1st IEEE Energy Efficiency Tutorial:

5G Densification and Network Power Efficiency

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Overview

- 5G Network Densification
- Small Cell Deployments and deployment challenges
- TCO & Energy Efficiency (Small Cell Focused)
- Techniques to improve energy efficiency

TCO – Total Cost of Ownership

What is a Small Cell?

Lower Powered Radio Access Nodes that have the following characteristics:

- **Small…**
  - Form Factor / Size: Typically ~3L for Indoor, ~10L for Outdoor
  - Coverage Area: Typical Range is between 10 meters & 2 Kilometers
- **Adapted for different environments/deployments..**
  - Indoor: Residential, Enterprise,.. (Existing Infrastructure,..)
  - Outdoor: Street Level, Metro,.. (Wireless Backhaul Option,..)
  - Public / Private Networks
- **Power Optimized**
  - Size/Power: Design target to reduce power consumption for small form factor
  - Indoor: Support for flexible deployments (PoE, etc.)
- **Support of different RATs, Spectrum options..**
  - Licensed / Unlicensed Spectrum: CBRS, LAA, ..
  - RAT Capabilities: WiFi, 3G, 4G, 5G

Femto

Pico

Micro

Metro

DAS

LP-RRH

Provide coverage & capacity solution for densely populated Urban Areas that cannot be sustained by Macro Cells

CBRS – Citizens Band Radio System; DAS – Distributed Antenna System; LAA – Licensed Assisted Access; LP-RRH – Low Power Remote Radio Head

Small Cells – Key enablers for tomorrow's applications

98% operators

"Small cells are essential for the future of our networks"*

Energy Efficiency

- Small Cells provide better energy efficiency as compared to Macro layer

Outdoor

- From Coverage to Capacity
- From Hot Spot to Hot Zone
- Help where Macros are difficult to deploy

Indoor

- Public indoor locations
- Enterprise deployments
- Reliable IoT coverage layer

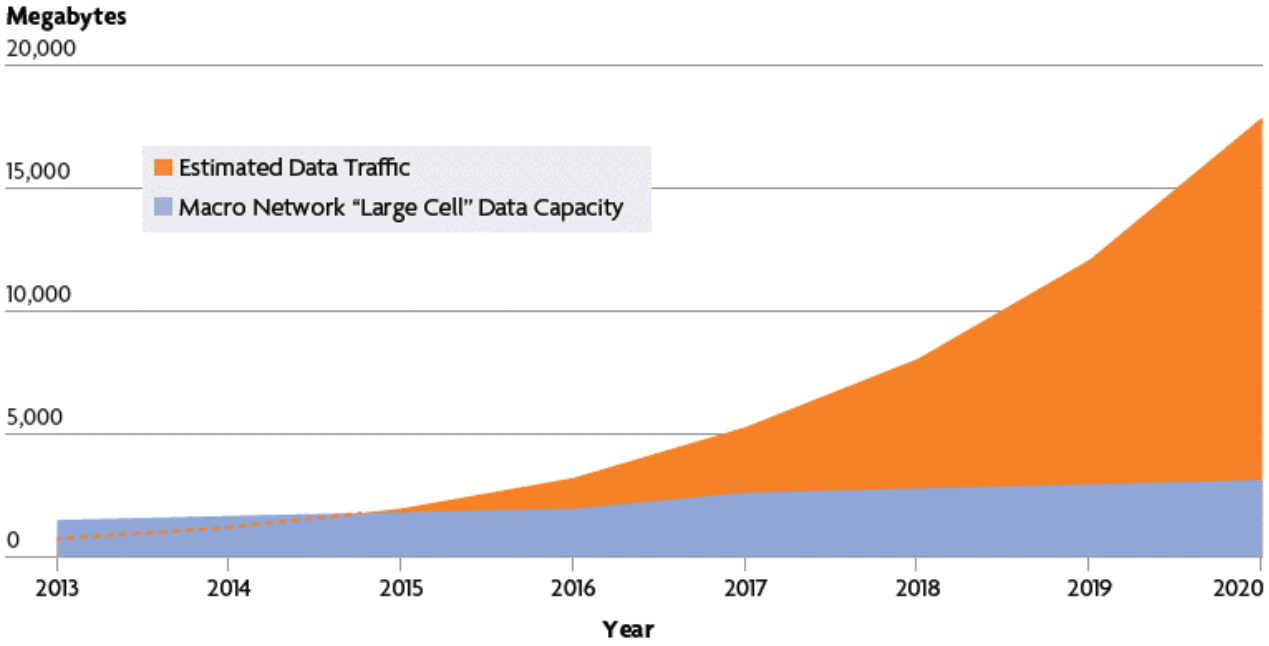
Other Scenarios

- SC open up new use cases
- Rural, Public Safety fast response, Petroleum, Mining, Stadiums, Protected buildings, etc.

* - Informa Telecoms & Media Survey

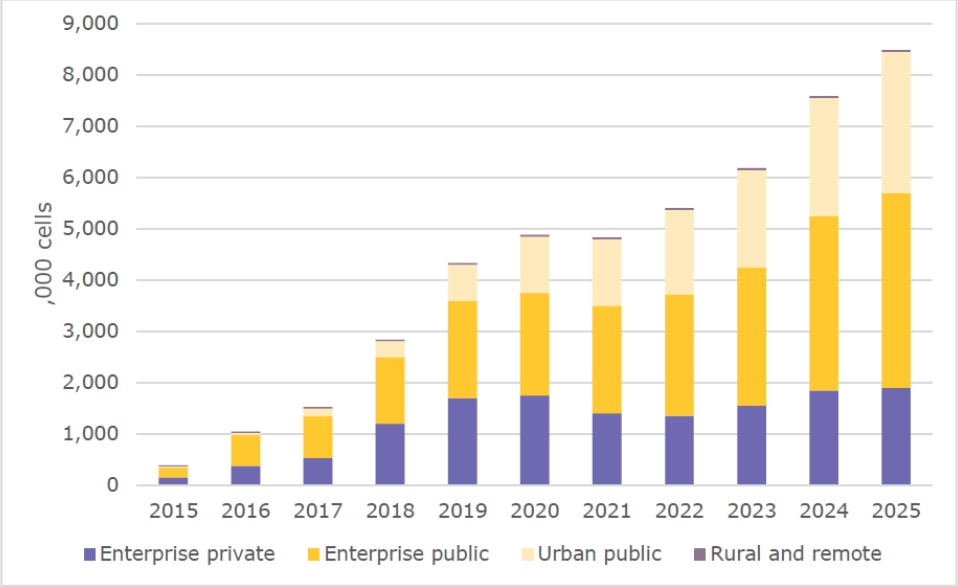
Small Cells Growth – Capacity & Coverage

Figure 1. Estimated Macro Cellular Mobile Data Traffic Versus Macro Network Data Capacity, US Only (2012-2020)



Source: Signals Research Group

New Non-Residential Small Cell deployments predicted to grow at annual rate of 36%



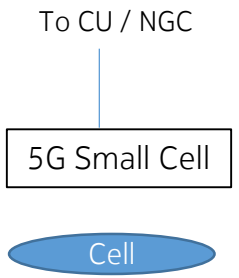
New non-residential Small Cell Deployments forecast (2015-2025)

Source: Small Cells Forum [1]

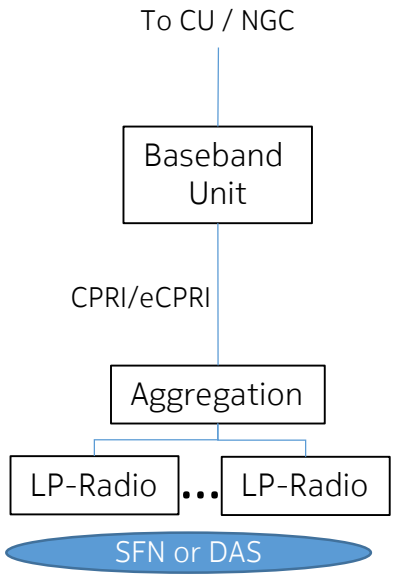
Higher Cell/Site Density leading to higher energy demands

Small Cells 5G Architecture Variants

Indoor Variants

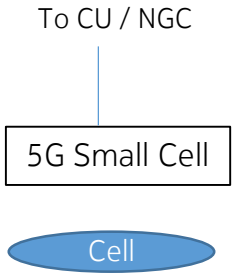


- Distributed Baseband with Integrated RF
- Coverage or Capacity Uplift
- Delay tolerant ethernet fronthaul. Public/private backhaul
- Small Form Factor and PoE capable – design optimized for low power

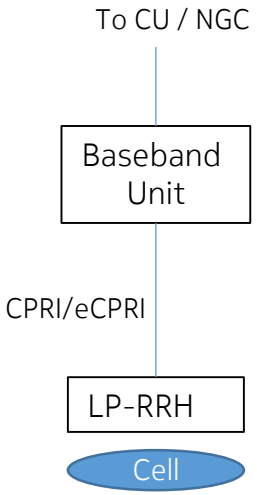


- Distributed Radios with Centralized Baseband
- In-Building coverage solution
- Low-latency fiber between Baseband Unit and aggregation point
- End nodes power efficient, but system not optimized for power

Outdoor Variants



- Distributed Baseband with Integrated RF
- Coverage or Capacity Uplift
- Delay tolerant ethernet fronthaul or Wireless backhaul
- Street level/pole deployment - design optimized for low power/size

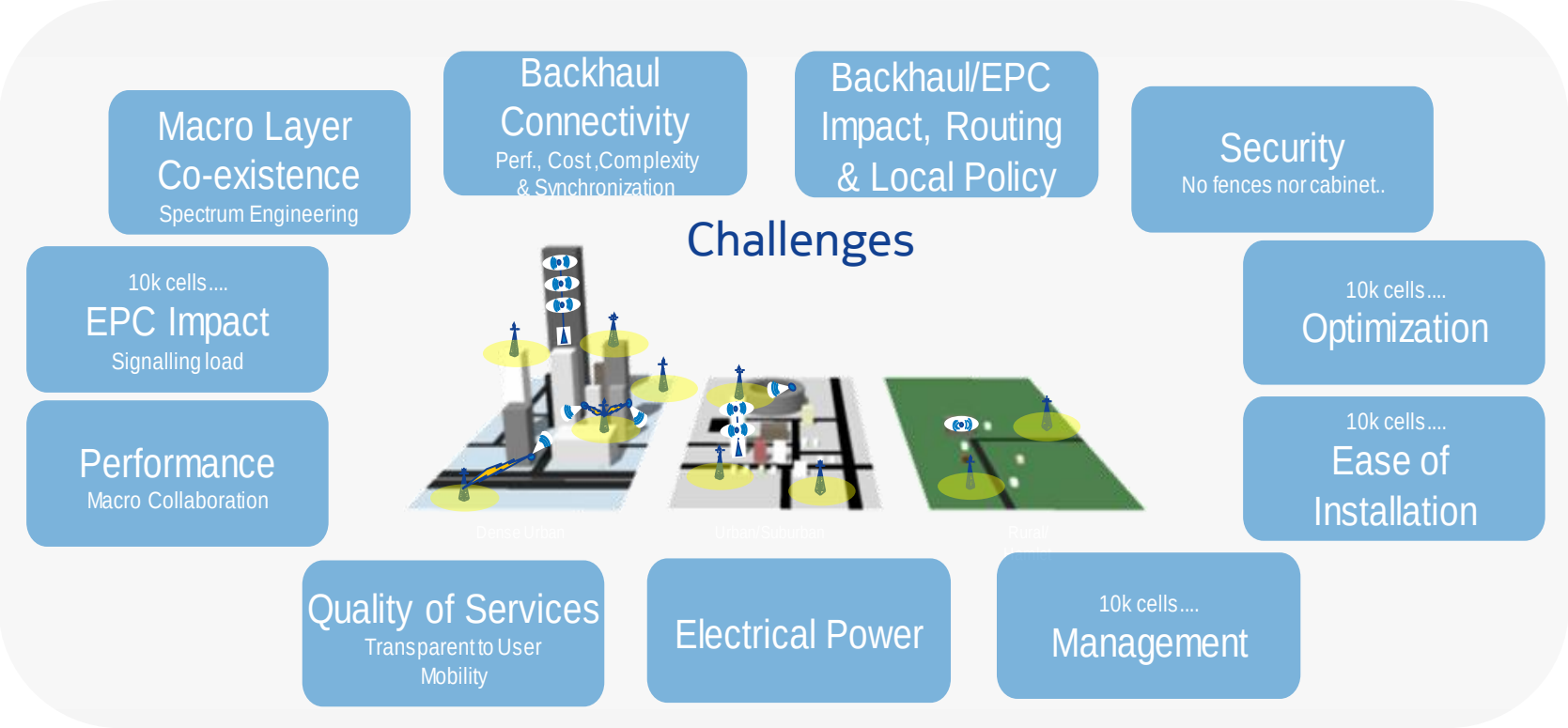


- Centralized baseband with distributed Radios
- Coverage or Capacity Uplift
- Low latency fiber between Baseband Unit and LP-RRH
- Power distributed between Baseband, fiber distribution and Radios

CU – Central Unit; DU – Distributed Unit; DAS – Distributed Antenna System; LP-RRH – Low Power Remote Radio Head; NGC – Next Generation Core; SFN – Single Frequency Network

Small Cell Deployment Consideration->Magnified with 5G

Higher Bandwidth, Spectrum increases small cell density



Deployment/Operation

- Form Factor / Stealth designs
- Site Value Index
- Advanced SON for No-Touch

Site Acquisition costs including access to power (24x7) play big role in Outdoor Small Cell Deployments

Small Cells Deployment Examples

Some deployments allow for easier access to backhaul/power, and better coverage.

Harder to deploy and access Small Cells in some deployments. Varying power sources based on region.

Small Cells on Street poles often times co-located with other auxiliary equipment (e.g. wireless backhaul, surveillance camera, etc.) that also needs power.

Compounding factors will lead to Small Cells playing an early role in 5G

5G deployment challenges

High frequency bands

- Location of available macro sites leads to 5G coverage holes
- Outdoor and Indoor use cases are dependent on continuous 5G coverage

Ultra broadband is mainly indoors

- Existing dedicated indoor solutions (esp. DAS) are not extendable to 5G

Difficulty in getting macro site acceptance drives small cell needs

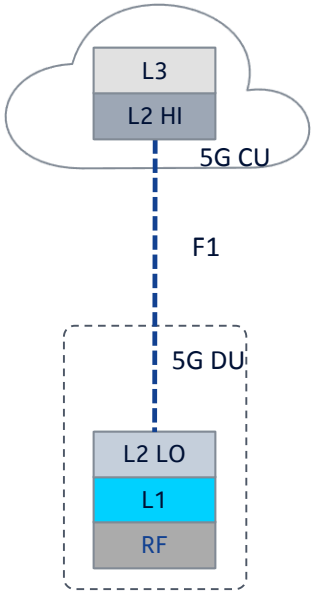
5G small cells

- **Coverage densification** – Compact underlay of 5G macro
- **Hot zones** – Compact 5G ultra broadband
- **Outside-in boost** – Street-level 5G to penetrate indoors
- **Indoor** – Dedicated 5G indoor densification

Energy Efficiency needs to be addressed across the diverse Small Cell 5G Deployments (Outdoor/Indoor, cmWave/mmWave)

Other 5G Deployment considerations

- **5G Distributed gNB (CU-DU) Deployments**
  - Functional split between CU & DU
  - Drive towards open interfaces (ORAN/xRAN)
  - CU hosted on Cloud / Virtualized HW
  - *Energy Efficiency needs to be considered from E2E perspective based on deployment*



- **Massive MIMO support**
  - Higher antenna count for mmWave with analog beamforming
  - Higher TRXs for cmWave with digital beamforming
  - *Massive MIMO systems increase the BTS energy demands due to higher RF power consumption*

CU – Central Unit
DU – Distributed Unit
MIMO – Multiple-Input Multiple-Output
ORAN – Open RAN
TRX - Transceiver

Networks OpEx and Energy Consumption

RAN Network data / non-Small Cells / Pre-5G

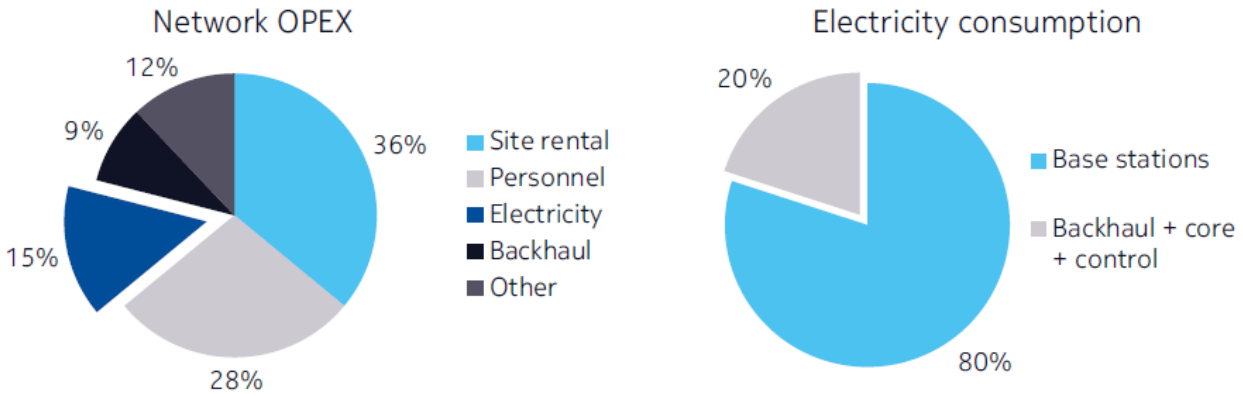


Figure 1. Electricity is typically 15 percent of the network OPEX. Base stations take 80 percent of mobile network energy

Energy cost can represent up to 60+% of 5y TCO*

- Energy cost typically higher than Product cost

Small Cells TCO Factors:

- Site acquisition costs
- OpEx (transport/power consumption)
- HW/SW costs
- Cell Density

TCO – Total Cost of Ownership
OPEX – Operational Expenses

* Macro Single RAN Deployments (2G/3G/4G)[2]

Small Cells TCO and 5G considerations

5G influence on Small Cells TCO (as compared to LTE)

- Site acquisition costs ⟷
- OpEx (transport/power consumption) ← Addressing energy costs for 5G Small Cells is key to reducing TCO and increasing energy efficiency.
- HW/SW costs ↗ ← **Newer devices, active antenna arrays. Lower costs over time**
- Cell Density ↑ ← **e.g. >>10x number of mmWave Small Cells as compared to LTE Small Cells**

Power Consumption & Network loading

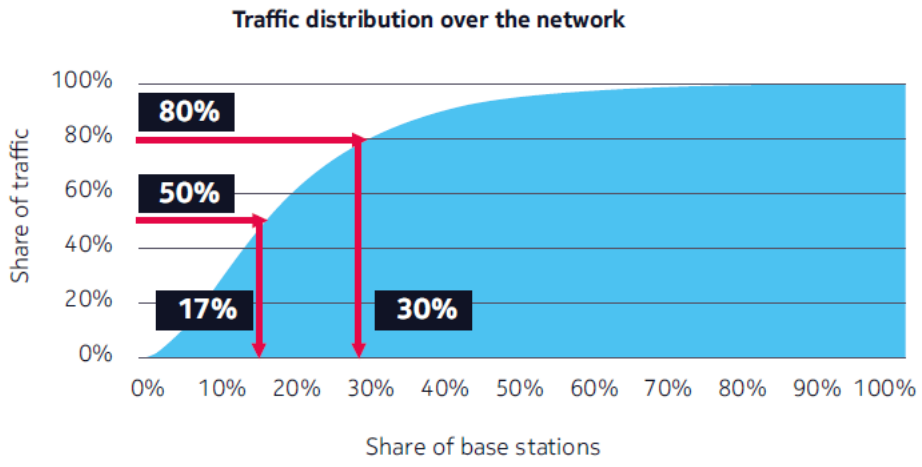
- **Daily average traffic over 24h modelled through 3 traffic loads (per ETSI ES 202 706-1)**

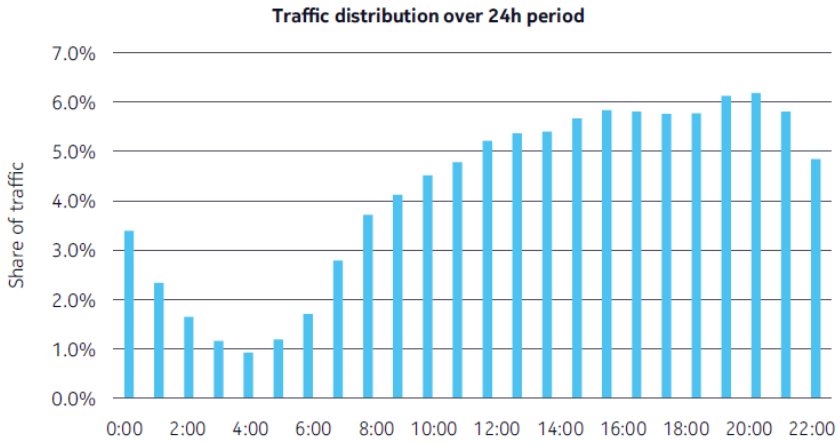
Table 2: Load level duration for daily average calculation

Low load	Medium load	Busy hour load
6 hours	10 hours	8 hours

- **Each load is defined to emulate an "RF load" as below (% of commissioned RF max power)**

ETSI Load models for LTE 20MHz	
100% load	E-TM1.1 TS 136 141
ETSI Busy Load	52,0%
ETSI Medium Load	33,0%
ETSI Low Load	5,2%
ETSI Avg Load	**32,4%**





Radio network loading varies across sites and also during different times of the day

Power Savings Opportunities and breakdown

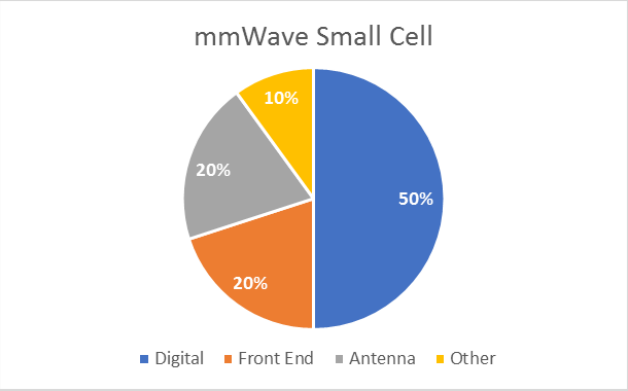
Load based Power Scaling - Example

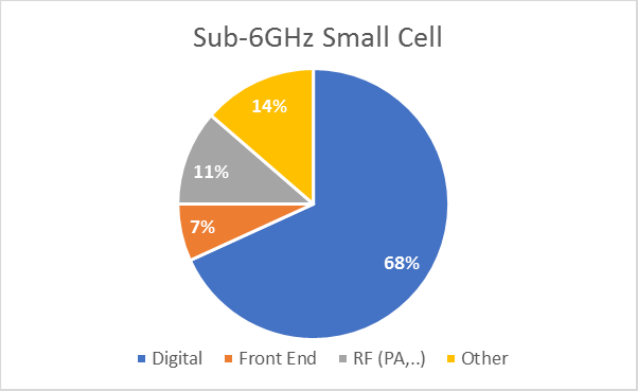
Traffic Load	100	50	30	0	24h Average
Power saved [W] (ideal*)	0	100	140	200	**141.7**
Hours/day	0	8	10	6	-

OPEX saved = (141.7/1000) kw x 5 years x (6.63c per kwh) x 50k nodes
= **~20 million US Dollars**

- Example assumes 200W power consumption per node, 50k nodes in deployment (outdoor). It suggests that if power usage can be scaled on load basis, it could result in significant savings.
- In practice, not all system components scale with load and not all components have dynamic power scaling capabilities. Idea is to maximize energy efficiency across the system.
- Reduction in both static and dynamic power consumption is key!

5G Small Cells Power Breakdown*





Observations:

- High Digital power contribution due to lack of integrated SoCs
  - ➢ Opportunity to improve static power consumption
- PA Efficiency much lower for initial mmWave Active Antenna systems. Much higher power consumption due to high Active antenna array counts
  - ➢ Opportunity to improve dynamic power consumption

EE Goal: Lower energy consumption with increased user traffic (i.e. maximize bits/Joule)

* Based on trends in current chipsets / silicon / RF Technologies (100% loading)

5G Small Cells EE Areas of Focus

Hardware Efficiency

Technology Evolution

- RF Design with optimized Power Amplifier Technology
- Power efficient and integrated System-on-Chip and Memory devices

Software Functionality

Adapt Power consumption to user traffic

- Load based power savings (HetNet)
- Micro DTX, Tuning Sync burst periodicity for 5G Small Cells, Muting, ML/AI leverage,..

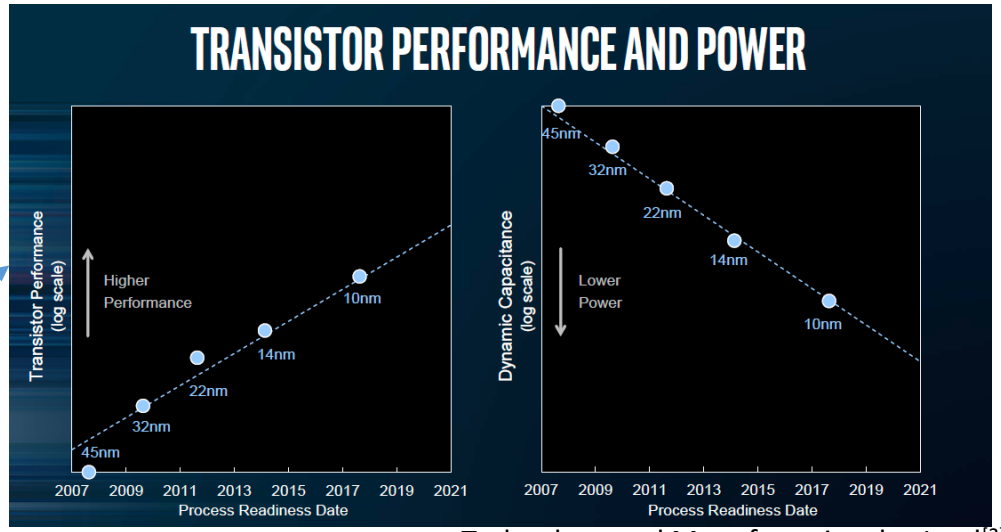
Energy Management

RAN Level Intelligent Energy Management (e.g. SON)

- KPI based dynamic switching of network resources (units, cells, etc.)
- Monitoring / Reporting of Energy Status & Data

Hardware Energy Efficiency

- **Digital baseband hardware (L1-L3)**
  - 5G L1 in ASIC / SOC enabler for low footprint Digital design
  - Upper Layer (L2+) processing needs vary based on Classical versus DU mode of operation
  - Significant improvement in SoC technology (14nm->10nm->7nm) and dynamic power scaling allowing for energy efficient digital designs



Technology and Manufacturing day Intel[2]

- **RF hardware (integrated RF in Small Cells)**
  - Integrated DFE/TRX Processing efficiencies
  - Analog RF
    - 5G NR systems benefit from advances in PA efficiency for wider bandwidths. Next generation devices with Envelope Tracking and advanced GaN expected to push PA efficiency beyond 50%.
    - mmWave RFICs/PAs expected to improve in terms of RF efficiency over time.

Beamforming gains

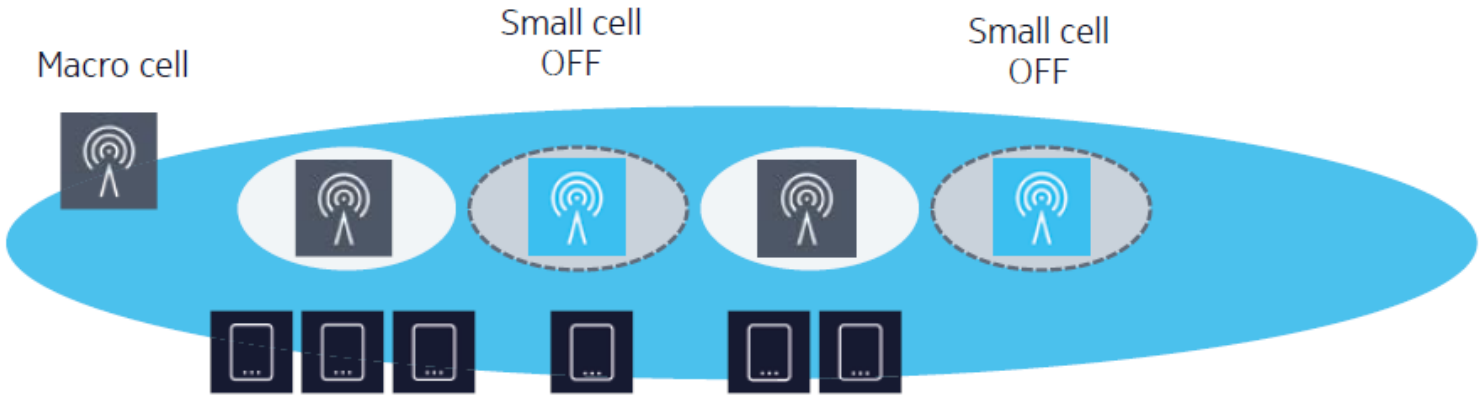
Beamforming helps address RF power efficiency as it provides higher EIRP (beamforming gain) than higher power PAs

- Example
  - Traditional:
    - 4x10W with 7dBi Directional Antenna = 53dBm EIRP
    - 40W/40% PA Eff. = 100W
  - cmWave Solution:
    - 8x3W with 64 Element Array = 63 dBm EIRP
    - 24W/40% PA Eff = 60W

ASIC – Application Specific Integrated Circuit; DFE – Digital Front-End; PA – Power Amplifier; SOC – System-On-Chip

Software Energy Savings Techniques

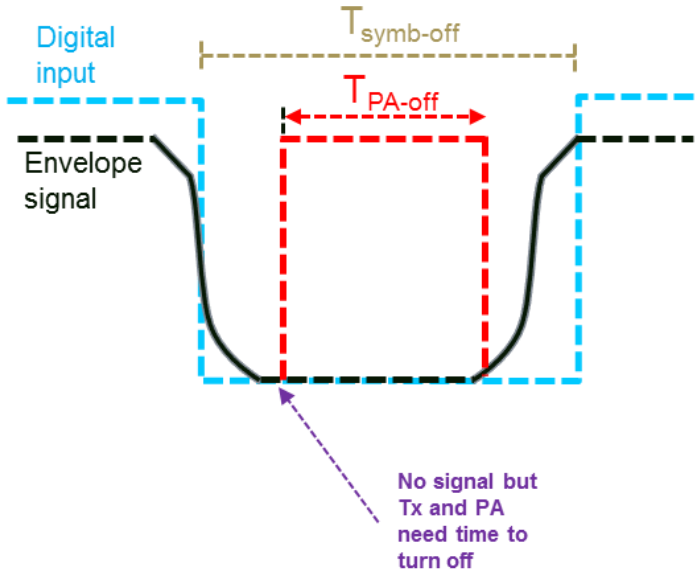
Load Based Power Savings (HetNet)

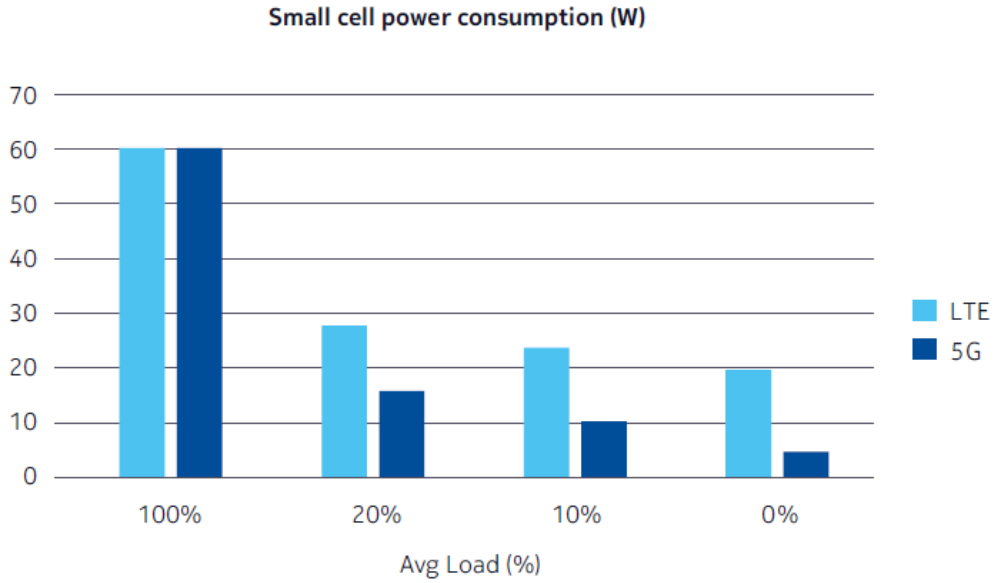


- Applicable to HetNet scenario where Small Cells are deployed for capacity uplift with Macro Overlay.
- Small Cell Shutdown at operator adjustable condition (time of day, traffic threshold, macro coverage).
- Assuming 6 hours of no activity on small cells, up to 20% power savings (less for 5G).

Software Energy Savings Techniques

Discontinuous Transmission (DTX) for Energy Efficiency for 5G





- Power saving by switching off the cell's power amplifier(s) during idle period
- DTX controls the PA supply voltage simply as
  - No data: no supply voltage to PA
  - Data: supply voltage to PA

- In LTE reference symbols need to be transmitted 4 times every 1 ms, limiting sleep mode duration.
- 5G bring significant improvement in power consumption with flexible reference signal design.
- Network level power savings of ~50% for 10-20% network utilization!

Software Energy Savings Techniques

Other 5G EE Techniques

Sync burst periodicity

- 3GPP standards support different Synchronization (SS) Burst periodicity to decrease power consumption. SS Block periodicity can be varied between 5 and 160ms.
- Increased SS Burst periodicity reduces power consumption in low load conditions.
- Higher periodicity may result in UE synchronization loss, especially for mmWave and high speed UEs.

Muting / RF Resources

- mMIMO muting at lower loads. Turning off/on TRXs on load.
- Disabling mmWave Antenna sub-panels/elements at low loads (reduced spectral efficiency/throughput).

Intelligent RAN Energy Management

KPI based dynamic switching of network resources

Managing energy consumption at network level

- Capability to temporarily shut down gNBs during low traffic periods.
- Controlled network resource shutdown and startup based on preset schedule

Energy Saving Metering

- BTS Energy Metering and reporting the consumption via dedicated PM counters (Voltage and Power) to Network Management system

SON for Multi-RAT/Multi-layer EE Management

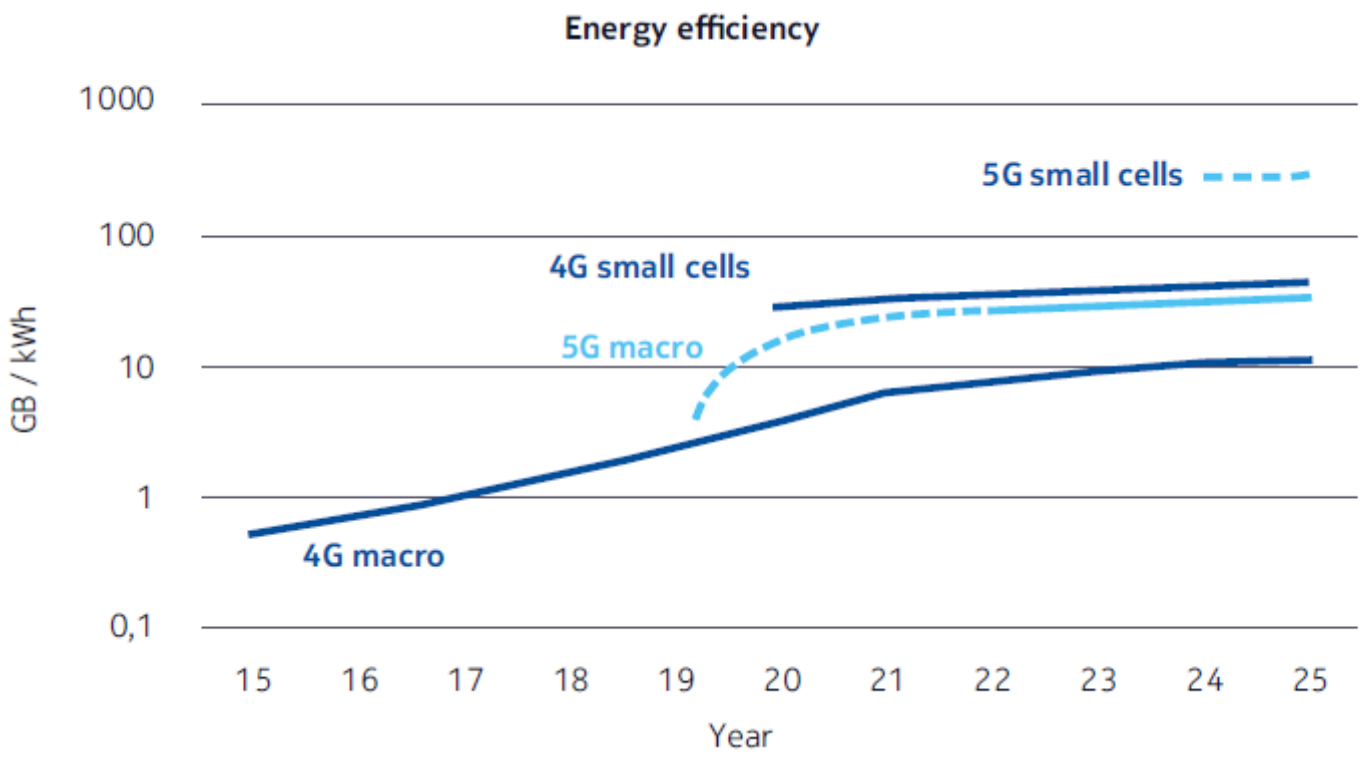
- Improving energy efficiency of the multi-RAT system based on loading of the cells at network level
- Support heterogeneous network comprising of Macro overlay and Small Cells underlay

Predictive SON based on EE counters and AI/Machine Learning - FFS

Leveraging Cloud RAN/OpenRAN for better Network energy efficiency - FFS

KPI – Key Performance Indicators; RAT – Radio Access Technology (2G/3G/4G/5G); SON – Self-Organizing Network

5G Small Cells / EE Impact Summary



- 5G more energy efficient due to wider bandwidth, better air interface design, more advanced antennas, base station sleep modes and applying other EE techniques
- 5G Small Cells outperform 5G macro cells due to lower output power, more efficient design and reduced number of users.

Based on ~60% traffic growth and 5G launch in 2020

Conclusions

- Demand for higher capacity and better coverage leading to proliferation of Small Cells deployments. Energy costs remain a big component of the Networks OpEx.

- Radio network loading varies across sites and also during different times of the day. 5G air interface design lends itself to better tuning of power consumption for different loads and deployments.

- Several load based EE techniques can be adopted in 5G networks to reduce power consumption at component, box, network level.

- 5G Small Cells promise to provide improved energy efficiency while meeting the demands of next generation networks.

Q & A

Thanks a lot for your time and attention!

Any questions and/or comments?

References

1. Small Cells Forum - https://scf.io/en/documents/194_-_Deployment_plans_and_business_drivers_for_a_dense_HetNet_SCF_operator_survey.php
2. Nokia RAN Energy Efficiency – link
3. Moore's law leadership – Intel – link