Rural Macro (3GPP TR 36.837)			
Shadowing	Log-normal Distribution (Mean: 0 dB, SD: 6 dB)			
Fast Fading	mPC: Winner II (D1-Rural Macro)			
rast rading	LTE-R: Winner II (D2a-Rural Macro)			
MCS	MCS 0 ~ MCS 28			
Transmission Mode	SISO $(1 \times 1)$			
Thermal Noise Density	174 dBm/Hz			
Scheduling	Proportional Fair Traffic			

Figure 3 shows the network layout with the mPC deployed in coexisting PS-LTE and LTE-R networks. There is one PS-LTE base station at the center of the region of interest (ROI), which consists of three sectors, and PS-LTE users are represented by the blue circles. On the left side of the simulation layout are four LTE-R base stations that consist of two sectors each, represented by red circles. LTE-R users are marked by blue squares. The only mPC that exists in the measuring area is represented by a red circle, and the mPC user located near the mPC is represented by a black circle.



Figure 3. Network layout.

#### Simulation Results and Discussion

The benefit of mPC deployment is evaluated by conducting computer simulations in the two overlapping LTE networks. The CCI issues are addressed by employing the proposed QoS\_mPCD scheme. Moreover, eICIC is a suitable candidate in a complex coexisting environment in which interference with the users offloaded onto the mPC can be further reduced.

The average user equipment (UE) throughput can be verified by using a transport block (TB). The average UE throughput can be calculated with the following equation:

$$UE_{overall}Average Throughput = \frac{TB_{LTE-R UE} + TB_{PS-LTE UE} + TB_{mPC UE}}{Accounted_{TTIs} \cdot TTI\_Time} Mbps$$
(11)

 $TB_{LTE-R UE}$  represents the TB for LTE-R users;  $TB_{PS-LTE UE}$  is for PS-LTE users, and  $TB_{mPC UE}$  denotes mPC users. UE<sub>Overall</sub> average throughput always includes the performance of LTE-R users.

Equation (9) represents the calculation of  $UE_{PS-LTE}$  average throughput for PS-LTE users, and  $UE_{mPC}$  average throughput for mPC users is calculated with Equation (10).

$$UE_{PS-LTE}Average Throughput = \frac{TB_{PS-LTE} UE}{Accounted_{TTIs} \cdot TTI\_Time} Mbps$$
(12)

$$UE_{mPC}Average Throughput = \frac{TB_{mPC} UE}{Accounted_{TTIs} \cdot TTI\_Time} Mbps$$
(13)

**UE Average Throughput:** The analysis of throughput is done by considering the cumulative distribution function (CDF) at the 50th percentile (%). Figure 4 shows that the value of UE average throughput for mPC users is higher than for PS-LTE users, because mPC users are located near the mPC and are provided with a higher throughput service. The average overall UE throughput, which includes LTE-R users, is about 2.08 Mbps at 50% of the CDF. In addition, at 50% of the CDF, the average UE throughput for mPC users is about 1.66 Mbps, and the average UE throughput for PS-LTE users is about 0.82 Mbps, showing a difference of approximately 1.26 Mbps between mPC users.



Figure 4. User equipment (UE) average throughput.

**UE Rx Interference:** Figure 5 shows the UE Rx interference to compare the widely distributed PS-LTE user in PS-LTE coverage. The mPC user is located near the mPC, and we consider only the user's mPC interference from the different eNBs. Figure 5 shows that the UE Rx interference with mPC users is lower than interference with PS-LTE users because mPC users are located near the mPC and are only affected by interference from other eNBs. The overall UE Rx interference, which included LTE-R

users, is -71.67 dBm at 50% of the CDF. In addition, at 50% of the CDF, the UE Rx interference for mPC users is approximately -79.26 dBm, and the UE Rx interference for PS-LTE users is approximately -69.35 dBm, which shows the difference between the mPC users as approximately 9.91 dBm.



**UE Outage Probability:** Figure 6 shows that the UE-received SINR for mPC users is higher than PS-LTE users because mPC users are located near the mPC and are provided with more signal power. So, the UE-received SINR for the mPC user is higher than the UE-received SINR for the PS-LTE user for the entire CDF. The overall UE-received SINR is 3.15 dB at 50% of the CDF, including LTE-R users. In addition, at 50% of the CDF, the UE-received SINR for the mPC users is approximately 4.39 dB, and the UE-received SINR for PS-LTE users is approximately –3.71 dB, showing a difference of approximately 7.68 dB between mPC users.



Figure 6. UE outage probability.

# 5. Conclusions

In this paper, we analyze the QoS of priority-based mPC deployment for coexisting PS-LTE and LTE-R networks. The procedure for deploying an mPC is presented by applying it to practical conditions of the integrated public safety network in Korea. The proposed scheme advances the user-association issue by using PS-LTE user priority. The scheduling priority step is applied using the LTE priority gates model, giving a higher priority to PS-LTE UE. The important performance metrics indexes, such as average UE throughput, UE-received SINR, and UE Rx interference, are considered in order to analyze the proposed mPC deployment. At 50% of the CDF, QoS from the proposed priority-based mPC deployment scheme is better than the mPC average UE throughput at around 1.26 Mbps, the UE Rx interference difference is around 9.91 dBm, and the UE outage probability difference is around 7.68 dB, compared to PS-LTE UE throughput, the PS-LTE UE Rx interference, and the PS-LTE UE outage probability, respectively. Hence, the QoS\_mPCD scheme is appropriate for application in coexisting scenarios of next-generation public safety networks. Although the problem of co-channel interference is critical, because of the moving and unplanned deployment of an mPC in the complex coexisting environment of two LTE networks, the proposed scheme efficiently utilized the RBs and reduced the interference as well. So, we concluded that the proposed QoS\_mPCD scheme can improve spectrum efficiency for next-generation, overlapping public safety networks.

Author Contributions: I.A. added the abstract, introduction, system methodology, simulations, and part of the conclusion. He corrected the sequence of sections, and added important details for the proposed scenario. He conducted the simulations and corrected the English mistakes in the overall manuscript. In addition, he corrected the technical issues related to the manuscript and the proposed schemes. J.J. drew the system model figure and added the priority gates model, channel model, and part of the conclusion, along with the necessary details. He wrote the equations with their descriptions, and added the tables, along with the simulation parameters. He helped write the discussion of simulation results. Moreover, he helped in the proposed schemes. K.C. was the technical leader for this manuscript. He suggested all the technical issues for the proposed QoS\_mPCD scheme for aspects of the simulation. In addition, he corrected the simulation methodology for this manuscript, and corrected mistakes in the simulation environment as well as in the structure of the overall manuscript. All authors have read and agreed to the published version of the manuscript

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