Industry Session #: Power Packaging

5G is Broken and the Heatsink is to Blame

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OVERVIEW

- **The Paradigm Shifts in Power Brought by 5G**
- **The 5G Energy Gap**
- **Transmitter Power Amplifier (PA) Physics & Thermals**
- **Improving Efficiency for 5G Viability**
- **Summary / Conclusions**

The Paradigm Shifts in Power Brought by 5G

- **Power Challenges in 5G**
  - 1000x Traffic
  - 10-1000x Number of Devices
  - Availability of Power
  - Sustainability of Power
  - Impact to Global Power Footprint
  - Impact to Global Carbon Footprint

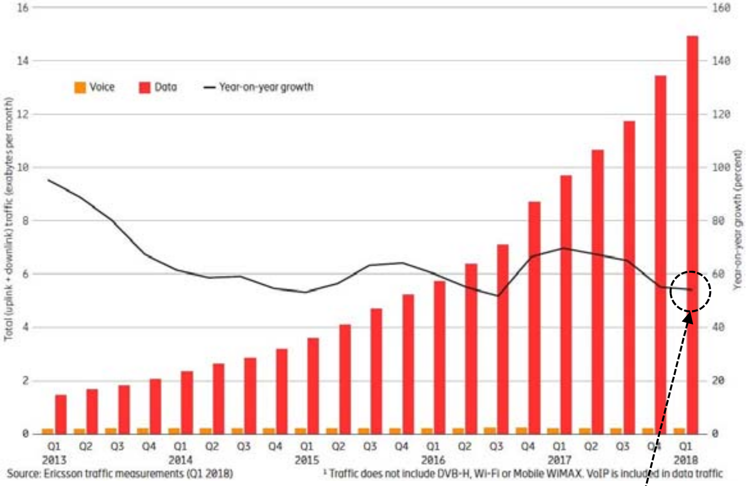
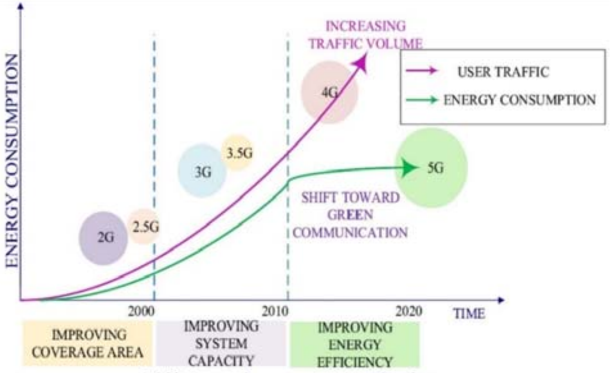


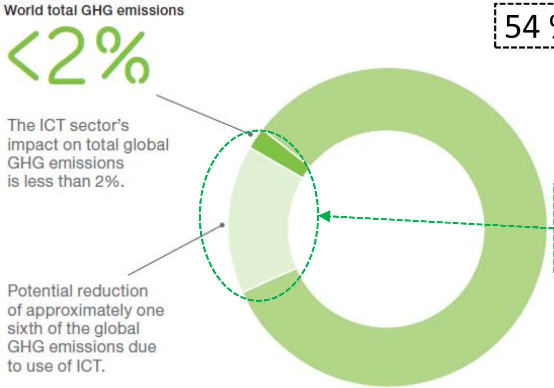
IMAGE CREDIT: "Ericsson Mobility Report 2018," Ericsson, June 2018.

54 % YoY growth!!!



Shift toward green communication.

IMAGE CREDIT: A. Abrol and R. K. Jha, "Power Optimization in 5G Networks: A Step Towards GrEEn Communication," in IEEE Access, vol. 4, pp. 1355-1374, 2016.



Indirect, but makes a big difference!

IMAGE CREDIT: "Ericsson Energy and Carbon Report," Ericsson, June 2014.

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The Paradigm Shifts in Power Brought by 5G

- **Base Stations: From Macro to Micro (to Femto)**
  - Moving from Macro Model to Small Cells
    - Massive Opportunity for Power Savings

Take note of the major differences here.

Holy smokes!!!
(and this info is even dated)

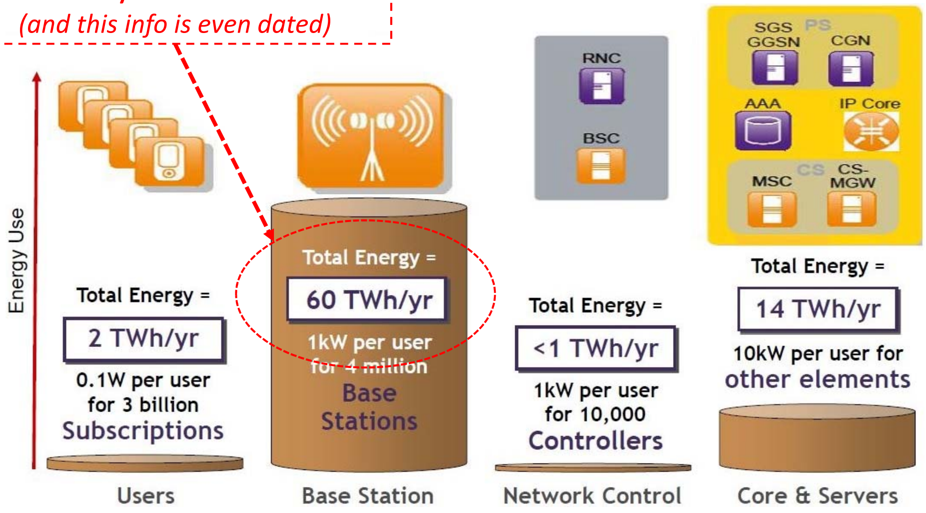

IMAGE CREDIT: Dr. Gee Rittenhouse, "Green Wireless Networks," Alcatel-Lucent GreenTouch, April 2012.

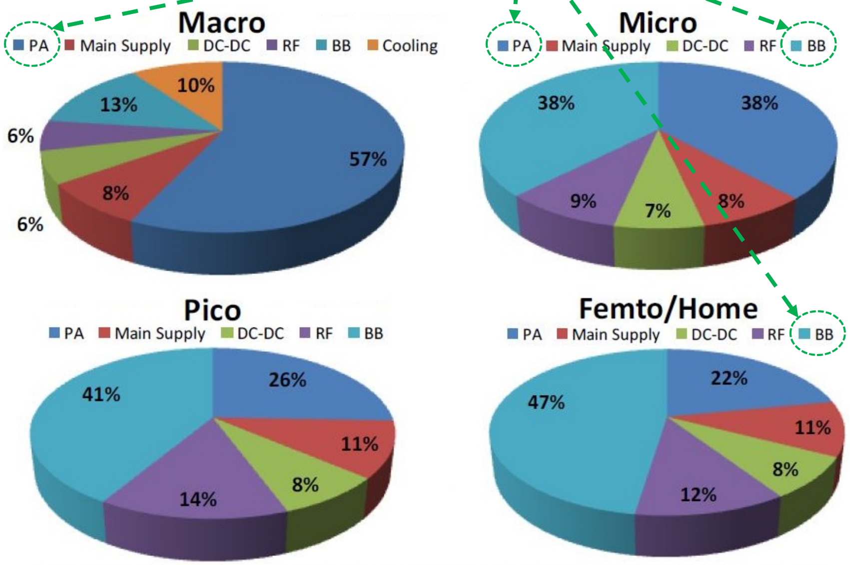

FIGURE 12. BS power consumption breakdown for different deployment scenarios.

IMAGE CREDIT: "Energy efficiency analysis of the reference systems, areas of improvements and target breakdown," EARTH, Deliverable D2.3 v2.00, January 31, 2012.

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The Paradigm Shifts in Power Brought by 5G

- **The Migration to Small Cells**
  - Started with 4G-LTE
  - Kicked Into High Gear with 5G

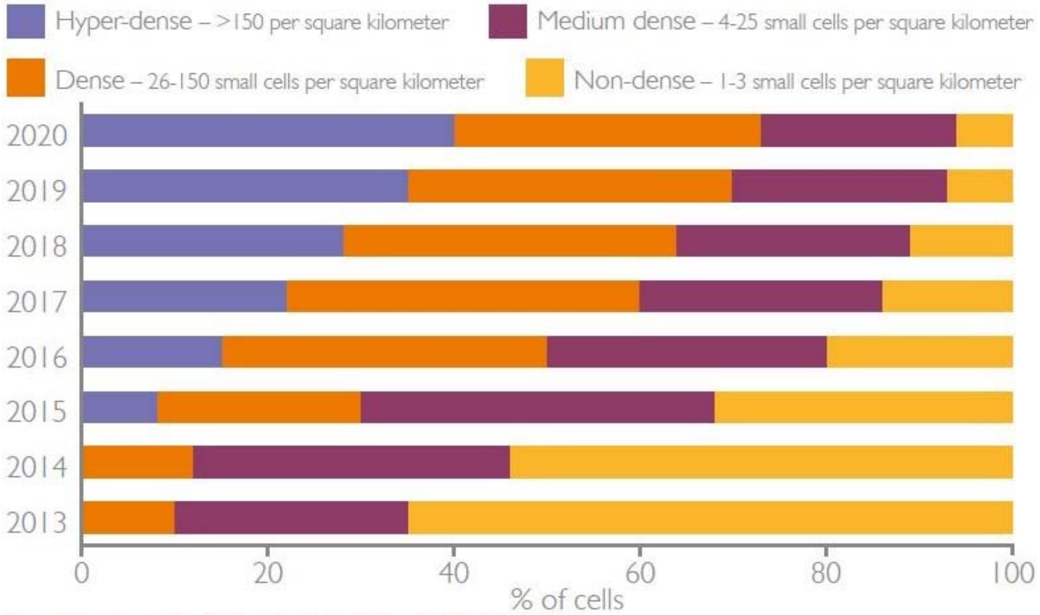


Figure 3. Percentage of small cells deployed in various levels of density 2013-2020

IMAGE CREDIT: "Crossing the Chasm: Small Cells Industry November 2015," Smart Cell Forum, November 2015.

The Paradigm Shifts in Power Brought by 5G

- **Network-Level Efficiency Improvements**
  - GreenTouch Consortium Green Meter Research Study
    - *"The study concluded that it is possible through the combination of technologies, architectures, components, algorithms and protocols to reduce the net energy consumption in end-to-end communications networks by up to* ***98%*** *by 2020 compared to the 2010 reference scenario defined by GreenTouch."*
      - *"****10,000-fold*** *increase of energy efficiency in mobile access networks"*
      - *"****254-fold*** *increase in energy efficiency in residential fixed access networks"*
      - *"****316-fold*** *increase in energy efficiency in core networks"*

	Energy Efficiency Improvement Factor (2020 vs. 2010 Reference Scenario)	Traffic Growth (from 2010 to 2020)	Net Energy Reduction of 2020 Relative to 2010
Mobile Access	10,000x	89x	99%
Fixed Access (Residential)	254x	8x	97%
Core Network	316x	12x	96%

Table 7: Summary of the Green Meter Research study with the energy efficiency gains, traffic growth and net energy reductions that can be achieved in the mobile access, fixed access and core networks.

IMAGE CREDIT: "GreenTouch Final Results from Green Meter Research Study," A GreenTouch White Paper, Version 2.0, August 15, 2015.

The 5G Energy Gap

- **What is the true cost of 1 mW?**
  - Now, let us consider a tiny, wireless IoT device.
    - Transmission of Power in **Base Station**
      - From Grid to RF Transmitter
    - Transmission of **Data to UE (i.e. – Smartphone)**
      - From Base Station RF Transmitter to UI RF Receiver

IMAGE CREDIT: http://www.aetherica.com/ip_camera.html

The 5G Energy Gap

- **What is the true cost of 1 mW?**

IMAGE CREDIT: https://commons.wikimedia.org/wiki/File:Base_transceiver_station.jpg

BASE STATION EXAMPLE

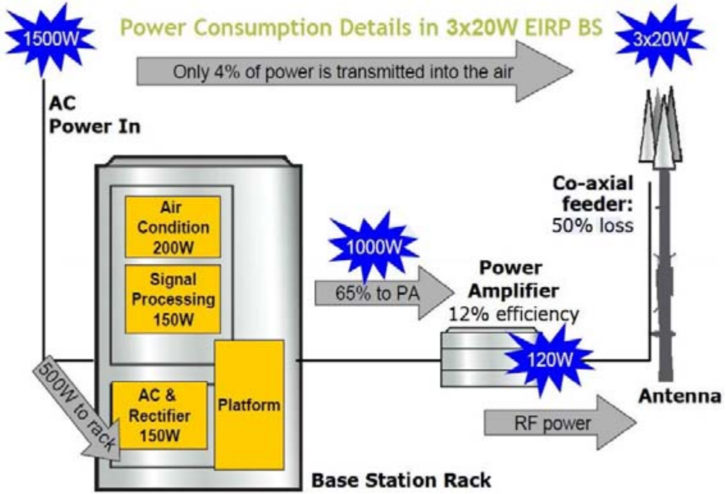
POWER (~20-25%) → OVERHEAD (~10-20%) → BASEBAND UNIT (BBU) (~20-30%) → POWER AMP (PA) (~80-90%) → Tx ANTENNA (~50%)

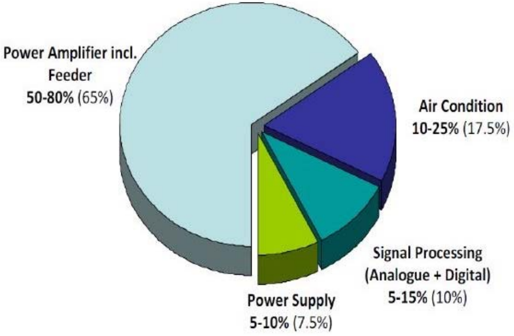
[Combined Power Solution & Cooling]

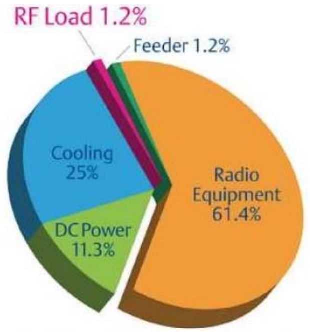
=

You have lost ~94-98 % of your power getting from grid to the transmitting antenna.

EFFICIENCY FOR THIS STAGE = ~6 % (BEST-CASE)







IMAGES CREDIT: Alberto Conte, "Power consumption of base stations," Alcatel-Lucent Bell Labs France, TREND Plenary meeting, Ghent, 14-15/02/2012.

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The 5G Energy Gap

- **What is the true cost of 1 mW?**

SMARTPHONE EXAMPLE

(Modified) Friis Transmission Equation

$$P_R = \frac{P_T G_T G_R c^2}{(4\pi R f)^2}$$

SOURCE: Friis Equation - (aka Friis Transmission Formula) = ***http://www.antenna-theory.com/basics/friis.php***

- 0 dBm = 1 mW reference
- 10 dBm per power order of magnitude
- ***Rx power falls dramatically with distance and/or frequency***

IMAGE CREDIT: ***https://commons.wikimedia.org/wiki/File:Base_transceiver_station.jpg***

IMAGE CREDIT: ***https://www.flickr.com/photos/alpat/8798930518***

You have lost ~99.9 % of your power transmitting from base station to smartphone.

EFFICIENCY FOR THIS STAGE = ~0.1 % (BEST-CASE)

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The 5G Energy Gap

- **What is the true cost of 1 mW?**
  - 1 mW Rx Power = ***1-2 W*** Tx Base Station Power *(~0.1% best-case efficiency)*
  - 1 W Tx Power = ***16.7-50 W*** Base Station Power *(~6% best-case efficiency)*
  - 8-15 % Lost in Transmission

So the true cost of *EACH 1 mW* of received data at the edge requires *~18,000x-60,000x (18-60 W)* of power generated at the power plant!

Now, multiply that by 10s of billions or event 1 T devices!!!

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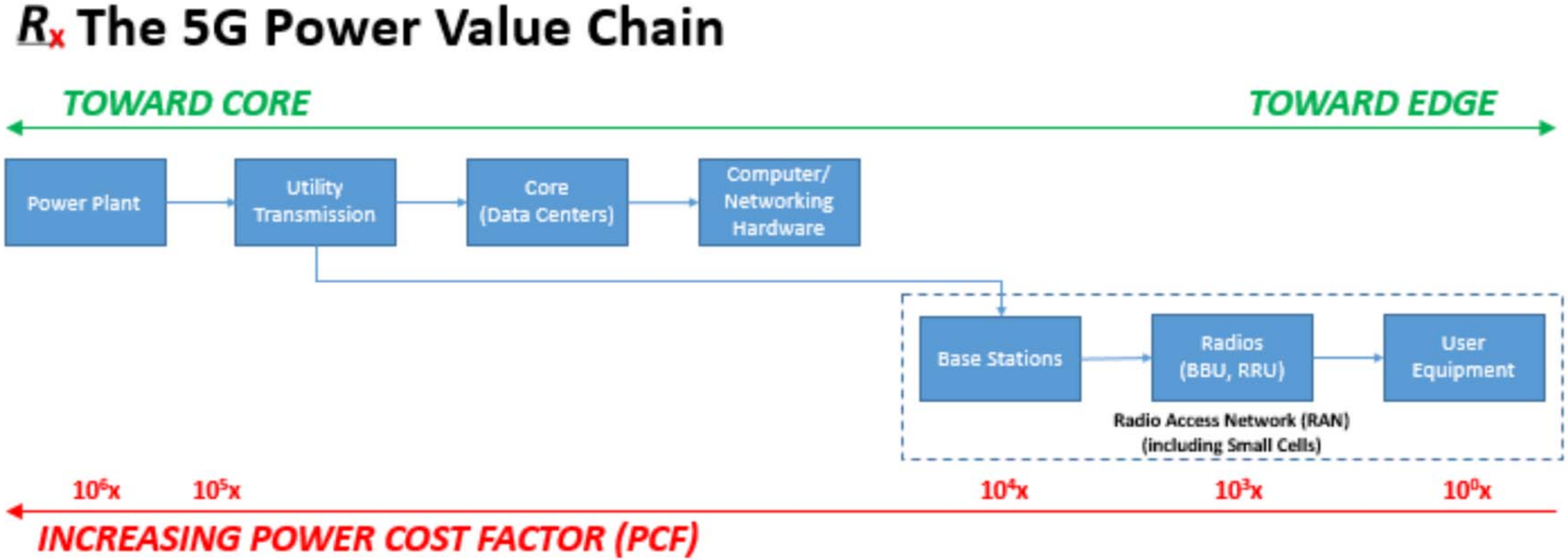
The 5G Energy Gap

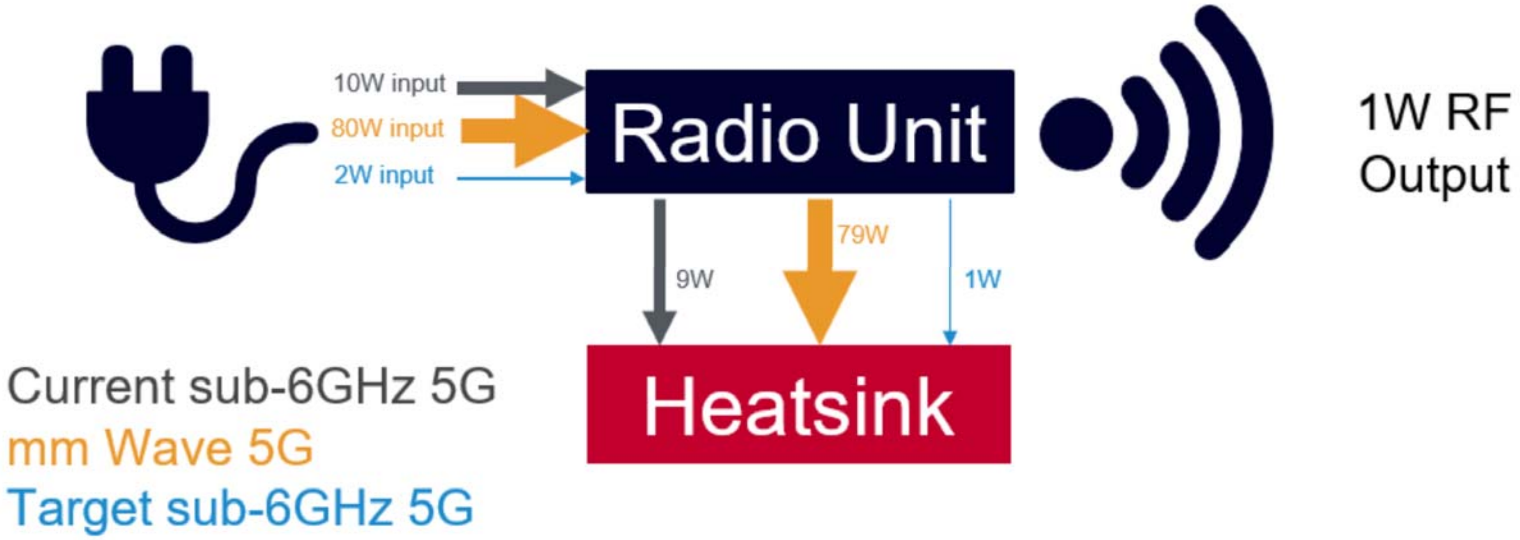
- **Power Value Chain (PVC)**
- **Power Cost Factor (PCF)**



IMAGES CREDIT: Brian Zahnstecher, "The 5G Energy Gap," IEEE Power Electronics Magazine, Vol. 6, No. 4, December 2019.

Transmitter Power Amplifier (PA) Physics & Thermals

The Infrastructure Power Problem



Transmitter Power Amplifier (PA) Physics & Thermals

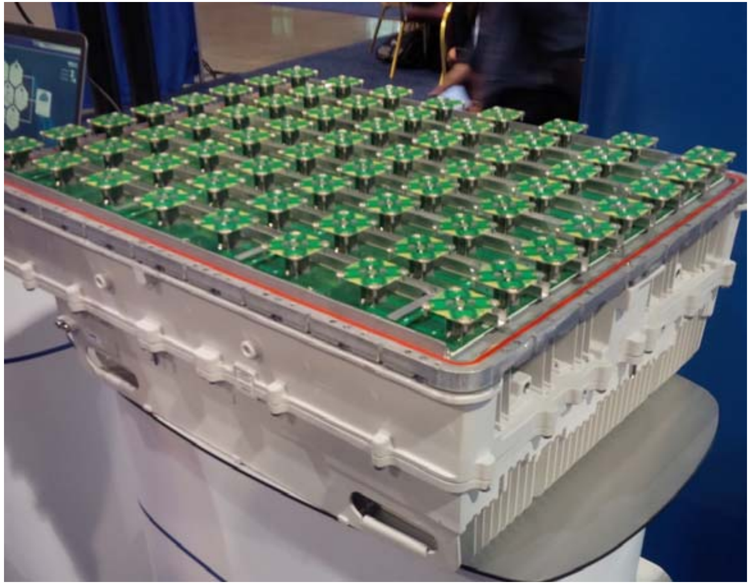
Consequences: a lot of wasted energy

We'd prefer to cover the planet with 5G without melting it

Transmitter Power Amplifier (PA) Physics & Thermals

Consequences: this is your heat sink

Equipment gets heavier, more expensive, and harder to install



Example from public exhibition

8x8 mMIMO prototype (@ICC 2018)
2.6 GHz ; 1.8W/element
>10 cm heatsink fins
47 kg (= 104 pounds)

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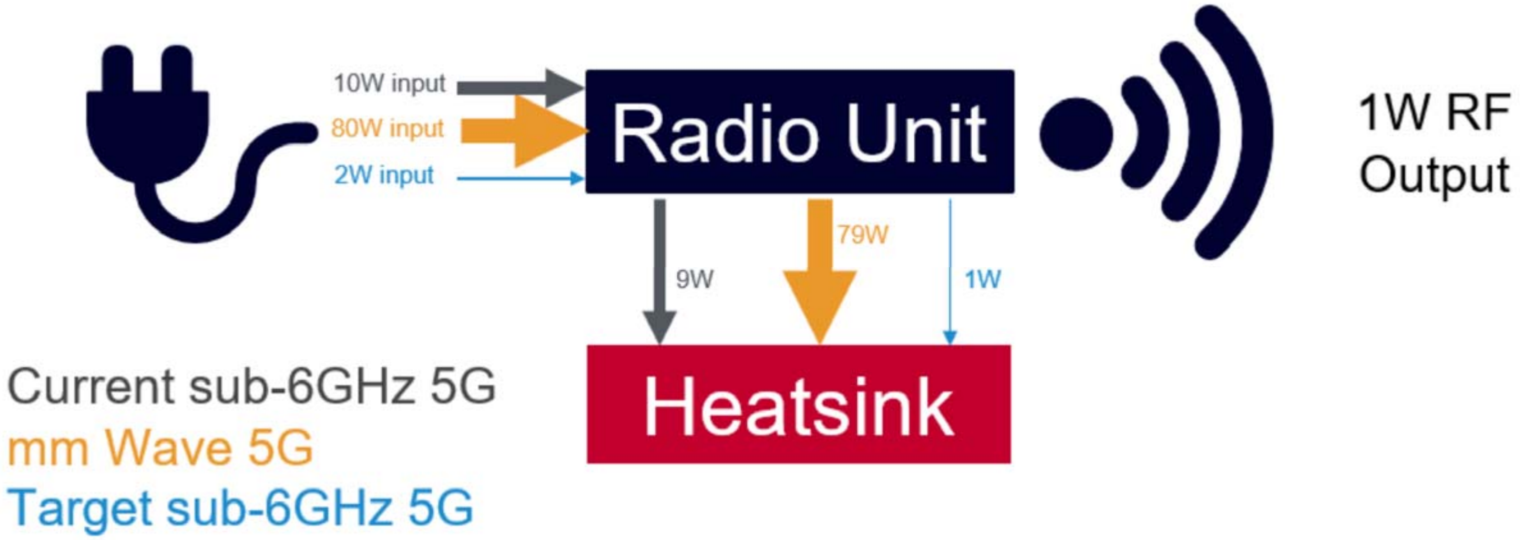
Transmitter Power Amplifier (PA) Physics & Thermals

Consequences: small cells aren't small

Increases installation costs, reduces flexibility and irritates the neighborhood

Transmitter Power Amplifier (PA) Physics & Thermals

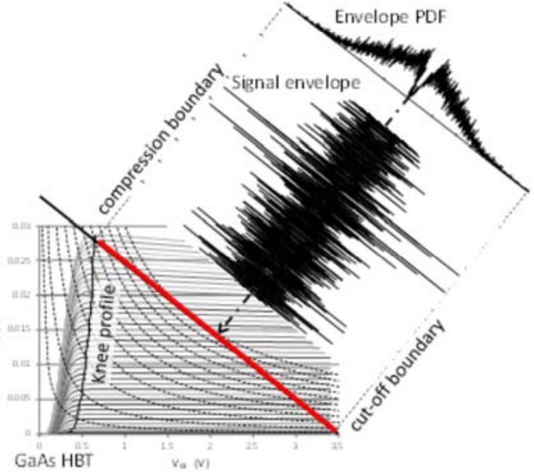
The Infrastructure Power Problem



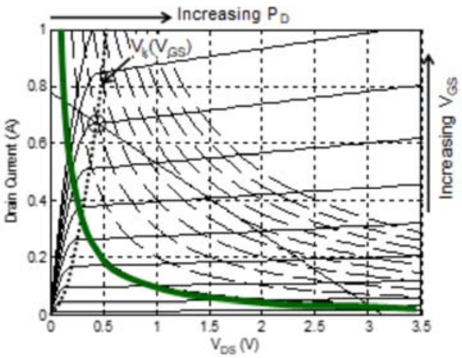
Transmitter Power Amplifier (PA) Physics & Thermals

Transmitter Physics

Linear Transmitter



Efficient Transmitter



Linear transmitters *cannot be efficient*

- A direct consequence of Ohm's Law

Efficient transmitters *cannot have circuit linearity*

- Class-E approximates this profile

At-power sampling transmit architectures can be 'linear' and efficient

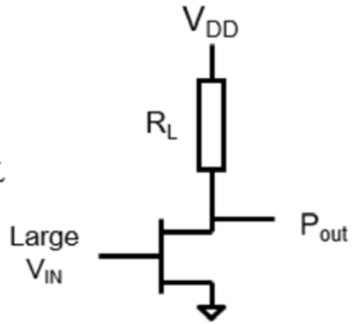
- Sampling theory allows waveform precision
- Operates at load line endpoints

Transmitter Power Amplifier (PA) Physics & Thermals

Physically Available Options

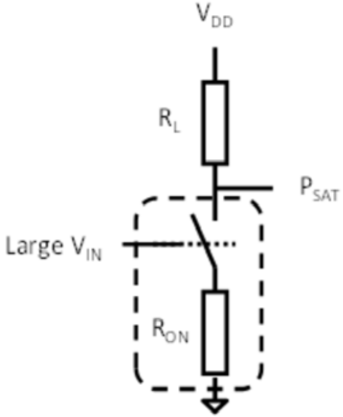
- Actual transmitter objective: ***modulation accuracy at-power***
- Traditional approach: Linear Network Theory
  - Modulate at small signal levels
  - Increase signal power with linear amplifiers
  - Maintains modulation accuracy, as long as all amplifiers remain linear (mathematical sense)

$$V_{out} = I_D \cdot R_L$$



- Alternative approach: Sampling Theory
  - Also provides modulation accuracy
  - Supply voltage precision is important

$$V_{out} = \frac{V_{SUPPLY}}{R_L + R_{ON}} \cdot R_L$$



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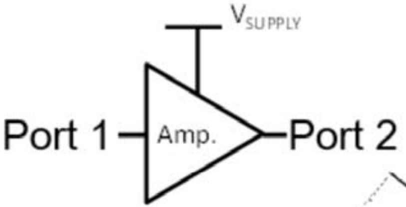
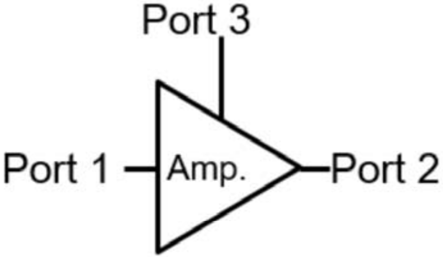
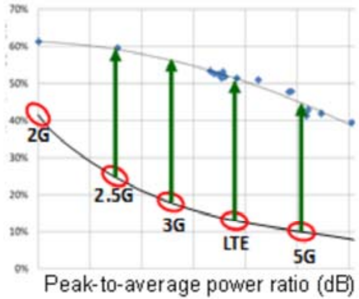
Transmitter Power Amplifier (PA) Physics & Thermals

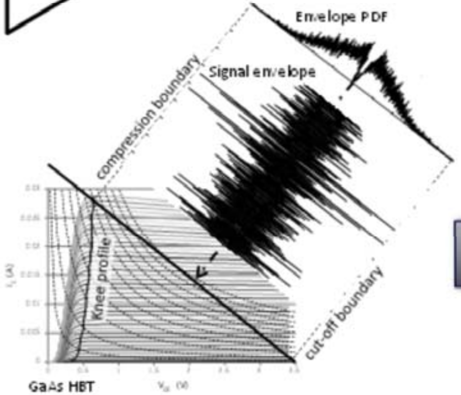
New Tradition in Radio Circuitry

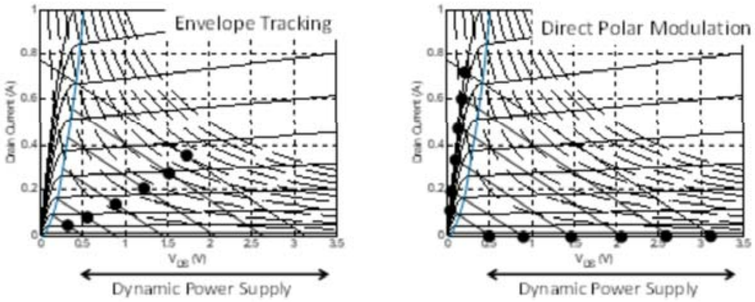
Use all 3 ports of electronic amplifiers







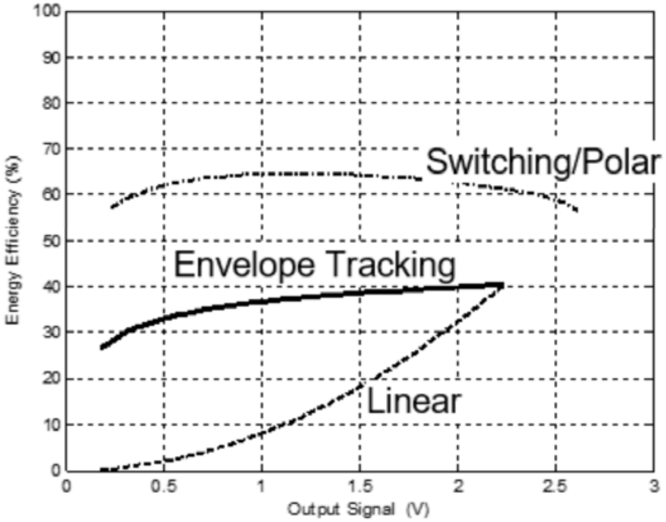




We have ***NOT*** reached physical limits yet!

Improving Efficiency for 5G Viability

Efficiency Comparisons



Envelope Tracking

- Maintains linear PA operation
- Maintains best-case linear PA efficiency across its dynamic range
- Good modulation accuracy

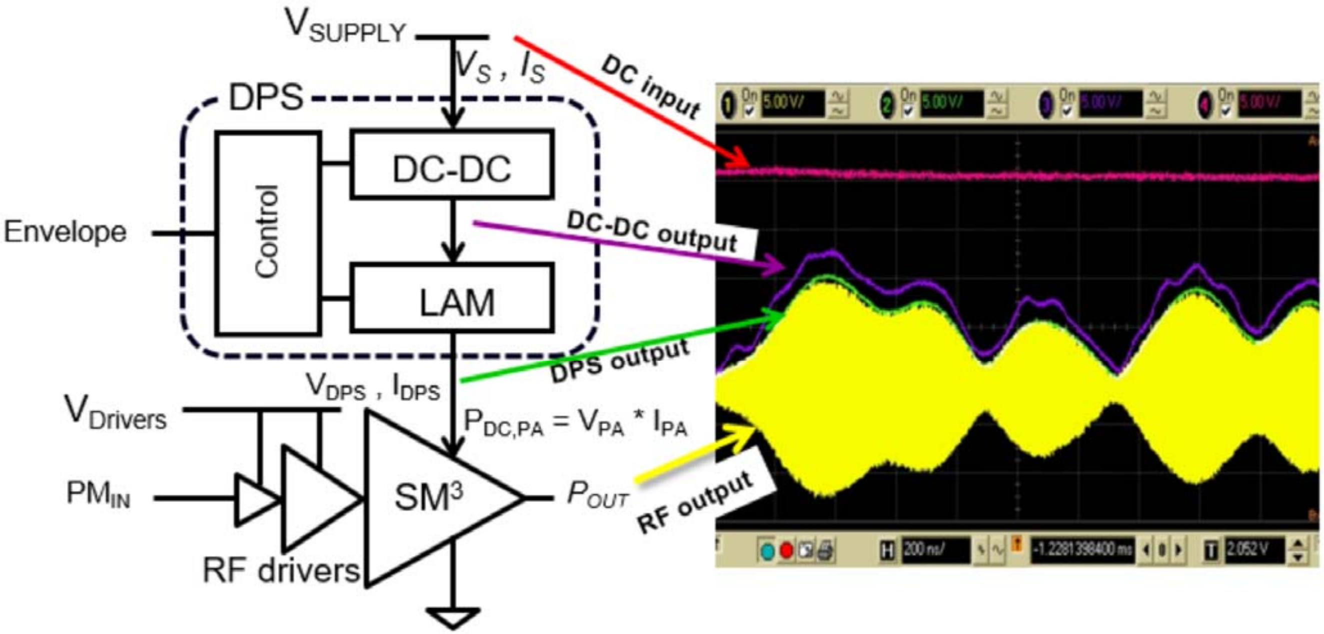
Polar TX

- Higher output power
- Higher energy efficiency
- No circuit linearity
- Good modulation accuracy

Both are much better than a linear PA

Improving Efficiency for 5G Viability

At-Power Sampling Transmitter

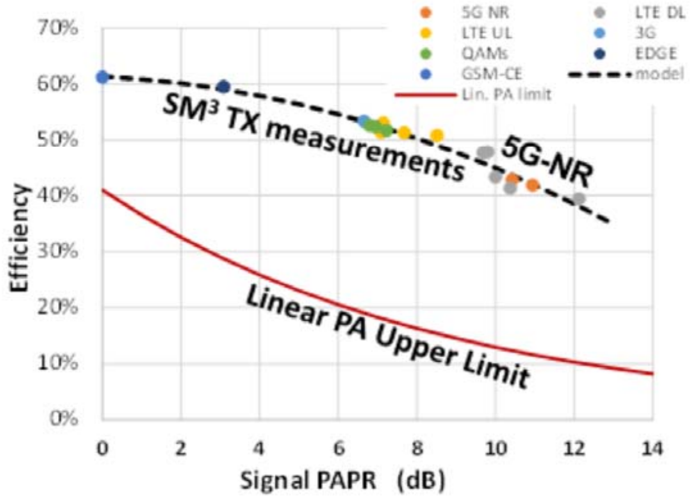


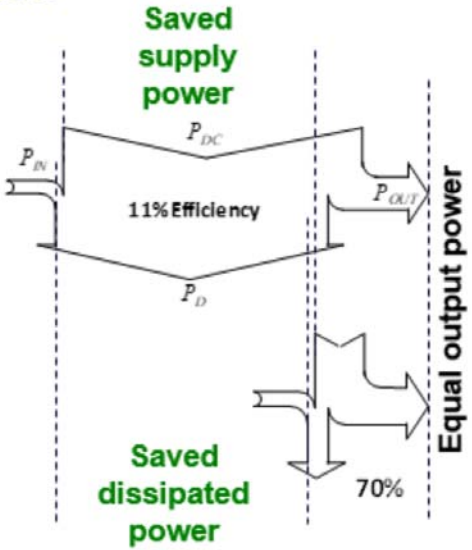
ELIMINATES **the power amplifier**

Improving Efficiency for 5G Viability

Measured Transmitter Efficiency

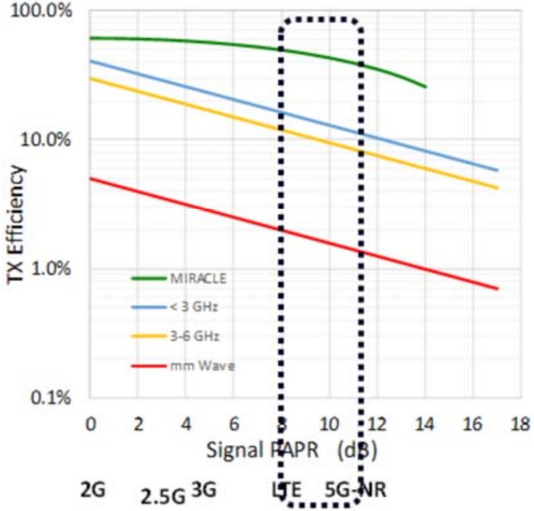
Sampling architecture *eliminates* the linear PA
Physically possible now to achieve much higher efficiencies
Strong dependence on signal PAPR is gone
Power supply and heatsink both shrink: **CapEx and OpEx benefits**

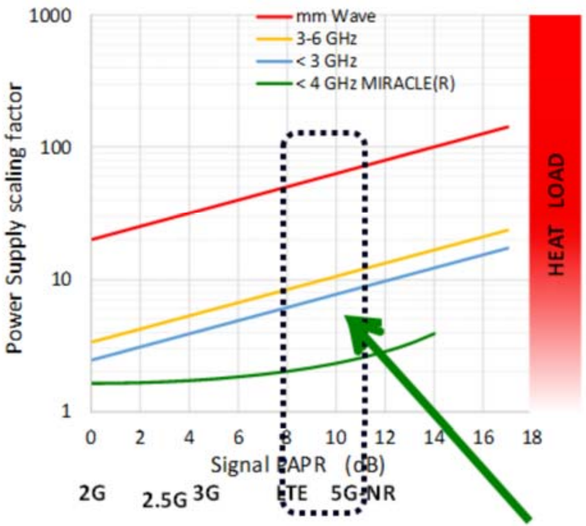




Improving Efficiency for 5G Viability

5G-NR Efficiency Improvement





All signal types now operate here

- Sampling based transmitter; measured efficiency
- Costs fall for all of the present modulations
- Input power is reduced by 6x
- Heatsink size drops by 7x
- Achieves the industry-preferred range : 40 to 60 %
- **5G can now be profitable to build and operate**

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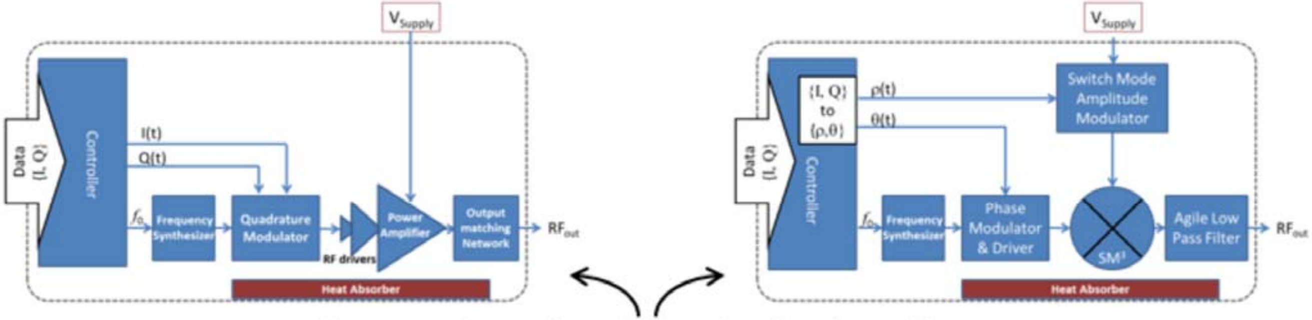
Improving Efficiency for 5G Viability

Architecture Trade-offs – Nothing is Free

Traditional Linear Amplifier

Direct Polar SM³



Comparison is at the dashed outline

Feature	Linear TX	Doherty TX	MIRACLE™ TX
Tuning range (f_{high} : f_{low})	1.22 : 1	1.22 : 1	50 : 1
5G signal efficiency	9%	22%	43%
Data density (max)	6 bps/Hz	6 bps/Hz	>14 bps/Hz
Power supply (W)	1x (normalized)	0.4x	0.2x
Heat absorber (m^3)	8.4x	2.5x	1x (normalized)
Maximum frequency	f_t / 3	f_t / 6	f_t / 10

*Current GaN process has an f_t of 65GHz

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Improving Efficiency for 5G Viability

What does improved transmitter efficiency mean for packaging?

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Summary / Conclusions

- **All the awesome applications enabled by the many enhanced specs and features of the 5G network provide many power challenges as well as opportunities.**
- **The biggest consumer of network power is also the biggest opportunity for power savings.**

There is hope!
Sub-6 GHz RAN technology is now beyond the traditional limits

The world has changed

5G deployment at scale, without melting the planet
Operators can demand the performance they really need from their suppliers

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Q & A

Thanks a lot for your time and attention!

Any questions and/or comments?

References

- A. Abrol and R. K. Jha, "Power Optimization in 5G Networks: A Step Towards GrEEn Communication," in IEEE Access, vol. 4, pp. 1355-1374, 2016.
- "Ericsson Mobility Report 2018," Ericsson, June 2018.
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- Friis Equation - (aka Friis Transmission Formula) = http://www.antenna-theory.com/basics/friis.php.