ENERGY PERFORMANCE OF 5G-NX WIRELESS ACCESS
UTILIZING MASSIVE BEAMFORMING AND AN ULTRA-LEAN SYSTEM DESIGN

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Ultra-lean design and the high beamforming gain, enabling longer and more efficient sleep at BS.

At expected traffic levels beyond 2020, 5G-NX can decrease the energy consumption by more than 50% while providing ~10 times more capacity.

Carrier aggregation with 5G-NX provides >> 100 Mbps user throughput with lower energy consumption (-35%) despite the comparably energy-inefficient LTE layer at expected traffic levels beyond 2020.

100% + 1% ≠ 101%
OUTLINE

› 5G at a Glance
› Scope of the Study
› Definitions & Methodology
  – Energy Performance
  – Cell DTX
  – Energy Performance Assessment Methodology
› Power Consumption Models
  – LTE Systems
  – 5G-NX Systems
› Simulation Setup and Results
› Conclusions
› Appendix
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.

Two key features
- Massive beamforming
- Ultra-lean design
SCOPE OF THE STUDY

COVERED EVALUATIONS

Baseline Scenario

Energy Performance Improvement with cell DTX

Further Energy Performance Improvement due to Beamforming @15 GHz

Baseline [LTE@2.6 GHz] Without Cell DTX
- Default deployment
- 3-sector, without beamforming

LTE@2.6 GHz with Cell DTX
- Default deployment
- 3-sector, without BF
- Cell DTX applied for energy saving

LTE@2.6+ LTE@15 with Cell DTX
- Default deployment
- 3-sector, without BF
- Cell DTX applied for energy saving

5G-NX@15 GHz with Cell DTX
- Default deployment
- BF on the BS side
- Cell DTX is applied

LTE@2.6 + 5G-NX@15 with Cell DTX
- Default deployment
- BF on the BS side
- Cell DTX is applied
DEFINITIONS & METHODOLOGY
DEFINITION
ENERGY PERFORMANCE

ENERGY PERFORMANCE

HIGHER
ENERGY EFFICIENCY

&

LOWER
ENERGY CONSUMPTION
Energy performance is defined as the **daily averaged area power consumption**, unit is kW/km².

Daily traffic profile proposed by EARTH is used for evaluations.

\[
EP = \frac{1}{A} \sum_{t=1}^{24} \sum_{i=1}^{N_{BS}} \left[ (P_{active}) \eta_i^t + P_{sleep} (1 - \eta_i^t) \right]
\]

**Cell DTX** is a hardware feature enabling sleep mode operation at BS side during empty transmission time intervals (TTIs).
POWER CONSUMPTION MODELS
Power consumption of a Macro BS 2x2 MIMO configuration

- EARTH Model

\[ P_{tot} = \begin{cases} 
N_{TRX} (\Delta_P P_{radiated} + P_0) & \text{BS is active (transmitting)} \\
N_{TRX} P_0 & \text{BS is inactive} \\
N_{TRX} \delta P_0 & \text{BS is on sleep mode} 
\end{cases} \]

\[ \delta = \begin{cases} 
1 & \text{without cell DTX} \\
0.84 & \text{with cell DTX} 
\end{cases} \]

<table>
<thead>
<tr>
<th>Notation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta_P)</td>
<td>4.7</td>
</tr>
<tr>
<td>(P_{radiated})</td>
<td>40</td>
</tr>
<tr>
<td>(P_0)</td>
<td>130</td>
</tr>
<tr>
<td>(P_{sleep})</td>
<td>(0.84P_0; \delta \in (0,1))</td>
</tr>
</tbody>
</table>
POWER MODEL FOR 5G-NX

- Proposed power consumption model of large scale antenna systems with \( N \) RF branches
  - Based on [1,2,3]

\[
P_{\text{tot}} = N_{\text{sec}} \times \begin{cases} 
P_{\text{radiated}} + NP_c + P_0 & \text{BS is active (transmitting)} \\ 
\frac{\epsilon P_0}{\delta P_0} & \text{BS is inactive} \\
\delta P_0 & \text{BS is on sleep mode}
\end{cases}
\]

- Notation
  - \( P_{\text{radiated}} \): Radiated power per sector
  - \( \epsilon \): Efficiency of the PAs
  - \( P_0 \): Baseline power consumption
  - \( P_c \): Circuit (Hardware) power RF branch
  - \( P_{\text{sleep}} \): Sleep power consumption

- \( \delta = \begin{cases} 
1 & \text{without cell DTX} \\
0.29 & \text{with cell DTX}
\end{cases} \)

SIMULATION PARAMETERS AND RESULTS
NETWORK LAYOUT
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Capacity grid
- Center macro
- 7 sites/21 cells
- 200 m ISD
- ~45 m antenna height (rooftop)

Coverage grid
- Surrounding macro
- 28 sites/84 cells
- 400 m ISD
- ~30 m antenna height (rooftop)

Evaluated Cases
- LTE@2.6
- LTE@2.6+LTE@15
- 5G-NX@15
- LTE@2.6+5G-NX@15
Even at high traffic, cell DTX can bring savings due to high difference between day-night traffic.


Advantages of 5G-NX:

1. In a given deployment, beamforming gain provides higher user data rate.
   - Same traffic will be served by utilizing less amount of resources. → Longer time to sleep.

2. New system control plane enables BSs to sleep for longer consecutive time durations.
   - Deeper sleep for BSs → Lower sleep power consumption compared to LTE.
Carrier aggregation with 5G-NX always increases the energy consumption.

- Almost 5 times increase in 5-percentile user throughput requires up to 38% increase in energy consumption.
- Most of the traffic is offloaded 5G-NX (>70%), taking advantage of efficient transmission.

LTE@2.6 → 17%, loaded
5G-NX@15 → 13% loaded

LTE@2.6 layer is the dominant consumer, responsible of >60% of total energy consumption.
LTE can still serve the traffic with acceptable 5-percentile user throughput.

5G-NX enables up to 65% energy saving compared to LTE@2.6 while increasing the 5-percentile user throughput 7 times.

Both carrier aggregation solutions increases the energy consumption.

- Increased static power consumption due to the new system cannot be compensated by the reduction in dynamic power due to lower utilization.

Traffic levels are so low to fully benefit from carrier aggregation in order to reduce the energy consumption.
LTE@2.6 cannot handle the traffic. (Maximum ~500 Mbps/km2).

5G-NX alone can provide 70 Mbps 5-percentile throughput, with 64% energy saving.

LTE@2.6+5G-NX@15: Serve the 5-percentile users consuming less dynamic power.

- Efficient transmission at NX layer and offloading benefits at LTE layer.

LTE@2.6 +5G-NX@15 can provide >> 100 Mbps user throughput with lower energy consumption, despite the comparably energy-inefficient LTE layer.
CONCLUSIONS

› Standalone 5G-NX is the most energy efficient solution (-64% energy consumption for 1200 Mbps/km2)

› LTE@2.6 +5G-NX@15 can provide >> 100 Mbps user throughput with lower energy consumption (-35% for 1200 Mbps/km2).

› In order to achieve the potential energy savings, we have to fully utilize all the benefits obtained by 5G-NX (high BF gain, higher BW, ultra-lean design, etc) with cell DTX.
  
  – Implementation is the key!
APPENDIX

I want the red one!

Bit/Joule

Inverted metric: $y = \frac{1}{x}$

Large improvement of index

Little improvement of index

Minor improvement of system that is already good

Large improvement of a “bad” system
I want the green one!

Large improvement of index

Little improvement of index

Minor improvement of system

Large improvement of system
**POWER MODEL FOR 5G-NX**

**System Signature Index (SSI):**
- 0.4 ms every 100 ms

**Access Information Table (AIT):**
- 3.6 ms every 1-10 second(s)

**LTE-NX:**
- PA on time ratio ≈ 0.5%
- DTX duration ≈ 99.6 ms

**LTE:**
- PA on time ratio ≈ 52%
- DTX duration ≈ 0.2 ms

\[ \delta = \begin{cases} 1 & \text{without cell DTX} \\ 0.29 & \text{with cell DTX} \end{cases} \]
If energy performance is included into the design of LTE-Nx **from the start**, ultra-lean design will enable significant energy savings with cell DTX.
Wrap-around:
- No-wrap around.
- Simulate larger system, discard statistics from edge cells

Path Loss Model
- New frequency dependent model is used.
- Height dependent probability that the building is of type “new”
- More information at FRA 160 90 percent presentation
## SIMULATION ASSUMPTIONS

**LTE @2.6 GHz/LTE @15 GHz/LTE-NX @15 GHz**

**LTE @2.6 + LTE@15 GHz/ LTE@2.6+LTE-NX@15 GHz**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>20 MHz/100 MHz/100 MHz /40+100 MHz /40+100 MHz</td>
</tr>
<tr>
<td>UE Transmit power</td>
<td>23 dBm</td>
</tr>
<tr>
<td>BS Transmit power</td>
<td>46 dBm</td>
</tr>
<tr>
<td>Number of UE receive antennas</td>
<td>2</td>
</tr>
<tr>
<td>UE max antenna gain</td>
<td>-8 dBi/3dBi/3 dBi**/ -8 dBi + 3 dBi*/ -8 dBi + 3 dBi*</td>
</tr>
<tr>
<td>BS Antenna</td>
<td>742215_fitted*/742215_fitted/Antenna array/742215_fitted*/742215_fitted*+Antenna array***</td>
</tr>
<tr>
<td>Indoor traffic</td>
<td>80%</td>
</tr>
<tr>
<td>Duplex mode</td>
<td>TDD Configuration 5 (1 8 1)</td>
</tr>
<tr>
<td>Noise Figure UE</td>
<td>9 dB</td>
</tr>
<tr>
<td>Noise Figure BS</td>
<td>2.3 dB</td>
</tr>
<tr>
<td>Beam-forming at BS</td>
<td>No/No/UE-specific BF (GoB)/No/UE-specific BF (GoB)</td>
</tr>
</tbody>
</table>

- Max Gain = 18, Horizontal Half Power Beamwidth = 65, Front-To-Back Ratio = 25, Vertical Half Power Beamwidth = 6.5, Side Lobe Level = -17, Max Total Attenuation = 30
- ** More information on UE antenna gain can be found in the appendix.

**Antenna array with (5x20)**