institute IMdea
madrid institute for advanced studies

www.networks.imdea.org

Bounds on QoS-Constrained Energy Savings in Cellular Access Networks with Sleep Modes

Balaji Rengarajan, Gianluca Rizzo,
and Marco Ajmone Marsan

ITC 2011

institute IMdea networks

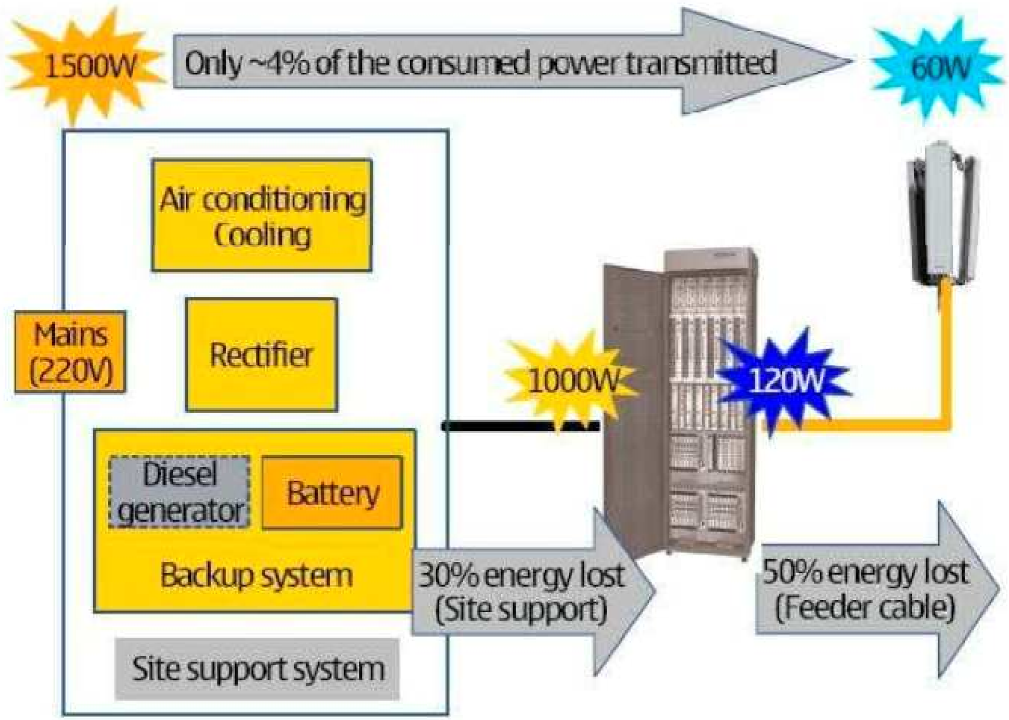
madrid institute for advanced studies

Introduction

- ICT must become energy efficient
  - They account for 2% to 10% of total power consumption

- In wireless access networks, greener is (much) cheaper
  - For mobile operators, energy is a large share of the OPEX
  - Base stations consume 60% to 80% of the total power

Wasteful Design

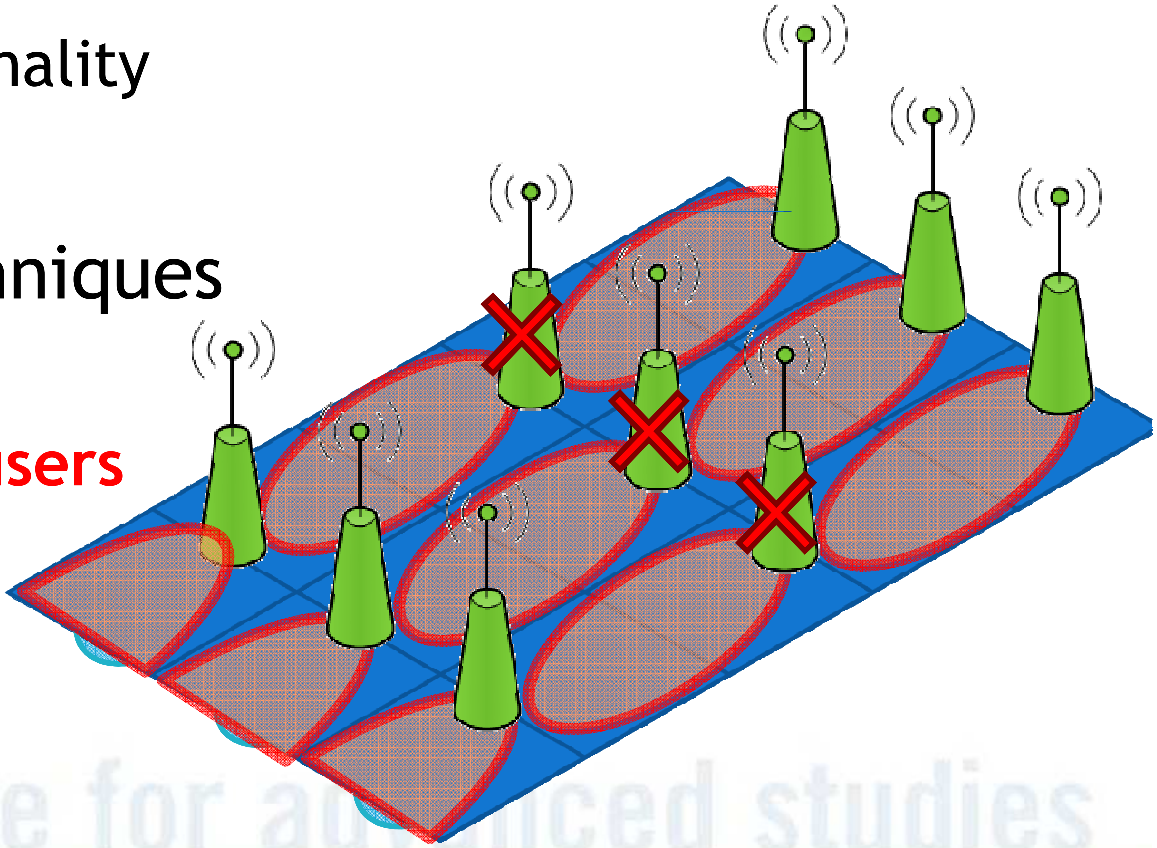


- BSs today consume the same power irrespective of traffic

- Networks are provisioned for peak load

How Can We Improve?

- Build better base stations
  - Energy-proportionality
- System level techniques
  - Sleep modes
  - **Transparent to users**

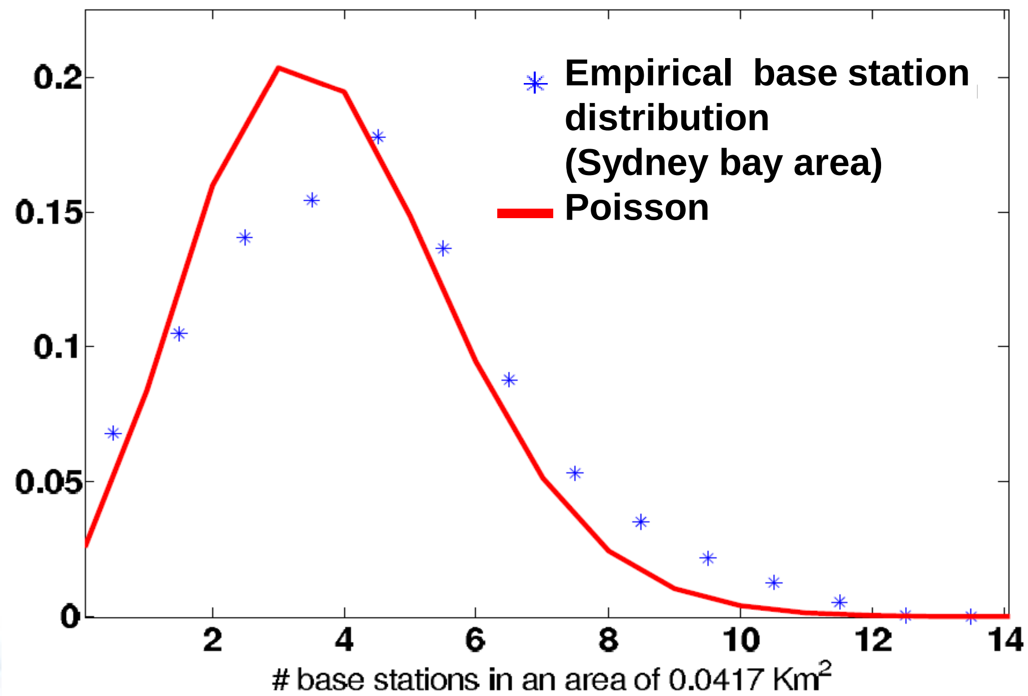


How much power can be saved with QoS-constrained sleep modes?

- Several sleep mode algorithms exist
  - Very different techniques, different performance
- Open issues:
  - What are the maximum achievable power savings in sleep modes with QoS constraints?
  - Should we improve base stations or adopt sleep modes?
- QoS Metric: per-bit delay perceived by a typical user, τ
  - Maintain below a threshold, τ^0

System model

- Users: homogeneous planar Poisson point process
- Base stations layout: Manhattan, Hexagonal, or Poisson point process
  - User associate to the closest base station
  - Only best effort traffic
  - Processor Sharing
  - Transmit power is fixed



We evaluate the impact of load proportionality on power savings

- When on, power consumption is:

$$k_1 + k_2 U$$

  - U= $\frac{\tau}{\tau_0}$ base station utilization

- k1 >> k2: “On-off” energy model (current BSs)
- k2 > k1: load proportional energy model
- Energy Proportionality: $\frac{k_2}{k_1 + k_2}$

Computing Expected Per-bit Delay

$$\tau = \mathrm{E}^0 \left[\frac{\text{Number of users sharing the serving base station}}{\text{Capacity to the serving base station}} \right]$$

- Manhattan, hexagonal BS layouts
  - Regular cells
  - More users farther from BS than close by
- Poisson layout
  - Variable cell sizes
  - More users belong to larger cells

Finding the energy optimal BS density

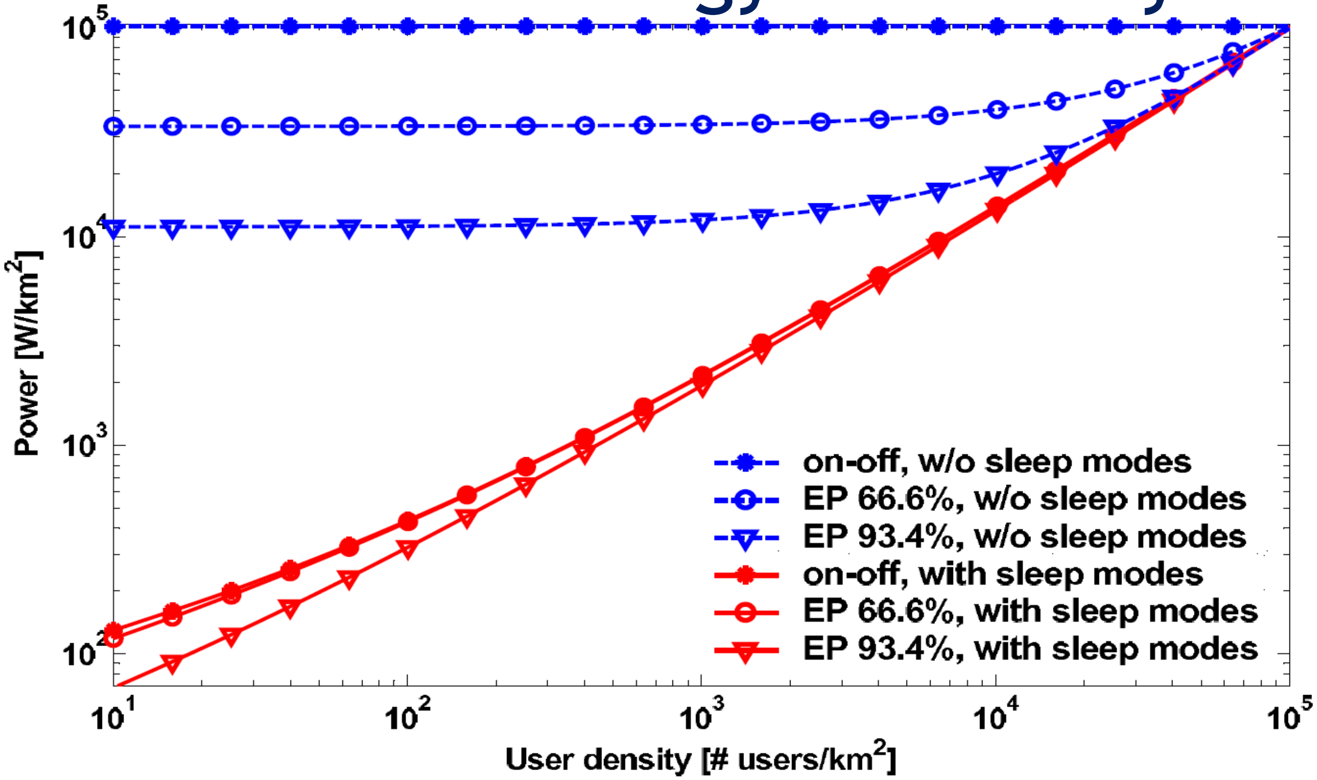
- Given density of base stations and users, we can find per-bit delay seen by a typical user.
- On-Off model: Use binary search to find the minimum BS density satisfying threshold τ_0
- Load-proportional model: BS utilization is $\frac{\tau}{\tau_0}$

A bound on BS density

- A BS-layout independent bound on the minimum base station density

- A feasible BS layout with density at most 17% higher exists.

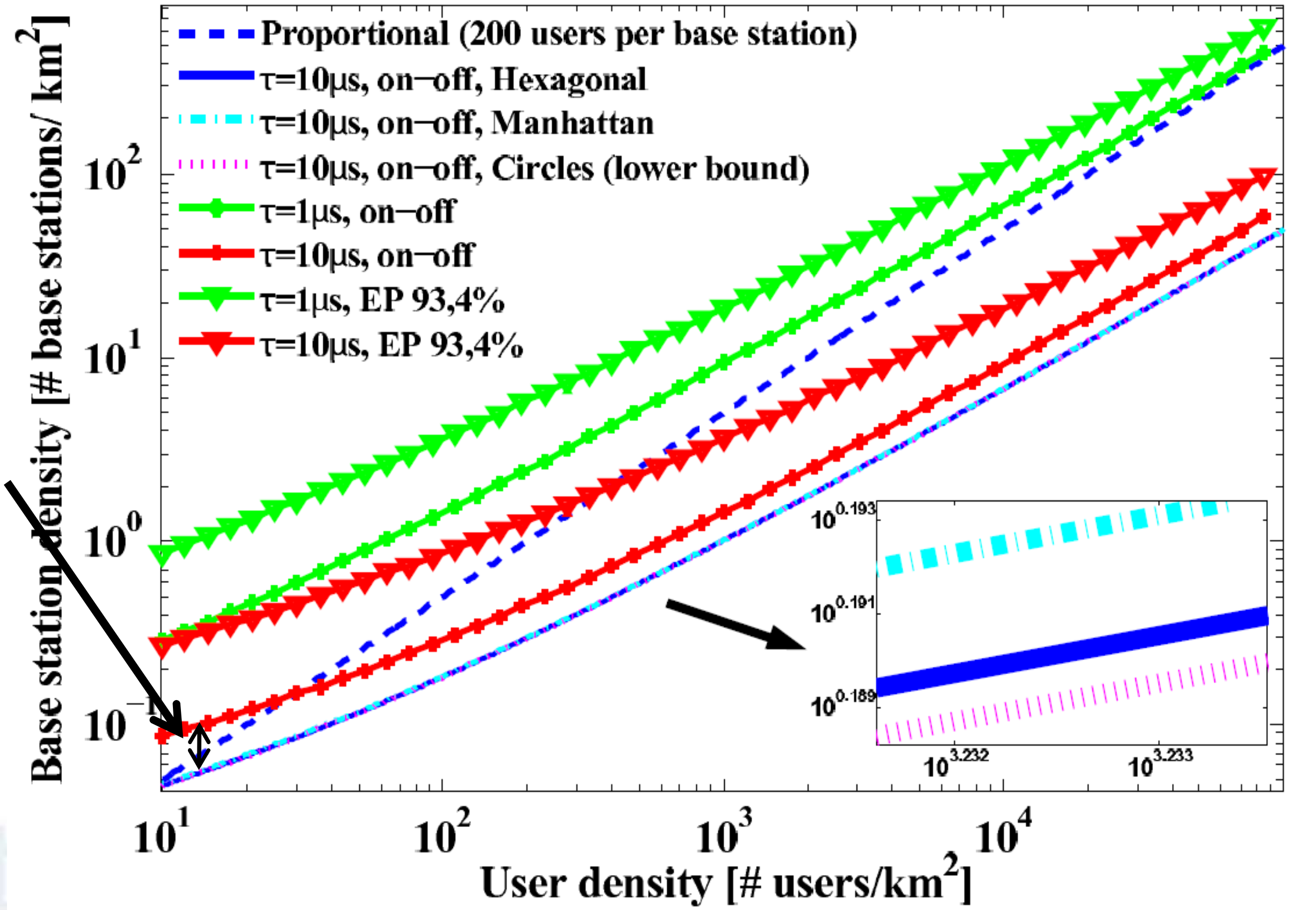
A holistic approach is essential to achieving maximum energy efficiency



- High user densities: energy proportional hardware is enough
- At low user densities, sleep modes perform better

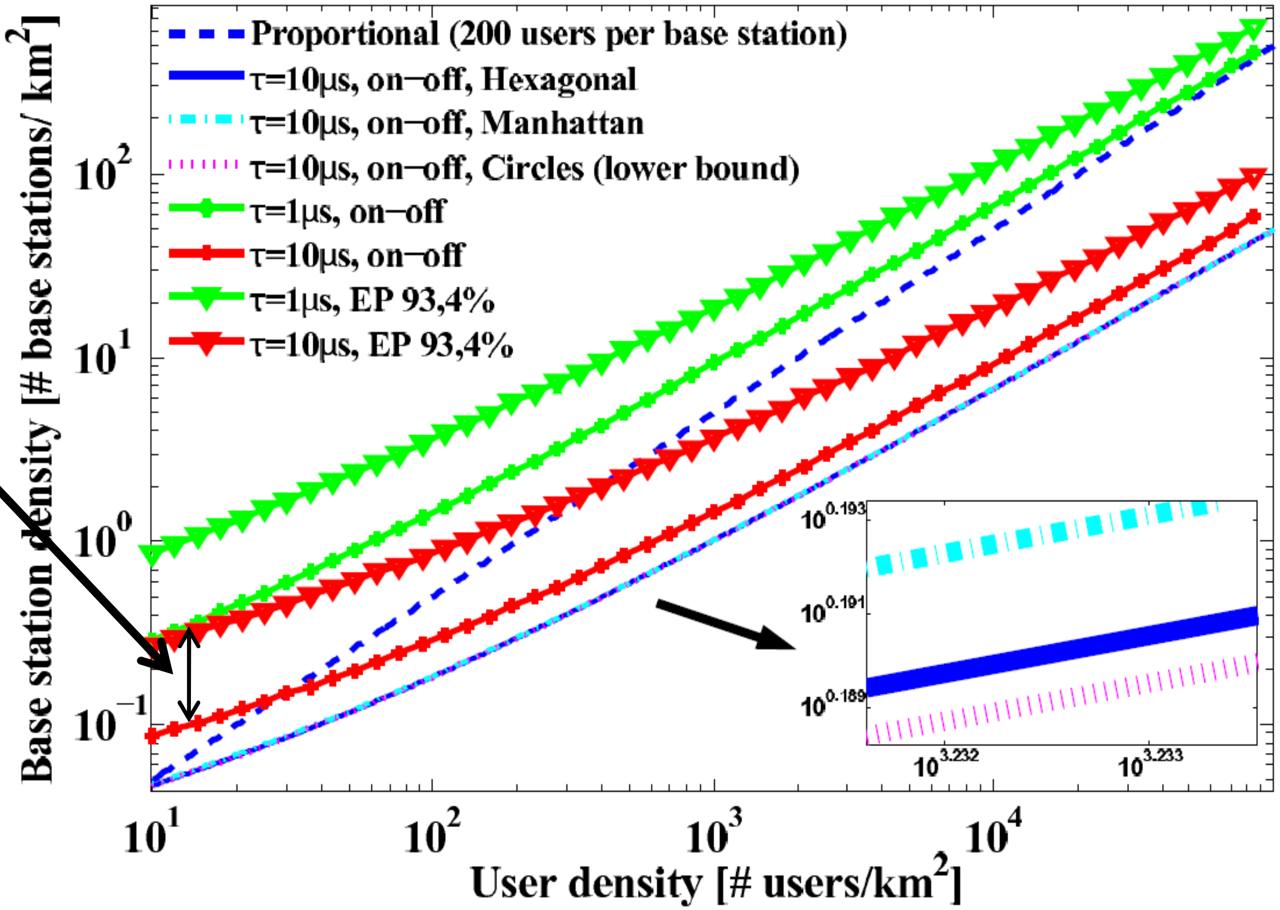
Under QoS constraints, the energy-optimal base station density is not proportional to user density

- Regular base station layouts are more efficient



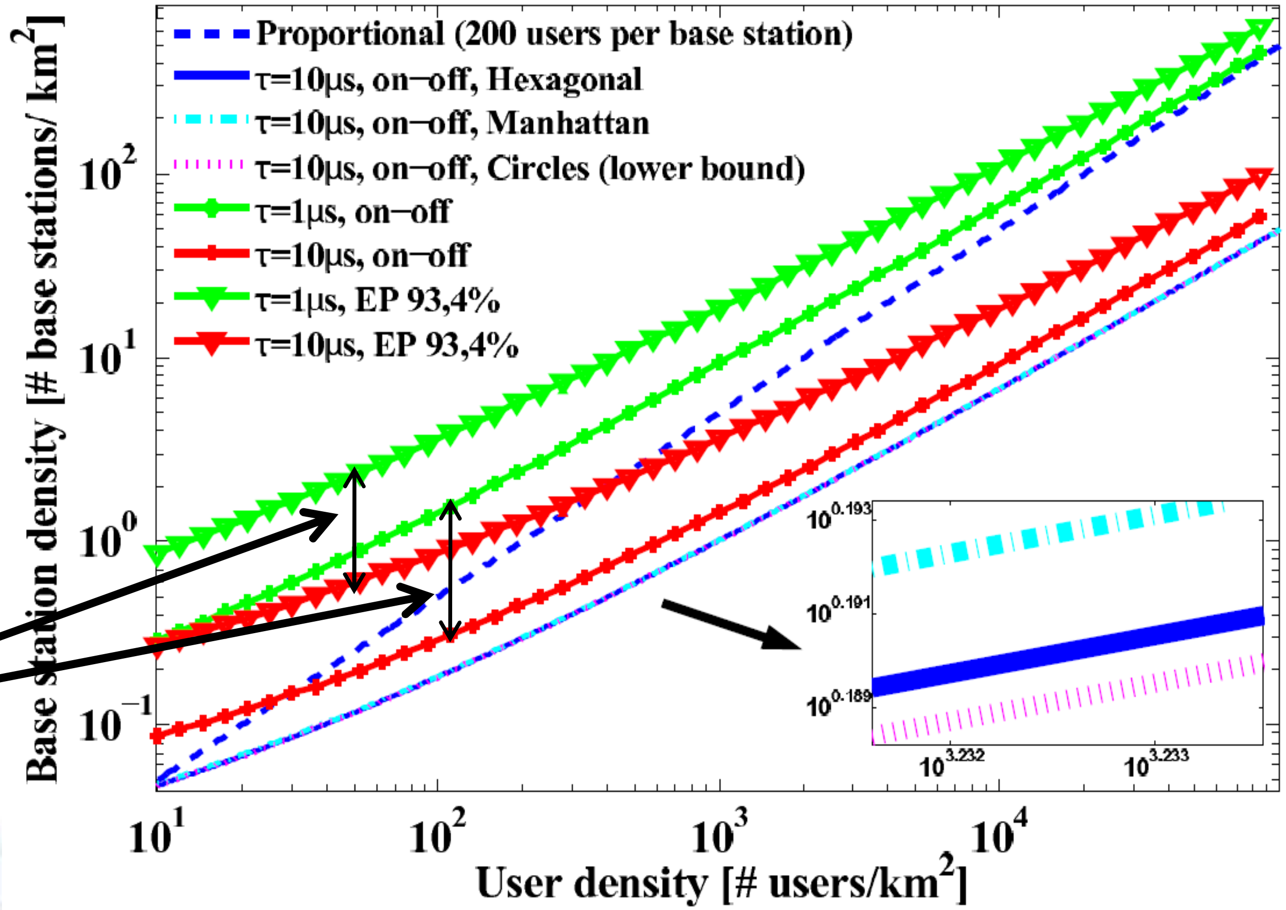
Under QoS constraints, the energy-optimal base station density is not proportional to user density

- higher energy proportionality brings to higher base station densities



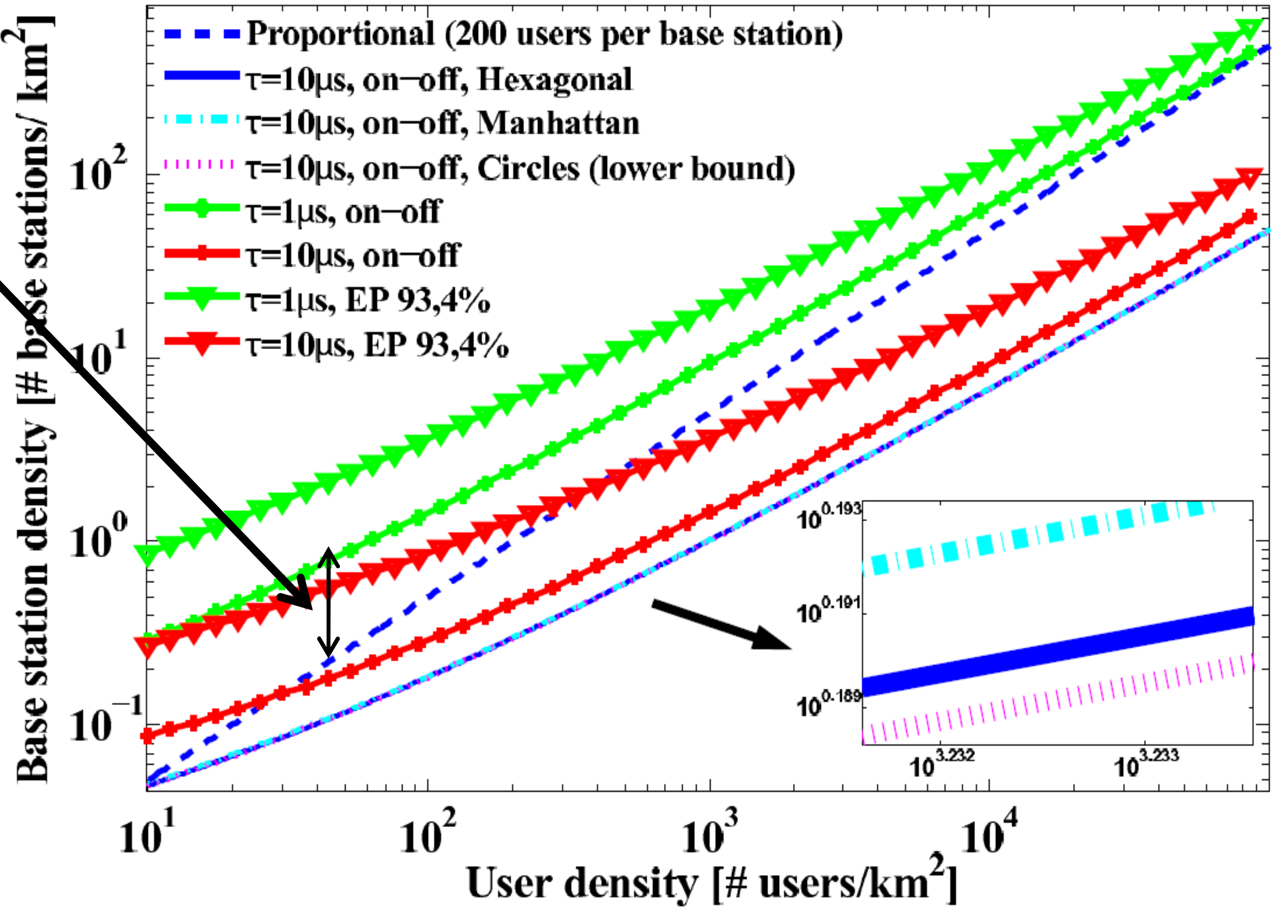
Under QoS constraints, the energy-optimal base station density is not proportional to user density

- Tighter QoS constraints lead to higher bs densities

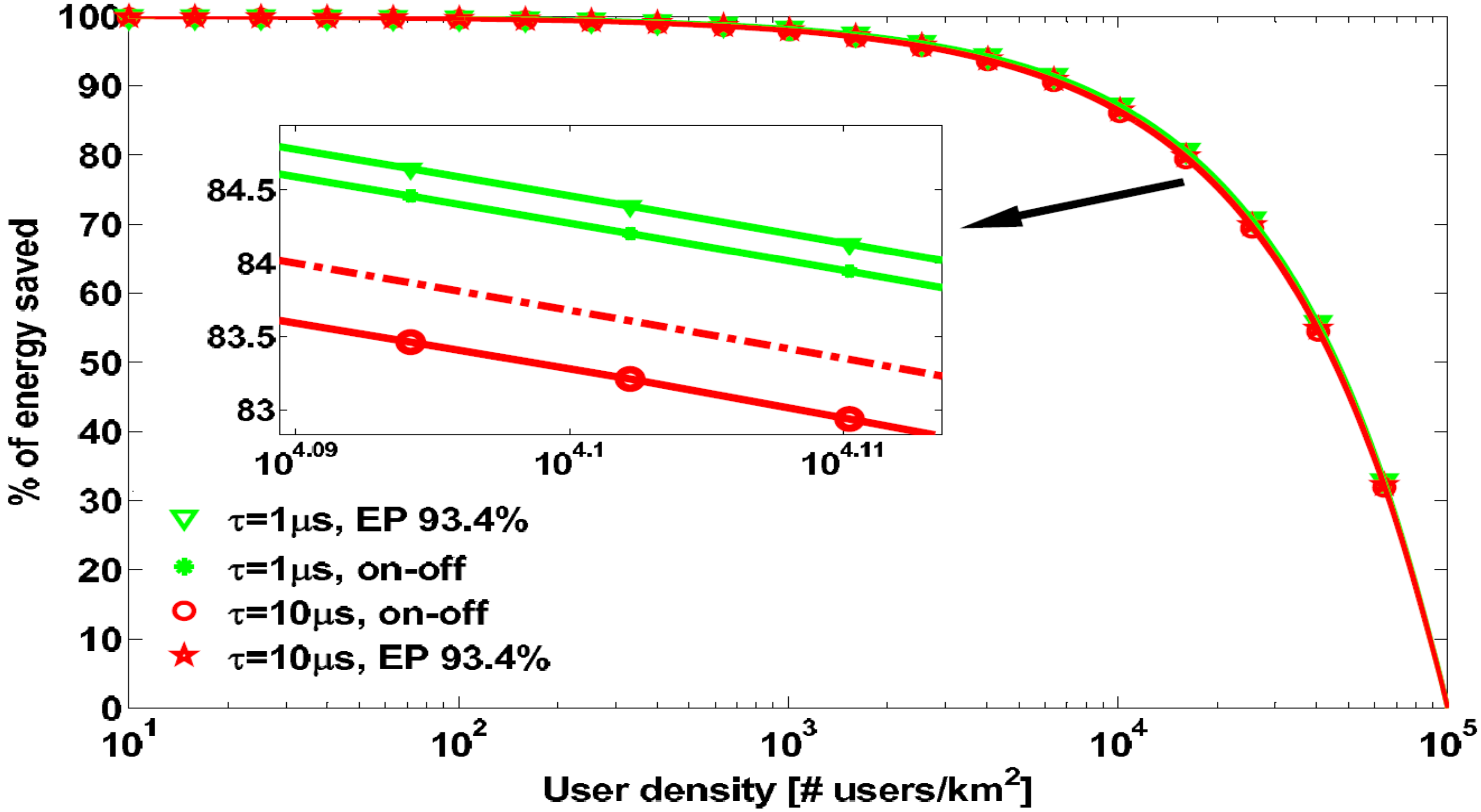


Under QoS constraints, the energy-optimal base station density is not proportional to user density

- QoS constraints increase bs density at low loads



A discrete set of base stations densities allows to achieve high energy savings

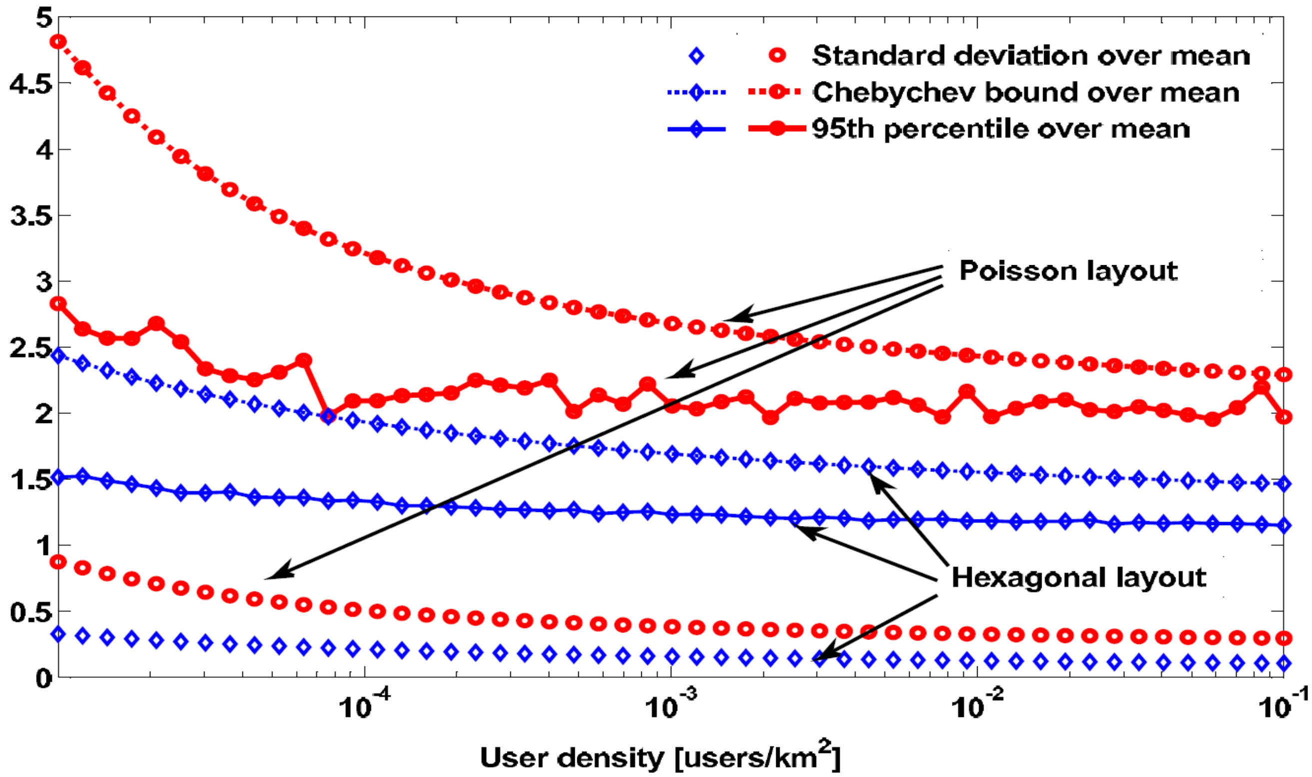


Conclusion

- We derived QoS-aware estimates of possible energy savings in wireless access networks with sleep modes
  - Large (theoretical) margins for energy savings
- Energy proportional base stations cannot substitute for sleep modes
  - System-level techniques and hardware improvements are complementary
- Extensions of this work:
  - Clustered user distributions
  - Mixed voice/best effort traffic

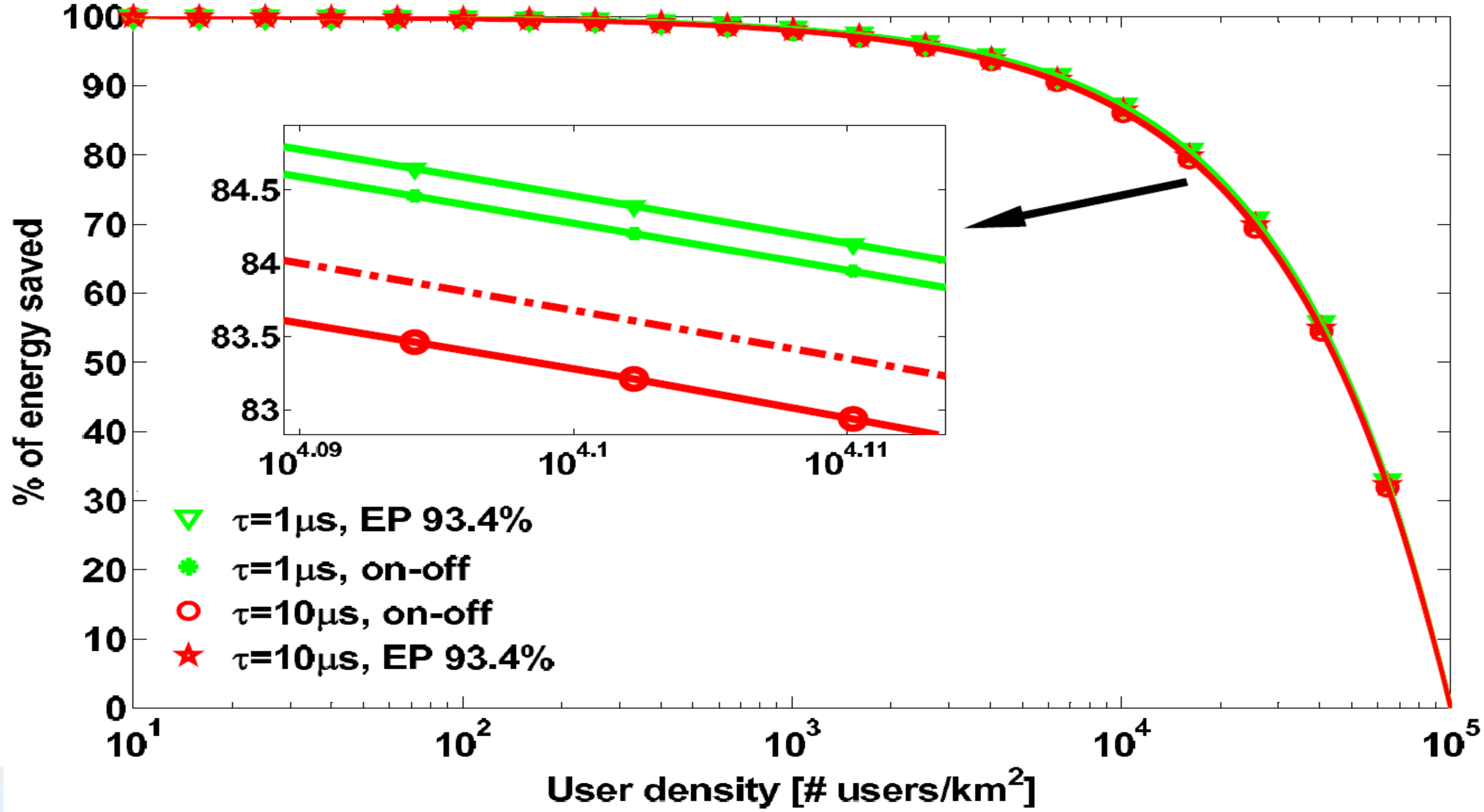
OTHER SLIDES

The mean per-bit delay is a reliable estimate of the global QoS perceived by users

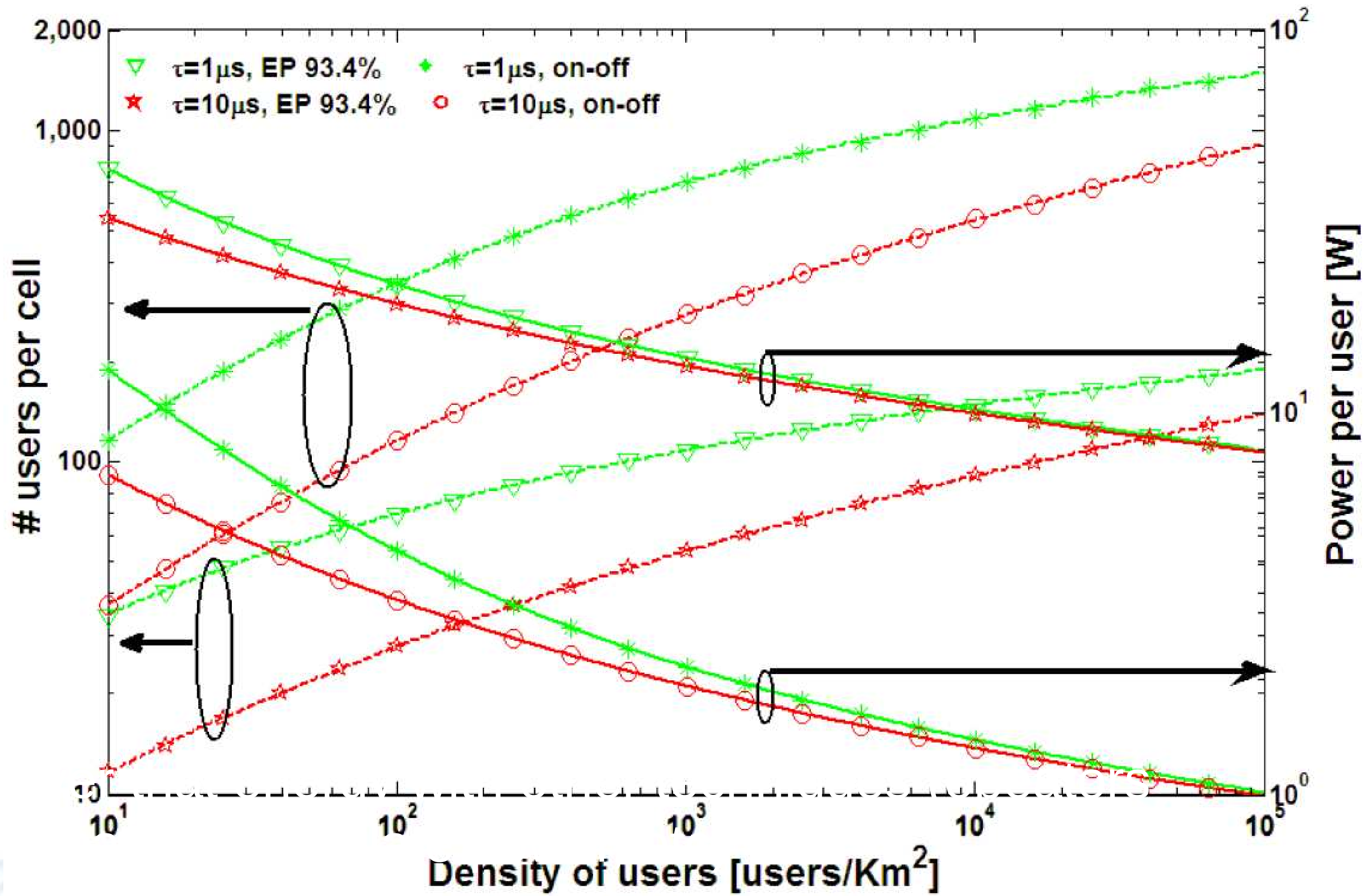


We can safely design the system using mean per bit delay

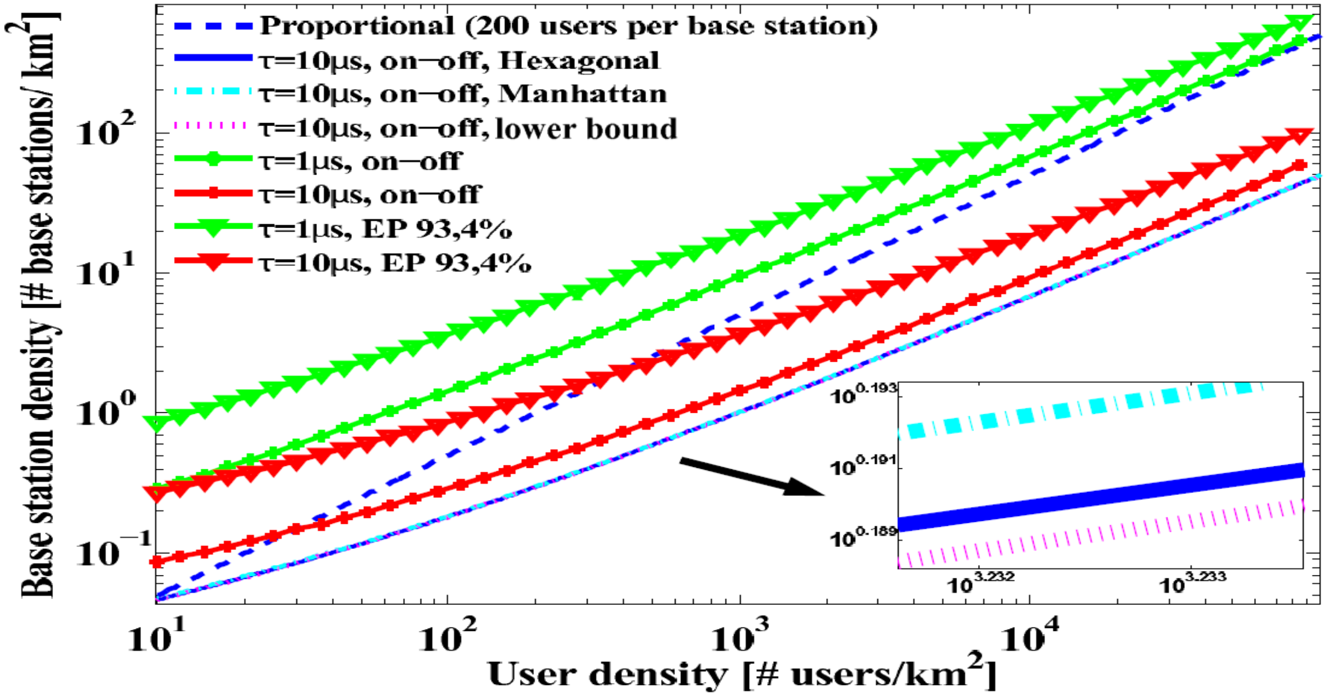
A discrete set of base stations densities allows to achieve high energy savings



Serving users at low loads is inefficient

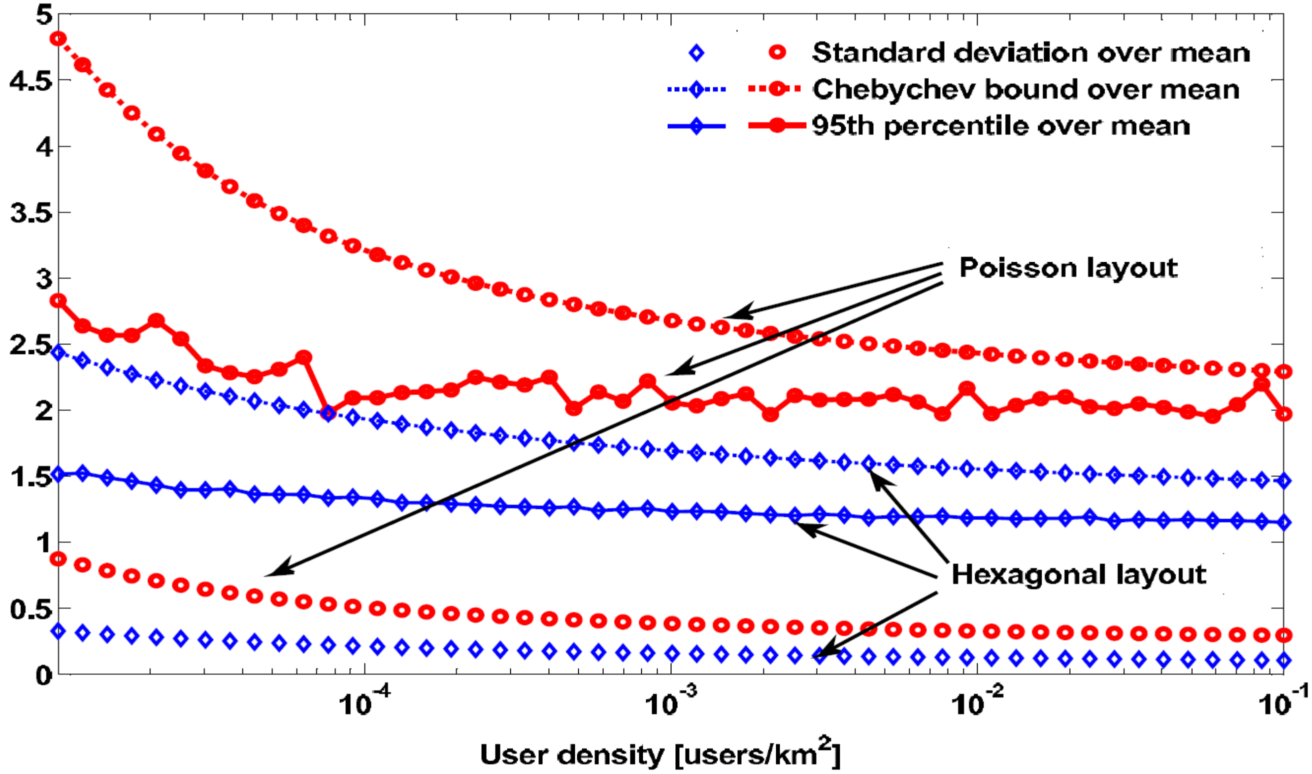


Under QoS constraints, the energy-optimal base station density is not proportional to user density



With EP base stations, energy optimal configurations have higher bs densities and bs are less loaded

The mean per-bit delay is a reliable estimate of the global QoS perceived by users



We can safely design the system using mean per bit delay