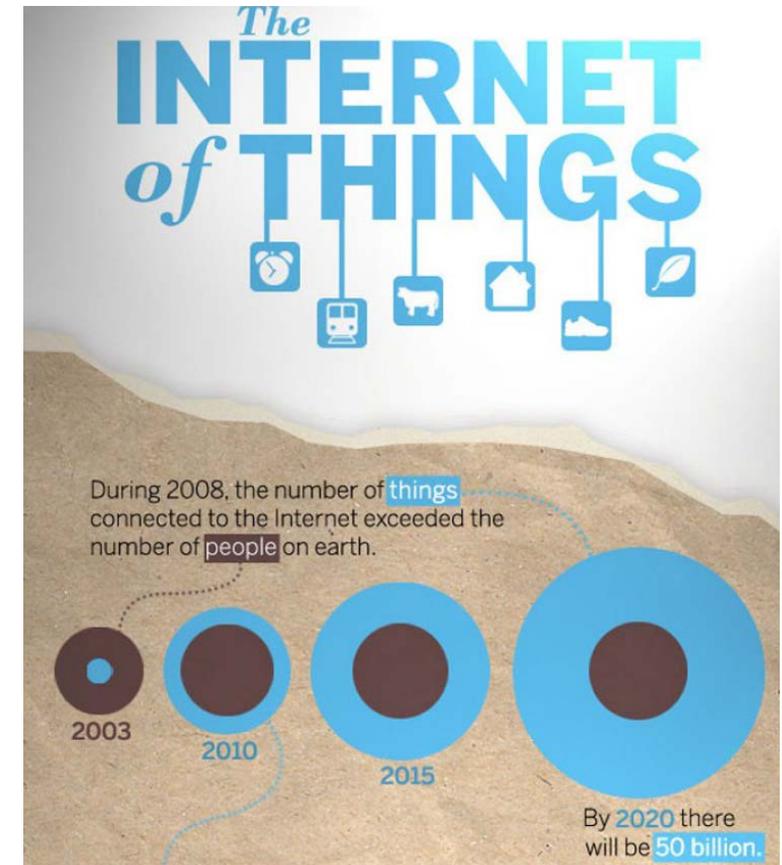


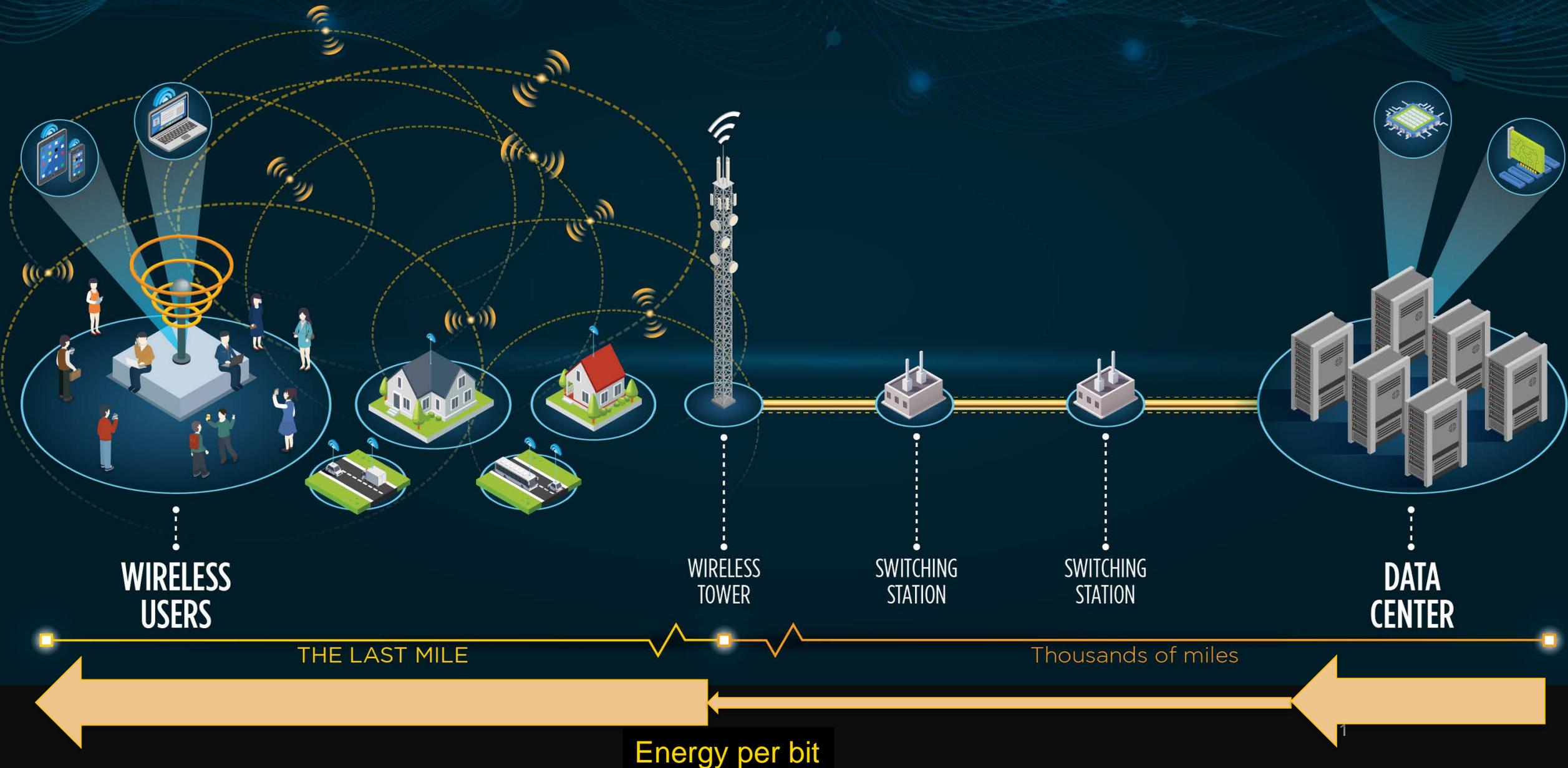
# The “*Last Mile*” - Can we realize the ~10,000X wireless energy reduction opportunity?

Dr. Michael Haney, ARPA-E Program Director



# E/bit required in the “last mile” is $\sim 100X >$ E/bit in the rest of the network

(CEET whitepaper, Greentouch GWATT tool)



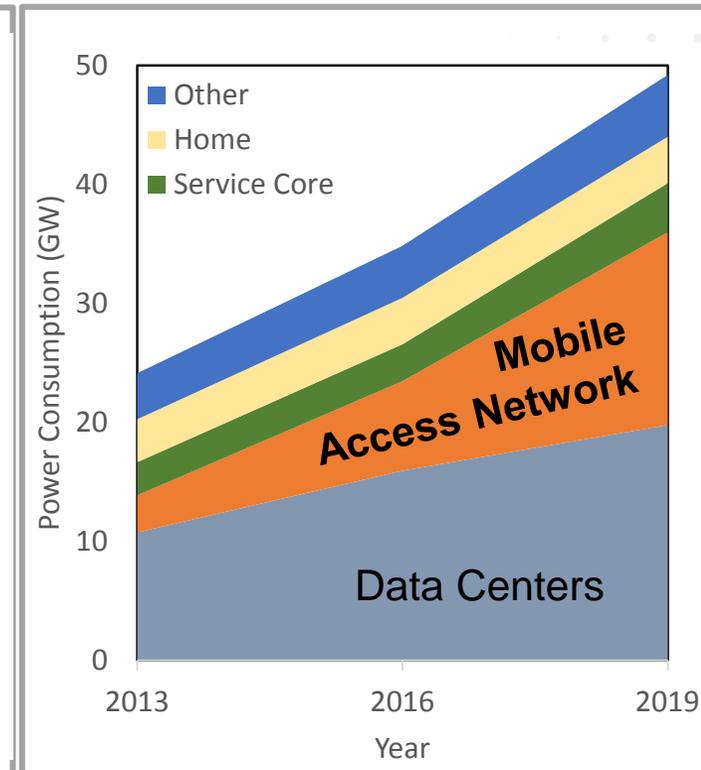
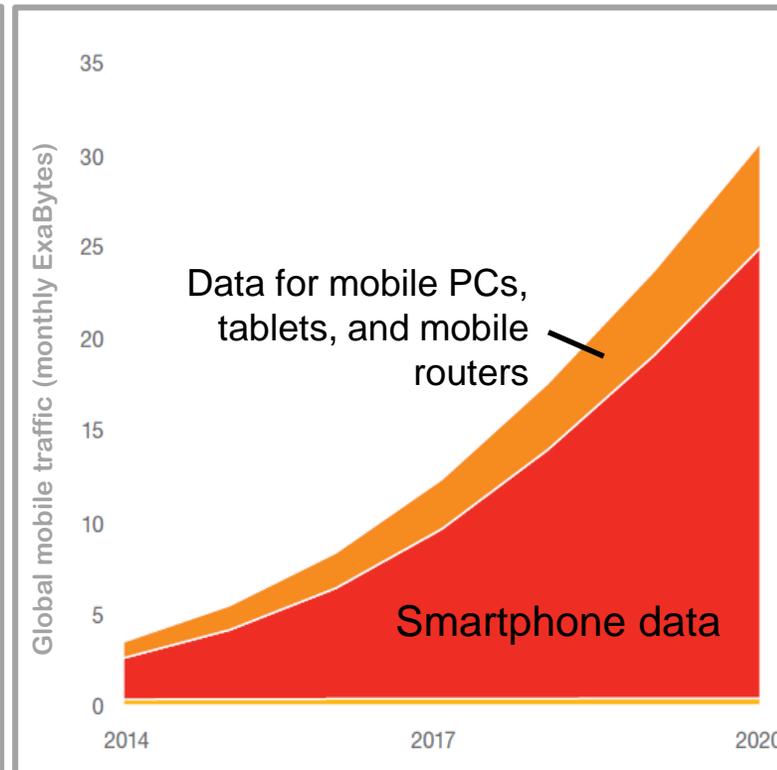
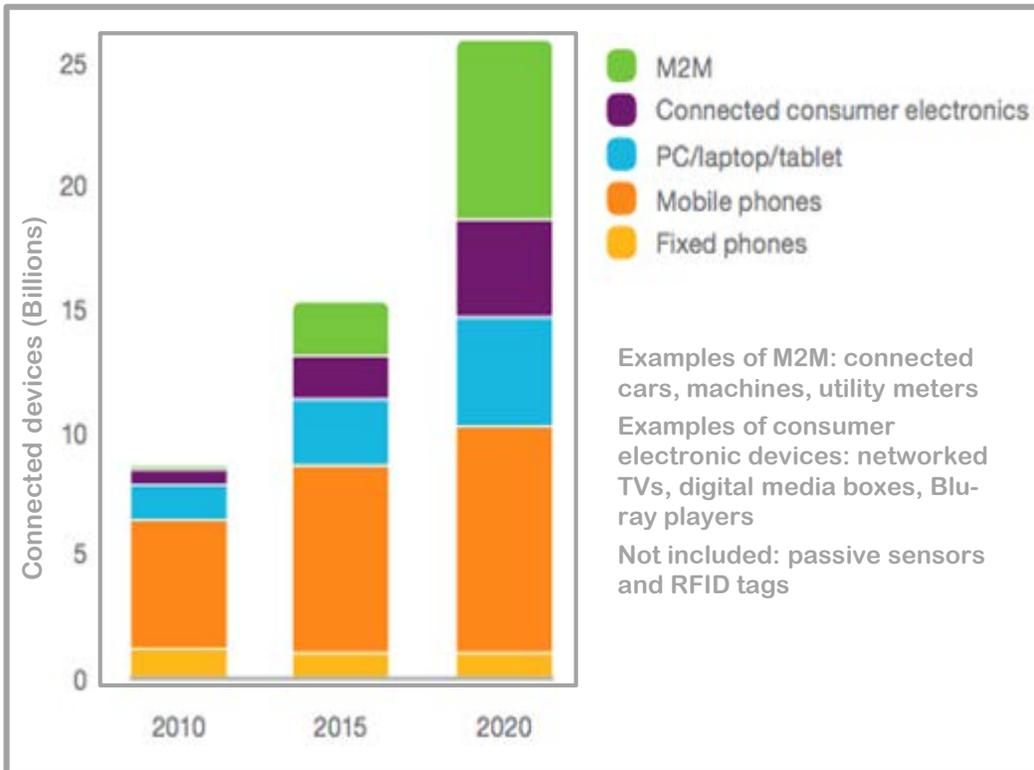
# Wireless Energy Needs are Growing at a High Rate

~5% of global electricity consumed by the ICT Sector in 2012 <sup>1</sup>

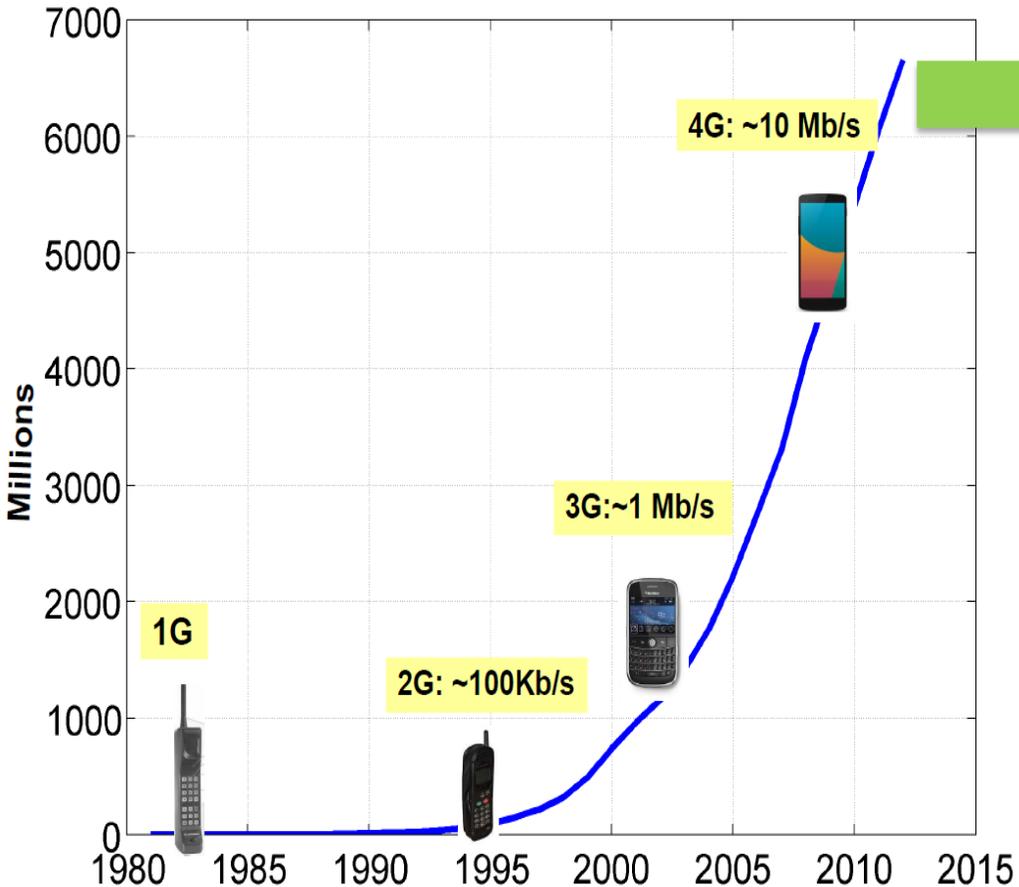
The number of mobile devices will likely double in the next few years<sup>2</sup>...

... accompanied by a 10X growth in data traffic<sup>2</sup>...

... and increased power consumption by MANs<sup>3</sup>



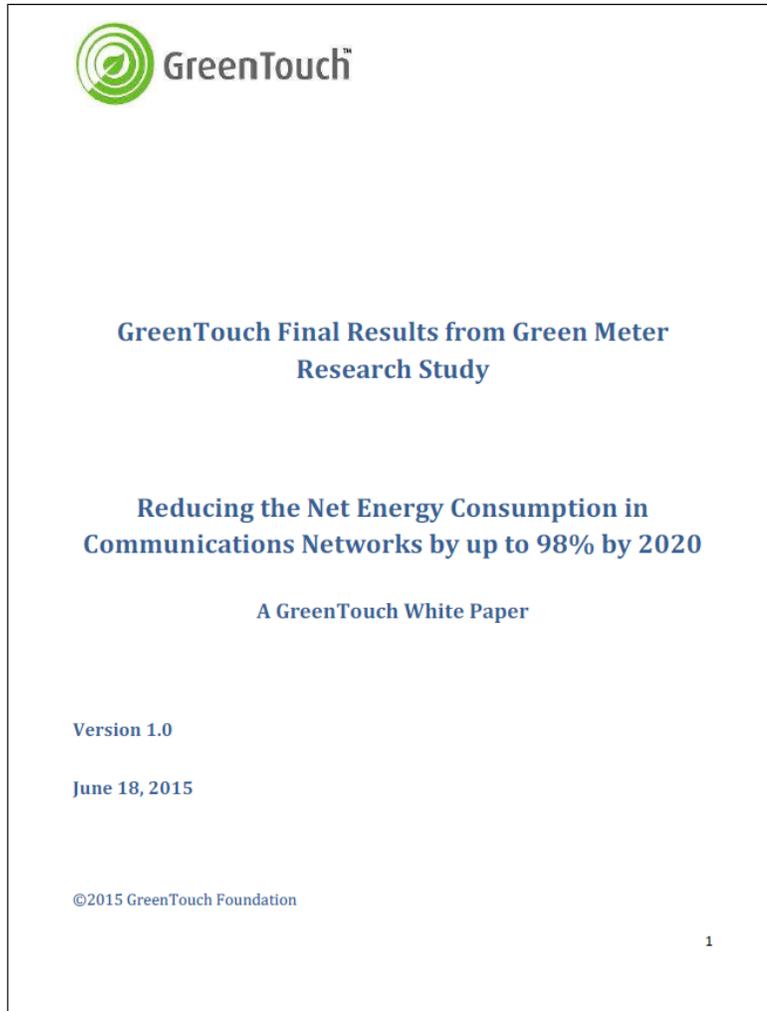
# Is there an opportunity to enhance the coming 5G Technology?



## 5G:

- To be deployed in the 2020's,
- No standards yet (!),
- ~100Mb/s per user,
- Much higher subscriber density,
- Will need spectral efficiency enhancements,
- Millimeter wave carrier bands,
- Significantly reduced latency.

# 2015 GreenTouch study found that a ~10,000X reduction in energy use for wireless is possible



## Conclusions center on three approaches:

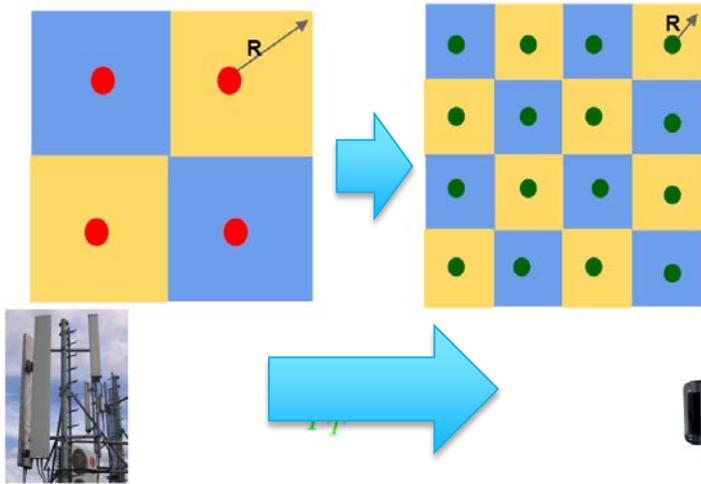
- **Small-cell Architecture**
- **Signal processing**
- **Beam-forming**

Approach	Dense Urban	Urban	Suburban	Rural
Small Cell Architecture	8,000X	9,000X	2,500X	4,000X
Signal Processing	5,500X	7,500X	7,000X	5,000X
Beam-forming + Small Cell	<b>14,500X</b>	10,500X	2,500X	1,500X
Signal Processing + Small Cell	7,500X	<b>14,500X</b>	<b>12,500X</b>	<b>7,500X</b>

**Improvement factors for different deployment environments & different mobile architectures & technologies**

# Small Cell Architecture Concept

Exploit path loss exponent laws  
Small cells deployment



## Potential Benefits of Small Cell Architectures:

- Lower overall power consumption,
- Intelligent sleep modes,
- Separated signaling and data functions,
- .....

Environment	Path Loss exponent, $\gamma$
Free Space	2
Urban Area	2.7 to 3.5
Suburban Area	3 to 5
Indoor (line-of-sight)	1.6 to 1.8

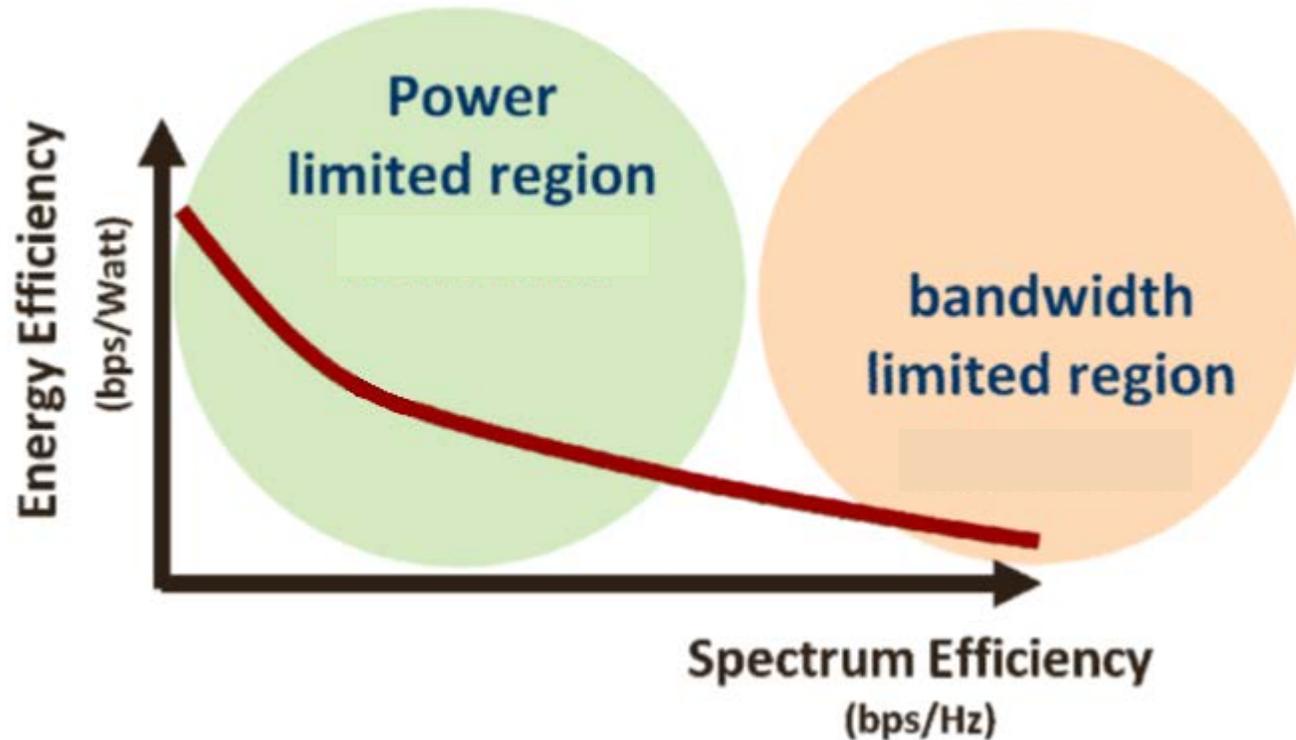
Power of n cells

Power of one large tower

$$nP_S = n^{1-\frac{\gamma}{2}} P_L$$

Less than one for  $\gamma > 2$

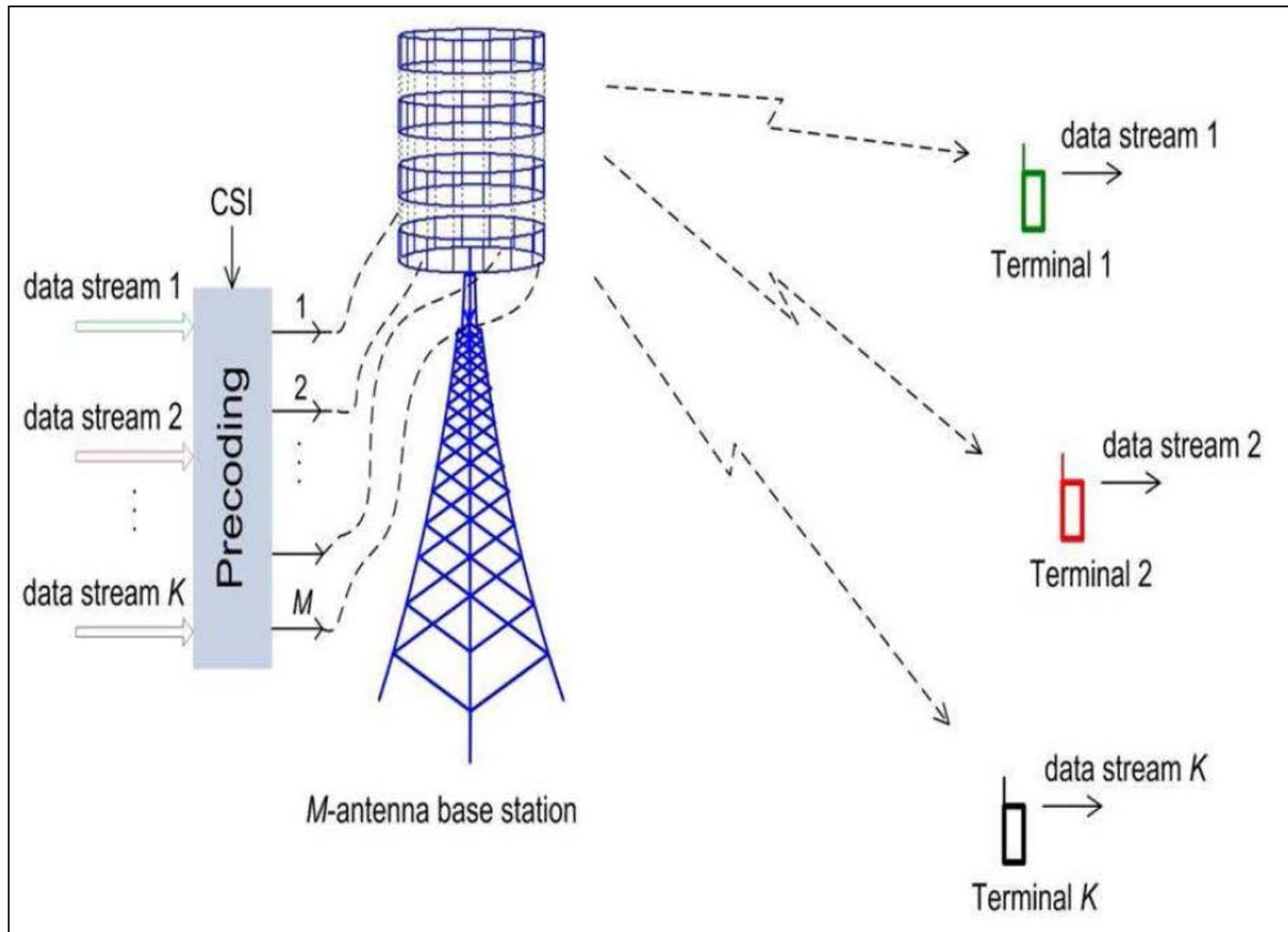
# Wireless Signal Processing Opportunity



**Technologies to optimize tradeoff between spectral efficiency and energy efficiency:**

- Single user and multi-user MIMO,
- Coordinated multi-point transmissions,
- Interference alignment.
- .....

# Antenna Beam-forming



**Replace cellular macro base stations with large number of antennas:**

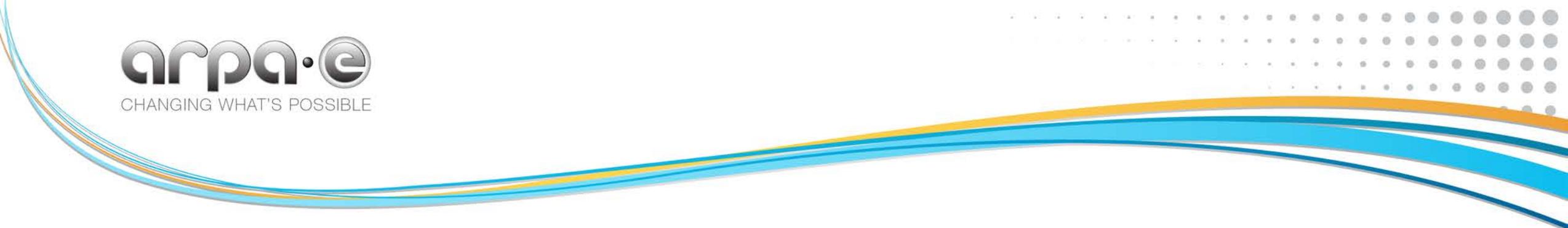
- Much smaller physically,
- Low-power,
- Individually-controlled,
- Delivering many user-selective data beams.
- .....

# Many Questions/Technical Challenges to ponder .....

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- ▶ How should small cell architecture be configured?
- ▶ How should we best exploit massive MIMO/antenna diversity?
- ▶ Are there other strategies that remain unexplored?
- ▶ What are the challenges and benefits of >20GHz spectrum (5G) deployment?
- ▶ Can RF energy harvesting help?
- ▶ Energy efficiency vs. cost of deployment trade-off?
- ▶ ... etc.

..... but which ones, if answered, could be *transformative*?



***Thank You!***

