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Data-driven optimal antenna planning for enhanced 4G mobile networks under realistic environment

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ABSTRACT

Recently different capacity boosting technologies, including 3D beamforming and expanding operating bandwidth have been investigated and included in the enhanced fourth generation (4G) and fifth-generation standards. For mobile operators to enhance their network performance, applying these advanced technologies is vital. To achieve that, planning and optimization work need to consider the spatiotemporal distribution of users. Although the capacity impact of advanced antenna technologies is investigated well, deployment options to exploit their benefits in a cost-effective manner considering a realistic network environment are seldom reported. This work presents a data driven and multi-objective based optimal vertical beams placement for an enhanced 4G mobile network with the newly introduced C-band. The method is utilized for an area located in Addis Ababa, Ethiopia, taking into account the existing 4G mobile network as a reference configuration. Users are distributed based on the data collected by ethio-telecom network management system. Findings indicate that optimal vertical beams placement achieved for gradual deployment with consideration cell edge and aggregate throughput performances while reducing network cost. While being cost-effective, up to 69.2% and 73.8% cell edge performance gain is achieved at 20 and 30 pareto points relative to an existing macro mobile network.

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1. INTRODUCTION

Mobile data traffic has been growing and is predicted to rise due to the introduction of new services and applications [1]–[4]. To respond to this enormous data traffic and provide mobile users satisfaction, network operators need to enhance their network capacity. For that, several capacity boosting technologies have been introduced and incorporated into different generation's standards. Network densification, expanding operating bands to sub-6 GHz and mm-Wave, and applying 3D beamforming are among the most important ones [5]–[9].

When the release 8 long-term evolution (LTE) standards are introduced with multiple-input multiple-output (MIMO) technology, it is expected to provide up to 150 Mbps downlink data rate speed with 4x4 MIMO and 20 MHz bandwidth [10]. Later, LTE advanced came up with carrier aggregation and expected to provide up to 1 Gbps [10]. The performance limits set by 3GPP are theoretical and hard to realize in a practical situation. This is because those pick values can only be achieved if the network system uses higher order modulation and coding scheme in a good channel state condition which able to support them. However, in practice, the actual throughput performance of a wireless network is far from the theoretical value due to the fading nature of a wireless channel. Some works of literature show the performance of wireless network under fading environment. For example [11] analyzes the average channel capacity of MIMO system under Rayleigh fading spread spectrum and provides closed form expression. According to the result, channel capacity of fading channel is less than the theoretical one. Release 12 introduces a full dimensional MIMO that can steer beams in both horizontal and vertical planes (3D beamforming). This scheme enables splitting the cells in vertical domain in addition to horizontal in either static or dynamic fashion [12].

While analyzing the performance impact of different MIMO schemes, use cases of 3D beamforming were also investigated and presented in several works of literatures [13], [14]. Densifying cells in the vertical domain considering user demand is the other practical aspect of 3D beamforming to enhance network capacity [15]. The method is called cell splitting where macro sectors are split into two or more beams which use the same frequency resource blocks [16], [17]. Unlike micro cell densification, cell splitting using vertical beams does not need extra sites and network elements which decrease total cost.

Recent studies, [18]–[22] presented the capacity gains that will be obtained due to cell splitting under theoretical 3rd generation partnership project (3GPP) simulation environments. The performance impact of manipulating antenna parameters such as electrical and mechanical tilt, half power horizontal and vertical beamwidth, and transmit power optimization are presented in [23]–[27]. The researchers [28], [29] experimental works to examine the actual performance of cell densification for single cell single user cases are conducted. These performance analyses, optimization, and experimental works illustrate that network capacity improvement can be achieved through vertical cell splitting. However, cell splitting will degrade throughput performance of cell edge users because of the introduction of added interference in the cells. One way of overcoming this problem is applying different carrier configurations or optimizing antenna parameters among neighboring cells [30]. Although the throughput impact of cell splitting via 3D beamforming is researched well a data driven based deployment approach that optimizes aggregate capacity, cell edge performance, and the number of upgrading cells under a realistic network environment and sub 6 GHz bands is rarely reported. A data driven approach is carried out in [31], however, it does not consider cell edge performance as a performance metric. For micro and Pico cells densification, performance analysis, and optimization taking into account realistic network environment for Addis Ababa use cases are presented in [32]–[36].

Hence, this work presents a data-driven and multi-objective-based optimal placement of vertical beams on top of existing cells. The method is illustrated under realistic network environments. The approach uses Matlab as a simulation tool and Addis Ababa digital map as a network layout.

The rest of the paper is organized as follows. Section 2 presents system model and the band configuration used in simulation. Section 3 describes the methodology that we followed to come up with the results. Section 4 presents simulation results and discussion. Finally, Section 5 gives the conclusion and future works.

2. SIMULATION ENVIRONMENT

To achieve the objective of this study, which is to identify the pareto points, the work considers the existing LTE down link mobile network as a baseline configuration located in Ethiopia, Addis Ababa, around Bole where the highest data traffic is recorded. It contains about 54 macro cells and covers an area of about 5.47 km^2 shown in Figure 1. On the top of the existing cells, vertical beams are deployed to analyze the performance impact of the identified approaches. The inner and outer beams are configured with different combination of 1800 MHz and 3600 MHz operating bands.

Figure 1. Performance studied area

3. METHOD

As it can be recalled from section 2, once the deployment area and band configurations are identified, vertical beams upgrading is applied as follows: First, users are distributed according to the data collected from ethio-telecom network management system. The traditional way of locating demand nodes is approximating the number of users' densities and applying the available user's distribution model. This overstates the actual locations of demand nodes. In this work, demand nodes are located according to reference [37] which uses telecom operator's data. The number of demand nodes in each pixel is calculated using (1);

$$N_{(m,n)} \frac{a\ x\ g_{(m,n)}}{r} \quad (1)$$

where r is the individual data rate in Kbps and subscripts *n* and *m* represent longitude and latitude of the studied location correspondingly.

Second, different combinations of upgrading options are identified and a multi-objective problem is formulated as follows. To generalize, let $X = [x_{(1)}, x_{(2)} \ldots x_{(k)} \ldots x_{(N_M)}]$, refer to a network that contains existing macro and upgraded cells. If $x_{(k)}=0$, it represents the existing macrocell, and $x_{(k)}=1$, it refers to an upgraded vertical beam. During network operation, a user will be associated with either an existing cell or an upgraded beam depending on received power strength. Accordingly, a user from location u_m, its SINR performance is given by (2);

$$SINR(u_m) = P_0^{Rx}(u_m) / \left(\sum_{k=1}^{N_M - 1} P_k^{Rx}(u_m) x(k) + P_N\right) \quad (2)$$

where P_O^{RX} refers received power from serving cell, P_K^{RX} is received power from other cells, P_N is the noise power and N_M is number of macro cells. The user throughput performance is given by [38], [39].

$$TP = N_{PRB} * BW_{PRB} * BW_{eff} * \log_2 (1 + \frac{SINR}{SINR_{eff}}) \quad (3)$$

where N_{PRB} is number of PRB, BW_{PRB} is bandwidth per physical resource block (PRB), BW_{eff} is bandwidth efficiency and $SINR_{eff}$ is *SINR* efficiency. Based on the individual throughput, the aggregate throughput of the network (network capacity) is given by (4).

$$C = \sum_{m=1}^{L} TP(u_m) \quad (4)$$

If we assume *R* numbers of macro LTE cells upgraded with vertical beams, L_1 number of users will be served by *M-R* macro LTE cells and L_2 numbers of users will be served by *2R* numbers of upgraded beams. Thus, total capacity of the network is given by (5);

$$C' = \sum_{m=1}^{L_1} TP(u_m) + \sum_{m=1}^{L_2} TP'(u_m) \quad (5)$$

where $\sum_{m=1}^{L_1} TP(u_m)$ is an aggregate throughput served by macro cells and $\sum_{m=1}^{L_2} TP'(u_m)$ is aggregate user throughput served by upgraded beams. Based on the network capacity, the gain can be obtained as (6).

$$\Gamma = \frac{C' - C}{C} \quad (6)$$

For each *M* number of cells upgrading, there could be *P* number of network alternatives formulated as (7).

$$P = \frac{N_M!}{(N_M - M)! * M!} \quad (7)$$

From those *P* options, finding the optimal network that provides maximum performance while reducing the number of upgrading cells is a type of multi-objective problem that can be formulated as (8);

$$\text{Min}_{x} f(x) = [f_1(x), -f_2(x)] \quad (8)$$

where f_1 represents the number of upgrading cells which are associated with cost and f_2 is network performance(either aggregate capacity or cell edge performance).

Finally genetic algorithm is applied to find the optimal network. Evolutionary methods are preferred for evaluating (8) because the objective function does not require convexity or continuity [31]. Non-dominated sorting genetic algorithm II (NSGA-II) has less complexity, faster convergence, and is empirically near optimal compared to other multi-objective algorithms, according to [40] and [41]. As a result, the algorithm chosen is this one.

Initial populations, fitness function, and halting condition are all inputs to the NSGA-II, which outputs the best fitness values [41]. While the algorithm iterates, the reproduction option is used to generate new generations. As indicated in Figure 2, these alternatives are selection, recombination, and mutation.

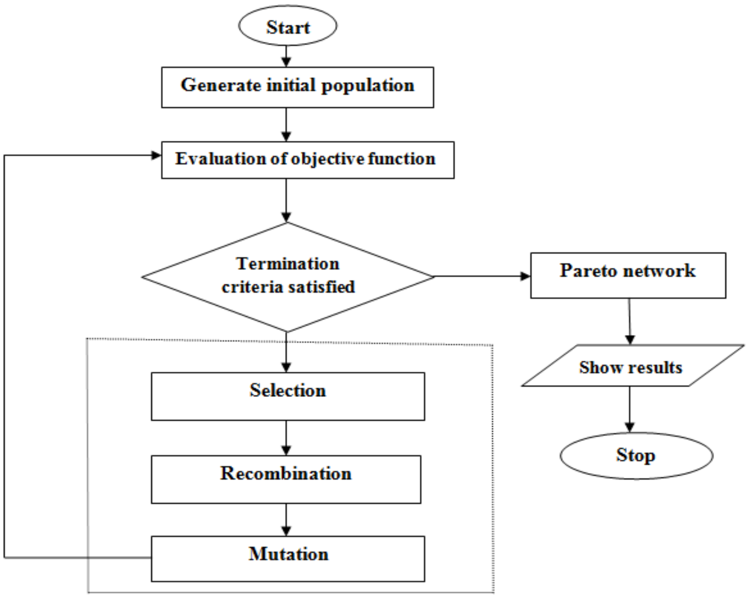

Figure 2. Flow chart of genetic algorithm

The genetic algorithm generates Z number of randomly selected populations to begin simulation, which is denoted by the vector X given as (9).

$$\mathbf{X} = \begin{bmatrix} x_{1,1} & x_{2,1} & \cdots & x_{i,1} & \cdots & x_{M+N,1} \\ \vdots & \vdots & \vdots & & \ddots & \vdots \\ x_{1,1} & x_{2,2} & \cdots & x_{i,z} & \cdots & x_{M+N,Z} \\ & & & \vdots & & \\ & & & \vdots & & \\ & & & \vdots & & \\ & & & \vdots & & \\ x_{1,Z} & x_{2,Z} & x_{i,Z} & \cdots & x_{M+N,Z} & \end{bmatrix} \tag{9}$$

where z =1, 2 …Z. is the number of population and $x_{i,z}$ shows the status of macro cells whether upgrading is applied or not. Each row of vector X consists of M+N number of randomly selected populations with different combinations of 0 and 1 which indicates the status of macro LTE cells. Then, based on the fitness values of candidate networks, the best one is selected or combined with other networks for the next iteration. The iterations are continued until the ending criterion of multiobjective optimization (MOO) is fulfilled.

4. RESULTS AND DISCUSSION

The performance impact of data-driven optimal vertical beam placement on top of existing macro sites with different inner and outer band configurations is presented in this section. As a benchmark, the existing macro only network is considered as a reference configuration. The following dynamic Matlab-based system level simulation is used to generate results. First, users are distributed according to (1) stated in section 3. Then, based on the strength of the reference signal received power (RSRP), users are assigned to their serving cell, and resource blocks are planned in a round robin fashion. Finally, using (2) and (3), the signal to interference plus noise ratio (SINR) and user throughput is determined. This operation is repeated for the specified number of iterations, after which the statics are gathered and plotted, and analyzed. User throughput is used as a fitness value while optimization is performed.

The performance gain of the identified approach is accompanied by cumulative distribution function of user equipment signal to interference plus noise ratio (cumulative distribution function (CDF) of a UE SINR) and throughput. Figure 3 provides the performance impact of the studied scenarios with respect to CDF of UE SINR taking the existing macro only LTE network as a reference configuration. Upgrading macro cells with different operating bands considerably enhance CDF of UE SINR in all percentiles, according to simulation results. For example, UE SINR values of macro only (MO), 1800/1800 MHz and 1800/3600 MHz, at 10%-ile are: -3.44dB, -5.04dB and -2.76dB, at 50%-ile: 1.46dB, 0.51dB and 3.24 dB and at 90%-ile: 10.12 dB, 8.96 dB and 11.99 dB respectively (see Figure 3).

Figure 4 is plotted to find pareto points that optimize cell-edge performance of the network with 1800/3600 MHz configuration. Those points can be used for the step wise upgrading of macro LTE network if the choice operator is optimizing cell edge performance while reducing the cost. As it can be seen in the figure below, a significant 10%-ile throughput gain can be obtained using the identified approach. For example, at 20 and 30 pareto points, 69.2% and 73.8% cell edge gain is achieved.

In addition to cumulative distribution function of user equipment signal to interference plus noise ratio (CDF of UE SINR) and cell edge user performances, the aggregate throughput and capacity gain of the identified configurations are also studied. Based on simulation results, the aggregate throughput of the upgraded macro cells with 1800/1800 MHz, 1800/3600(20/20) MHz, 1800/3600(20/100) MHz, and the reference configurations are, 2.4058 Gbps, 3.9595 Gbps, 6.813 Gbps, and 1.6224 Gbps correspondingly. On the basis of these figures, the associated comparative total throughput gains of the examined scenarios are 48.3, 144.1, and 319.93 respectively.

Figure 5 is plotted to find the pareto points of 1800/1800 MHz and 1800/3600 MHz that optimize system capacity which is used for step wise deployment of the existing network. The aggregate throughput of upgrading all cells with 1800/1800 MHz and 1800/3600 MHz configurations and the existing macro LTE network is used as an asymptotic value. The graph depicts how system throughput changes as the pareto point advances or the number of vertical beams grows. Figure 5 show that when the number of vertical beams rose, aggregate throughput increased as well.

Figure 6 compares the UE throughput gain of 28 pareto locations of 1800 MHz/1800 MHz with 1800/3600 MHz configurations for aggregate capacity and 1800/3600 MHz configurations for cell edge performance at 10, 50, and 90 percentiles. Relative to the existing macro LTE arrangement, all VS configurations deliver significant user throughput gains. For example, at 10 % -ile, 50% -ile, and 90% -ile, respectively, a comparable gain of about 33.1%, 39.6 %, and 86.3 percent is achieved for 1800/1800 MHz. At the 10% -ile, 50% -ile, and 90% -ile, a gain of 58.6 percent, 98.2 percent, and 151.7 percent is achieved for the 1800/3600 configuration (pareto points for aggregate capacity). Finally, for the case of 1800/3600 MHz configuration (pareto points for cell edge performance) a gain of 73.2%, 81.4%, and 118.9% is achieved relative to macro configuration.

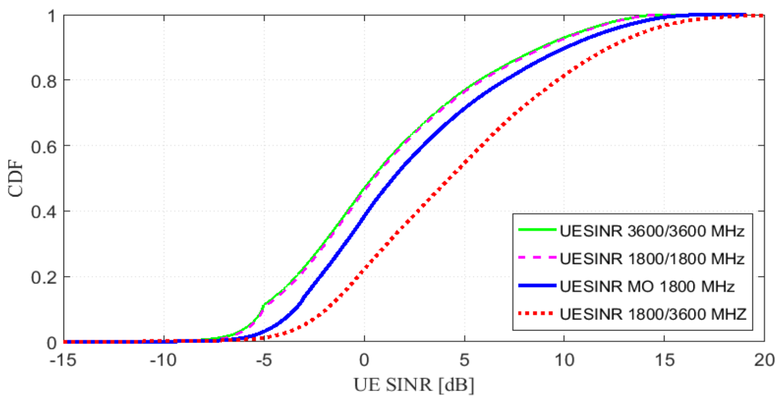

Figure 3. CDF of users for an upgraded network

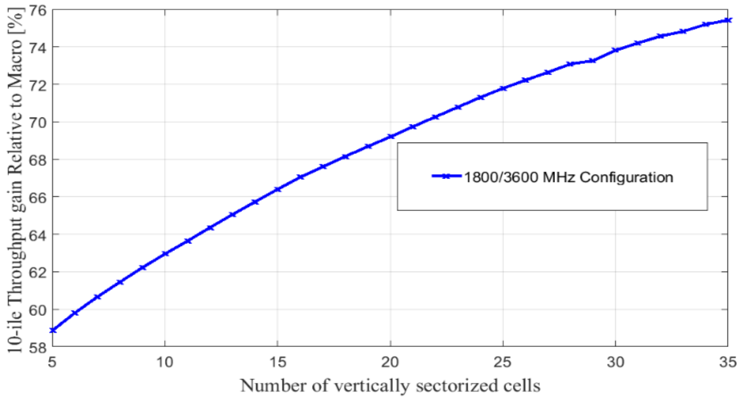

Figure 4. 10%-ile user throughput gain and pareto points

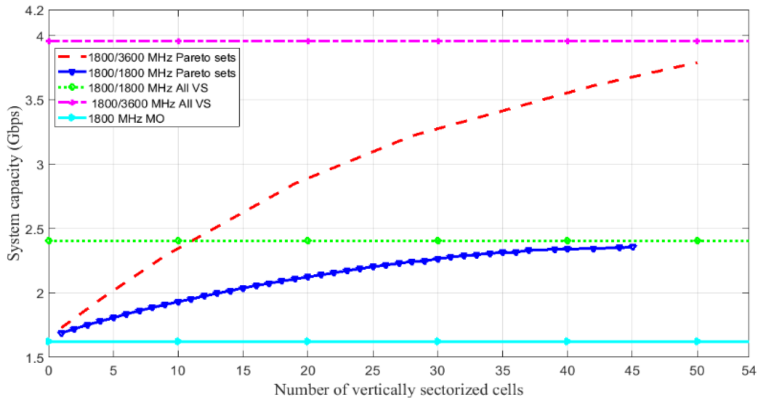

Figure 5. System capacity for different scenarios

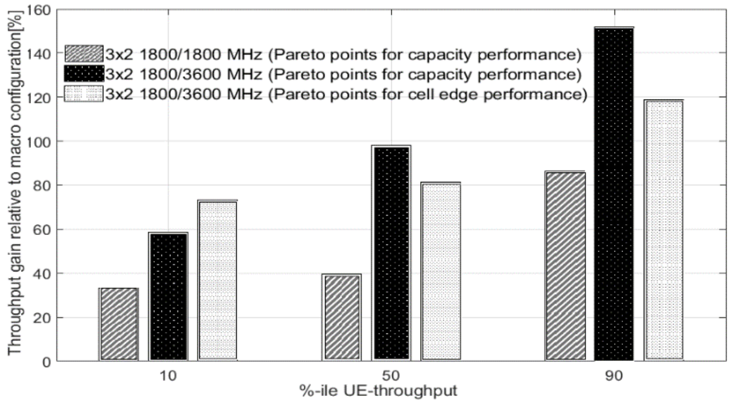

Figure 6. 10% -ile, 50% -ile and 90% user throughput gain

5. CONCLUSION

This research work presents a data-driven and multi-objective based upgrade option for gradual deployment of vertical beams in a realistic network context. Simulations are run to locate the optimal Pareto frontier for system capacity and cell edge performance. According to simulation results, 3D vertical beams with different operating bands increase system performance depending on the type of performance indicators. For example, in the case of 1800/3600 MHz, 28 common pareto points for cell edge performance provide a relative gain of about 73.2 percent, 81.4 percent, and 118.9 percent at the 10% -ile, 50% -ile, and 90% -ile, respectively; in the case of 1800/3600 MHz, common pareto points for capacity performance provide a relative gain of 58.6 percent, 98.2 percent, and 151.7 percent at the 10% -ile, 50% -ile From a planning and optimization standpoint, the performance impact of static 3D beams in high-rise buildings and user-centric 3D beams in multi-cell and multi-user 5G mobile networks are crucial future studies.

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