Optimal sleep-wakeup modes for small cells in mobile networks

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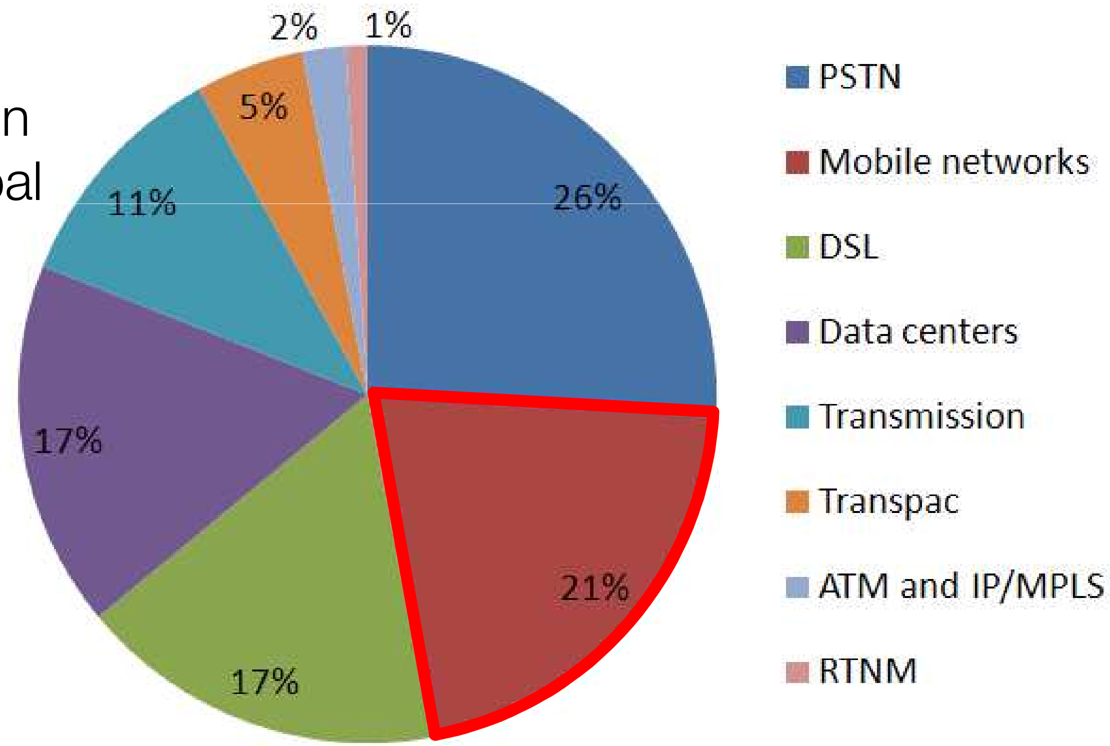
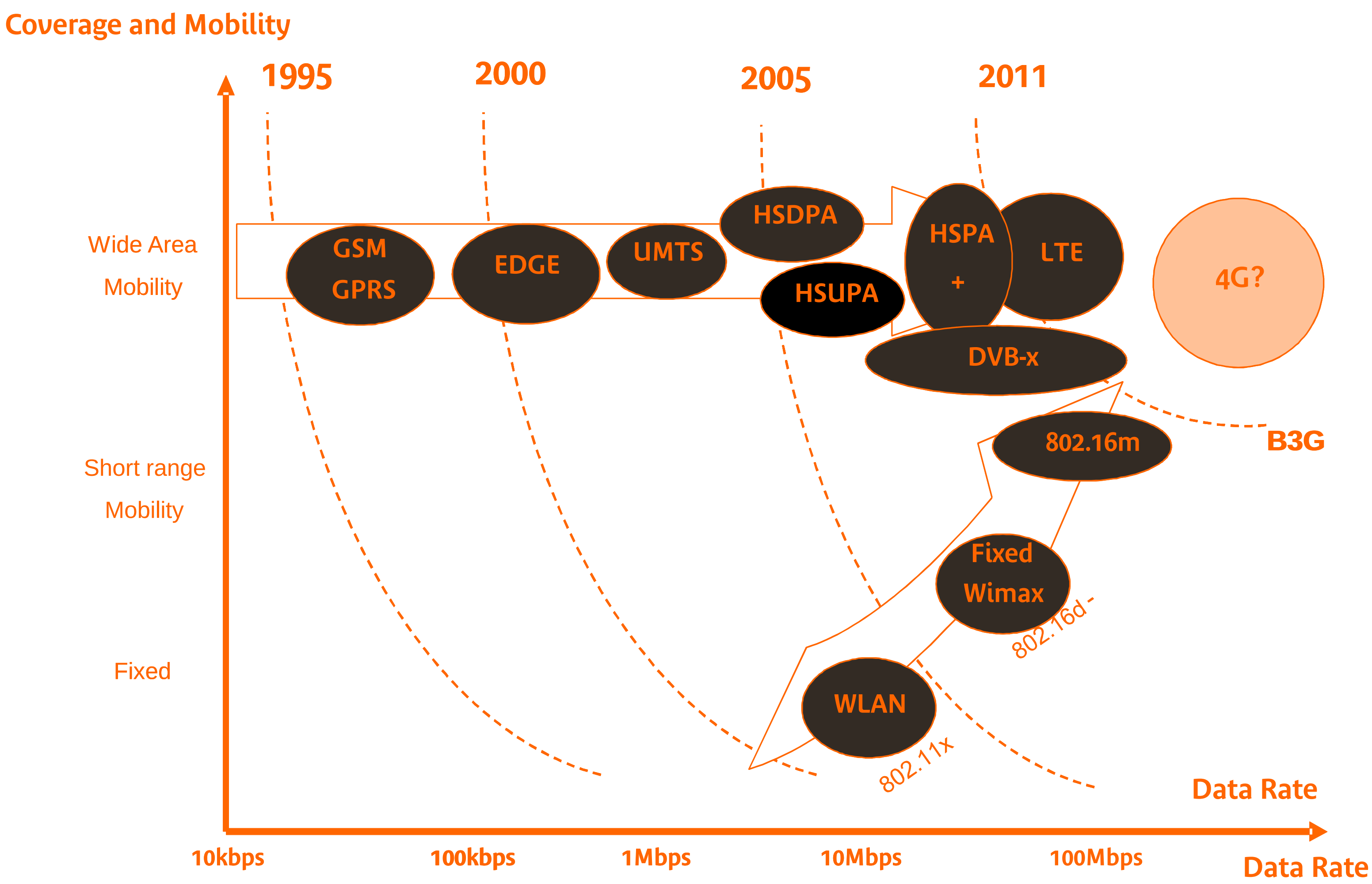
Mobile networks have a significant energy consumption

- More than 50% of the energy consumption of ICT sectors is due to telecommunication networks
- France Telecom wants to reduce its CO_2 footprint by 20% by 2020 compared to 2006 levels
- Mobile networks consumption accounts for 21% of the global power consumption of operators
- Making them green is thus essential

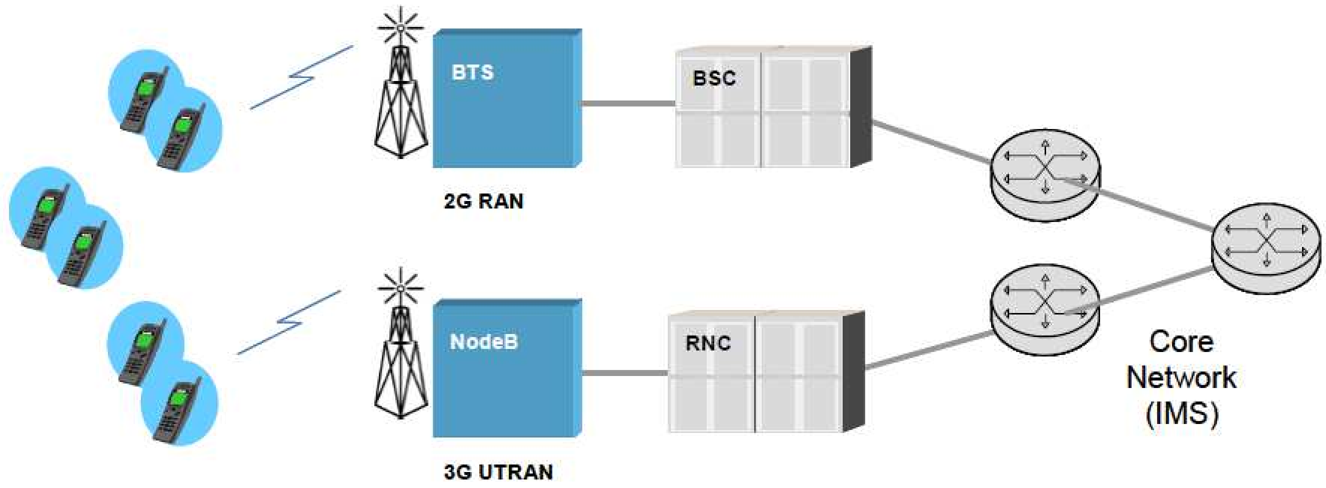


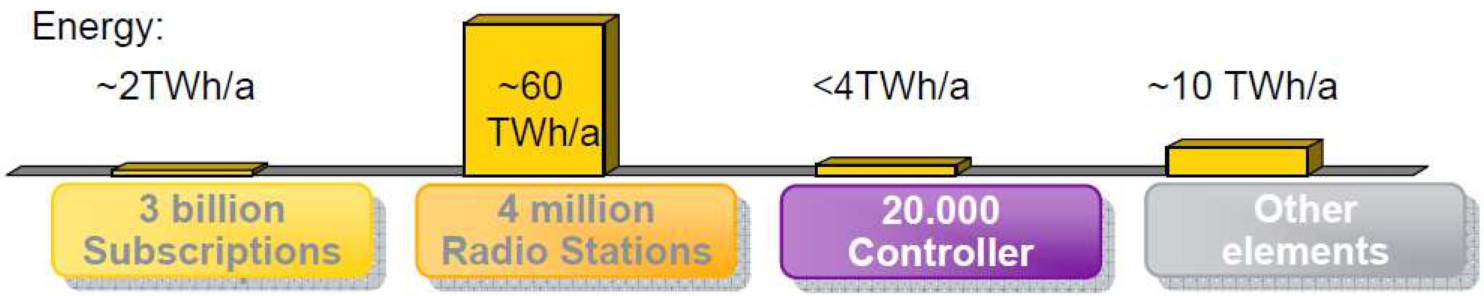
Operator's energy consumption

new mobile networks are being installed:
we have to reduce energy consumption while adding new systems



what are the nodes that consume the most in the mobile network?





- base stations are the most consuming nodes (~80%) :
  - optimize them to optimize overall consumption
  - device energy consumption is also essential for increased autonomy

actions to minimize consumption of the access network at short, mid and long terms

- short term objective: reduce consumption of 2G/3G/LTE

- mid term objective: optimize design of LTE-Advanced networks

- long term objective: propose natively green networks

optimize energy consumption of LTE-Advanced: focus on small cell deployments

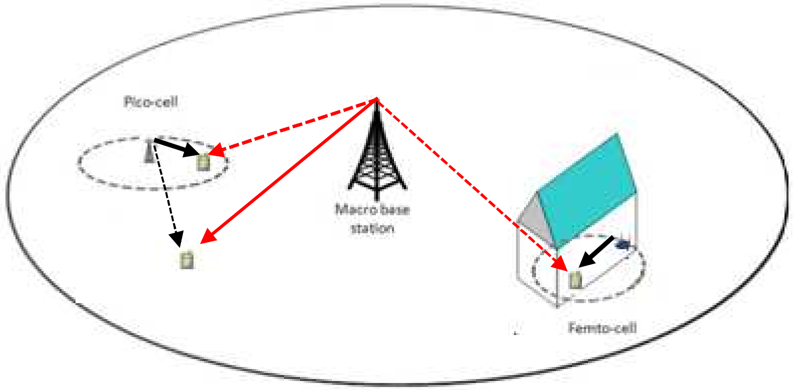
- short term objective: reduce consumption of 2G/3G/LTE

- mid term objective: optimize design of LTE-Advanced networks

  – energy efficiency of heterogeneous networks
  – sleep mode of small cells

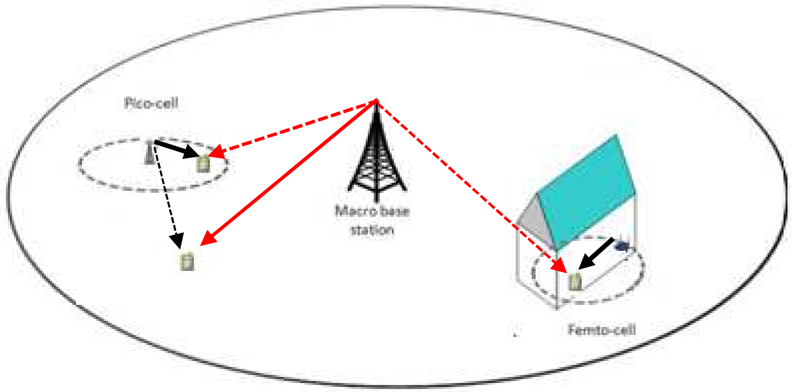
- long term objective: propose natively green networks

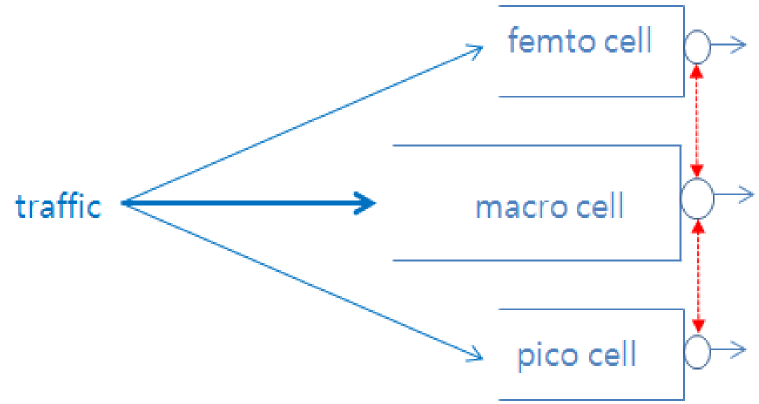
LTE-Advanced networks will be heterogeneous: small cells will cooperate with macro cells



- heterogeneous networks in LTE-A:
  - operator installed pico cells
    - in traffic hotspots
  - client installed femtocells
    - indoor coverage
- small cells will reuse spatially the spectrum and offload traffic
- they nevertheless
  - generate interference
  - consume energy
- the gains in QoS and in energy concumption are not obvious

the network is modeled as several processor sharing queues that are coupled between them due to interference

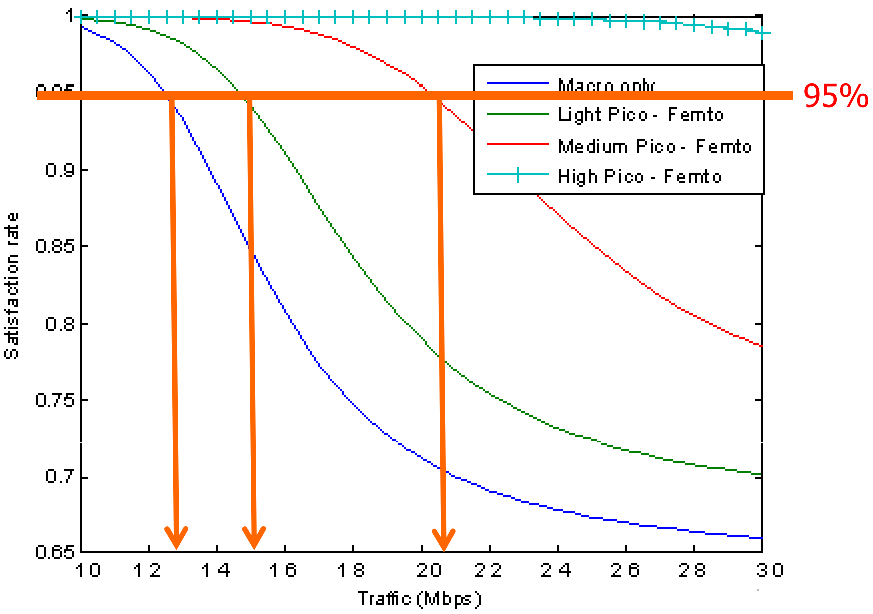




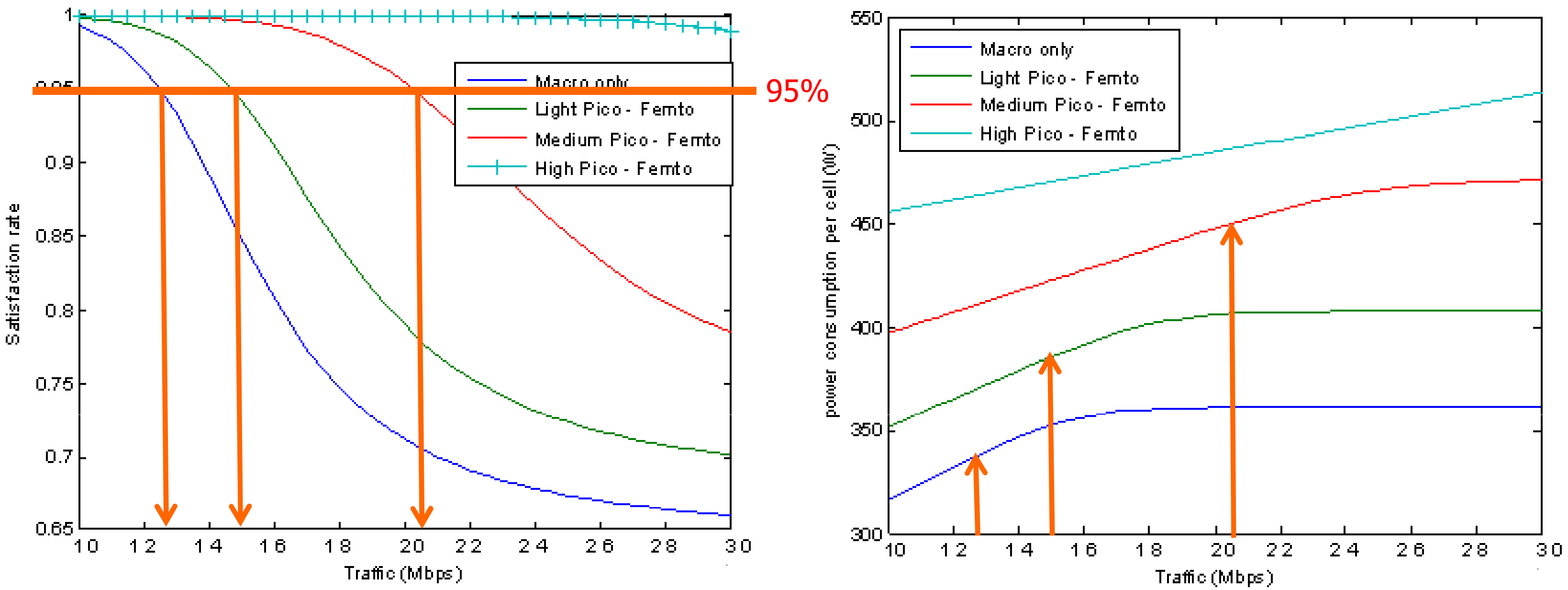
- let C_{macro} be the original average throughput of the macro cell
- after the deployment of small cells, two impacts are observed on C_{macro} :
  - positive impact: small cells offload traffic from cell edge and indoor zones
  - negative impact: small cells generate interference on macro users
- the capacity of a small cell is also affected by interference from macrocell
- steady-state probabilities of the number of users in cell i (macro or small):
  - Pr[n users in cell i]=$load_i$^n *(1-$load_i$)
  - $load_i$=traffic covered by cell i / capacity of cell i

QoS and capacity are enhanced when more small cells are deployed

- three deployment scenarios
  - light pico-femto: 3 picos and 5 femtos per macro site (in average)
  - medium pico-femto: 6 picos and 15 femtos per macro site (in average)
  - high pico-femto: 9 picos and 30 femtos per macro site (in average)
- QoS defined as the percentage of users having more than 750 Kbps
- capacity is defined as the maximal traffic so that more than 95% of users are satisfied
- Capacity is increased when small cells are deployed



but energy consumption also increases as small cells consume a constant energy



- energy consumption increases
  - even if load of macro cell decreases
  - as small cells consume energy even if they carry no traffic
- sleep mode is needed for decreasing energy consumption

optimize energy consumption of LTE-Advanced by putting small cells in sleep mode

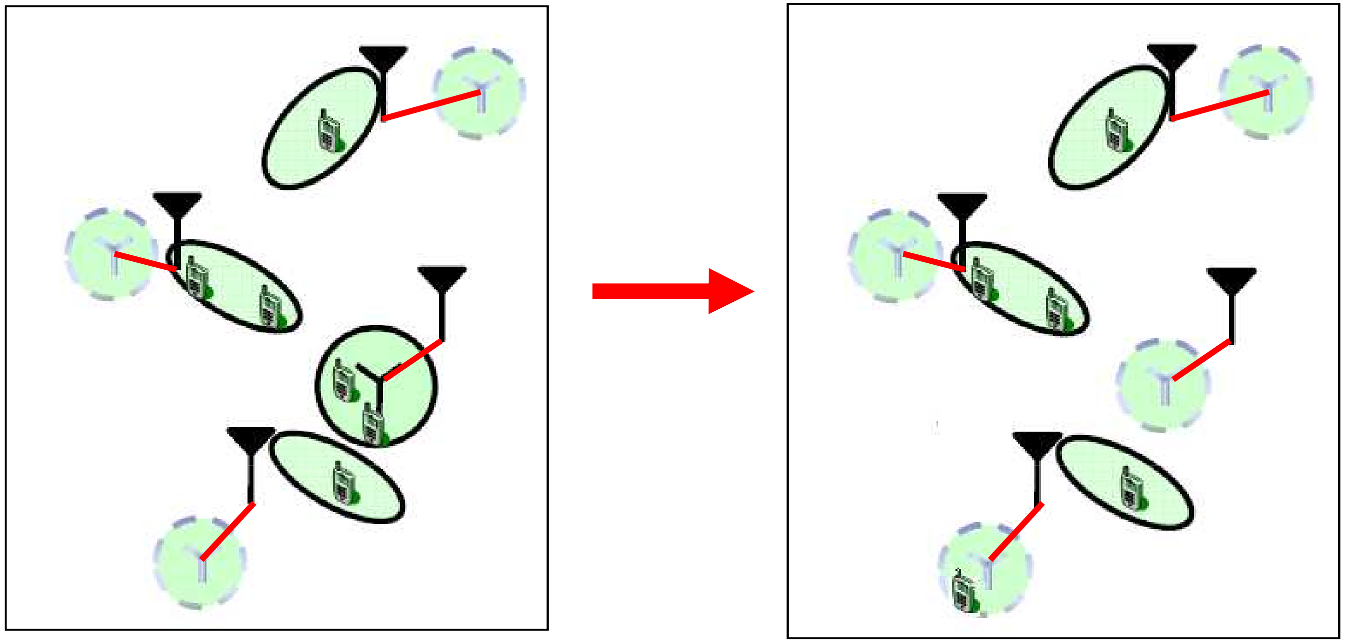
- short term objective: reduce consumption of 2G/3G/LTE

- mid term objective: optimize design of LTE-Advanced networks

  - energy efficiency of heterogeneous networks
  - sleep mode of small cells

- long term objective: propose natively green networks

easy: put a small cell in sleep mode when its traffic is low
difficult: wakeup it when traffic increases

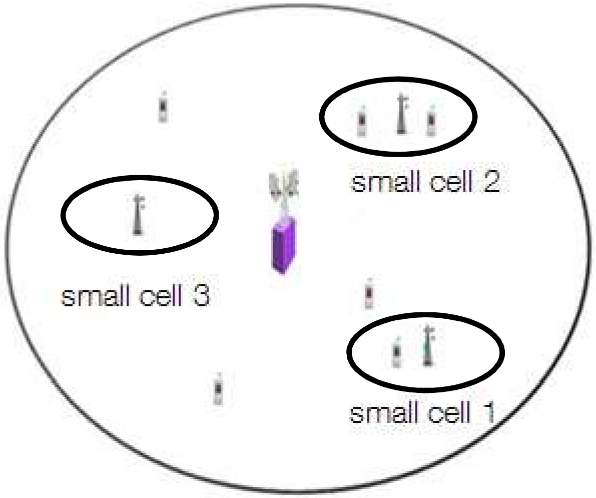


- when traffic is low in a small cell, it can enter into sleep mode
- when traffic changes, how the small cell will know and wakeup?

- macro cells can send wakeup commands to small cells:
  - via X2 backhaul interface
- intelligent controllers are needed in macro base stations to awaken small cells

optimal controller for sleep/wakeup with complete information: classical MDP

- example: one macro cell and three small cells
  - s_i: small cell i
  - the exact position of each user is known
  - system state: **s** = (n_{macro}, n_{small1}, n_{small2}, n_{small3})



- Markov Decision Processes (MDP) theory is used
  - derive the optimal control policies for sleep/ wake up
  - reward: energy reduction
  - cost: QoS degradation

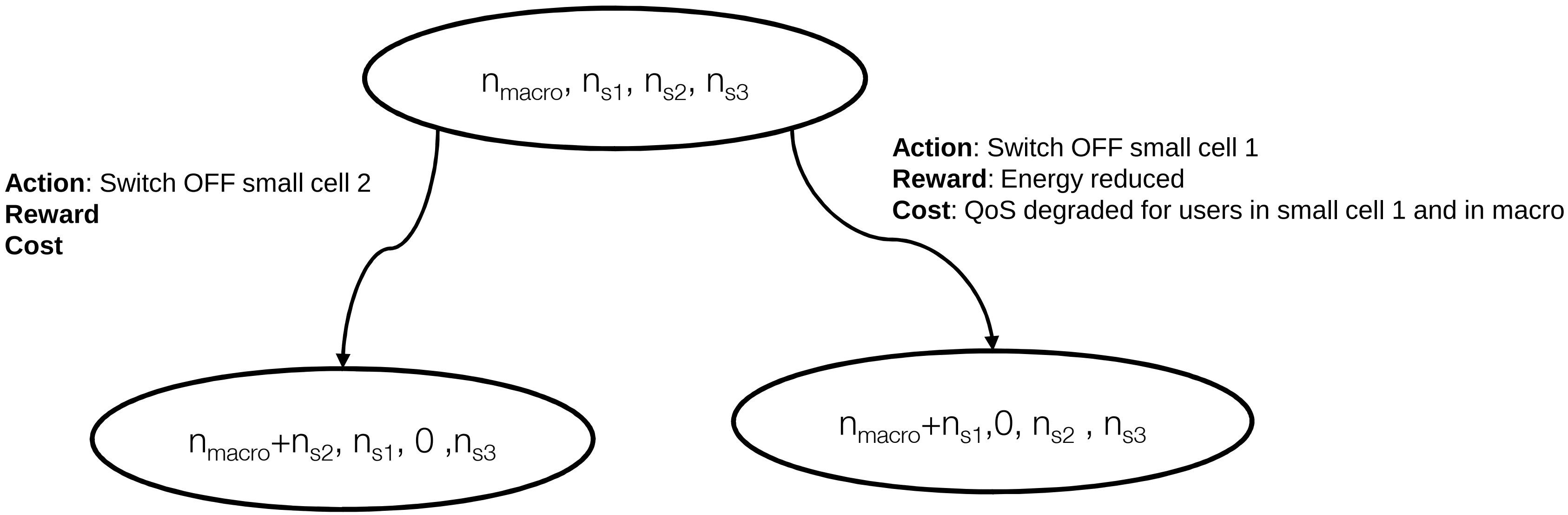
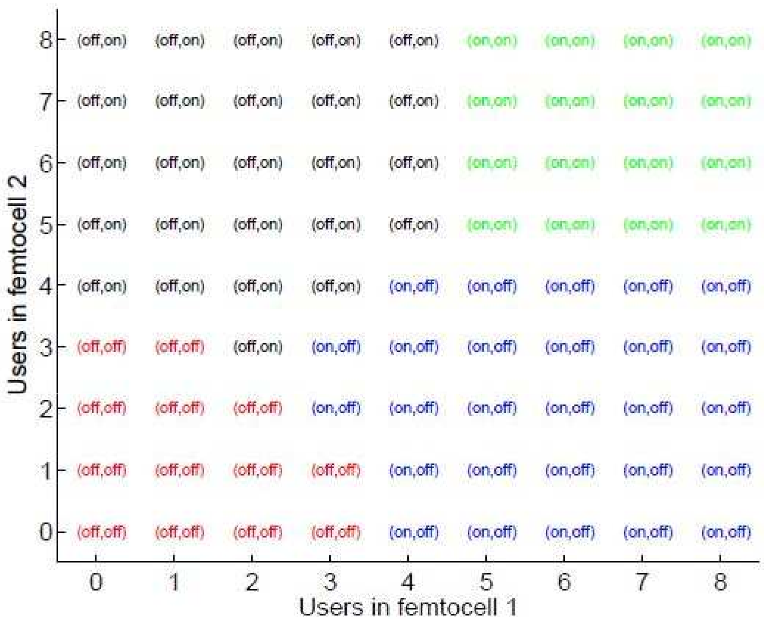
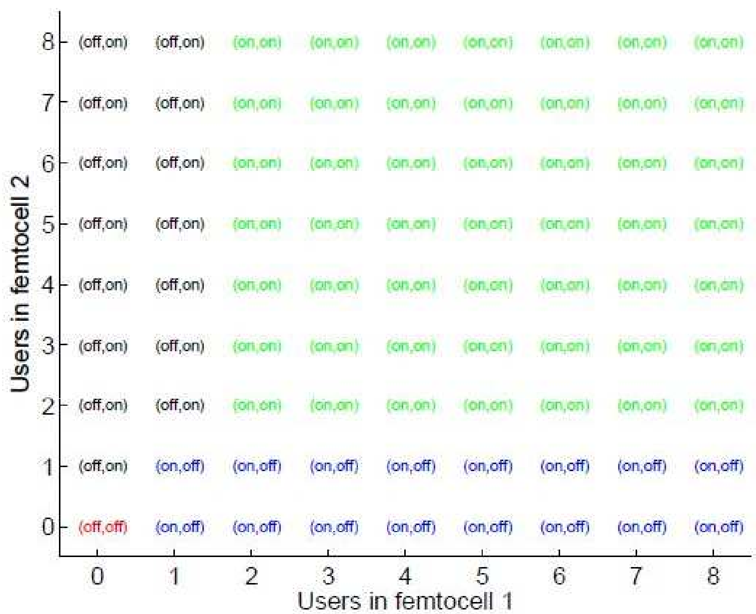


illustration of the solution: the optimal policy seems to be a threshold policy

3 users in the macro cell



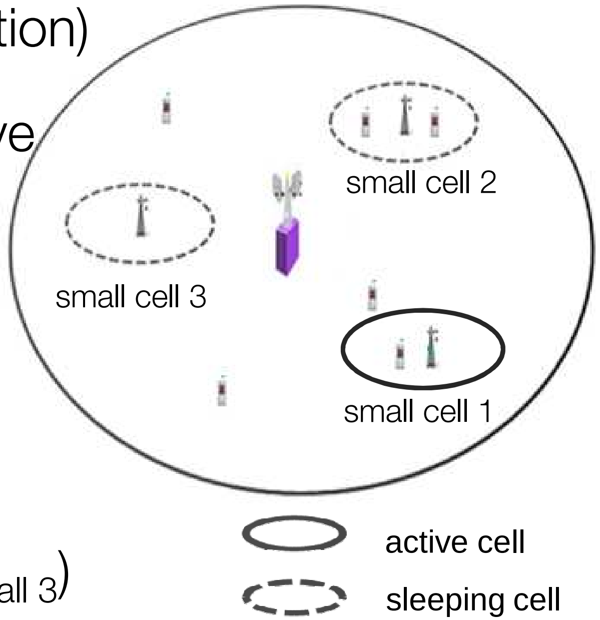
6 users in the macro cell



- intuitive results
  - if many users are in the small cell coverage area, switch it on
  - if more users are in the macro coverage, you cannot switch off small cells
- interesting result: the optimal policy is, almost, a threshold policy on each small cell

in many practical cases, we have to guess where is traffic POMDP are used

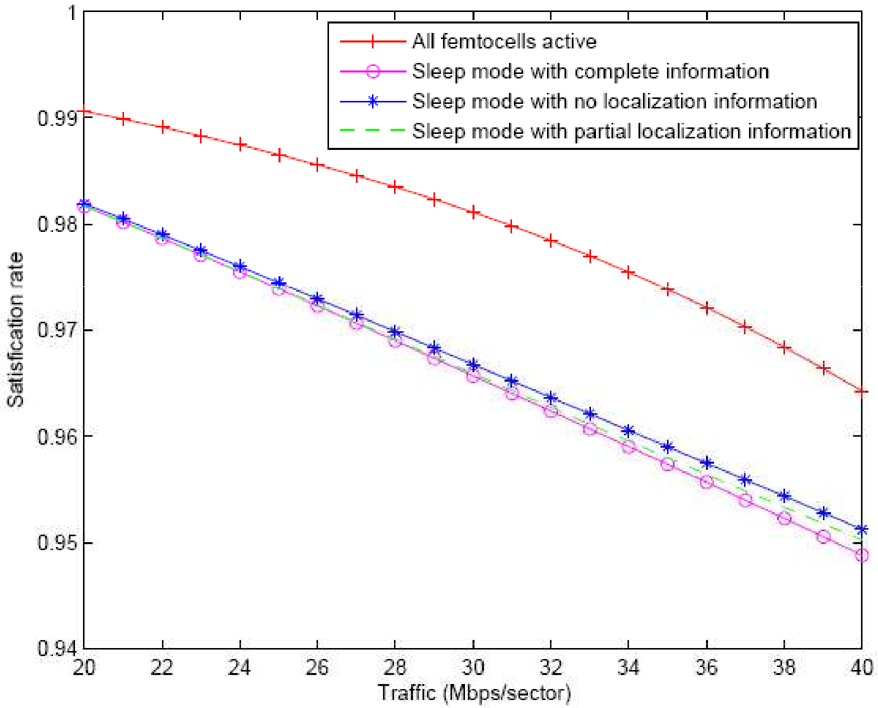
- inaccurate localization methods (e.g. triangulation)
- example: 3 small cells, only small cell 1 is active
- hidden state: $s=(n_{macro}, n_{small\ 1}, n_{small\ 2}, n_{small\ 3})$
- information known for sure:
  - traffic in macro cell and active small cells
  - $n_{macro}+n_{small\ 2}+n_{small\ 3}$ and $n_{small\ 1}$
- observed state: $s_{obs}=(n_{macro}, n_{small\ 1}, n_{small\ 2}+n_{small\ 3})$

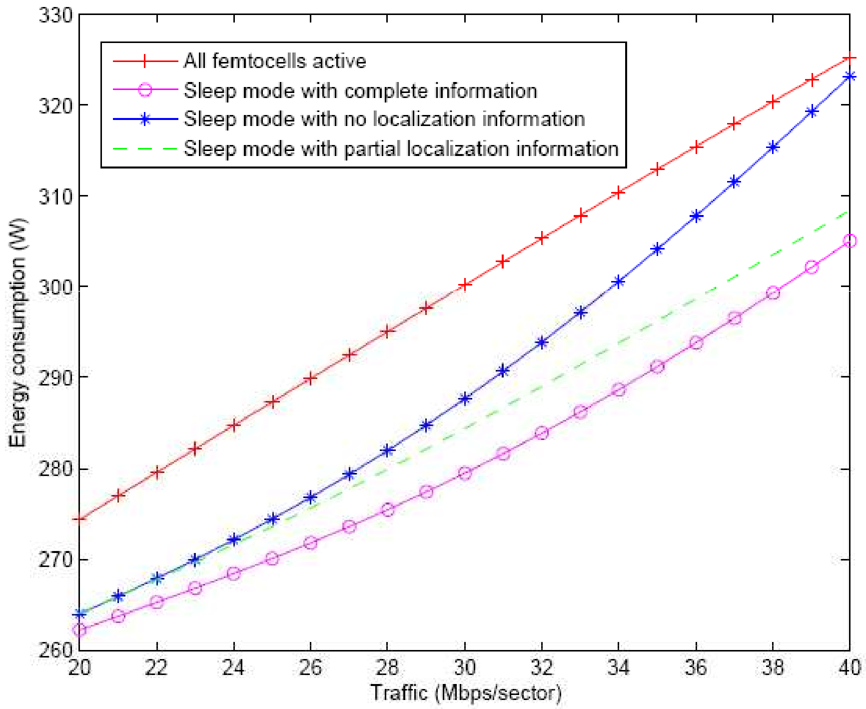


- …and some **belief** $b(s|s_{obs})$ expressing our confidence in the information:
  - $b(s|s_{obs})$ =1, if we know for sure where traffic is
  - $b(s|s_{obs})$ =1/number of states, if we do not have any guess
- Partially Obvervable MDP (**POMDP**) is used
  - apply action that corresponds to the hidden state maximizing belief

illustration of sleep mode with inaccurate information

- Target throughput = 500 Kbps
- Outdoor small cells (2 per sector), P_{small} = 50W





- sleep mode decreases energy consumption, but decreases QoS
- more traffic localization information leads naturally to larger gains

in some cases, information about localization is becoming more accurate with time : Delayed MDP

- localization information may arrive after some delay
  - If complex signaling between cells is involved
- wakeup decisions may be obsolete
  - localization information arrives after a delay T
  - traffic may have changed
- hidden state: $s=(n_{macro}, n_{small\ 1}, n_{small\ 2}, n_{small\ 3})$
- observed state: $s_{obs}=(n_{macro}, n_{small\ 1}, n_{small\ 2}+n_{small\ 3})$
- additional information
  - exact traffic localization some times ago
- Delayed MDP (DMDP) is used
  - equivalent to the case where wakeup decision is taken instantaneously, but is effective only after a delay T
  - information about the actions that have been taken in [t-T,t[is necessary when taking a decision at time t

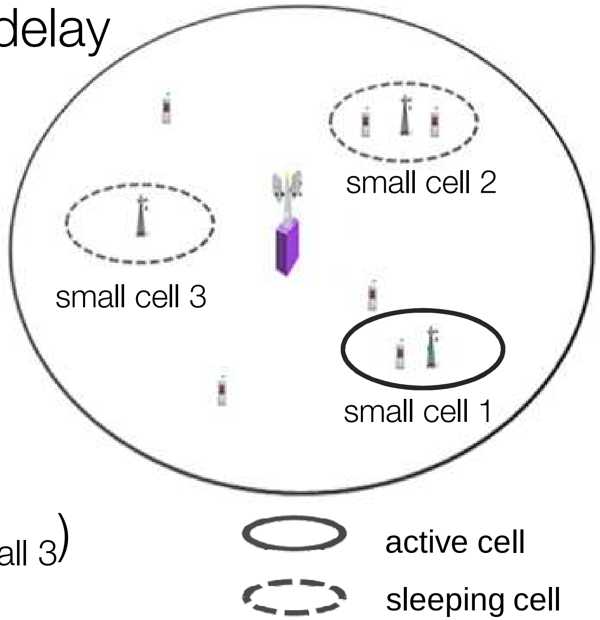
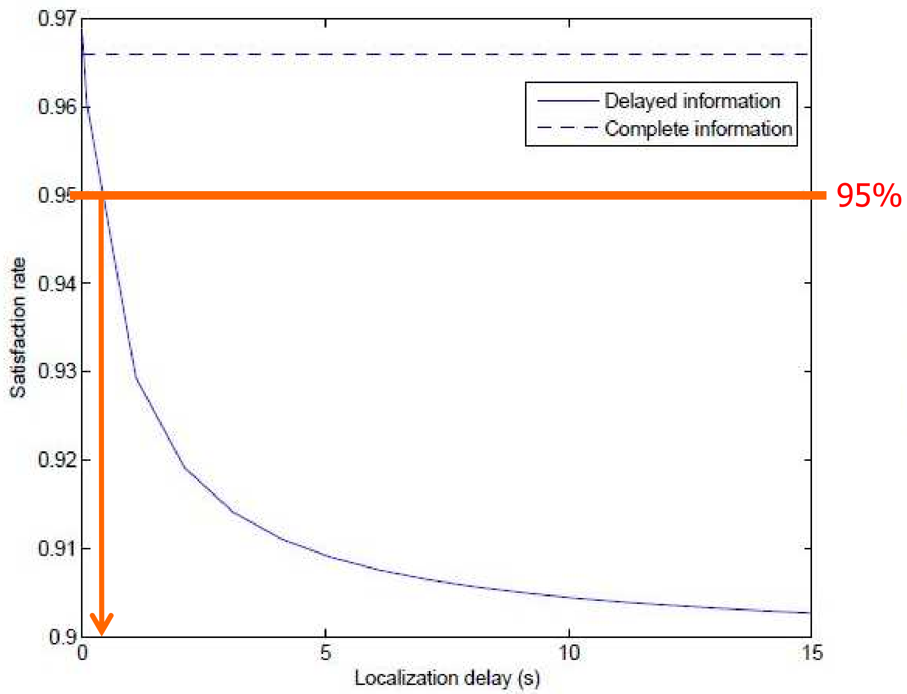
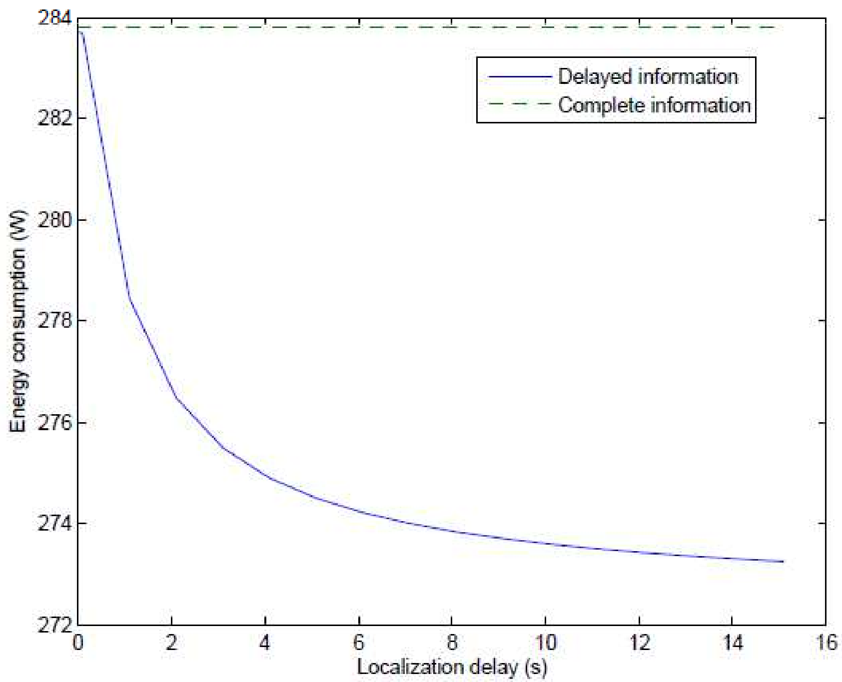


illustration of sleep mode with delayed information

- as small cells are not activated instantaneously
  - negative impact: localization delay decreases QoS
  - positive impact: but also decreases energy consumption
- however, the impact on QoS is too large
  - only a small delay is acceptable if a high QoS is sought





conclusion

- making networks greener is not an easy task
  - more networks are deployed and traffic is increasing
- small cells can increase the capacity:
  - if small cells are authorized to offload macro cell traffic
- sleep mode of base stations is the best way to increase energy efficiency of cellular networks:
  - use resources only when needed
- optimal controllers are needed to drastically increase efficiency:
  - MDP theory is used to wakeup small cells
- localization errors are taken into account using POMDP
- localization delays are taken into account using Delayed MDP
  - only small localization delays are acceptable