Dynamic resource management algorithms for interference prediction in 5G new radio scenarios

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Dynamic resource management algorithms for interference prediction in 5G new radio scenarios

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Abstract

Efficient Radio Resource Management is a key mechanism in interference management in 5G New Radio (NR) networks, specifically in the case of the presence of mobile users moving at high speed. To this end, the prediction and the evaluation of the propagation channel sensitivity requires that the radio resources allocation in NR must be efficient and powerful. Therefore, several scheduling algorithms have been developed and tested using the mmWave model of NS-3 simulator, with the aim of enhancing their contribution to improving the quality of the signal received by users. The performances have been evaluated in terms of Signal-to-Interference-and-Noise-Ratio (SINR) and signal Block Error Rate (BLER). The simulations were run for different types of data flows, and achieved satisfactory results for most schemes. The achievements clearly show the importance of scheduling algorithms in lowering received interference, but they have also demonstrated the stability and reliability of some of those strategies.

Keywords: 5G, Flexible numerology, New radio, Radio Resource Management (RRM), scheduling algorithms, SINR, TBER, BLER.

1 Introduction

5G NR systems is characterized by application diversity. It supports three main use cases. First, enhanced mobile broadband (eMBB) for applications that will need a very high transmission speed (eMBB could reach a data rate of 20 Gb/s in Downlink (DL)) [1].

Secondly, Ultra-reliable and low latency communications (URLLC) which is used for applications with very critical response time constraints (URLLC system has latencies of 1ms) [2].

The third use case is Massive Machine Type Communications (mMTC). This scenario is dedicated to networks with a large number of connected devices (Internet of Things (IoT)). mMTC may allow the connection density of up to 1 million devices per km^2 [1] [2].

Other network characteristics, with the improvements offered by 5G NR, are presented in Table 1 [3][4][5].

The Radio Resource Management (RRM) in 5G systems is very complex. The assignment of Resource Blocks (RB) is based on dimensions of space, frequency, and time. RRM at the NR level has brought several improvements compared to the old version used in the LTE series. In the frequency domain, various sub-bands of the radio spectrum should be allocated to each use case, using proper numerology, whereas in the time domain, and for each of those spectrum portions, the available radio resources will be assigned, every Transmission Time Interval (TTI) to the Data Radio Bearers (DRBs) using a packet scheduling algorithm [6].

RRM could be considered as an essential key factor for satisfying the requirements of the 5G environment, in terms of efficient management of available spectrum and harmful interference, in addition to fairness and Quality of Service (QoS) requirements [7].

The packet scheduling, which is the main function of the RRM, is managed by the Medium Access Control (MAC) sub-layer at the level of the gNB/ng-eNB (Next Generation Node Base Station/Next Generation eNode B) which allows rapidity of communication between the base station and the users, as well as a prompt decision-making by the RRM entity. The element responsible for the allocation of radio resources (scheduling) is called "Scheduler". This is a key element for a quick and efficient assignment of RBs [8].

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Table 1 5G System parameters

Specifications	5G NR values
Radio Frame Duration	10ms
Number of subframes in a frame	10
Number of slots in a frame	20
Maximum number of data subcarriers	3300
Number of RBs	Higher or equal to 100
Carrier Aggregation (Maximum Component Carriers)	16
TTI (Transmission Time Interval)	Flexible (TTI = # of symbols * symbol length)
Subcarrier Spacing	Flexible: 15, 30, 60, 120, 240, 480 KHz.
Frequency Bands	Up to 100 GHz
Carrier Bandwidth	Variable, maximum per Component Carriers is 400 MHz: Below 6 GHz band: From 100 to 200 MHz Above 6 GHz band: From 100 MHz to 1 GHz.
Beamforming	With and without DL/UL reciprocity
Modulation	QPSK, 16-QAM, 64-QAM and 256-QAM
MIMO (Multiple-Input Multiple-Output)	Up to 8X8
Channel Coding Scheme	Control plan: NR Polar codes; User plan (Data): NR LDPC.

The NR scheduler (for DL and UL) must satisfy several constraints, such as monitoring of the channel quality of each UE, as well as the control of the available resources in each TTI for scheduling [9].

The packet scheduling algorithms (for DL and UL) are implemented in the MAC layer at the level of the gNB/ng-eNB base station. At each TTI, resources are allocated to different users [2] [10].

As we can observe in Fig. 1, the interaction between the DL/UL packet scheduler and other entities, to schedule the incoming/outgoing flows, is presented.

Based on the Channel Quality Indicator (CQI) reports, delivered by the users to the base stations, the scheduler decides on the assignment of the RBs to each UE, according to the scheduling strategy approach used by the gNB. The data transmitted between the UL/DL schedulers and the network entities (UE, other layers...) are forwarded via multiple physical (PHY) channels.

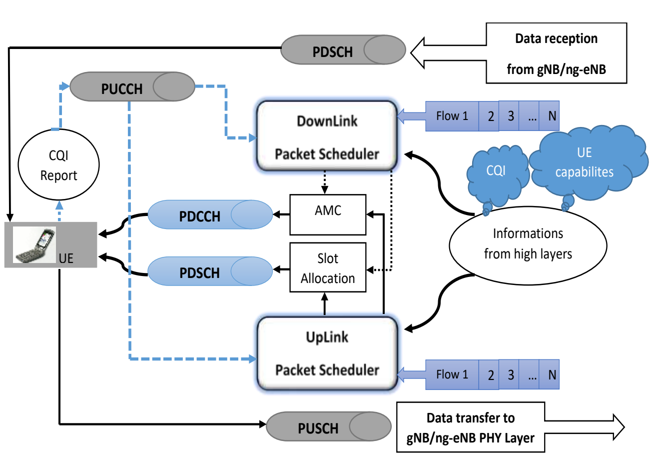

Fig. 1 5G NR scheduler schematization for UL and DL

This paper deals with the scheduling mechanism in the bands above 6 GHz, also called Millimeter waves (mmWave). We have chosen to study the RRM in this band, which are the frequencies between 30 GHz and 300 GHz, because of the lack of work carried out on this aspect, in addition to the great opportunity offered by this band for 5G NR networks, and also because it is a favored candidate for IMT (International Mobile Telecommunications) systems [11]. Technically, the mmWave band offers bandwidths of at least 800 MHz and going to 1 GHz for eMBB. The use of mmWave frequency bands for mobile cellular communications becomes a necessity, following the enormous use of the band below 6 GHz [12] [13].

Taking into consideration that the dynamic allocation of radio resources in 5G NR networks, which is the main task of the RRM component, must be carried out in a precise and efficient manner, the study and the choice of the best scheduling algorithms, precisely for the DL transmission, are of fundamental importance [14]. So, the scheduling schemes, characterizing the method followed by gNB/ng-eNB to assign available RBs to active users requesting to receive packets, must be proposed, implemented, and tested by the scientific community.

This field is a new area in which the carried-out studies suffer from a great lack of details and analyzes. So, it is needed to propose efficient and powerful strategies for 5G NR MAC layer. These new algorithms must consider the channel sensitivity prediction, to improve the quality of experience (QoE) of mobile users.

Although the field of scheduling algorithms for 5G networks is interesting, few studies have been launched to address its various questions and to suggest new resource management approaches.

The authors in [15] have proposed a two-level MAC scheduling framework whose objective is to reduce latency for URLLC services. This strategy, named Slice Specific Resource Management (SSRM), has its Network Function (NF) to schedule its users, both in UL and DL. The flexibility of SSRM to make dynamic slice management decisions, and its ability to improve timely data delivery has been demonstrated while respecting the heterogeneous needs of the coexisting eMBB and mMTC applications.

Eisen et al. [16] have introduced a control optimal scheduler that reserves one or two subframes in each 5G frame, in order to schedule the low latency traffic used for control. The efficiency of the use of the limited available RB by allocating radio resources relative to underlying control system dynamics and states has been demonstrated.

In [17], Agile 5G scheduler has been suggested, featuring a new end-to-end QoS architecture, which improves the application layer and works in harmony with the Agile MAC scheduler lower layer. The new MAC scheme offers many options including scheduling with dynamic TTI sizes and different PHY numerologies and flexible synchronization. The results show throughput up to 20 Mbps, and latency values of about 0.2 ms.

On the other hand, some works have been devoted to the analysis of the scheduling operation in the mmWave band. In [18], the QoS-oriented joint optimization problem of resource allocation and the concurrent scheduling between backhaul and access link has been investigated. For this purpose, an enhanced reverse-Time Division Duplex (TDD) frame, called ER-TDD, is designed for the mm-wave integrated backhaul and access network (IBAN). The achieved throughput for different scenarios is about 30 Gbps.

Furthermore, the authors in [19] have driven further studies of outage reduction with joint scheduling and power allocation in 5G mmWave cellular networks, whereas the scheduling method introduced in [19] has demonstrated that the beam-aware MAC framework improves throughput under power constraint.

Moreover, the receiver reference sensitivity requirements for 5G NR have not been significantly addressed or analyzed by the scientific community. Among the rare works dealing with this field, we cite the reference [20] which introduces an ML-based technique named Non-linear Auto-Regressive External/Exogenous (NARX)-based Artificial Neural Network (ANN) for predicting SINR in order to mitigate the radio resource usage in cellular mobile networks. Therefore, the throughput has achieved 77 Mbps (64QAM) whereas the bandwidth efficiency is about 80%.

Additionally, inter-numerology interference (INI) needs to garner more attention in recent researches. NR reference sensitivity, based on the signal-to-noise ratio (SNR), has been evaluated in [21] for both sub-6 GHz and millimeter-wave frequency ranges, only for UL streams. The performance results in terms of throughput and block error rate (BLER) have been presented with low-density parity-check (LDPC) code compared to turbo code. They show that in frequency selective channels, the reference sensitivity is better with the LDPC code.

Also, Chen et al. [22] and in order to solve the interference issue in a mmWave 5G system, have suggested a new mechanism to perform the scheduling in an outdoor urban downlink scenario served by mmWave gNB. At the first level, the orthogonality concept is used in spatial-time domain resource allocation, to improve throughput and system fairness. And then, a new design of the MAC layer, which reduces the inter-cell interference.

The overall goal of this work is to investigate the scheduling algorithms performance in a 5G NR environment, and to demonstrate their contribution in the prediction/prevention of interference, via two parameters, namely SINR (Signal-to-Interference-and-Noise-Ratio) and BLER (Block Error Rate).

Taking into consideration the importance of the receiver sensitivity, defined as the minimum power of the received signal at a specific BLER by the UE, in the RRM, specifically for the band above 6 GHz, as well as the relationship between the scheduling operation and the channel resistance to interference, the main contributions of this work can be summarized as follows:

- To extend the mmWave model [23] of the NS-3 tool [24], dedicated to simulating 5G networks, by developing the well-known scheduling strategies. For this purpose, eight (8) new schemes have been programmed in C++ and simulated in a typical 5G system model.
- To analyze the behavior of the proposed algorithms in terms of BLER and SINR, in order to evaluate the mobile UE sensitivity to interference. Two specific python programs have been developed to allow us to extract the results from the large files generated by the tool.

This paper is divided into four sections. The second section describes the aim of the study, with a clear description of all processes and algorithms to be used for RRM in 5G NR. In addition, the assumptions and the simulated system model are presented. The third section introduces the simulations results with analysis and discussion. In the section four, the main conclusions and an explanation of the importance and relevance of the study to the field are provided.

2 Methods

2.1 Flexible multi-numerology domain scheduling

The importance of interference management grows. One of the new 5G NR principles, which allows overcoming that challenge is the multi-numerology waveform design.

The waveform is a central technological component for 5G NR, which uses orthogonal frequency division multiplexing with cyclic prefix (CP-OFDM) modulation for DL and UL, in addition to the Discrete Fourier Transform Spread Orthogonal Frequency Division Multiplexing (DFT-S-OFDM) in UL [25].

NR transmission is well established in time and frequency. The numerology in NR represents the parameters of physical transmission such as the Sub-Carrier Spacing (SCS), the duration of the OFDM symbols, as well as the size of the CP [26].

The SCS in NR, dedicated to the data channels, are 15 kHz supersets, and the number of slots increases with υ , as explained in (1), making numerology flexible in 5G [27].

$$SCS(\Delta f) = 15\text{kHz} \times 2^{\upsilon}, \text{avec } \upsilon \in \{0,1,2,3,4,5\} \qquad (1)$$

The NR frame has a duration of 10ms and consists of 10 subframes, each with a duration of 1ms. A subframe consists of 2υ (with $5 >= \upsilon >= 0$) slots depending on the slot size [27].

An NR slot is made up of 12 or 14 OFDM symbols (for extended or normal CP respectively). The length of a slot is variable according to the used SCS and the exploited spectrum [27].

The TTI is variable and it depends on the number of symbols and the symbol length [28].

As a summary, Table 2 shows the 5G NR multi-numerology parameters, according to the 3GPP standard [28].

In NR, we define the resource grid, as presented in Fig. 2, with the dimensions N_{SC}^{RB} as the number of subcarriers per RB, and $N_{Symb}^{Subframe,\upsilon}$ as the number of symbols per subframe. One RB in NR (RB_{NR}) is defined as 12 consecutive subcarriers in the frequency domain. There are three types of RB, namely common resource blocks (CRB), physical resource blocks (PRB), and virtual resource blocks (VRB) [26].

Several resource grids are defined in NR, according to the numerology already presented in Table 2.

2.2 Interference management-based scheduling algorithms

Although the use of a multi-numerology system has provided significant flexibility required for the various applications in 5G networks, several new problems have arisen. This has introduced a non-orthogonality into the system, which causes additional interference, called inter-numerology interference, between the multiplexed numerologies [29].

The problem caused by INI becomes more complex when the coexisting numerologies adopt, in a flexible way, different parameters (SCS, number of sub-carriers, Power Offset...) [29].

In addition, the lower numerologies, depending on the value of the adopted SCS, can support a greater number of low-power devices, simultaneously connected to the network [27].

The new 5G NR frame design needs more efficient scheduling schemes, to deal with the issues like interference management, in order to fulfill diverse service requirements [30].

This section presents the mathematical models of the different scheduling algorithms, which will be simulated using our scenario, in order to investigate the performance of the 5G NR system in terms of resistance to interference, according to the used RRM strategy.

For this purpose, we assume that $W_{i,j}$ is the metric assigned to the i-th stream on the j-th subchannel, which defines the priority of a UE to transmit or receive using the allocated RB.

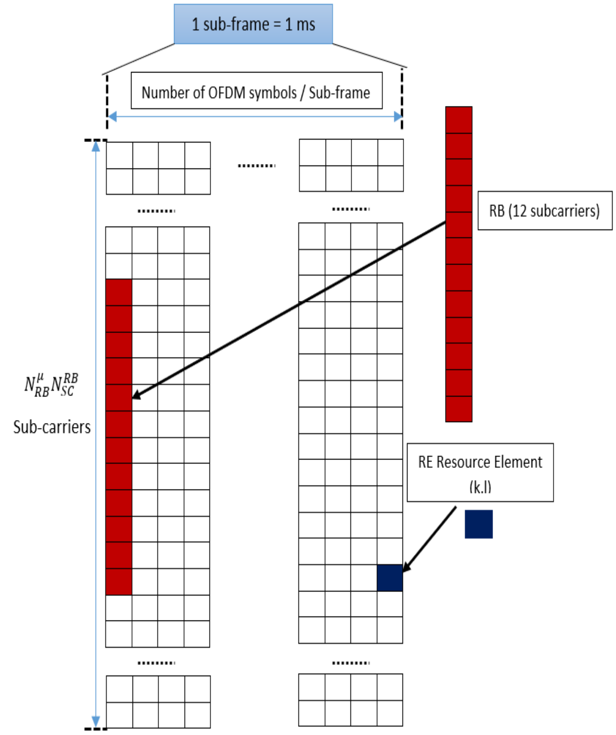

Fig 2. Representation of the resource blocks grid in NR

2.2.1 Maximum Rate (Max-Rate)

The approach applied by this scheduler is based on the history of data rates reached during the last TTI, in order to maximize the overall rate of the system. The scheduler will allocate the current RB to the UE which achieved the highest throughput in the last TTI interval. The calculation of the metric is done based on the average past data rate $R_i(k)$ [31]. R_i is estimated at each TTI, and it is given in (2), where $R_i(k)$ is the achieved data rate assigned to the i-th stream during the k-th TTI, and $R_i(k-1)$ is the estimated average data rate during the previous TTI [10].

$$\mathrm{R_i(k) = \beta R_i\,(k-1) + (1-\beta)R_i(k), 0 < \beta < 1} \quad (2)$$

For this purpose, we introduce $l\_R_i(k)$ and $r\_R_i(k)$ as the throughputs of the first and the second UE (l for left and r for right) in the current TTI. The user who can maximize the current throughput (highest previous throughput) will be served first as explained in (3).

$$\mathrm{W_{i,j\_MT} = \sum_{i=0}^{n} max(l_{R_i}(k), r_{R_i}(k))} \quad (3)$$

Table 2 Characteristics of the NR frame according to the Sub-Carrier Spacing (SCS)

υ	SCS (Δf)	Slot length	Number of symbols per slot	Duration of an OFDM + CP symbol	Number of slots / subframe	Number of subframes / frame	Number of slots per frame	Number of symbols / sub-frame	Frame duration	Subframe duration
0	15kHz	1 ms	14	71.42 us	1	10	10	14	10ms	1ms
1	30kHz	500 us	14	35.71 us	2	10	20	28	10ms	1ms
2	60kHz	250 us	14	17.85 us	4	10	40	56	10ms	1ms
3	120kHz	125 us	14	8.92 us	8	10	80	112	10ms	1ms
4	240kHz	62.5 us	14	4.46 us	16	10	160	224	10ms	1ms
5	480kHz	31.25 us	14	2.23 us	32	10	320	448	10ms	1ms

2.2.2 Earliest Deadline First (EDF)

EDF is a channel-independent scheduling scheme. Consequently, the propagation channel is considered to be time-invariant and error-free channel. The packet with the minimum deadline (the minimum $W_{i,j}$) will be first scheduled [32], as shown in (4).

$$\mathrm{W_{i,j\_EDF}} = \sum_{i=0}^{n} \min(\mathrm{l\_deadline}, \mathrm{r\_deadline}) \tag{4}$$

2.2.3 Proportional Fair (PF)

The PF scheduler is proposed to achieve a balance between fairness and spectral efficiency among different users, while a minimum bit rate is guaranteed. The metric of this algorithm can be expressed as the ratio between the instantaneous flow rate available for the i-th stream in the j-th subchannel ($r_{i,j}$) and the average data rate of the past transmission ($R_i(k-1)$) [33]. Equation (5) presents the metric computation following the PF approach.

$$\mathrm{W_{i,j\_PF}} = \frac{\mathrm{r_{i,j}}}{\mathrm{R_i(k-1)}} \tag{5}$$

The used parameters can influence the expected throughput. Consequently, the UE in bad conditions could be served, in a window of time.

2.2.4 Modified Largest Weighted Delay First (MLWDF)

M-LWDF can handle different services with different QoS requirements while improving system capacity. Equation (6) is used to calculate the metric of this algorithm. It aims to give priority to the RT streams having the least delay and the best propagation conditions on the radio channel [34].

$$\mathrm{W_{i,j\_MLWDF}} = \alpha_i \mathrm{D_{HOL,i}} \frac{\mathrm{r_{i,j}}}{\mathrm{R_i(k-1)}} \tag{6}$$

Where:

$$\alpha_i = \frac{-log\delta_i}{\tau_i} \tag{7}$$

In addition to the instantaneous and the previous bit rates ($r_{i,j}$ and R_i), $D_{HOL,i}$ is the Head of Line (HOL) packet delay, whereas α_i is a variable which characterizes each flow *i*. It is calculated from the ratio between the packet loss probability δ_i and the delay threshold τ_i (see (7)) [35].

$D_{HOL,i}$ represents the time between the arrival of a specific packet and its successful transmission. The delay threshold value is based on the type of the requested service. Table 3 illustrates τ_i values according to each application and its priority [36].

On the other hand, the probability that $D_{HOL,i}$ of a specified packet exceeds the value of the delay threshold must be less than or equal to the probability of losing this packet (δ_i) during its transmission, as shown in the inequality (8).

Table 3 Threshold delay values vs. data type

Data	Priority	Delay threshold τ_i (s)
Voice	2	0.1
Video	7	0.1
TCP-based protocols (HTTP and FTP)	8	0.3

TCP: Transmission Control Protocol, HTTP: Hypertext Transfer Protocol and FTP: File Transfer Protocol.

$$\Pr\left\{\mathrm{D_{HOL,i}} > \tau_i\right\} \leq \delta_i \tag{8}$$

To measure the packet loss probability, a two-state Markov Model (success and failure states) was introduced in [37], where the packets are transmitted successfully just in the first state due to its low error probability. During the failure state, each packet that has not succeeded in being transmitted is retransmitted until the time limit (threshold) is exceeded. We then go to the next packet.

In order to simplify this model (and simplify the equation calculating the packet loss probability δ_i), the authors in [35] consider that the success state is the most suitable scenario for the scheduling operation.

Considering that ε_i is the error probability in each state and B_i is the probability to change from a state to another (here from failure to success state), δ_i is calculated according to (9).

$$\delta_i = \varepsilon_i (1 - \mathrm{B_i})^{\tau_i} \tag{9}$$

To minimize the packet loss probability, ε_i must have the lowest possible value and it must be less than B_i. Supposing that the parameters ε_i and B_i have constant values, whereas τ_i is changing according to the application type, the equation of δ_i can be simplified [35].

As reported by [37] and during the success state, the fixed values of the two constants could be $\varepsilon_i = 0.01$ and $B_i = 0.1$, whereas τ_i is variable. Equation (9) will be presented as in (10).

$$\delta_i = 0.01 * (1 - 0.1)^{\tau_i} = 0.009^{\tau_i} \tag{10}$$

On the other hand, and during the failure state, $\delta_i \approx \varepsilon_i \approx 1$, the system is not usable.

2.2.5 Exponential MLWDF (EXP-MLWDF)

Our new algorithm EXP-MLWDF applies the exponential function to the time part of the MLWDF scheme. It was initially proposed in [38] to prioritize the UE with better channel conditions, but also to serve users with critical channel conditions.

EXP-MLWDF presents good results and satisfies QoS requirements for RT flows in a high mobility and dense area scenario [38].

To compute its metric, EXP-MLWDF uses the approach in (11).

$$W_{i,j\_EXP-MLWDF} = \alpha_i * \frac{r_{i,j}}{R_j(k-1)} * \exp\left(\frac{\tau_i}{(\tau_i - D_{HOL,i})}\right) \quad (11)$$

The different parameters have already been introduced.

2.2.6 *Exponential Rule (EXP-Rule)*

EXP-Rule mainly aims to ensure a QoS requirements compromise, namely between system data rate, fairness, and delay optimization [39].

This algorithm is based on an exponential function. It tries to minimize the delay in order to maintain a balance between the data rate and the average waiting time. This minimization was achieved by compromising the throughput of all the UEs, then the delay [32].

Noting that N is the number of streams waiting in the queue, the metric of the EXP-Rule is calculated as presented in (12) and (13). All other parameters have already been introduced.

$$W_{i,j\_EXP-Rule} = \frac{r_{i,j}}{R_i} * \exp\left(\frac{\alpha_i * D_{HOL,i}}{1+\sqrt{Y}}\right) \quad (12)$$

With: $$Y = \frac{1}{N}\sum_{i=1}^{N} D_{HOL,i} \quad (13)$$

2.2.7 *Exponential PF (EXP-PF)*

The EXP-PF is a variant of the PF scheme, allowing improvements for RT packets, where the HOL Delay (D_{HOL}) is very close to the delay threshold (τ_i) [40].

Considering τ_i, δ_i and $D_{HOL,i}$ as introduced previously, and N_{RT} as the number of RT flows to be transmitted, the equation for calculating the metric of this algorithm is split into two parts, as shown in (14) and (15) (for RT flows) and in (16) (for NRT flows).

if RT packet:

$$W_{i,j_{EXP/PF\_RT}} = \exp\left(\frac{\alpha_i * D_{HOL,i} - X}{1+\sqrt{X}}\right) * \frac{r_{i,j}}{R_i} \quad (14)$$

Where $$X = \frac{1}{N_{RT}}\sum_{i=1}^{N_{RT}} \alpha_i * D_{HOL,i} \quad (15)$$

else (NRT packet):

$$W_{i,j_{EXP/PF\_NRT}} = \frac{D_{HOL,i}}{M^{(t)}} * \frac{r_{i,j}}{R_i} \quad (16)$$

With $M^{(t)}$ is the average number of packets at time t.

2.2.8 *Logarithmic Rule (LOG-Rule)*

LOG-Rule was designed by the authors in [41] in order to satisfy a large number of users, in terms of QoS requirements regarding the delay, the data rate, and the robustness of the system (load balancing).

This algorithm uses a logarithmic delay function to make the scheduling decision. Equation (17) shows the calculation of its metric.

$$W_{i,j\_LOG-Rule} = \frac{r_{i,j}}{R_j(k-1)} * \log\left(1 + D_{HOL,i}\right) \quad (17)$$

2.3 Assumptions and system model

The simulated scenario is shown in Fig. 3. It is a typical 5G environment, with 5 gNB / ng-eNb, to cover 5 cells with a radius of about 1 km (microcell). The chosen number of mobile users is 10 UE, distributed randomly over the 5 cells, and connected at the start of the simulation to the nearest of the 5 base stations.

The use of microcells, operating at high frequencies (mmWave band), guarantees high data rates, and remarkable spectral and energy efficiency.

The 5 gNB / ng-eNB (with a power of 30 dBm) are separated from each other by a distance of approximatively 500 m. On the other hand, the 10 UEs move using the linear mobility model with a constant speed of 120 km/h, in correspondence with the mobility model "*ConstantVelosityMobilityModel*".

The simulations were also carried out using 20 UEs. Noting that the results with 10 UEs and 20 UEs have the same behavior for the SINR and the TBER, we have chosen to present only those with 10 UEs.

For the simulation of our scenario, the mmWave model [23], dedicated to the analysis and validation of 5G networks for frequencies above 6 GHz, of the multi-models NS-3 tool, was used.

Therefore, we developed in C++ the well-known packet scheduling strategies, dedicated to ensuring the management of radio resources in 5G networks, namely EDF, Max-rate, PF, MLWDF, EXP-MLWDF, EXP-rule, EXP-PF, and LOG-rule.

The *.h* and *.cc* files of each algorithm have been added to the mmWave model sub-folder '*ns3-mmwave-new-handover/src/mmwave/model*', to allow their simulation in the created environment. The *.h* and *.cc* programs of these schemes can be downloaded via [42].

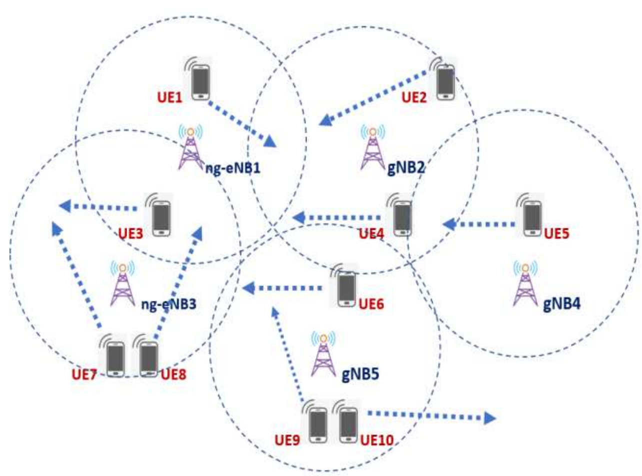

Fig. 3 Simulated system model

The performance of the programmed 08 scheduling schemes was analyzed in the proposed environment, according to the variation of the mean value of SINR and TBER. The study concerned three types of flows, namely Voice over Internet Protocol (VOIP), Video over 5G (Vi5G), and Best-effort delivery (BE).

Several RRM approaches are used in conventional interference management. Consequently, SINR and TBER aim to estimate the interference values of previous samples.

Other relevant parameters used in our scenario are listed in Table 4.

Table 4 Simulation parameters

Parameter	Value
TX power [dBm] used by gNBs	30 dBm
MmWave Propagation Loss Model	LOS (Line of sight)
Number of gNB/UE	5/10
Cell radius	1 km (microcell)
Period of estimated SINR update of all UE	1.6ms
Transient period (in microseconds) in which just collect SINR values without filtering the sample	320ms
Loss (dB) in the Signal-to-Noise-Ratio due to non-idealities in the receiver	5.0 dB
UE speed	120 km/h
UE mobility model	Constant Velocity

3 Results and discussion

The presented 08 scheduling algorithms have been simulated in the model introduced in Section V for three types of data streams, namely, BE, Vi5G, and VOIP. SINR and TBER are the two parameters that have been used to measure the participation of the RRM in the evaluation and protection against interference in 5G mMTC networks.

Two Python programs have been created in order to extract the average values of the two parameters (SINR and TBER) from the output files.

3.1 SINR optimization

The SINR is defined as the power of the signal of interest S divided by the sum of the powers of all the interference signals I and the power of certain background noise N. It indicates how much stronger the wanted signal is than noise and interference (see (18)) [43].

$$SINR(dB) = \frac{S}{N+I} \tag{18}$$

This parameter is measured by the user (receiver), which makes it possible to choose the most appropriate modulation and coding scheme (MCS) for data transmission. In a 5G NR system, it is calculated on each RB, converted into a CQI by the UE, then sent to the gNB [43].

Fig. 4, 5, and 6 illustrate the evolution of the mean SINR values for VOIP, video, and BE type streams respectively. As it is well noticed, the SINR decreases as time goes by, for all the algorithms and all the data types.

Throughout the observation period, the 08 patterns have similar values. For VOIP, MLWDF and EXP-Rule show remarkable superiority for SINR over other schemes (> 25 dB). The performance of other strategies varies over time.

For video, MLWDF and EXP-Rule are, at the start of the simulation, the schemes that allow the best performance with values above 28 dB. These two patterns lose their dominance over time in favor of the Max-Rate, which stabilizes before all other algorithms, thus allowing the maximum SINR to be reached.

The same behavior was observed for BE flows with maximum values between 21 dB and 22 dB, reached by MLWDF, EXP-Rule, and EXP-MLWDF. Gradually, it is PF and Max-Rate which ensures better stability and performance.

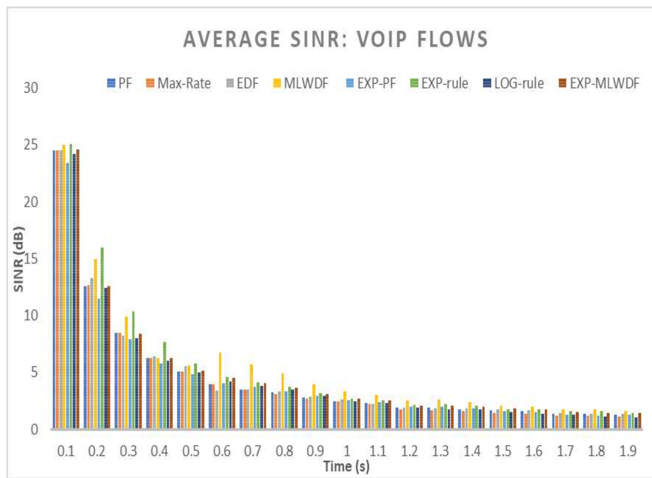

Fig. 4 Average SINR for VOIP data streams

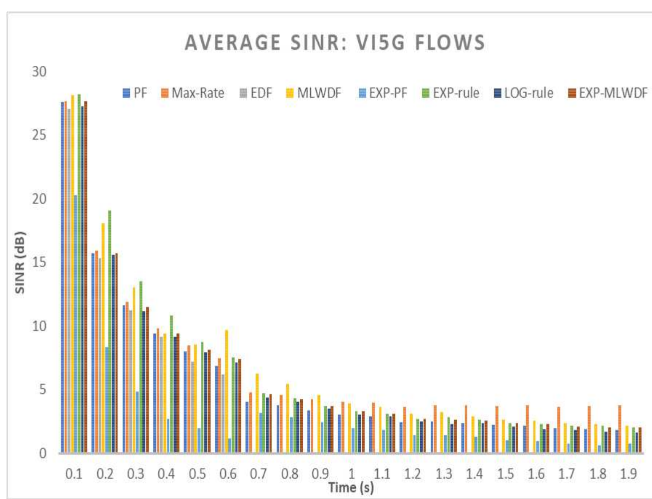

Fig. 5 Average SINR for video data streams

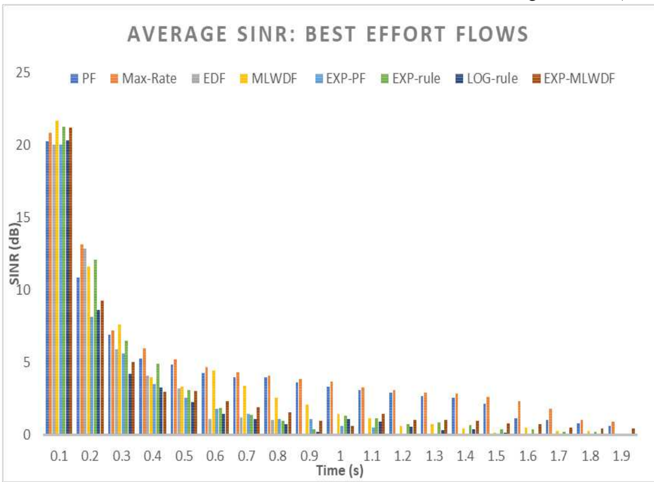

Fig. 6 Average SINR for BE data streams

According to the presented results, and assuming the high movement speed (120 km/h) of the different UEs, the total prediction accuracy decreases. Therefore, SINR is more difficult to predict. This is well explained by the random movement of the UEs (which move closer and further away from the base stations).

The MLWDF, EXP-Rule, and EXP-MLWDF algorithms are much more reliable than other schemes for RT streams. For data where the network does not provide any guarantee of delivery or QoS, PF and Max-Rate are the most recommended schemes.

According to our simulations, the densification of the 5G network by new connected devices should not degrade the performance of the SINR for the best schemes mentioned above. Interference management is well mastered.

3.2 BLER evaluation for interference sensitivity

The BER (bit error rate), often expressed as a percentage, is the number of erroneous bits on reception, divided by the total number of transferred bits during a studied time interval Δt (see (19)):

$$BER(\Delta t) = \frac{Erroneous\ bits}{Sent\ bits} \tag{19}$$

BLER is defined as the ratio of the number of received erroneous blocks to the total number of sent blocks. An erroneous block is defined as a transport block with an incorrect cyclic redundancy check (CRC) [43].

BLER is an important parameter in cellular mobile technologies, where it is used to determine the indication of synchronization or desynchronization during radio link monitoring (RLM). Its normal value is 2% for a synchronization condition and 10% for a desynchronization condition [43].

For the BLER analysis, we compare the simulation results of the eight scheduling methods, as shown in Fig. 7, 8, and 9.

For the case of RT flows (VOIP and Vi5G), we have observed that all the algorithms stabilize quickly, with values below the limit threshold for the synchronization condition (2%). In addition, 05 algorithms (PF, EXP-PF, EXP-Rule, Log-Rule, and EXP-MLWDF) ensure low and optimal values of TBER (less than 0.5% for VOIP and less than 0.2% for video).

Therefore, system stability is well guaranteed in terms of error rate and the impact of TBER on interference sensitivity.

On the other hand, and in the case of BE packets, the planning schemes will need more time to set their pace. For PF and EDF, stability appears difficult to achieve. EXP-Rule and MLWDF (which did not perform well for RT data) have the best values, being the only patterns to drop below 0.5% of TBER.

Based on the above comparison, and taking into account the reasonable achieved block error rate, the 08 strategies can be used for scheduling in the 5G NR system (where it is recommended to avoid Max-Rate and EDF for RT flows, and PF and EDF for NRT flows). The performed BLER clearly shows the contribution of RRM algorithms in the resistance to channel interference.

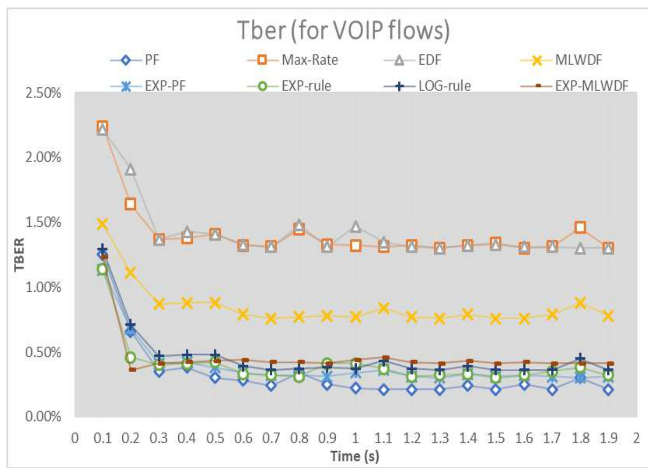

Fig. 7 Average TBER using different scheduling schemes (VOIP)

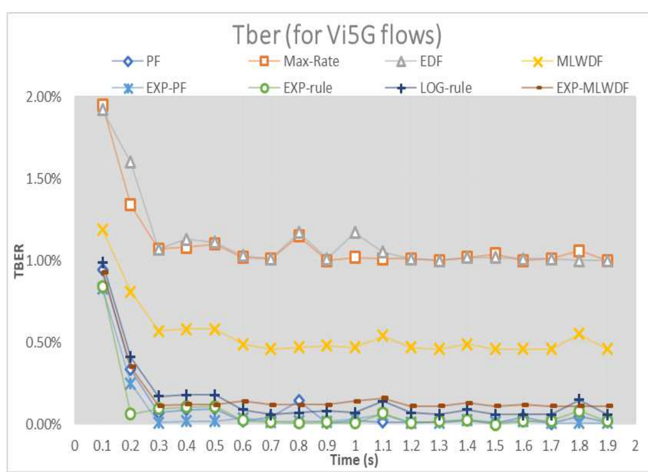

Fig. 8 Average TBER using different scheduling schemes (Vi5G)

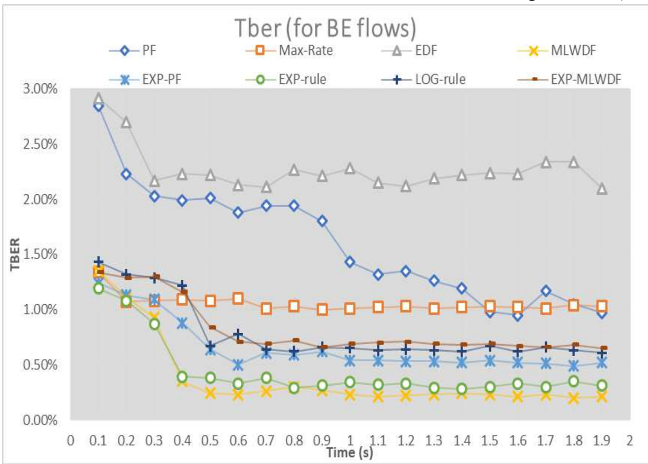

Fig. 9 Average TBER using different scheduling schemes (BE flows)

4 Conclusion

In this work, eight scheduling strategies were programmed and simulated in the mmWave model of the NS-3 simulator, to show the important role of RRM in the prediction and protection against interference in 5G NR networks.

The comparison was made in terms of SINR and BLER, where the schemes exploit the channel sensitivity in order to improve the QoE offered to mobile users.

The simulations showed that the prediction of SINR in the case of UEs high speed (120 km/h) is difficult. On the other hand, some resources planning schemes allow achieving good SINR values, thus demonstrating their efficiency in the signal-to-noise ratio improvements.

Additionally, the necessary robustness against interference in frequencies above 6 GHz is well guaranteed via a powerful RRM. The achievements in terms of BLER are encouraging for most of the scheduling algorithms.

Abbreviations

5G: Fifth Generation; ANN: Artificial Neural Network; BE: Best Effort; BLER : Block Error Rate; CP-OFDM: Orthogonal Frequency Division Multiplexing with Cyclic Prefix; CQI: Channel Quality Indicator; CRB: Common resource block; DFT-S-OFDM: Discrete Fourier Transform Spread Orthogonal Frequency Division Multiplexing; DHOL: Head of Line Delay; DL: Downlink; DRB: Data Radio Bearer; EDF: Earliest Deadline First; eMBB: enhanced mobile broadband; eNB: eNodeB; FTP: File Transfer Protocol; ER-TDD: enhanced reverse-Time Division Duplex; EXP-MLWDF: Exponential MLWDF; EXP/PF: Exponential PF; EXP-Rule: Exponential Rule; gNB: Next Generation Node Base Station; HTTP: Hypertext Transfer Protocol; IBAN: integrated backhaul and access network; IMT: International Mobile Telecommunications; INI: Inter-numerology Interference; IoT: Internet of Things; LDPC: low-density parity-check; LOG-rule: Logarithmic Rule; LOS: Line of Sight; LTE: Long Term Evolution; MAC: Medium Access Control; Max-Rate: Maximum Rate; MIMO: Multiple-Input Multiple-Output; MLWDF: Modified Largest Weighted Delay First; mMTC: Massive Machine Type Communications; mmWave: Millimeter waves; NARX: Non-linear Auto-Regressive External/Exogenous; ng-eNB: Next Generation eNB; NR: New Radio; NS-3: Network Simulator-3; PF: Proportional Fair; PHY: Physical layer; PRB: Physical resource block; QAM: Quadrature amplitude modulation; QoS: Quality of Service; QPSK: quadrature phase-shift keying; RB: Resource Block; RRM: Radio Resource Management; SCS: Sub-Carrier Spacing; SINR: Signal-to-Interference-and-Noise-Ratio; SNR: signal-to-noise ratio; SSRM: Slice Specific Resource Management; NF: Network Function; TBER: Transport Block Error Rate; TCP: Transmission Control Protocol; TDD: Time Division Duplex; TTI: Transmission Time Interval; UE: User Equipment; UL: Uplink; URLLC: Ultra-reliable and low latency communications; Vi5G: Video over 5G; VOIP: Voice over Internet Protocol; VRB; Virtual resource block.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request. Please contact the corresponding author at Ismail.angri@gmail.com.

Authors' contributions

IA developed the algorithms using the C++ language and carried out the simulation. He also drafted the manuscript. MM and AN revised the manuscript. All the authors participated in shaping the main idea, analyzed and interpreted the results, and read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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Figures

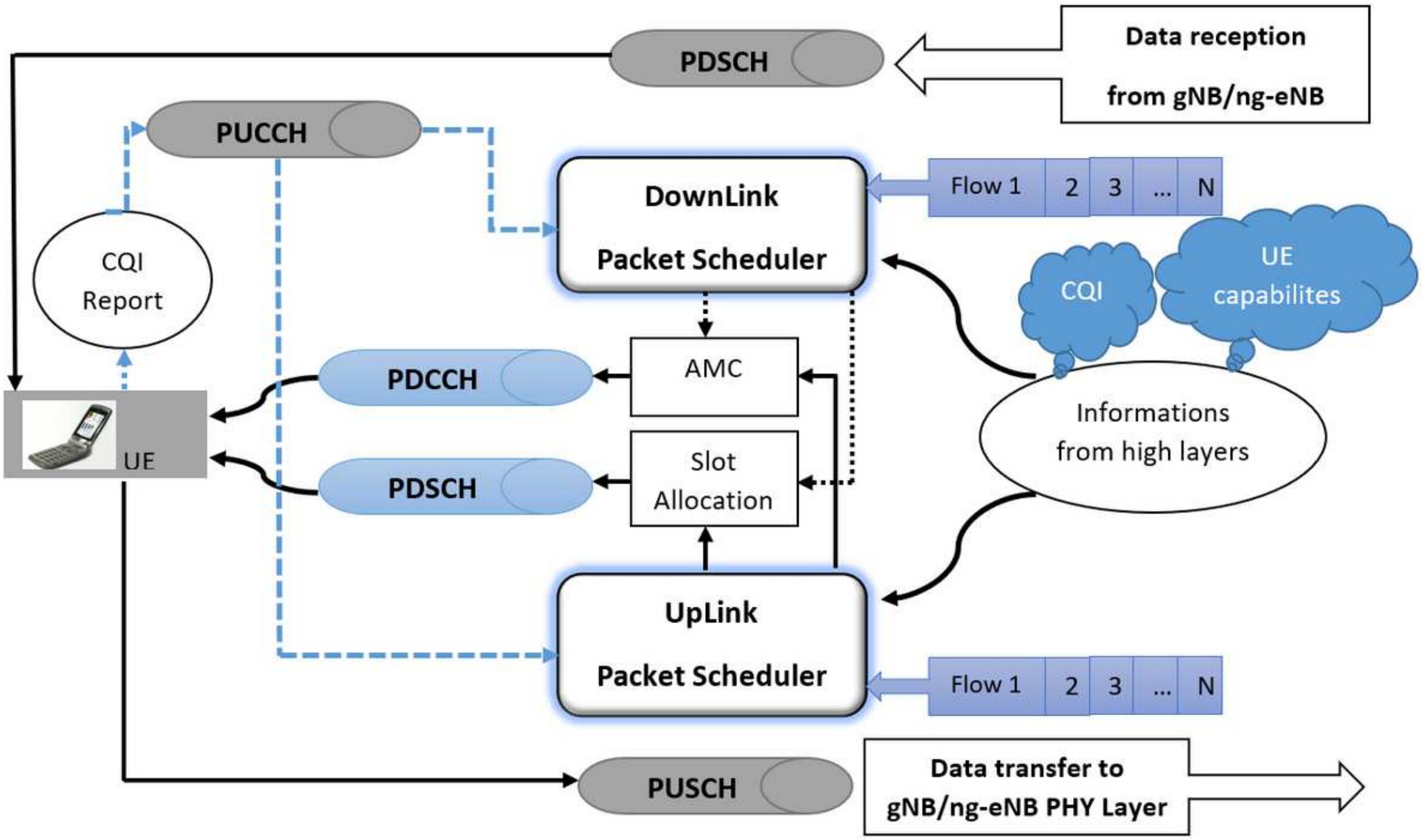

Figure 1

5G NR scheduler schematization for UL and DL

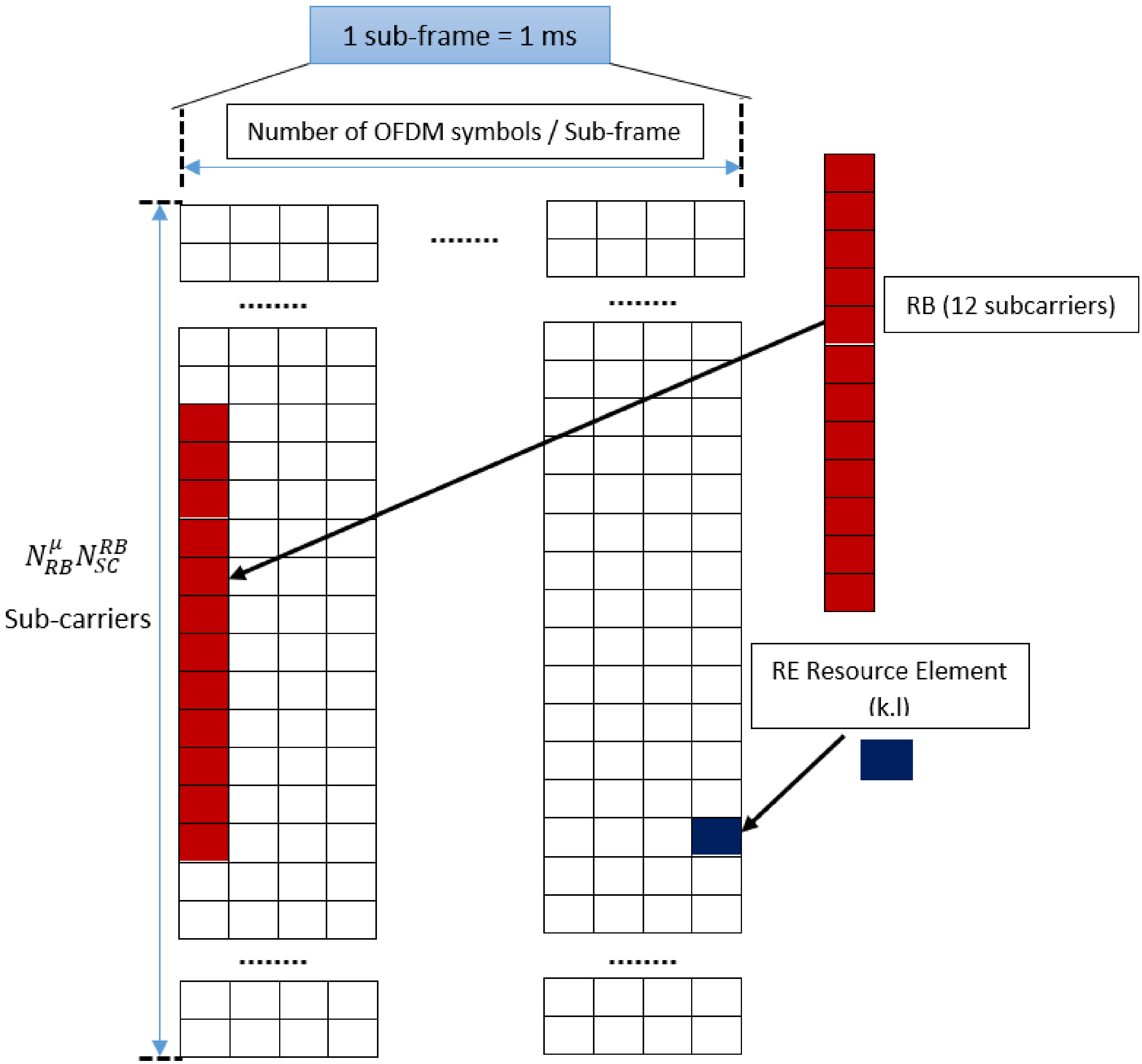

Figure 2

Representation of the resource blocks grid in NR

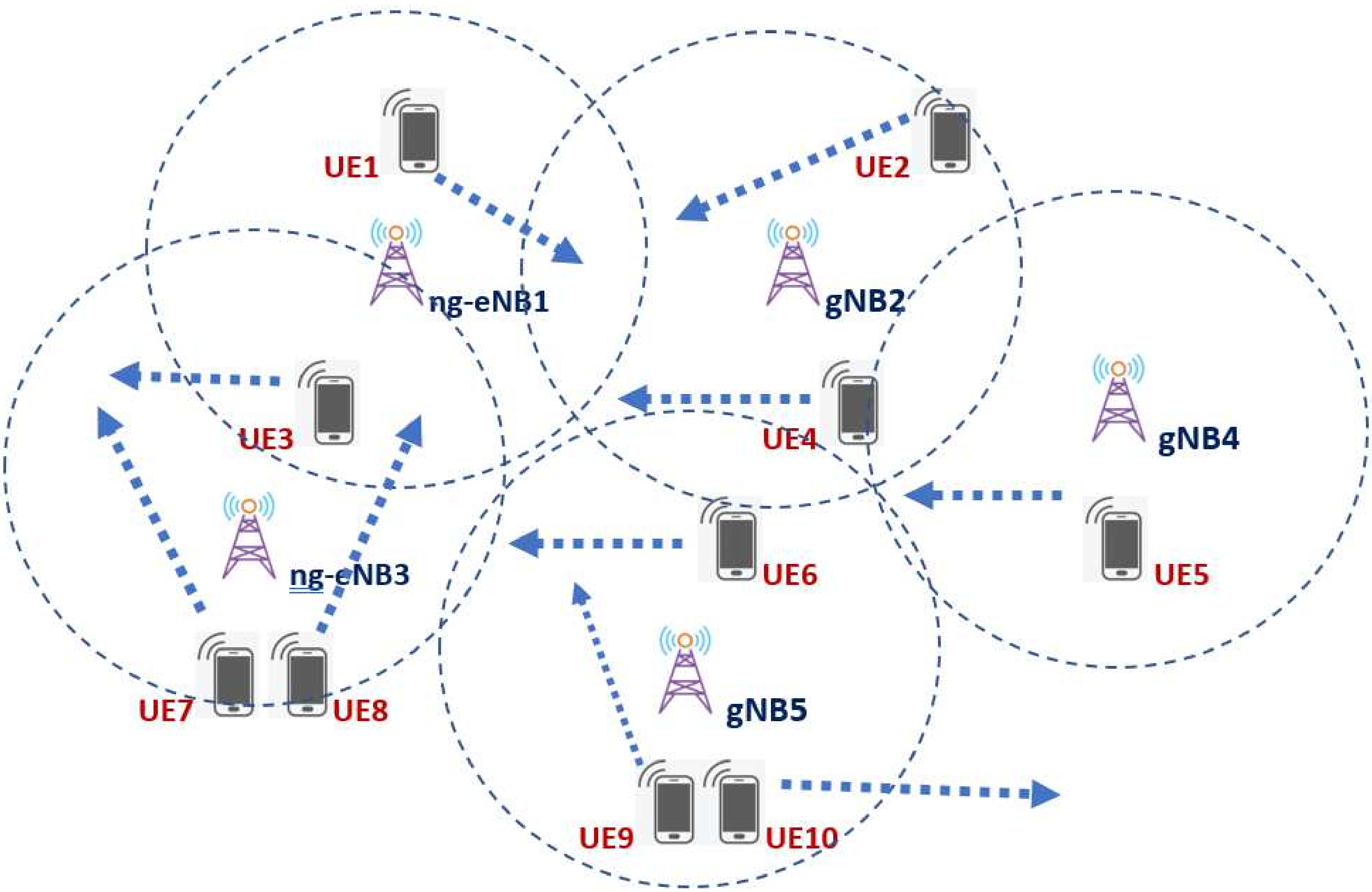

Figure 3

Simulated system model

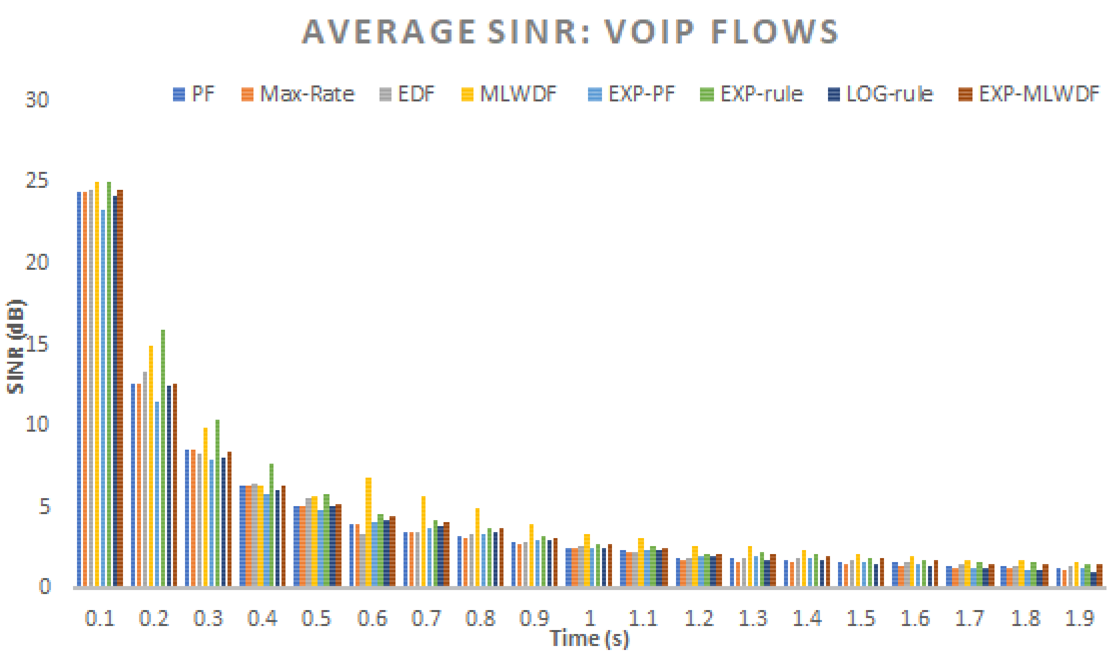

Figure 4

Average SINR for VOIP data streams

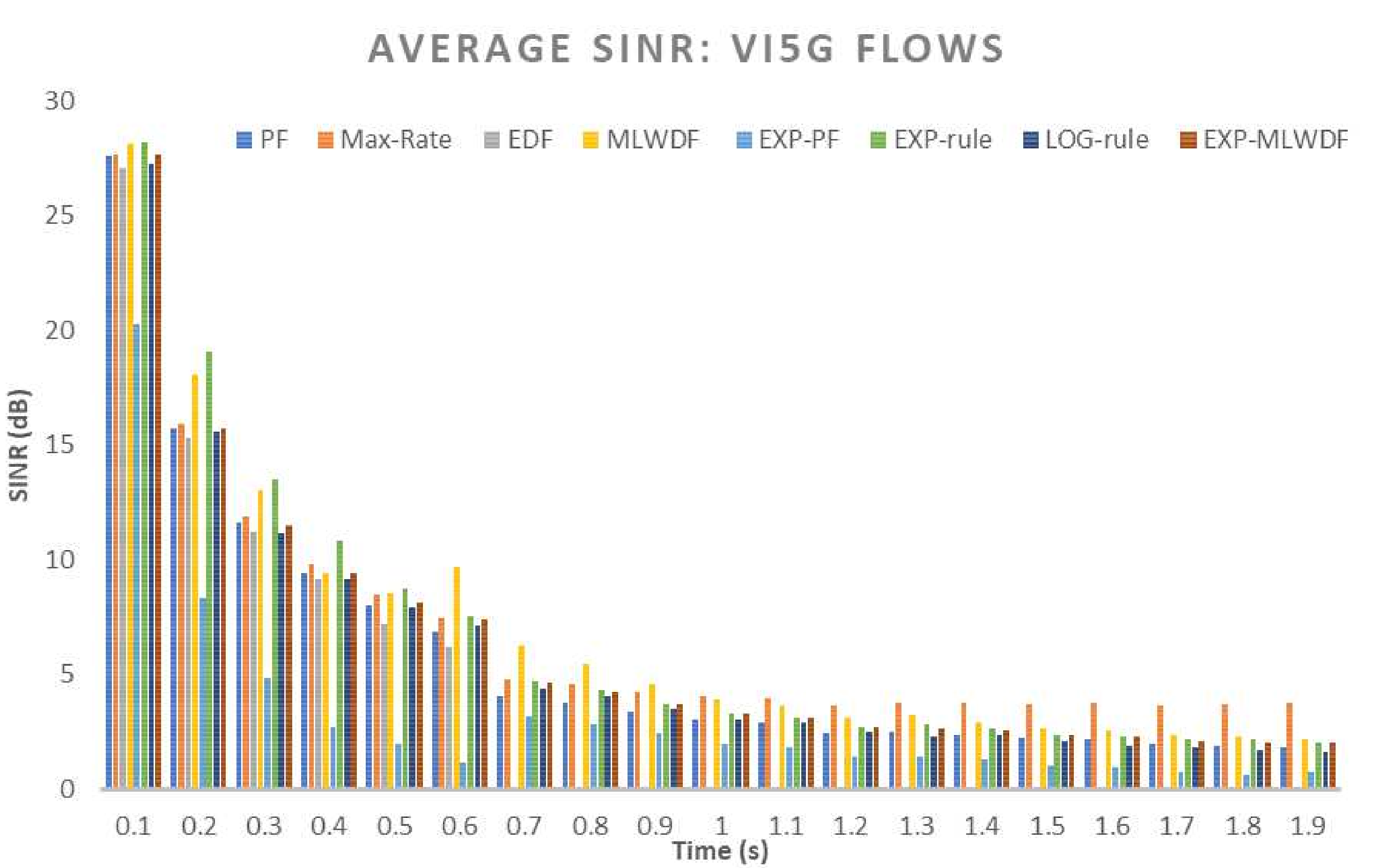

Figure 5

Average SINR for video data streams

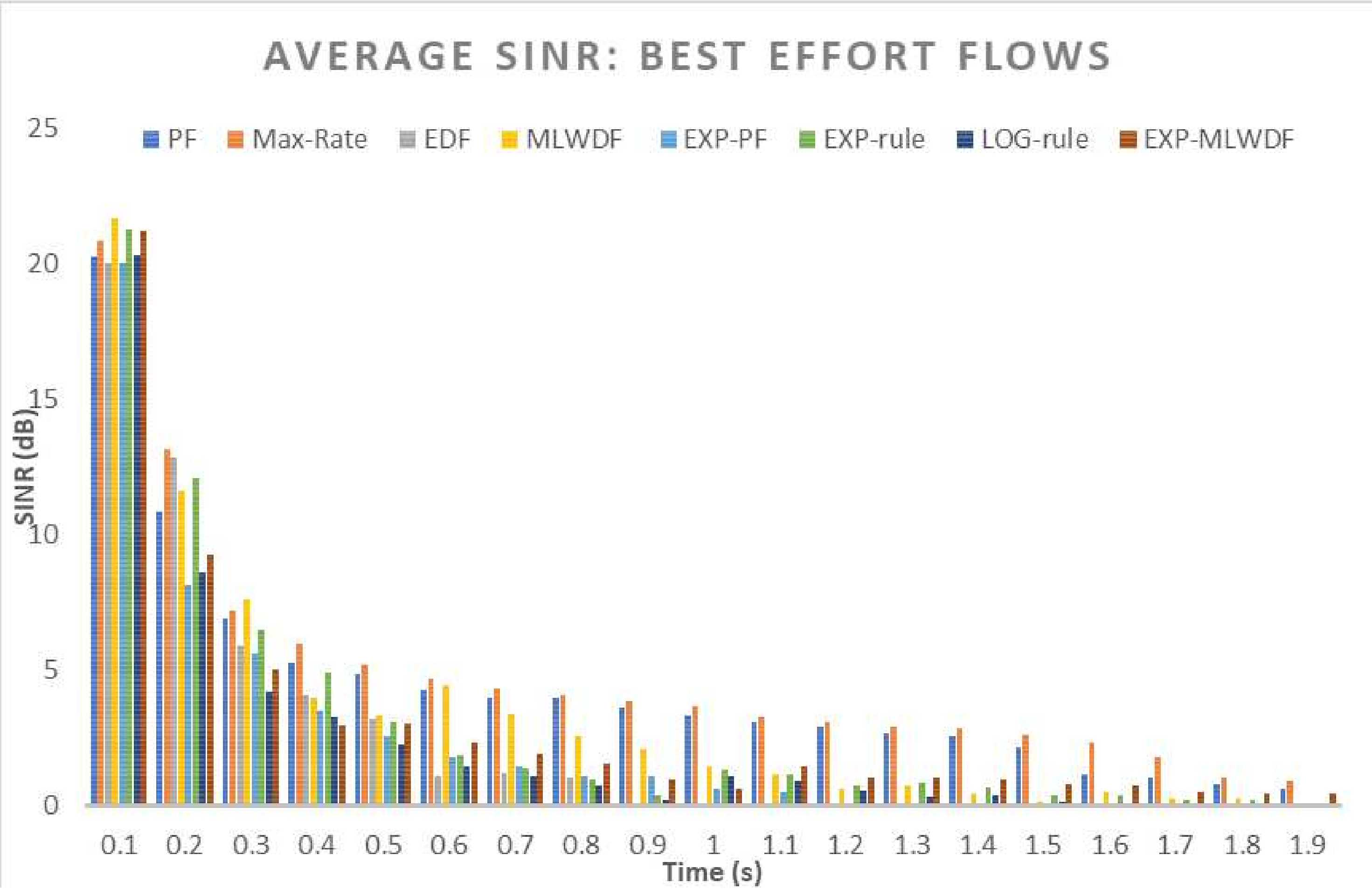

Figure 6

Average SINR for BE data streams

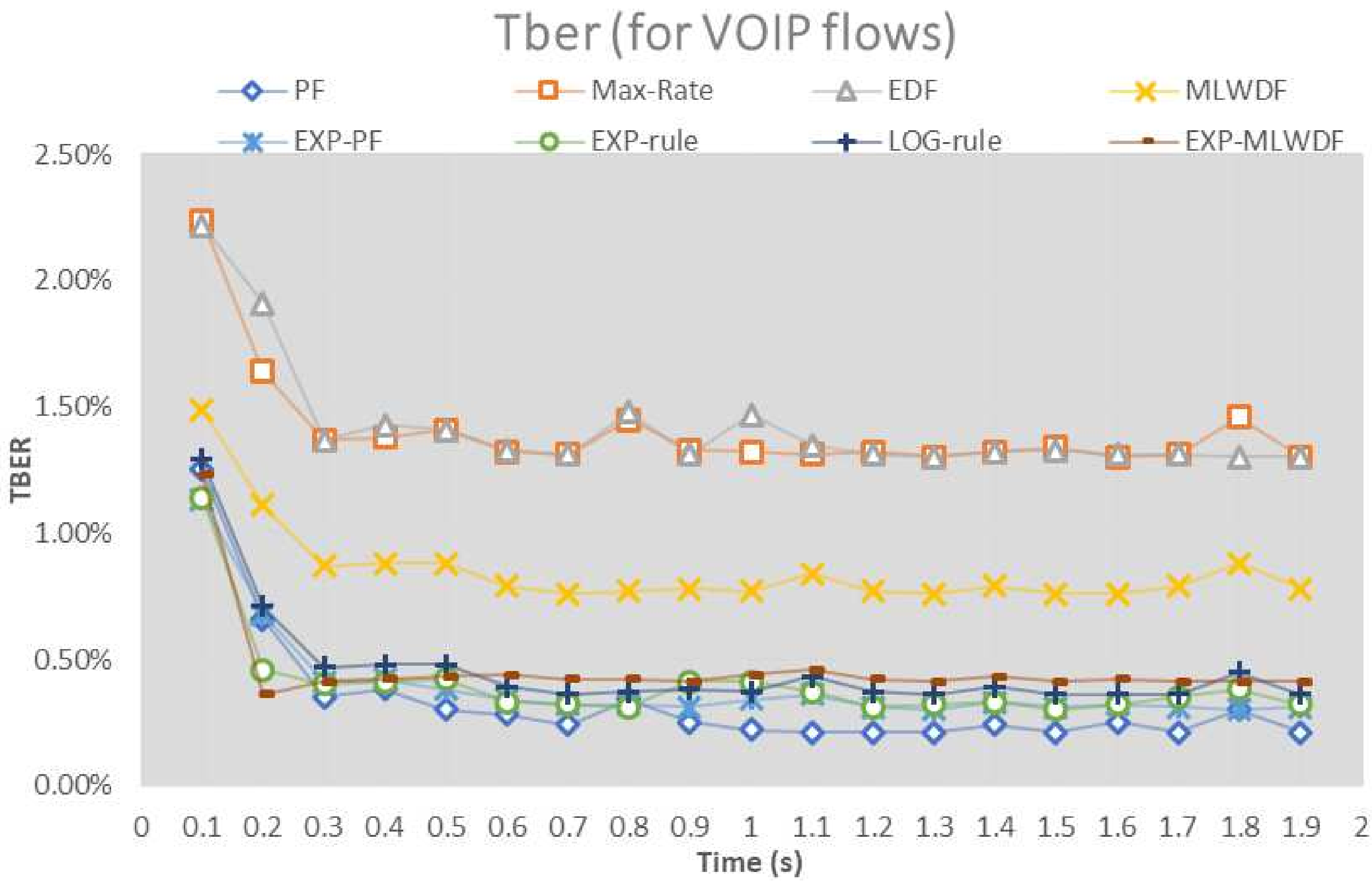

Figure 7

Average TBER using different scheduling schemes (VOIP)

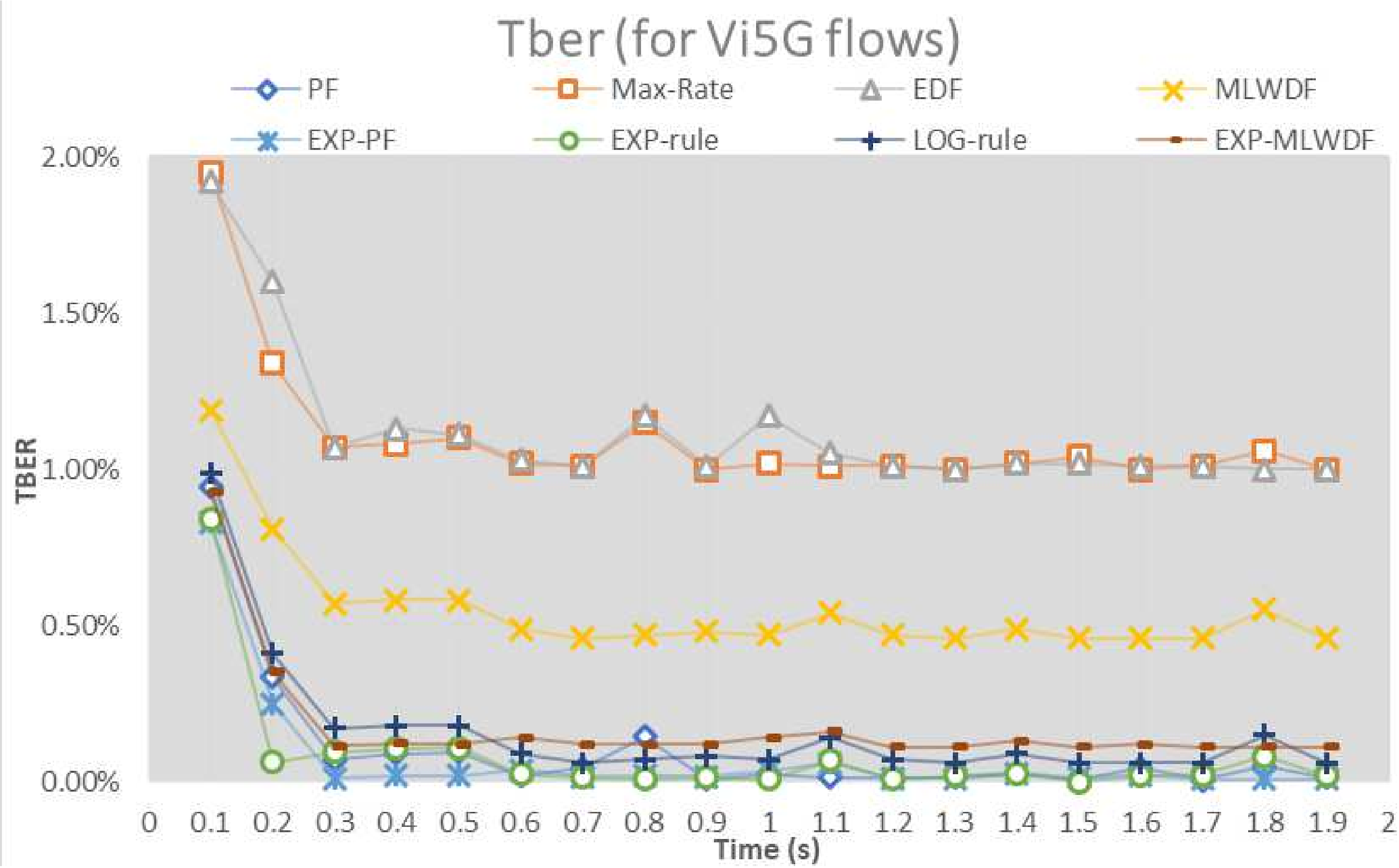

Figure 8

Average TBER using different scheduling schemes (Vi5G)

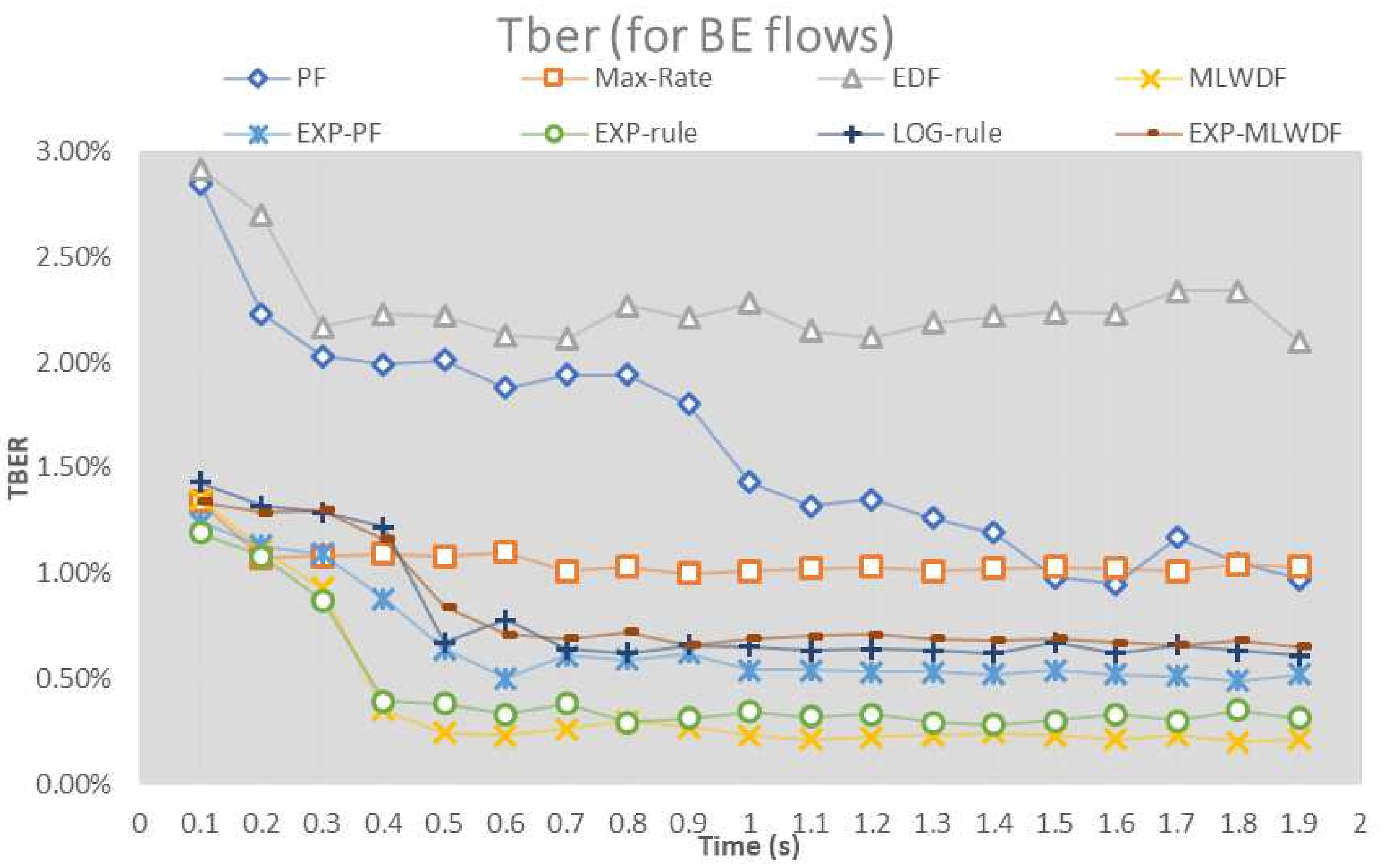

Figure 9

Average TBER using different scheduling schemes (BE flows)