OSS Data based Evaluation Algorithm for Radio Utilization Rate under 5G Massive MIMO

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***Abstract*—As a key technology of 5G, massive MIMO technology is widely applied in wireless cellular network, which significantly increases the number of accepted users and effectively absorbs the hotspot traffic. Meanwhile, radio network resource expands from time domain and frequency domain to space domain. The traditional method which only consider the resource in frequency domain cannot satisfy the requirement of load evaluation. Consequently, the metrics of radio resource utilization rate needs to be studied and redefined. In this paper, a new algorithm of radio resource utilization rate of 5G under MIMO scenario is proposed, in order to precisely evaluate the network load. OSS (Operation Support System) data collected from the current network is analyzed and displayed to verify the effectiveness of the algorithm proposed in this paper.**

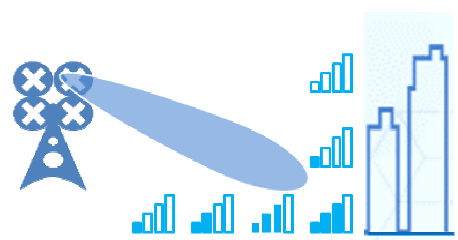
***Keywords*—5G, massive MIMO, OSS, spatial capability, radio resource utilization rate, fitting**

I. INTRODUCTION

MIMO (Multi-Input-Multi-Output) technology was introduced for the first time in 4G, and is maturely deployed in 5G. It multiplexes time and frequency resource with the method of increasing the number of receiving and transmitting antennas, thereby improving the capability of radio network of 5G system [1][2]. The number of antennas used in traditional MIMO technology is small and the coverage of the actual signal is limited to one single horizontal direction, namely 2D-MIMO [3][4].

In recent years, telecom operators have deployed 5G system worldwide [5]-[8]. One of the 5G system design goals is to achieve network coverage with large bandwidth, high capacity, and big number of access users [9]-[11]. New technologies need to be introduced to achieve the above goals, and massive MIMO technology came into being accordingly. Massive MIMO, which is an enhancement of traditional MIMO technology, dramatically increase the number of antennas in the implementation, from 2/4/8 antennas of 4G to as many as 64/128/256 antennas of 5G [12]. The radiation direction of signal is also extended from single horizontal dimension to horizontal and vertical dimensions, forming 3D-MIMO technology with space beam scanning capability [13].

Massive MIMO technology can be divided into SU-MIMO (Single-user MIMO) and MU-MIMO (Multi-user MIMO) according to the number of UEs scheduled on the same time-frequency resources. In the realization of SU-MIMO technology, one single user is scheduled on the same time-frequency resource, and the user adopts multi-rank transmission mode to realize the spatial multiplexing. MU-MIMO technology is to schedule multiple users on the same time-frequency resource simultaneously, and each user applies different coding weight to accomplish resource multiplexing. The application of SU-MIMO technology can increase the peak throughput of single users. However, the number of antennas that can be supported by user terminals is limited, usually 4 antennas for 5G terminals and the number of scheduled layers is less than or equal to the number of antennas in the user terminal. Consequently, the capacity advantage of massive MIMO technology cannot be exploited in SU-MIMO scenario [14][15]. On the other hand, in MU-MIMO technology which is widely used in radio network of 5G, multi-users are paired to simultaneously transmit data to the network side. With this method, we can increase cell capacity and maximize the gains brought by massive MIMO technology. At the same time, resource on radio interface in 5G system can be expanded from the two dimensions, time domain and frequency domain, to three dimensions, which are time domain, frequency domain and space domain [2].



(a) 4G 2D-MIMO

(b) 5G massive MIMO

Fig. 1. Comparison of 4G and 5G MIMO technology

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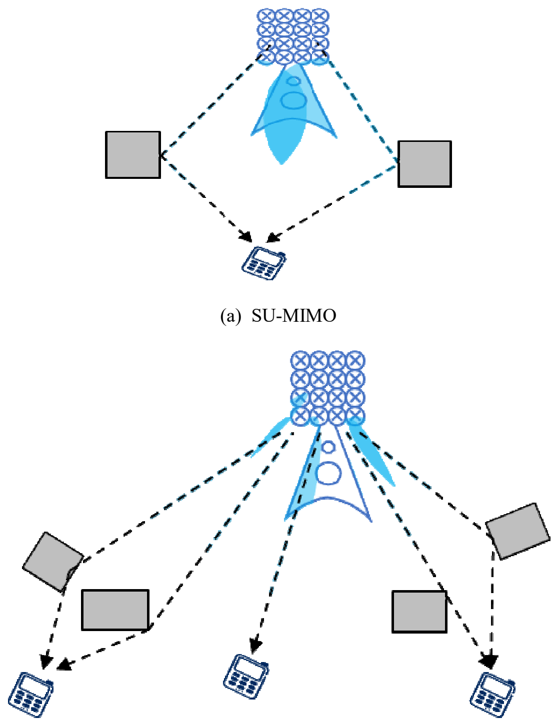


(a) SU-MIMO

(b) MU-MIMO

Fig. 2. Comparison of SU-MIMO and MU-MIMO technology

On one hand, the radio resource of 5G system expanded form 2-dimension to 3-dimension, on the other hand, the evaluation system of resource utilization in 5G is not perfect. MASSIVE MIMO technology has been applied on a large scale in 5G, but there is still no accurate representation method of cell space resources. In the current studies, the factor used to represent the spatial capability in the algorithm of radio resource utilization is limited to a constant value which is not in accordance with the characteristics of MIMO technology.

In this paper, several methods to describe the spatial capability of a cell are studied and the best of them is selected as a part of denominator of the PRB usage formula which can accurately indicates the load of 5G radio network.

The rest of the paper is organized as follows. In section II, we introduces the existing algorithm of radio resource utilization rate. In section III, the new model and algorithm of scheduled layers and radio resource utilization rate proposed in this paper are elaborated. The data verification and analysis are revealed in section IV. Section V gives the conclusion.

II. RADIO RESOURCE EVALUATION AND PROBLEM ANALYSIS

Massive MIMO, as a new technology, has been introduced into 5G network, and consequently the capacity of radio interface is greatly improved in space domain. Therefore, it is essential to remodel the radio resource evaluation model and design the algorithm.

A. Resource Utilization Rate in Current network

In the traditional 4G network, the antenna configuration commonly used by FDD base station equipment is 2T2R, and that commonly used by 4G network terminals is 1T2R [16]. In FDD-LTE networks, due to the limitation of the antenna number, usually two transmission layers are used in the downlink and one transmission layer in the uplink, which does not require user pairing. That is, it is only applicable to SU-MIMO scenarios with low RANK. When evaluating the radio resource utilization rate of 4G network, only the two dimensions, time and frequency, need to be considered. Therefore, PRB utilization rate can be used to evaluate the radio resource load in LTE and the corresponding model and algorithm are relatively simple.

In 5G wireless network, base stations have a great improvement on the number of antennas. Most of gNodeBs are equipped with 64-Transmit-64-Receive antenna channels. The maximum number of downlink configuration layers can reach as many as 16, and that of uplink can also reach 8. In the meantime, commercial terminals of 5G has also been upgraded to support 1-Transmit-4-Receive antenna channels. The simultaneous improvement on the both sides provides a strong guarantee for the implementation of massive MIMO technology. Base stations in 5G network which can support both SU-MIMO and MU-MIMO transmission modes are able to select the transmission mode dynamically according to the different user distribution and different channel state in order to maximize the utilization of time, frequency and space resources. When evaluating the radio resource utilization rate for 5G, three-dimension modelling is needed to investigate the three-domain resources and to design the algorithm accordingly.

Measurement and calculation methods about radio resource utilization rate of 5G have been defined in both 3GPP TS28.552 [17] and 3GPP TS38.314 [18]. 3GPP TS28.552 defines the calculation method of PBR usage in 5G following the traditional way the same as that of LTE, which only takes the usage percentage of time and frequency domain. The definition in 3GPP TS38.314 defines a new equation to calculate PRB usage under massive MIMO scenario in 5G. On the basis of frequency domain resources, an evaluation of space domain resources is added. The calculation equation is as (1):

$$M(T) = \left\lfloor \frac{\sum_{\forall i} \sum_{\forall j} \{M1_{ij}(T) * L_{ij}(T)\}}{N(T) * P(T) * Alpha} * 100 \right\rfloor \quad (1)$$

The parameters in formula (1) are described in TABLE I.

TABLE I. PARAMETER DESCRIPTION FOR FORMULA

Name	Definition
M(T)	Total PDSCH PRB usage per cell which is percentage of PRBs used, averaged during time period *T* with integer value range: 0-100;
$M1_{ij}(T)$	The number of PRB occupied by UE i at sampling occasion j;

Name	Definition
$L_{ij}(T)$	The scheduled layers number of UE i at sampling occasion j;
N(T)	The total number of sampling occasions taken during time period T;
P(T)	The total number of PDSCH PRBs available for 1 sampling occasion on single MMO layer per cell;
Alpha	The spatial factor, is a constant value configured by OAM with integer value range:1-100. With this parameter, M(T) should be reasonable, not more than 100

In the above PRB usage formula on MIMO scenario, variables representing the number of layers are added to the numerator and denominator respectively, where $L_{ij}(T)$ in the numerator indicates the actual layers occupied by PRB and *Alpha* in the denominator indicates the available layers of the cell.

B. Problem Analysis of Existing Algorithms

By analyzing formula (1) defined in 3GPP, it shows that frequency domain resources are taken into consideration in conjunction with space domain resources when evaluating resource utilization rate in 5G. In the formula defined in TS 38.314, the numerator contains the number of actually occupied PRBs and the number of actually scheduled layers per PRB. The denominator contains the number of PRBs available for each layer and space factor Alpha, which represents the number of available layers of the cell.

The characteristics of MIMO technology indicates that the number of layers available for a cell is related to three key factors: the cell geographic environment, radio wave propagation model and user distribution [19]. When the channel state of a cell and the distribution of users change, the available layers of a cell will change as well. In the above formula, there is no detailed suggestion and no specific method for the value of Alpha in the denominator, but only a requirement is put forward which is the value of Alpha as a constant cannot make the overall PRB utilization rate under MIMO scenario greater than 100%.

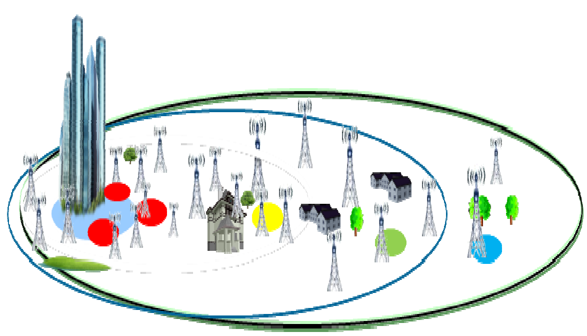
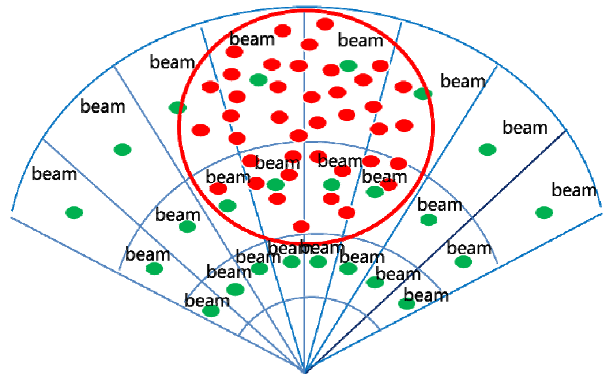
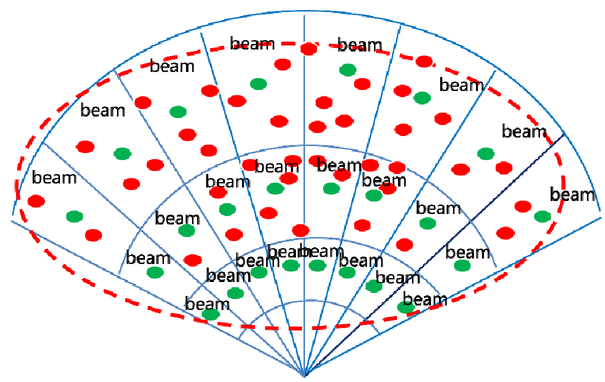


Fig. 3. Geographic environments of different cells

Different cells are located in different geographic environments. Cells that are responsible for the coverage of urban areas usually experience more complex multipath condition which is easy to achieve higher number of MIMO scheduled layer. However, cells covering rural area generally have flat geographic environments which will lead to poor spatial capability. Geographic environments of different cells are shown in Fig. 3.



(a) User distribution 1: Gathered



(a) User distribution 2: Scattered

Fig. 4. Distribution of user in typical commercial scenario

For a single cell, users' distribution will always change with time. Fig. 4 illustrates a user case of users distribution in typical commercial scenario. The upper sub-figure shows the user distribution in a cell at one sampling occasion when the users are gathered together while the lower sub-figure shows the user distribution in the same cell at another sampling occasion when the users are scatter to somewhere else. Obviously, the lower the correlation of users is, the higher the probability of MU-MIMO paring is.

In the evaluation of actual radio resource utilization, factors such as the geographical environment where each cell is located, the distribution of users connected to the cell, the types of services a cell carried and the volume of a cell are all different, which will cause the number of spatial layers that the cells can reach to be different. The number of available layers will change with time and space dynamically. The constant integer, Alpha, in the current PRB usage formula defined in TS 38.314 cannot represent the spatial capabilities in different cells under different scenarios. If Alpha is artificially unified to a fixed constant, it will result in radio resource utilization rate anomalies:

- When alpha is set large, the unreachable limit capacity is used in the denominator for some cells, which leads to the low utilization rate of PRB but poor user perception.
- When alpha is set small, the PRB usage of some cells may exceeds 100 which is not reasonable.

Based on the above reasons, this paper aims at optimizing and updating the space multiplexing factor algorithm in the formula. Therefore, it can precisely reflect the actual spatial capabilities of different cells under different user distribution scenarios.

III. PROPOSED OPTIMIZED ALGORITHM FOR RESOURCE UTILIZATION IN MASSIVE MIMO

The allocation method and schedule algorithm of time-frequency resource in 5G are similar to those of 4G, so the bullet point of modeling the new algorithm of radio resource utilization rate is the explicit representation of spatial capability of a cell. For a given time range and given bandwidth, available time resource and frequency resource of a cell are fixed, that is the number of available PRBs is fixed. Different from the above fixed calculation method, spatial resource of a cell is dynamically changing.

MU-MIMO technology needs to schedule multiple users paring and transmitting data on the same time-frequency resource block simultaneously. It requires that channel quality and correlation of paired users meet certain thresholds to trigger MU-MIMO function to start. Under different user distributions in the same cell and under different channel environments in different cells, the spatial capabilities of the cells are different, and dynamically change with the user distribution's change. Therefore, designing a core algorithm to dynamically and accurately reflect the spatial capabilities of different cells has the highest priority for completing the 5G radio resource utilization evaluation.

Based on the above consideration, several algorithms to dynamically describe the spatial capability of a cell are studied and we explore the advantages and disadvantages of every algorithm to choose the best one to represent the available layer.

Available layer number is a metric to measure the spatial capability of a cell. Using an algorithm to accurately and dynamically describe the number of available layers of a cell is an effective method to explicitly describe spatial capabilities.

In the first part of this chapter, we compare three kinds of algorithm to calculate the available layer number of a cell and every one of them has some disadvantages. The proposed algorithm, time domain averaged maximum scheduled layer number, is introduced in the second part. The third part gives the resource utilization rate formula proposed in this paper using the chosen method to represent the available layer number.

A. Related Works about Spatial capability

1) Configuration layer number as available layer number

In the first scheme, available layer number equals to the configuration layer number which is configured when opening the gNodeB according to the license provided by the vendor who manufactured the gNodeB.

Configuration layer number is a concept in OAM system which is the upper limit of the gNodeB hardware regardless of the other factors. Available layer number will be much more overestimated if the configuration layer number is used. Hence, the corresponding PRB usage will be significantly underestimated.

2) Time and frequency domain maximum layer number as available layer number

In the second scheme, available layer number equals to the time and frequency domain maximum layer number. In the statistical period, at every sampling occasion the maximum scheduled layer number of all PRBs is collected as sampling value. At the end of statistical duration, the maximum of all the sampling values is the time and frequency domain maximum layer number. We take the downlink as an example, the formula is shown as follows:

$$LMM(T) = MAX_j\{L_{\max_j}(T)\} \quad (2)$$

The parameters used in formula (2) are depicted in the following table:

TABLE II. PARAMETER DESCRIPTION FOR FORMULA

Name	Definition
LMM(T)	The time and frequency domain maximum layer number of PDSCH in time period T.
$L_{\max_j}(T)$	The maximum number of scheduling layer of PDSCH at sampling occasion *j*.
j	The sampling occasion during time period *T*. A sampling occasion is 1 symbol.

The result of this scheme is the maximum of all sampling values. Usually the statistical period of OAM system is 15 minutes which is much larger than the sampling interval, 1 symbol. The time and frequency domain maximum layer number is the top 1 value of all the scheduled layer numbers in the statistical period of all PRBs, the occurrence of which is a low probability event having a degree of chance. It only can represent the spatial capability of the sampling occasion at which the maximum is collected rather than the others.

If time and frequency domain maximum layer number is used as available layer number in the PRB utilization rate formula, the result will be underestimated because the spatial factor is overestimated and cannot represent the real spatial capability.

3) Time and frequency domain averaged layer numer as available layer number

In the third scheme, available layer number equals to the time and frequency domain averaged layer number. In the statistical period, at every sampling occasion number of PRBs used is accumulated corresponding with the scheduled layer number. At the end of statistical duration, the time and frequency domain averaged layer number is the average value of scheduled layers among all PRBs that are used within the period in the cell. The average value is obtained by this formula:

$$LA(T) = \frac{\sum_{\forall i} i * \sum_{\forall j} R_{ij}(T)}{\sum_{\forall i} \sum_{\forall j} R_{ij}(T)} \quad (3)$$

The parameters used in formula (3) are depicted in the following table:

TABLE III. PARAMETER DESCRIPTION FOR FORMULA

Name	Definition
LA(T)	The time and frequency domain averaged layer number of PDSCH in time period T.
$R_{ij}(T)$	the number of PDSCH PRBs multiplexed by i MIMO layers at sampling occasion j.
i	An integer denotes a MIMO layer number that is scheduled in time period T;
j	The sampling occasion during time period *T*. A sampling occasion is 1 symbol.

The result of this scheme is obtained by computing the average value of scheduled layers of all PRBs that are used in the statistical duration in a cell. The spatial resource occupation can be revealed by this indicator. However, it represents the amount of spatial resource that is occupied rather that of available.

On the other hand, if the time and frequency domain average layer number is used as spatial factor in the PRB utilization rate formula, the factors used in the denominator and in the numerator are the same and will be eliminated, which leads to the PRB utilization rate in MIMO scenario falling back to the traditional PRB usage algorithm only considering the time and frequency domain without space domain.

B. Time Domian averaged Maximum Scheduled Layer Nmuber

Based on the above consideration, a new algorithm to calculate radio resource utilization rate based on dynamic spatial factor is proposed in this paper. The indicator, Time domain averaged maximum scheduled layer number, is introduced to dynamically represent the actual spatial capability of a cell. Because the result of time domain averaged maximum scheduled layer number is predefined by algorithm and automatically calculated by OAM system, the radio resource utilization rate calculated with this algorithm is guaranteed not more than 100 and indicates the real-time available spatial resources of different cells under different user distribution scenarios.

The proposed optimization algorithm of radio resource utilization rate used in massive MIMO scenario will be introduced in this section. Business traffic volume of downlink is usually higher than that of uplink in the current network traffic model, which result in an earlier resource limitation in the downlink channels than that in the uplink channels [20]-[24]. In this paper, the research of algorithm takes the downlink channel as an example, which is also applicable in the uplink.

Time domain averaged maximum scheduled layer number is defined as: in the statistic period, sampling is carried out at fixed intervals, the maximum number of scheduled layers on all PRBs at each sampling occasion is taken as the sampling value. At the end of the statistical period, the average value of all non-zero sampling values is calculated as the time domain averaged maximum scheduled layer number. Among them, the maximum scheduled layer number of every sampling occasion is the maximum number of MU-MIMO paired layers or SU-MIMO scheduled RANK. The sampling occasions at which the scheduled layers is/are zero don't participate into the calculation of average value. The formula of time domain averaged maximum scheduled layer number is shown in (2) (3):

$$LM(T) = \frac{\sum_j L_{\max_j}(T)}{K(T)} \quad (4)$$

$$K(T) = \sum_{j, L_{\max_j}(T) \neq 0} 1 \quad (5)$$

The parameters in formula (4) and formula (5) are shown in TABLE IV.

TABLE IV. PARAMETER DESCRIPTION FOR FORMULA

Name	Definition
LM(T)	The time-domain average maximum scheduling layer number of PDSCH in time period *T*.
$L_{\max_j}(T)$	The maximum number of scheduling layer of PDSCH at sampling occasion *j*
K(T)	The number of sampling occasions at which is not 0.;
T	Time Period during which the measurement is performed
j	The sampling occasion during time period *T*. A sampling occasion is 1 symbol.

C. Optimization Algorithm of Radio resource Utilization Rate in massive MIMO

LM(T), the time domain averaged maximum scheduled layer number is used as a dynamic factor to characterize the space multiplexing capability of a cell. Therefore, the formula for calculating the utilization rate of downlink radio resources under massive MIMO scenario is as follow:

$$M_E(T) = \left\lfloor \frac{\sum_{\forall i} i * \sum_{\forall j} R_{ij}(T)}{N(T) * P(T) * LM(T)} * 100 \right\rfloor \quad (6)$$

The parameters defined in formula (6) are illustrated in the following table.

TABLE V. PARAMETER DESCRIPTION FOR FORMULA

Name	Definition

Name	Definition
$M_E(T)$	Total PDSCH PRB usage per cell which is percentage of PRBs used, averaged during time period T with integer value range: 0-100.
$R_{ij}(T)$	The number of PDSCH PRBs multiplexed by i MIMO layers at sampling occasion j.
N(T)	The total number of sampling occasions taken during time period T;
P(T)	The total number of PDSCH PRBs available for 1 sampling occasion on single MMO layer per cell;
LM(T)	The time-domain average maximum scheduling layer number of PDSCH in time period T.
T	Time Period during which the measurement is performed
j	The sampling occasion during time period *T*. A sampling occasion is 1 symbol.
i	An integer denotes a MIMO layer number that is scheduled in time period T;

$M_E(T)$ can be applied to evaluate the resource load of radio network in 5G and the algorithm can be deployed both in Sub-6 GHz of FR1 and mm Wave of FR2.

IV. Result and Analysis

Section IV tries to verify the effectiveness of the model and algorithm for radio resource utilization rate proposed in this paper. Therefore, we enabled the MU-MIMO function in some high load areas in the actual commercial 5G network, and some OSS data in busy hours have been collected from the live network. We applied the proposed algorithm on the original OSS data to calculate the radio resource utilization rate. Fig.3 shows the trend of the radio resource utilization rate calculated by the algorithm proposed in this paper with the downlink traffic volume of the cell. In order to demonstrate the effectiveness of the algorithm, the traditional algorithm to calculate PRB usage which only takes time and frequency domain into consideration is also given in Fig. 5.

In Fig. 5, the abscissa is the downlink RLC layer traffic volume of the cell, and the ordinate is the downlink resource utilization rate of the cell in percentage. The blue scatters represent the PRB utilization rate where only time-frequency domain is considered, while the gray scatters represent the radio resource utilization rate calculated by the proposed algorithm in this paper. The curves of different colors represent the fitting trend based on the corresponding scatters.

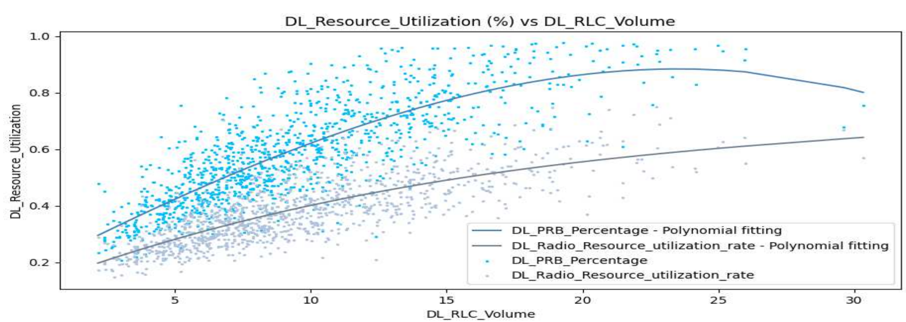


Fig. 5. Relationship between downlink radio resource utilization rate and downlink traffic volume

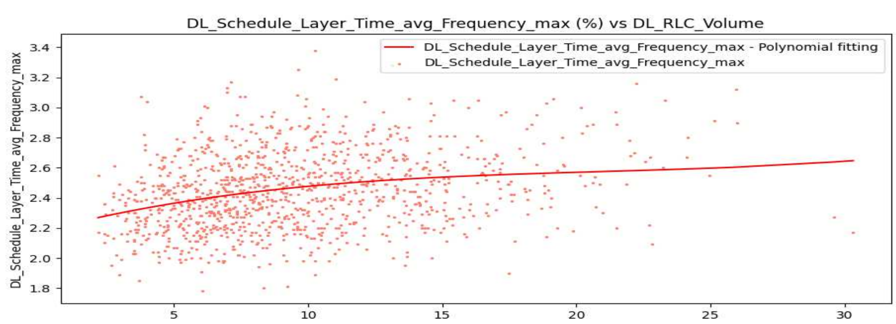


Fig. 6. Relationship between time domain averaged maximum scheduled layer number and downlink traffic volume

By analyzing the above figure, it can be seen that the radio resource utilization rate calculated by the algorithm proposed in this paper rises smoothly with the increase of traffic volume. This algorithm is compatible in both SU-MIMO and MU-MIMO scenarios, and there is no need to switch algorithm frequently depending on whether MU-MIMO function is triggered, so the fitting curve is very smooth. The time domain averaged maximum scheduled layer number is adopted as spatial capability factor to calculate the radio resource utilization rate the result of which is reasonable and can reflect actual load of network.

As a comparison, the PRB utilization rate only considering time and resource of frequency domain without that of space domain results in an artificially high utilization rate. In addition, when the traffic volume increase to a certain threshold to trigger MU-MIMO function, the users who meet the conditions preferred to be paired to realize the space multiplexing, resulting in an unreasonable trend that the traffic volume increases with a decrease of the PRB usage rate. Consequently, the PRB usage rate could not accurately reflect the real network load after the application of massive MIMO technology.

Fig. 6 shows the trend of time domain averaged maximum scheduled layer number along with the traffic volume. The abscissa is downlink RLC layer traffic volume of the cell, and the ordinate is the time domain averaged maximum scheduled layer number of cell. The red scatters represent the current network scheduling layer number data calculated by the algorithm proposed in this paper, and the curve represents the corresponding fitting trend. With the increase of traffic volume of the cell, time domain averaged maximum scheduled layer number rises smoothly, which can reflect the change trend of spatial multiplexing capability of a cell under different scenarios.

In this paper, the proposed dynamic spatial multiplexing capability calculation algorithm performs arithmetic average of all effective sampling points during the statistical period. Since the statistical period is much larger than the sampling interval, we can accumulate a large number of sampling points. The large number of collected data can effectively shield the influence of singular points on the overall value. Therefore, the calculation result can reflect the actual capacity of a cell.

Overall, the algorithm of this paper provides a detailed, operable and realistic method to represent the actual spatial multiplexing capability of a cell and explicitly and dynamically display the spatial schedulable resource of a cell. There is no need to frequently adjust the fixed parameter or algorithm according to different cell scenarios, different user distributions and whether the MU-MIMO function is triggered. Applying our proposed model and algorithm, which calculate the radio resource utilization rate of 5G network, can jointly investigate on total radio resource occupancy of time domain, frequency domain and space domain. It can assist telecom operators and vendors to be aware of the load of wireless network and to decide whether to expand the capacity of the network in massive MIMO scenario.

V. CONCLUSIONS

A new algorithm of radio resource utilization rate in 5G network is proposed in this paper. The new algorithm takes the resource of time domain, frequency domain and space domain into consideration simultaneously. The result of the new algorithm can reflect the actual resource utilization of a cell after MU-MIMO is activated in the early stage of 5G and help operators be aware of whether a cell has experienced high load in the late stage of the network.

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