Energy Performance of 5G-NX Wireless Access Utilizing Massive Beamforming and an Ultra-lean System Design

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***Abstract*—This paper presents the energy performance of a new radio access technology (RAT) component in 5G, here denoted as 5G-NX. The 5G-NX RAT encompasses massive beamforming and an ultra-lean design as two of its key technology components. The user throughput, resource utilization of the cells and daily average area power consumption are evaluated by means of system level simulations in an Asian city scenario, and the results are compared with a traditional LTE deployment using the same network layout. The simulation results indicate that the new 5G-NX system provides much better energy performance compared to LTE and this is primarily due to the ultra-lean design and the high beamforming gain that provides both longer and more efficient component sleep in the network. At expected traffic levels beyond 2020, 5G-NX is shown to decrease the network energy consumption by more than 50% while providing around 10 times more capacity.**

***Index Terms*— Massive beamforming, 5G, NX, power model, energy efficiency, green wireless networks, system level simulation.**

I. Introduction

In recent years, operators have been facing an exponential traffic growth due to the proliferation of portable devices that use high-capacity connectivity [1]. This situation continuously pushes operators to expand their networks in order to increase capacity in the network. Since the average revenue per user does not grow as quickly, this increases the significance of expanding the network capacity using highly cost effective solutions. Another consequence of the rapid increase in data traffic is that the network energy consumption will continue to increase, unless concerted countermeasures are taken. For a long time the network energy consumption was not a significant concern for operators and vendors. This has changed dramatically over the last couple of years as concerns with environmental sustainability, energy security and cost have emerged on the agenda. For telecom vendors, energy consumption is today a key performance indicator on par with spectrum efficiency and it is recognized as a key factor to improve in order to reduce product volume and weight. Operators today also realize that building a best performing network includes ensuring the best user experience as well as ensuring that their network has the best energy performance.

5G wireless access will be required to handle this energy and user experience challenge, and provide connectivity for a wide range of new applications with a dramatic reduction in energy consumption by extending the capabilities beyond previous generations. In contrast to earlier generations, 5G wireless access is not a specific radio access technology; rather it is an overall wireless access solution addressing the various requirements of mobile communication. Today, we foresee that the overall 5G wireless access consists of two key elements; backwards-compatible LTE evolution, and the new radio access technology, here denoted NX, which initially will be deployed at new spectrum, primarily above 6 GHz, mainly due to the availability of larger bandwidth. More specifically 5G-NX is the non-backwards compatible air interface in 5G, providing higher flexibility to achieve the 5G requirements [2].

In this paper, we evaluate the energy performance of 5G-NX at various capacity requirements considering two of its key technology components: massive beamforming and ultra-lean design. Beamforming is a critical component to counter the more challenging propagation conditions at higher frequencies and enable very high bit rates [2]–[4]. The ultra-lean design of 5G-NX minimizes any transmissions not related to the delivery of user data and thus enables base stations (BSs) to sleep for longer consecutive time durations when the network is idle [2], [4]. Combined with beamforming, which effectively increases the user data rate and hence provides shorter packet transmission times, we show in this paper that this has a significant effect on the amount of time the network nodes can operate in a very low energy consuming sleep state. The technology potential of using these components to enhance energy performance of wireless access is quantified and compared with legacy LTE deployments using system level simulations.

The outline of the paper is as follows. Section II introduces the two key technology components of 5G-NX systems that are the prime focus of this paper. The system model and network layout are presented in Section III. The energy performance evaluation methodology and the power consumption models for LTE and 5G-NX systems are explained in Section IV. Finally Section V presents the simulation results and Section VI concludes the paper.

II. 5G Wireless Access

A. *UE Specific Beamforming*

A key technical component of 5G is user equipment (UE) specific beamforming. This has the potential to mitigate the increased propagation loss at higher frequencies and increase the performance by a more spatially focused transmission and reception [2]–[4].

In this paper, a grid-of-beams (GoB) beamforming concept is considered. For downlink transmission, dual-stream transmission is utilized, using dual-polarized antennas. The beam grid is created by applying discrete Fourier transform (DFT) weight vectors over the antenna elements. The beamforming is separable in azimuth and elevation so that separate DFT vectors are applied over the antenna array columns and rows. In each antenna dimension (horizontal and vertical) the DFT is oversampled by a factor two, i.e., there are twice as many beams as antenna elements in each dimension. For a 5x20 array, this amounts to 400 beams in the grid.

For each UE, the beam in the grid that gives the highest beamforming gain is selected. The beamforming gain for a candidate beam in a given cell is proportional to the power that would be received by the UE if that beam was used for transmission. This is calculated according to equation below:

$$P_r = \mathbf{w}^H \mathbf{R}\, \mathbf{w} \tag{1}$$

where $\mathbf{w}$ is the candidate beamforming weight vector and $\mathbf{R}$ is the channel covariance matrix between the BS antenna elements and the first antenna on the UE.

Here, the channel covariance matrix is calculated by using the propagation models introduced in Section III.B. We assumed that the antenna array at the BS has dual-polarized antenna elements and that UE-specific beamforming is performed per polarization and that the two polarizations enable dual-layer transmission/reception.

B. Ultra-lean Design

The basic principle of ultra-lean design is to minimize any transmissions not related to the delivery of user data. Such transmissions include the signals for synchronization, idle-mode mobility and system and control information [2], [4].

This solution not only improves the system performance by reducing the interference of non-user-data related transmissions, but also presents a great opportunity for better energy performance by enabling network nodes to stay at low-energy states in longer durations.

III. Network Layout and System Model

A. Network Layout

We consider an Asian city scenario (i.e., inspired by Tokyo and Seoul) with an area of 2×2 km where there are 1442 multi-floor buildings with different heights (i.e., distributed between 16m and 148m) as shown in Fig. 1. We assume that the traffic is served by a macro network with an inner and an outer layer, with different inter-site distances and antenna heights. For the inner layer with high rise buildings, 7 three-sector macro sites located at rooftop (at average height of 45 m) are considered. In the inner layer, the inter-site distance is 200 meters. On the other hand, the outer layer consists of 28 three-sector macro sites located at rooftop (at average height of 30 m), corresponding to an inter-site distance of 400 meters.

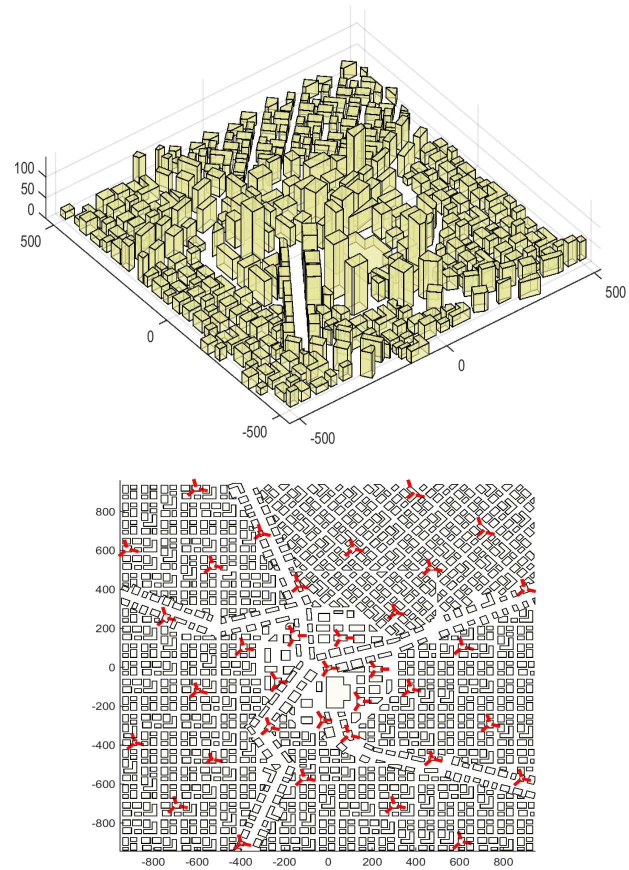


Fig. 1. City model in the evaluation area (top) and site deployment in the entire simulation area (bottom).

In this scenario, 80% of the traffic is assumed to be generated inside the buildings.

B. Propagation Model

The propagation model is composed of several sub-models taking into account free space propagation in line-of-sight, diffraction, scattering modeling in non-line-of-sight, building penetration loss (BPL), and indoor loss. The basis for each of these sub-models has been taken by selecting appropriate models described in the COST 231 Final Report [5].

In addition, frequency-dependent models for BPL and indoor loss are adopted based on [6] with some modifications as described below. In this model, the building penetration loss is defined based on the type of the building characterized by building material (e.g. the percentage of concrete walls and glass walls, the thickness and type of the walls, etc.). Two different building types are considered, i.e., old and new, the former is assumed to consist of 20% two-layered glass windows and 80% concrete and is more common in the low-rise area of the city, whereas the latter consists of 90% infrared reflective glass (IRR) and 10% concrete and has a higher occurrence in the high-rise area of the city.

The total loss through the standard glass (L_{gw}) and the coated glass windows (L_{cgw}) of the "old" and "new" buildings is estimated according to Eq. (2a) and Eq. (2b) respectively.

Eq. (2c) gives the concrete wall loss estimate (L_{cw}). Note that frequency (f) is expressed in GHz in the equations.

$$L_{gw}[dB] = 0.2\,f + 2 \tag{2a}$$
$$L_{cgw}[dB] = 0.3\,f + 23 \tag{2b}$$
$$L_{cw}[dB] = 4\,f + 5 \tag{2c}$$

The indoor environment is assumed to be open, with standard, alternatively plaster, indoor walls. The loss model per wall is calculated as a function of the carrier frequency and an average wall distance (D_w) based on Eq. (3a), (3b) and Eq. (4). The basic approach in the model is to assume different values for the indoor loss per meter ($\mathcal{L}$) for indoor distances that are below a certain threshold and for those that exceed this threshold.

$$\alpha_1[dB] = \frac{0.15\,f + 1.35}{D_w} \tag{3a}$$
$$\alpha_2[dB] = \frac{\alpha_1}{0.05\,f + 0.7} \tag{3b}$$

$$\mathcal{L} = \begin{cases} \alpha_1, & \text{if } d \leq d_{break} \\ \alpha_2, \quad \text{for } (d - d_{break}) & \text{if } d > d_{break} \text{ and } f > 6 \\ \alpha_1, & \text{if } d > d_{break} \text{ and } f < 6 \end{cases} \tag{4}$$

where D_w is the distance in meters between two walls.

C. Antenna Models

In the LTE simulations the BS antenna is assumed to be a standard macro antenna with electrical and mechanical tilt, with an antenna gain of 18 dBi. No UE-specific beamforming is performed. A Gaussian radiation pattern is modeled where the main beam is with 65° azimuth half-power beam width (HPBW) and 6.5° elevation HPBW. The same antenna pattern model has been used for 2.6 GHz and 15 GHz. Cell-individual tilt values were set based on internally developed tilting guidelines. On the other hand the UE is assumed to have isotropic antennas with -8 dBi antenna gain. This low gain value is used to model shadowing effects close to the UE.

In the 5G-NX simulations, the BS antenna is assumed to be a rectangular array with M×N dual-polarized elements, where M is the number of columns and N is the number of rows. The radiation pattern of a single antenna element is modeled by Gaussian main beam. The azimuth and elevation HPBW is 65° and 90°, respectively, and the gain is 8 dBi. For the UE antenna, we assume an effective antenna gain of 3 dBi by taking into account the UE beamforming capability, and reduced shadowing due to physically separated antenna elements.

D. Node Selection

In the LTE evaluations, node selection is based on highest reference signal received power (RSRP).

In the 5G-NX evaluations, we assume that the UE is served by the best beam, providing the highest received power, in the entire network. Due to the fact that a search over all beams in the network for all UE positions creates a huge computational effort in the simulations, we adopt a simplified approach consisting of a two-stage procedure. In the first step, the best node is found based on the radiation pattern of a single antenna element. In the second step, we select the best beam offered by the node by picking the beam with highest received power according to $\mathbf{w}^H\,\mathbf{R}\,\mathbf{w}$.

IV. Energy Performance Evaluation Methodology

Traditionally bit/Joule (or traffic served per Watt consumed) is used to quantify the energy performance of wireless access networks. Despite its wide-acceptance for link-level performance evaluations, the bit/Joule metric is shown to be inadequate for network-level evaluations [7]. The main reason is that bit/Joule indicates an improvement with the increased traffic despite the fact that energy usage is also increased, though at a lower rate. Therefore, in this paper, we define energy performance as the daily averaged area power consumption, represented by W/km^2.

A. Power Consumption Models

In this subsection, we introduce the power consumption models used to evaluate the energy performance of LTE and lean-carrier based 5G systems.

1) Power Consumption Model for LTE: In order to assess the energy consumption of a reference LTE base station, we use the EARTH power models as defined in [8]. This widely used model constitutes an interface between the component and network levels, and enables the assessment of energy efficiency in wireless access networks. In the model, the total power consumption of a BS, when active, is divided into two parts: (i) The idle power consumption, i.e., the power consumed in the BS even when there is no transmission (P_{tx} = 0); (ii) The traffic load dependent power consumption, which is expressed as below:

$$P_{BS}^{LTE} = N_{TRX} \times \begin{cases} \Delta_p\,P_{tx} + P_0 & \text{if } P_{tx} > 0 \\ P_0 & \text{if } P_{tx} = 0\,\text{(without cell DTX)} \\ \delta\,P_0 & \text{if } P_{tx} = 0\,\text{(with cell DTX)} \end{cases} \tag{5}$$

where P_{tx} and N_{TRX} denote the transmit power and the number of transceivers, respectively. On the other hand, Δ_p represents the portion of the transmit power dependent power consumption due to feeder losses and power amplifier, whereas P_0 accounts for the power consumption because of the active site cooling and the signal processing.

Traditional BSs consume a considerable amount of power even when there is no user in the cell, i.e, P_0. However, a hardware feature called cell discontinuous transmission (cell DTX) [9], which enables the deactivation of some components of a BS during the empty transmission time interval (TTIs), significantly lowers the idle power consumption, i.e., $P_{sleep} = N_{TRX}\delta P_0$, where $0 < \delta < 1$.

In our LTE evaluations, we accounted for the mandatory LTE signals for the calculations of sleep mode power consumption. Considering the fact that the mandatory transmissions required by the LTE standard only allows for very short consecutive DTX periods (i.e., max 0.2 ms), and thus preventing deep sleep in LTE cells, we assume δ=0.84 in our simulations.

2) Power Consumption Model for 5G-NX: In order to assess the power consumption of 5G-NX, we proposed a simplified power consumption model based on [10], [11], considering the impact of two key features of 5G-NX systems: i) ultra-lean design (where as little as possible are transmitted from an BS when there are no data to transmit); ii) massive-beamforming (which requires hundreds of active antenna elements), given as:

$$P_{BS}^{5G-NX} = N_s \times \begin{cases} \frac{P_{tx}^s}{\varepsilon} + NP_c + P_B & \text{if } P_{tx}^s > 0 \\ P_B & \text{if } P_{tx}^s = 0 \, \text{(without cell DTX)} \\ \delta P_B & \text{if } P_{tx}^s = 0 \, \text{(with cell DTX)} \end{cases} \quad (6)$$

where N_s, N and ε denote the number of sectors in a site, number of RF chains and power amplifier (PA) efficiency respectively. P_c represents the additional digital and RF processing needed for each antenna branch whereas P_B is the baseline power consumption for each sector. Note that here, unlike in Eq. (5), P_{tx}^s denotes the transmit power per sector.

In this paper, we consider fully digital beamforming. Therefore, the number of RF chains (N) is twice the number of dual-polarized antenna elements.

We assume that the equivalent sleep mode power consumption of a 5G-NX BS is lower compared to an LTE BS due to fact that 5G-NX provides significant reduction in mandatory idle mode transmissions, allowing longer consecutive DTX periods, up to 99.6 ms. We assume that the longer DTX ratio can result in a factor κ lower sleep power consumption of the hardware components. In this study we will use the value δ=0.29 which correspond to κ=2.

B. Daily Average Area Power Consumption

Daily average area power consumption is used as the energy performance indicator which relates the total power consumed in the network throughout a day to the corresponding network area, $\mathcal{A}$, which is measured in W/km^2 as below:

$$\mathcal{P}_{area} = \frac{1}{24} \frac{\sum_{t=1}^{24} \sum_{i=1}^{N_{BS}} P_{active}\,\eta_i^t + P_{sleep}(1-\eta_i^t)}{\mathcal{A}}. \quad (7)$$

Here N_{BS} is the total number of BSs in the network, P_{active} and P_{sleep} denote the power consumption of each BS when it is transmitting and when it is in sleep mode respectively. As aforementioned, the power consumption values in Eq. (7) will be different for LTE and 5G-NX systems. On the other hand, η_i^t represents the resource utilization of the BS i during given hour t. Here, the resource utilization is defined as the fraction of time-frequency resources that are scheduled for data transmission in a given cell during an hour. It also represents the probability of that BS i is transmitting.

We calculate the daily average power consumption by identifying the resource utilization of each BS in the network throughout the day using the daily traffic fluctuation pattern proposed in [8] for a given peak data traffic demand in the area (Mbps/km^2).

V. Simulation Setup and Results

In order to assess the energy performance of 5G-NX systems, we have carried out system level evaluations using the network layout presented in Section III-A. In this section, we first clarify the simulation setup and methodology, and finally present the simulation results.

A. Simulation Setup and Methodology

In this paper, we consider four different systems for evaluations:

- Case 1: LTE@2.6
- Case 2: LTE@2.6+LTE@15
- Case 3: 5G-NX@15
- Case 4: LTE@2.6+5G-NX@15

In the baseline scenario, the traffic is assumed to be served by an LTE system with 2×2 MIMO configurations operating at 2.6 GHz. This case represents the performance of the current deployed networks. We also consider three futuristic systems that are relevant for year 2020 and beyond. Firstly, we assume an LTE carrier aggregation scenario with 140 MHz total bandwidth of which 40 MHz carrier is at 2.6 GHz and 100 MHz time division duplex (TDD) carrier is at 15 GHz, each with 2×2 MIMO configurations. The reason for choosing TDD for the 15 GHz carrier is that spectrum around 15 GHz will probably be unpaired. Additionally, TDD simplifies beamforming since channel reciprocity can be utilized. This case might represent a transition scenario where LTE has been evolved to allow higher bitrates and carrier frequencies. Moreover, we consider two scenarios using the new, 5G-NX system which is characterized by UE specific beamforming and ultra-lean design. In the first scenario, the 5G-NX standalone system is deployed at 15 GHz using an 5×20 antenna array to cope with the traffic demand in the network. In the second scenario, we assume that 5G-NX@15 GHz is deployed together with the existing LTE@2.6 using carrier aggregation.

The performance of these systems is evaluated considering the network layout presented in Fig. 1. For the carrier aggregation cases, all sites in the network are assumed to have the multi-RAT capability. We consider that all systems are employing a frequency reuse of one, i.e., the same time and frequency resources are used for transmission in each cell, and there is no cooperation among sites. The detailed assumptions on simulation setup and power consumption parameters are listed in Table I.

TABLE I
SIMULATION ASSUMPTIONS

System and Path Loss Parameters	
Parameter	**Value (Case 1 / Case 2 / Case 3 / Case 4)**
Carrier frequency	2.6 / 2.6+15 / 15,/ 2.6+15 GHz
Bandwidth	20 / 40+100 / 100 / 40+100 MHz
Duplex scheme	FDD/ FDD+TDD/ TDD/ FDD+TDD
UE antenna gain	-8 / -8 + -8 / 3 / -8 + 3 dBi
Beamforming at BS	None / None+None / UE specific BF / None + UE specific BF
Max BS antenna gain	18dBi / 18 + 18 dBi / Antenna Array / 18 dBi+Antenna Array
Number of UE Rx/Tx branches	2/1
TDD configuration	5
Noise figure UE	9 dB
Noise figure BS	2.3 dB
Traffic Model	Packet download, equal buffer
Indoor traffic	80%
Distance between two indoor walls	D_w=4 m
Indoor threshold distance	d_{break}=10 m
Power Consumption Parameters	
Parameter	**Value**
Power slope	ζ=4.7
Number of transceivers for LTE	N_{TRX}=6
Transmit power per transceivers for LTE	P_{tx}=20 W
Baseline power consumption for LTE	P_0=130 W
Cell DTX performance for LTE	δ=0.84
Circut power per RF branch 5G-NX	P_c=1 W
Transmit power per sector for 5G-NX	P_{tx}^s=40 W
Power amplifier efficiency for 5G-NX	ε=25 %
Baseline power consumption for 5G-NX	P_B=260 W
Cell DTX performance for 5G-NX	δ=0.29

B. User Throughput and Capacity

The end-user performance of the evaluated systems is illustrated in Fig. 2. Firstly, we observe that 5G-NX system yields significantly improved cell-edge user throughput which is 5 to 10 times higher compared to baseline LTE system. Moreover, it is seen that a large capacity improvement is achievable when operating at higher frequencies despite the increased propagation loss. This shows that the beamforming capability of 5G-NX system, load balancing effect of carrier aggregation and availability of larger bandwidth re-gains much of the SNR loss by going up in frequency. Note also the synergy effect of aggregating LTE at 2.6 GHz with 5G-NX at 15 GHz. Operating stand-alone these systems can maximally carry around 400 Mbps/km^2 and 2300 Mbps/km^2, respectively. When aggregated they are able to carry more than 3700 Mbps/km^2.

C. Energy Performance

Considering the fact that the evaluated systems have different performance under the same traffic conditions, we conduct energy performance evaluations using the methodology introduced in Section IV. In Fig. 3, we illustrate the daily average area power consumption of the baseline LTE@2.6 system and the carrier aggregation scenario where LTE@15 is deployed together with the legacy LTE system operating at 2.6 GHz in order to improve the user throughput with wider bandwidth. Here we assume that static power consumption of a site will be increased by 45% when the LTE@15 system is deployed due to additional RF components and PA power consumption.

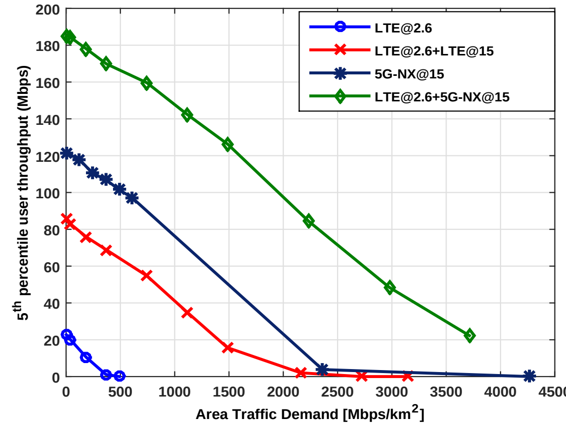


Fig. 2. 5-percentile DL user throughput vs. area traffic demand for the different simulation cases.

Moreover, we assume that all the BSs have DTX capability which means that cells can be put into sleep mode when there is no traffic. We observe that at traffic levels where LTE@2.6 can still serve the traffic with acceptable 5-percentile user throughput ($\mathcal{T}$=200 Mbps/km^2), carrier aggregation increases the energy consumption by more than 25 percent. This shows that increased static power consumption due to the new system cannot be compensated by the reduction in dynamic power due to lower utilization. On the other hand, it is seen that at high traffic where the LTE@2.6 system is highly utilized ($\mathcal{T}$=450 Mbps/km^2), carrier aggregation provides a 16% reduction in energy consumption, while at the same time providing much better end-user performance. Note that, we haven't considered any long-term sleep mechanisms that enables the activation and deactivation of the unused carriers during non-busy hours.

Fig. 4 shows the daily variation of area power consumption of a 5G-NX system for two cases: i) the BSs don't have DTX capability (a BS cannot be put into sleep mode when there is no traffic); ii) the BSs have DTX capability (the baseline power consumption of the BSs will be lowered when there is no traffic in the network). Here we evaluate the system under two different area traffic demands, i.e., $\mathcal{T}$=750 Mbps/km^2 (red curve) and $\mathcal{T}$=2500 Mbps/km^2 (blue curve) representing different utilization levels in the network. It is seen that area power consumption varies significantly during the day due to the high difference between day-night traffic. Moreover we observe that cell DTX brings striking savings in 5G-NX wireless access, even at higher traffic, where up to 67% saving is feasible during least busy hours due to two main reasons. The first reason is that ultra-lean design increases the DTX duration by 500 times compared to LTE systems enabling much lower sleep power consumption as explained in Section IV. Secondly, 5G-NX wireless access provides very high beamforming gain and the possibility to use very wide transmission bandwidths, which increase the user throughput significantly. As a result, the same traffic is served in shorter time compared to LTE systems, enabling longer time for sleep. Table II presents the achievable energy savings in percentage

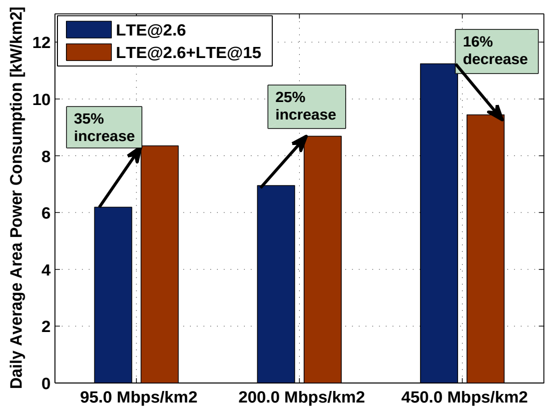


Fig. 3. Energy performance comparison of LTE@2.6 and LTE@2.6+LTE@15 systems at various traffic levels.

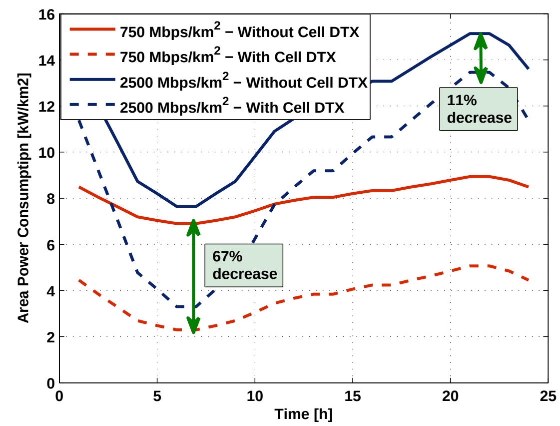


Fig. 4. Daily variation of area power consumption for two different traffic levels for 5G-NX@15.

at different traffic levels considering the average area power consumption throughout a day with and without cell DTX. As expected, the savings are shown to be lower at high traffic demands due to the fact that the BSs are highly utilized, and therefore load-dependent power consumption dominates the total power consumption.

Finally, we compare the energy performance of the four evaluated systems at various area traffic demands shown in Fig. 5. Here we illustrate the daily average area power consumption in two parts: i) static (power consumed even when there is no traffic), and ii) dynamic (power consumed based on the served traffic).

In Fig. 5a, we observe that when the traffic is low (95 Mbps/km^2), 5G-NX wireless access enables up to 65% energy saving compared to LTE@2.6 while increasing the 5-percentile user throughput around 6 times as shown in Fig. 2. This shows that the reduction in dynamic power consumption due to the better energy-focusing, and the efficient cell DTX capability outweighs the increase in power consumption when the BS is active due to the extra circuitry and processing required for 100 dual-polarized antenna elements (requiring 200 RF chains per sector). It also highlights the fact that the 5G-NX system is not only beneficial at extreme traffic scenarios. Furthermore, we observe that that static power consumption strictly dominates the total power consumption for all the systems. For 5G-NX stand-alone system, it is mainly due to efficient transmission with beamforming which decreases the utilization levels significantly, and thus the dynamic power consumption. On the other hand, for the other systems, the high sleep power consumption of LTE due to frequent signaling causes the dominance of static power consumption. We should also note that in the evaluations of the LTE@2.6+5G-NX@15 system, we assume that static power consumption is strictly additive, which means that LTE@2.6 and 5G-NX@15 are not able to share any hardware in the same site unlike the LTE@2.6+LTE@15 system. Under these assumptions, we observe that traffic levels are not high enough to fully benefit from carrier aggregation solutions in order to reduce the energy consumption.

At moderate traffic levels (450 Mbps/km^2), we know from Fig. 2 that the LTE@2.6 system is highly utilized, and thus the user performance is significantly degraded. This also increases the dynamic power consumption significantly as shown in Fig. 5b. In this scenario, both 5G-NX system and carrier aggregation solutions are able to provide more than 70 Mbps cell-edge user throughput with lower energy consumption, where the 5G-NX system is the most energy efficient system providing 73% energy saving. It should be noted that the reason behind the higher energy consumption in LTE@2.6+5G-NX@15 is the high static power consumption of the LTE layer. At 450 Mbps/km2, we observe that the LTE layer is responsible of more than 60% of the total power consumption despite the fact that most of the traffic is carried by the 5G-NX@15 layer. This is mainly due to the mandatory transmissions of non-user data related signals in LTE layer which does not allow deeper sleep when there is no traffic.

Finally, Fig. 5c shows that at expected traffic levels beyond 2020 (1200 Mbps/km2), 5G-NX reduces the energy consumption by 64% while providing around 10 times more capacity. It should be noted that LTE@2.6 is not at all able to handle this high busy hour traffic as can be seen in Figure 2. Therefore, the system is fully utilized except the least-busy hours. Here, we use LTE@2.6 for illustration only. We also observe that LTE@2.6+5G-NX@15 can provide more than 100 Mbps user throughput with 35% reduction in energy consumption, despite the comparably energy-inefficient LTE layer. This shows that at high traffic levels, the increase in static power consumption due to the LTE layer is compensated by the reduction in dynamic power consumption due to lower utilization.

Note that, in order achieve the aforementioned energy savings, we have to fully utilize all the benefits obtained by 5G-NX wireless access (i.e., high BF gain, higher BW, ultra-lean design, etc.) with cell DTX. Therefore, it is essential to incorporate energy-awareness in the design of 5G-NX systems from the start.

TABLE II
ENERGY SAVING WITH CELL DTX AT 5G-NX SYSTEMS.

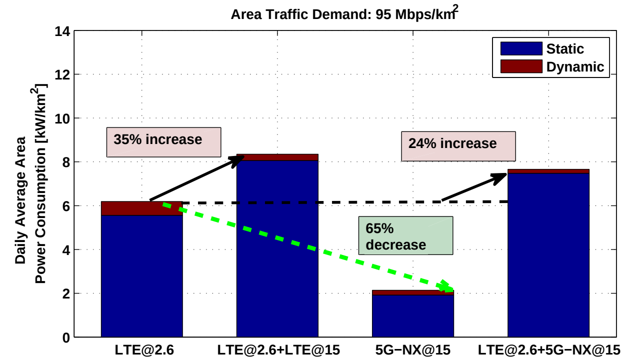
Area Traffic Demand [Mbps/km^2]	100	750	1200	2500
Daily Average APC without cell DTX [kW/km^2]	6.76	8.04	8.95	11.34
Daily Average APC with cell DTX. [kW/km^2]	2.30	3.84	4.92	8.31
Daily Energy Saving [%]	65.9%	46.6%	33.3%	13.3%

VI. CONCLUSION

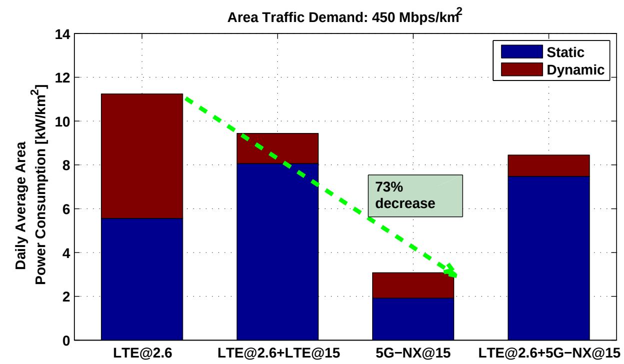
In this paper, we evaluated the energy performance of 5G-NX systems characterized by ultra-lean design and massive beamforming, and we compared this with an LTE system in a dense urban (major Asian city) scenario. We also presented novel power consumption models where the sleep power is defined based on the maximum allowed DTX periods by each system.

The results show that 5G-NX systems provide much better energy performance compared to LTE due to the ultra-lean design and the high beamforming gain, enabling longer and more efficient sleep. At expected traffic levels beyond 2020, 5G-NX is shown to decrease the energy consumption by more than 50% while providing around 10 times more capacity. Furthermore, carrier aggregation was shown to be a promising solution that combines the benefit from higher bandwidth and beamforming capabilities at 15 GHz, and the better propagation conditions at 2.6 GHz. As a result, at expected traffic levels beyond 2020, carrier aggregation with 5G-NX provides superior performance with lower energy consumption despite the comparably energy inefficient LTE layer.

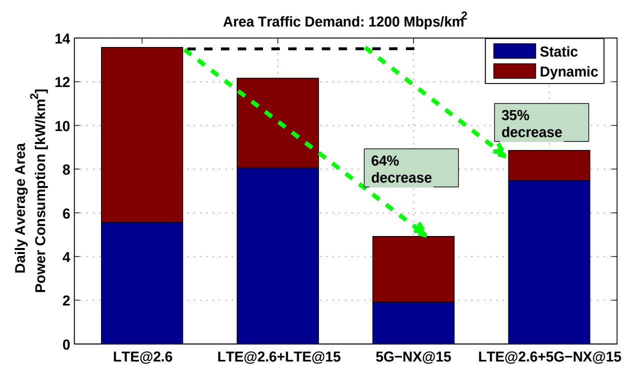
The main focus of future work will be to evaluate the energy saving potential of 5G-NX at country level considering more scenarios, alternative deployments and operating frequencies.



(a)



(b)



(c)

Fig. 5. Energy performance comparison of evaluated cases at different area traffic demands.

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