IEEE Future Networks

Enabling 5G and Beyond

International Network Generations Roadmap (INGR) Virtual Workshop

Energy Efficiency

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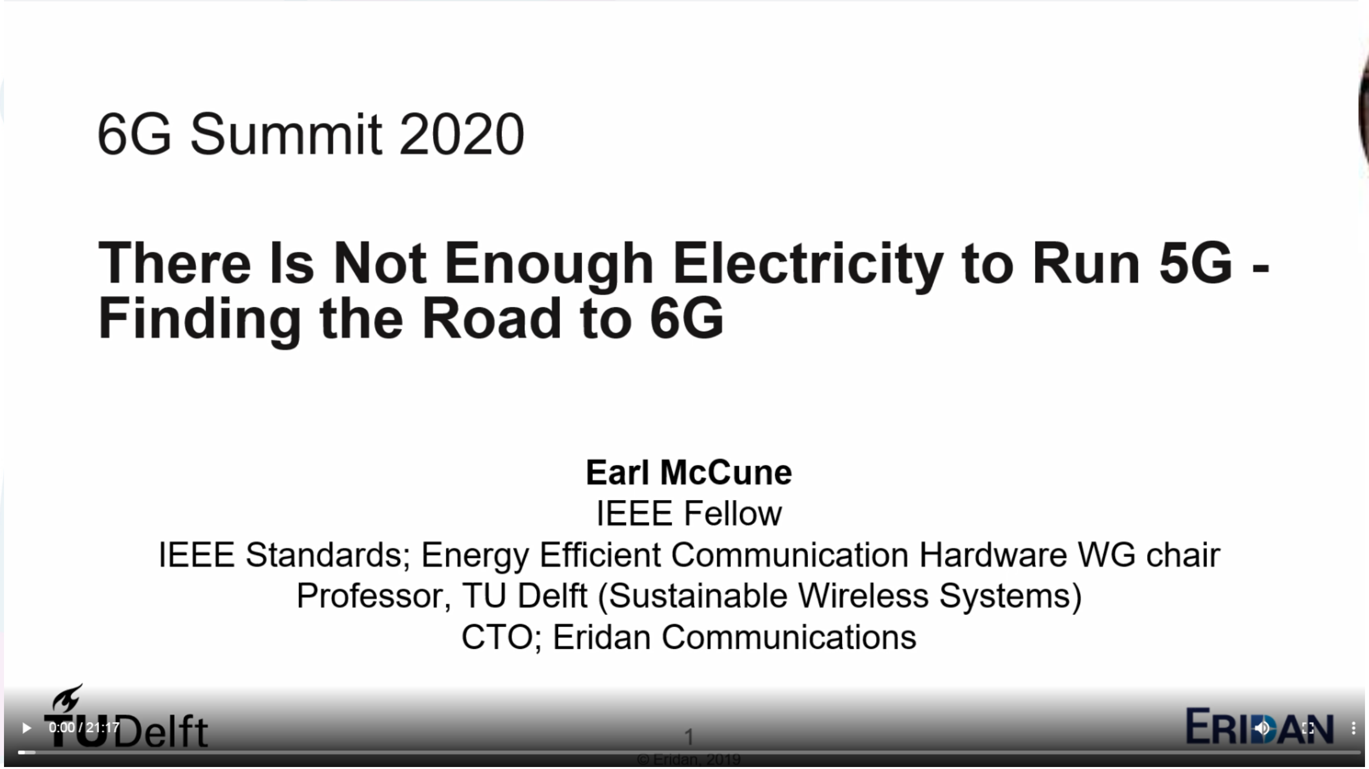
IEEE

In Memoriam


6G Summit 2020
There Is Not Enough Electricity to Run 5G - Finding the Road to 6G
Earl McCune
IEEE Fellow
IEEE Standards; Energy Efficient Communication Hardware WG chair
Professor, TU Delft (Sustainable Wireless Systems)
CTO; Eridan Communications
TUDelft
ERIDAN
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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 global deployment will not be equitably executed from a socioeconomic perspective.

10-year Vision

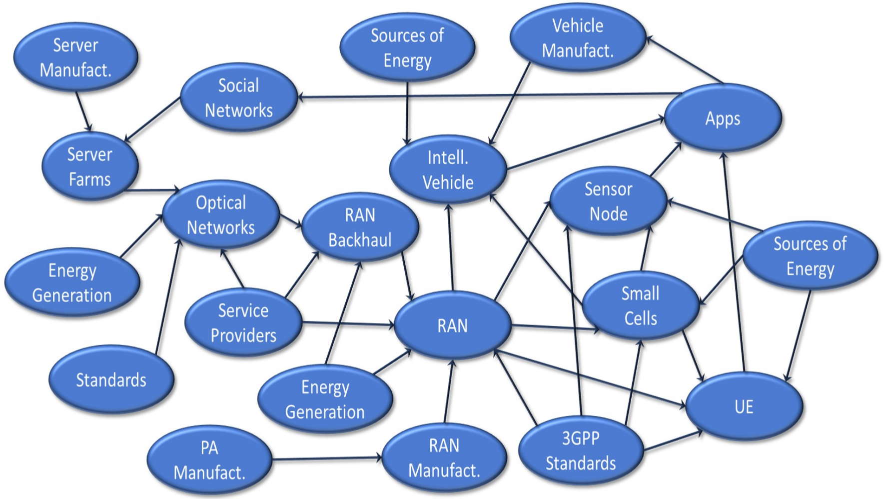
- Energy consumption seen as the “currency” that determines business viability, as it fundamentally impacts both CAPEX and OPEX.
- Linkage of HW/SW hooks enabling self-optimization at all points of the network.
- Universal availability of EE-centric tools/processes/models (maybe standards?) applied across the ecosystem and global infrastructure.
- Utilization of System-level Metrics (technical & financial) to drive stakeholders, so that:
  - All technologies Are 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)

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"
- The effort will stop short of covering other important issues like:
    - Embodied Energy (cradle-to-grave energy impacts), Energy Security, linkage of technical/economical to socioeconomic factors, and other aspects…
    - …which we hope will be addressed in future editions

Today's Landscape

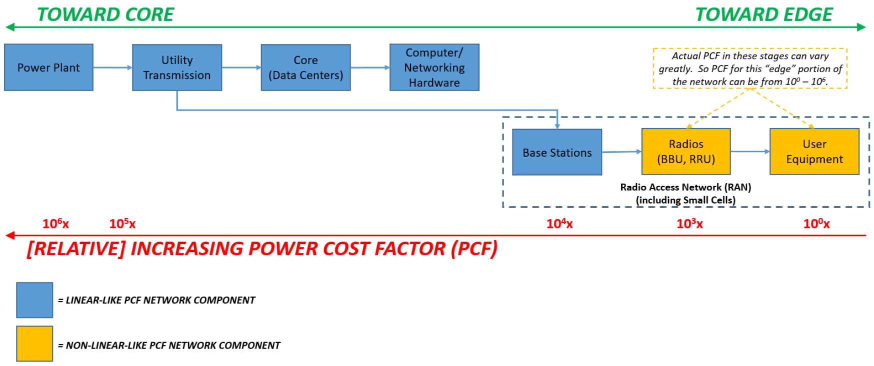
- Diverse, Heterogeneous Players Contribute To The Ecosystem
- Different Business Models And Incentives
  - Payback Model Uncertainty/Risk?
  - Poor Linkage to Socioeconomic Impacts (The Unconnected)
- Siloed Technology Development
- No Shared Metrics



Opportunity for Action

- 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.

The 5G Power Value Chain



	INGR Working Group Name	1. Massive MIMO	2. mmWave & Signal Processing	3. Hardware	4. Energy Efficiency	5. Edge Automation Platform	6. Satellite	7. Optics	8. Standardization Building Blocks	9. Testbed	10. System Optimization	11. Deployment	12. Applications & Services	13. Security	14. Connecting the Unconnected	15. Artificial Intelligence/ Machine Learning
		ACCESS				NETWORKS			SYS. & STANDARDS			ENABLERS & USERS				
	ACCESS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Massive MIMO		X	X					X	X						
2	mmWave and Signal Processing	X					X		X	X			X			
3	Hardware	X	X		X	X	X		X	X			X	X		
4	Energy Efficiency	X	X	X		X			X		X	X	X		X	X
	NETWORKS															
5	Edge Automation Platform	X								X			X	X	X	
6	Satellite	X	X	X	X	X		X	X				X	X		X
7	Optics*															
	SYSTEM AND STANDARDS															
8	Standardization Building Blocks	X	X	X	X	X	X	X		X	X	X	X	X	X	X
9	Testbed	X	X	X		X	X		X				X	X		
10	System Optimization*															
	ENABLERS AND USERS															
11	Deployment	X	X							X			X	X		
12	Applications and Services	X	X	X	X	X	X	X	X	X	X	X		X	X	X
13	Security	X	X			X			X	X	X		X		X	X
14	Connecting the Unconnected				X	X	X		X	X	X	?	X	X		
15	Artificial Intelligence/Machine Learning*															

Top Needs for 10-year Vision

- 5 MAJOR NEED TOPICS FROM ROADMAP TIMELINE TABLE

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)
4. **Economic Factors** (Technical/Economic Analysis Enablement, Industry Metrics, Socioeconomic Impact, Energy-centric Network Simulation Models)
5. **Grid/Utility** (Utility-level Impacts/Risks, Networking Electricity, Real-time Energy Market Impacts)

NEED #1: Network Efficiency

- Optimize System Design for Power & Energy Utilization
- Leverage Energy Harvesting (Edge and Data Center Levels)
- Rethink Data Architecture (Mobile Edge Computing, Computational Memory)
- Optimize RAN (Improved PAE, mMIMO, Small Cell Coordination, Radio Stripes)

Key
WHITE = Sol'n Exists
YELLOW = Sol'n Being Pursued
RED = Sol'n Unknown

NEED #1: Network Efficiency

(10x increase by 2030?)

	Current State (2020)	*3 years (2023)*	*5 years (2025)*	*Future State (2030)*
Challenge(s) for Need #1	The 5G Energy Gap (5GEG)	The 5G Energy Gap (5GEG)	- Densification - mmWave, mMIMO Deployments	Ubiquitous HetNets of Small Cells
Possible Solution for Challenge	Edge Buffering	Energy Harvesting (device-level)	Energy Harvesting (base station-level)	Energy Harvesting (data center-level)
	Awareness & Education	Mobile Edge Computing (MEC)	Standardized "5G Small Cell" with Interference Coordination	Radio Stripes
	Optimizing System Design for Power & Energy Utilization	Optimizing RAN for Power & Energy Utilization	Greatly Improved PAE (perhaps requiring use of WBG devices)	
	3GPP DTx Features	Migration of Data Center Efficiencies from HPC/ Exascale to Enterprise Applications	Continue Migration of Data Center Efficiencies Toward Edge	

NEED #2: Small Cell Migration

- Adjust Power for Real-time Traffic/Energy Demands
- Scalable Interference Management
- AI-driven, Real-time, Optimal Spectrum Utilization
- Base Station Power Optimization (Support for Multiple RF Bands, mMIMO with “Handset-grade” HW, Telemetry-based Control Loops)

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NEED #2: Small Cell Migration

	Current State (2020)	*3 years (2023)*	*5 years (2025)*	*Future State (2030)*
Need #2	Dynamic/Adaptive Base Stations	Dynamic/Adaptive Small Cells	Disaggregated Centralized Network	Cell-free Architectures
Challenge(s) for Need #2	Complicated Control Plane	Increased Inter-cell Interference	Major Network Architecture Paradigm Shift	TBD
	Departure from Norms	Need for Scalable Interference Management		
Possible Solution for Challenge	Adjust Power for Real-time Traffic/Energy Demands	Small Cell Situational Awareness	AI-facilitated Dynamic Spectrum Allocation	Fully AI-driven, Real- time, Optimal Spectrum Utilization
	mMIMO with Spatial Interference Rejection	Coordinated Multipoint Methods	User Centric No Cell (UCNC)	Cell-free mMIMO Networks to Alleviate Interference

NEED #3: Base Station Power

- Optimization of Real-time Cell Energy Consumption
- Supporting the Migration to Ubiquitous Small Cells
- Ensuring Multi-band Support, Backwards Compatibility
- Assessing mMIMO Impacts
  - Including mmWave PLUS mMIMO Impacts
- Identifying/Enabling Telemetry/Analytic Needs
  - Proper Characterization of Majority (By **A LOT**) Energy Consumer in Global Network
  - Bidirectional, Energy-centric Feedback Loops

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NEED #3: Base Station Power

	Current State (2020)	*3 years (2023)*	*5 years (2025)*	*Future State (2030)*
Need #3	Reduced Power Dissipation in Base Station Radios	Reduced Power Dissipation in UE Radios	Network-wide Energy Awareness	Regional/Global Energy Awareness
Challenge(s) for Need #3	Requirements on Out-of-band Distortion Must Be Satisfied	Requirements on Out-of-band Distortion Must Be Satisfied	Power/Energy Telemetry Data Acquisition	Enabling/Deploying Energy-optimal Control Feedback Loop(s)
		Support for Many RF Bands	Power/Energy Data Analytics	
	Determining Macro Vs. Small Cell Size/Needs Vs. Freq.	Heatsink/Package Size Becomes Impractical for PAE	Defining Energy-optimal Control Feedback Loop(s)	
Possible Solution for Challenge	Use mMIMO radios with many low-gain antennas with handset-grade hardware instead of few high-gain antennas.	Dedicated Circuit Design With Reduced Distortion Margins	TBD	TBD
		Cross-band Optimization For Energy Efficiency	WBG FET Driver Technology Improvement	

NEED #4: Economic Factors

- Develop/Apply the 5G "Economic Gap" and "Derate Factor" to Determine Business Objectives' Sensitivity
  - Facilitate Understanding of Differences/Dependencies Between Technical and Economical Factors
- Assess Payback Period Targets Driving Socioeconomic Disparity
- Develop Component-level Energy Utilization Metrics
- Define System-level Utilization Requirements to Achieve Sustainable Operation For "Equitable Access"

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NEED #4: Economic Factors

	Current State (2020)	*3 years (2023)*	*5 years (2025)*	*Future State (2030)*
Need #4	Enhanced Economic Modeling	Network-Component-Based Economic Models	End-to-end Network Economic Models	Global Economic Models
Challenge(s) for Need #4	Defining the 5G Economic Gap (5GEcG)	Characterizing individual components (specific yet compatible)	Cooperation Between Network Stakeholders	Cooperation Between Global Stakeholders
	Defining the 5G Derate Factor (5GDF)		Model Complexity	Model Complexity
	Strict Payback Period Targets Driving Socioeconomic Disparity		Model Validation	Model Validation
				Socioeconomic Considerations
Possible Solution for Challenge	Applying the 5G Economic Gap Analysis (5GEcG)	Network Component Energy Utilization Metric(s)	Disaggregated Network Metric(s)	Demonstration of ability to optimize energy utilization from micro to macro levels
	Applying the 5G Derate Factor (5GDF)	Energy Efficiency Metric Standardization	Demonstration of Energy & TCO Savings	Validated Model Database
	Considering the 5G Equality Gap (5GEqG)			

NEED #5: Grid/Utility

- Synergistic Interaction Between Utility and Network Infrastructure
- Use of Small Cell Deployment to Monitor Utility and Improve Energy Forecasting and Availability
  - Potential Utilization of "Better" Sources based on Real-time Grid Data
- Networked Electricity: Major Proposed Ecosystem Upgrade

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NEED #5: Grid/Utility

	Current State (2020)	*3 years (2023)*	*5 years (2025)*	*Future State (2030)*
Need #5		Real-Time Energy Price Distribution	Cell Infrastructure Grid Sensor Network	Networked Electricity
Challenge(s) for Need #5		Data Distribution	- Independently-owned Infrastructures - 5G HW Power Characterization Standard	- Ecosystem Paradigm Shift - Physical Layers For Digitally Managed Power
		Communications Medium(s)	Grid Fault Response Time	Adoption by Energy Storage/Generation Products
Possible Solution for Challenge		Leverage Existing Mediums	Data Sharing	Major Infrastructure Change
		- Bidirectional Feedback Loop - Feedback Through Aggregate Consumption Metering	Grid Data Analytics/Database	Major Device Standard Change

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.)

Contributing Working Group Members

- **Brian Zahnstecher, PowerRox**
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- David Su, Atmosic
- Rajesh Uppal, Self
- *Earl McCune, Eridan Communications* ***(IN MEMORIAM, RIP)***

Get involved!

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QUESTIONS?