A Mechanism for Improving the Spectral Efficiency in mu-MIMO for 5G and Beyond Networks

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ABSTRACT

The ultimate challenge that arises in 6G and 5G and beyond networks is how the mobile networks of the future will be able to cope with the constantly increasing number of devices. In Multiuser Multiple-Input and Multiple-Output (mu-MIMO), the base station basically serves many users at the same time using the same frequency. The topic considered in this paper is the spectral performance in Downlink mu-MIMO. This paper's goal is to improve the achieved spectral efficiency of the communication system, as well as the achieved reliability of the communication link. An algorithm based on downlink scheduling and the resource allocation is proposed to achieve maximum spectral use of the system. Considering user's demands, this paper's mechanism is able to allocate the potential user of the queue to the "best antenna" based on its demands and distance. That provokes a larger number of devices that can be supported, always according to the specifications stated in IEEE 802.11ax.

CCS CONCEPTS

• **Networks** → **Mobile networks**; **Network simulations**.

KEYWORDS

5G; MIMO; mu-MIMO; bandwidth; spectral efficiency; networks

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1 INTRODUCTION

6G mobile networks aim at new technologies in order to improve post-transmission performance, e.g. high data speed, low latency and low power consumption. Such technologies include communication with very dense heterogeneous network, millimeter wave (mmWave), multiple input multiple output (MIMO), orthogonal frequency-division multiplexing (OFDM) and non-orthogonal multi-access (NOMA)[4],[9].

Mu-MIMO isolates the traffic of each subscriber and allows them to transmit and receive concurrently between multiple subscribers. Only one beam per set of antenna elements could be formed and now seven beams can be used. MIMO is a range of technologies used to multiply the capacity of a wireless connection without requiring additional spectrum by using the horizontal and vertical polarities of the radio wave. Each, carrying a separate data stream to transmit and receive data because the two polarities are perpendicular to one another. A system's spectral efficiency is basically depended on the Signal-to-Noise Ratio (SNR), channel estimated accuracy [11],the spatial correlation in the propagation environment [3] and is also limited by the theoretic capacity [8].

Lately, research community is focused on mu-MIMO system of wireless communication. Mu-MIMO systems come with no propagation limitations. Antenna correlation or channel rank loss (unlike single user MIMO systems), are some of them and construct the mu-MIMO system a perfect candidate for the upcoming wireless systems and standards [1]. In order to achieve the higher data rates, reliability and traffic demands that concerns the 5G and beyond era, new approaches is needed to improve those metrics [14]. In [6] the authors have shown how MIMO technology can promote the capacity of the communication system and can increase the reliability of the link as it uses a variety of schemes beyond the spatial diversity. According to our knowledge, there are currently no templates dictating the channel capacity of mu-MIMO systems. In this regard, [10] has analyzed the performance of such systems inside the capacity region in. This metric can be defined in the usual Shannon sense and consists the highest rates that can be achieved with arbitrarily small error probability. The capacity of each one of the users is calculated and then the capacity region for which maximum achievable rates are reached is decided. Massive

MIMO is the most efficient technology for Mobile Network Operators (MNOs) in order to achieve their purpose on increasing their network capacity [13]. The authors in [2] pointed out five massive MIMO related research directions such as extremely large aperture arrays, large-scale MIMO radar, intelligent and holographic massive MIMO, six-dimensional positioning. The article in [12] is about massive MIMO 2.0 and it presents the theoretical capacity with no limits of massive MIMO. Compared to Long Term Evolution (LTE), the continuous increase of network capacity has been trialed to be up to 10 times together with the deployment of 5G massive MIMO [5]. Another test in real-time experiment is presented in [7] and includes up to 100 number of antennas. The research works presented a framework for designing real-time testbed for massive MIMO implementation but the number of the users is limited.

Taken in account all the previous research works in MIMO or mu-MIMO based on spectral efficiency and their results, this paper's goal is to deal with mu-MIMO in Downlink with multiple antenna users. Deciding whether an antenna is able to serve a user or not, the mechanism proposed in this paper aims to serve as many users as possible based on their demand and their location, calculating the remaining bandwidth and the interference that may occur to the device. Paper's highest goal is to succeed in providing the best Quality of Service (QoS) for all the connected devices, respecting their demands.

The remainder paper is organized as: in Section II we describe the system model. Section III explains the proposed mechanism and the parameters given to the simulation model. In Section IV the results of simulation are presented and the paper is concluding in Section V, while in Section VI possible future work and ideas for further research work are suggested.

2 SYSTEM MODEL

Mu-MIMO using multiple antenna and users with single antenna may increase capacity without expanding network bandwidth. It is shown that the use of multiple antennas at the ends of communication links improves the spectral efficiency of the communication system and the reliability of the communication link.

According to Shannon, the capacity C of a radio channel is dependent on Bandwidth B and the signal-to-noise ratio *SNR*, where S stands for Signal power and N for noise power. Conventional systems use one transmit and one receive antenna. In MIMO technology this is called single input single output.

$$C = B\, log_2\ (1 + \frac{S}{N}) \tag{1}$$

A MIMO system typically consists of more than one transmits and more than one receive antennas. Using the same channel, every antenna receives the components intended for it, but also the indirect components that are intended for the other antennas. The data that needs to be transmitted is divided into independent data streams. The number of the streams is always less than or equal to the number of antennas. In a 4x4 system, four or fewer streams can be used to transmit the signal. That comes to the conclusion that the capacity increases linearly with the number of the streams and the Shannon-Hartley theorem for MIMO is

$$C \leqslant M\, B\, log_2\ (1 + \frac{S}{N}) \tag{2}$$

The maximum data rate that a system can achieve is equal to M pulse levels, multiplied to bandwidth, multiplied by the base 2 logarithm of the *SNR* plus 1.

$$MaxDR = B\, log_2\ (1 + SNR) \tag{3}$$

On the other hand though, if the SNR is low, the max data rate *MaxDR* increases almost linearly. It is not efficient to aim only to a high SNR, it is better to share the SNR between the streams and that will lead to a multiplication of the maximum available data rate. The way to share the SNR is actually by the spread spectrum techniques. Code Division Multiple Access(CDMA) is one of them where the transmission is multiplexed over a wider bandwidth.

Mu- MIMO technology will be used in order to increase the system capacity and the reliability of the communication. The mu-MIMO mode is especially useful when it comes in uplink because user equipment using one antenna for transmit, keeps the complexity at minimum. This paper aims to take advantage of multiple antennas on both user and BS ends of the communication link in order to improve the achieved spectral efficiency and the reliability of the communication system and communication link.

Spectral efficiency (SE), actually means the sum of the spectral efficiency of the transmissions inside a cell of a cellular network. The SE is measured in bit/s/Hz and multiply it with the bandwidth, gives the cell throughput that is measured in bit/s. It is known that the bandwidth cannot be improved, so it is a better and preferable option to improve the cell throughput. To do so spectral efficiency must be improved and increased. The best way to achieve the improvement of spectral efficiency is to reassure that our system can serve as many User Equipments (UEs) as possible simultaneously in the cell, using the same bandwidth. This is actually Massive MIMO's existence.

Approximately Spectral Efficiency of 5G New Radio (NR) (bits/sec/Hz) can be calculated as follow:

$$SE_{5G} = \frac{5G\ Throughput, bps}{Channel\ Bandwidth, Hz} \tag{4}$$

Based on the 3GPP standard recommendation, to obtain the correct result of spectral efficiency calculator in a network, it is necessary to calculate 5G throughput that is depended on number of MIMO layers, bandwidth, frequency range, modulation type. To have valid result number of aggregated component, carriers should be 1. Then the 5G throughput has to divided by the channel bandwidth.

Fig. 1 shows a mu-MIMO coordinated network in a cellular network including three different classes of cells. These three kind of cells are: a) Coordinated cells (cells surrounding the Central cell), b) Central cell (the main cell) and c) Interfering cells (all the others). Central Station (CS) is responsible for the connection link between cells. Such mechanisms aim to mitigate the drawbacks of inter-cell interference.

By simulating a network we can predict the achievable spectral efficiency and that's our purpose and goal.

This Section describes the algorithm that is being used in a simulated network. The network follows the topology of Fig. 1 and is

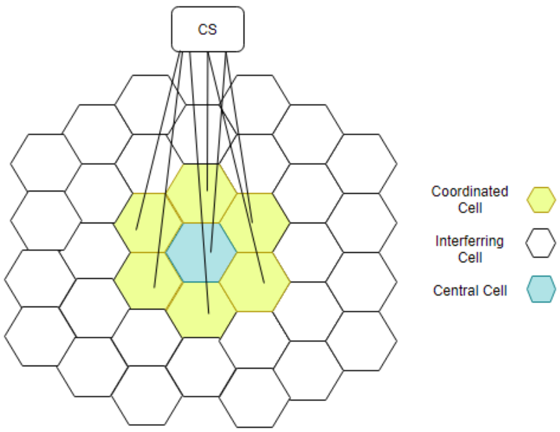

Figure 1: Coordinated Network in mu-MIMO

consisted of 25 antennas that serve a varying number of users. In 5G NR Frequency Radio 2 (FR2) type, depending the deployment environment, the number of users differ. In the proposed topology, micro cells and metro cells are consider and that's why the maximum number of users that can be served at micro cell are 256 while metro cell can serve more than 250 users and that is why one of the experiments explained later, are about a topology with more than 250 users In this paper, an answer will be given on how many UEs can be served and should be scheduled per cell in a network, in order to improve and maximize its spectral efficiency. It is difficult when it comes to multi-cell systems, various parameters and standards are needed for the validation of results. That is why, block lengths, number of antennas, hardware, pilot allocation, and many other parameters are considered during the simulation. Uplink (UL) and Downlink (DL) transmission modes will play a key role for the performance of UEs in simulated network topology. Mu-MIMO system in downlink is considered, where the base station uses a number N of antennas to communicate with user equipment's (UE) deployed with M single antenna. Both conventional and linear processing schemes are considered, such as maximum ratio (MR) combining/transmission and zero-forcing(ZF), and a new full-pilot zero-forcing (P-ZF) scheme that actively suppresses inter-cell interference in a fully distributed coordinated beamforming system. For this scheme, it is assumed that precoding matrix for each scheduled user is almost identical so that the same matrix can be used for in queue scheduled users. It is also assumed that each UE performs single user detection and that the user's bit rate is based on its bandwidth and its SNR as follow ,where f_l is actually a function that describes the link performance.

$$R_b = B \times F_l\ (SNR) \tag{5}$$

SINR can also be defined by the user's location as a function SINR(x). The spectral efficiency at a UE's location is calculated by the ratio of bit rate to the bandwidth of user in a specific location X. According to algorithm presented before, each Base Station serving a cell, allocates subcarriers of the total bandwidth to each user. It does that in a way that two different users in the same cell served by the same BS have different subsets of subcarriers. Since each BS also transmits a constant power, a user in the cell gets interference from the base station.

Algorithm 1 Efficient Mechanism for mu-MIMO

```
Simulate Network Topology
for Uniform and Random topology do
    for each UE_I do
        if i is connected then
            increase active users by one
            calculate the SINR(x) from neighbors cells
            based on user's location
            calculate UE's interference received
            from its determined Base Station
            calculate each user's R_b
        else
            for each UEi in queue (trying to connect) do
                calculate the max data rate it can Achieve
            end for
        end if
    end for
    for each cell in topology do
        calculate Base Station's power
        allocated to connected users
        compare the two scenarios results
        with the default allocation
        print RBs Usage figure
        print SINR values figure
        print Average Data Rate figure
        print Comparison Figures
    end for
end for
```

Table 1: Used Parameters

Parameter	Value
Scenario	Four Antenna AP
Antennas	25
Users for each scenario	200,250,300
Bandwidth	160 MHz
Link Rate	867 Mbits/s
Capacity speed	3.39Gbits/s
Receiver Noise Power	-32 dBm
Downlink rates	20 Gbps
Uplink rates	10 Gbps
Resource block frames UL	275
Resource block frames DL	275
Carrier Bandwidth	400 MHz
Sub Carrier Spacing	120 kHz

Table 1 presents the parameters used in simulated topology and are explained in the next paragraphs.At 90% the devices will randomly set inside the topology while at 10% there will be some outside the cells. MU-MIMO, are able as we already mentioned to increase channel capacity and transmit to multiple devices simultaneously using all the available streams. With downlink mu-MIMO an access point is able to transmit concurrently to multiple stations. In mu-MIMO the devices are separated to different spatial streams and specifically in 802.11ax, MU-MIMO and OFDMA technologies can be used simultaneously and come with 160 MHz capability that will provide significant benefits even when the devices are using smaller bandwidths.

In 5GHz AC Radio maximum Linnk Rate (Mbps) is at 867 Mbps of Class designation AC1300. A 5G macro cell antenna, it is assumed that will be placed up on a building's roof. The total height above ground is about 30m. The path loss to be at 82.5dB which leads the receiver's power at -32 dBm. The higher frequency bands in range FR2 are aimed at providing very high data rate capability for the 5G radio. Resource blocks number comes up to 275 as is the maximum number for 5G NRBlocks for any Sub Carrier Spacing (SCS) while its maximum bandwidth is at 400 MHz.

3 PERFORMANCE EVALUATION

In this section the simulated scenario is described as well as the models that are used for evaluation. Then, the results are presented and explained. The above scenario defines a geographical area containing 25 macro cells. Macro cells' base stations are shown with a black square in the middle of cells. The users who can operate in mu-MIMO are the blue circles with a cross in it and the number differs in each scenario (200,250,300). On the other hand the users that do not operate in mu-MIMO are red while the users that are outside the covered area an antenna can serve, are colored with a black circle. There are two simulated position allocation scenarios, (random and uniform user distribution) and three subscenarios. The three subscenarios concern the number of users in simualated topology as explained before, and in all three of them, the users' position is fixed for computational reasons, the users are not moving so there position is static during the whole process of the simulation.

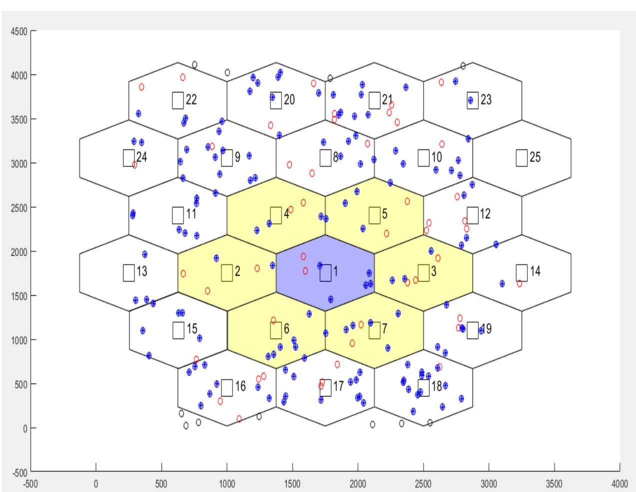

Figure 2: Scenario 1: Random Allocation

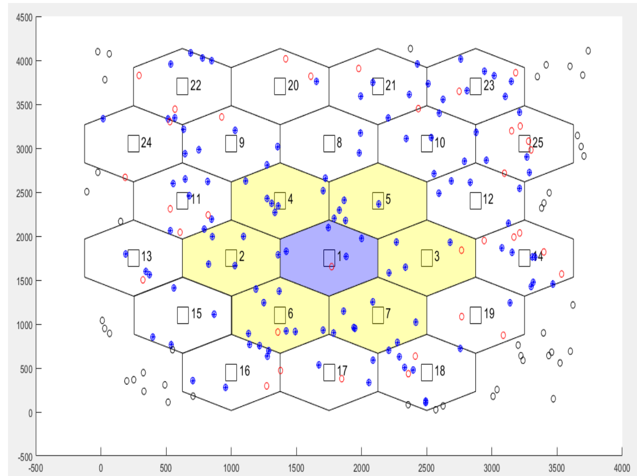

Figure 3: Scenario 2: Uniform Allocation

In the first scenario, all the users are randomly allocated. That has as a result the most of the users are mainly allocated in the center of the topology and some cells have way more users to serve than others. That second scenario is allocating the users uniformly in the topology. The first scenario is the more realistic one, while the second is expected to have greatest results because of the each user's location. In both Fig. 2 and Fig. 3, there are 150 active devices and 50 inactive in order to distinguish each one of them in the topology, while a bigger number would make the figure difficult to understand. The second one is about a uniform allocation where the users are evenly allocated all over the topology so each antenna has approximately the same number of users to serve. The simulation will also run in subscenarios of different number of users and different demands of the users respectively. The positions of UEs are set randomly. Because of the antenna type,4x4, the bandwidth will be set at 160 MHz and carrier frequency at 2575 MH,z as 5G and beyond networks are able to use. Each device and antenna are numbered for better understanding.

4 RESULTS

In both figures below, Fig. and 4 Fig. 5 the results of the main scenarios and the performance of the mechanism is presented. The results refer to the three different scenarios. In each case the number of devices differ (three subscenarios) as well as the demands of the users are (each users is either selected or not based on its demand for resource blocks). The results for each scenario are presented. Each antenna calculates the distance between itself and the user, in combination with user's demands it decides whether it can serve the UE or not. Each antenna can serve multiple users, and it constantly calculates the resources that are used so at any moment can know the maximum remaining users that can be served and the interference that occurs between them. The proposed mechanism sets a random demand for each user in downlink and uplink. Considering the throughput usage, each antenna decides whether to serve or not the user in uplink or downlink. The total Resource Blocks allocation is calculated and presented as a percentage, referring to the whole network usage.

```
------------ RBs Results ------------

[DOWNLINK] RBs usage : 91.67 %
[UPLINIK] RBs usage : 87.50 %

------------ Device Data Rate Results ------------

[DOWNLINK] Average data rate : 4046.20 (Mbps)
[UPLINK] Average data rate : 2926.48 (Mbps)

------------ Network Results ------------

[DOWNLINK] Network Throughput : 1011550.86 (Mbps)
[UPLINK] Network Throughput : 731619.72 (Mbps)

------------ SINR Results ------------

[DOWNLINK] Average cell SINR : 87.12
[UPLINK] Average cell SINR : 64.12
```

Figure 4: Scenario 1 Results

```
------------ RBs Results ------------

[DOWNLINK] RBs usage : 75.00 %
[UPLINIK] RBs usage : 62.50 %

------------ Device Data Rate Results ------------

[DOWNLINK] Average data rate : 4145.27 (Mbps)
[UPLINK] Average data rate : 2980.90 (Mbps)

------------ Network Results ------------

[DOWNLINK] Network Throughput : 829054.69 (Mbps)
[UPLINK] Network Throughput : 596180.68 (Mbps)

------------ SINR Results ------------

[DOWNLINK] Average cell SINR : 82.55
[UPLINK] Average cell SINR : 59.55
```

Figure 5: Scenario 2 Results

Taken in account all of the devices demands and the bandwidth of network which is at 160 MHz as mentioned above, the data rate for each device, the average of network data rate as well as the network throughput are calculated. For each one of the devices, the distance between the user and the antenna, as well as the distance from other devices are also being calculated. Considering the path loss and the channel gain too for each one of the cells, the interference that occurs between the devices and the antenna in a cell, indicates the average SINR value for each cell in both above-mentioned scenarios.

5 COMPARISON

It is assumed that there are three categories of demands depending on their significance and purpose. Each demand category is presented with a percentage of the potential use of RBs. Considering the different total number of users in each scenario, as well as the previous mentioned demand category the mechanism allocates efficiently the resources to its network's users. In all three graphs, the random resource allocation (default), seems the worst scenario for the network. In Fig. 6 the usage of resource blocks as well as the SINR is way highest than the two others. It is clear that in all three subscenarios where number of users differ, the second scenario is more efficient. All of the already above-commented numbers are better in uniform allocated topology. In Fig. 7 can be seen that the resource usage is better than the random allocation and it is very critical for the network in order to be able to serve all of its users efficiently. In Fig. 8 the total interference that occurs between the devices and the antenna in a cell is presented and shown that when the users are by default served and allocated the interference is higher. In random scenario where the users are served based on their demands as well as the distance from the antenna is better than the default but worse than the uniform allocation scenario which is expected. As it is mentioned above the best way to achieve the improvement of spectral efficiency is being able to serve simultaneously as many UEs as possible using the same bandwidth in the same cell. Serving more users in each scenario and keeping the RBs usage under 100% as well as the QoS means that the mechanism is efficient. Deciding the sequence of the users that are going to be served, based on their demands, can umprove the spectral efficiency.

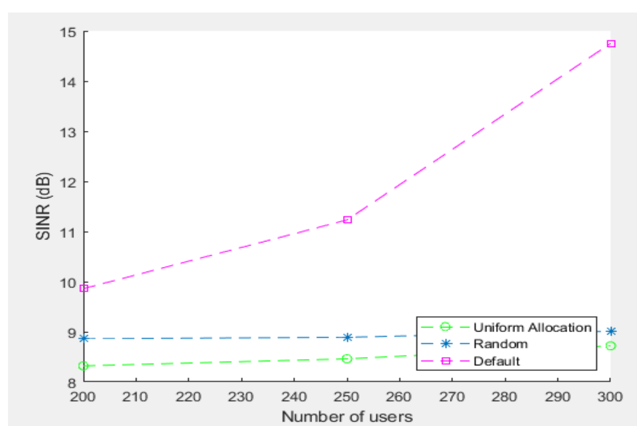

Figure 6: SINR

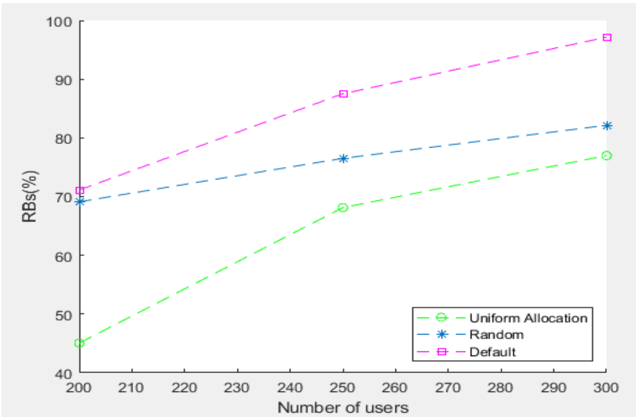

Figure 7: Resource Usage

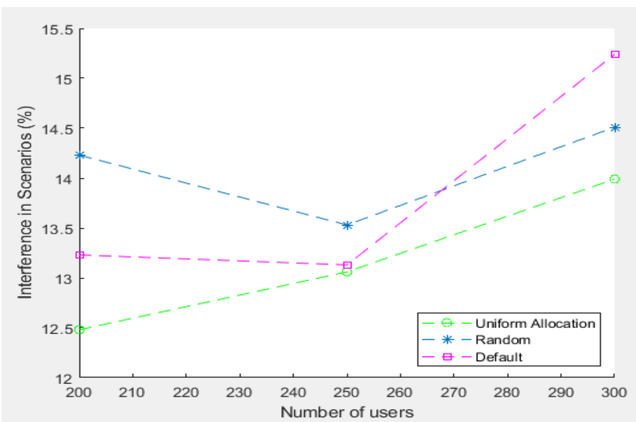

Figure 8: Interference

Comparing the default resource allocation with the algorithm mentioned above, excluding the interference figure, the proposed algorithm is more efficient in terms of RBs usage and the SINR. The results show that if the resource allocation is done based on each user's demand and importance, the system is more efficient even when the number of users is increased. Given that random distributuion is the most realistic scenario and seeing that with a uniform distribution of users the system is much more efficient we conclude to one thing. If each antenna can choose which and how many users can serve then the system's overall performance is way better and should be considered in the future. It also must be mentioned that the three scenarios were run at a total of fifty times. In all fifty times, the uniform allocation had the best results. We ought to admit that in 13 out of 50, the default scenario was better than the proposed algorithm, where at the rest of them the mechanism worked efficiently for all the users in simulated topology.

6 CONCLUSIONS

Considering LTE, mu-MIMO is one of the very promising key techniques that will change the way of perspective in 5G and beyond networks. One of the most critical challenges of this technology is to achieve the maximum spectral efficiency while balancing energy in mu-MIMO. In this paper, an efficient algorithm is proposed for spectral efficiency in Downlink mu-MIMO system simulated in MATLAB. The results showed that in a great scenario where users are uniformly allocated, the network serves more users and it is more efficient. Giving priority to some users depending on their demands and available RBs, a network system can work efficiently, maintaining the QoS of the system for all of its users. If antennas can decide whether or not to serve a user or if it is better to handover to the nearest antenna then a network for everyone's benefit can occur.

7 FUTURE WORK

In this final Section, some ideas for further research on this field are suggested. Some of this future work, based on this research, can be a scenario with way more users. An idea is while using metro cells and the user's location not being static, but moving in the simulated topology. Moving users is the realistic scenario of a topology and the results can definitely be more useful to the future of this technology but it is also much more difficult to calculate and simulate such a topology. That happens because each time, the bandwidth of an antenna as well as the QoS of the user can change.

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