Flexible Multiplexing Mechanism for Coexistence of URLLC and EMBB Services in 5G Networks

Abstract: 5G mobile networks are envisioned to support both evolved mobile broadband (eMBB) and ultra-reliable and low latency communications (URLLC), which may coexist and interfere with each other in the same service cell in many scenarios. In this paper, we propose a dynamic 2-dimension bitmap resource indication to cancel eMBB services with a finer uplink cancellation granularity and a lower probability of false cancellation. Meanwhile, a resource indication based power control method is introduced to dynamically indicate different power control parameters to the user equipment (UE) based on different time-frequency resource groups and the proportion of overlapping resources, by which the reliability of URLLC transmission is guaranteed while the impact on the performance of the eMBB service is minimized. Furthermore, a dynamic selection mechanism is proposed to accommodate the varying cases in different scenarios. Extensive system level simulations are conducted and the results show that about 10.54% more URLLC UE satisfy the requirements, and the perceived throughput of eMBB UE is increased by 23.26%.

Keywords: 5G; eMBB; power control; resource indication; uplink cancellation; URLLC

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1 Introduction

Wireless communication services cover more and more application scenarios with the development of social digitization. Among them, enhanced mobile broadband (eMBB), ultra-reliable and low latency communication (URLLC) and massive machine type of communication (mMTC) have become three major scenarios supported by 5G systems[1–2]. Large flow mobile broadband services such as ultra-high definition and 3D video are mainly included in eMBB, providing the ultimate communication experience for people. The unmanned driving, industrial automation, etc. are mainly covered by URLLC, requiring low-latency data and an extremely reliable connection, i. e., one-way latency up to 1 ms with 10^{-5} outage probability. The scene of large-scale machine communication in the Internet of Things is mainly supported by mMTC[3–4]. From the current development trend, 5G mainly focuses on eMBB for basic daily needs and URLLC for emerging industries. Generally, the priority of a URLLC service is higher than that of an eMBB service[5–7]. In the practical application, eMBB services and URLLC services will appear in the same network, and the scheduling of a URLLC service by next-generation Node B (gNB) will inevitably conflict with the eMBB service as the triggering of the URLLC service is sporadic[8]. Once the URLLC service arrives, the gNB shall allocate appropriate uplink (UL) resources to it as soon as possible to meet the stringent latency requirements. However, the resources may have been allocated to uplink data transmission for eMBB in advance. The latency and reliability requirement of URLLC transmission can hardly be guaranteed due to no resource being used within a certain time interval[9–10]. Therefore, it is valuable to study how to multiplex the transmission resources between a URLLC service and an eMBB service.

Currently, power control and UL cancellation indication (CI) mechanisms are introduced into the Third Generation Partnership Project (3GPP) protocol as two independent and basic solutions to URLLC and eMBB service multiplexing[11]. However, these baseline methods have some inherent disadvantages. More specifically, the baseline cancellation indication (BCI) method is based on the semi-static 2-dimension (2D) bitmap implementation. However, the URLLC service is dynamic and mutative, and the semi-static pattern indication is difficult to meet the changing service requirements[12]. For the baseline power control (BPC) method, the power boosting is based on a relatively fixed value. For some cases where the proportion of overlapping resources over all scheduled resources is very small, the fixed setting of power boosting value will cause power waste and degrade the eMBB performance[13]. On the other hand, the BPC cannot further boost power to protect URLLC transmission in the case of poor channel quality[14]. This paper is mainly to solve these existing technical problems mentioned above.

In this paper, a dynamic pattern cancellation indication (DPCI) is proposed for making up the shortcomings of BCI. The proposed DPCI method enhances the current 2D bitmap pattern from semi-static to dynamic, so that the indication pattern can be adjusted flexibly according to the service arrival to obtain a more accurate indication. This can reduce the false indication and protect the eMBB service. Then, a resource occupancy based power control (ROPC) is proposed to enhance the current BPC method. Based on ROPC, it becomes possible for gNB to dynamically indicate different power control parameters to user equipment (UE) on different sets of time-frequency resources, which will further ensure URLLC transmission performance and protect the normal eMBB transmission. Furthermore, a dynamic selection of DPCI and ROPC is proposed. Because the scene is complex in the real deployment, each multiplexing mechanism has its advantages and disadvantages, and a combination of these mechanisms will get more robust and better performance.

The paper is organized as follows. Section 2 introduces the service multiplexing system model. In Section 3, the proposed design for DPCI, ROPC and the dynamic selection mechanism is described in detail. Extensive system level simulation results are introduced in Section 4, and the conclusions of this paper are given in Section 5.

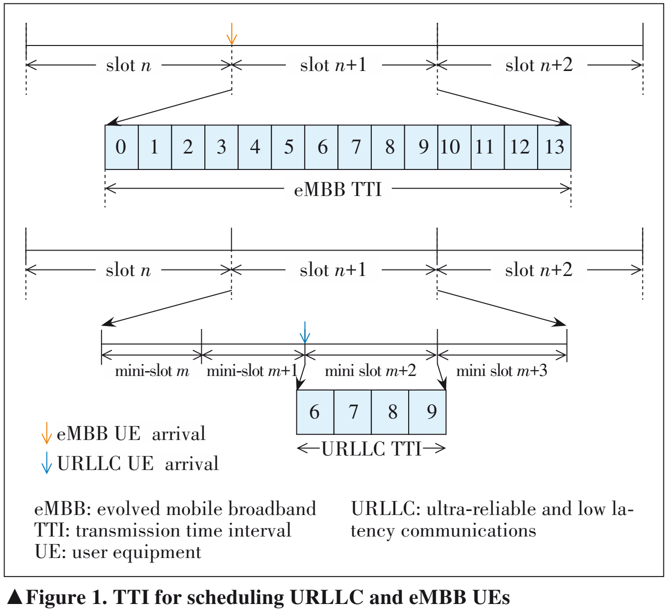
2 Service Multiplexing System Model

A 5G new radio (NR) uplink system is considered, where there are N cells, each equipped with Kr receiving antennas, and randomly distributed M user devices, each equipped with Kt transmitting antennas. Each cell includes two types of uplink transmission UE: URLLC UE and eMBB UE. The amount of URLLC UE and eMBB UE in each cell is M_{URLLC} and M_{eMBB} respectively, and $M_{\mathrm{URLLC}} + M_{\mathrm{eMBB}} = M$. The packets arrival for each eMBB user device is file transfer protocol (FTP) model 3 with Poisson arrival and the packet size is $B_{\min} - B_{\max}$ bytes with Pareto distribution[17]. The packet arrival for each URLLC user device is sporadic with an average arrival rate of 1 packet per T ms and the packet size is B bytes. In the system model, users are distributed indoors and outdoors in a random proportion, and o% of users are outdoors and i% of users are indoors, where $o + i = 100$.

A flexible frame structure is adopted for the service multiplexing system model, where URLLC and eMBB UE are scheduled with different transmission time intervals (TTIs). As an example in Fig. 1, the scheduling granularity is set to 14 orthogonal frequency division multiplex (OFDM) symbols for eMBB and 4 OFDM symbols for URLLC in order to achieve a latency reduction. The monitoring periodicity of UL cancellation signaling should be equal to the URLLC physical downlink control channel (PDCCH) monitoring interval, i.e. minislot level[15]. In the frequency domain, the smallest scheduling unit is the resource block (RB) which is composed of 12 resource elements (RE).

For a UL CI based solution, the remaining part of the eMBB transmission is dropped by assuming the phase continuity of UL eMBB transmission cannot be guaranteed. For a UL power control based solution, P dB power boosting of URLLC transmission is assumed in case of overlapping with grant-based eMBB transmission respectively. In our simulation, each PDCCH monitoring occasion occupies one symbol with 32 CCEs. When considering reserving some candidates for eMBB scheduling, the PDCCH search space set configuration for UL cancellation signaling is assumed as the aggregation level (AL) ={1,2,4,8,16} with corresponding candidate numbers {4,4,2,1,1} respectively. The AL of the UL cancellation signaling is selected according to a PDCCH channel condition with a target block error rate (BLER) requirement. For a UL cancellation based solution, a group common PDCCH is adopted. In addition, the additional signaling caused by method improvement is carried by the PDCCH.

In this system model, the algorithm of the gNB receiver is



▲Figure 1. TTI for scheduling URLLC and eMBB UEs minimum mean square error-interference rejection combining (MMSE-IRC), which adopts MMSE criterion[16]. The objective function is to minimize the mean square error between the transmitted signal vector $\boldsymbol{s}_1$ and the received signal vector linear combination $\boldsymbol{W}^H{}_y$, shown as :

$$\min_{W} E\left[\left(\boldsymbol{W}_y^H - \boldsymbol{s}_1\right)^H\left(\boldsymbol{W}_y^H - \boldsymbol{s}_1\right)\right] \quad , \tag{1}$$

where $\boldsymbol{s}_1$ is the signal source symbol of a service cell, y is the signal received by the receiver, and $\boldsymbol{W}$ is the $Kt \times Kr$ weighted matrix of dimension. When the gradient is used to find the optimal solution, the information of the known interference channel matrix is fully used, and the MMSE-IRC weighting matrix can be obtained as:

$$\boldsymbol{W}^H = \boldsymbol{H}_1^H\left(\boldsymbol{H}_1\boldsymbol{H}_1^H + \frac{I_{oc}}{E_s}\boldsymbol{H}_2\boldsymbol{H}_2^H + \frac{N_0}{E_S}\boldsymbol{I}_{K_t}\right)^{-1} \quad , \tag{2}$$

where $\boldsymbol{H}_1$ represents the channel matrix from the service cell to the receiver, $\boldsymbol{H}_2$ represents the channel matrix from the interference cell to the receiver, E_s is the average power of the transmitting source symbol, and the noise power and interference power are I_{oc} and N_0 respectively. When there are multiple interference cells, the MMSE-IRC weighting matrix formula can be extended as:

$$\boldsymbol{W}^H = \boldsymbol{H}_1^H\left(\boldsymbol{H}_1\boldsymbol{H}_1^H + \sum_n^N \frac{I_{oc}}{E_s}\boldsymbol{H}_n\boldsymbol{H}_n^H + \frac{N_0}{E_S}\boldsymbol{I}_{K_t}\right)^{-1} \quad . \tag{3}$$

3 Multiplexing Methods

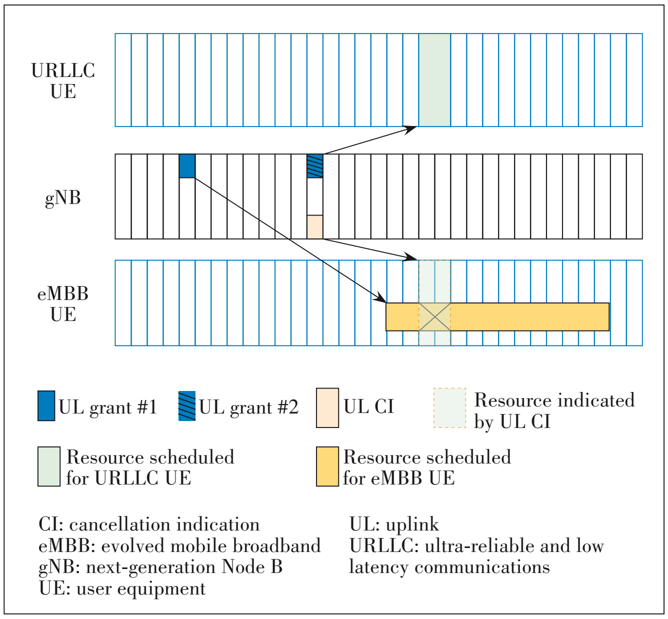
In Fig. 2, an example of BCI for UL multiplexing transmission is shown. The resource for grant-based eMBB and URLLC is scheduled by UL grant #1 and UL grant #2 respectively. Meanwhile, a URLLC resource indication can be transmitted to eMBB UE by the UL CI. The eMBB UE should cancel its uplink transmission when the UL CI is detected. In this case, the resource region in which the URLLC cancellation resource indicated by the UL resource indication is named as Reference Uplink Resource (RUR).

A BPC for UL multiplexing transmission is another alternative, i.e. boosting the URLLC transmission power on the colliding resources. When one user device is transmitting uplink data via an eMBB physical uplink shared channel (PUSCH) and another user device has urgent URLLC data to be sent on the same resource, relatively higher power can be applied than for the case without overlapping eMBB transmission. For the power control scheme, the gNB can still receive the eMBB transmissions. The URLLC transmission may have interference on the eMBB transmission, but it can still be possible for the gNB to decode the eMBB transmission block correctly without retransmission.

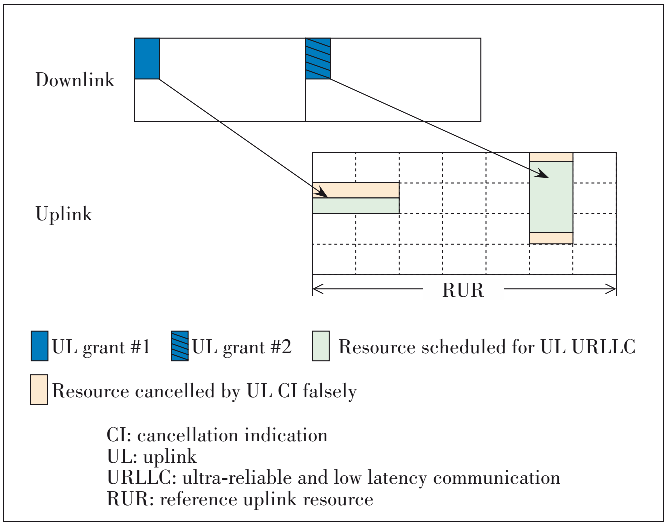
3.1 Design for DPCI

URLLC UE is randomly distributed at both the center and edge in a cell. For cell center UE, it is reasonable to allocate a "thin-tall" type of time-frequency resource to latency reduction. While for cell edge UE which is subject to greater inter-cell interference and larger path loss, higher power is expected to meet the reliability requirement. It tends to allocate less frequency resources to such UE due to a power limitation issue, and instead more symbols have to be scheduled for them. Then, a "fat-short" type of time-frequency resource is more suitable for cell edge UE. As a result, dynamic scheduled resources are different between cell center UE and cell edge UE. Fig. 3 shows an example of the gNB allocating resources to cell center UE and cell edge UE for the BCI method. In Fig. 3, the RUR is divided into 7×4 resource sub-blocks by a 2D bitmap with a size of 28 bits. The first green resource in RUR is allocated to a cell edge UE by gNB, which occupies 2 resource sub-blocks in the time domain and only 1 in the frequency domain. The second green resource block in the RUR is allocated to cell center UE by gNB, which occupies only 1 resource sub-block in the time domain and 3 resource sub-blocks in the frequency domain. Furthermore, different use cases are identified for URLLC services, such as power distribution, factory automation, transport industry, etc. In accordance with different traffic characteristics, different resource allocations are required for different use cases. For example, a service with a larger packet size and higher reliability requirement expects more resource allocation compared with a smaller packet size or lower reliability requirement. In the actual network deployment, various URLLC services could coexist in one cell.

The resource indication pattern under BCI is configured



▲Figure 2. An example of baseline cancellation indication (BCI) multiplexing method



▲Figure 3. Allocated resources to cell center UE and cell edge UE for baseline cancellation indication (BCI) method

semi-statically, e.g, 4×7 resource sub-blocks as shown in Fig. 3. A semi-static 2D bitmap pattern cannot provide a flexible frequency domain granularity indication, which causes a large number of eMBB transmissions to be cancelled falsely. From the overall performance, the loss outweighs the gain. In order to make better use of spectrum resources in different scenarios for URLLC and reduce the probability of eMBB being canceled by error, a dynamic configuration of the resource indication pattern should be supported. Instead of using the indication bits to indicate the frequency resource occupation uniformly for all time domain occasions, only the time domain occasions occupied by URLLC PUSCH are valid for further frequency indication in DPCI. Thus, the occupied time domain occasions are indicated firstly, and the time-frequency resource corresponding to the occupied time domain occasions is indicated by a dynamic 2D bitmap in DPCI. More specifically, the bit construction of DPCI is illustrated as follows.

• Q bits are used for indicating which time domain occasion is occupied, where “Q” equals the number of occasions in the time domain per RUR.

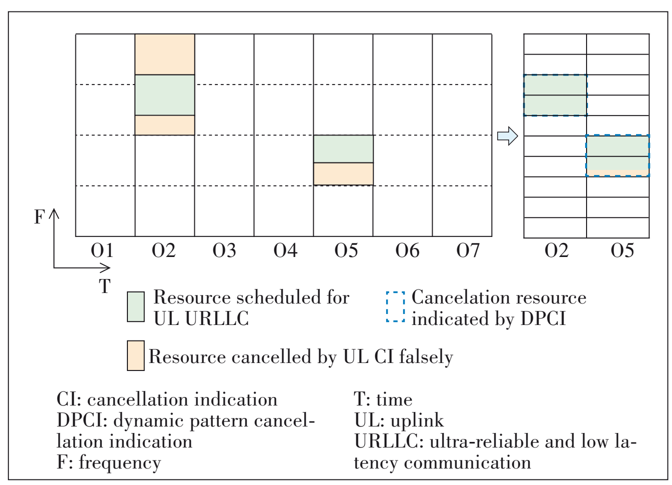
• $\mathbf{C}_{m\times n}$ is a 2D bitmap for frequency domain indication, i.e., the occupied time domain occasions are divided into “a×b” portions, and each portion is indicated by a bit in the 2D bitmap, wherein a represents the number of occupied time domain occasions and b represents the frequency domain granularity. Both of them are determined according to the indication of Q bits dynamically.

As shown in Fig. 4, the total number of occasion is 7, corresponding to Q=7; The number of occasion with scheduled resouce for URLLC is 2, corresponding to a =2; The O2 and O5 occupied by URLLC service are divided into 10 parts in the frequency domain, corresponding to b=10. The total bit-number is 27. Compared with BCI, which requires 28 bits, this method can make the frequency domain indication granularity (FDIG) finer with the same number of bits. This could reduce the false cancellation probability for better protection of eMBB PUSCH. As shown in Table 1, as long as the number of occupied time domain occasions (OTDOs) is less than 5, the minimum frequency domain indication granularity for each time domain occasion of DPCI is finer than that of BCI.

3.2 Design for ROPC

In order to ensure the flexibility of URLLC transmission, gNB should schedule the most appropriate time-frequency resources for URLLC UE without caring whether it overlaps with eMBB transmission. For BPC, once the resource of URLLC overlaps with that of eMBB, URLLC UE will perform P dB power boosting, i.e., 6 dB. However, the eMBB transmission will cause quite different interferences on URLLC time-frequency resources under some situations. For example, as shown in Fig. 5, the transmission power of different eMBB UE is different in the same RUR, and the proportion of overlapping resources to the total resources of URLLC services is different in different RURs. A fixed value of power boosting will not only lead to insufficient or serious power waste for URLLC transmission, but also affect the transmission performance of normal eMBB services.

Compared with fixed power adjustment according to resource multiplexing, the following two points are enhanced in ROPC: 1) defining different power control parameters for dif-



▲Figure 4. Resource indicated by dynamic 2D bitmap

▼Table 1. Minimum indication granularity with different numbers of the occupied time domain occasions

BCI	the number of OTDOs	1 – 7						
	FDIG	1/4						
DPCI	the number of OTDOs	1	2	3	4	5	6	7
	FDIG	1/21	≤1/10	1/7	≤1/5	≤1/4	≤1/3	1/3

BCI: baseline cancellation indication
DPCI: dynamic pattern cancellation indication
OTDO: occupied time domain occasion
FDIG: frequency domain indication granularity

ferent resource groups; 2) boosting power according to the proportion of overlapping resources to the total resources of URLLC services. More details are provided on the above two enhancements in the following subsections.

3.2.1 Different Power Control Parameters for Different Resource Groups

In an RUR, multiple groups of a time-frequency resource can be indicated by gNB to URLLC UE. Different groups of time-frequency resources correspond to different power control parameter sets. The URLLC transmission power is determined according to the power control parameter set corresponding to the group of time-frequency resource which overlaps with eMBB.

As shown in Fig. 6, the control information of ROPC includes at least one time-frequency resource indication field. Each time-frequency resource indication field can indicate a group of time-frequency resources. The power control parameters for each group of time-frequency resources will be configured via radio resource control signaling. If the resource scheduled for URLLC transmission overlaps with more than one group of time-frequency resources, transmission power will be calculated based on each power control parameter respectively, and a higher one or an average value will be selected.

3.2.2 Boosting Power Based on Overlapping Resource Proportion

Multiple overlapping resource proportion thresholds are defined in advance, among which the overlapping resource proportion is defined as the proportion of overlapping resources to URLLC resources. The threshold includes 10%, 40% and 80%. Table 2 defines a mapping relationship between the actual overlapping resource proportion x and a power promotion value. For example, the overlapping resource proportion is 40%, if the URLLC resource is 10 RB and the overlapping resource is 4 RB. In such cases, the transmission power of URLLC will be increased by 3 dB.

The execution procedure of ROPC is summarized as follows:

1) The gNB determines which group of URLLC time-frequency resources overlaps with the eMBB.

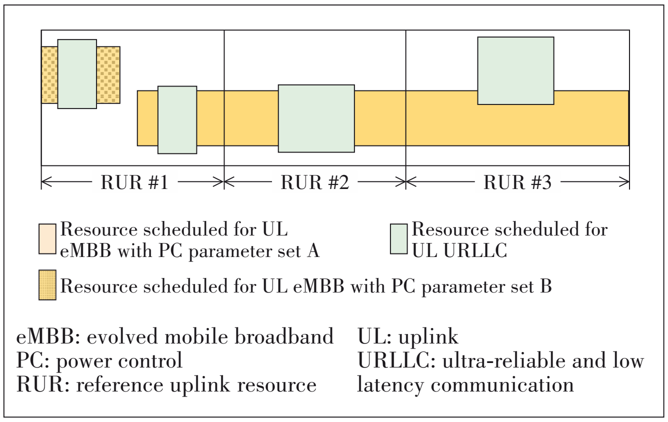
2) The gNB computes the overlap proportion between each group of URLLC time-frequency resources and eMBB time-frequency resources.

3) The gNB sends the control information carrying the index of power control parameters corresponding to each resource group according to the calculation result of the second step.

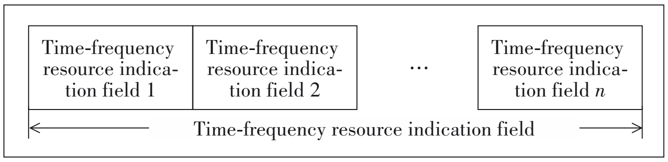
4) The URLLC UE receives and decodes the control information of ROPC.

5) The URLLC UE determines the power value to be enhanced for each group of time-frequency resources according to the index in the time-frequency resource indication field.

The introduction of overlapping resource proportion enables URLLC UE to adjust the transmission power to be optimal, while limiting the interference for the eMBB transmission. What's more, interpreting different power control parameters for different transmission time-frequency resources further improves the accuracy of power control.



▲ **Figure 5. Various situations of overlapping between the URLLC physical uplink shared channel (PUSCH) and the eMBB PUSCH**



▲ **Figure 6. Time-frequency resource indication field**

▼ **Table 2. Power boosting value according to actual overlapping resource proportion**

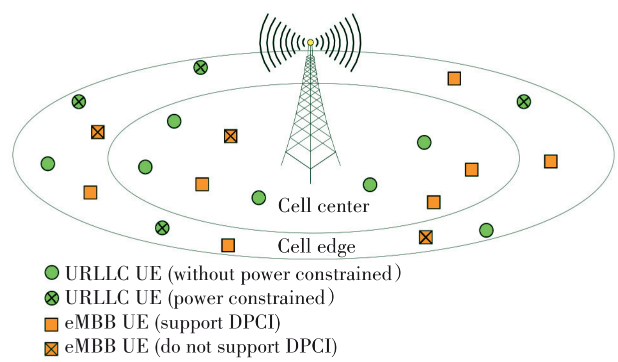
Index	Actual Overlapping Resource Proportion x	Power Boosting/dB
0	$x \le 10\%$	0
1	$10\% < x \le 40\%$	3
2	$40\% < x \le 80\%$	6
3	$x > 80\%$	9

3.3 Design for Dynamic Selection of DPCI and ROPC

In this subsection, we combine DPCI with ROPC to obtain better performance. Two methods for the multiplexing application can be considered in the service multiplexing system model, and the most suitable method is selected for execution in one TTI. Fig. 7 shows an example for dynamic selection multiplexing methods based on the location and function configuration of the UE. There are both URLLC UE and eMBB UE in a cell. For URLLC UE, one kind of UE can perform ROPC without the power constrained, and the other kind cannot perform PC with the power constrained. For eMBB UE, one kind of UE supports DPCI and the other kind does not support DPCI. In practical application, there are three options for multiplexing scheduling: ROPC, DPCI and no scheme, and Fig. 8 shows the selection procedure of the multiplexing mechanism.

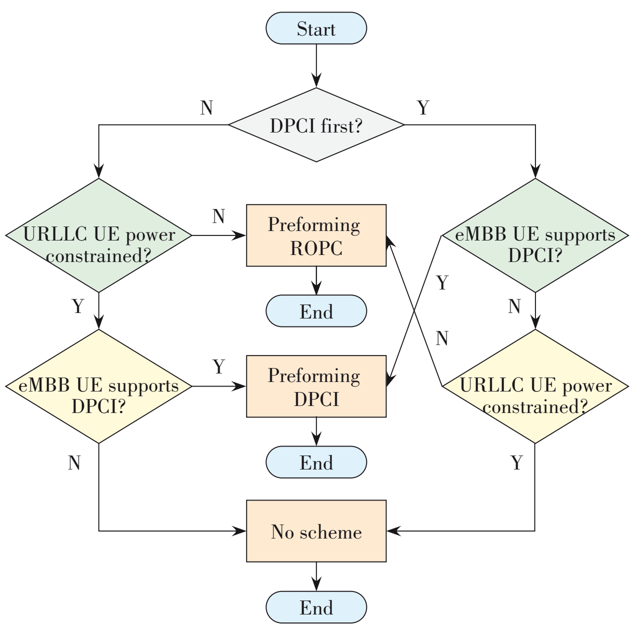
4 Simulation Results

In this section, system level simulation results based on dif-



DPCI: dynamic pattern cancellation indicatione
eMBB: evolved mobile broadband
UE: user equipment
URLLC: ultra-reliable and low latency communication

▲**Figure 7. An example of dynamic selection**



ROPC: resource occupancy based power control
DPCI: dynamic pattern cancellation indication
URLLC: ultra-reliable and low latency communications
UE: user equipment
eMBB: evolved mobile broadband

▲**Figure 8. The dynamic selection procedure**

ferent multiplexing methods are provided. The simulation mainly includes the following four aspects:

- Percentage of time domain occasions occupied by URLLC per RUR;
- Minimum boosted power value for URLLC to meet the reliability requirement;
- System performance comparison for different multiplexing methods;
- System performance comparison for the dynamic selection mechanism and baseline methods.

The above four simulation aspects are based on a service multiplexing system model proposed in Section 2. The details of simulation assumptions are listed in Table 3.

4.1 Percentage of Time Domain Occasions Occupied by URLLC per RUR

To compare the BCI and DPCI method, the percentage of the number of time domain occasions occupied by the URLLC per RUR is evaluated via system-level simulation. The duration of RUR is set as 1 slot. Within each RUR, there are 7 time domain occasions, and each of them has 2 OFDM symbols. As shown in Fig. 9, the number of occasions actually scheduled for URLLC transmission is relatively small. In each cell load setup scenario, the ratio of cases that the occupied RURs contain less than 3 time domain occasions occupied by URLLC is more than 94%. Together with the analysis in Table 1, we can infer that a finer frequency domain indication granularity can be expected by DPCI in most cases. In other words, DPCI has more accurate indication granularity.

4.2 Minimum Boosted Power Value for URLLC to Meet the Reliability Requirement

To prove that it is reasonable to grade multiple values for power boosting, we intercept 100 times of conflict between URLLC and eMBB in a system simulation. We repeated 10 times for each conflict with different power values, and se-

▼**Table 3. System-level simulation assumptions**

Parameters	Value
Carrier frequency	4 GHz
Simulation bandwidth	40 MHz
SCS	30 kHz
Channel model	UMa in TR 38.901
Antenna configuration	4 receiving antenna ports 2 transmitting antenna ports
gNB receiver	MMSE-IRC
Cell load setup	K_{eMBB}: 5, 10, 20, K_{URLLC}: 5, 10, 20 $\Omega = \left(K_{URLLC}, K_{eMBB}\right)$
TTI configuration	URLLC: 2, 3, 4 OFDM symbols eMBB: 14 OFDM symbols
HARQ	Max number of transmissions=4 with target BLER=0.01% (URLLC) or 10%(eMBB)
Traffic model	eMBB: • Packet arrival per UE: FTP Model 3 • Packet size: 50 – 600 bytes URLLC: • Packet arrival per UE: periodic with arrival rate of 1 packet per 2 ms • Packet size: 32 bytes
UE distribution	80% of users are outdoors 20% of users are indoors
eMBB UE function configuration	90% of users support DPCI 10% of users do not support DPCI

DPCI: dynamic pattern cancellation indication
eMBB: evolved mobile broadband
FTP: file transfer protocol
BLER: block error rate
BSgNB: next-generation Node B
HARQ: hybrid automatic repeat request
MMSE-IRC: minimum mean square error-interference rejection combining
SCS: sub-carrier spacing
TTI: transmission time interval
UE: user equipment
uMA: uUrban Macro
URLLC: ultra-reliable and low latency communications

lected a minimum power value for URLLC UE to meet the reliability requirement. If URLLC UE cannot meet the reliability requirement, the maximum boosted power value will be selected. For the system simulation, the cell load setup is set Ω = (10, 10), and the minimum and maximum boosted power are 0 dB and 9 dB, respectively. The duration of RUR is assumed as 1 slot, which contains 4 time domain occasions. The simulation results are shown in Fig. 10.

As shown in Fig. 10, the most suitable boosted power value may not always be 6 dB, and we divide the power increase value into four levels with dotted lines equal to 0, 3, 6 and 9. In this experiment, 6 dB power boosting cannot meet the reliability requirement for URLLC in 17 out of 100 conflicts, and 6 dB power boosting becomes wasteful in 40 out of 100 conflicts. For ROPC, 9 dB can be boosted in scenarios where 6 dB cannot meet URLLC transmission requirements, while 3 dB and 0 dB can be boosted in scenarios of good channel condition quality to save power.

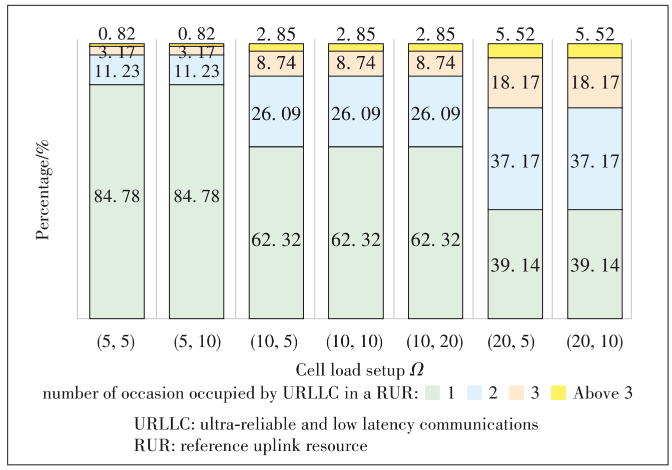
4.3 System Performance Comparison for Different Multiplexing Methods

To compare the performance of different multiplexing methods as described above, the performance of the URLLC transmissions and eMBB UE perceived throughput (UPT) are evaluated. The corresponding simulation assumptions are shown in Table 3.

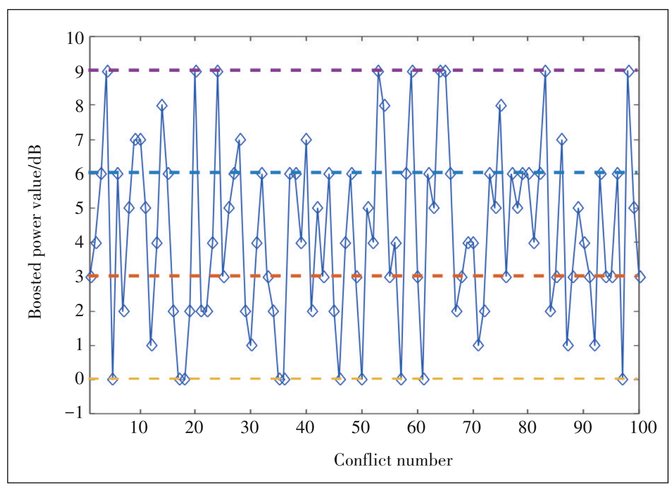
The scheduling granularity is set to 14 OFDM symbols for eMBB and 3 or 4 OFDM symbols for URLLC. For BCI, the 2D bitmap pattern is set as 4×7, which means that the RUR is divided into 4 parts in the time domain and 7 parts in the frequency domain. For BPC, 6 dB power boosting of URLLC transmission is assumed in case of overlapping with eMBB transmission. For DPCI, 4 bits are used for indicating which time domain occasions is occupied, and 2D bitmap pattern is dynamically set based on the actual number of occasions occupied, such as 1×24, 2×12, 3×8, and 4×6. For ROPC, the power boosting value is set according to the actual overlapping resource proportion, and it is divided into 4 levels, such as 0 dB, 3 dB, 6 dB, and 9 dB. The system-level simulation results are shown in Fig. 11, Fig. 12 and Table 4. As a reference, URLLC performance of UL inter-UE multiplexing with no scheme is also listed.

For the performance of eMBB transmission, we can see from Fig. 11 and Fig. 12 that with the increase of cell load, UPT of eMBB transmission shows a downward trend. In all cell load scenarios, ROPC has the largest UPT for eMBB transmission, which is mainly due to the dynamic selection of boosted power value. It can be observed that DPCI has a maximum gain of 13.78% compared with BCI, and ROPC has a maximum gain of 12.50% compared with BPC.

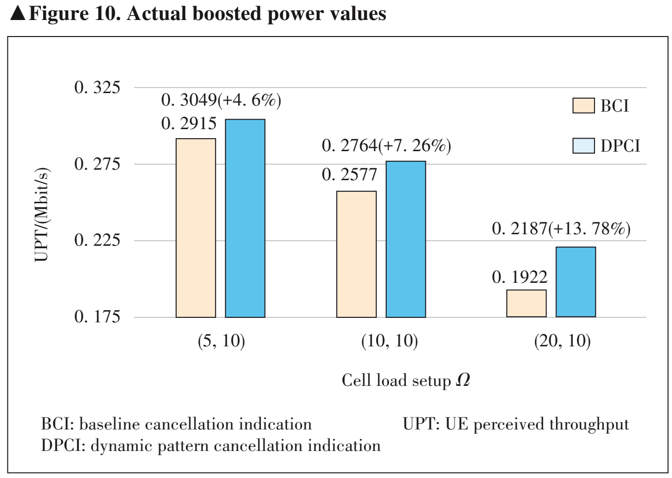
Although the cancellation method has a bigger impact on the eMBB transmission, it can effectively eliminate the interference of eMBB transmission on URLLC transmission. This is proved by the simulation results in Table 4, where DPCI and BCI show better performance compared with power control-based methods for the performance of URLLC transmission. From Table 4, we can also see that the performance of the URLLC using DPCI is almost the same as that of BCI.



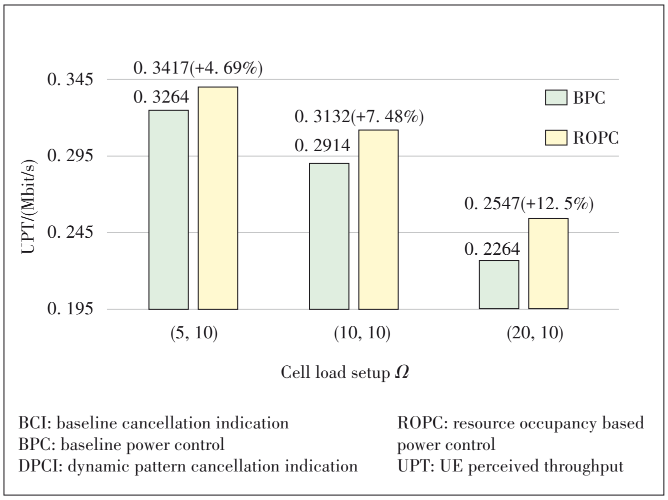
▲Figure 9. Statistics of time domain occasions occupied by URLLC



▲Figure 10. Actual boosted power values



▲Figure 11. UPT of evolved mobile broadband (eMBB) transmission for BCI and DPCI



▲ **Figure 12. UPT of evolved mobile broadband (eMBB) transmission for BPC and ROPC**

▼ **Table 4. Percentage of UE satisfying reliability and latency requirements for URLLC transmission in different multiplexing methods**

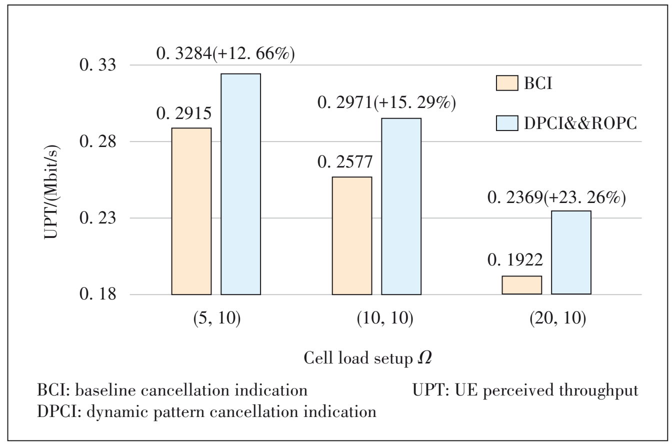
Multiplexing Method	Ω = (5,10)	Ω = (10,10)	Ω = (20,10)
No scheme/%	84.37	78.64	66.71
BCI/%	93.33	89.87	80.64
DPCI/%	93.27	89.64	80.62
BPC/%	87.78	83.97	73.84
ROPC/%	88.34	86.47	76.77

This is because both DPCI and BCI can cancel the eMBB transmission, which means no interference on URLLC transmission. From Table 4, the URLLC UEs' satisfaction rate of ROPC is increased by 2.93% compared with BPC, which is mainly because ROPC can dynamically boost the power by 9 dB under the condition that 6 dB cannot ensure the normal URLLC transmission.

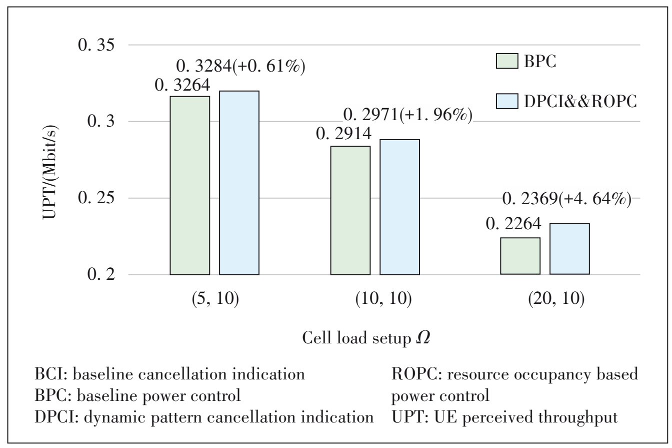
4.4 System Performance Comparison for the Dynamic Selection Mechanism and Baseline Methods

In this subsection, we provide the simulation results for the dynamic selection of DPCI and ROPC method. The simulation assumption is the same as that described in subsection 4.3. The system-level simulation results about UPT of eMBB transmission and the performance of the URLLC transmissions are shown in Fig. 13, Fig. 14 and Table 5.

As shown in Fig. 13 and Fig. 14, the dynamic selection method shows the best performance of eMBB transmission in all scenarios. For eMBB transmission performance, it can be observed that the dynamic selection mechanism has a maximum gain of 23.26% compared with BCI and a maximum gain of 4.64% compared with BPC. In Table 5, the percentage of URLLC UE satisfying the requirements of the dynamic selection mechanism is increased by 3.75% and 10.54% compared with BCI and BPC, respectively. It is mainly due to the two methods that can complement each other, which means another method can be used when one method is not supported.



▲ **Figure 13. UPT of evolved mobile broadband (eMBB) transmission for BCI and the dynamic selection mechanism**



▲ **Figure 14. UPT of evolved mobile broadband (eMBB) transmission for BPC and the dynamic selection mechanism**

▼ **Table 5. Percentage of UE satisfying reliability and latency requirements for URLLC transmission in different baseline methods and the dynamic selection mechanism**

Combination Case	Ω = (5,10)	Ω = (10,10)	Ω = (20,10)
BCI/%	93.33	89.87	80.64
BPC/%	87.78	83.97	73.84
DPCI&&ROPC/%	96.14	92.99	84.38

BCI: baseline cancellation indication
BPC: baseline power control
DPCI: dynamic pattern cancellation indication
ROPC: resource occupancy based power control
UE: user equipment
URLLC: ultra-reliable and low latency communications

5 Conclusions

To solve the coexistence problem of eMBB and URLLC UE in one service cell, the service multiplexing system model is provided. Based on the model, DPCI with a 2D bitmap resource indication and ROPC with dynamically indicating multiple levels of power control parameters are proposed for making up the shortcomings of the existing multiplexing methods. In addition, a dynamic selection mechanism based on DPCI and ROPC is proposed to accommodate the varying cases in different scenarios. Extensive system level simulations and analyses are conducted, results of which show that about 10.54% more URLLC UE satisfies the requirements, and the user perceived throughput of eMBB UE is increased by 23.26%.

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