Energy Efficiency in Cellular Networks

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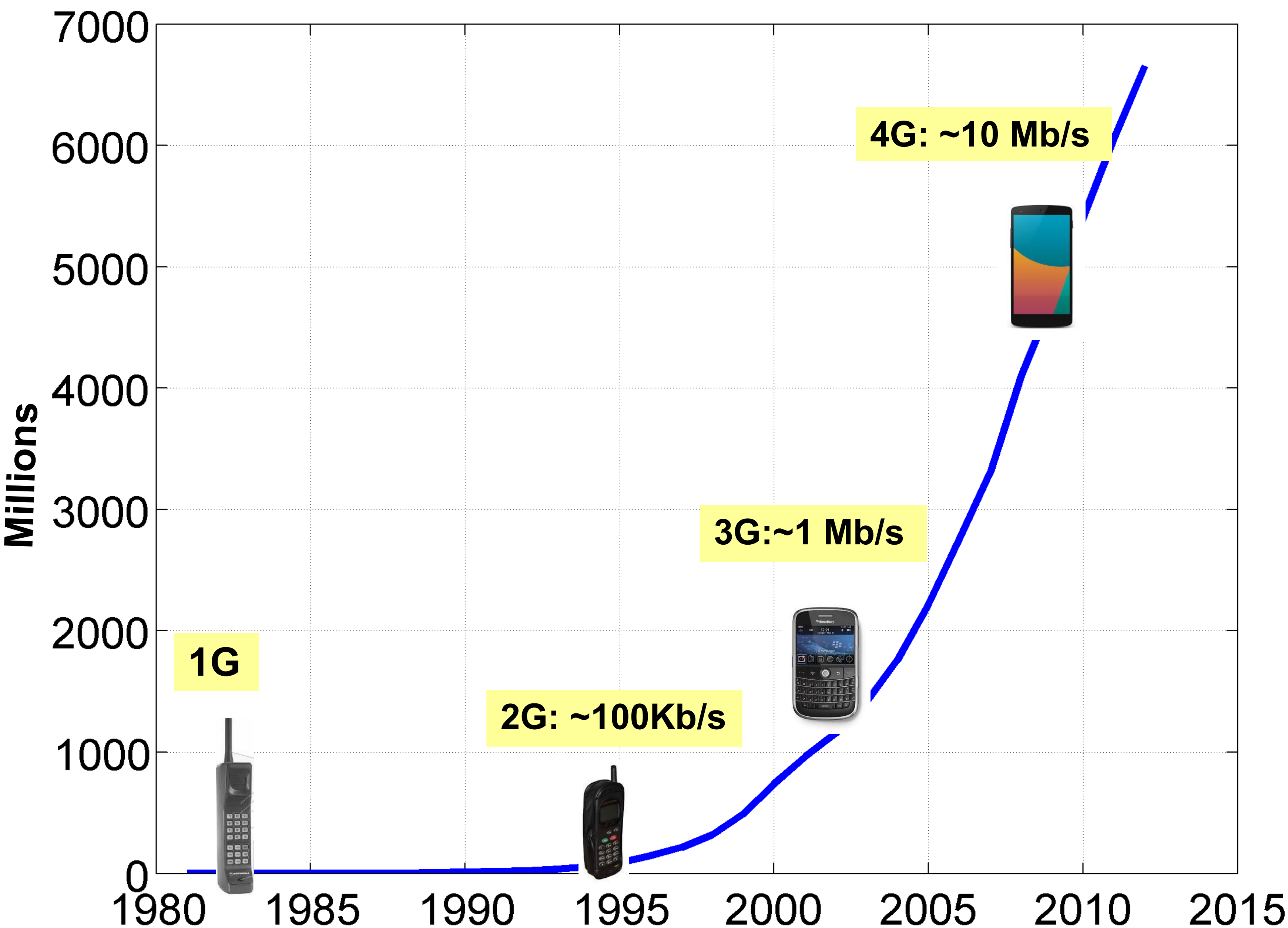
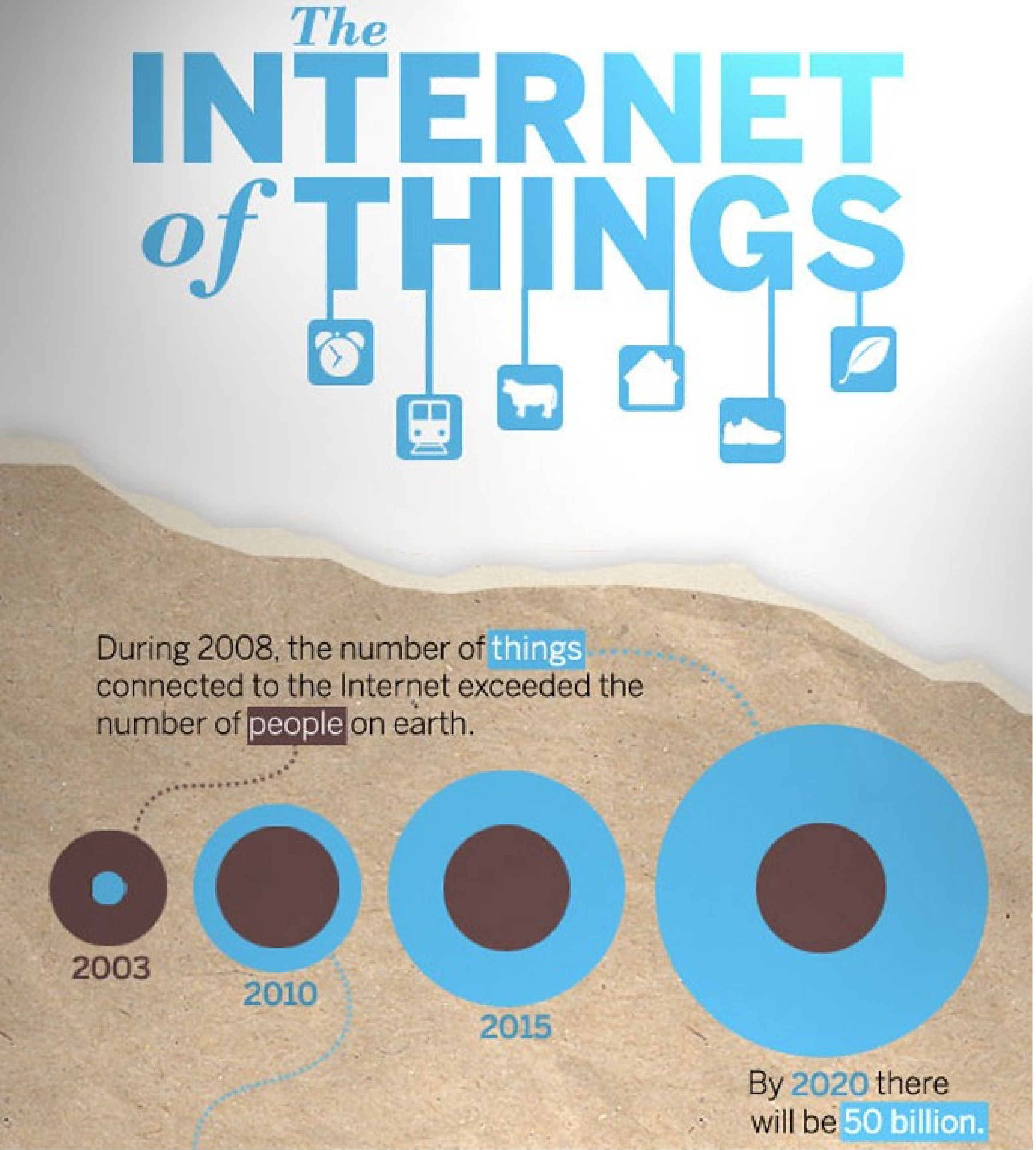


7000
6000
5000
4000
3000
2000
1000
0
Millions
1980
1985
1990
1995
2000
2005
2010
2015
1G
2G: ~100Kb/s
3G:~1 Mb/s
4G: ~10 Mb/s



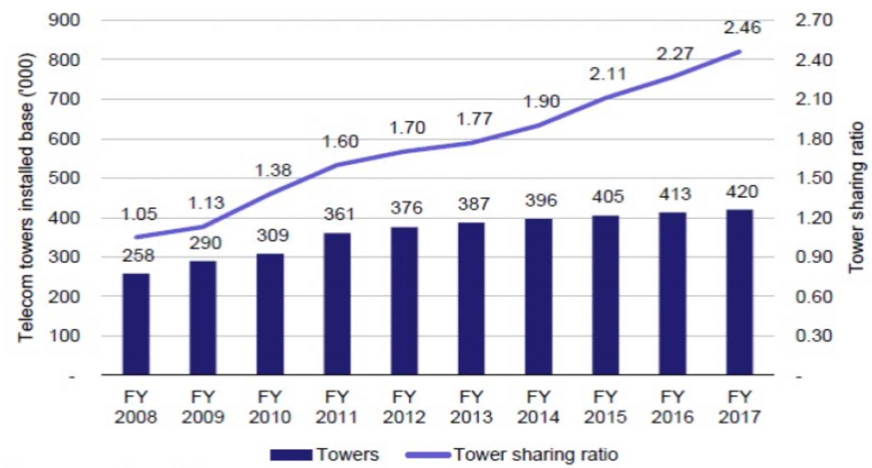
Cellular Network will connect the IOT

Source:Cisco

Case Study: Mobile Networks in India

- India has over 400,000 cell towers today
- 70%+ sites have grid outages in excess of 8 hours a day; 10% are completely off-grid
- Huge dependency on diesel generator sets for power backups
  - India imports 3 billion liters of diesel annually to support these cell sites
  - CO_2 emission exceeds 6 million metric tons a year
  - Energy accounts for ~25% of network opex for telcos
- As mobile services expand to remote rural areas, enormity of this problem grows

Telecom towers installed base and tenancy in India, financial year 2008 – financial year 2017

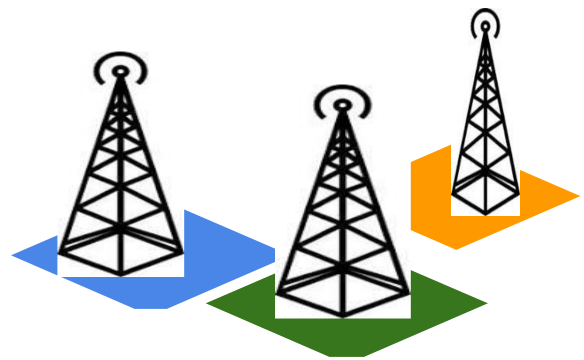


Source: Analysys Mason.

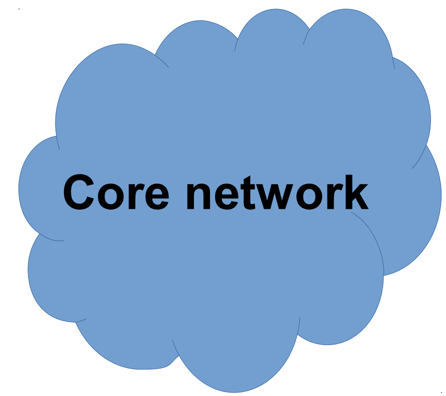
Cell Tower, DG Set, Grid

Power consumption breakup

Mobile devices



Radio access network



0.1 W x 7 B = 0.7 GW

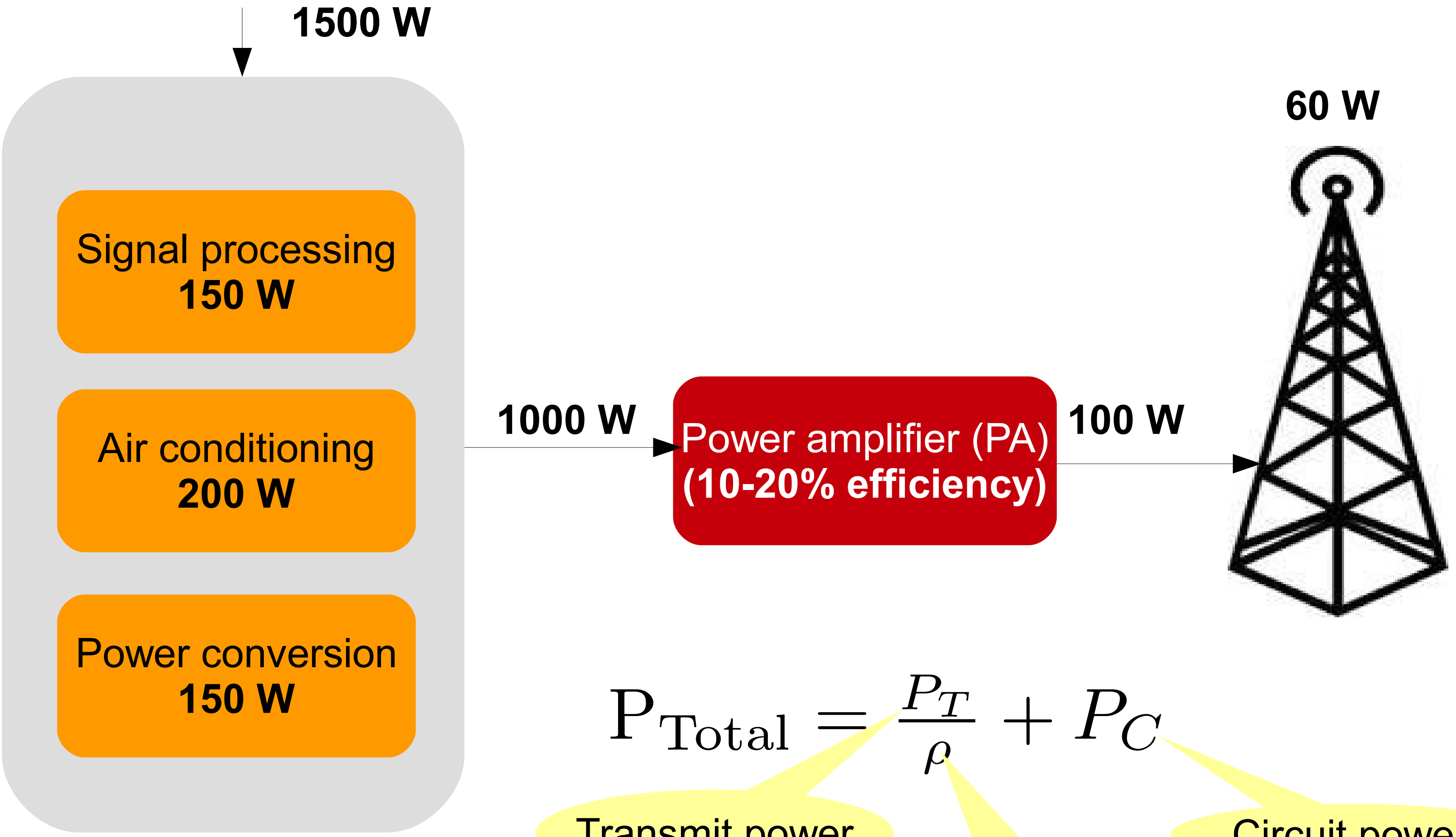
2 kW x 5M = 10 GW

10 kW x 10K = 0.1 GW

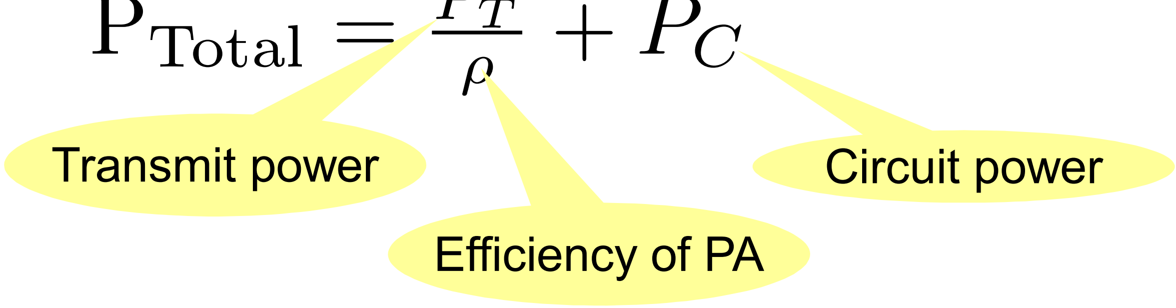
*Reference: Mid-size thermal plant output 0.5 GW

Source: Peng Mobicomm 2011

Base station energy consumption



$$P_{\mathrm{Total}} = \frac{P_T}{\rho} + P_C$$



Spectral Efficiency: bps/Hz (Shannon)

$$\eta_s = \log_2\left(1 + \frac{P_T R^{-3.5}}{N_0 B}\right)$$

Transmit power (P_T)

Distance (R)

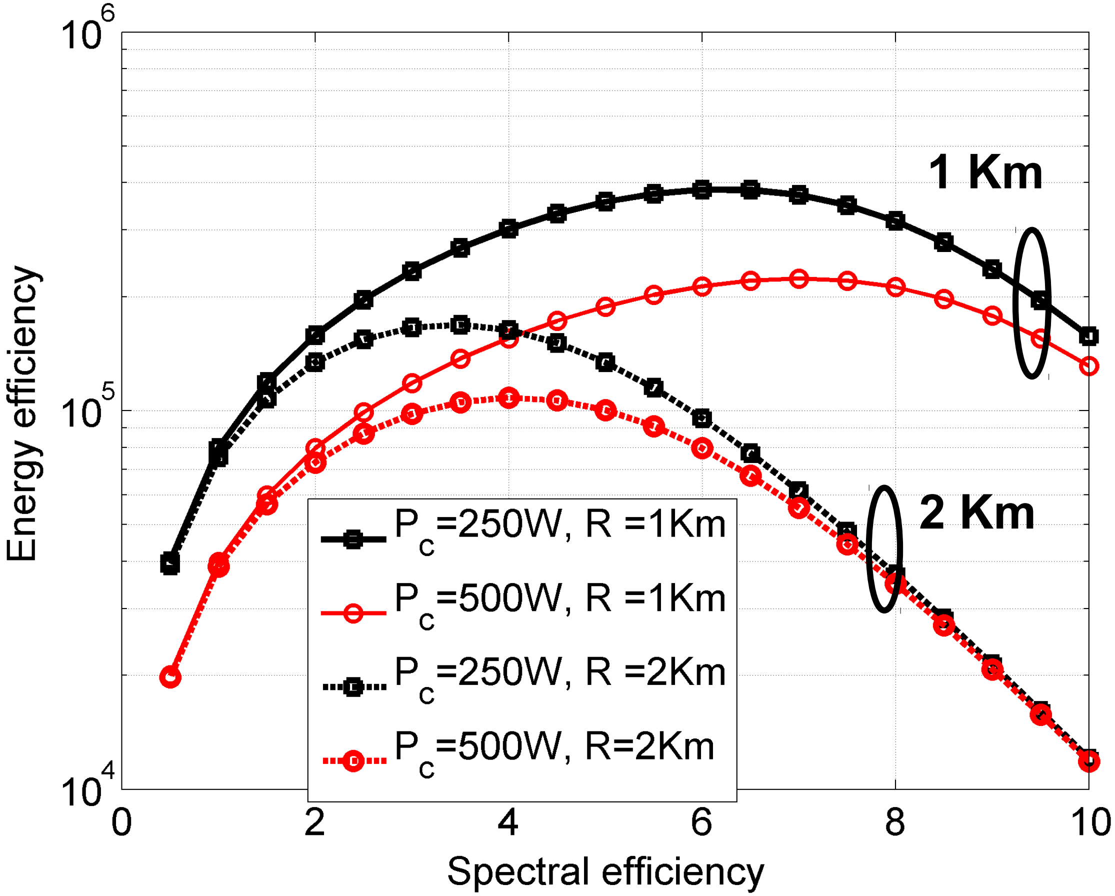
Bandwidth (B)

Noise power
Spectral density (N_0)

Cellular Standard	Spectral efficiency
1G (AMPS)	0.46
2G (GSM)	1.3
3G (WCDMA)	2.6
4G (LTE)	4.26

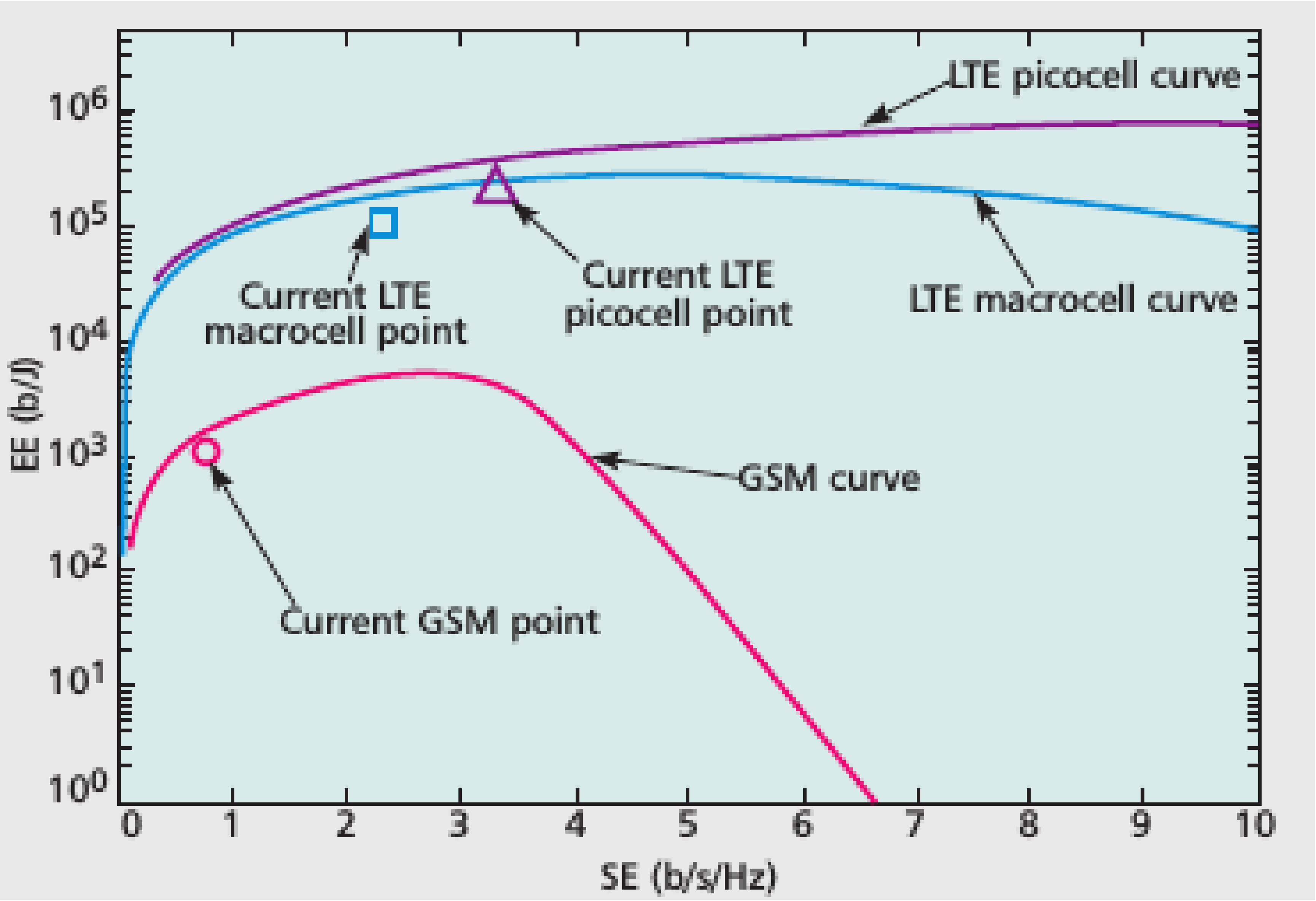
Energy Efficiency: Bits per Joule

$$\eta_E = \frac{\eta_s B}{\frac{P_T}{\rho} + P_C}$$



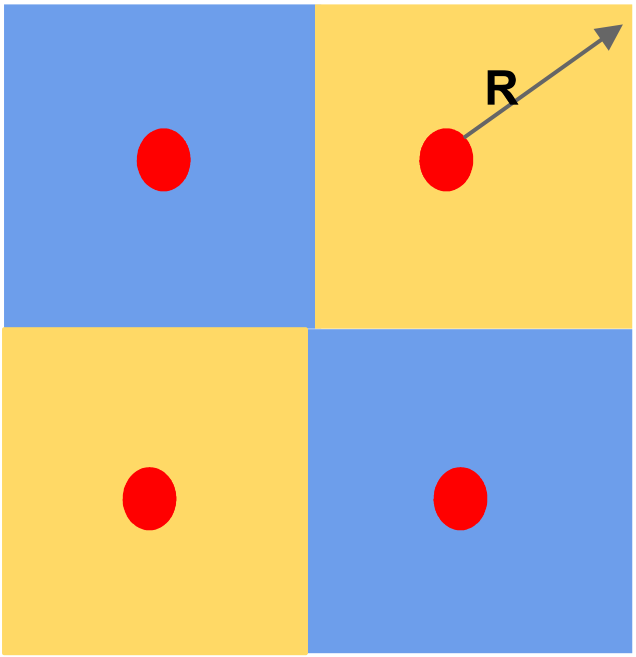
EE versus SE for PA efficiency of 20%

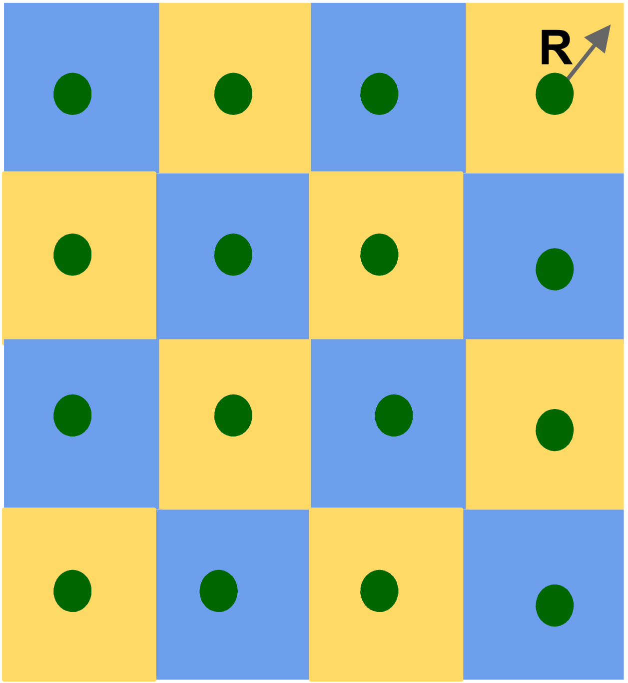
Current status



Source: IEEE Wireless Comm. Mag.

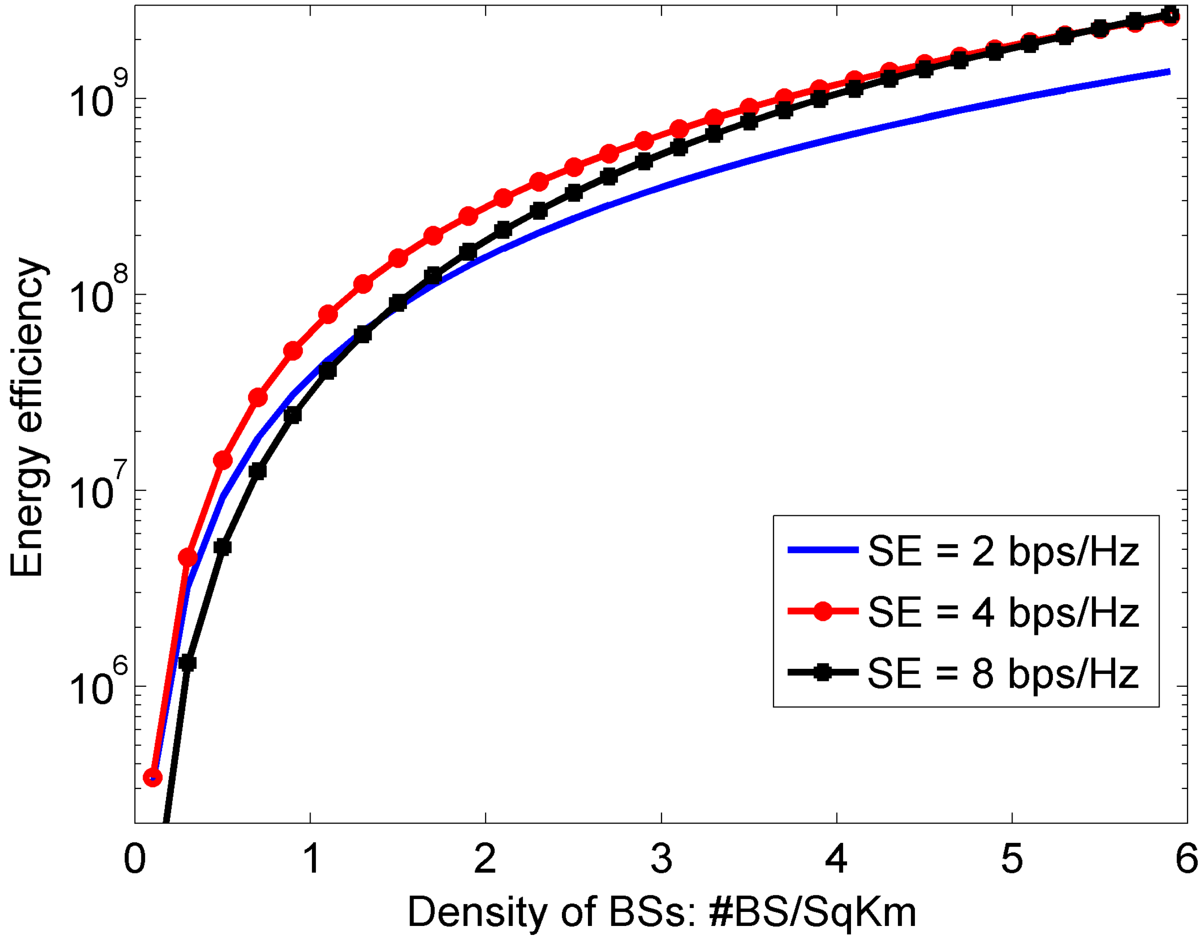
Small cells





$$\frac{P_T}{P_T} = 2^{3.5}$$

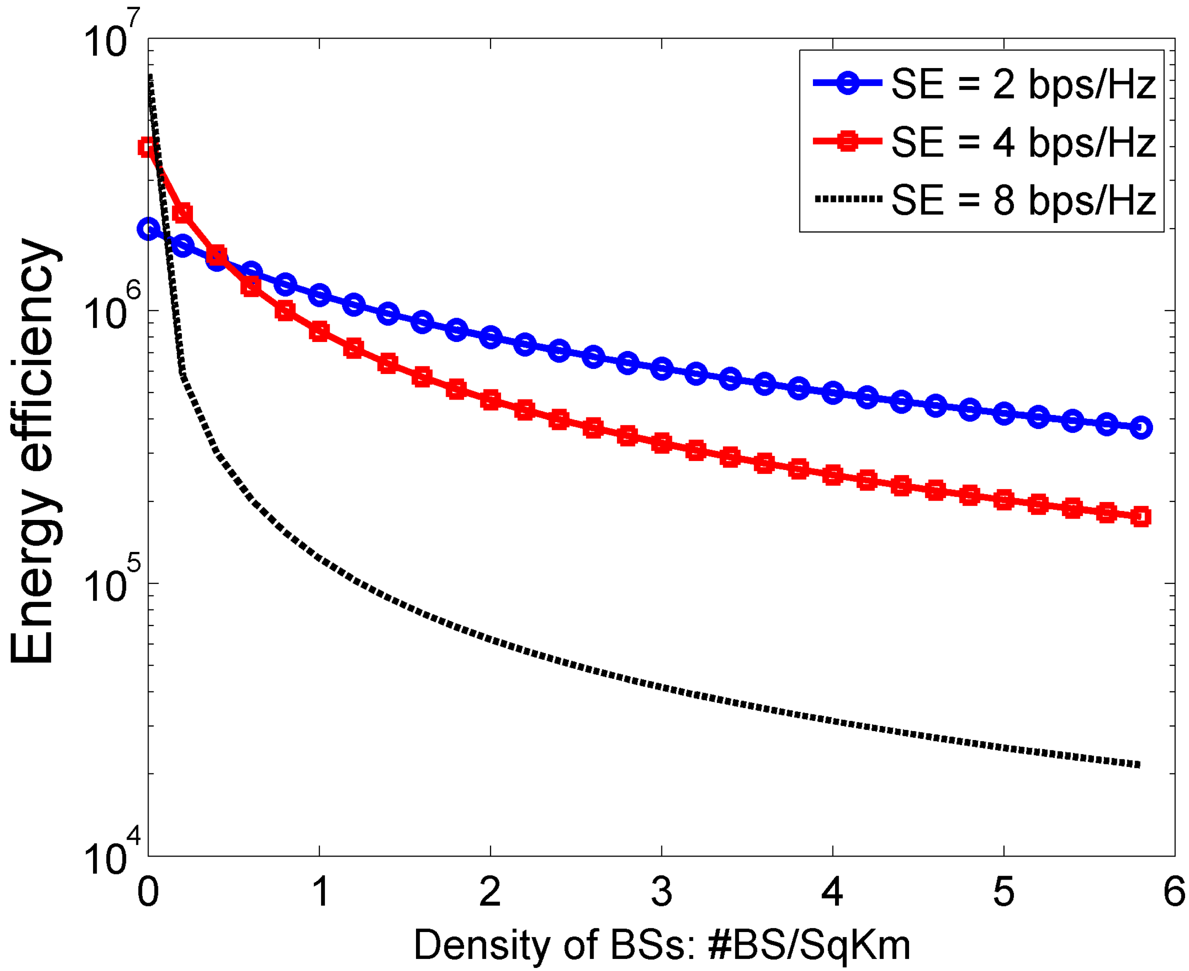
EE versus BS density: Single cell



EE versus base station density **without** inter-cell interference

Reduction in transmit and operational power

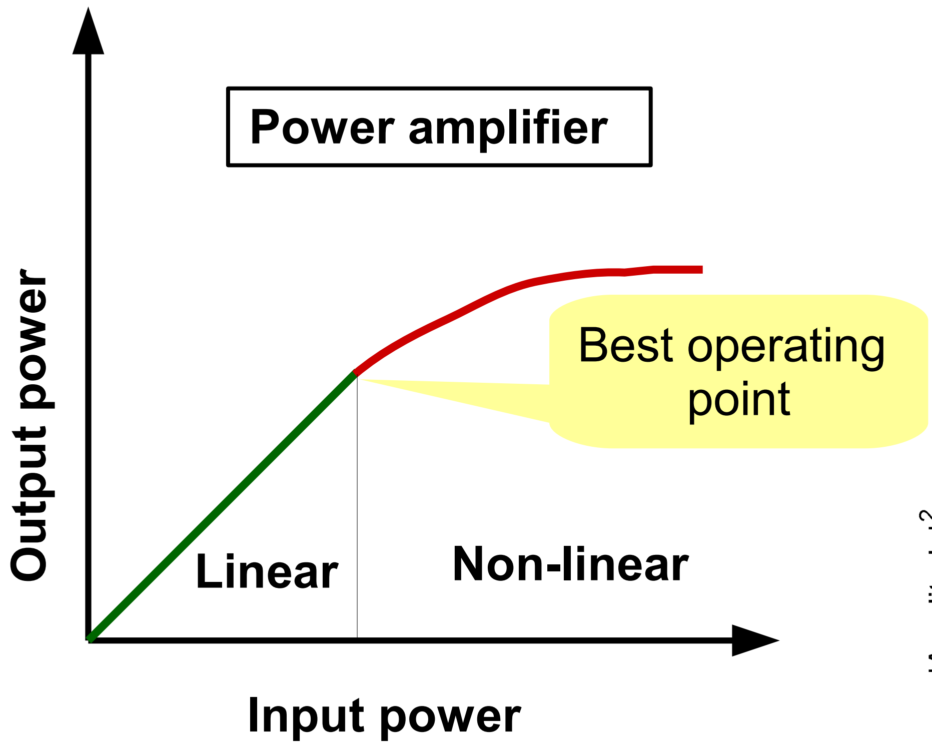
EE versus BS density: Multicell



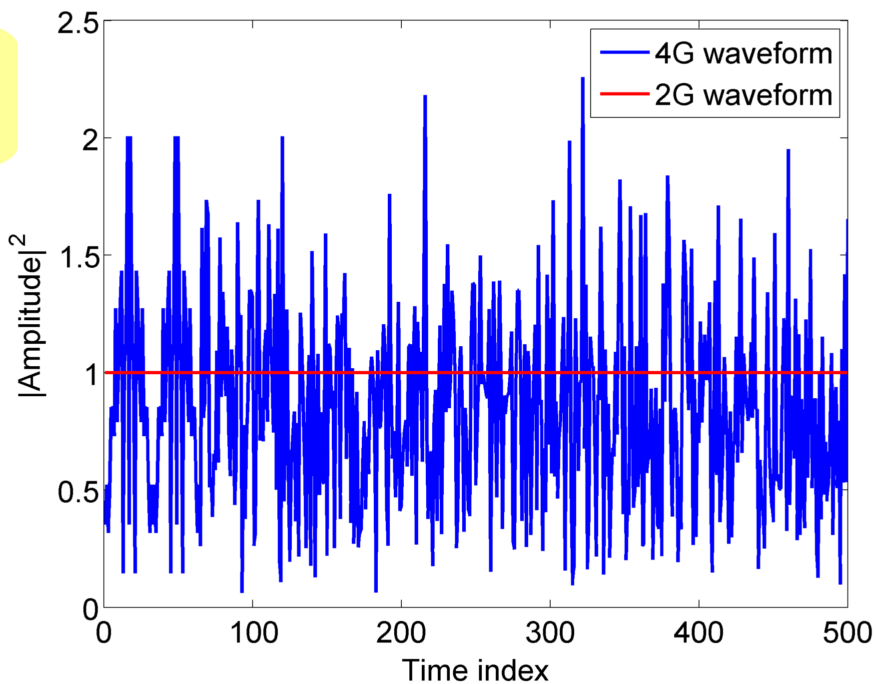
EE versus base station density **with** inter-cell interference

Challenge: Interference management

Transmit waveform

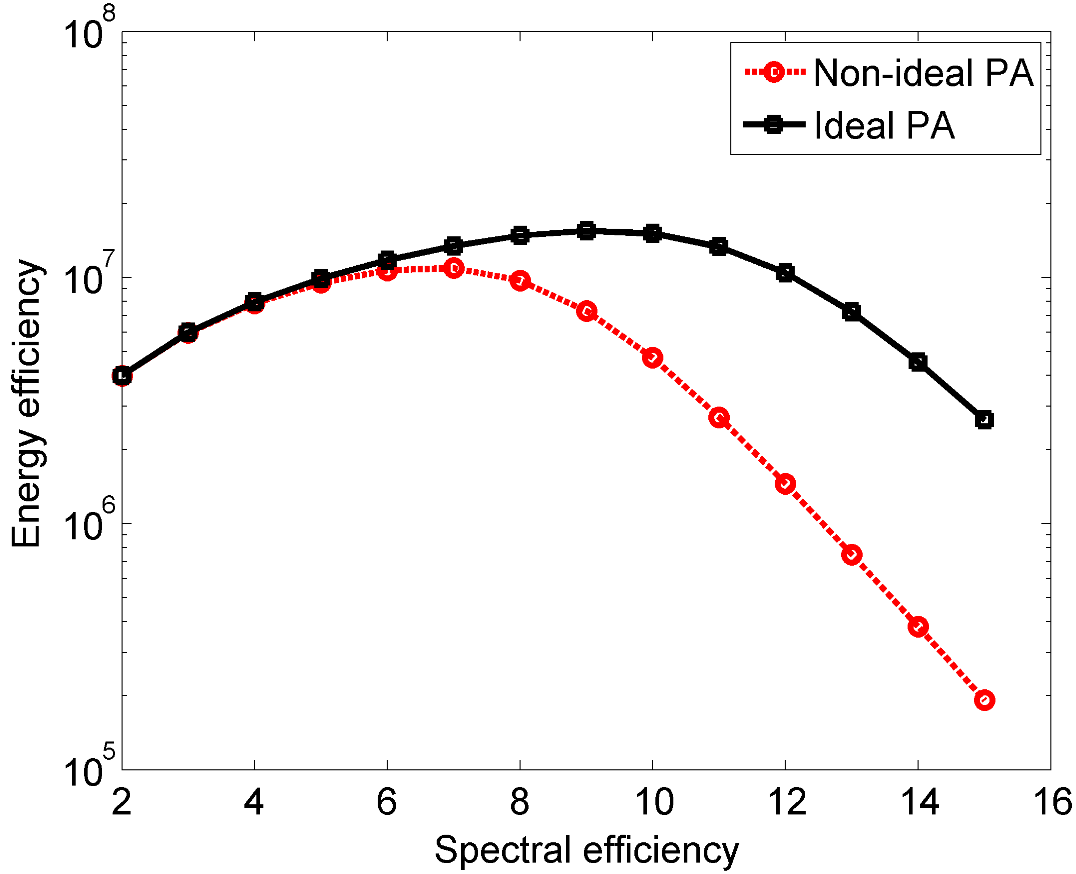


- Operating point depends on the swing of the signal
  - Peak-to-average power ratio (PAPR)
- Spectral efficiency is proportional to signal PAPR



2G versus 4G

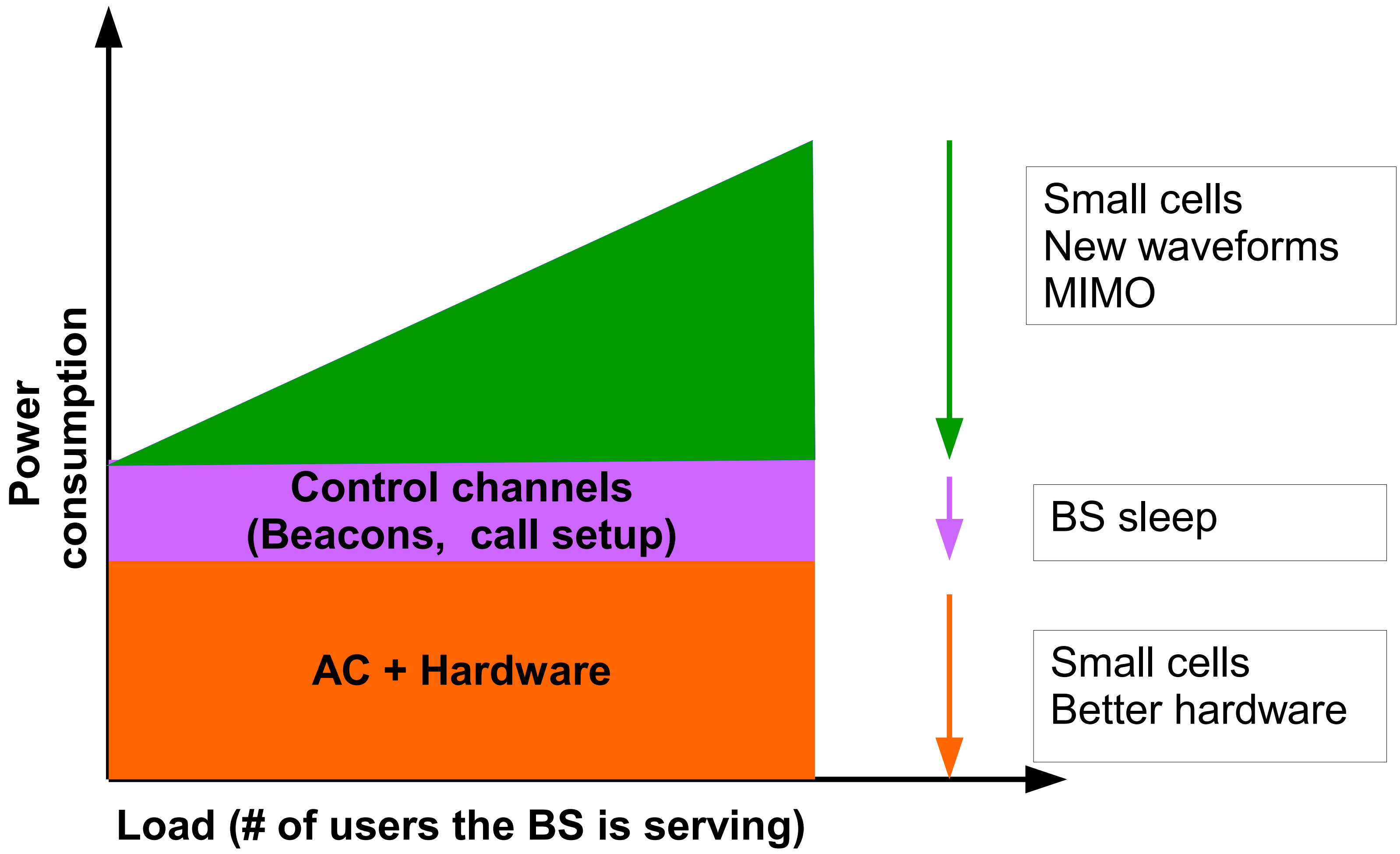
EE versus SE: non-ideal PA



EE versus SE

Challenge:Designing better waveforms

BS energy consumption versus load



Conclusions

- Great potential for energy savings
  - EE should be a norm (rather than a consequence)

- Scope for innovative ideas
  - EE improvement with interference
  - Better waveforms
  - Cellular system without control channels
- PA main culprit
  - Better efficiency required