A Proposal for Radio Resource Allocation of TDM Inter-Cell Interference Coordination to Heterogeneous Networks with Pico Cells in LTE-Advanced

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Abstract—**This paper proposes an actual down link radio resource allocation scheme at pico base stations (PBS) in time domain multiplexing - inter-cell interference coordination (TDM-ICIC). Since TDM-ICIC is useful for a heterogeneous network coexisting with macro BSs (MBS) and PBSs, considerable research has been conducted on TDM-ICIC. However, previous studies have not explored actual resource allocation, but have instead focused on theoretical capacity clarification. In the proposed method, user equipment (UE) attached to a PBS is classified into two groups: one is defined as the "A-PUE" and the other as the "CRE-UE". The A-PUE is a UE which is always attached to the PBS. The CRE-UE becomes attached to the PBS through the application of cell range expansion (CRE). In the proposed method, UE prioritization based on the UE classification takes precedence over proportional fairness scheduling (PFS). The UE prioritization depends on the interference condition due to the transmission condition at the MBS. System level simulations demonstrate two reasonable candidates in resource allocation when the MBS mutes the signal. One is based on PFS and is an effective approach for improving the average user throughput in each UE group compared to that without the TDM-ICIC. The other is prioritized resource allocation for the CRE-UE, which can correct the imbalance in the average user throughput between two groups. By applying the prioritized resource allocation, the imbalance in the average user throughput decreases from more than 200% to 25%.**

Keywords—**LTE-Advanced, Heterogeneous network (HetNet), Pico cell, Radio resource allocation, Inter-cell interference coordination, Proportional fairness scheduling**

I. INTRODUCTION

In order to cope with the explosive increase in user data traffic with the popularization of functional mobile terminals, such as smartphones, it is indispensable for future mobile and wireless communication systems to have a huge network capacity. For the sake of further improvements in the network capacity of the existing long term evolution (LTE) [1] system, LTE-Advanced [2] is required to support heterogeneous network (HetNet) deployment [3]. Note that LTE-Advanced corresponds to LTE Release 10 and beyond in terms of the LTE specification release. The initial radio area network becomes a homogeneous network composed of only macro base stations (MBS). As opposed to the homogeneous network, the HetNet consists of not only MBSs but also various local BSs, which have low transmission power and small coverage compared with an MBS. Since a local BS is smaller and cheaper than an MBS, the HetNet deployment can be rapid and cost-effective compared to a homogeneous network.

This paper discusses a downlink transmission in HetNet composed of macro and pico BSs (PBSs). The PBS has the same digital processing functions as the MBS and is wire-connected to the backbone network. However, the coverage area of the PBS is smaller than that of the MBS. In order to offload a sufficiently large amount of user data traffic into the PBSs from the MBSs, so-called "cell range expansion (CRE) with time domain multiplexing - inter-cell interference coordination (TDM-ICIC)" has been proposed in [4].

Although detailed explanations of CRE and TDM-ICIC are given in Section II, TDM-ICIC is attractive because it can be applied to an LTE network operating with a single component carrier. Therefore, much research has been devoted to TDM-ICIC as in [5] to [8]. However, much of the existing research has focused on serving cell selection or clarification of an optimized combination of the CRE bias value and the ratio of muted subframes. The "CRE bias value" and "ratio of muted subframes" are key parameters in TDM-ICIC and these are described in more detail in Section II, while the subframe is a resource unit of LTE in the time domain. Moreover, no research related to radio resource allocation assuming an actual radio packet scheduler can be found. For example, the literature [7] investigates the capacity of HetNet using an analytical approach with the aid of the Shannon capacity theorem. In [8], the throughput performance depending on the CRE bias value and the ratio of muted subframes is evaluated by a system level simulation study. Both the previous reports are useful for researchers but do not discuss actual radio resource allocation.

Therefore, this paper proposes several candidates for radio resource allocation at the PBS in TDM-ICIC. It is important to clarify the radio resource allocation of the PBS compared to that of the existing MBS because the PBS is to be distributed in the near future. The proposed method is evaluated through a system level simulation similar to an actual LTE system, and a practical radio resource allocation method is made obvious quantitatively.

The "radio packet scheduler" is a resource management function installed in the BS and the proportional fairness scheduling (PFS) algorithm is well-known [1]. PFS can maximize the average user throughput, while maintaining fair radio resource allocation among users. The reason for the lack of research into actual radio resource allocation can be attributed to the fact that many researchers think the required scheduler gain can also be obtained by applying feasible PFS in TDM-ICIC. However, in TDM-ICIC, the interference condition at the user attached to the PBS is dynamically changed due to MBS's instantaneous alternation of transmission and muting. This dynamic change in the interference condition might be beyond the capacity of PFS. This is because PFS optimizes the

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radio resource allocation by observing the signal to interference plus noise power ratio (SINR) variation due to instantaneous fading. The dynamic range in SINR variation due to the MBS's alternation exceeds that of instantaneous fading. The transmission and muting pattern of the MBS is pre-determined and shared among adjacent PBSs. Therefore, the pre-determined information will improve scheduler gain at the PBS.

This paper is organized as follows. Section II summarizes the CRE and TDM-ICIC. Section III explains the proposed radio resource allocation. Section IV presents the system level simulation results. Finally, Section V concludes this paper.

II. OVERVIEWS OF CRE AND TDM-ICIC

CRE is one of the load balancing techniques in LTE-Advanced. When the BS and user equipment (UE, i.e., mobile terminal) indexes (ID) are i and j, respectively, the serving BS ID of jth UE $s(j)$ is then given by

$$s(j) = \arg\max_{i}(B(i)P(i,j)) \tag{1}$$

where $B(i)$ denotes a bias value in CRE and $P(i, j)$ is the downlink reference signal received power (RSRP) measured and averaged over the long-term at the jth UE. By setting the CRE bias value of the PBS to a higher value than that of the MBS, CRE allows the UE to be offloaded into the PBS from the MBS. Fig. 1 depicts the classification of the UE in this paper. In this paper, a UE always attached to the MBS regardless of CRE is called "A-MUE", whereas a UE always attached to the PBS regardless of CRE is called "A-PUE". In addition, this paper defines a "CRE-UE". The CRE-UE is in a boundary area between the MBS and PBS and is attached to the MBS when CRE is not applied. By applying CRE, the CRE-UE becomes attached to the PBS.

Under the high CRE bias value conditions of the PBS, the CRE-UE suffers from severe interference from the MBS. As shown in Section IV, the average geometry (i.e., long-term averaged wideband SINR) of the CRE-UE is -5.5 dB under a CRE bias value of 8 dB. This high interference condition frequently causes radio link failure for the CRE-UE because orthogonal interference coordination is almost impossible on the downlink control channel. The available radio resources for the downlink control channel are sufficiently restricted and given by BS, UE and/or subframe IDs. Although LTE has various downlink control channels, this section refers to a physical downlink control channel (PDCCH). It is used to notify the UEs of information related to the resource assignments of their traffic channels. This means that erroneous PDCCH transmission also causes errors in downlink traffic transmission. Therefore, the PDCCH interference issue leads to fatal system performance degradation. Accordingly, TDM-ICIC is then proposed.

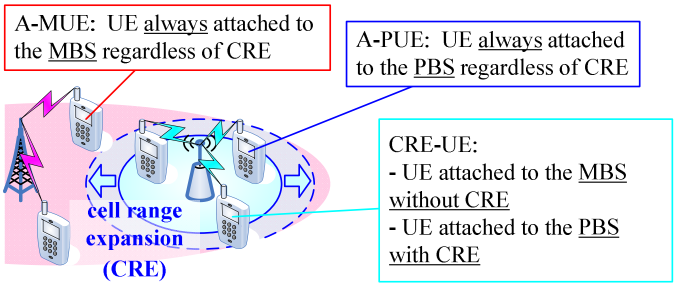

Fig. 1 Classification of the UE in this paper

In TDM-ICIC, the MBS partially mutes the subframe. The MBS can mute not only the downlink traffic channel but also the downlink control channel. As a result, the CRE-UE is protected from severe interference. Note that a subframe (SF) where the MBS mutes signals is called a "muted SF", while a subframe where the MBS transmits is called a "normal SF". The subframe timings when the MBS's subframes become the muted and normal SFs are called "muted SF timing" and "normal SF timing", respectively.

III. RADIO RESOURCE ALLOCATION AT PBS IN TDM-ICIC

This section explains the proposed radio resource allocation at the PBS in TDM-ICIC. The radio resource allocation in the normal SF timing is first explained. When the resource allocation for the CRE-UE is prioritized in the normal SF timing, the CRE-UE frequently causes radio link failure. Therefore, the prioritization of the A-PUE is a "general practice" in the resource allocation in the normal SF timing. The proposed candidates for resource allocation in the normal SF timing are summarized as follows:

- Method *N1*: resource allocation based on the PFS criterion (conventional)

  This resource allocation is based on the conventional PFS. PFS determines which user is preferentially assigned resources among all A-PUEs and all CRE-UEs.

- Method *N2*: exclusive resource allocation for the A-PUEs

  In this resource allocation, only A-PUEs are assigned resources. The prioritization among the A-PUEs is based on PFS.

- Method *N3*: prioritized resource allocation for the A-PUEs

  In this resource allocation, the A-PUEs are assigned resources in advance. If available resources remain after the completion of resource allocation for all A-PUEs, the residual resources are assigned to the CRE-UEs. The prioritization among the A-PUEs is based on PFS, as is the prioritization among the CRE-UEs. Note that the A-PUE is the dominant user among those served by the PBS. The coverage of the PBS is small and the number of users attached to the PBS is low. This means that available resources are often left over after completion of the resource allocation for the A-PUE.

Radio resource allocation in the muted SF timing will now be explained. Since the A-PUE is prioritized in resource allocation in the normal SF timing, the CRE-UE is prioritized in the muted SF timing. The resource allocation procedure in the normal SF timing is expanded taking the prioritization of the CRE-UE into account, and then used to determine the resource allocation in the muted SF timing. The proposed candidate methods for resource allocation in the muted SF timing are summarized as follows:

- Method *M1*: resource allocation based on the PFS criterion (conventional)
- Method *M2*: exclusive resource allocation for the CRE-UEs
- Method *M3*: prioritized resource allocation for the CRE-UEs

In conventional PFS, in order to determine the priority metric of resource allocation in each UE, PFS also estimates the average throughput in each UE. When PFS estimates the average throughput in the *n*th subframe, PFS refers to the average throughput estimated in the *n*-1th subframe. When the *n*th and *n*-1th subframes are normal and muted SFs, respectively, the PFS at the PBS in this paper estimates the average throughput in the *n*th subframe also referring to the average throughput estimated in the *n*-1th subframe. Namely, even if the MBS transmission/muting conditions differ between adjacent subframes, PFS at the PBS updates the average throughput obtained by the adjacent subframes.

IV. Performance Evaluation of the Proposed Radio Resource Allocation Method

This section evaluates the proposed radio resource allocation methods by employing a system level simulation. The system level simulation takes into account not only long-term fading determined by path loss and shadowing fading but also instantaneous fading generated by spatial channel modeling [9]. All BSs conduct radio resource allocation of every subframe, while all interfering BSs contribute to the SINR calculation like an actual LTE system. In order to execute the above mentioned powerful system level simulation, a blade server system composed of 8 blade units is employed. Since the number of CPU cores per blade unit is 8, 64 CPU cores operate in parallel to obtain the following simulation results.

A. Simulation Conditions

The simulation condition is based on Table A.2.1.1-2 Case 1, Table A.2.1.1.2-3 Model 1, and Table A.2.1.1.2-5 Configuration #4b in [9]. Note that the carrier frequency is modified to 800 MHz from the above mentioned methodology. Seven tri-sectored hexagonal cells are arranged in a single ring, and the inter-sight distance is 500 m. The number of hotspots is 2 per sector, and 1 PBS is dropped in the center of each hotspot. Ten UEs are randomly dropped in the hotspot with a radius of 40 m. An additional 10 UEs are randomly dropped in the macro sector area, hence, the total number of UEs per sector is 30. The CRE bias values of all PBSs and MBSs are 8 and 0 dB, respectively. As a result, the ratios of the numbers of A-MUE, A-PUE, and CRE-UE become 50.6, 27.1, and 22.2%, respectively. The transmission timing of the downlink subframe is aligned among all BSs, and the ratio of the muted subframe is 25%. A full-buffer traffic model is assumed as the user traffic model.

B. Simulation Results

Fig. 2 shows the average user throughput when TDM-ICIC is applied. In this section, a combination of the resource allocations in the normal and muted SF timing is denoted as "*N?* + *M?*". TDM-ICIC in Fig. 2 uses a combination of *N1* + *M1*, which is subsequently referred to as the "baseline". Fig. 2 also shows the average user throughput without TDM-ICIC as a reference. The condition without TDM-ICIC means that the CRE bias value and the ratio of muted SFs are 0 dB and 0%, respectively. Fig. 2 shows that TDM-ICIC improves the average user throughput in every UE group. The average user throughput gain due to TDM-ICIC is 8.3% in the A-MUE. As pointed out in [8], the adoption of an unreasonable combination of the CRE bias value and the ratio of muted SFs deteriorates average user throughput, especially in the A-MUE. It makes no sense to evaluate the resource allocation under the above mentioned condition. It is verified in Fig. 2 that the combination of a CRE bias value of 8 dB and a muted SF ratio of 25% is acceptable for evaluation of the resource allocation method. Fig. 2 also shows that the average user throughput gain in the CRE-UE is larger than that in the A-PUE. The average user throughput gain due to TDM-ICIC is 9.8% in the A-PUE, while in terms of the CRE-UE, the average user throughput with the TDM-ICIC is 5.3 times as high as that without the TDM-ICIC. In order to find the reason of this difference in average user throughput gains, the resource utilizations of both UE groups are measured and summarized in Table 1. The average geometry is also measured and listed in Table 2.

Table 1 shows that, in terms of the CRE-UE in all subframe timings, the difference in the resource utilization between the cases with and without TDM-ICIC is relatively small. However, in TDM-ICIC, the CRE-UE is frequently assigned resources in the muted SF timing. The probability of the CRE-UE being assigned resources in the muted SF timing is 62%. As shown in

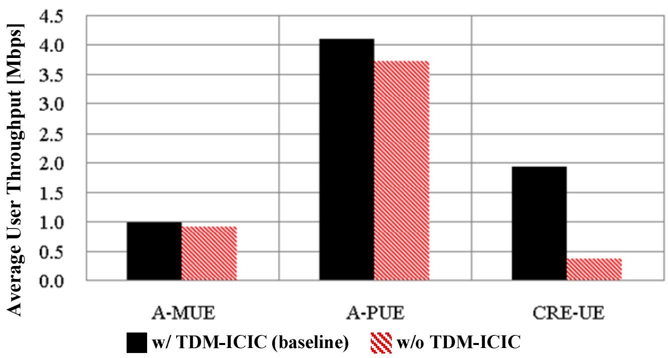

Fig. 2 Average user throughputs in each UE group

Table 1 Resource utilizations in A-PUE and CRE-UE

Method	A-PUE			CRE-UE		
	Nml. SF	Muted SF	All SF	Nml. SF	Muted SF	All SF
N1(+M1) = baseline	63.1	8.5	71.6	10.1	16.5	26.6
N2(+M1)	67.6	7.8	75.4	0.0	17.2	17.2
N3(+M1)	67.6	8.0	75.6	5.7	17.0	22.7
w/o TDM-ICIC	N/A	N/A	89.8	N/A	N/A	28.1

*Nml./Muted/All SF = normal/muted/all subframe timing

Table 2 Average geometries in A-PUE and CRE-UE

UE group	Normal subframe timing	Muted subframe timing	w/o TDM-ICIC
A-PUE	5.6 dB	23.0 dB	5.6 dB
CRE-UE	-5.5 dB	14.4 dB	0.6 dB

Table 2, the average geometry in the muted SF timing is larger than that without TDM-ICIC by 13.8 dB. Therefore, the average user throughput of the CRE-UE greatly increases due to TDM-ICIC. On the other hand, in terms of the A-PUE, the probability assigned to the muted SF timing is 11.9%, thus the A-PUE is dominantly assigned resources in the normal SF timing. Therefore, the average user throughput gain of the CRE-UE is large compared to that of the A-PUE.

Fig. 3 shows the average user throughputs in the A-PUE and CRE-UE when the resource allocation in the normal SF timing is changed. Fig. 3 shows that there is a small but significant difference in average user throughput when the resource allocation in the normal SF timing changes. The average user throughput gains in the A-PUE obtained by Methods *N2* and *N3* compared to the baseline are 1.2 and 2.0%, respectively. On the other hand, the average user throughput gains in the CRE-UE obtained by Methods *N2* and *N3* are -4.3 and -2.0%, respectively. When Method *N2* is substituted for the baseline, the average user throughput increases in the A-PUE and decreases in the CRE-UE. The reason why the average user throughput decreases in the CRE-UE is that Method *N2* does not assign resources to the CRE-UE in the normal SF timing. This reduction of resource utilization in the CRE-UE increases the available resources for the A-PUE. As a result, the average user throughput in the A-PUE increases. Table 1 shows that resource utilization in the A-PUE increases up to 75.4% when Method *N2* is used, while resource utilization is 71.6% with Method *N1*.

When Method *N3* is substituted for Method *N2*, both average user throughputs in the A-PUE and CRE-UE increase. The reason why the average user throughput increases in the CRE-UE is that Method *N3* assigns resources to the CRE-UE in the normal SF timing as well as in the muted SF timing. This reduces the resource utilization of the CRE-UE in the muted SF timing, as shown in Table 1. Then, the A-PUE in Method *N3* is frequently assigned resources in the muted SF timing compared to Method *N2*. This results in an increase in the average user throughput of the A-PUE. In summary, in terms of the average user throughput performance, it becomes clear that Method *N3* is suitable for the A-PUE and that Method *N1* is suitable for the CRE-UE.

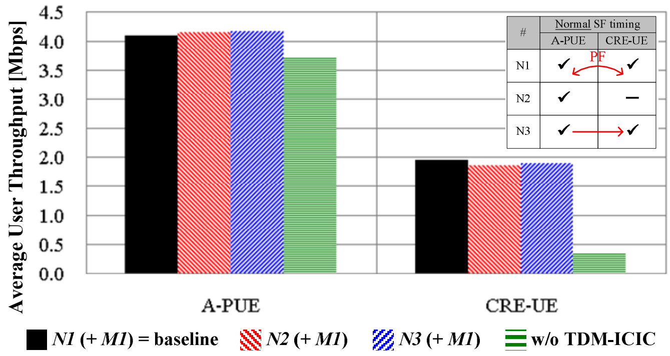

Fig. 3 Average user throughput depending on the resource allocation method in the normal subframe timing

Fig. 4 shows the outage probability (prob.) of the PDCCH when resource allocation in the normal SF timing is changed. The PDCCH outage prob. in this paper means the probability that the received SINR of the PDCCH is less than the required SINR. The required SINR means the SINR needed to achieve a packet error rate of 1%. The required PDCCH outage prob. is 1% and intended for all UEs including the A-MUE. Therefore, even if the CRE-UE, with a ratio of UEs of 22.2%, occupies the UE with a PDCCH outage, when the PDCCH outage prob. limited to the CRE-UE exceeds 4.5%, the requirement aimed at all UEs cannot be satisfied. Fig. 4 shows that, in terms of the CRE-UE, the outage prob. in the baseline is 5.7% and exceeds 4.5%. The baseline does not meet the requirement for PDCCH performance. The outage prob. in the baseline is about 3 times as high as that without TDM-ICIC. The outage prob. of the CRE-UE in Method *N3* is 4.2% and less than 4.5%. However, UEs with a PDCCH outage exist in the A-MUE and CRE-UE. In addition, the average user throughput gain obtained by Method *N3* is relatively small compared to Method *N2*. Therefore, Method *N2* should be considered to be an essential method for resource allocation in the normal SF timing. The outage prob. of the CRE-UE in Method *N2* is 2.1% and almost the same as that without TDM-ICIC. In terms of the A-PUE, the outage prob. decreases due to TDM-ICIC because the A-PUE is sometimes assigned resources in the muted SF timing with high SINR condition.

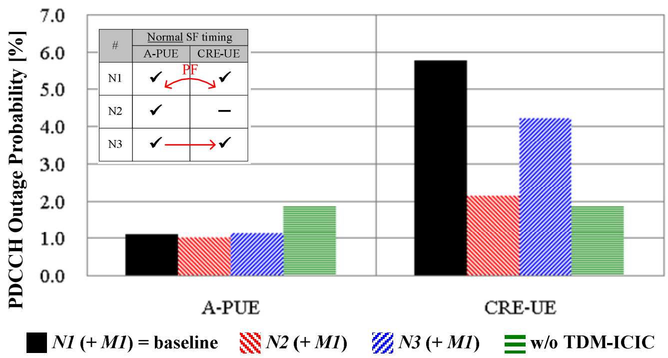

Fig. 4 Outage probability of the PDCCH depending on the resource allocation method in the normal subframe timing

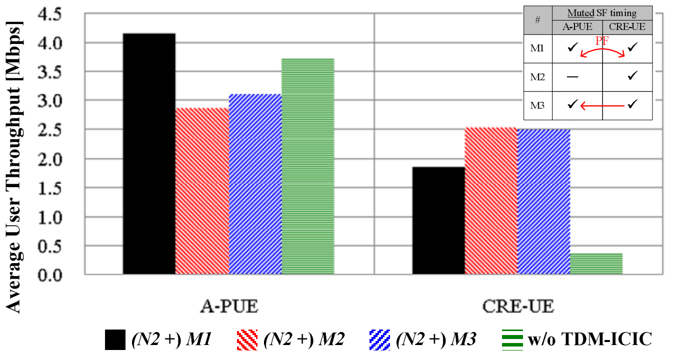

Fig. 5 Average user throughput depending on the resource allocation method in the muted subframe timing

Fig. 5 shows the average user throughputs in the A-PUE and CRE-UE when resource allocation in the muted SF timing is changed. Note that resource allocation in the normal SF timing employs Method *N2*. Fig. 5 shows that Methods *M2* and *M3*, which prioritize resource allocation of the CRE-UE, improve the average user throughput in the CRE-UE compared to the baseline. The average user throughputs in the CRE-UE are almost the same between Methods *M2* and *M3*. When Methods *M2* and *M3* are compared with respect to A-PUE, the average user throughput of Method *M3* is higher than that of Method *M2*. This is because, in Method *M3*, residual resources after completion of resource allocation for the CRE-UE are available for the A-PUE. In terms of the A-PUE, Method *M1* gives the best average user throughput among the three methods. When the resource allocation methods except *M1* are applied, the average user throughput in the A-PUE deteriorates compared to that without TDM-ICIC. The average user throughput gains obtained by Methods *M2* and *M3* are -23.0 and -16.7%, respectively, while the average user throughput gain obtained by Method *M1* is 11.2%. Moreover, when Method *M1* is applied, although the average user throughput in the CRE-UE is lower than that of the Method *M2* or *M3*, the average user throughput of Method *M1* is higher than that without TDM-ICIC. Therefore, in order to improve the average user throughput in both UE groups, Method *M1* is the best method.

On the other hand, when Method *M1* is applied, the average user throughput in the A-PUE is 2.2 times as high as that in the CRE-UE. If Method *M3* is substituted for the Method *M1*, the difference in the average user throughput is reduced to 0.25 times. If fair throughput performance between the A-PUE and CRE-UE is required for TDM-ICIC, Method *N3* is the best method.

V. CONCLUSIONS

For the sake of further improvement in the downlink throughput performance on the macro-pico HetNet, this paper proposes several candidate methods for radio resource allocation at the pico BS in TDM-ICIC. Throughput performance using the proposed radio resource allocation becomes obvious by system level simulation similar to an actual LTE system. Before the evaluation of radio resource allocation, it has been confirmed that the selected combination of the CRE bias value and the ratio of muted subframes is appropriate. This is because the selected combination does not deteriorate the average user throughput compared to that without TDM-ICIC in every user group. The conclusions are as follows:

- In the normal subframe timing when the macro BS transmits, it becomes clear that exclusive resource allocation is appropriate for the outage probability of the downlink control channel in the CRE-UE. The CRE-UE means a UE whose serving BS is changed from the macro BS to the pico BS by the application of the CRE. The exclusive resource allocation means that the radio packet scheduler only assigns resources to the A-PUE, who is always attached to the PBS regardless of CRE.
- In the muted subframe timing when the macro BS mutes signals, it becomes clear that the maximum average user throughput is obtained by determining prioritization between the A-PUE and CRE-UE based on the proportional fairness scheduling criterion. In this resource allocation, average user throughput improves in the A-PUE as well as CRE-UE compared to that without TDM-ICIC.
- If TDM-ICIC is required to balance throughput performances between the A-PUE and CRE-UE, prioritized resource allocation is the best way in the muted subframe timing. In this resource allocation, the CRE-UE is assigned resources in advance, then, the A-PUE is also assigned resources if available resources remain.

For future studies, radio resource allocation assuming a non-full buffer traffic model remains to be evaluated.

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