5G uplink interference simulations, analysis and solutions: The case of pico cells dense deployment

Balboul Younes[1], Fattah Mohammed[2], Mazer Said[3], Moulhime El Bekkali[4]
[1,3,4]Laboratory of Artificial Intelligence, Data Sciences and Emerging Systems, Sidi Mohammed Ben Abdellah University Fez, Morocco
[2]IMAGE laboratory, Moulay Ismail University, Meknes, Morocco

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ABSTRACT

The launch of the new mobile network technology has paved the way for advanced and more productive industrial applications based on high-speed and low latency services offered by 5G. One of the key success points of the 5G network is the available diversity of cell deployment modes and the flexibility in radio resources allocation based on user's needs. The concept of Pico cells will become the future of 5G as they increase the capacity and improve the network coverage at a low deployment cost. In addition, the short-range wireless transmission of this type of cells uses little energy and will allow dense applications for the internet of things. In this contribution, we present the advantages of using Pico cells and the characteristics of this type of cells in 5G networks. Then, we will do a simulation study of the interferences impact in uplink transmission in the case of PICO cells densified deployment. Finally, we will propose a solution for interference avoidance between pico cells that also allows flexible management of bands allocated to the users in uplink according to user's density and bandwidth demand.

Corresponding Author:

Younes Balboul
Laboratory of Artificial Intelligence, Data Sciences and Emerging Systems
Sidi Mohammed Ben Abdellah University
Imouzzer Road BP 2626 Fez 30000, Morocco
Email: younes.balboul@usmba.ac.ma

1. INTRODUCTION

The 5th generation mobile networks have come to respond to the new challenges imposed by the changing needs for connectivity and user services. According to "Ericsson" [1], one of the leaders in the deployment of 5G networks, by 2024 the global traffic of mobile data will be multiplied by 5 and this especially in dense urban areas where the density of users and industries is the greatest, and this trend will continue. The emergence of new communication models and new needs for modern and intelligent services such as 'V2V' communication, 'M2M' communication and the internet of things requires telecommunications operators to adopt a new managing network resources method which must be smarter and more flexible.

To cope with this data tsunami and the challenges of emerging services, significant efforts have been devoted to increasing the capacity of wireless networks. New radio techniques are being explored in 5G cellular systems. One of the main lines of research in this field focuses on the use of small 5G cells, the deployment of massive antenna techniques and the use of 'COMP' coordination techniques between cells [2].

The common idea between its axes of work already mentioned above is the use of small cells network densification to allow the increase of the bandwidth and at the same time considerably improving the quality of the signal by reducing average path losses and the shading effect [3, 4]. For 5G networks, the network densification by pico cells is a strategic choice compared to other types of small cells because of the correlation between capacity gain and the economic benefit for specifically deploying this type of cell.

With the densification of the 5G network and the use of new frequency bands from 3 Ghz to 28 Ghz or even reach 60 Ghz, new design challenges arise, among which the study of intercellular interference is a critical element. This study should be based on a new pathloss model which corresponds to the frequency bands and the radio techniques used by 5G. It is therefore necessary to carry out a study on the impact of interferences on the performance of mobile users in the case of 5G base stations densified deployment. In this perspective, our article carries out a study and analysis of the different types of uplink interference in the case of densified deployment of 5G pico cells.

Our article is organized as follows, first we will present the concept of small cells and the key importance of pico cells in 5G networks. Next, we will do a study by simulation followed by an analysis of intercell interference impact on the uplink transmission in the case of densified 5G pico cells deployment. Finally, we will conclude with our vision of an effective intercell interference uplink management technique, we will present 5 main techniques for agile interferences management which can be combined to create an innovative algorithm to avoid uplink interference in 5G networks.

2. SMALL CELL CONCEPT AND THE IMPORTANCE OF PICO CELL SOLUTION FOR 5G NETWORK

In all new mobile radio technologies standards, there are three main parameters; coverage, capacity or throughput and latency. 5G relies mainly on small cells to guarantee these three parameters. According to the small cell forum, the technology of small cells will become the key element of 5G and will dominate the cellular networks architecture [5, 6].

According to market studies carried out by fortune business insights, the deployment of small cells equipped with automated radio interface management will reach approximately 10.20 million by 2026 [7] to offer to operators and providers the 5G expected performances and services. Besides, the deployments cost is in the advantage of small cells compared to macro cells [8]. The small cells can be divided into 4 cell categories according to the transmission power, the size of the cell coverage, and the deployment mode as well as the type of the cell configuration (automatic or manually by the technical services' deployment). The following table summarizes the characteristics of small cells [9-11].

From Table 1, it is clear that each type of small cells can be a better candidate than the others depending on the deployment environment, the type of services or applications as well as the quality of communication. According to the analysis, it can be concluded that the "Fem to cell" is a better candidate in the case of indoor with very low coverage and high capacity; while the pico cell, that is our study subject in the next section of this article, is the best candidate for indoor or outdoor hotspots solutions especially in the case of high capacity industrial applications or outdoor densification for urban dense environments, as pico cells present the best compromise between coverage, capacity and latency as well as the cost of deploying the coverage solution [12].

Table 1. The different types and characteristics for small cells in 5G networks

Small Cell type	The Number of Users	Déploiement mode	Installed by	Typical Cell Radius	Power Range (Typical Value)
Metro	More than 100 users	Installed outdoors	Installed by network operators	Up to 1 km	20 W to 100 W (40 W)
Micro	More than 100 users	Usually installed outdoors, can be used temporarily for large events		250 m-1 km	1 W to 20 W (5 W)
Pico	Up to 100 users	Indoor or outdoor industry, larger indoor areas like, offices or train stations.		100 m-300 m	250 mW->1 W
Femto	Few users at a time	homes or small businesses	Installed by clients (with automatic configuration)	10 m-50 m	10 mWto 200 mW

With the increase in industrial and domestic applications that require even more connected objects and less latency such as IOT, more bitrates such as Big data, and social & internet data sources, the use of a single pico cell cannot support the desired needs, so it is necessary to use several pico cells of pre-studied sizes in order to achieve the targeted 5G quality of services. Moreover, the use of the same frequency band and transmission power to serve as well as to receive data from users requires a prior study to optimize the available radio resources [13]. In this layer, in the following section, we will study the performance of 5G pico cells in the case of deployment of several adjacent pico cells, so we will see the impact of interferences in the uplink transmission according to the physical characteristics of the deployed pico cells.

3. INTERCELL UPLINK INTERFERENCE SIMULATION AND ANALYSIS IN THE CONTEXT OF 5G PICOCELL DEPLOYMENT

To give a technical analysis of the impact for uplink interference in the case of PICO 5G cell deployment, we use computer-aided digital simulations which offer performance evaluation. To make our simulations we used the Vienna 5G LL simulator developed under MATLAB and which offers a very flexible object-oriented structure which allows easy integration of additional components and also the adaptation and integration of several scenarios using MATLAB scripts [14].

3.1. Scenario parameters

To Investigate Inter Pico Cell Interference We Use 3 Scenarios: the overall configuration of the topology is as follows. There are three base stations and one or more users per pico base station, the target study cell is pico cell 1 and the other two cells number 2 and 3 are considered to be interfering cells. However, to place the users virtually in a single cell and for the sake of simplification of simulations, we use the interference links and we define the inter-cell attenuation to the same value as the loss of channel path. As a result, the desired channels and the interference channels are no longer distinguished. This makes it possible to study the impact of interference between users in the case of uplink transmission.

For the three scenarios, we study the impact of interference on the uplink transmission for the user User1.pc1. This user has a fixed position and is placed in very good radio conditions compared to pico cell 1 with a fixed SNR of 40 dB. Figure 1 gives the overall scheme of the three simulation scenarios and Table 2 gives the specific parameters for scenario 1 and 2. Table 3 on the next page, gives the common simulation parameters for the three scenarios. The fact of fixing the position of the user User1.pc1 in a very good radio condition is to see the impact of the interfering users who move in the other cells in random ways.

For scenario 3 we want to experience interference due to the high out of band (OOB-Up) uplink emissions of discrete Fourier transform spread OFDM colled DFT-s-OFDM better known as single carrier frequency division multiplex (SC-FDMA), is still a valid access scheme and support is mandatory for any 5G terminal. We assume two users (User1.pc1 and User1.pc2) and only two pico cells (pico cell 1 and 2) that use the same frequency band but different numerologies (subcarrier spacings) and are therefore non-orthogonal to each other. The user "User1.pc1" are scheduled next to user "User1.pc2" in frequency as shown in Figure 2. Table 4 gives the specific parameters for scenario 3.

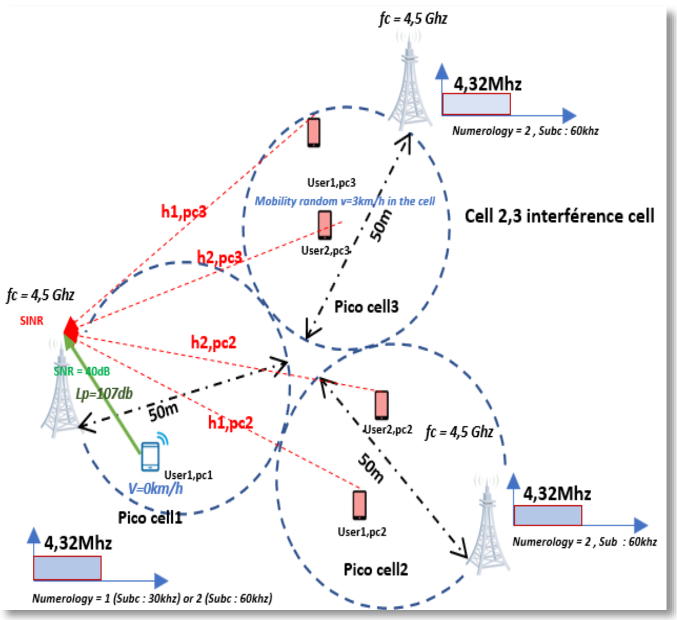
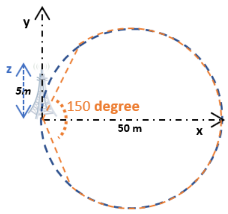


Figure 1. Overall scheme of the three simulation scenarios

Table 2. Additive simulation parameters for scenario 1 and 2

Parameters for User1.pc1	Scenario 1	Scenario 2
Numerology	1	2
Number of RB	12 for (4.32 Mhz of BW)	6 for (4.32 Mhz of BW)
Number of RB allocated to User1.pc1	RB1 to RB6 (2.16 Mhz)	RB1 to RB3 (2.16 Mhz)
CP (with 2 subcarriers for guard band)	(2.38 μs) * 2 = 4.76 μs	(1.19 μs) * 4 = 4.76 μs
CQI Parameters	CQI index 12 and 7 [Table 5.2.2.1-2.] [15] (Fixed CQI for user1.pc1)	
Modulation/Coding rate	Scenario 1.1 CQI:12 64QAM/666 Scenario 1.2 CQI:7 16QAM/378	Scenario 2.1 CQI:12 64QAM / 666 Scenario 2.2 CQI:7 16QAM / 378
Codage Canal	LDPC code For Data [16]	

Table 3. The simulation common parameters for the three interference study scenarios

Interferent cells parameters (Pico Cell 2 and 3)		The studied cell parameters (Pico Cell 1)	
Bandwidth (For Data)	4.32 Mhz	Bandwidth (For Data)	4.32 Mhz
Carrier frequency	4.5 Ghz	Carrier frequency	4.5 Ghz
Numerology	2	Waveform	DFT-s-OFDM
Waveform	DFT-s-OFDM	Frame duration	10 ms
Subcarrier spacing	60 khz	Subframe duration	1 ms
Number of symbols per Subframe	56	Interference calculation by Subframe duration of	1 ms
CP (with 4 subcarriers for guard band)	(1.19 μs) * 4 = 4.76 μs	Number of UE/Cell	1
Frame duration	10 ms	UE power	UE Class 1: 30 dBm
Subframe duration	1 ms	UE position	Position fixed during the whole simulation
Interference calculation by Subframe duration of	1 ms	UE speed	0 km/h
Number of RB	6	Pathloss	Fixed 107 dB
Number of UE/Cell	2	SNR at the Pico cell 1 receiver for user UE1.pc1	40 dB
Number of RB/UE	3	1 Chunk	10 Frames
UE power	UE Class 1: 30 dBm	Time between Chunks	10 s
UE speed	3 km/h	Simulation period	5000 Frame
UE position	Random (users don't leave their cells) /position calculation every Time between Chunks	Antenna (for reception and transmission) [17]	SISO (0 dB gain)
Channel model (For indoor industry)	Channel power delay profile: Pedestrian A [18] Channel number of paths: 50 Pathloss model (indoor with NLOS) [19]: 4.5 GHz omnidirectional V-Omni-FI model [20]	Position of pico cell station in the cell (x, y, z): Pico 1: (0, 0.5 m) Pico 2: (100 m, 0.5 m) Pico 3: (50 m, 100 m, 5 m)	
1 Chunk	10 Frames		
Time between Chunks	10 s		
Simulation period	3000 Frame		

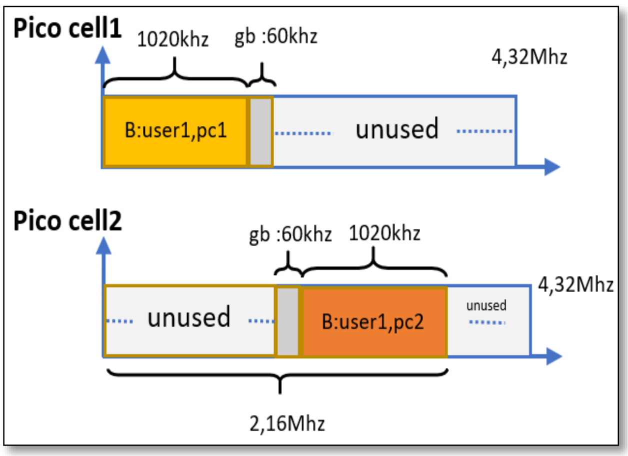


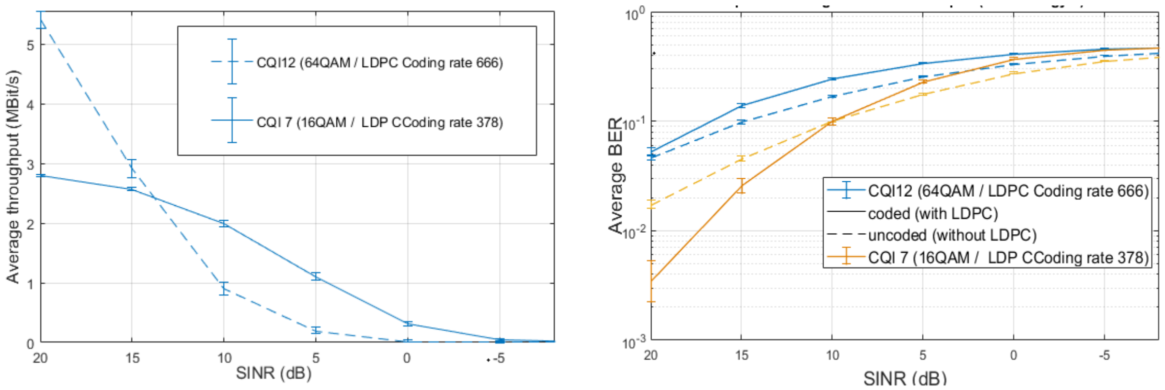
Figure 2. Frequency scheduling in scenario 3

Table 4. Specific parameters for scenario 3

Parameters for User1.pc1 and User2.pc2	Scenario 3
Numerology	Pico cell 1: 1 Pico cell 2: 2
Number of subcarriers	User1.pc1: 34 for (1.02 Mhz of Pico-cell 1BW) User1.pc2: 17 for (1.02 Mhz of pico-cell 2BW)
Subcarriers allocated to Users	User1.pc1 from Subcarrier 1 to 34 (in numerology 1) (Pico-cell 1BW) User1.pc2 from Subcarrier 19 to 36 (in numerology 2) (pico-cell 2BW)
Guard band	User1.pc1: Subcarrier 35 to 36 (60 khz) (in numerology 1 for Pico-cell 1BW) User1.pc2: Subcarrier 18 (60 khz) (in numerology 2 for Pico-cell 2BW)
Cyclic prefix duration	4.76 µs
CQI Parameters	CQI index 12 and 7 [Table 5.2.2.1-2.] [15] (Fixed CQI for user1.pc1)
Modulation / Coding rate	Scenario 3.1 CQI:12 - 64QAM / 666 Scenario 3.2 CQI:7 - 16QAM / 378

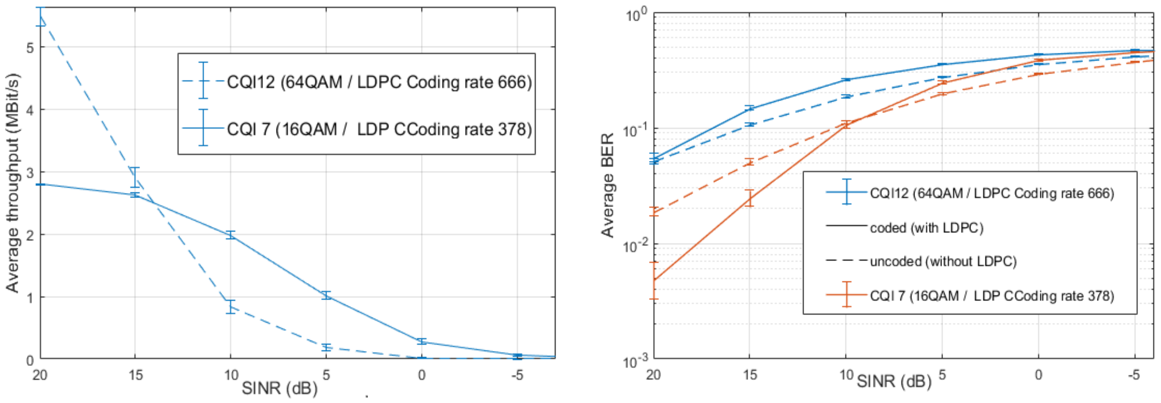
3.2. Simulation results

Figures 3(a) and 3(b) give the performance results in the uplink transmission for user1.pc1 using the numerology 1 with the presence of the interfering cells picocell 2 and 3. Figures 4(a) and 4(b) give the performance results in the uplink transmission for user1.pc1 using the numerology 2 with the presence of the interfering cells picocell 2 and 3. Figures 5(a), 5(b) and 5(c) give the performance results in the uplink transmission for user1.pc1 using the numerology 1 in picocell 1 and user1.pc2 with numerology 2 in picocell 2 depending on the transmission power of the user user1.pc2.



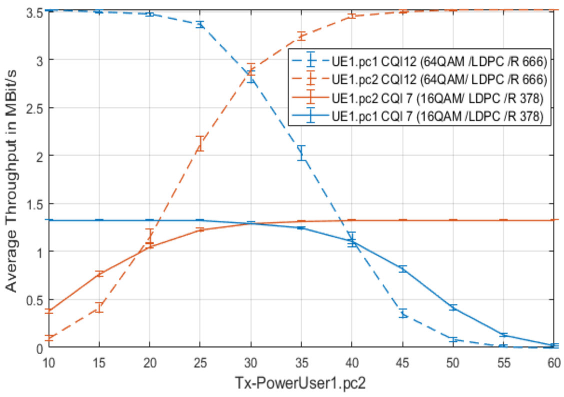
(a) (b)

Figure 3. Performance results in the uplink transmission; a) uplink user1.pc1 throughput for picocell 1 with numerology 1, b) uplink user1.pc1 BER for picocell 1 with numerology 1

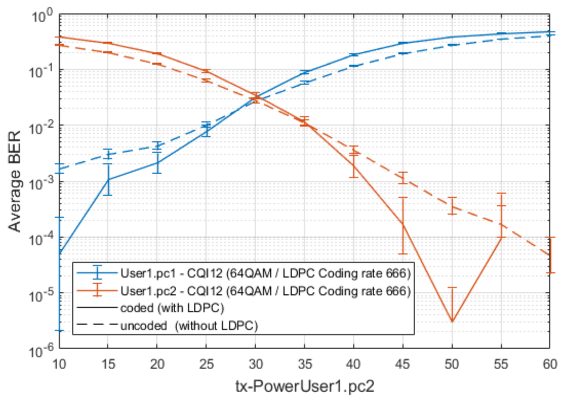


(a) (b)

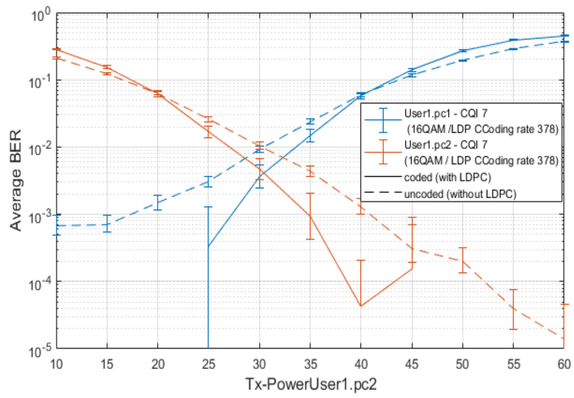
Figure 4. Performance results in the uplink transmission; a) uplink user1.pc1 throughput for picocell 1 with numerology 2, b) uplink user1.pc1 BER for picocell 1 with numerology 2



(a)



(b)



(c)

Figure 5. Performance results in the uplink transmission; a) the average throughput of users as a function of the co-interference between user1.pc1 and user1.pc2 depending on the transmission power of user1.pc2, b) the average BER of users as a function of the co-interference between user1.pc1 (CQI 12) and user1.pc2 (CQI 12) depending on the transmission power of user1.pc2, c) the average BER of users as a function of the co-interference between user1.pc1 (cqi 7) and user1.pc2 (cqi 7) depending on the transmission power of user1.pc2

3.3. Analysis of the obtained results

From the results of scenarios 1 and 2 it is clear that the impact of the interferences is the same for the two numerologies 1 and 2 used in the pico cell 1. Concerning the first two scenarios, the mean SINR experienced at the level of the pico cell 1 for user user1.pc1 varies approximately from 20 dB to -7 dB which reduces the uplink bit rate of this user from 5.4Mb/s to around 1kb/s for a CQI of 12 which is equivalent to the modulation 64-QAM and an LDPC coding rate of 666. The use of a modulation rate of 16QAM and an LDPC coding of 378 does not give better results and we can see a little improvement in the order of 5dB compared to the CQI 12 just in the SINR from 10 to 0dB but the throughput remains very low between 2.6Mb/s and 10kb/s which represents a deterioration of the uplink transmission from 40% to 99.9%. The same analysis can be applied concerning the BER for the two first scenarios. When SINRs are lower than 5dB, we notice that the LDPC coding (with coding rate of 666 and 378) does not improve the quality reception in uplink; so, performance with and without LDPC coding remains approximately the same in this rang of SINR.

In scenario 3 the use of adjacent frequency resources in the uplink transmission between user user1.pc1 (with numerology1) and user2.pc2 (with numerology2) as already illustrated in Figure 2 causes interference due to out of band of DFT-s-OFDM. With the increase in the power of the user's user1.pc2 transmitter, the guard band between the two users (about 120 kHz) does not prevent interference between the two users scheduled next to each other in frequency. From Figure 5(a) we notice that the transmission rate for the two users is inversely proportional, if the user "user1.pc2" increases their transmission power then their transmission quality as well as the uplink rate will be improved but this will automatically affect the "user1.pc1" which will see their uplink transmission quality deteriorate. From Figure 5(b) and 5(c) we note that even with the use of low order of modulation techniques and more robust coding rate (from CQI 12 to 7) the impact of interferences between adjacent channels is still present and considerably deteriorates the quality of pico cells reception. For class 2 and class 3 5G transmitters with a transmission power of 20 to 30 dBm [15], the uplink transmission rate in picocells with the same resources used in Table 4 will not exceed 1.4 Mb/s in the most optimistic simulations.

As a summary of our simulations of interference cases in the context of deployment of 5G pico cells at 4.5 GHz frequency, we can conclude that: The densified deployment of 5G pico cells deteriorates considerably the experience of users in uplink transmission, the percentage of throughput losses is estimated between 40% and 99%. The reduced coding and modulation rate allow a slight improvement in performance, but the deterioration in uplink transmission rates is still significant. Interference between users with adjacent resources and different numerologies as we can call it inter-numerology interference should be taken into account in the process of avoiding intercellular interference, a study on the size of the guard band should be made as well as the limitation of the user's uplink emission power which is in the scoop study of the release 16. [21]

Channel estimation techniques [22] and conventional cell deployment methods such as sectorization and allocation of radio bands by cells must be reviewed. A more fluid and intelligent management of radio resources which takes into consideration the environment of the cells and interferences is necessary in order to satisfy the performance objectives targeted for the 5G pico cells [21], in this context in the last section of our article we give our vision for managing uplink shared radio resources between several Pico cells to avoid intercell interference.

4. INTELLIGENT TECHNIQUES FOR 5G PICO CELLS NETWORKS TO AVOID UPLINK INTER CELL INTERFERENCE

5G New radio support the use of wave form with multiple numerology to provide flexibility in transmission parameters for different application like "eMBB", "URLLC" to support a variety of industrial use cases and applications [23-26]. The use of multi cell deployment and multi-numerology affects cells performance because of interferences between cells and also between numerology as we showed in the previous section of our article regarding the uplink transmission. Several research works support our research results, for example the references [27, 28] show that the interferences between numerology are more important in subcarriers called "edge subcarriers" located near the area between different numerologies, and consequently the SIR radio of the edge subcarriers is low.

To respond to this problem, we give five main techniques for managing radio resources in uplink and which combined will allow optimal management of bandwidth while respecting the distribution and the target quality of users services, these techniques can be summarized as follows:

a. Technique 1

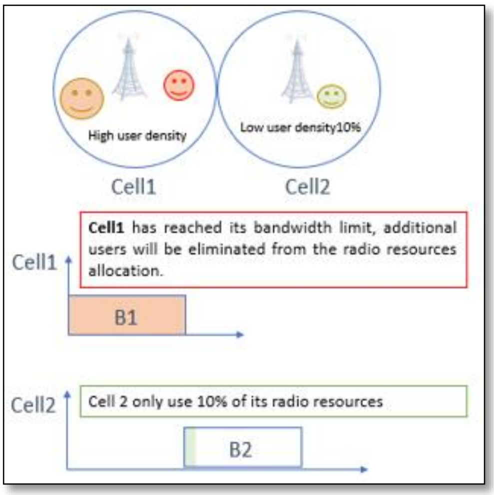
The use of a unified resource bandwidth with Mixed Numerologies between all the pico cells instead of a band reserved for each cell, the use of the unified band will depend on the user's density in each cell.

b. Technique 2

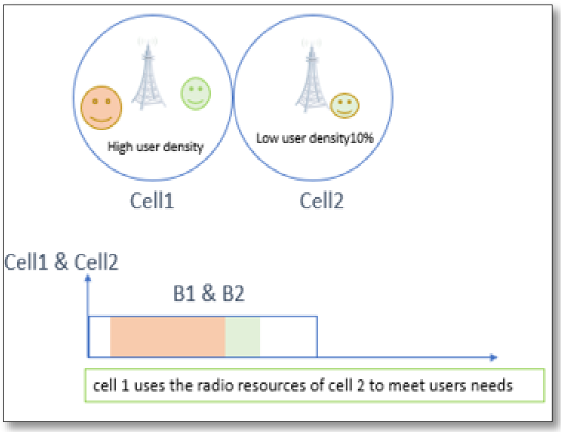
The use of fractional numerology domain "FND" to avoid inter numerology interference for users according to the quality of services targeted by the user. Technique 3: The use of uplink power control to adjust the user's uplink power to allow a large reduction in interferences between cells in the case where we cannot avoid the use of the same RB by two adjacent cells (dense user's environment). Technique 4: The choice of a centralized and simple management solution versus a distributed and complex management solution between all the cells. Technique 5: Coordination between all cells via the Xn interface to send the Information Tables and radio resource allocation decisions between cells. We will briefly describe each technique:

4.1. Technique 1: unified resource bandwidth with mixed numerologies

The concept of using a frequency band with unified management instead of a different bandwidth for each cell will allow better exploitation of radio resources based on the real resource need of each cell. Figure 6 explains this concept. In scenario a cell 1 has reached its bandwidth limits because of the high density of users and cannot accept other links requests, but the adjacent cell use only 10% of its capacity due to the low density of users in this cell, then there will be a big loss in the radio resources with this method. With scenario 2 the radio resources are shared between the two cells 1 and 2 then cell 1 can take advantage of the free bandwidth to accept new user requests and there will be no loss of radio resources in addition the shared band could be divided into multiple numerology to satisfy the different services.



(a)



(b)

Figure 6. Unified resource bandwidth concept, (a) shared bandwidth between cell1 and cell2, (b) separate management of the radio resources

4.2. Technique 2: fractional numerology domain

The Fractional numerology domain is a technique which splits the radio resources band into two distinct zones, inner zone and edge zone, the objective here is to offer more protection to the users who have more constraint of latency like URLLC, these users will be localized in the internal area of the numerology and therefore will be less affected by internumerology interferences In the literatures several researches adopt the technique of INI and there are versions to manage the INI problem Based on scheduling [29] and others which use filtering techniques [30, 31]. Figure 7 shows the principle of our version of this technique.

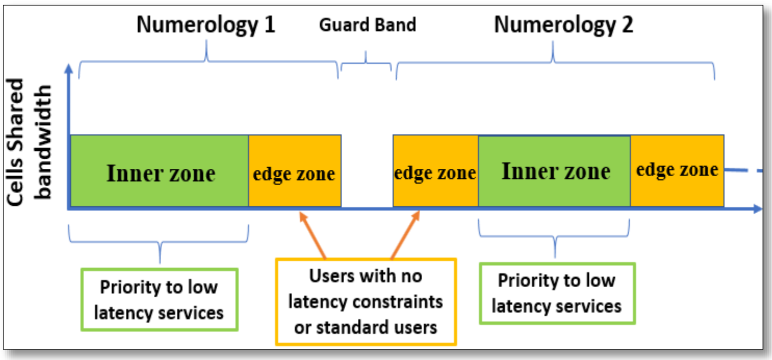


Figure 7. The proposed version of fractional numerology domain

4.3. Technique 3: uplink power control for interference reduction

When the density of users increases the possibility of offering an unused radio resource in several adjacent cells becomes low, the power control solution is necessary in order to reduce the effect of interference between the cells with the principal of uplink power transmission control of users [32]. The objective is the reduction of the Uplink "SINR" calculated at the reception level for all cells with users utilizing the same radio resources. Figure 8 gives an example of this technique.

4.4. Technique 4: centralized and simple management solution

The execution of the 3 first principles already mentioned of our algorithm requires a master cell which will have the task of receiving the information from the slave cells and establishes the decision of the resources allocated according to the requests. Each slave cell must periodically send its identifier, the identifiers of the users, their target quality of service, as well as the channel status in uplink per user. Based on the information received, the master cell establishes the scheduling decisions for radio resources and informs the slave cells to apply the changes to the resources.

4.5. Technique 5: coordination between cells via the Xn interface

Without the existence of communication interface with very low latency between the cells, it will be impossible to use a centralized coordination technique, thanks to the Xn interface which is a Standardized 5G interface for communications via RAN 5G Cell. The Xn is a point-to-point interface between two 5G RAN nodes [33]. The 5G standard allows us to use this interface to exchange all the information related to the cells which will allow us to exchange the necessary information in order to execute coordination algorithms [34].

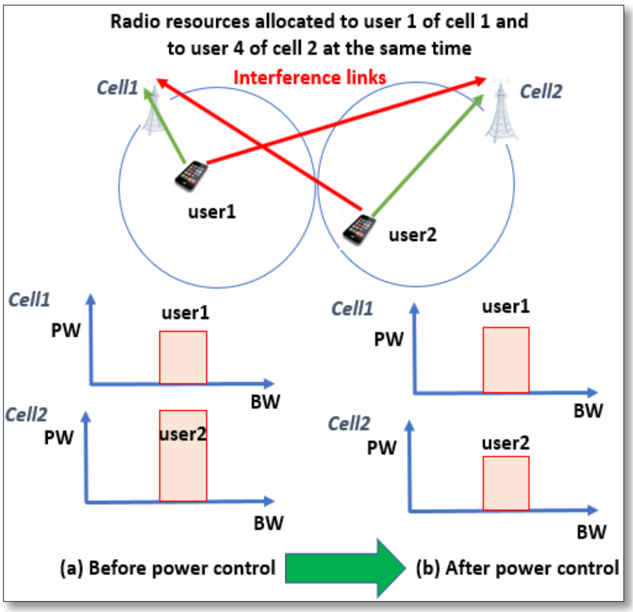


Figure 8. The concept of uplink power control for intercell interference reduction

5. CONCLUSION AND PERSPECTIVES

After a study by simulation of the intercellular interference (ICI) and inter numerology interference (INI) problems in a context of deployment of several 5G pico cells at 4.5 Ghz frequency for 5 Mhz of bandwidth, we have concluded that the degradation of the SINR causes a significant deterioration of the throughput and the quality of service (QOS) for all uplink users. To this end, we have given the main lines for ICI and INI interference avoidance techniques which can improve the user experience and the QOS in the cells. In our next work, we will give the implementation process of our new algorithm for intercell interferences avoidance and we will make a study by simulation of the cells capacity according to the users density to allow giving results and conclusions on the advantages of our algorithm compared to other scheduling techniques.

REFERENCES

[1] "Ericsson official website," 2020. [Online]. Available: www.ericsson.com/en/5g/what-is-5g, date of consultation.
[2] Y. Nakayama, T. Nishio, D. Hisano and K. Maruta, "Small Cells Enabled by Crowdsourced Radio Units Mounted on Parked Vehicles for Smart City," *IEEE Access*, vol. 8, pp. 17986-17998, 2020.
[3] A. Bonfante, D. López-Pérez, G. Geraci, M. Majid Butt and N. Marchetti, "5G Massive MIMO Architectures: Self-Backhauled Small Cells versus Direct Access," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 10, pp. 10003-10017, 2019.
[4] Ioannis P. Chochliouros, et al., "Using Small Cells for Enhancing 5G Network Facilities," *2017 IEEE Conference on Network Function Virtualization and Software Defined Networks (NFV-SDN)*, Berlin, 2017, pp. 264-269.
[5] P. Varzakas, "Optimal Radio Capacity for an Hybrid DS/SFH CDMA System in Cellular Radio," *Electronics Letters*, vol. 40, no. 7, pp. 440-442, 2004.
[6] "Small Cell Forum," 2020. [Online]. Available:https://www.smallcellforum.org/.

[7] Busines Insights Fortune, “Network Market Size, share & industry analysis, by application,” *communication infrastructure and regional Forcast*, 2019.
[8] “5G Small Cell, Pico Cell Understanding and Planning,” 2019. [Online]. Available: http://4g5gworld.com/blog/5g-small-cell-pico-cell-understanding-and-planning.
[9] “Small cells: Backhaul difficulties and a 5G future,” *RCR Wireless*, 2016. [Online]. Available: https://www.rcrwireless.com/20160711/network-infrastructure/small-cells-tag31-tag99.
[10] Fujitsu Network Communications, “High-Capacity Indoor Wireless Solutions: Picocell or Femtocell?,” *Fujitsu Network Communications Inc*., pp. 1-10, 2019
[11] Lászlon R. Costa, et al., “Radio resource allocation in multi-cell and multi-service mobile network based on QoS requirements,” *Computer Communication*, vol. 135, pp. 40-52, 2019.
[12] “Applications for 5G Small Cell Technology in Networks of the Future,” 2019. [Online]. Available: https://www.kmbdg.com/articles/5g-small-cell-technology/.
[13] Steven Bergren, “Design Considerations for a 5G Network Architecture,” *Computer Science, ArXiv*, pp. 1-16, 2017.
[14] Stefan Pratschner, et al., “Versatile mobile communications simulation: the Vienna 5G Link Level Simulator,” *EURASIP Journal on Wireless Communications and Networking*, no. 226, 2018.
[15] Technical Specication Group Radio Access Network, “3rd Generation Partnership Project, 3GPP NR, Physical layer procedures for data,” *3GPP TS 38.214 version 16.0.0 Release 16*, TS 38.214, 2019.
[16] Technical Specication Group Radio Access Network, “3rd Generation Partnership Project 3GPP, NR, Multiplexing and channel coding,” *TS 38.212. 3rd Generation Partnership Project (3GPP)*, 2018.
[17] Malik, P., and Parthasarthy, H., “Synthesis of randomness in the radiated fields of antenna array,” *International Journal of Microwave and Wireless Technologies*, vol. 3, no. 6, pp. 701-705, 2011.
[18] 3rd Generation Partnership Project (3GPP), “Technical Speci_cation Group Radio Access Network; High Speed Downlink Packet Access: UE Radio Transmission and Reception,” *TR 25.890. 3rd Generation Partnership Project (3GPP)*, 2002.
[19] Theodore S. Rappaport, et al., “Overview of Millimeter Wave Communications for Fifth-Generation (5G) Wireless Networks With a Focus on Propagation Models,” *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 12, pp. 6213-6230, 2017.
[20] Mohammed Bahjat Majed, et al., “Channel Characterization and Path Loss Modeling in Indoor Environment at 4.5, 28, and 38GHz for 5G Cellular Networks,” *International Journal of Antennas and Propagation*, vol. 2018, 2018.
[21] “3GPP officiel web site: Release 16,” 2020. [Online]. Available: https://www.3gpp.org/release-16.
[22] Nilofer Shaik, and Praveen Kumar Malik, “A Retrospection of Channel Estimation Techniques for 5G Wireless Communications: Opportunities and Challenges,” *International Journal of Advanced Science and Technology*, vol. 29, no. 05, pp. 8469-8479, 2020.
[23] L. Zhang, A. Ijaz, P. Xiao, R. Tafazolli, “Multi-service system: an enabler of flexible 5G air interface,” *IEEE Communications Magazine*, vol. 55, no. 10, pp. 152-159, 2017.
[24] A. Es-saqy, et al., “28 GHz balanced pHEMT VCO with low phase noise and high output power performance for 5G mm-Wave systems,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 5, pp. 4623-4630, 2020.
[25] D. Daghouj, et al., “UWB Coherent Receiver Performance in a Vehicular Channe,” *International Journal of Advanced Trends in Computer Science and Engineering IJATCSE*, vol. 9, no. 2, pp. 1996-2001, 2020.
[26] D. Daghouj, M. Fattah, S. Mazer, Y. Balboul, M. El Bekkali, "UWB waveform for Automotive Short Range Radar," *International Journal on Engineering Applications (IREA)*, vol 8, no 4, 2020.
[27] A. Yazar, and H. Arslan, “Flexible multi-numerology systems for 5G new radio,” *Journal of Mobile Multimedia*, vol. 14, no. 4, pp. 367-394, 2018.
[28] C. Jiang, H. Zhang, Y. Ren, Z. Han, K. Chen, L. Hanzo, “Machine learning paradigms for next-generation wireless networks,” *IEEE Wireless Communications*, vol. 24, no. 2, pp. 98-105, 2017.
[29] Yazar and Arslan, “Reliability enhancement in multi-numerology-based 5G new radio using INI-aware scheduling,” *EURASIP Journal onWireless Communications and Networking*, no. 11, pp. 1-14, 2019.
[30] L. Zhang, A. Ijaz, P. Xiao, A. Quddus, R. Tafazolli, “Subband filtered multi-carrier systems for multi-service wireless communications,” *IEEE Transactions on Wireless Communications*, vol. 16, no. 3, pp. 1893-1907, 2017.
[31] Lei Chen, and J. G. Yu, “Interference cancelation scheme with variable bandwidth allocation for universal filtered multicarrier systems in 5G networks,” *EURASIP Journal on Wireless Communications and Networking*, no. 1, pp. 1-10, 2018.
[32] V. Kavitha, M. K. Gupta, V. Capdevielle, Rahul Kishor, M. Majed Haddad, “Speed based optimal power control in small cell networks,” *Computer Communications*, vol. 142-143, pp. 48-61, 2019.
[33] 5G; NG-RAN; Xn general aspects and principles, 3GPP TS 38.420 version 15.0.0. Release 15. ETSI TS 138 420 V15.0.0 Version: 07-2018.
[34] Malik, P. K., Wadhwa, D. S., Khinda, J. S., “A Survey of Device to Device and Cooperative Communication for the Future Cellular Networks,” *International Journal of Wireless Information Networks*, no. 27, pp. 411-432, 2020.

BIOGRAPHIES OF AUTHORS

Younes Balboul is a professor in the National School of Applied Sciences at the Sidi Mohamed Ben Abdellah University (USMBA), Fez, Morocco. He is a member of Laboratory of Artificial Intelligence, Data Sciences and Emerging Systems. (younes.balboul@usmba.ac.ma)

Mohammed Fattah is a professor in the Electrical Engineering Department of the High school of technology at the Moulay Ismail University (UMI), Meknes, Morocco and he is a responsible of the research team 'Intelligent Systems, Networks and Telecommunications', IMAGE laboratory, UMI. (m.mohammedfattah@umi.ac.ma)

Saïd Mazer is a professor in the National School of Applied Sciences at the Sidi Mohamed Ben Abdellah University (USMBA), Fez, Morocco. He is a member of Laboratory of Artificial Intelligence, Data Sciences and Emerging Systems. (said.mazer@usmba.ac.ma)

Moulhime El bekkali is a professor in the National School of Applied Sciences at the Sidi Mohamed Ben Abdellah University (USMBA), Fez, Morocco. He is a member of Laboratory of Artificial Intelligence, Data Sciences and Emerging systems. (moulhime.elbekkali@usmba.ac.ma)