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Comparison of Multiobjective Optimal and Collocated 4G and 5G Small Cells Using Street Lampposts as Candidate Locations

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Abstract—To address the increasing capacity demand due to adoption of data-intensive services and broadband devices, densification of mobile networks by small cell deployments has been considered as one key systematic solution for both legacy fourth generation (4G) mobile networks and future fifth generation (5G) network upgrades. The cost-efficiency and capacity gains due to small cell deployments can be further enhanced by optimizing the number and locations of the dense small cell deployments. With network densification by 4G small cells imminent while 5G small cell upgrades envisioned, an interesting network planning dilemma emerges on whether to optimize small cell deployments for 4G or 5G small cells. In this paper, we confront this dilemma by utilizing multiobjective optimization (MO) based planning approach for comparing and contrasting performance of small cell topologies optimized for 4G and 5G deployments. Propagation computation is performed using deterministic ray-tracing dominant path model over a building and terrain map of the deployment scenario. Results show that 5G optimized scenario provides considerable network capacity gains compared to 4G optimized 5G co-location scenario for different optimal small cell topologies with same number of small cells. For instance, for 31 small cells topologies, it presents 21.5% more capacity gain relative to 4G optimized case. Furthermore, 5G optimized case presents 38% and 5% more peak and cell-edge user throughput gains, respectively.

Keywords—Small cells; Ultra-dense networks; Planning; Multiobjective optimization,

I. INTRODUCTION

In the African continent there is an unprecedented increase in penetration of mobile broadband services and adoption of data-intensive devices (smartphones, mobile dongles, mobile wireless routers etc.) [1], [2]. To address the subsequent increase data traffic growth and service quality demands, mobile operators in Africa are upgrading their networks to radio technologies providing higher network capacities and user throughputs [1]. A currently common scenario is for operators to maintain multi-standard radio access networks that include fourth-generation (4G) Long Term Evolution (LTE) standard and preceding technology generations. These operators are now evolving their LTE network (to LTE-Advanced and LTE-Advanced Pro), which will provide capacity scalability due to increased spectral efficiency in

existing bands (through higher order modulation and multi-antenna techniques) and aggregation of a larger number of carrier bands (both licensed and unlicensed).

Even as LTE network expansion in Africa is ongoing, mobile operators, equipment vendors and other industry stakeholders are already aggressively developing and trailing the fifth generation (5G) network technologies [1], which will support continued connectivity needs for next decade and beyond. To that end, 5G is envisioned to be a unifying connectivity fabric that will connect virtually everything around us — from enabling enhanced mobile broadband (eMBB) services and mission-critical communications to connecting the massive Internet of Things (IoT) — as well as support for use cases yet to be envisioned today. To fulfill increasing capacity demand of eMBB services, various capacity enhancing technologies have been for 5G [3]. It includes those technologies using more base stations/km² (denser small cell deployments) [4] and opening up new 5G spectrum bands in the low bands (sub-1 GHz), mid bands (1-6 GHz) and high bands (mm-wave bands within 24-28 GHz) [5].

Future networks are expected to be highly heterogeneous in terms of radio access technologies (4G and 5G), base station types (small cells and macrocells), spectrum band usage (4G and 5G bands), and kinds of interference to be managed due to the various capacity enhancing technologies that will be applied to achieve diverse network requirements in terms of capacity, coverage, user experience uniformity, diverse traffic demand, energy, cost and other factors. As result to plan and implement quality network, there is a need to take in to account this heterogeneity and the diverse network requirements with tight trade-offs among them. One of the interesting network planning dilemmas that emerges for operators is *whether to optimize their targeted dense small cell topologies (location and number of small cell sites) only for 4G or to optimize small cell network topology for 5G in advance during 4G small cell deployment phase?*

In conventional planning approach, experienced network planner makes planning compromises and optimizations through iterative simulations. To find optimal solution, it commonly applies a single random solution that is updated every iteration through deterministic procedure [6]. This

conventional planning method will not be straightforward and effective for dense/ultra-dense networks due to its heterogeneity and the diverse tightly-coupled network requirements. Thus, there has been noted a need for planning method that takes in to account the heterogeneity and diverse requirements of dense/ultra-dense networks. To that end, multiobjective optimization (MO) technique that aims to solving problems involving simultaneous optimization of several conflicting objectives has recently been considered [7], [8]. In MO process, different solutions will produce trade-offs between different objectives and a set of solutions is required to represent the optimal solutions of all objectives. In [8] we have developed planning framework that provide optimal ultra-dense network topologies considering multiple objectives in terms of key network requirements in terms of number of base stations, network capacity, cell-edge throughput and energy efficiency.

In this paper, using the MO network planning framework developed in [8], we investigate how to find efficient deployment topologies of 4G small cells (operating at 1.8 GHz) and 5G small cells (operating at 3.5 GHz band) for the dense Addis Ababa Meskel-Square area under existing umbrella LTE macro network. In particular, this case study is leveraged to gain more insights on the previously highlighted network planning dilemma on whether to optimize small cell network topologies for 4G or future 5G small cell deployments. Further practical considerations are taken for the case study by assuming existing street furniture (particular street lampposts) as candidate locations for small cell deployments. Moreover, a non-standalone architecture (NSA) is assumed, whereby, future 5G base stations are collocated with 4G base stations to provide an anchor towards a 4G evolved packet core network (EPC) [3].

The rest of the paper is organized as follows. Section II presents applied system model. In Section III, we explain the deployment scenario and simulation parameters. Then resulted topologies of the MO based planning of 4G and 5G small cell deployments and corresponding performance results are discussed in Section IV. Finally, concluding remarks are provided in Section V.

II. SYSTEM MODEL

We consider a downlink 4G LTE mobile networks with N_M umbrella macro cells in a dense urban deployment area and N_S closely-spaced candidate locations for 4G or 5G small cells in selected service area. For cluster based uniformly distributed users around the hot spots and also the whole deployment area, cell association is made based on user's received power from the macro cells and active small cells. Active cells of the network are indicated using a vector x of size $N_M + N_S$. When k^{th} cell is active, $x(k) = 1$ otherwise $x(k) = 0$. We refer x as network topology.

Received power of a user from k^{th} cell is computed as $P_k^{Rx} = P_k^{Tx} L_k^{SF} |h_k|^2 G_k / L_k(d_k) L^O$, where P_k^{Tx} , L_k^{SF} , h_k ,

G_k , $L_k(d_k)$ and L^O are transmit power, shadow fading, channel gain, antenna gain, average pathloss and other losses (e.g. cable loss) of k^{th} cell. Shadow fading is modeled with log-normal distribution and channel amplitude is obtained from Rayleigh fading statistics. Average pathloss is computed using deterministic ray tracing dominant path model over building and terrain map of the deployment area.

For small cell user u_s , SINR is formulated as

$$SINR(u_s) = P_0^{Rx}(u_s) / \left(\sum_{k=1}^{N_A-1} P_k^{Rx}(u_s) x(k) + P_N \right), \text{ where}$$

N_A is number of active small cells, index 0 refers the serving small cells, $k = 1, 2, \dots, N_A - 1$ refers interfering small cells and P_N is noise power. For macro user the SINR is given as

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

provided that all macro cells are assumed to be active.

Throughput (TP) results are obtained through mapping the SINRs results using a modified Shannon formula [9]:

$$TP = N_{PRB} B_{PRB} n^* \min(S_{max}, BW_{eff} \log_2 \left(1 + \frac{SINR}{SINR_{eff}} \right)), \quad (1)$$

Where N_{PRB} is the number of PRBs, BW_{PRB} is the bandwidth per PRB and n is 4G MIMO rank or 5G massive MIMO spectral efficiency gain. Note also that S_{max} is the maximum spectral efficiency, $SINR_{min}$ is the minimum required SINR, BW_{eff} adjusts bandwidth to fit with the system bandwidth efficiency and $SINR_{eff}$ reflects the SINR implementation efficiency. When obtained SINR is less than required minimum SINR, throughput becomes zero.

Performance Metrics: The focus of this paper is in two performance metrics: number of small cells N_A and aggregate network capacity C . While the number of small cells are formulated as

$$N_A = \sum_{k=1}^{N_S} x(k), \quad (2)$$

the network capacity is given as

$$C = \sum_u^{N_T} TP(u) \quad (3)$$

Where N_T is total number of users that are served by macro and small cells.

Multiobjective optimization problem and technique: The MO problem can be formulated as

$$\min_x f(x) = [N_A(x), -C(x)] , \quad (4)$$

Here the aim is to find the network topology x that minimize the number of applied small cells and maximize the aggregate network capacity. To solve the MO problems, evolutionary algorithms are effective metaheuristics as the mathematical structure of the objective functions does not feature convexity or continuity [10]. As a result, we use the popular multiobjective evolutionary algorithm called nondominated sorting genetic algorithm II [8], [11].

5G small cell deployment scenarios: The 4G optimized 5G colocation and 5G optimized scenarios are described in Table 1 below.

TABLE 1. 5G OPTIMIZED AND 4G OPTIMIZED 5G CO-LOCATION SCENARIOS

	4G optimized co-location scenario	5G optimized scenario
Operator's Strategy	First 4G small cells are deployed using 4G optimal topology and then 5G small cells collocated and macros stay as 4G	Leapfrogging 4G small cells, 5G small cells are deployed using 5G optimal topology and macros stay as 4G
Duplexing	Frequency division duplex (FDD) for 4G and Time division duplex (TDD) for 5G	FDD for 4G and TDD for 5G
Carrier frequency	1800 MHz macro, 2600 MHz 4G small cell and 3500 MHz 5G small cell	1800 MHz macro and 3500 MHz 5G small cell
Bandwidth	20MHz for 1800 MHz and 2600 MHz and 100MHz for 3500 MHz	20MHz for 1800 MHz and 100MHz for 3500 MHz
MIMO	2x2 MIMO for 4G and massive MIMO for 5G	2x2 MIMO for 4G and massive MIMO for 5G

III. DEPLOYMENT SCENARIO AND SIMULATION PARAMETERS

A. Deployment Scenario

We have used Meskel Square and its close surroundings in Addis Ababa, Ethiopia as a planning study area that exemplifies an urban scenario with dense hotspots. It covers an area of 1.25km×1.65km having buildings of various heights up to 79m on a terrain with topography range of 2000-3000m. In addition to Meskel Square, the study area includes the national stadium, exhibition center, hotel garden, as well as busy streets with light rail stations as major high-density spots. Ten tri-sector macro sites are deployed in the simulation area with locations formulated based on real locations of eNodeBs for

existing Addis Ababa LTE network. In the focus deployment area, 110 street lamp posts are spaced with 40 meter mutual distance and considered as outdoor candidate locations for small cell deployments. In Fig. 1, macro sites are identified with blue points and lamp posts are identified with the red markers.

Fig. 1. Planning area including macro sites and small cells candidate street lamp post locations

B. Planning Parameters and Assumptions

Our planning study focuses on downlink performance. The radio coverage estimations are based on realistic three-dimensional building vectors and topographical data for the simulation area and are evaluated using the dominant path model implemented in the WinProp propagation modeling tool [16]. Then Matlab based system-level simulations are then performed to investigate the network performance metrics (see equations (2) and (3)) and Matlab based MO is performed to solve the problem in (4). The macro and small cell parameter and system simulation assumptions follow commonly used 3GPP guidelines [12] [13], and are listed in Table 1. The SINR-to-throughput mapping parameters for 2x2 MIMO configurations are based on previous link-level simulations campaigns [14]. For simplicity, we also assume that massive MIMO provides three times more spectral efficiency compared to 2x2 MIMO and 70% time share for TDD downlink [15].

TABLE 2. SIMULATION ASSUMPTIONS AND PARAMETER VALUES

Parameter	Values/Assumptions
Deployment Scenario	Outdoor small cells deployment under overlaid macro network; separate frequency between macro and small cells;
Simulation	Radio propagation modeling (WinProp) [16], MO and system level simulation (Matlab), 5 m resolution
SINR-throughput mapping	For UEs
	$SINR_{min}$ (dB)
	BW_{off}
	$SINR_{off}$
Macro Parameters	
Macro Cells Parameters	
Transmit Power	46 dBm
Antenna Height	Realistic network data
Antenna Patterns	Kathrein 742215,
Small Cells Parameters	
SC candidate locations	110 street lamp posts
Location/Height	Deployed at height of 10 m
SC downlink	Omni antenna, 33 dBm transmit power
UE Parameters	
UE height/location	1.5 m UE height, 20% UEs dropped randomly in whole area (both indoor and outdoor), 80% UEs cluster-dropped within 20m radius of small cells
UE number	140 UEs in service area
UE other parameters	Noise Figure: 9 dB, Ant. Gain: 0 dBi
Buildings, Fading, Scheme and Scheduling Characteristics	
Shadow Fading	Log-normal with standard deviation of 8 dB and decorrelation distance 50 m
Fast fading	Rayleigh fading
Buildings	Heights 3 to 79 m Penetration loss: 20 dB
Cell association/Scheduling	Cell association: based on RSRP (with 4dB cell selection bias for small cells) Resource scheduling: frequency domain round robin scheduling for both macro cell and small cell

IV. RESULTS AND PERFORMANCE EVALUATION

Once simulation campaign is performed, optimal Pareto front results obtained for MOs problem (4) assuming 4G optimized and 5G optimized scenarios are depicted in Fig. 2. As expected, 5G optimized case provides significant aggregate capacity gain compared to the 4G optimized case for best found topologies with same number of small cells, mainly due to massive MIMO and five times more bandwidth usage.

Fig. 2. Multiobjective optimization solution for (4) for 4G and 5G Optimized small cells

Fig. 3. Aggregate capacity gains for 5G optimized and 5G co-location scenarios compared to 4G optimized case

Fig. 3 depicts aggregate capacity gains of 5G optimized and 5G co-location scenarios compared to 4G optimized case for 7 and 31 small cells optimal topologies. As can be seen in the figure, the 5G optimized and 5G co-location provide 200.2% and 178.7% capacity gains, respectively for 31 small cell topologies while they provide 155.4% and 114.8% capacity gains for 7 small cell topologies.

The topologies of the 4G and 5G optimized cases for the exemplary 31 number of small cells are depicted in Fig. 4. The two topologies commonly share 18 same small cell locations.

Fig. 4. Optimized topologies: Red(4G optimized co-location only), Black(5G optimized only) and Blue(Common for both)

For the common 31-topology, Fig. 5 shows UE throughput gains of 5G optimized and 5G co-location scenarios relative to 4G optimized case. The result shows the 5G optimized scenario provides 4.95% and 4.99% more gains for 10%-ile and 50%-ile UE throughput, respectively, while it provides 38.27% more gain for the 90%-ile.

Fig. 5. UE throughput percentage gains for 5G optimized and 5G co-location scenarios compared to 4G optimized case

V. CONCLUSION AND FUTURE WORKS

To meet the increasing mobile network capacity demand, dense and ultra-dense deployment of small cells has been considered as one key solution for 4G and 5G mobile systems. Planning of small cells is more challenging due to introduced heterogeneity and more tightly coupled capacity, coverage, cost, energy and other requirements. Moreover, this becomes more challenging for network planners when these network planning decisions occur against a backdrop of roadmaps already anticipating upgrades to 5G. In this paper, we apply MO planning framework to identify optimal network topologies considering the tight trade-offs among planning requirements for selected Addis Ababa deployment scenario. Specifically we addressed the network planning dilemma on whether to optimize small cell deployments for 4G or 5G small cells. From the simulation results of the selected study area we note that significant capacity gains are achieved by 5G optimized compared to 5G co-location for different optimal topologies. Furthermore, the 5G co-location scenario achieves 38% and 5% less peak and cell-edge user throughput gains compared to the 5G optimized scenario.

Future work includes comparison of other 5G scenarios combining the various 5G frequency bands (including mmWave bands). While this study focused on outdoor deployments it will be of interest to revisit the research question addressed in this paper in the context of indoor deployments (or combined outdoor and indoor deployments).

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