Improved Downlink Scheduler For Overloaded 5g Networks

Saloua Hendaoui, Nawel Zangar

Abstract: The 5G is designed to be ultra-dense network. Various services are connected to the same network. Mainly, the enhanced Mobile Broad Band (eMBB), Ultra Reliable Low Latency Communication (URLLC) and Massive Machine Type Communications (mMTC) coexist in a hybrid 5G network. This coexistence, in addition to the constraints at the physical layer, mainly the format of the packets, introduces a fundamental challenge concerning the radio resource allocation. In the present proposal, we design a smart downlink scheduler which aims to satisfy the variety of services connected to the 5G. The scheduler aims to overcome the challenge of the variance of the wireless channel in addition to the use of fixed budget delays. The main target of the proposal is to increase the capacity of the communication network with quality of service guarantee. The scheduler has been simulated and proved its efficiency by comparison with schedulers from the literature.

Index Terms: 5G, Scheduling, Downlink, Quality of Service, Dynamic adjustment, delay, capacity, ultra-dense.

1 INTRODUCTION

Human-centric communication and machine-centric communication are applications whose require ultra-low latency and high reliability. In fact, nowadays users expect ”flash” response of their connections whose must be instantaneous and accessible without waiting time. Health, safety, office, entertainment are some instances of human-centric communication. The same, Machine- to-Machine (M2M) communications must be as reliable as possible and must be achieved in real time concept. Among the M2M communications targeted by the 5G network, we cite: driver-less cars, enhanced mobile cloud services, real-time traffic control, emergency and disaster response, smart grid, e-health or efficient industrial communications [1]. In addition to the low latency and ultra-reliability mentioned above, ultra-dense environment presents a main challenge for the 5G network. Public events, stadiums, airports, open air festivals are cases where we can find a high number of users occupied by their smart devices connected to the network within the same cell. These users must be satisfied with instantaneous response from the network, regardless the charge of the network. 5G introduces the ultra-dense network solution which consists on using several small cells in conjunction with the macro cells. Moreover, due to the coexistence of the IoT with the telecommunication networks, the number of connected devices is exponentially increasing and is expected to exceed the number of user devices connected to the wireless communication networks. These things are with various requirements and exploit different services. The IMT expects a growth in the traffic load in the range of 10-100 times from 2020 to 2030 [1]. In table 1 we summarize the IMT requirements of the fifth wireless communication networks.

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The main challenge regarding the huge number of connected devices, in ultra-dense environment is to provide radio resources to all requests with quality of service (QoS) guarantee. Therefore, the 5G presents the evolved carrier aggregation, the combination of licensed and unlicensed spectrum, and the beamforming as key solution to extend the capacity of network. However, these techniques are not enough especially with the exponential growth of the number of connected devices.

User experienced data rate (Mbit/s)	100
data rate (Gbit/s)	100
efficiency	x3
Mobility (km/h)	500
Latency (ms)	1

Table 1: *IMT requirements of fifth wireless communication networks*

Smart scheduling was and still be a key enabler for extended network capacity and high QoS. In this paper, we present our novel downlink smart scheduler for 5G network. The present proposal extends and combines our previous proposals [2, 3, 4, 5, 6] in order to enhance the robustness of the radio resource management. To enhance the QoS, we seek to reach an efficient policy for scheduling the real-time applications. To overcome the problem of static budget delay, we extend our previous proposal [3]. The proposed algorithm makes the budget delay as dynamic as possible, by adjusting it with the variation of the wireless channel. In addition, at packets reception, we give two proposals to determine the estimated reception time of real-time packets. The current proposal explores the estimated reception time in the prediction algorithm to determine the expected packet of loss ratio (PLR) in order to anticipate the variation of the wireless channel. The proposed scheduler is entitled smart downlink scheduler. The remaining of this paper is organized as follows: Section 2 gives the main 5G techniques for extended network capacity. Section 3 deals with the 5G system model. In section 4 and 5 we describe and evaluate our proposed smart downlink scheduler. Section 6 concludes the paper and opens the future perspectives.

2 5G TECHNIQUES FOR EXTENDED NETWORK CAPACITY

In the following, we describe the techniques that are used by the 5G to respond to the above mentioned challenges. Mainly, we concentrate on the carrier aggregation, combination of licensed and unlicensed spectrum, and the beamforming as they are the key enablers for extended 5G network capacity.

2.1 Evolved carrier aggregation

The 5G deploys the advanced long term evolution (LTE-A) carrier aggregation capability in order to provide larger bandwidth. As mentioned above, the main challenge for the promising 5G is to increase the system capacity. This can be achieved by increasing the system bandwidth. Hence, carrier aggregation is the adequate technology for this goal. Figure 1 presents the carrier aggregation in order to extend the network capacity. It is not always possible to guarantee the 100 MHz in a contiguous spectrum. Hence, the non-contiguous aggregation is the solution. The aggregated component carriers are non-contiguous in the same spectrum band or non-contiguous in various spectrum bands.

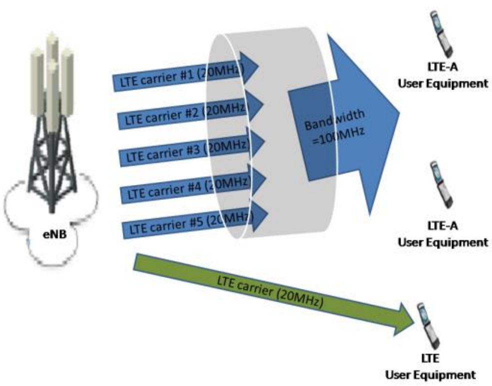


***Figure 1**: Carrier aggregation to extend the bandwidth*

Figure 2 presents these different aggregation cases. Each of the component carriers is provided by a serving cell where a cell may be macro, micro, pico or femto cells. A component carrier may be primary or secondary. The radio resource control is carried by the primary carrier handled by the primary serving cell.

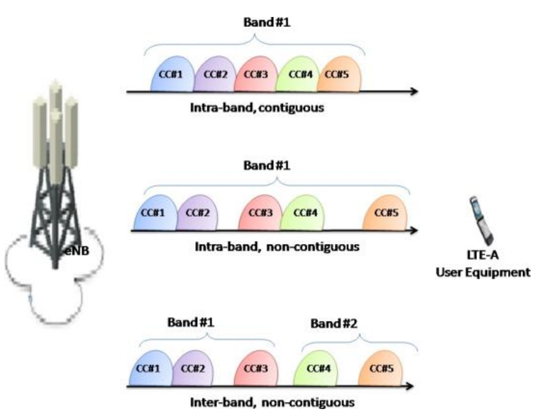


***Figure 2:** Non-contiguous carrier aggregation*

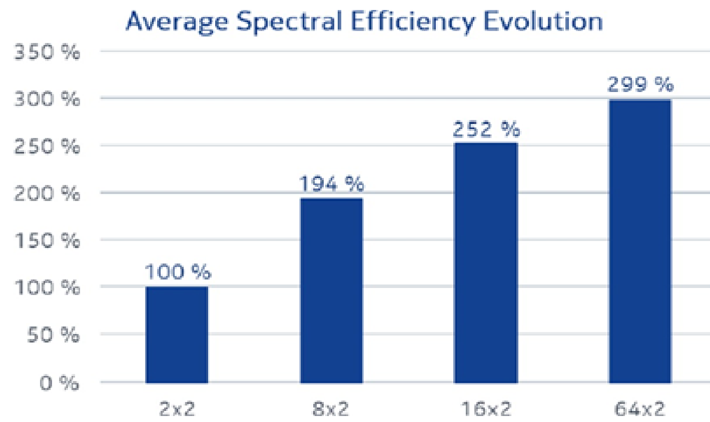


***Figure 3:** Spectral efficiency evolution [11]*

2.2 Combination of licensed and unlicensed spectrum

Access to shared and unlicensed spectrum will extend 5G in multiple dimensions such as providing more capacity, higher spectrum utilization, and new deployment scenarios [7]. As mentioned above, in 5G, carrier aggregation is performed using the LTE licensed band. However, with the growth of traffic volume, the licensed band is not able to serve all the demanding users. In addition, the connected devices are able to use the unlicensed spectrum. Therefore, the 5G aggregates the licensed band with the unlicensed band, allowing improving the system capacity and enhancing the peak data rate. The 5 GHz band is the best candidate thanks to its free gaps available for the user transmissions. The 5G achieves the aggregation of the unlicensed band via either the Licensed Assisted Access (LAA) or by interworking with the closest WiFi network using the LTE-Wi-Fi aggregation (LWA) feature. Using LAA, 5G aggregates the licensed band with the unlicensed band which is highly efficient against the traffic overload. In fact, using the licensed band, the 5G can send the control data, the signaling data and the real time data. The unlicensed band can be used to carry the data which require high data rates. Using the dual connectivity and carrier aggregation, already defined by LTE-A, 5G is able to combine the licensed band with the unlicensed band. Dual connectivity (DC) allows user equipment's (UEs) to receive data simultaneously from different base stations in order to boost the performance in a heterogeneous network with dedicated carrier deployment [8] The unlicensed band is not continually available for transmission (opportunistic usage of the unlicensed band). Subsequently, we must manage the traffic split between the licensed and the unlicensed bands. As an instance, the control procedures, low latency traffic and QoS sensitive data must be achieved under the LTE licensed band. To ensure the QoS, the network must guarantee service continuity. This can be guaranteed by the primary cell using the licensed band, which is not the case of the secondary cell using the unlicensed band, due to the reasons explained above.

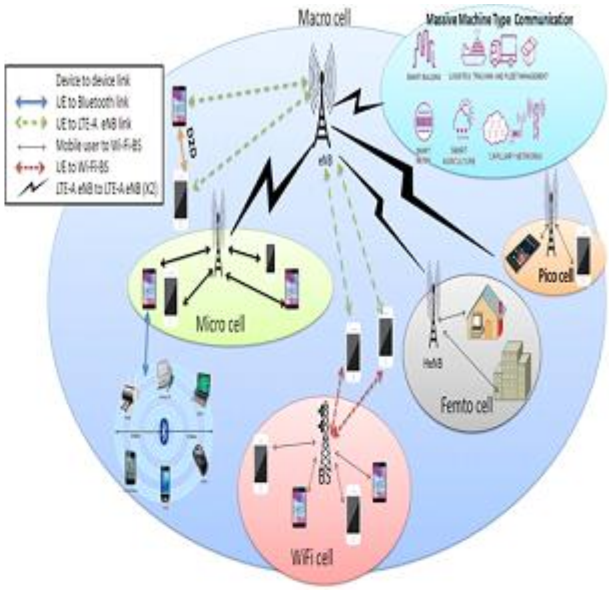
2.3 Enhanced spectral efficiency with beamforming (3D MIMO)

With the design of new 5G new radio(NR) networks, MIMO becomes massive and crucial for 5G NR deployments [9]. The 5G supports the 3-dimensional (3D) beamforming, also called Full Dimensional MIMO (FD-MIMO).It consists on highly increasing the number of transceivers at the base stationMainly, many of the recently released and announced 5G modems and transceivers are able to be updated via software, and offer throughput handling capabilities that account for greater bandwidth availability at currently unavailable mmWave frequencies [10]. The 3D-MIMO is mainly designed to increase the sytem spectral efficiency. Figure 3 presents the gain of the average system spectral efficiency versus 3D MIMO.

3 SYSTEM MODEL

3.1 Network architecture

5G optimizes the frame structure on the physical layer. The Transmission Time Interval (TTI) is equal to 0.14 ms. Shortening the TTI by reducing the number of symbols is the most promising approach when seeking to maintain backwards compatibility and usability in existing LTE [11]. Figure 4 presents our proposed radio access network architecture of the 5G network.



Figue 4: *Proposed 5G architecture*

Within the macro cell, there are micro pico and femto LTE-A cells along with Wi-Fi cells. Each cell has a separate frequency band, but they cover all the same geographical area[2] . The macro cell provides a continuous connection to the equipment within the cell. The other cells aim to increase the system capacity as well as the system spectral efficiency. In the system architecture there are four user categories:

- UEs connected directly to the 5G system via the LTE-A macro cell. For this user's type, both user plane and control plane are transmitted directly via the macro cell.
- UEs connected to the pico, micro or femto cells. The aim of such cells is to increase the capacity of the special sub-areas, such as hot spots [13]. The energy saving procedure in the coverage micro, pico and femto cells may be triggered in case that they carry light traffic However, the energy saving is deactivated when the macro cell fall in traffic overload.
- UEs connected to the Wi-Fi cells. The Wi-Fi base station transmits data in the unlicensed spectrum while the macro cell transmits data in the licensed spectrum. In that case, users data is split between the licensed and unlicensed spectrum. The data plane is transmitted via the unlicensed spectrum while the control plane is transmitted via the licensed spectrum.

The proposed architecture encompasses the internet of things (IoT) communication. The devices connected to the 5G network can be connected to several devices via various PANs (Personal area networks) systems such as the Bluetooth, zgbee and irDA. Device data can be directly routed via the closely mobile user without need to traverse the macro cell. The short communication established between the device and the mobile device improves the system spectral efficiency and the throughput, along with delay decreasing for the time sensitive applications. The proposed architecture supports the massive machine type communication. Various MTC devices are connected to the macro cell, which is responsible for managing the data of these machines. The massive number of machines connected to the base station can cause congestion. Hence, micro, pico and femto cells can be used to increase the system capacity.

3.2 Frame Structure

The 3GPP defines three frame types of frame structure presented with details in [14].

3.2.1 Frame structure type 1

The frame structure type 1 is used with the Frequency Division Duplex (FDD) systems. The frame has a length equal to 10 ms divided into 10 sub-frames of 1ms for each of them. Depending on the sub-carrier spacing,∆f, the number of slots per sub-frame varies, as presented in table, as presented in table 2.

Table 2: *Number of frame slot's versus sub-carrier spacing*

Sub-carrier spacing (∆f)	Number of time slots	Slot length (ms)
7.5 KHz	2	0.5
15 KHz	2	0.5
1.25 KHz	1	1

3.2.2 Frame structure type 2

The frame structure type 2 is used with the Time Division Duplex (TDD) systems. The radio frame has a length equal to 10ms divided into two half-frames of length 5 ms for each of them. Each half-frame consists of five sub-frames with length equal to 1 ms . Each sub-frame consists of two slots of 0.5 ms for each one. Sufficient details about the frame structure type 2 are available in [14] The uplink-downlink configuration in a cell may vary between frames and controls in which sub-frames uplink or downlink transmissions may take place in the current frame [14].

3.2.3 Frame structure type 3

Frame structure type 3 is appropriate for the LAA secondary cell operation with normal cyclic prefix only [14]. Each radio frame consists of 20 sub-frames of 0.5ms for each of them. Two consecutive slots compose a one sub-frame. The 10 sub-frames per frame are available for downlink or uplink transmissions using one or several consecutive sub-frames.

3.2.4 Radio block structure

A radio slot is composed by a set of radio blocks (RB). The number of RBs per downlink slot depends on the downlink transmission bandwidth. A RB has a number of OFDM symbols in the time domain and a number of sub-carriers in the frequency domain. The number of OFDM symbols per slot depends on the subcarrier spacing, SCf, and on the length of the cyclic prefix. A RB is composed by a set of Resource Elements (RE). The RE is the smallest unit for downlink transmission. The number of REs per RB, NRB is computed by eq. 1

(1)

$$N_{RE}^{RB} = N_{Sym}^{RB} * N_{SC}^{RB}$$

Subsequently, the number of slots per radio element is computed by eq. 2.

$$N_{RE}^{Slot} = N_{RE}^{RB} * N_{RB}^{DL} \qquad (2)$$

4 PROPOSED SMART DOWNLINK SCHEDULER

Our proposed smart scheduler is adaptive with the traffic type. We propose to divide traffic into two main classes: throughput-sensitive traffic and time-sensitive traffic. For each of the traffic classes we apply a specific scheduling policy. After reception of the traffic by the base station, the traffic is clustered according to the QoS class indicator (QCI). The standardized characteristics associated with standardized QCI values are summarized in table 6.1.7-A and table 6.1.7-B in [15]. As mentioned above, we extend our previous proposal [6] in which we specify the scheduling policies to be adopted for each class of traffic. In the present proposal, we extend our previous policy by making the budget delays for the real time traffic as dynamic as possible.

4.1 Dynamic budget delay

As mentioned above, RT oriented schedulers are generally based on per budget delay comparison. The problem presented is the use of fixed and exact thresholds (These budgets are fixed by the 3GPP [15] and they are dependent on the service class.). In practical systems, it is unfeasible to consider the same budget for all users belonging to the same class of service. Even for the same mobile user, it may tolerate various delays depending on its experienced quality of the wireless channel. This problem is resulted from the Inter Cell Interference (ICI). Moreover, the instability of the wireless channels is a major challenge for the 5G network. To surpass this problem, some researches proposed the adaptation of fuzzy logic method. However, policies based on fuzzy logic are not feasible with a high number of wireless users. We treated this problem and we propose to enhance the use of the budget delay depending on the experienced channel quality. For real-time applications, the delays and the PLR are strongly related. If the packet exceeds its deadline in the buffers of the base station it will be dropped. This may increase the experienced PLR and requires the retransmission of that packet. Same, if an expired packet is sent, then it will be dropped by its destination. This leads to resources wasting. Subsequently, the delay tolerated by the mobile users is not fixed. It is dependent on the PLR. If the PLR is higher than the tolerated value, the budget delay can be increased. If the experienced PLR is higher than the threshold, the budget delay may be decreased. In both cases, the budget delay shall not exceed the standard budget delay, fixed by the 3GPP 9 Table 6.1.7-A and Table 6.1.7-B in [15]). We propose an algorithm called ”delay budget adjustment”. It determines the suitable budget delay for time-sensitive traffic depending on the experienced PLR. In algorithm 1, we use the following parameters:

- µi is the budget delay for traffic i (in this algorithm we take the Real Time Gaming traffic which has a budget delay µ = 0.05s).
- PLRi is the PLR experienced by the i[th] user.
- σi is the PLR budget for the i[th] time-sensitive traffic.
- ε is the value that can be extracted from the budget delay. It is a positive scalar value which depends on the service class.

For all the exchanged time-sensitive traffic, the base station examines the QoS, especially the PLR. If the experienced PLR of traffic i, PLR_i, is higher than the budget one, σ_i, then the QoS of the traffic cannot be met. Hence, the budget delay, μ_i, must be decreased. In the other case, the budget delay, μ_i, must be increased by the fact that the QoS is met. The quantity of time, E, to be added to or extracted from the budget delay depends on the traffic type. As an instance, for the Real Time Gaming traffic, this value can be initialized to 0.0005 and to 0.0015 for video traffic. Of course the budget delay must be strictly positive and must not exceed the standard value fixed by the 3GPP. The delay budget adjustment is presented and studied in detail in [4].

Algorithm 1 Delay budget adjustment

```
/*The procedure returns the budget delay for each traffic*/
/*Suppose that we have N Real Time Gaming flows*/
μi = 0.05;
for(i=0 ; i < N ; i++)
if(PLRi > σi)and (μi − ϵ >0)
μi = μi − ϵ;
else
μi < 0.05 − ϵ
μi = μi + ϵ;
```

4.2 Adaptive time-sensitive, throughput-sensitive policies

At this stage, the base station has two different strategies for computing the scheduling metrics for both throughput-sensitive and time-sensitive traffic. The wireless communication system carries mixed traffic and metrics must be comparable. Regarding this, we studied this problem by testing the scheduling metrics of the three used schedulers. Figure 5 summarizes the used scheduling policies in the smart downlink scheduler.

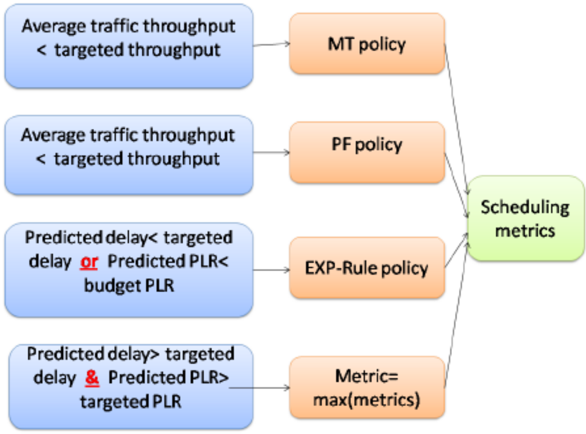


Figure 5: *Used policies in the smart downlink scheduler*

As shown in figure 5, the Maximum Throughput (MT), Proportional Fair (PF) and EXP-Rule policie are executed depending on the required QoS constraint. These schedulers along with their rules for traffic metric computation are detailed in our previous research paper [6]. The EXP-Rule scheduler executes the PF policy for computing traffic weights and increases the weights of time-sensitive traffic with high-waiting delays. Similarly, we execute the PF scheduler of the throughput-sensitive traffic with acceptable throughput and enhance the weights of the throughput-sensitive traffic with average throughput less than the average one by applying the MT policy. Also, we increase the weights of the time-sensitive data by applying the EXP-Rule policy and we maximize the weights of traffic with high-expected PLR. We studied the metric's variation for each scheduling policy by simulating the same scenario for these three strategies. Figure 6 draws the metric's variation using these policies.

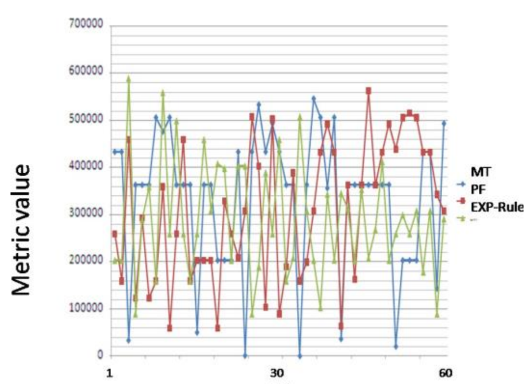


Figure 6: *Metric's variation of MT, PF and EXP-Rule schedulers*

As clearly shown in figure 6, the metrics of all the schedulers are approached. Hence, the scheduling metrics of the proposed adaptive smart downlink scheduler can be mixed and simply compared. According to this figure, it can be seen that the MT scheduler, often, has metrics close to zero. These measures relate to the traffic with poor channel conditions. Figure 7 presents the metric variation of the proposed throughput-sensitive and time-sensitive strategies.

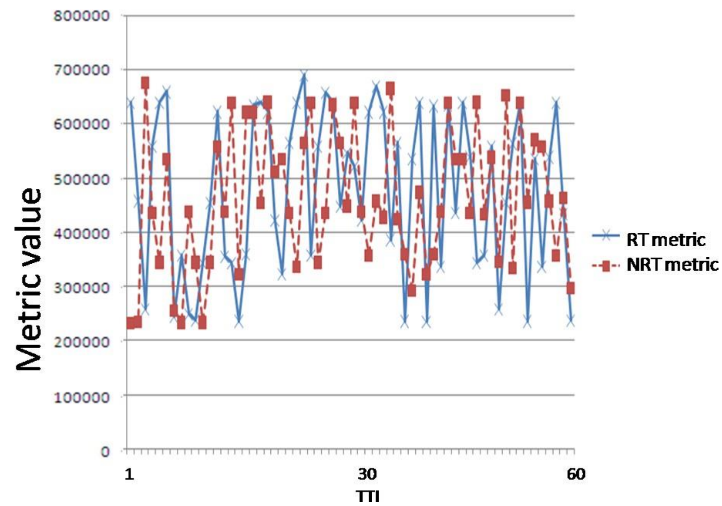


Figure 7: *Metric's variation of the adaptive smart downlink strategies*

As figure 7 reports, the metrics of the two proposed strategies are comparable. Thus, after computing the metrics of all the flows, the smart downlink scheduler save the metrics on a common matrix and then it assigns the radio resources to the traffic with the highest metric.

5 PERFORMANCE EVALUATION

5.1 Simulation Scenario

Table 3 summarizes the simulation parameters.

Table 3: *Simulations parameters*

Parameter	Value
Simulation duration	100 s
Physical parameters	Bandwidth: 20MHz
	OFDM Symbols per TTI: 14
	SubFrame length (TTI): 1 ms
	SubCarries per RB: 12
	SubCarrier spacing: 15 kHz
	Base station: Power transmission = 46 dBm
Link Adaptation	QPSK, 16QAM,
Modulation Schemes:	and 64QAM
Traffic Models	infinite buffer, VoIP, Video

5.1.1 Performance metrics

The parameters used to evaluate the scheduling method for the throughput-sensitive data includes the system throughput, the system spectral efficiency and the fairness. The simulated schedulers are the PF, MT and the proposed smart downlink scheduler.

System throughput: The system throughput is expressed by the total transmitted packets per second and can be analytically expressed by eq. 3.

$$Sys_{thr} = \frac{1}{T} * \sum_{i=1}^{N} \sum_{t=1}^{T} Tot_{tr_i}(t) \qquad (3)$$

Where Tottri (t) is the size of transmitted packets to user i at time t, N is the total number of users and T is the total simulation time.

System spectral efficiency: it is expressed using eq. 4.

$$Sys_{speff} = \frac{Sys_{thr}}{B} \qquad (4)$$

B is the system bandwidth.

Fairness level: this metric is defined by the variation in service between the most and least satisfied users. The service level means the size of the total transmitted packets. It is computed using eq. 5.

$$fairness = 1 - \frac{max(Tot_{tr}(t)) - min(Tot_{tr}(t))}{\sum_{i=1}^{N}\sum_{t=1}^{T}(Totrec_i(t))} \qquad (5)$$

A time-sensitive scheduler must guarantee the QoS of all the services. The delay and the PLR are the key requirements of the time-sensitive traffic. In addition to the system spectral efficiency and the fairness presented above, we study the delay and the PLR variation. We define the following formulas:

PLR: The system PLR is equal to the ratio between the total size of discarded packets and the total size of all packets coming to the serving base station buffer. It is mathematically expressed by eq. 6.

$$(6) \qquad PLR = \frac{\sum_{i=1}^{N}\sum_{t=1}^{T} Tot_{widh_i}(t)}{\sum_{i=1}^{N}\sum_{t=1}^{T} Tot_{rec_i}(t)} \qquad (6)$$

Where Tot_{widhi} (t) is the size of discarded packets of user i at time t and Tot_{reci} (t) is the size of received packets from the same user at the same sub frame.

Average system delay: The average system delay is defined by the average HOLD for all the simulation time. It is computed using eq. 7.

$$\frac{1}{T * N}\sum_{t=1}^{T}\sum_{i=1}^{N} HOLD_i(t) \qquad (7)$$

For time-sensitive traffic, we tested the following schedulers: M-LWDF, EXP, EXP-Rule, LOG-Rule and the smart downlink scheduler.

5.2 Results discussion

Figure 8 reports the average system throughput experienced with the above mentioned schedulers. As figure 8 reports, the MT scheduler performs the highest system throughput. Thus, it assigns the available radio resources to the users experiencing the best channel conditions. However, users experiencing bad CQIs are not served. As proved by figure 8, the PF and the proposed smart downlink scheduler experience close results. In fact, these schedulers aim to guarantee acceptable throughput along with fairness guarantee. In the case where the user experienced throughput is higher than the targeted one, the smart downlink scheduler executes the PF policy.

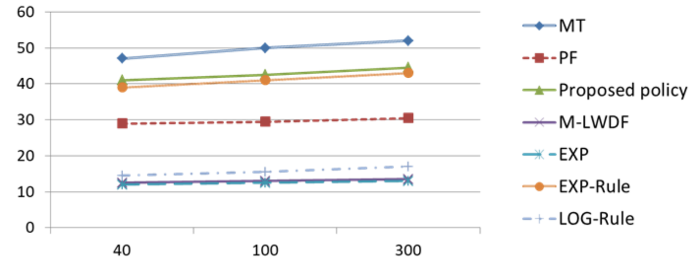


Figure 8: *Average System throughput*

The M-LWDF, EXP, EXP-Rule and LOG-Rule guarantee lower throughput compared to the PF, MT and the proposed smart downlink schedulers. In fact, they all aim to guarantee low delays for RT traffic. Thus, in their metrics, they prioritize traffic with the highest delay at the cost of the ones with the best channel conditions. The advantage of the smart downlink scheduler is that it is adaptive with the traffic carried by the network. For throughput-sensitive traffic, a specific scheduling strategy is executed after the comparison of the budget throughput with the experienced average user throughput. This makes the smart scheduler a well choice for the 5G network. It is sufficient to adapt the budget throughput with the network generation. Figure 9 reports the average system spectral efficiency versus the used downlink scheduler. As clearly reported by the figure, the MT scheduler performs the highest spectral efficiency. The proposed smart downlink scheduler applies the MT strategy whenever the experienced throughput is less than the budget value. We can remark that, for the MT, PF, smart downlink scheduler and EXP-Rule schedulers, the system spectral efficiency slightly increases with the number of users. This is expressed by the multi-user diversity which increases with the user's number raising the probability of selecting users with good channel conditions. However, with M-LWDF, EXP and Log-Rule schedulers the system spectral efficiency slightly decreases with the increase of the user's number. In fact, those schedulers aim to decrease the delay at the cost of lower spectral efficiency, especially in an overloaded system.

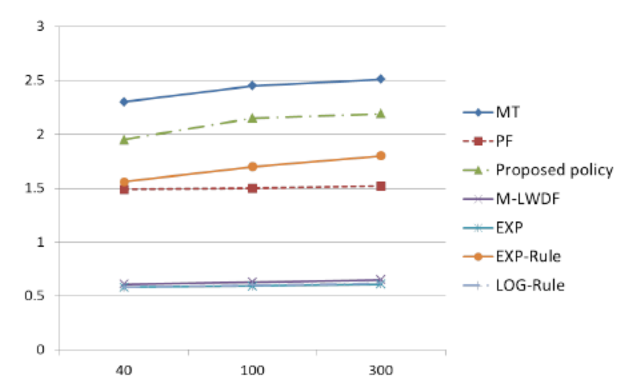


Figure 9: *Average system spectral efficiency*

One of the biggest constraints of the wireless telecommunication networks schedulers is fairness. In fact, users with the worst CQIs may suffer from famine in term of radio resources. This is addressed in our proposal using the PF policy which has an acceptable trade-off between the system throughput and the system fairness.

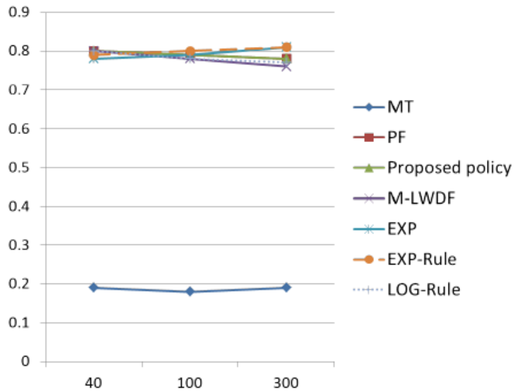


Figure 10: *Average system fairness*

Figure 10 shows the system fairness using various schedulers. Results prove that the MT scheduler results the lowest fairness. This is due to the priorities given to the users with the best CQIs at the cost of traffic with worst channel conditions.

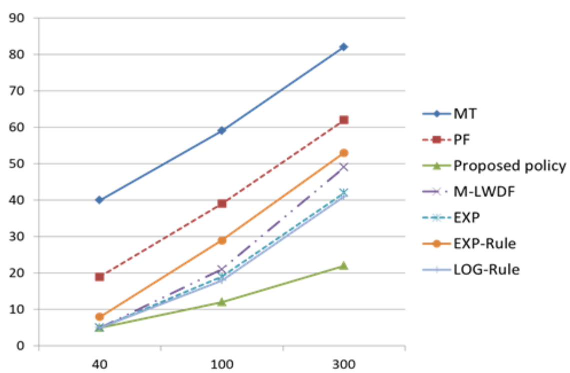


Figure 11: *System PLR vs. used scheduler*

Figure 11 draws the average system PLR regards the applied schedulers. As shown, the PLR is high in different cases due to the overload in the base station buffers.

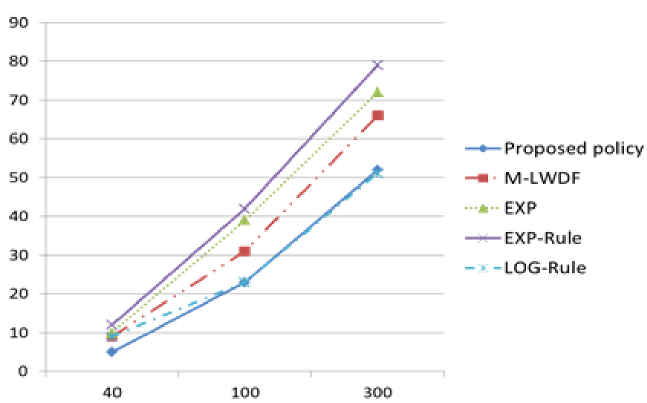


Figure 12: *Average system delay*

As shown, the PLR is high in different cases due to the overload in the base station buffers. As clearly shown, delays are proportional with the users number. In case of overloaded systems, devices with bad channel conditions experience the highest delays.

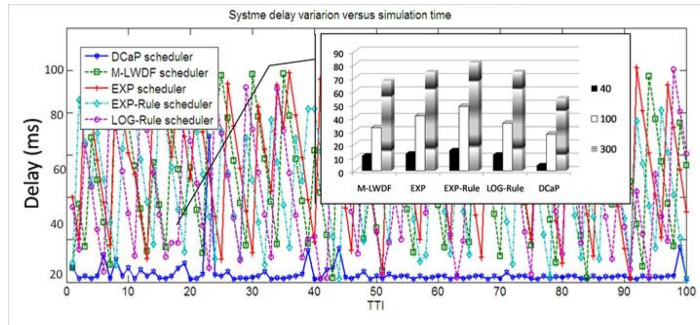


Figure 13: *Variation of the delay*

Figure 13 draws the delay variation in case of 300 connected devices. Since the PF and MT schedulers are not delay aware, they are not presented in figure 13. In addition, all the QoS-aware strategies guarantee the delivery of the packets within the tolerated delay (100 ms in this scenario). In fact, during the metric computation, all these schedulers drop packets, from the base station buffers, whose delay exceeds the targeted deadline. With the M-LWDF, EXP, EXP-Rule and LOG-Rule schedulers the delay varies between 0 and 0.1s. We can see that the variance of the delay is too much less using the smart downlink scheduler. This is expressed by the use of the delay budget adjustment algorithm. In fact, the budget delay is not fixed but it is adjusted depending on the experienced PLR. Hence, the variance of the wireless channel does not have a significant impact using the proposed smart downlink scheduler, which is not the case with the existing schedulers. To illustrate the effect of the variance of the delay, we measured the jitter. Figure 14 presents the variance of the jitter using the different schedulers. In fact, for the time-sensitive QoS, jitter is a main issue.

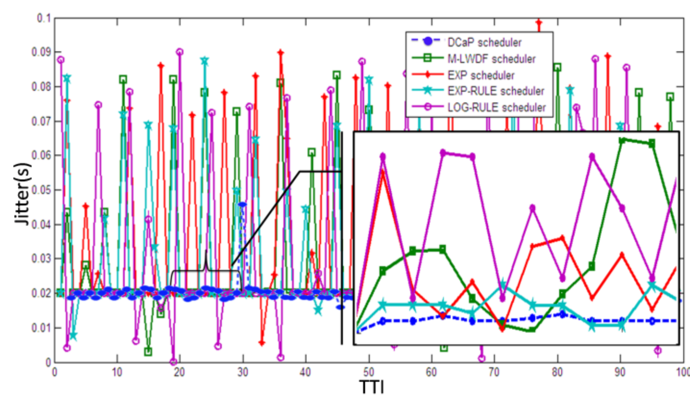


Figure 14: *System jitter for VoIP traffic*

Using the M-LWDF, EXP, EXP-Rule and LOG-Rule schedulers, the jitter is not constant and it varies between 0.001 to 0.09 seconds. Whereas using the smart downlink scheduler, the jitter is not only the lowest (it is close to 0.002 second) but also it is almost constant, as figure 14 illustrates. This proves the efficiency of the delay budget adjustment algorithm which helps us to reduce the jitter, as a main requirement for the time-sensitive date in both the 4G as well as the 5G networks.

6 CONCLUSION AND FUTURE WORK

6.1 Conclusion

The present proposal gives a novel smart downlink scheduler. The main contribution consists of prediction of PLR and delay to overcome the problem of variance of the wireless channel. In addition, the proposed algorithm of the dynamic budget delay permits to reduce the jitter due to the reduction of delay variance. The proposal has been simulated and its efficiency has been proved due to comparison with existed schedulers from the literature. Findings prove that the proposed smart downlink scheduler guarantees an enhanced system throughput in addition to system spectral efficiency. For time- sensitive traffic the QoS has been enhanced by guaranteeing lower delays, PLR and jitter.

6.2 6.2 FUTURE WORK

As perspectives, we propose to provide an algorithm which classifies the traffic according to their experienced QoS. Then, whenever possible, according to the traffic clustering, include the satellite to reduce the overload in ultr-dense environments. The targeted proposal must guarantee the QoS for both hybrid terrestrial and satellite networks.

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