Analysis and Optimization of the High Uplink PRB Utilization Rate Problem in LTE Networks

Liqiong Huang, CunLi Duan*

Xi'an Technological University, Xi'an 710021, China
**Corresponding author: Duancunli2003@126.com*

Abstract: *With the continuous growth in the number of mobile network users, the issue of high uplink Physical Resource Block (PRB) utilization rate has become increasingly prominent, severely restricting the improvement of network performance and user experience. This paper starts from the physical layer resource allocation mechanism of LTE networks, deeply explores the causes of high uplink PRB utilization rate, and proposes targeted optimization strategies based on practical cases. By adjusting pre-scheduling parameters, optimizing Scheduling Request (SR) false alarms, and managing abnormal User Equipment (UE) scheduling, the uplink PRB utilization rate is effectively reduced, significantly enhancing network performance and user perception. The research results demonstrate that reasonable configuration of network parameters plays an important role in improving the overall performance of LTE networks.*

Keywords: *LTE network; uplink PRB utilization rate; PUSCH; pre-scheduling; SR false alarms*

1. Introduction

In modern wireless communication systems, Long Term Evolution (LTE) technology has become one of the world's mainstream mobile communication standards due to its outstanding performance and wide range of application scenarios. Although 5G is rapidly being deployed, LTE remains the primary bearer network in many countries and regions because of its extensive coverage and widespread terminal adoption. According to statistics, by the end of 2024, LTE accounted for approximately 40% to 50% of global mobile data traffic. However, with the continuous increase in the number of users and the explosive growth in data service demands, resource allocation and utilization efficiency issues in LTE networks have gradually emerged. High uplink Physical Resource Block (PRB) utilization not only causes network congestion but also reduces users' access success rates and data transmission speeds, seriously affecting user experience. Therefore, an in-depth study of the causes of high uplink PRB utilization and the proposal of effective optimization strategies hold significant theoretical and practical value for improving the overall performance of LTE networks and user satisfaction.

1.1 Research Background

With the widespread adoption of smartphones and mobile internet applications, user demand for mobile data has experienced explosive growth. As the current mainstream mobile communication technology, LTE networks carry a large volume of user data traffic. However, network resources are limited, and how to utilize these resources efficiently to meet user demands has become a significant challenge for network operators. Uplink PRB utilization rate is one of the key indicators for measuring network resource utilization efficiency. Its high level not only affects network performance but may also lead to increased user complaints, thereby impacting operators' market competitiveness. Therefore, studying the causes of high uplink PRB utilization and proposing optimization strategies holds important significance for improving network performance and user experience.

1.2 Significance of the Study

The study of the high uplink PRB utilization issue allows for an in-depth understanding of the shortcomings in the LTE network resource allocation mechanism, providing a theoretical basis for network optimization. Meanwhile, implementing optimization strategies can effectively reduce the uplink PRB utilization rate, enhance network performance and user perception, decrease user complaints, and strengthen operators' market competitiveness. Furthermore, the research findings can offer valuable references for resource management in future 5G networks, possessing significant theoretical and practical value.

2. PUSCH and PRB Principles in LTE Networks

2.1 Principle of PUSCH (Physical Uplink Shared Channel)

The Physical Uplink Shared Channel (PUSCH) is a shared channel in LTE networks used for uplink data transmission, carrying uplink service data from User Equipment (UE) to the base station (eNodeB). The resource allocation and scheduling mechanism of PUSCH is one of the key factors affecting LTE network performance. In LTE systems, PUSCH resource allocation is achieved through dynamic scheduling. The base station allocates a certain number of Physical Resource Blocks (PRBs) to each user for data transmission based on factors such as the user's Channel State Information (CSI), service priority, and network load. The scheduling strategy of PUSCH directly influences the utilization of uplink resources and the user's transmission performance.

The resource allocation process of PUSCH can be divided into the following steps:

2.1.1 Channel State Information Feedback

The UE obtains channel state information by measuring downlink Reference Signals (RS) and reports it back to the base station.

2.1.2 Resource Allocation Request

The UE sends a Scheduling Request (SR) or Buffer Status Report (BSR) to the base station according to its own service requirements, requesting uplink resource allocation.

2.1.3 Resource Allocation Decision

The base station allocates PUSCH resources to the UE based on the UE's channel state information, service priority, and network load, and notifies the UE through an Uplink Grant (UL Grant) message.

2.1.4 Data Transmission

The UE performs uplink data transmission based on the allocated PUSCH resources.

The resource allocation strategy for PUSCH needs to comprehensively consider multiple factors, including channel quality, user priority, service type, and network load. A reasonable resource allocation strategy can improve resource utilization, reduce transmission delay, and enhance user experience.

2.2 Principle of PRB (Physical Resource Block)

The Physical Resource Block (PRB) is the basic unit of resource allocation in LTE networks. Each PRB contains a certain number of subcarriers (typically 12 subcarriers with a bandwidth of 180 kHz). PRBs serve as the fundamental units for resource allocation and scheduling in LTE networks. The base station allocates a certain number of PRBs to the User Equipment (UE) to manage resources for both uplink and downlink channels. The method of PRB allocation directly affects network resource utilization and user transmission performance.

In LTE networks, PRB allocation methods can be divided into two types: static allocation and dynamic allocation. Static allocation refers to assigning fixed PRB resources to users during system initialization, which is suitable for services with high real-time requirements, such as VoLTE. Dynamic allocation refers to allocating PRB resources dynamically based on the user's channel state information and service demands, suitable for services with varying bandwidth needs, such as video streaming.

The utilization rate of PRBs is an important indicator for measuring the efficiency of network resource allocation. Its calculation formula is as follows:

PRB utilization rate=PRB occupancy average/PRB Available Average*100%

The definition of uplink PRB utilization rate is:

Uplink PUSCH PRB utilization during busy hours=The occupancy of the upward PUSCH PRB during busy hours/(Average available PUSCH PRB during busy hours * k)*100%

Here, K is the adjustment coefficient, usually set to 0.5. The busy hour refers to the hour with the highest combined uplink and downlink traffic.

3. Problem Description

In the LTE network of a certain area, despite the implementation of measures such as deploying dual-layer networks, inter-frequency networking, and micro cells, the uplink PRB utilization rate in some cells remains high, leading to an increase in user complaints. Analysis of three key indicators at half-hour intervals across the entire network reveals that the total number of RBs allocated for uplink pre-scheduling in the PUSCH exceeds the actual number of RBs used by users. This indicates a significant waste of pre-scheduled PRB resources, which is one of the main reasons for the high uplink PRB utilization rate.

3.1 Phenomenon Analysis

Detailed analysis of cells with high PRB utilization reveals the following issues:

3.1.1 Waste of Pre-scheduled Resources

The number of RBs allocated in pre-scheduling is significantly greater than the actual RBs required for data transmission, resulting in substantial resource waste.

3.1.2 Excessive Retransmission Rate

More than 13% of resources are used for HARQ retransmissions, further exacerbating the high uplink PRB utilization.

3.1.3 Abnormal UE Scheduling

Some UEs exhibit abnormal scheduling behavior, occupying a large amount of PRB resources while transmitting very little actual data.

3.1.4 SR False Alarm Issue

SR false alarms cause numerous unnecessary retransmissions, increasing the uplink PRB utilization.

3.2 Impact Analysis

High uplink PRB utilization has multiple negative impacts on network performance and user experience:

3.2.1 Network Congestion

High PRB utilization leads to resource contention, preventing the network from accommodating additional user connections and degrading overall performance.

3.2.2 Reduced User Access Success Rate

Resource scarcity may cause new connection requests to be denied, lowering the user access success rate.

3.2.3 Decreased Data Transmission Rate

Insufficient resource allocation under high PRB utilization reduces users' data transmission rates, adversely affecting user experience.

3.2.4 Increased User Complaints

Deterioration in network performance results in more user complaints, undermining the operator's market competitiveness.

4. Cause Analysis

4.1 Unreasonable Configuration of Pre-scheduling Parameters

By conducting CellDT tracking on the cell with the highest uplink PRB utilization during busy hours in the live network, the RB allocation of PUSCH within one hour was statistically analyzed. The results are shown in the table below:

TYPE	Total number of uplink RB allocations	Proportion	Parametric Note
CQI_ONLY	1361	0.52%	CQI
CTRL_SIG	2372	0.90%	Control signaling
DynHarq	35320	13.43%	retransmission
DynHarqConf	1732	0.66%	retransmission
HAPPY	31189	11.86%	data transmission
Preamble	441	0.17%	Random Access
Presch	178895	68.04%	Pre scheduling
SR	11623	4.42%	First transmission

The table shows that the number of RBs allocated through pre-scheduling is significantly greater than the actual RBs required for data transmission, indicating that most of the pre-allocated resources are not effectively utilized. In addition, over 13% of the resources are used for HARQ retransmissions, which is another issue contributing to the overall high uplink PRB utilization.

4.2 Excessively Long Duration of Intelligent Pre-scheduling

The pre-scheduling parameter configuration of the tracked site is shown in the table below:

BS name	Local community identification	The ratio of system bandwidth available to pre scheduled users per TTI (%)
H327654	1	75
H327654	2	75
H327654	3	75

The proportion of bandwidth allocated for pre-scheduling is excessively high, with a recommended value set at 25%. A further inspection of the pre-scheduling parameter settings across the entire network revealed that almost all cells have the intelligent pre-scheduling duration configured at 160 ms, which is three times the recommended value. This leads to a large number of empty packets, further exacerbating the high uplink PRB utilization.

The setting of the intelligent pre-scheduling duration has a significant impact on network performance. If the duration is too long, pre-scheduling will occupy a large amount of PRB resources even when users have no data transmission needs, causing resource waste. For example, assuming a user triggers intelligent pre-scheduling once due to downlink data within 160 ms, but the UE has no uplink data or signaling to send during this period, the pre-scheduling result will be an empty packet. With a 50 ms parameter, up to 10 empty uplink pre-scheduling packets may be triggered, whereas with a 160 ms parameter, up to 32 empty uplink pre-scheduling packets can be triggered.

4.3 SR False Alarms and Preamble False Alarms

Analysis of the scheduling situation for individual users revealed that most users exhibit continuous abnormal behavior: the initial request type is SR, followed by four consecutive retransmissions, indicating a high probability of SR false alarms. Statistical analysis of the network-wide hourly average uplink retransmission rate shows that the retransmission rate during early morning hours is significantly higher than during the day, consistent with the temporal characteristics of SR false alarms.

In addition, the calculation formula for the probability of preamble false alarms is:

Preamble false alarm

$$\text{rate}=\frac{(\text{L.RA.GrapA.Resp}+\text{L.RA.GrapB.Resp})-(\text{L.RRC.ConnReq.Msg}+\text{L.RRC.ConnReq.Msg.disc.FlowCtrl})}{\text{L.RA.GrapA.Resp}+\text{L.RA.GrapB.Resp}}*100\%$$

Statistics on the network-wide daily preamble false alarm probability reveal that 1,117 cells have a daily preamble false alarm probability exceeding 10%. This further highlights the severity of the preamble false alarm issue.

5. Solutions

5.1 Optimization of Pre-scheduling Parameters

Based on the above analysis, the unreasonable configuration of pre-scheduling parameters is one of the main causes of high uplink PRB utilization. Therefore, it is recommended to optimize the pre-scheduling parameters by adjusting the system bandwidth ratio available for pre-scheduled users per TTI from 75% to 25%, and reducing the duration of intelligent pre-scheduling from 160 ms to 50 ms. Adjusting the pre-scheduling parameters can effectively reduce the waste of RB resources allocated by pre-scheduling and lower the uplink PRB utilization.

5.2 Optimization of SR False Alarms

The SR (Scheduling Request) false alarm issue in LTE mainly results from misjudgments during the transmission and reception of the SR signal. SR is a request sent by the UE (User Equipment) to the eNodeB (Evolved Node B) to apply for uplink resources for data transmission. After the UE sends the SR signal, the eNodeB may fail to correctly decode the signal for various reasons, causing false alarms. The SR false alarm problem leads to a large number of unnecessary retransmissions, increasing uplink PRB utilization. Therefore, it is recommended to optimize the SR false alarm detection algorithm to reduce the SR false alarm probability. Specific measures include:

Adjusting the SR false alarm threshold to reduce misjudgments;

Optimizing the SR detection algorithm to improve detection accuracy;

Enabling the PUSCH DTX detection function to reduce empty packet transmissions caused by UE inactivity.

5.3 Optimization of Abnormal UE Scheduling

Abnormal UE scheduling causes significant resource wastage, increasing uplink PRB utilization. Therefore, it is recommended to optimize the scheduling of abnormal UEs to reduce their resource occupation. Specific measures include:

Enabling the function to stop scheduling abnormal UEs, reducing their resource occupation;

Optimizing UE scheduling strategies to allocate resources reasonably based on the UE's channel conditions and service requirements.

5.4 Verification of Optimization Effects

After implementing the above optimization measures, Cell DT tracking was conducted on the optimized cells to collect statistics on PUSCH RB allocation. The results are shown in the table below:

TYPE	Total number of uplink RB allocations	Proportion	Parametric Note
CQI_ONLY	583	0.53%	CQI
CTRL_SIG	6574	5.92%	Control signaling
DynHarq	29110	26.23%	retransmission
DynHarqConf	894	0.81%	retransmission
HAPPY	19281	17.38%	data transmission
Preamble	1553	1.40%	Random Access
Presch	40292	36.31%	Pre scheduling
SR	12678	11.43%	First transmission

The table shows that when the pre-scheduling parameters are set properly, the proportion of RBs occupied by pre-scheduling significantly decreases, while the proportion of RBs occupied by retransmissions noticeably increases. This indicates that the optimization measures effectively reduce the wastage of pre-scheduled resources and lower the uplink PRB utilization.

5.5 Network-wide Optimization Effects

To further verify the effectiveness of the optimization measures, parameters across the entire network were adjusted, and the following indicators were measured before and after optimization: uplink PRB utilization rate, uplink retransmission rate, uplink block error rate, and proportion of high-interference cells. The results are shown in the table below:

Area	Optimization Content	Uplink PRB Utilization	Uplink Retransmission Rate	Uplink Block Error Rate	High Interference Cell Ratio
1	Full Parameter Optimization	Improved	Improved	Improved	Improved
2	Intelligent Pre-scheduling Duration	Improved	No Change	No Change	Slightly Improved
3	Abnormal UE Scheduling Stop	Slightly Improved	Improved	Improved	No Change
4	SR False Alarm	Slightly Improved	Slightly Improved	Slightly Improved	No Change

Through the above optimization measures, the effective uplink DRB usage remained stable, the uplink pre-scheduled PRB usage decreased overall, and the total PRB usage on the PUSCH also reduced accordingly. The optimized network performance improved significantly, with a substantial reduction in user complaints.

6. Conclusion

This paper conducted a detailed analysis of an LTE network in a certain region, exploring the causes of high uplink PRB utilization and proposing targeted optimization strategies. The research results indicate that adjusting pre-scheduling parameters, optimizing SR false alarm detection, and improving abnormal UE scheduling can significantly reduce uplink PRB utilization, thereby enhancing network performance and user experience.

TD-LTE capacity is often limited by the uplink; to ensure access for more users, the PUCCH channel must occupy more resources, which leads to a reduction in available resources on the PUSCH channel and a decrease in the number of usable RBs. To further improve user experience and reduce PRB utilization, resource waste should be minimized, user demand should be fully accommodated, and the number of available RBs should be increased to rationalize utilization. Future research can further explore more efficient resource allocation algorithms and scheduling strategies to meet the growing user demands and data traffic.

Nonetheless, some issues still require further investigation. Future research directions include exploring more efficient resource allocation algorithms to handle increasing user demand; studying resource management strategies for 5G networks to adapt to more complex service requirements; and optimizing resource allocation strategies through user behavior analysis to further enhance user experience.

With the popularization of 5G networks and the rapid development of the Internet of Things, wireless network resource management faces greater challenges. Future studies can further explore efficient resource allocation algorithms and scheduling strategies, combining artificial intelligence and machine learning technologies to develop intelligent network resource management solutions that meet users' demands for high-quality communication services.

References

[1] Wang Xiaoming. LTE Network Optimization Practice and Case Analysis [M]. Beijing: Posts & Telecom Press, 2015.
[2] Zhang Hongke. Wireless Communication Network Optimization [M]. Beijing: Publishing House of Electronics Industry, 2014.
[3] Li Jiandong. Modern Wireless Communication Network Technology [M]. Beijing: Science Press, 2013.