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Using Beamforming for Dense Frequency Reuse in 5G

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ABSTRACT Implementing an efficient frequency reuse (FR) plan is significantly important to meet the demand on high data rates and the required quality of service for 5G. In this paper, we use the direction of arrival algorithms and the correlator to determine the directions of the desired user and the interferers in the cell. Then, we use the beamformer to produce a beam towards the desired user and nulls in the direction of the interferers. Moreover, we implement the synthesizer to smartly form the desired beam shape and make the nulls deeper. We take the advantage of the smart antennas, beamforming capabilities, and the radiation pattern synthesizing techniques to build up an efficient FR plan for 5G. In addition, we develop a formula for calculating the signal to interference and noise ratio (SINR) in terms of the desired and the interferers directions. Our objective is to maintain the SINR at the minimum levels required for data calls with accepted quality while reducing the beam sizes, and hence increase the FR factor. Our simulation results show that with a uniform linear antenna of 11 elements, we can achieve the desirable SINR levels using beams of 10° width, which raises the FR factor from 1 to 18 and subsequently increases the number of mobile users by 18 times.

INDEX TERMS Frequency reuse, smart antenna, beamforming, DOA, synthesizing.

I. INTRODUCTION

Nowadays, the applications that require high quality of service (QoS), and therefore high data rates, are increasing while the resources are limited [1]. The key element to fulfill this demand is by implementing an efficient Frequency Reuse (FR) plan that can meet this exponentially increasing demand. In the cellular mobile networks, there is always a difficulty in choosing a proper FR plan that can satisfy the required QoS of the mobile users. The Inter Cell Interference (ICI) represents the main challenge of any implemented FR plan [2]. Large ICI values lead to small Signal to Interference and Noise Ratio (SINR) values at the cell edges. Small SINR values limit the FR factor which significantly reduce the system capacity and the provided QoS levels.

The earliest generation of the mobile networks was built based on using a single high transmitting antenna with maximum power that might cover the whole intended coverage area. In contrast, the second generation (2G) of the mobile communication networks is built based on splitting the entire coverage area into small subareas called cells. Each cell has a low power transmitter that might cover it. The cells are grouped into sets called clusters [3]. The whole available bandwidth is divided between the cells of each cluster. Then, it is reused per cluster. The simplest FR plan is achieved by reusing the available frequency band by factor of $m = 1$, where m represents the number of the cells in the cluster. The third generation (3G) of the mobile communication networks uses the Code Division Multiple Access (CDMA) as a multiple access technique. This keeps the ICI at minimum [4]. Although, the FR plans which are applied in 2G and 3G offer very acceptable ICI values, they represent a large capacity loss by factor of $1/m$. Long Term Evolution (LTE) was firstly introduced in the Third Generation Partnership Project (3GPP) Release 8 [5]. LTE has adopted the Orthogonal Frequency Division Multiple Access (OFDMA) as a radio access technique [6]. LTE aims to implement a FR plan of FR factor equal to one. Inter-Cell Interference Coordination (ICIC) is a technique where each cell allocates its resources in a way that improves the whole network performance [7].

Fractional Frequency Reuse (FFR) is an ICIC technique introduced for OFDMA based wireless networks [8]. The concept of the FFR is based on dividing each cell into two parts, inner part and outer part. The available bandwidth is allocated in a way that the cell-edge users do not interfere with each other. The FFR has two modes, Strict FFR mode and Soft FFR mode [9]. In the Strict FFR mode, the available bandwidth is partitioned into two sub-bands [10]. The first sub-band is allocated to the inner part of each cell in the cluster with FR factor equal to one. The second sub-band is allocated to the outer parts of the cells in the cluster with a FR factor equal to $1/m$. In the Soft FFR, the available bandwidth is divided into sub-band groups [11]. These groups are allocated between the inner and the outer parts of the cluster cells in a way that keeps the ICI at minimum and the FR factor at one. In addition to the FFR, Coordinated Multipoint transmission and reception (CoMP) represents another method to reduce the ICIC [12]. However, it does not increase the FR factor. The working principle of the CoMP is, as the mobile user gets closer to the cell edge, the serving cell signal becomes weaker while the interfering signals which are coming from the neighboring cells become stronger. Using CoMP, the neighboring antennas contribute to increase the received power at the cell edge, decrease the interference, and raise the aggregated data rates. There are many techniques to implement the CoMP. One of these techniques is known as Coordinated Scheduling/Beamforming (CS/CB) [13]. In CS/CB, only one point can transmit which is selected via regular handover scheme and is periodically changed. Jungnickel *et al.* [14] have concentrated on the advanced techniques of higher spectral efficiency and improved coverage for the cell edge users. They have introduced a combination of using small cells, joint transmission coordinated multi-point (JT CoMP), and Massive Multiple Input Multiple Output (MIMO) to enhance the spectral efficiency.

5G represents the next generation of mobile communications. It is supposed to provide high data rates to the mobile users. These rates are expected to be in the range of tens of gigabits per second (Gb/s) [15]. There are five main research directions in the way towards the 5G. These directions include millimeter waves, massive MIMO, full duplex, small cells, and beamforming [16]. The millimeter waves (mm Wave) are in the range of 30 Ghz [17]. In this range, there are greater bandwidths available to be utilized. In the massive MIMO direction, the base stations are equipped with an extensive number of antennas [18]. These antennas are used to simultaneously serve large number of co channel users. The full duplex direction refers to using transceivers that can transmit and receive at the same time [19]. The smaller cells direction is used to increase the overall system capacity. The small cells are referred to as pico and femto cells with ranges of 10-200 m [20]. Haider *et al.* [21] have combined the femto cell with the relay mobile in one concept called Mobile Femto (MFemto) cell. Since the wireless users spend 80% of their calling times in the indoor areas while they spend 20% of their calling times in the outdoor areas, Wang *et al.* [22] have proposed to separate the indoor and outdoor users in two different scenarios in one potential cellular structure. This increases the overall system complexity. The beamforming research direction refers to using beamforming techniques in order to identify the best data delivery route for a specific user, in addition to decrease the interference coming from nearby users [23]. Applying the beamforming techniques might significantly enhance the system capacity, decreases the interference, and reduces the power consumption which satisfies the 5G needs [24]. Lee *et al.* [25] have designed a three dimensional beamforming by appending the vertical beamforming along with the horizontal beamforming. However, this technique can not adapt with the users movements. Razavizadeh *et al.* [15] have studied the three dimensional beamforming as a promising technique for 5G. They have shown that the three dimensional beamforming may increase the data rate of each user and reduces the inter-sector interference. Jang *et al.* [26] have proposed a real time three dimensional hybrid beaforming technique for 5G. This proposed technique includes implementing of too large scale antenna arrays at small cell.

Increasing the system capacity and efficiently utilizing the available resources represent one of the most challenging issues for 5G. An efficient FR plan is required to significantly increase the system capacity in a bid to fulfill the 5G high data rate requirements. Designing an appropriate FR plan for 5G is a hard task to do. This is because any suggested FR plan should meet the exponentially increasing demand on data and the limited available bandwidth. Yang [27] has mentioned the soft FR as one of the most powerfull tools for increasing the system capacity in 5G. He proposed a multi-level soft FR and resource allocation scheme in order to increase the spectral efficiency at the cell edge. Saha and Aswakul [28] have addressed the spectral efficiency demands for 5G. They have suggested a method for clustering, FR, and resource allocation for 5G. They have proposed to deal with each apartment in a building as a femto cell, then they apply the FR based on this assumption. In [29], a new resource allocation for heterogeneous networks is introduced. Instead of dividing the standard cells into inner part and outer parts as its applied in the recent releases of the LTE, the authors have divided each standard cell into a number of parts. Although the authors in [27]–[29] have considered the ICIC, they did not put a mechanism on how to handle the handover. In 5G proposals the emphasis is on cell-free operation and full FR. In order to implement full FR or even dense FR, other enabling technologies have to be used. One of these techniques is the digital beamforming which represents one of the fundamental technologies for 5G networks.

In this paper, we address the small cell and the beamforming approaches. We introduce a very efficient mechanism for implementing an optimum FR plan based on beamforming for 5G. Our system model starts with implementing the DOA and the correlator to find the directions of the users in the cell [30]. Then, we introduce the usage of the beamformer to enhance the accuracy of the obtained Direction of Arrival (DOA), tracking the users while they are moving, and produce a beam towards the desired direction and nulls in the directions of the interferers [31]. In addition, we implement the synthesizer in order to perfectly form the shape of the beam Radiation Pattern (RP)s and to make the nulls deeper.

Subsequently, we implement the knowledge of the users and inerferers directions and the capability of tracking in a very efficient FR plan. We build up our FR plan based on our proposed system capabilities. Also, we develop SINR formula that calculates the SINR in terms of the desired and interferers directions.

The rest of the paper is organized as follows. In Section 2, we give an introduction to the DOA, beamofrming concept, and the RP shaping. In Section 3 we include our proposed FR mechanism which involves SINR calculation, frequency reuse plan, worst case scenario, and the implementation procedure. In Section 4 we present our simulation results. We conclude the paper in Section 5.

II. DIRECTION OF ARRIVAL AND BEAM SHAPING

This section covers the concept of the DOA, beamforming, and the RP shaping which are used to implement our proposed FR plan.

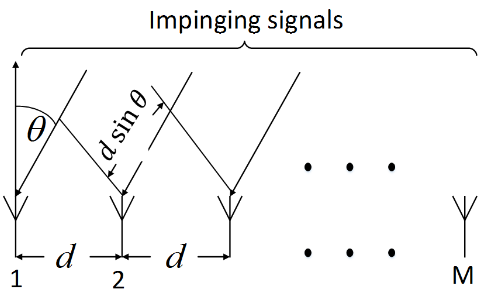

FIGURE 1. A uniform linear antenna of M antenna elements.

A. DIRECTION OF ARRIVAL

Based on the time delay between the received signals by the antenna elements, the DOA of these signals can be calculated [32]. Fig.1 shows a Uniform Linear Antenna (ULA) composed of M antenna elements.

$$\Delta_i = \frac{(i-1)\, d\, \sin(\theta)}{c} \tag{1}$$

where i refers to the antenna element number, $i = 1, 2, \ldots, M$, θ represents the incident angle, c indicates the speed of light, and d expresses the element spacing.

Consequently, the DOA angle is computed as [33]:

$$\theta\ = \sin^{-1}(\theta) = \frac{\Delta_i\ c}{(i-1)\, d} \tag{2}$$

The steering vector of the antenna is expressed as:

$$\bar{a}(\theta) = [1\ \ e^{-jkd\sin(\theta)}\ e^{-2jkd\sin(\theta)}\ \ldots\ e^{-(M-1)jkd\sin(\theta)}] \tag{3}$$

where k represents the wave number.

B. BEAMFORMING PROCESS

The beamforming process involves adjusting the weights of the antenna elements to receive and transmit from a certain direction [34]. It increases the gain of the antenna in the desired direction. Furthermore, it creates nulls at the directions of the intereferers.

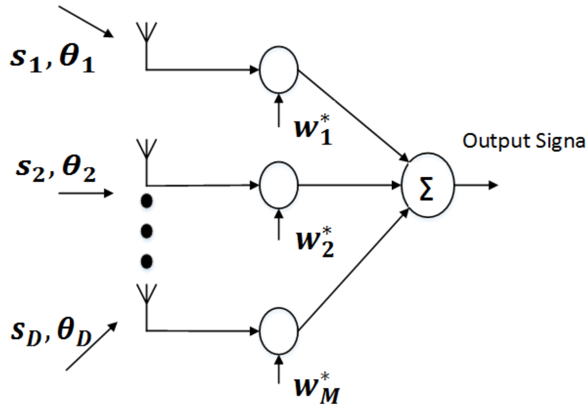

FIGURE 2. A general beamforming system.

Fig.2 explains the receive beamforming concept. s_i represents the signal coming from the source i at angle θ_i. The signal impinging on the antenna elements will be multiplied by the complex conjugate of the antenna elements weights w_m^*, where $(.)^*$ represents the complex conjugate of the antenna element weights. The output signal of the beamformer at any time n, $y_n(\theta)$, is a linear combination of the signal at the M antenna elements. This is expressed as:

$$y_n(\theta) = \sum_{m=1}^{M} w_m^* \bar{x}_m(n), \quad n = 1, 2, .., N \tag{4}$$

where $\bar{x}_m(n)$ represents the received signal vector of length M at time n. Equation (4) is written in the vector form as [35]:

$$y_n(\theta) = \bar{w}^H \bar{x}(n) \tag{5}$$

where $\bar{w}$ represents the antenna weighting vector of length M, and $(.)^H$ represents the Hermitian transpose, i.e., $\bar{w}^H = [w_1, w_2, \ldots, w_M]$ of length M at time n. The received signal $\bar{x}(n)$ is composed of the source signal and the noise. It is given by:

$$\bar{x}(n) = \bar{s}(n) + \bar{v}(n) \tag{6}$$

where $\bar{s}(n)$ represents the source signal and $\bar{v}(n)$ represents the Additive White Gaussian Noise (AWGN) at the same source. The number of the received samples is indicated by N, i.e., $n = 1, 2, .., N$. Both $\bar{s}(n)$ and $\bar{v}(n)$ are vectors of length N.

Since $(\bar{A}\ \bar{B})^H = \bar{B}^H\ \bar{A}^H$, where $\bar{A}$ and $\bar{B}$ are matrices, the beamformer output is written as:

$$y_n(\theta) = \bar{x}^H(n)\bar{w} \tag{7}$$

In the case of transmit beamforming, the output of the beamformer is expressed as:

$$y_n(\theta) = \bar{x}_t^H(n)\bar{w} \tag{8}$$

where $\bar{x}_t(n)$ represents the signal to be transmitted. Equation (8) represents the output of the transmit beamformer. Although, the study of the optimum beamforming algorithms is beyond the scope of this paper, we assume that, the weighting vectors of all beamformers which are considered in our system model are optimum at the desired directions.

C. RADIATION PATTERN SHAPING

The RP shaping or synthesizing is used to smartly shape the beam RP towards the desired direction, making deep nulls toward the interferers, and minimizing the Side-Lobe Levels (SLL). This can be achieved by finding the optimum weights of the antenna elements for a given beam-width, array elements positions, individual antenna RPs, and desired and interferers directions. This problem can be considered as a convex problem. The procedure is to choose the weights in Equation (4) to achieve the desired pattern, therefore we would like to maximize $y(\theta_i)$ in the range $|\theta_i - \theta_{des}| \leq \alpha$ where α represents the Half Power Beam Width (HPBW), θ_i represents the angle of the RP range, and θ_{des} represents the angle of the desired direction. Also, we want to minimize the gain out of this range, i.e $|\theta_i - \theta_{des}| \geq \alpha$. Our concern on minimizing the SLL. This is formulated as:

$$\begin{aligned} &\text{minimize } max_i\, |y(\theta_i)| \\ &\text{subject to } y(\theta_{des}) = 1 \end{aligned} \tag{9}$$

By introducing a new variable τ, Equation (9) is expressed as a convex formula as following:

$$\begin{aligned} &\text{minimize } \tau \\ &\text{subject to } |y(\theta_i)| \leq \tau \\ &\qquad\qquad y(\theta_{des}) = 1 \end{aligned} \tag{10}$$

This represents a convex problem which can be solved using the interior point methods [36]. In the subsequent section, we use the DOA, beamforming concept, and the RP shaping implement our proposed FR mechanism.

III. PROPOSED FREQUENCY REUSE MECHANISM

In this Section, we introduce our proposed FR mechanism. We start by developing formulas for calculating the SINR based on the knowledge of the desired users and the interferers directions. Then, we introduce our proposed FR plan based on beamforming for 5G. After that, we set up the scenario and the formulas of the worst case. The last part includes our proposed mechanism for implementing the FR based on beamforming for 5G.

A. SINR CALCULATION

Assume that, the location of any user can be found [30]. Let the desired user is located at the point $P(r, \theta_1)$, where r represents the distance and θ_1 represents the direction of the mobile user. Moreover, suppose the travel of the users from beam to another can be tracked [31]. Furthermore, assume four beamformers are located at the center of a circular cell as shown in Fig.3. Each transmitted signal will be multiplied by the weighting vector of the beamformer.

Let S-i, $i = 1, \ldots, 4$ represents the information source of the beaformer i. Each beamformer is composed of M antenna elements. The surrounding conditions such as the path loss and the shadowing factor are the same for all the beamformers. Assume DSP-i, $i = 1, \ldots, 4$ are digital signal processors used to optimally steer the beamformers toward

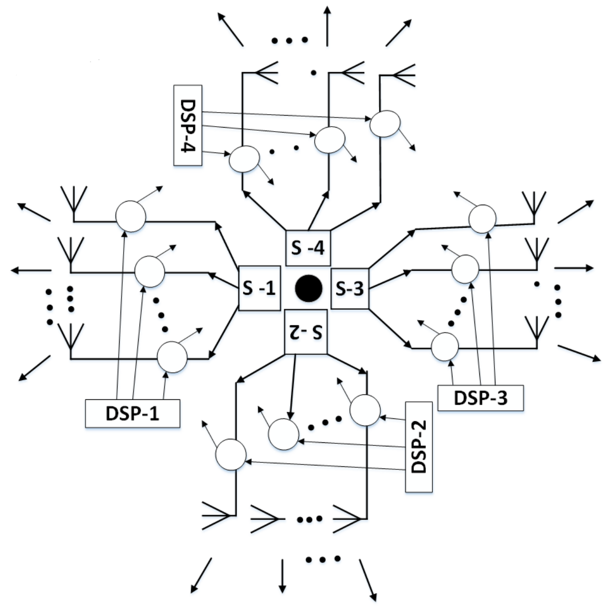

FIGURE 3. Four beamformers located at the cell center.

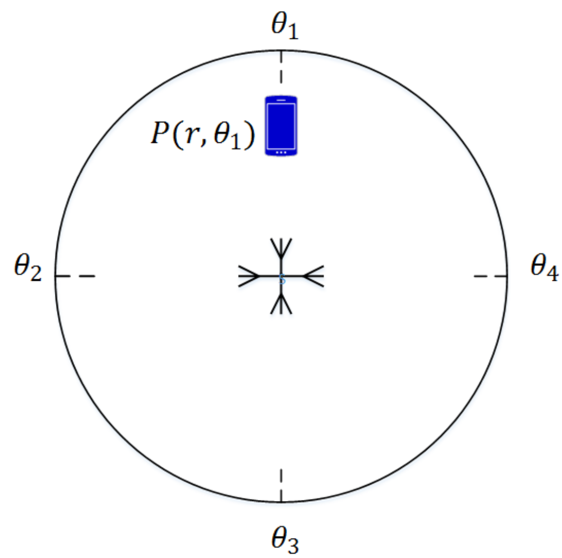

FIGURE 4. Four beamformers located at the cell center and mobile place at point $P(r, \theta_1)$.

the desired directions. The output signal of each beamformer at time n is given by:

$$y_{n_i}(\theta) = \bar{x}_i^H(n)\ \bar{w}_{i\theta_i} \tag{11}$$

where $\bar{w}_{i\theta_i}, i = 1, \ldots, 4$ represents the weighting vector of the beamformer i which generates a beam RP centered at θ_i, and $\bar{x}_i(n)$ represents the output signal of the beamformer i which will be multiplied by the antenna weighting vector. Fig.4 shows a mobile device placed at the point $P(r, \theta_1)$ which is located in the coverage area of the first beamformer. Since we assume the direction of any user in the cell is known, the mobile will adjust the weights of its antenna elements to transmit and receive from the first beamformer. This means, both, the beamformer and the mobile will use compatible weighting vectors to maximize their gain. For simplicity, we consider they use the same weighting vectors. Based on this, we can express the average power of the desired signal received by the mobile as:

$$S_{des} = \frac{\sum_{n=1}^{N} | \sum_{m=1}^{M} \; y_{n_1(\theta_1)} w^*_{1_{\theta_{1_m}}} |^2}{Nr^p} \tag{12}$$

where $\bar{w}_{1_{\theta_1}}$ represents the weighting vector of the first beamformer at θ_1, i.e., $\bar{w}^H_{1_{\theta_1}} = [w_{1_{\theta_{1_1}}}, w_{1_{\theta_{1_2}}}, \ldots, w_{1_{\theta_{1_M}}}]$.

On the other hand, the signals which are coming from the other beamformers are considered as interfering signals. They will be multiplied by the weighting vector of the mobile which is different from them. The interfering signals are originally sent at the angles θ_2, θ_3, and θ_4. However, due to the reflections and the diffractions during their path toward the mobile, they will be received at the mobile at the angles $\hat{\theta}_2$, $\hat{\theta}_3$, and $\hat{\theta}_4$, where $(\hat{.})$ represents an estimation of the original value.

Therefore, the interfering signals is expressed as:

$$S_{interf} = \frac{\sum_{n=1}^{N} | \sum_{m=1}^{M} \; y_{n_2(\hat{\theta}_2)} w^*_{1_{\theta_{1_m}}} |^2}{Nr^p} + \frac{\sum_{n=1}^{N} | \sum_{m=1}^{M} y_{n_3(\hat{\theta}_3)} w^*_{1_{\theta_{1_m}}} |^2}{Nr^p} + \frac{| \sum_{n=1}^{N} | \sum_{n=1}^{N} m = 1^{M} y_{n_4}(\hat{\theta}_4) w^*_{1_{\theta_{1_m}}} |^2}{Nr^p} \tag{13}$$

and the *SINR* is written as

$$SINR = \frac{S_{des}}{S_{interf}} \tag{14}$$

The generalized formula of the SINR at the beamformer k is written as:

$$SINR_{at\ k} = \frac{\sum_{n=1}^{N} | \sum_{m=1}^{M} \; y_{n_k}(\theta_k) w^*_{k_{\theta_{k_m}}} |^2}{\sum_{i=1, i \neq k}^{K} (\sum_{n=1}^{N} | \sum_{m=1}^{M} \; y_{n_i}(\hat{\theta}_i) w^*_{k_{\theta_{k_m}}} |^2)} \tag{15}$$

where K represents the number of the beamformers. Note that, since we know the directions of the interferers, we can send deep nulls towards them. We will use this fact in calculating the SINR value.

B. FREQUENCY REUSE PLAN

We use the triangular shape as an approximation of the RP of the directional antennas. The triangular shape represents the cells in our proposed system model. These cells are described by the triangle that connects between the center of the cell and the two 0.707 power points at the RP. These two points can be defined in terms of their corresponding angles in the Polar coordinates θ_+ and θ_-. In addition, each two triangular cells represent a mini-cluster in our proposed model. Fig.5 shows the graphical representation of our proposed triangular beam cells. Also, it explains how we combine two beam cells in one mini-cluster.

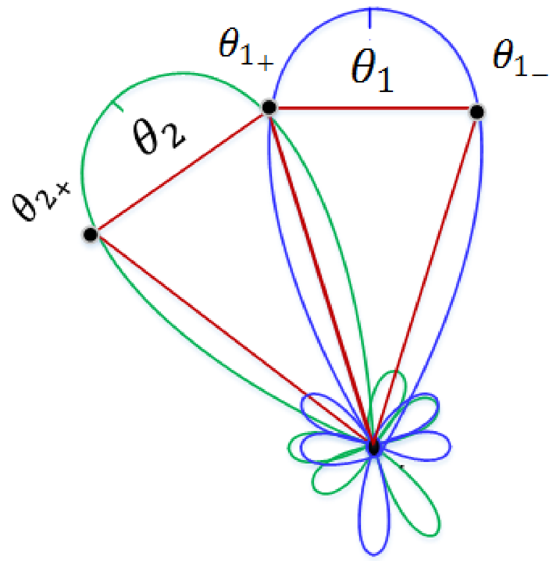

FIGURE 5. A mini-cluster composed of two triangular cells.

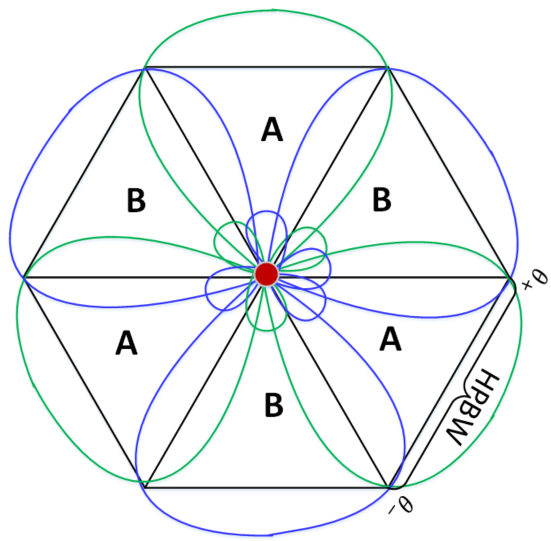

FIGURE 6. Our proposed cluster.

Furthermore, we use the hexagonal shape to approximate the clusters of our proposed model. Fig.6 shows the combination of our mini-clusters in one cluster, where A's and B's represent two sets of frequencies to be reused per each mini-cluster.

To avoid the interference that might result form combining the clusters together, we choose A's such that they do not face other A's from the other clusters. Fig.7 shows how we combine our proposed mini-clusters and clusters in one FR plan. This combination is used to cover the whole intended coverage area.

Our goal is to move from one large beam cells to smaller beam cells as long as the required SINR is satisfied. This means going from Fig.8 (a) to 10 (b), 10 (c), and 10 (d).

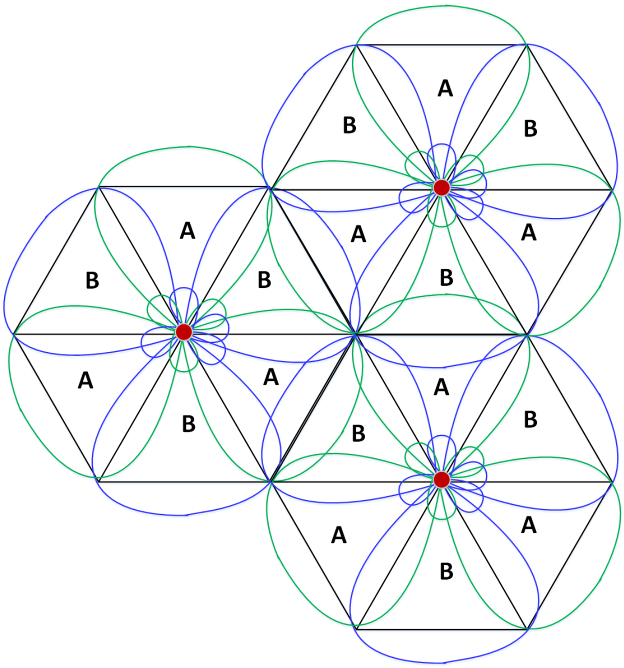

FIGURE 7. A combination of mini-clusters and clusters in one FR plan.

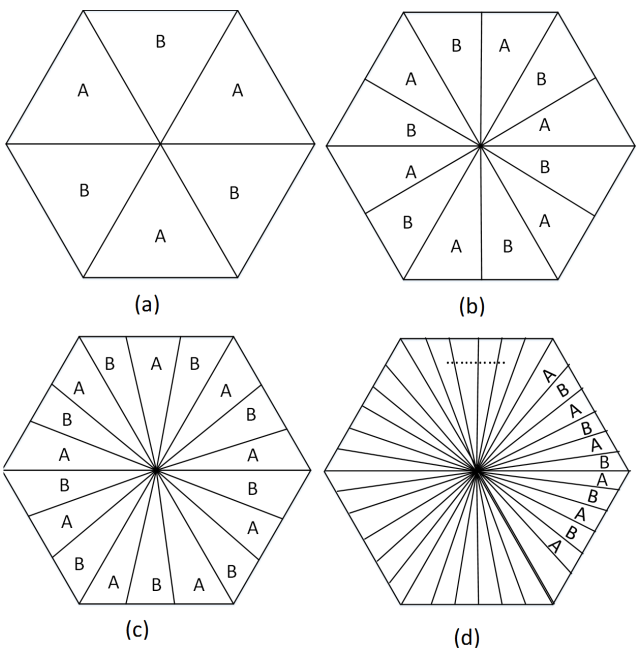

FIGURE 8. (a) Cluster of 6, (b) 12, (c) 18, and 36 cells.

C. WORST CASE SCENARIO CALCULATIONS

For the worst case scenario, consider a Base Station (BS) provided with the Smart Antenna (SA) capabilities located at the center of a standard cell. We call this BS as BS_1. BS_1 has a beam RP centered at θ_1. This is illustrated in Fig.9. The boundaries of the BS_1's beam RP are described by $\theta 1_+$ and $\theta 1_-$. Consider a mobile located at one edge of the two beam RP edges of BS_1, let it be $\theta 1_+$.The mobile is also provided with the SA capabilities. Since the directions of BS_1

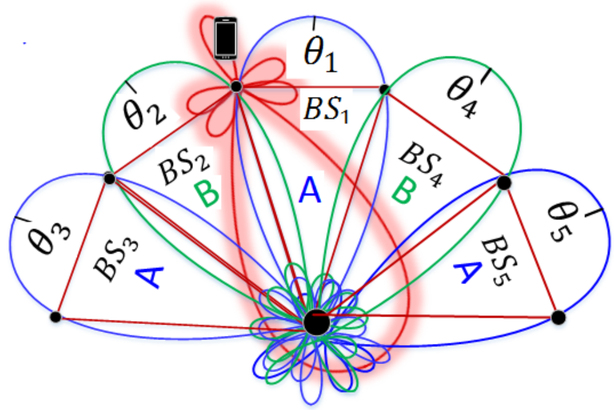

FIGURE 9. Worst case scenario.

and the mobile are known, the mobile will adjust its SA in order to maximize its SINR and keep its gain maximum.

The mobile can maximize its gain by steering its beam RP to be centered at $\theta 1_+$, where $\theta 1_+$ represents the angle between the mobile and BS_1. The received signal at the mobile is expressed as:

$$S_{des} = \frac{\sum_{n=1}^{N} |\sum_{m=1}^{M} y_{n_1(\theta_1)} w^*_{1_{\theta+m}}|^2}{Nr^p} \quad (16)$$

Furthermore, consider additional four base stations located at the center of the cell. Let them be BS_2, BS_3, BS_4, and BS_5. Assume that they have beam RPs centered at $\theta_2, \theta_3, \theta_4$, and θ_5, respectively. Due to the path reflections and defrations, the signals which are transmitted by BS_2, BS_3, BS_4, and BS_5 will be received at the mobile at the angles $\hat{\theta}_2$, $\hat{\theta}_3$, $\hat{\theta}_4$, and $\hat{\theta}_5$, respectively. The received signals from BS_3 and BS_5 represent interference for BS_1 since they use the set of frequencies. The received signals from BS_3 and BS_5 will be multiplied by the weighting vector of the mobile at $\theta 1_+$. This is expressed as:

$$S_{interf} = \frac{\sum_{n=1}^{N} |\sum_{m=1}^{M} y_{n_3(\hat{\theta}_3)} w^*_{1_{\theta+m}}|^2}{Nr^p} + \frac{\sum_{n=1}^{N} |\sum_{m=1}^{M} y_{n_5(\hat{\theta}_5)} w^*_{1_{\theta+m}}|^2}{Nr^p} \quad (17)$$

and the SINR is written as:

$$SINR_{at\ Mobile} = \frac{\sum_{n=1}^{N} |\sum_{m=1}^{M} y_{n_1(\theta_1)} w^*_{1_{\theta+m}}|^2}{\sum_{i=3,5}(\sum_{n=1}^{N} |\sum_{m=1}^{M} y_{n_i(\hat{\theta}_i)} w^*_{1_{\theta+m}}|^2)} \quad (18)$$

D. IMPLEMENTATION PROCEDURE

Fig.10 shows our proposed configuration for implementing the FR based on beamforming in 5G. This configuration is composed of DOA, correlator, adaptive beamforming, and synthesizer. We use the DOA and the correlator to find the users directions in the cell. Then, we use the adaptive beamforming process to produce a beam towards the desired user, nulls in the directions of the main beams of the interferers, and keep tracking the users. After that, we implement the synthesizer to make the radiation beam more focused towards the

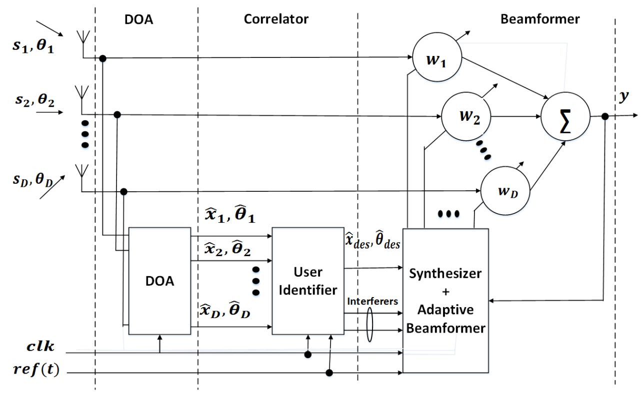

FIGURE 10. Our proposed configuration.

desired user and the nulls are deeper toward the interferers. This means, we apply a window that passes the desired user signal and significantly reduces the interference coming from the interferers.

Consider D signals are transmitted at the angles $\theta_1, \theta_2, \ldots, \theta_D$ as illustrated in Fig.10. The steering vectors that correspond to these angles are given by:

$$\bar{a}(\theta_i) = [1 \;\; e^{-jkd\sin(\theta_i)} \;\; e^{-j2kd\sin(\theta_i)} \;\; \ldots e^{-j(M-1)kd\sin(\theta_i)}]^T \tag{19}$$

where $i = 1, \ldots, D$. The output of the ULA is expressed as:

$$\bar{x}(k) = \begin{bmatrix} \bar{x}_1(k) \\ \bar{x}_2(k) \\ \vdots \\ \bar{x}_D(k) \end{bmatrix} = [\,\bar{a}(\theta_1)\,\bar{a}(\theta_2)\ldots.\;\bar{a}(\theta_D)\,] \begin{bmatrix} \bar{s}_1(k) \\ \bar{s}_2(k) \\ \vdots \\ \bar{s}_M(k) \end{bmatrix} + \bar{n}(k) \tag{20}$$

The DOA part will give us estimated values of the transmitted angles at $\hat{\theta}_1, \hat{\theta}_2, \ldots, \hat{\theta}_D$. Therefore, the actual output of the DOA part is written as:

$$\hat{\bar{x}}(k) = \begin{bmatrix} \hat{\bar{x}}_1(k) \\ \hat{\bar{x}}_2(k) \\ \vdots \\ \hat{\bar{x}}_D(k) \end{bmatrix} = [\,\bar{a}(\hat{\theta}_1)\,\bar{a}(\hat{\theta}_2)\ldots.\;\bar{a}(\hat{\theta}_D)\,] \begin{bmatrix} \bar{s}_1(k) \\ \bar{s}_2(k) \\ \vdots \\ \bar{s}_M(k) \end{bmatrix} + \bar{n}(k) \tag{21}$$

Using the DOA part, we get peaks on the power spectrum at $\hat{\theta}_1, \hat{\theta}_2 \ldots \hat{\theta}_D$. By applying the cross correlation between the Reference Signal (RS) and the incoming signals, we might estimate the desired user signal and direction [12]. The correlation process is included in the User Identifier (UI) part. The UI separates the desired signal and the interference. We have applied the *clk* function as an organizer. First, it turns "ON" the DOA and the UI while it keeps the beamformer and the synthesizer "OFF". Then, the *clk* function turns "ON" the beamformer and the synthesizer while maintaining the DOA and the UI "OFF". The output signal of the UI is given by:

$$y_{UI}(k) = \bar{a}(\hat{\theta}_{des})^H \, \hat{\bar{x}}_{des} \tag{22}$$

where $\hat{\bar{x}}_{des}$ and $\hat{\theta}_{des}$ represent the estimated values of the desired user signal and direction, respectively. In the first cycle, the RS is compared with the output of the UI. This means, instead of comparing the RS with the ULA output which leads to a slow convergence and weak tracking capabilities, we provide the beamforming part with initial estimations of the desired user signal and direction. Therefore, the error at time t is written as:

$$e_{(t)}(k) = s_{ref}(k) - y_{(UI)}(k) = s_{ref}(k) - \bar{a}^H(\hat{\theta}_{des})\,\hat{\bar{x}}_{des}(k) \tag{23}$$

It should be noted, we have expressed $e_{(t)}$ as a function of time because our model will keep comparing with the re-transmitted RS every small period of time. This is done for the tracking purpose. By taking the square of the Equation (23) and taking the expectation of it, we get:

$$E\{|e_t(k)|^2\} = E\{(s_{ref}(k) - y_{(UI)}(k))(s_{ref}(k) - y_{(UI)}(k))^H\} \tag{24}$$

It should be pointed out that $y_{(UI)}(k)$ is an estimation of the desired user signal, therefore, the error from the beginning will be small. Equation (24) is a quadratic equation with a unique minimum. By taking the derivative with respect to $\bar{w}$ and solving, we get:

$$\bar{w}_{opt} = \bar{R}^{-1}_{x_{des}x_{des}} \, \bar{r}_{rd} \tag{25}$$

where $\bar{w}_{opt}$ expresses the optimum weights obtained by our algorithm, $\bar{R}^{-1}_{x_{des}x_{des}}$ and $\bar{r}_{rd}$ are given by:

$$\begin{aligned} \bar{R}_{x_{des}x_{des}} &\cong \bar{x}_{des}(k)\,\bar{x}^H_{des}(k) \\ \bar{r}_{rd} &\cong s^*_{ref}(k)\,\bar{x}_{des}(k) \end{aligned} \tag{26}$$

The updating equation of the beamformer is given by:

$$\bar{w}(k+1) = \bar{w}(k) - \mu[\bar{R}_{x_{des}x_{des}}\bar{w} - \bar{r}_{rd}] \tag{27}$$

where μ represents the step size and Its limited by:

$$0 \leq \mu \leq \frac{1}{2\lambda_{max}} \tag{28}$$

where λ_{max} indicates the largest eigenvalue of $\bar{R}_{x_{des}x_{des}}$. After the first cycle and obtaining the optimum weights, the *clk* will turn "ON" only the adaptive beamforming and the synthesizer parts. This means, the RS will be compared with the ULA output during the tracking process. If the user travel to a new place, the difference between the RS and the ULA output will be increased which means the adaptive beamforming and the synthesizer parts will modify the antenna weights to redirect the antenna to the new direction. It is worth to note that, the classical adaptive beamforming algorithms can not work at large amount of interference. Providing the adaptive beamforming algorithms with the estimation of the desired signal and direction speeds up the convergence and makes the tracking process is possible. We apply the adaptive beamforming part to emphasize the DOA accuracy, produce beam towards the desired user and nulls in the directions of the interferers.

In addition, we use the synthesizer to specifically control the antenna RP. This control includes forming a window that passes signals from the desired directions, producing nulls in the directions of the interferers, and controlling the SLLs.

IV. SIMULATION RESULTS

In this section we have developed a simulation model to evaluate the performance of our proposed FR plan. We have used the Matlab R2017b to obtain our simulation results. Our simulation model uses the Convex Optimization method to perform the synthesizing process, and to calculate the minimum required number of antenna elements at each specified beam size at different SINR values. As an example, Fig.11 shows a scenario of cluster composed of 24 beams and mobile placed at a beam boundary. Each beam has size of 15° width measured at the two HPBW points. A and B represent a set of frequencies to be reused inside the cluster. The boundaries of the beams are also shown in the same figure. We consider a mobile placed at the boundary between two beams at angle 90° which represents the worst case scenario.

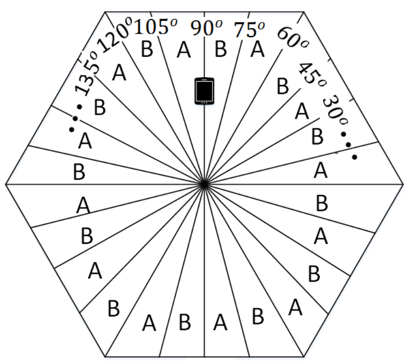

FIGURE 11. Cluster of 24 beams and mobile placed at a beam boundary.

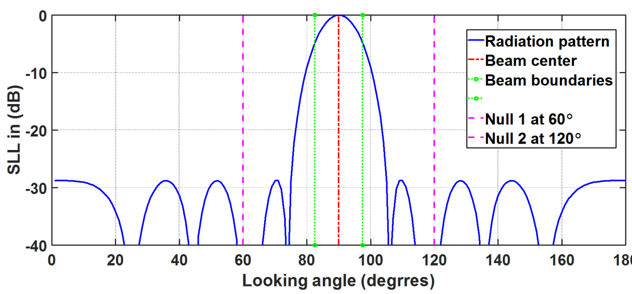

FIGURE 12. Beam shape in the Cartesian coordinates with $HPBW = 15°$ centered at 90°.

We assume the mobile detects the interfering signals coming at the angles 60° and 120°. Using the combination of the beamformer and the synthesizer, the mobile should place the nulls at the angles 60° and 120°. We present Fig. 12 to illustrate how we can get the desired beam shape and place the nulls at the desired directions. Fig.12 shows a beam centered at 90° with beam-width of 15° measured at the two -3 dB points. The x and y axes represent the looking angle in degrees and the SLL in dB, respectively. The solid line shows the antenna RP. Moreover, it shows the SLL reduction value. The two dotted lines indicate the beam boundaries. They represent the portion of the beam which will be passed after the synthesizing process. The two dashed lines illustrate the positions of the nulls.

Fig.13 sketches the same results in the Polar coordinates. It shows the RP, SLL value, beam boundaries, and the nulls placements.

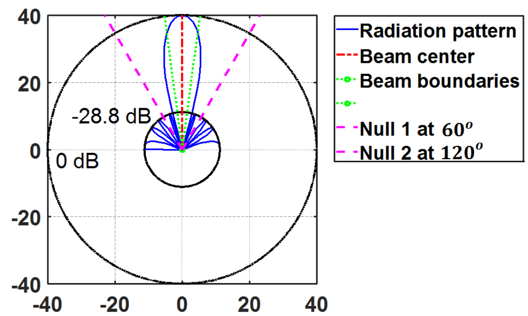

FIGURE 13. Beam shape in the Polar coordinates with $HPBW = 15°$ centered at 90° and $SLL = -28.7$ dB.

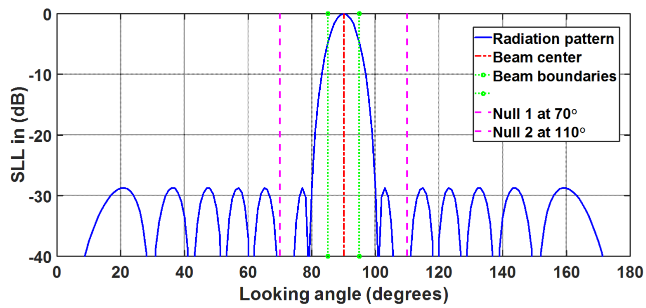

FIGURE 14. Beam shape in the Cartesian coordinates with $HPBW = 10°$ centered at 90°.

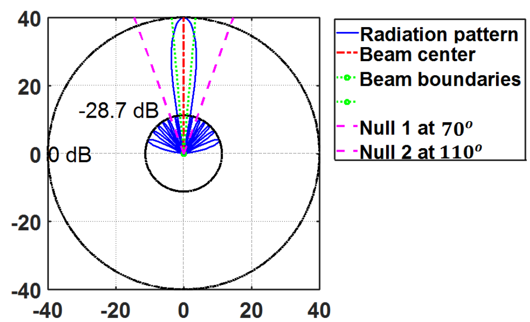

FIGURE 15. Beam shape in the Polar coordinates with $HPBW = 10°$ centered at 90° and $SLL = -28.8$ dB.

As an additional example, Fig.14 and Fig.15 depict a beam RP of 10° width in the Cartesian and Polar coordinates, receptively. Here, we assume the mobile detects the interfering signals coming at the angles 10°, and 70° . The dashed pink lines show the nulls placements.

Furthermore, we present Fig.16 to show that we can realize a FR plane based on small size beams, and small number of antenna elements while keeping the SINR at

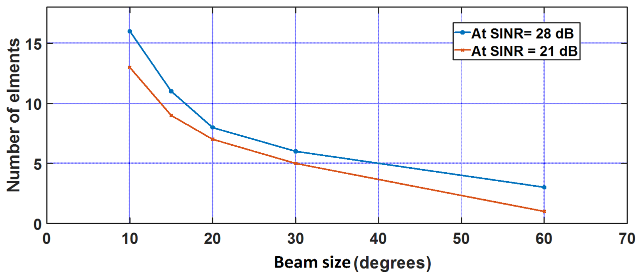

FIGURE 16. Beam size with number of antenna elements.

acceptable levels. Fig.16 shows the relationship between the required number of antenna elements and the proposed beam sizes. For instant, to build up a FR plan based on beams of size 60° width, we need a SA composed of about 4 elements to provide $SINR = 28\,dB$. Also, we need a SA composed of 2 elements to provide $SINR = 21\ dB$ for the same frequency reuse plan. Note that, $SINR = 21\ dB$ provides a very acceptable LTE data calls.

V. CONCLUSION

In this paper, we propose a practical mechanism to implement an efficient FR plan based on beamforming for 5G. Our proposed mechanism combines the DOA, correlator, beamformer, and the synthesizer. We use the DOA and the correlator to find the directions of the desired users, and the interferers. Also, we use the beamformer and the synthesizer to track the users, and smartly shape the desired beam radiation patterns. Then, we develop a formula for calculating the SINR based on the obtained directions. After that, we build a FR plan that efficiently reuses the available bandwidth. Our simulation results verify that, using a ULA of 11 elements, we can achieve the preferable SINR values using beams of 10° width. This will significantly increase the FR factor from 1 to 18 and multiplies the number of mobile users by 18 times.

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