In Memoriam

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There Is Not Enough Electricity to Run 5G - Finding the Road to 6G

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Motivations

• Today’s existing (and proposed) 5G deployments are at-risk of being non-sustainable from both technical and economic perspectives.
• Lack of consistency across ecosystem stakeholders, particularly with focus on Energy Efficiency.
• Energy Efficiency determines the success of any application and its viability on a global scale.
• Concern that global deployment will not be equitably executed from a socioeconomic perspective.
10-year Vision

- Energy consumption seen as the “currency” that determines business viability, as it fundamentally impacts both CAPEX and OPEX.
- Linkage of HW/SW hooks enabling self-optimization at all points of the network.
- Universal availability of EE-centric tools/processes/models/standards applied across the ecosystem and global infrastructure.
- Utilization of System-level Metrics (technical & financial) to drive stakeholders’ decisions, so that:
  - All technologies are optimally leveraged (Energy Provisioning and Harvesting, Radio and Network Infrastructure, Data Processing, Storage and Distribution)
  - Benefits are achieved (Cost-effective and Equitable Availability of Services, and Sustainable Infrastructure and Business Models)
Today’s Landscape

• Diverse, Heterogeneous Players Contribute To The Ecosystem
• Different Business Models And Incentives
  • Payback Model Uncertainty/Risk?
  • Poor Linkage to Socioeconomic Impacts (The Unconnected)
• Siloed Technology Development
• No Shared Metrics
Scope

• The EE WG is committed to education on energy-related issues/concerns/opportunities across all industry stakeholders.
• From HW configuration to SW architecture, everything impacts power consumption, often in a poorly understood way.
• The Roadmap Chapter on Energy Efficiency will cover:
  • Analysis of current technology trajectories at-risk of leading to unsustainable outcomes.
  • New Metrics that enable assessing and optimizing energy consumption from system- to grid-level and socioeconomic impact.
  • Technologies that can overcome the risk of the “Energy Gap” (from Energy Harvesting and Radio architectures at the Edge to Computational structures and AI in the Network, and Energy Storage and distribution).
  • Opportunities to Improve Sustainability and “Connecting the Unconnected”
Challenges and solutions for 10-year Vision

1. **Network Efficiency** (Edge Optimization, EE System Design Philosophies, Micro-to-Macro Assessment, 3GPP DTx, Data Centers)

2. **Small Cell Migration** (Macro-to-Micro Control Plane, Real-time Power Optimization, mmWave Impacts, Cell-free Architectures)

3. **Base Station Power** (mMIMO Impacts, Multi-band Support, Telemetry/Analytic Needs, Energy-centric Feedback Loops)


5. **Grid/Utility** (Utility-level Impacts/Risks, Networking Electricity, Real-time Energy Market Impacts)
Need for coordination

- Comprehensive, multi-level analysis and coordination is required to achieve the needed efficiency targets.
- Ripple effects across the ecosystem...
- Metrics/Models to harmonize technical & economic analyses across stakeholders with “universal currency” of energy.
An Ecosystem Made of Many, Partially Siloed Stakeholders
How can they “talk” to each other?

• Select a common “language:” the global “currency” of energy.
• Enable interconnection of subsystems with the use of a standardized “black box” definition.
• Define input variables that are “block-specific.”
• Define standardized output variables that enable (i) connecting the sub-systems, (ii) assessing bottlenecks and (iii) optimizing system efficiency (delivered performance/cost).
We Needed a New Lexicon and Metrics

- A way to relate blocks in terms of the flow of energy from generation to consumption: the **Power Value Chain (PVC)**
- A way to assess blocks in terms of global energy impact: the **Power Cost Factor (PCF)**
- A way to describe the impact of bottlenecks, which cause a reduction of overall system performance from the designed objectives: the **5G Derate Factor (5GDF)**
Linking the Heterogeneous Subsystems

The 5G Power Value Chain

TOWARD CORE

Power Plant → Utility Transmission → Core (Data Centers) → Computer/Networking Hardware

TOWARD EDGE

Actual PCF in these stages can vary greatly. So PCF for this "edge" portion of the network can be from $10^6 - 10^7$.

Radio Access Network (RAN) (including Small Cells)

Base Stations → Radios (BBU, RRU) → User Equipment

[RELATIVE] INCREASING POWER COST FACTOR (PCF)

$10^6x$ $10^5x$ $10^4x$ $10^3x$ $10^0x$

= LINEAR-LIKE PCF NETWORK COMPONENT

= NON-LINEAR-LIKE PCF NETWORK COMPONENT
Defining the “Black Box”

BLACK BOX TEMPLATE:

SoS GENERIC BLACK BOX TEMPLATE

(PCF = #x)

BLOCK INPUTS
- Unique, intrinsic inputs to this block.

BLOCK OUTPUTS
- Power Cap
- Energy Cap
- Thermal Cap
- PCF
- Applicable Time Period
- Utilization Factor??
Defining the “Black Box”

- **Inputs**: “performance demand” placed on that block. A static or dynamic set of values, depending on the analysis we want to conduct.

- **Outputs**: the most important factors that impact the box’s energy footprint and utilization factor.

- **Input to Output relationships**: a set of functions that can be easily defined by the “experts” for the block, and can be updated for “what if” analyses and assessment of future performance expectations.
THE PVC CHAIN ANALYSIS

1: Static Assessments

- Energy Footprint Based on Designed Performance
- System Bottlenecks Due to Energy Caps

5GDF / POWER VALUE CHAIN CALC EXAMPLE:

- BLACK BOX #1 (PCF = 4x)
- BLACK BOX #2A (PCF = 20x)
- BLACK BOX #3A (PCF = 20,000x)
- BLACK BOX #2B (PCF = 20x)
- BLACK BOX #3B (PCF = 20,000x)
- BLACK BOX #3C (PCF = 20,000x)

CHAIN ASSESSMENT OUTPUTS

- 5GDF
- Gaps (from 5GDF=1.0)
  - Identify Power/Energy/
    Thermal Bottlenecks
  - PCF Mismatches
THE PVC CHAIN ANALYSIS

2: Dynamic Assessments

• System Optimization
• Financial Analysis

NETWORK/SYSTEM OPTIMIZATION/UTILIZATION
CHAIN CALC EXAMPLE:

EXTERNAL PERFORMANCE INPUTS

CAPEX Limits (i.e. – available power/energy/cooling)
Desired Performance (i.e. – bandwidth, # users, QoE, etc.)
Monetary Targets (i.e. – payback period, utility bill, etc.)
Real-time Energy Pricing

DELIVERABLES
- Achievable SGDF
- Resource Allocation Recommendations
- PCF Optimization Recommendations
- Peak Power/Energy/Thermal Predictions
- Energy Utilization Prediction
- Cost Prediction
- Risk assessment?
Each Sub-block Can Be Represented by a “Black Box”
Implementing the System of Systems (example)

**SUB-BLOCK EXAMPLE (arbitrary):**

**BLOCK INPUTS**
- Available Bandwidth
- Traffic Serviced
- QoS/QoE
- Spectral Efficiency
- Applicable Time Period
- Environmental Factors

**SMALL CELL BASE STATION**

(PCF = 20x)

**BLOCK OUTPUTS**
- Power Cap
- Energy Cap
- Thermal Cap
- PCF
- Applicable Time Period
- Utilization Factor
Energy Sources Optimization (Static or Dynamic)
The Steps in the Process: Divide and Conquer

- Determine which black box(es) from the SoS are to be assessed.
- Determine the appropriate stakeholders and subject matter experts to apply to the template assessment.
- Determine the appropriate block inputs (e.g. – key characteristics unique to the block in question).
- Determine the relation of the block inputs to the block outputs and translate into a sub-block diagram.
- Translate the sub-block model into proposals for functions that relate block inputs to the universal block outputs.
- Provide the information to the EE WG for integration into the full SoS.
Stakeholders

ALL OF THEM!!! (EE TOUCHES ALL)
- No Stakeholder Without Direct Impact/Consequence Related to Energy Efficiency
- No Real Value In Listing Out Even Major/Marketing Groups (i.e. – HW, SW, Economic, Business Development, Municipalities, NGOs, etc.)

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QUESTIONS?

Read our Whitepaper at