Performance Study for Small Cell Deployments in Densely Populated Informal Settlements

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I. BACKGROUND

Mobile broadband network coverage in African urban areas is typically from 3G Wideband Code-Division Multiple Access (WCDMA) and High Speed Packet Access (HSPA) macrocellular networks [1][2][4]. The increased mobile broadband subscriptions, traffic growth and intensifying competition has prompted most operators in the region to upgrade their networks to evolved HSPA and increasingly deploy Long Term Evolution (LTE) networks in major urban areas [4]. Network densification through rollout of new cell sites allows operators to increase reuse of their limited spectrum and provide needed capacity gains in urban areas [1], particularly in the in fast expanding dense informal settlement areas [3]. However, rolling out of new sites in those settlements is complicated by lack of fixed lines for backhaul, energy scarcity, need for securing network assets at sites and limited ARPU to justify the additional investment [1]. This calls for alternative approaches for network densification and operation models that are better suited for aforementioned areas.

In this paper we carry out extensive simulation study of an alternative densification scenario through small considered depicted in Figure 1. The HSPA macro site represents the legacy deployment with majority of user equipment (UE) being HSPA-compliant. Macro LTE upgrades are then implemented to cater for minority but gradually expanding base of LTE UEs. The multi-RAT small cells are then deployed to offload traffic from HSPA macro cells. Unplanned deployment by end users (households, microenterprises etc.) of shared access small cells provides cost-effective network densification from operators' perspective and affordable connectivity from user perspective. Moreover, it allows for novel business models that provide incentives (e.g. revenue share) for end users deploying and operating the small cells. The LTE radios in the small cell are then only used to provide a low-cost flexible broadband backhaul connections towards the LTE macro sites without the need for operator intervention.

II. PERFOMANCE STUDY METHODOLOGY

To exemplify a high-density urban dwelling area we have used Hanna Nassif ward in, Dar es Salaam, Tanzania as a simulation study area. Hanna Nassif has an estimated population of 40000 people, living in a 1 km^2 land area. The area includes around 3000 (mostly single story) buildings and is located on a terrain with a topographical difference of 19 m. The small cells are deployed at random buildings by end-users in the service area. We consider two possible deployment scenarios: (a) indoor deployment; (b) rooftop deployment (akin to a television antenna). Indoor deployment enables small cells to provide indoor coverage and indoor-to-outdoor coverage for other UE in close proximity of the building. Rooftop deployed smalls provide increased range for outdoor coverage (see Figure 2), but at the expense of reduced signal strength for indoor users (outdoor-to-indoor coverage) due to building penetration losses. Furthermore, rooftop small cells allow for a better backhaul links towards LTE macro cell. Moreover, their placement on the roof is convenient for harvesting energy from renewable sources (solar, wind, etc.) and as a result minimize the operational challenges due to frequent power outages or even lack of access to grid power [2].

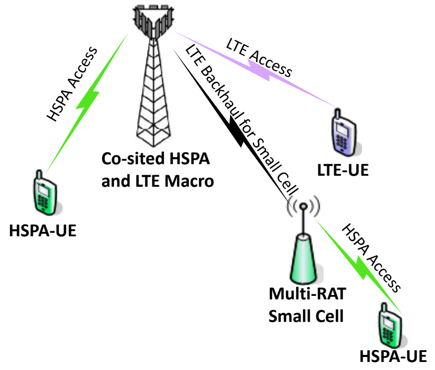

Figure 1 Overall deployment scenario

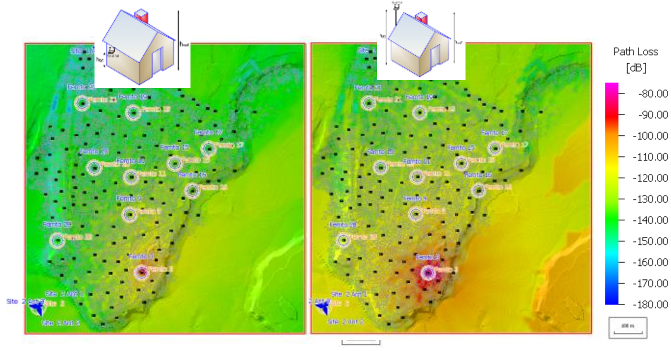

Figure 2 Example comparative pathloss maps for a small cell deployed indoors (left) and on rooftop (right) in the Hanna Nassif area (WinProp simulation result)

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The parameter and system simulation assumptions follow commonly-used 3GPP guidelines (see Table I).

TABLE I. SIMULATION PARAMETERS AND ASSUMPTIONS

Parameter	**Values/Assumptions**		
Air Interface	HSPA FDD, LTE FDD		
Carrier Freq./ Bandwidths	LTE: 800 MHz / 10 MHz and 2 x 10 MHz HSPA: 2112.5 MHz / 5 MHz		
Simulation	Radio propagation modeling (WinProp) [6], Static system level simultion (Matlab), 2.5 m resolution		
Macro Paramaeters			
Macro Sites	Site1 (3 cells)	Site2 (3 cells)	Site3 (1 cells)
Transmit Power	LTE: 46 dBm, HSPA: 37.8 dBm (10% for CPICH)		
Antenna Height	10 m	15 m	10 m
Antenna Patterns	Kathrein 741984		
Sector Azimuths	20°,140°,260°	0°, 120°, 240°	250°
Intersite distance	955 m, 880 m, 585 m		
Small Cells Parameters			
SC number	Three cases considered: 10, 30 and 60 small cells		
Location/Height	Randomly deployed, Indoor:1.5 m, Rooftop: 4 m or 7 m		
LTE backhaul	Antenna Gain: 0 dBi, Noise Figure: 9 dB, Antenna config: 2x2, 4x4, 8x8 MIMO		
HSPA access	Tx power 20 dBm (10% for CPICH), Omni, 0 dBi antenna gain, 3 dB cell selection bias		
UE Parameters			
UE height/location	1.5 height, 100% LTE-UEs and 50% HSPA-UEs dropped randomly in whole area, 50% HSPA-UEs cluster-dropped within 40m radius of small cells		
UE number	30 LTE-UEs, 45 HSPA-UEs in service area		
LTE-UEs	Noise Figure: 9 dB, 2 × 2 MIMO, Ant. Gain: 0 dBi		
HSPA-UEs	Omni.; 0 dBi gain, -99dBm noise; 15Code HSDPA		
Buildings and Fading Characteristics			
Shadow Fading	Shadow fading: WinProp ray tracing		
Fast fading	Rician (for small cell-eNB, K =2), Rayleigh (for UEs)		
Buildings	Variable dimensions, heights 3-6 m, penet. loss: 10 dB		

III. SIMULATION RESULTS AND DISCUSSIONS

Figure 3 demonstrates that unplanned deployment of shared access small cells in dense informal settlements can provide significant throughput gains even for limited small cell penetration. The throughput gains are more equitably distributed when the small cells are deployed on rooftop with relatively offloading from macro cells achieved compared to indoor small cell case (see Table II). The small cell LTE backhaul link performance was studied for different combination of scheduling strategies: fair round robin (FR) versus priority round robin (PR) allocating resources first to meet small cell backhaul capacity needs; MIMO configuration (2x2, 4x4, 8x8); and carrier allocation (10 MHz, 2x10 MHz carrier aggregation) (see Table III). The objective of the simulation study was twofold: first to understand how different LTE/LTE-Advanced link enhancements can enable the HSPA small cell backhaul needs to be met (Table IV), secondly to observe how this LTE resource sharing (with small cell backhaul) impacts normal LTE UEs (Table V). Simulation results suggested that prioritizing LTE resource allocation to HSPA small cell backhaul together efficient small cell antenna designs is best way of meeting backhaul capacity requirements without significant performance impact on normal LTE UEs. Additional research is being carried out to understand how techniques, such as, MIMO link adaption, traffic steering and backhaul load balancing can provide both performance and energy-efficiency for the deployment scenario considered here.

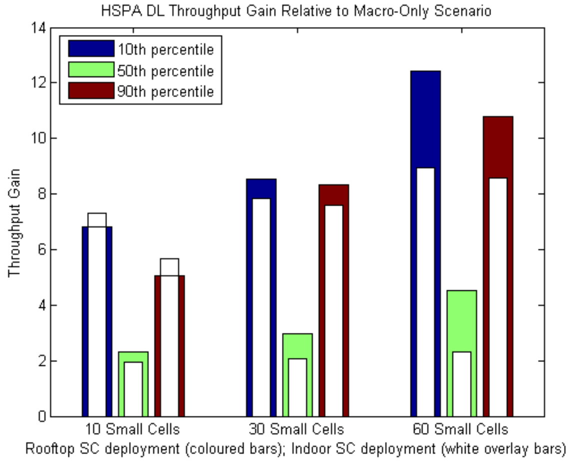

Figure 3 HSPA throughput gain

TABLE II. AVERAGE JAIN'S THROUGHPUT FAIRNESS INDEX

Macro only	**# Indoor Small Cells**			**# Rooftop Small Cells**		
	10	**30**	**60**	**10**	**30**	**60**
0.29	0.29	0.26	0.25	0.40	0.38	0.40

TABLE III. SIMULATED CASES OF LTE BACKHAUL FOR HSPA SMALL CELLS

	Case1	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**
Scheduling	FR	FR	PR	PR	PR	PR
MIMO	2x2	4x4	2x2	4x4	2x2	8x8
Carrier (MHz)	10	10	10	10	2 x 10	2 x 10

TABLE IV. AVERAGE PERCENTAGE OF SMALL CELLS WITH BACKHAUL CAPACITY NEEDS FULLY MET BY LTE CONNECTION

	# Indoor Small Cells			**# Rooftop Small Cells**		
	10	**30**	**60**	**10**	**30**	**60**
Case 1	35.4%	34.7%	34.9%	48.4%	43.1%	40.6%
Case 2	57.6%	54.0%	53.3%	70.1%	62.8%	60.3%
Case 3	97.8%	86.7%	80.0%	99.3%	90.4%	79.4%
Case 4	100%	98.0%	95.8%	99.4%	99.2%	97.0%
Case 5	97.8%	86.7%	80.0%	99.3%	90.4%	79.4%
Case 6	100%	99.8%	99.3%	100%	100%	99.4%

TABLE V. PERCENTAGE OF LTE UES IN OUTAGE

	# Indoor Small Cells			**# Rooftop Small Cells**		
	10	**30**	**60**	**10**	**30**	**60**
Case 1	5.3%	6.9%	7.4%	7.8%	5.3%	7.7%
Case 2	5.3%	6.9%	7.4%	7.8%	5.3%	7.7%
Case 3	5.3%	12.3%	22.0%	28.2%	5.3%	10.6%
Case 4	5.3%	7.9%	11.9%	15.1%	5.3%	7.5%
Case 5	2.2%	2.8%	3.2%	3.4%	2.2%	2.7%
Case 6	2.2%	2.2%	2.5%	2.6%	2.2%	2.2%

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