Green Algorithm Design

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ICT and Environment

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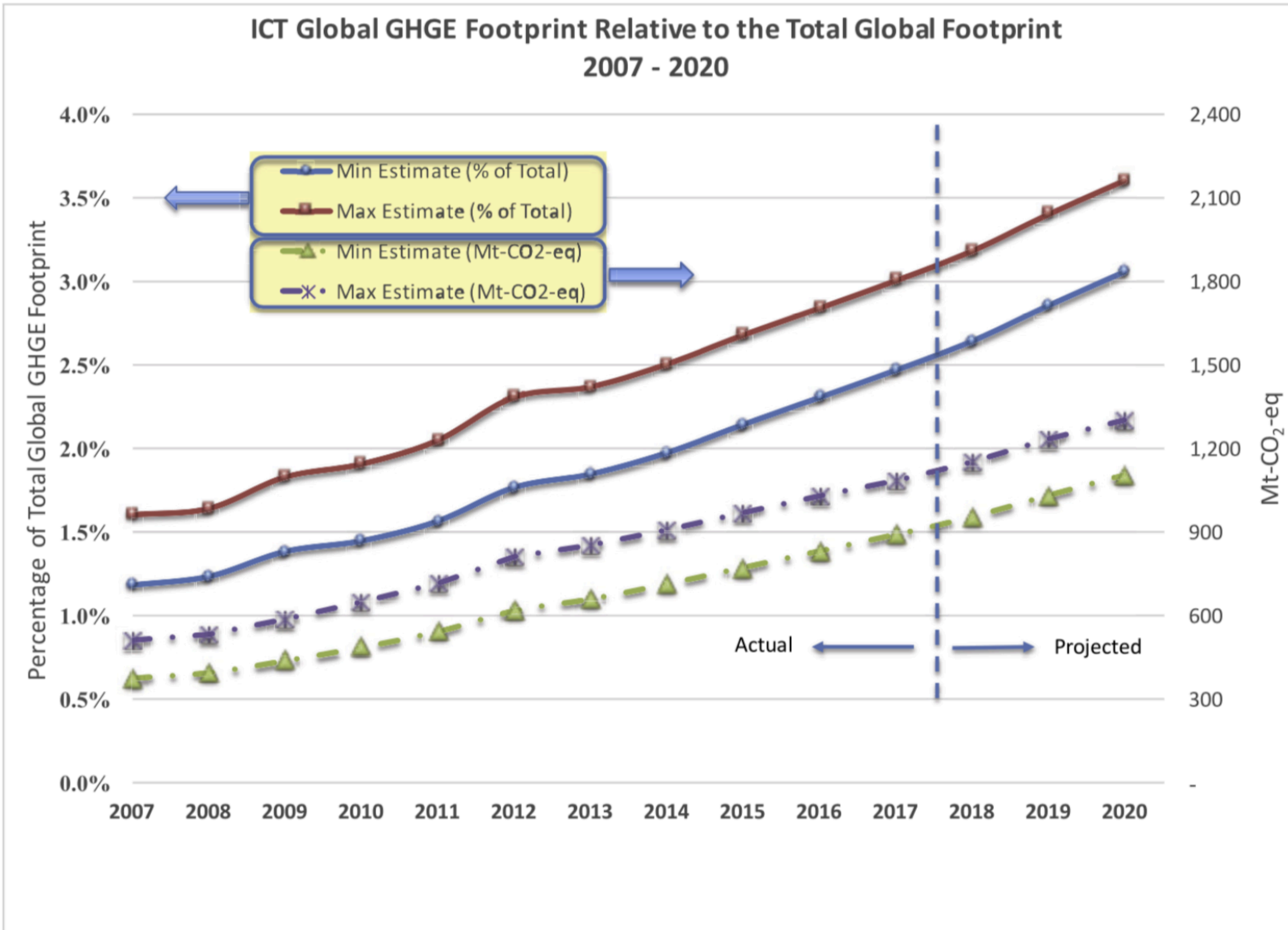
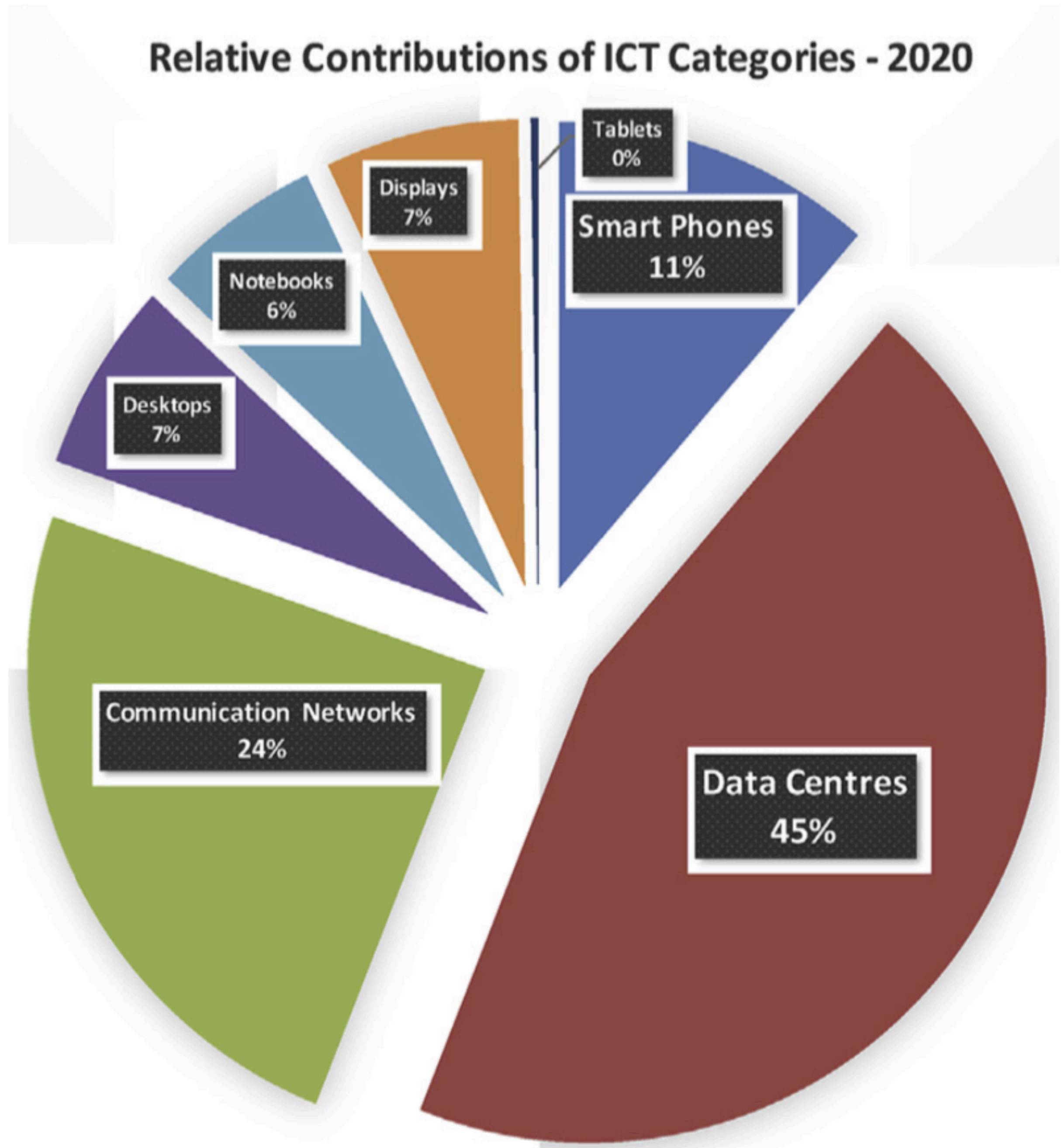
Internet Energy Consumption



3-4% and increasing

Internet Energy Consumption



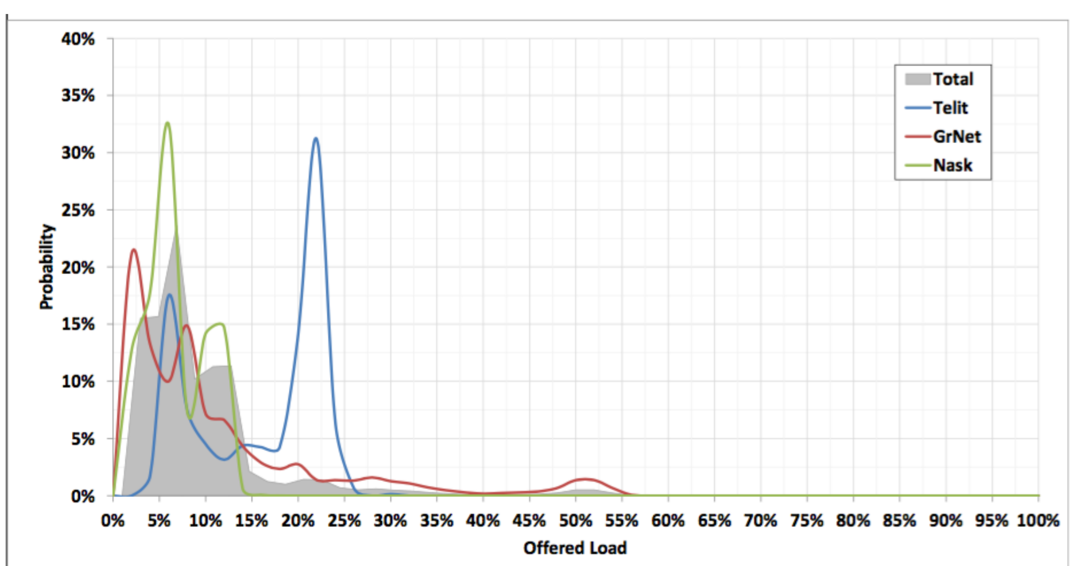
Data centers and Networks

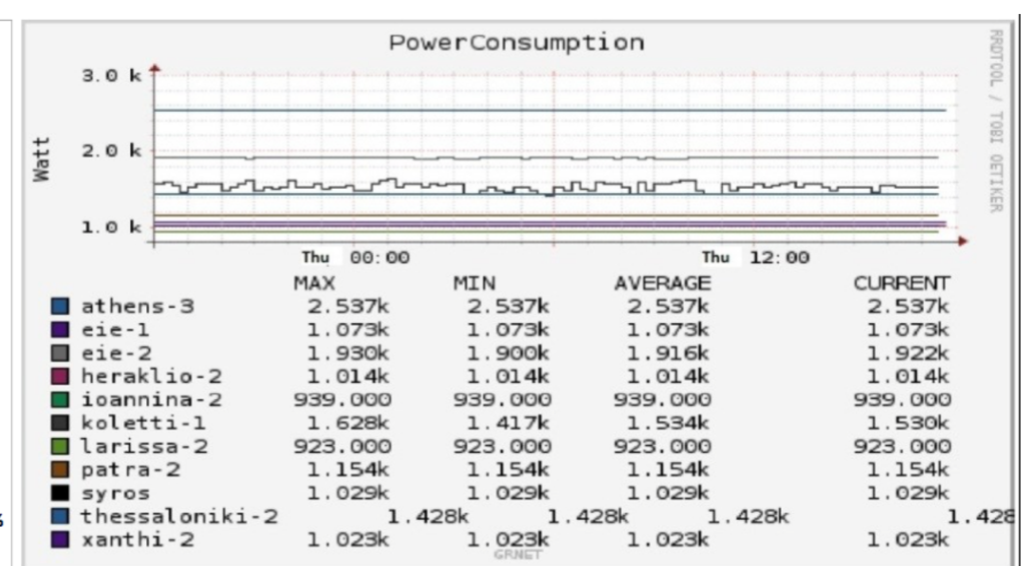
Reasons for energy inefficiencies...

- The origin of these trends can be certainly found in current Internet infrastructures, technologies and protocols, which are designed to be extremely **over-dimensioned** and **available 24/7**.

- Links and devices are **provisioned for rush hour load**.

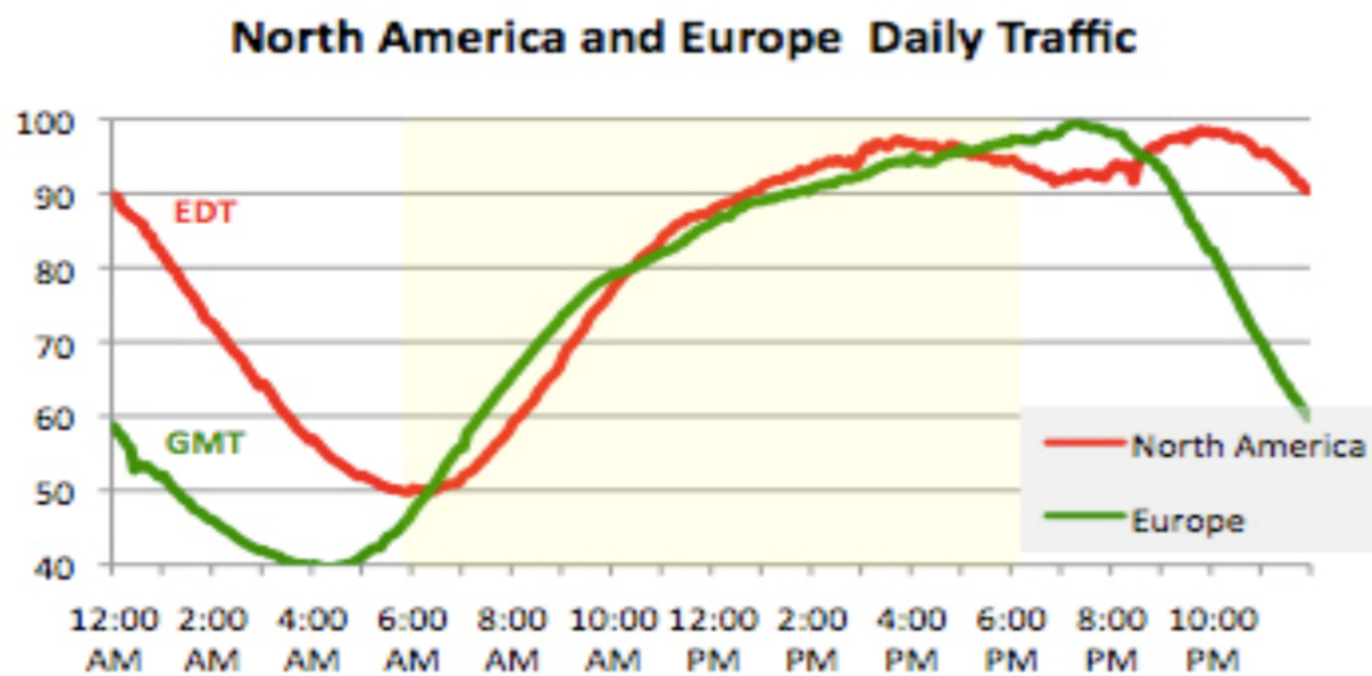
- The **overall power consumption** in today's networks **remains more or less constant** even in the presence of **fluctuating traffic loads.**

- 



...despite wide traffic variations

- The profiles exhibit regular, daily cyclical traffic patterns with Internet traffic dropping at night and growing during the day.



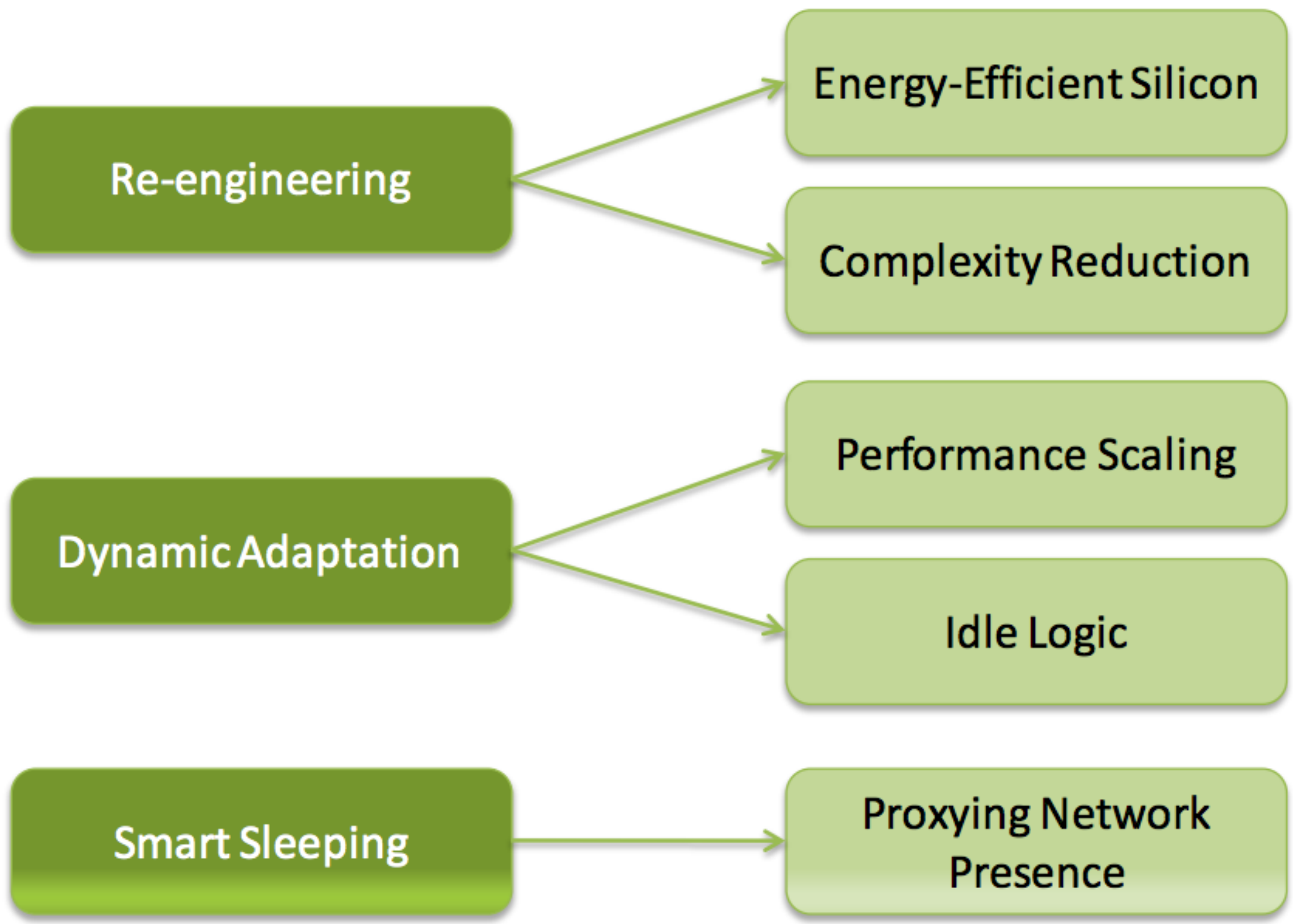
Traffic load fluctuation at peering links for about 40 ISPs from USA and Europe (percentage / peak level)

Source: http://asert.arbornetworks.com/2009/08/what-europeans-do-at-night/

History

- **Ground-breaking works on energy consumption in the Internet:** [Gupta et al. 2003], [Christensen et al. in 2004], showing that this is a mandatory issue to improve the energy efficiency of the whole Internet.
- However, **massive effort** in this direction by researchers, operators, and device manufacturers only **2008-2009**.

Classifying Proposed Methods



Taxonomy of undertaken approaches for the energy efficiency of the Future Internet.

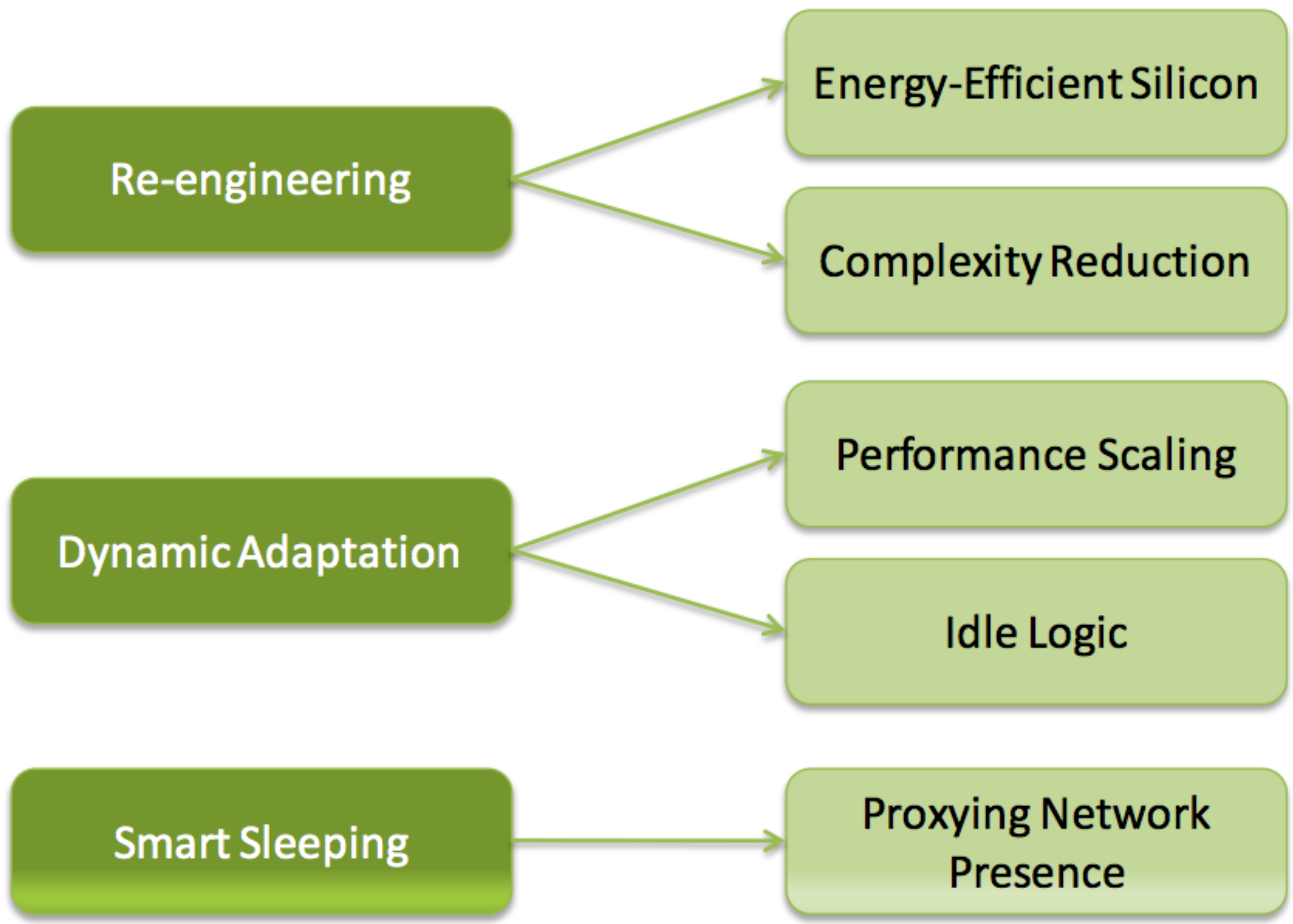
Re-engeenering approaches

- **Re-engineering approaches** aim
  - at **introducing and designing more energy-efficient elements** for network device architectures,
  - at suitably dimensioning and **optimizing internal organization devices**, as well as
  - at **reducing their intrinsic complexity levels**.

Re-engeenering approaches

- **Example:**
  - adoption of **pure optical switching architectures** for replacing the **current electronic based devices.**
  - They can potentially provide terabits of bandwidth at **much lower power dissipation than current network devices**
  - **Lots of work [Baliga 2007] but adoption still far from reality.** Current technological problems mainly regard the Control Plane.

Classifying Proposed Methods



Taxonomy of undertaken approaches for the energy efficiency of the Future Internet.

Dynamic Adaptation

- **Dynamic adaptation of network/device resources:** modulate capacities of packet processing engines and of network interfaces, to meet actual traffic loads and requirements.

- This can be performed by using two main power aware capabilities, namely,

  - **dynamic voltage scaling** and

  - **idle logic**,

Dynamic Adaptation: Power scaling

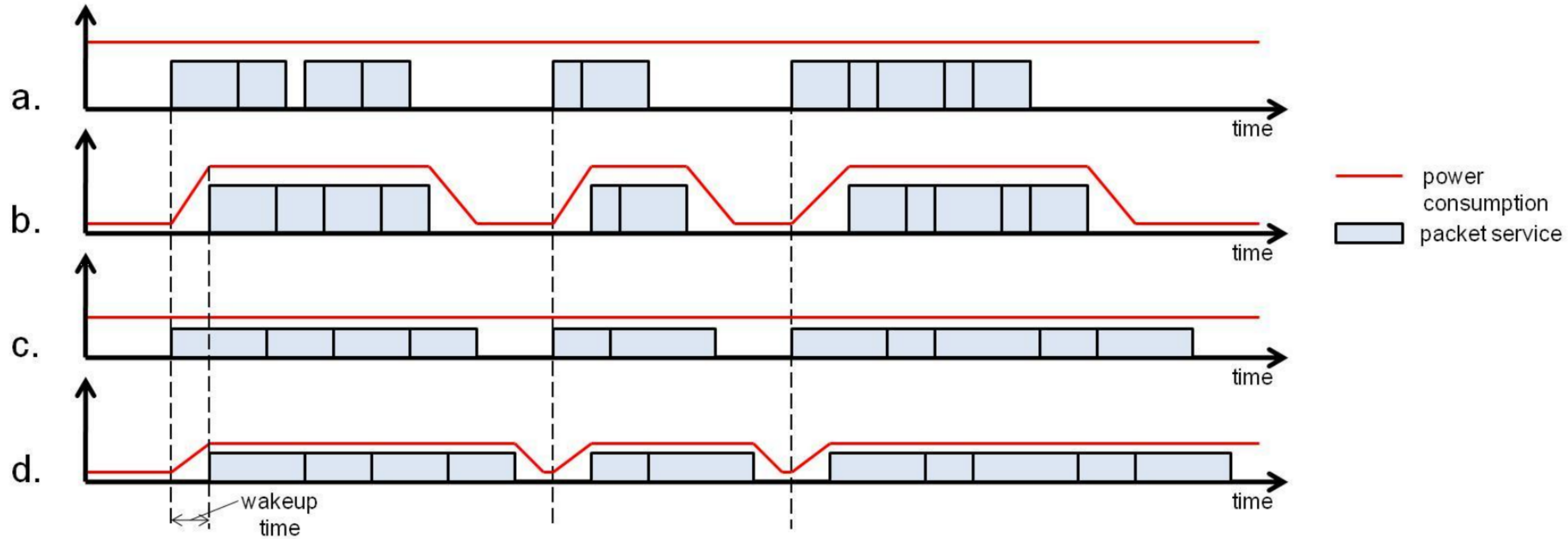
- Key feature in today's processors
- But, nowadays, **not included in the largest part of current network equipment**.
- Power scaling capabilities allow **dynamically reducing the working rate** of processing engines or of link interfaces. This is usually accomplished by tuning the **clock frequency** and/or the **voltage of processors**

Dynamic Adaptation: Idle logic

- Idle logic allows reducing power consumption by **rapidly turning off sub-components** when no activities are performed, and by **re-waking them up** when the system receives new activities.

- In detail, wake-up instants are triggered by a **system internal scheduling process** (e.g., the system wakes itself up every certain time periods, and controls if there are new activities to process).

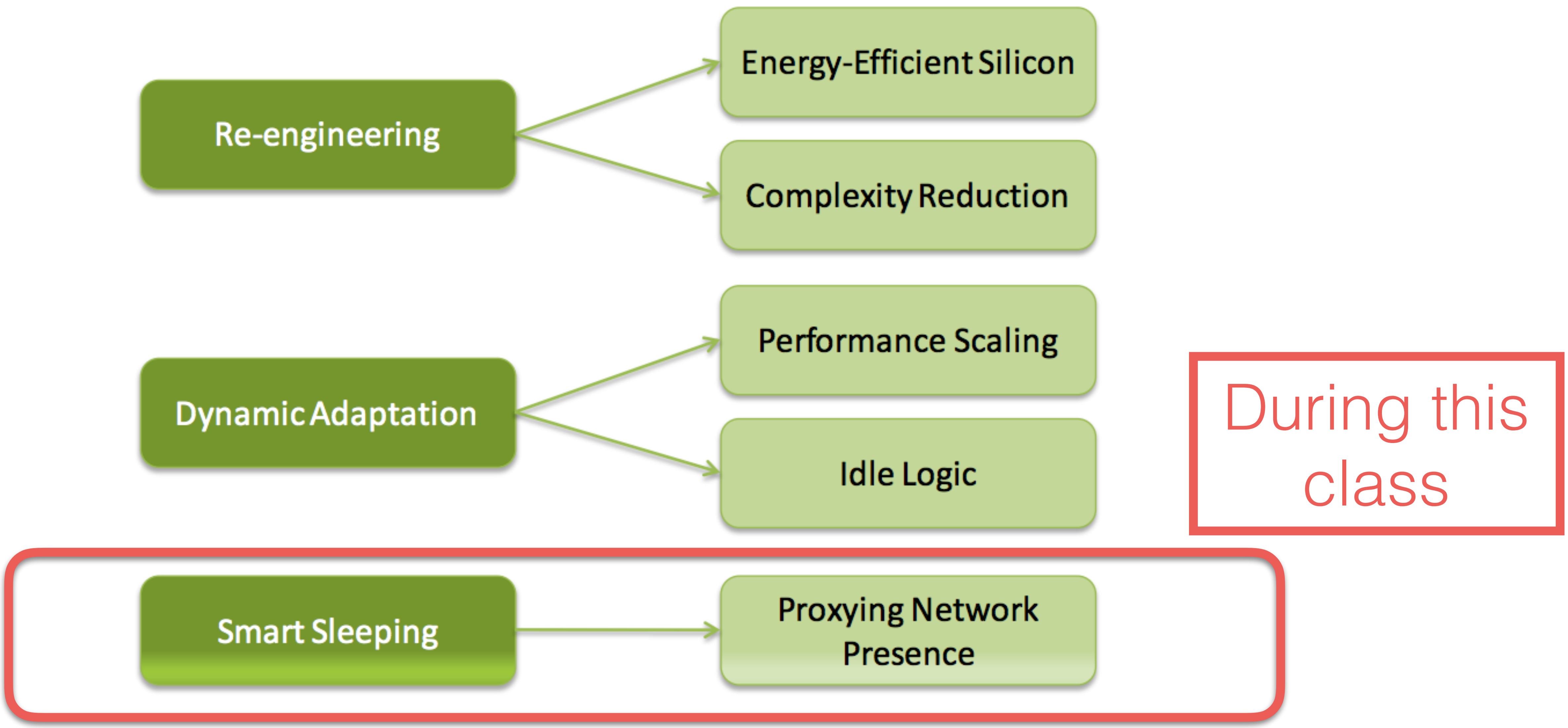
Dynamic Adaptation



Packet service times and power consumptions in the following cases [Nevedschi et al. 2008]:

(a) no power-aware optimizations,
(b) only idle logic,
(c) only performance scaling,
(d) performance scaling and idle logic.

Classifying Proposed Methods



Taxonomy of undertaken approaches for the energy efficiency of the Future Internet.

Sleeping/standby Approaches

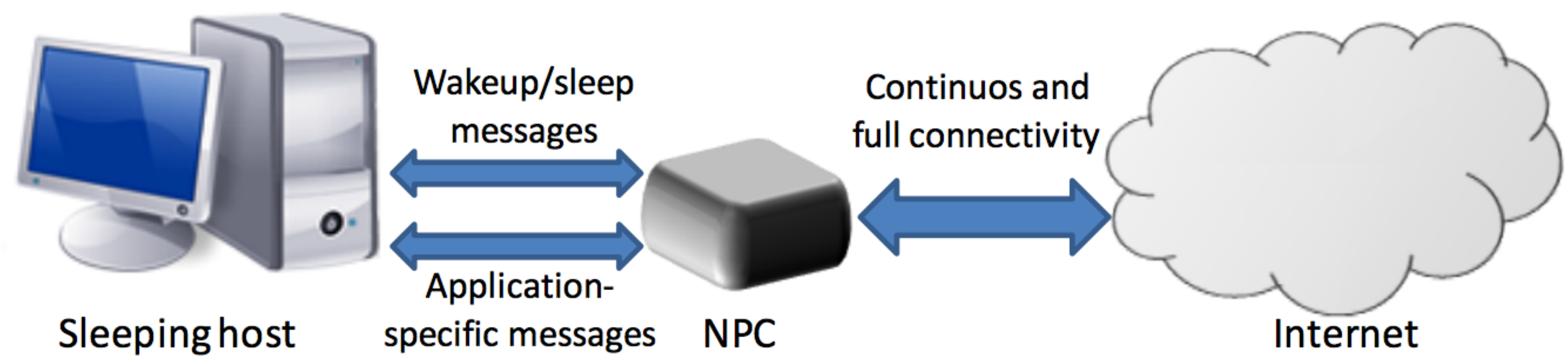
- **Sleeping/standby approaches** are used to **smartly and selectively drive unused network/device** portions to low standby modes, and to **wake them up** only if necessary.

- However, today‘s networks and related services and applications designed to be **continuously and always available.**

- Standby modes have to be explicitly supported with **special proxying techniques** able to maintain the —network presence of sleeping nodes/components

Sleeping/standby Approaches

- [Christensen and Nordman 2004] directly faced energy efficient enhancements in such kind of scenario.



Example of Network Connection Proxy.

- **Solution:** maintain continuous network presence by having ***a network host transfer network presence to a proxy***, namely Network Connectivity Proxy (NCP), when entering sleep mode.

Classifying Proposed Methods

- All these approaches are not exclusive among themselves,
- All such directions in order to effectively develop new-generation green networks.

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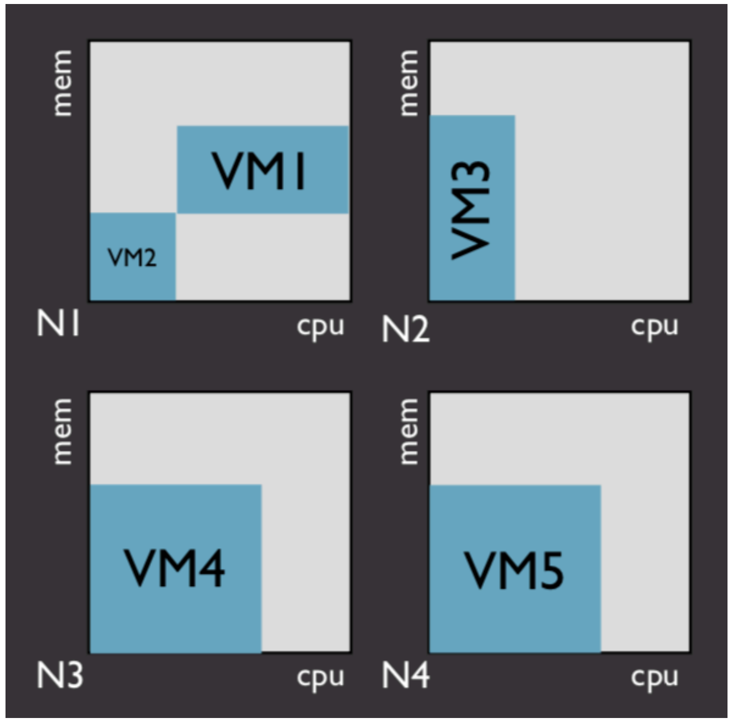
Inside a data center

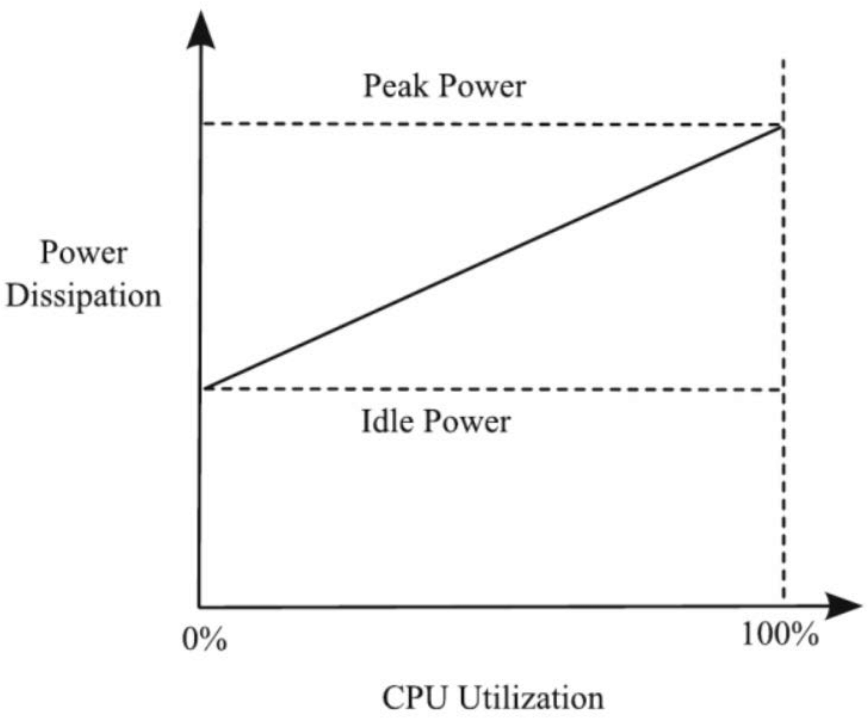
- Racks of servers to compute/store/run applications
- Applications launched in isolated environment: Virtual Machines (VMs)
- Scheduler places VMs on servers
  - with sufficient ressources
  - to have an "efficient" data center

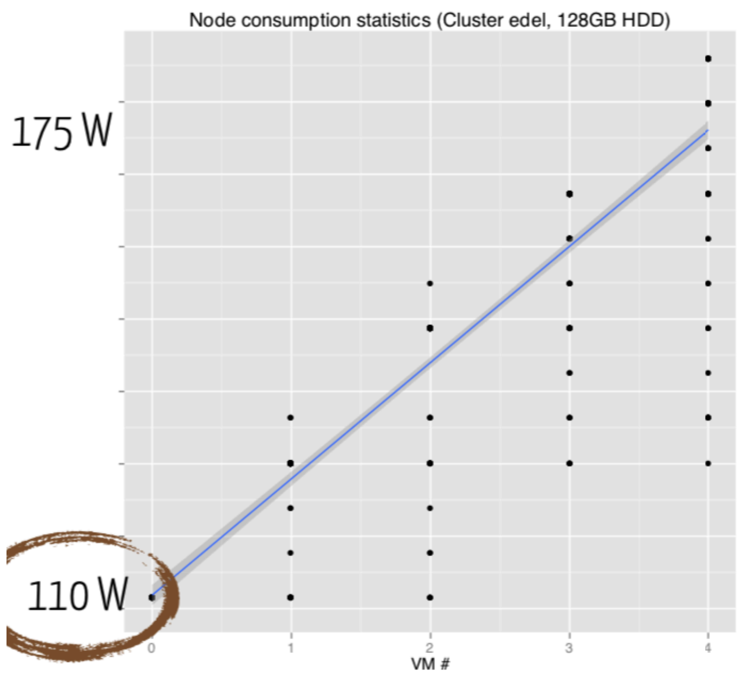


Power Model

- Servers are not energy efficient
  = not energy proportional to usage

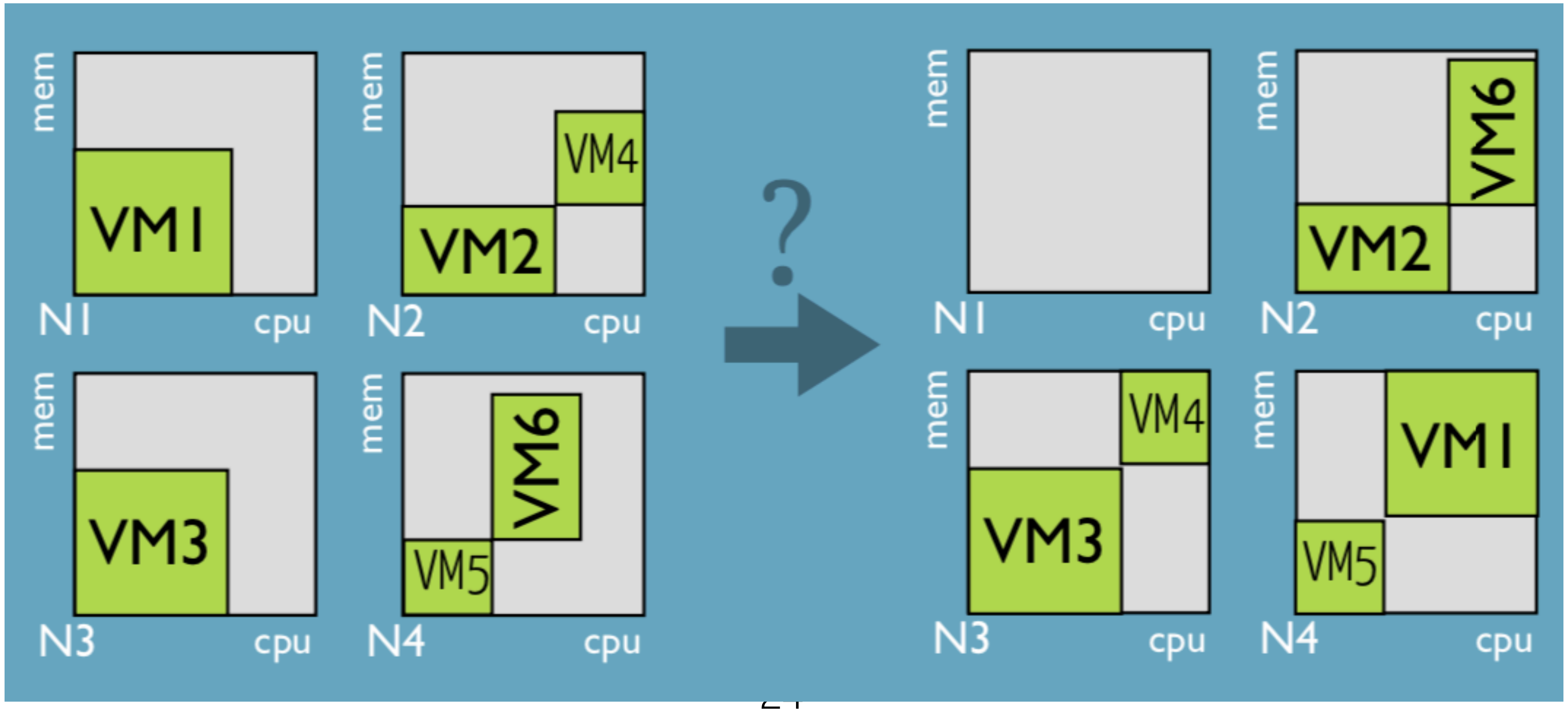
- Close to an ON/OFF Model.



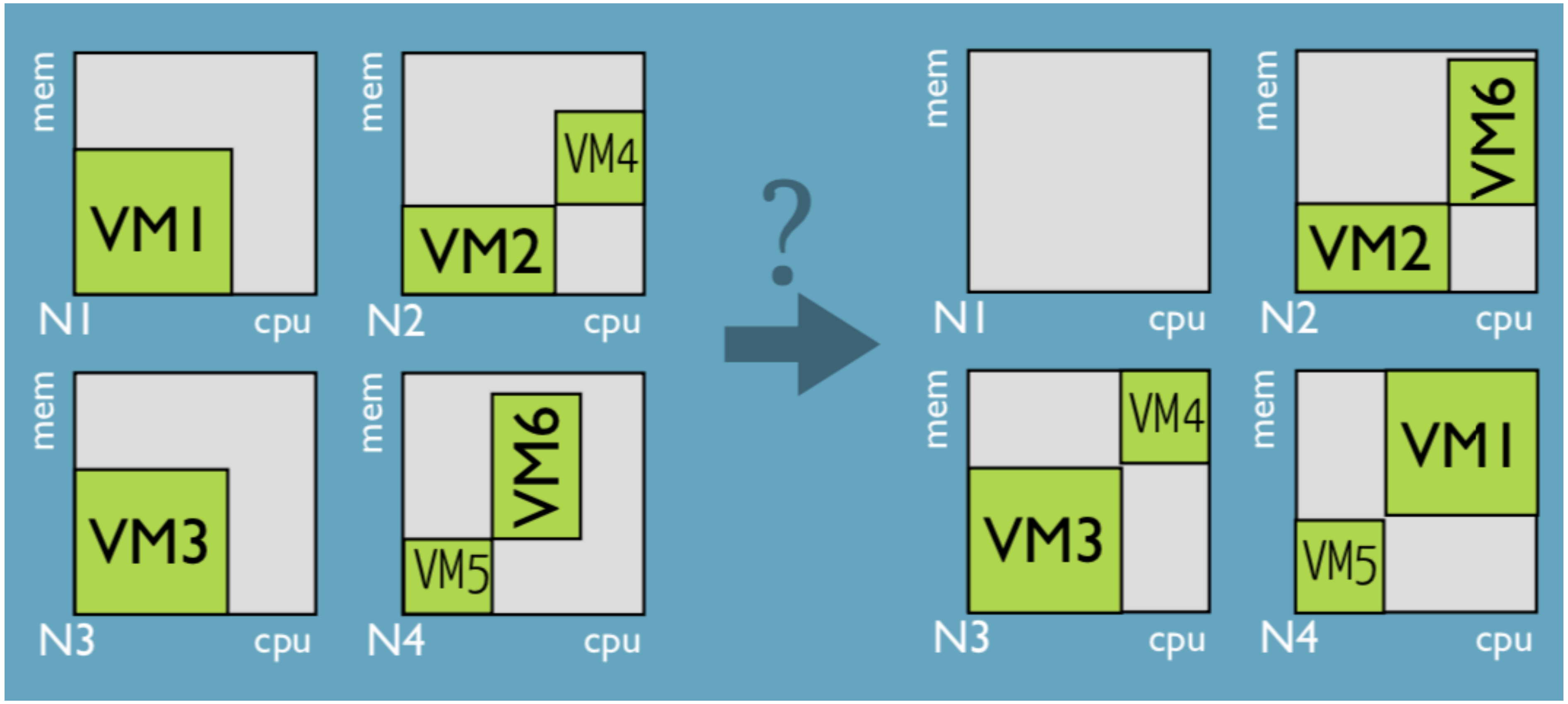


Saving Energy

- Solution to save energy:
  - Consolidation of VMs on a minimum number of servers
  - Putting to sleep unused servers



Challenge



How to find the placement using the minimum number of servers?

Combinatorial Problem

Classic Problem: Bin Packing
Instance: Finite set I of items. A size s(i) N for each iI, a positive bin capacity B and a positive integer K.
Question: Is there a partition of I into disjoint sets I1,,IK, such that the sum of the sizes of the items in each Ij is B or less?

Optimization variant.
What is the minimum value of K?
A solution is optimal if it has minimal K. The K-value for an optimal solution for a set of items I is denoted by OPT(I) or just OPT if the set of items is clear from the context.

Bin Packing - An Example

- Input: I = {4, 8, 1, 4, 2, 1}. Bin Capacity B = 10.
- Question: How many bins are necessary?

Bin Packing - Exercises

- Input: I = {9, 8, 2, 2, 5, 4}. Bin Capacity B = 10.
- Question: How many bins are necessary?

- Input: I = {2, 5, 4, 7, 1, 3, 8}. Bin Capacity B = 10.
- Question: How many bins are necessary?

- Question: Propose efficient algorithms to solve the pb

Bin packing - Complexity

- The bin packing problem is strongly NP-complete.
- No approximation algorithm with absolute approximation ratio smaller than 3/2 unless P = NP.
- Bin packing is solvable in pseudo-polynomial time for any **fixed** number of bins K, and solvable in polynomial time for any **fixed** bin capacity B.

Bin packing - Algorithms

- **First-Fit (FF)** keeps all bins open, in the order in which they were opened. It attempts to place each new item into the first bin in which it fits. Approximation ratio FF(L) 1.7 OPT.

Aparté: Approximation algorithms

Definition: An approximation algorithm produces
 - in **polynomial time**
- a **feasible solution**
 - whose objective function value is close to the optimal OPT, by close we mean **within a guaranteed factor** of the optimal.

Example: A 2-approximation algorithm for Bin Packing partition the tasks into a number of bins <= 2*OPT (OPT=minimum number of bins)

Bin packing - Algorithms

- **First-Fit (FF)** keeps all bins open, in the order in which they were opened. It attempts to place each new item into the first bin in which it fits. Approximation ratio FF(L) 1.7 OPT.

- Input: I = {5, 7, 3, 4, 8}. Bin Capacity B = 10.
- Question: Apply FF algorithm.

Bin packing - Algorithms

- **First-Fit (FF)** keeps all bins open, in the order in which they were opened. It attempts to place each new item into the first bin in which it fits. Approximation ratio FF(L) 1.7 OPT.

- **Best-Fit (BF)**, too, keeps all bins open, but attempts to place each new item into the bin with the maximum load in which it fits. Approximation ratio1.7 OPT.

Bin packing - Algorithms

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- Input: I = {5, 7, 3, 4, 8}. Bin Capacity B = 10.
- Question: Apply BF algorithm.

Bin packing - Algorithms

- Input: I = {5, 7, 2, 4, 3, 8}. Bin Capacity B = 10.
- Question: Apply FF and BF algorithms.

Bin packing - Algorithms

- Input: I = {5, 7, 2, 4, 3, 8}. Bin Capacity B = 10.

- Question: Apply FF and BF algorithms.

- **First-fit-decreasing (FFD)** - orders the items by descending size, then calls First-Fit. Approximation ratio FFD(I)=11/9 OPT(I)+6/9}.

Bin packing - Algorithms

- Input: I = {5, 7, 2, 4, 3, 8}. Bin Capacity B = 10.
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- Input: I = {5, 7, 2, 4, 3, 8}. Bin Capacity B = 10.
- Question: Apply FFD algorithm.

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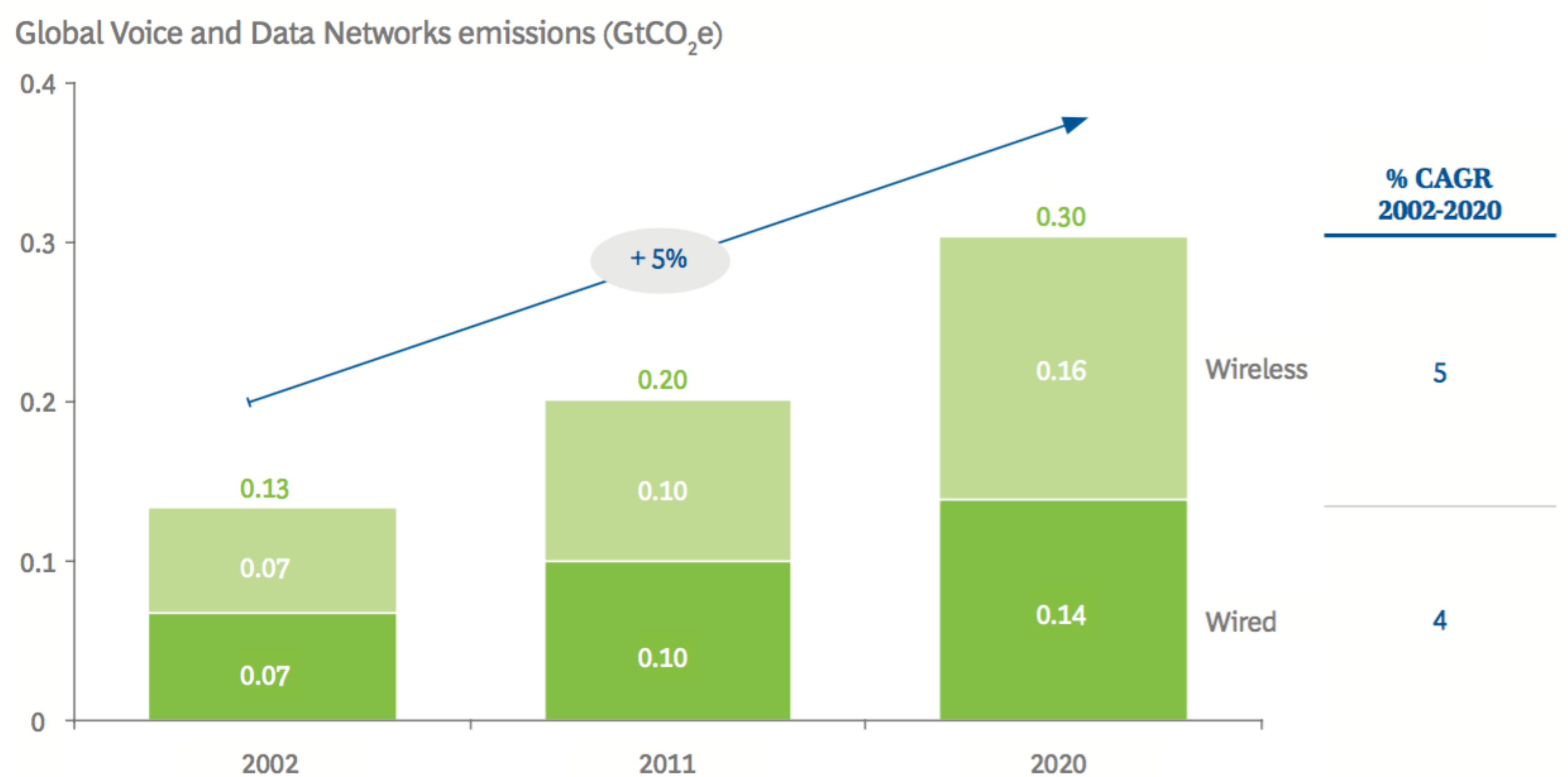
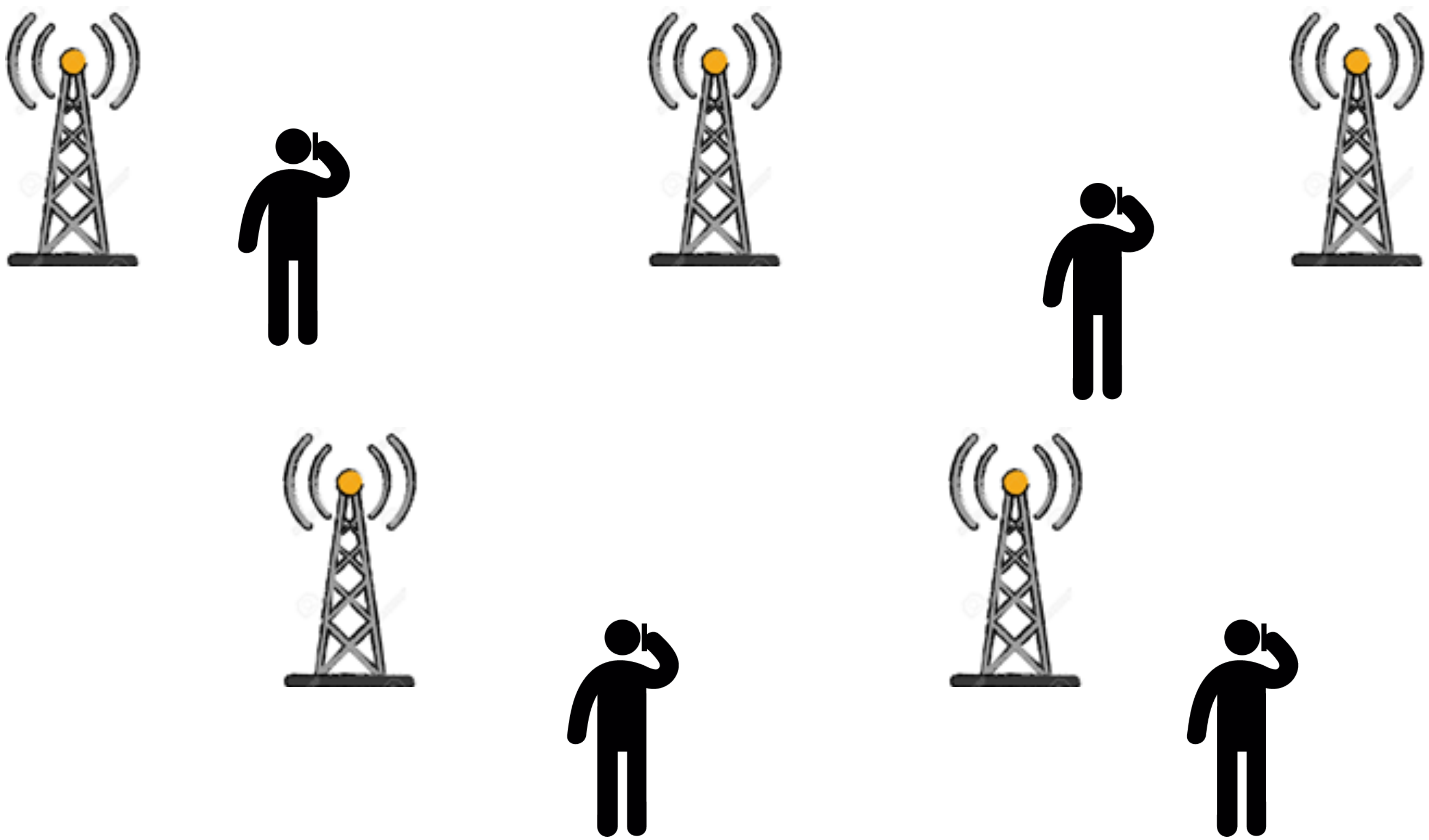
Wired vs Wireless Networks



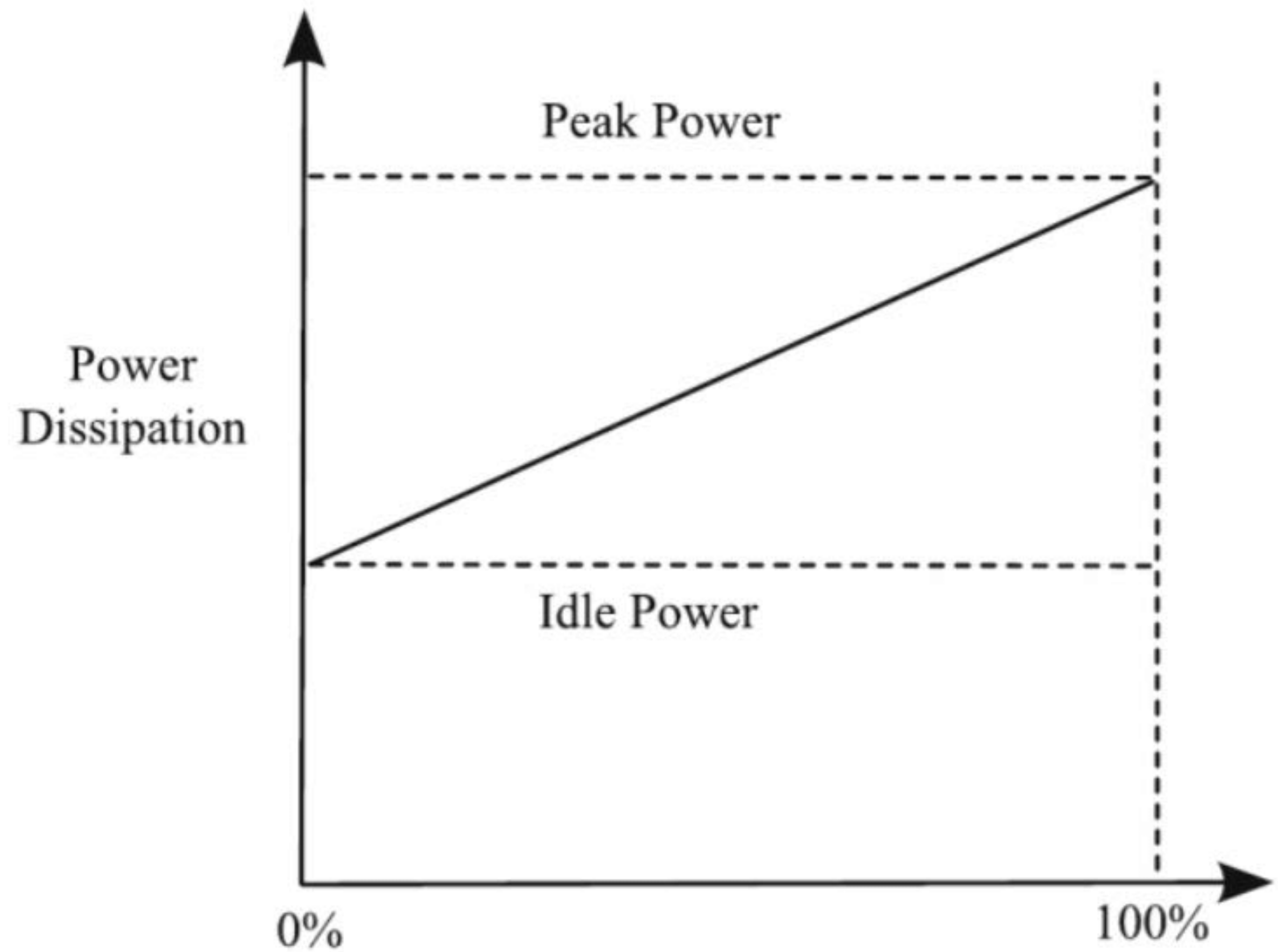
- **Wired network footprint = Wireless network footprint.**
- But **Mobile network emissions expected to grow faster** than wired networks emissions

Mobile Networks



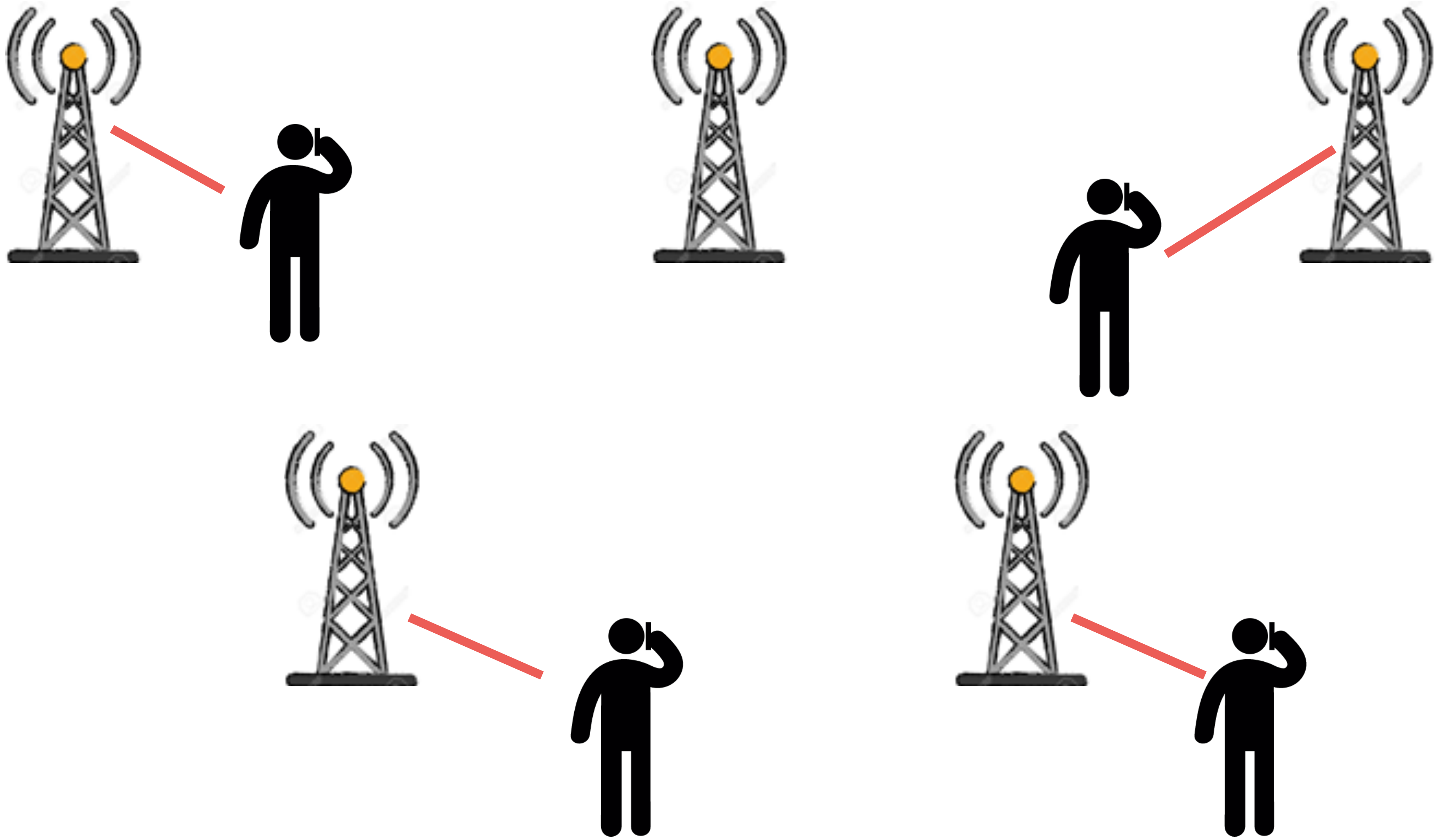
Power models of Antennas

- Again: energy consumption not proportional to traffic
- A solution to save energy: put antennas to sleep mode



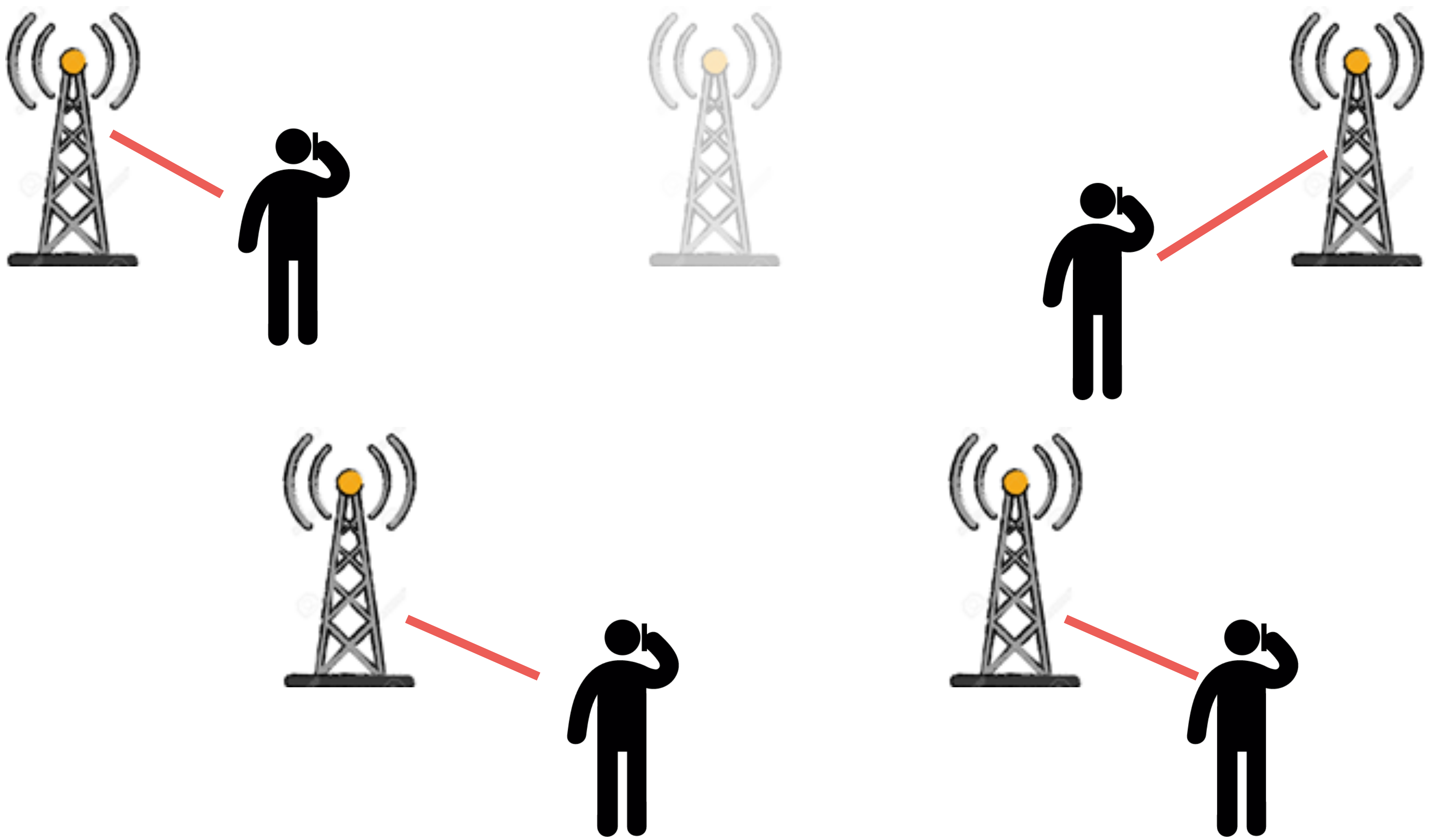
Traffic received and emitted

Mobile Networks



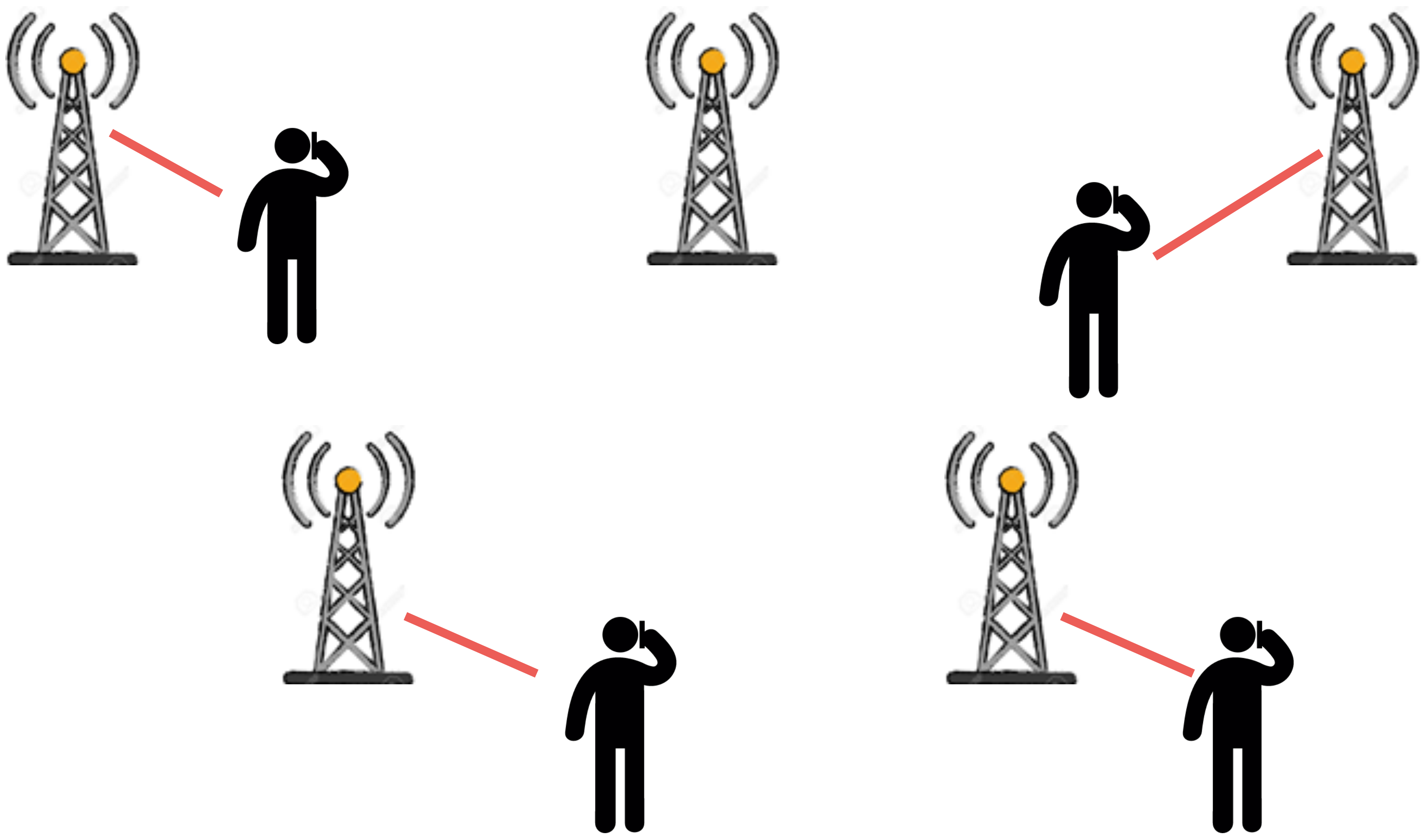
Association user phone - Antennas

Mobile Networks



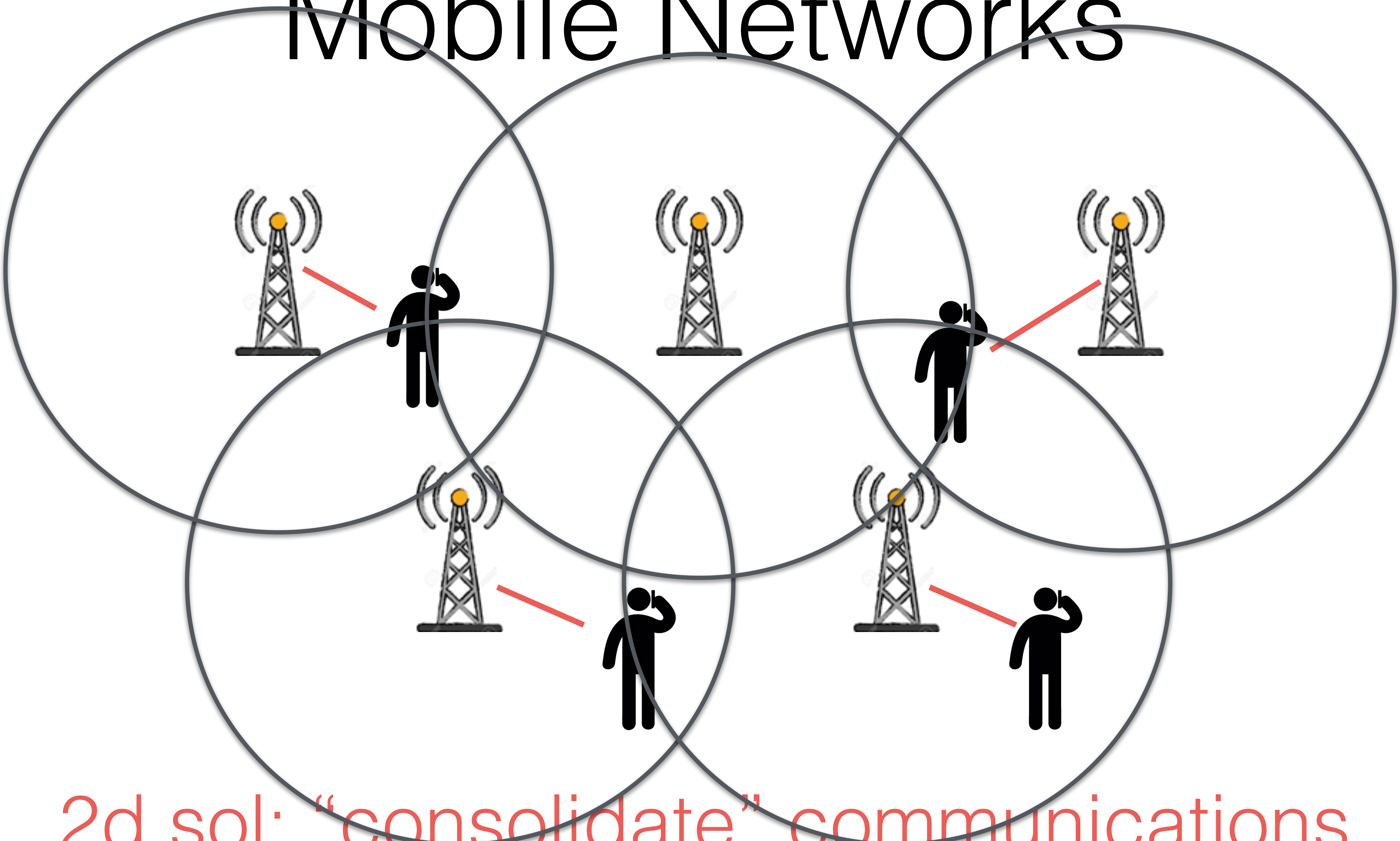
1st sol: Put to sleep unused antennas

Mobile Networks



2d sol: “consolidate” communications

Mobile Networks



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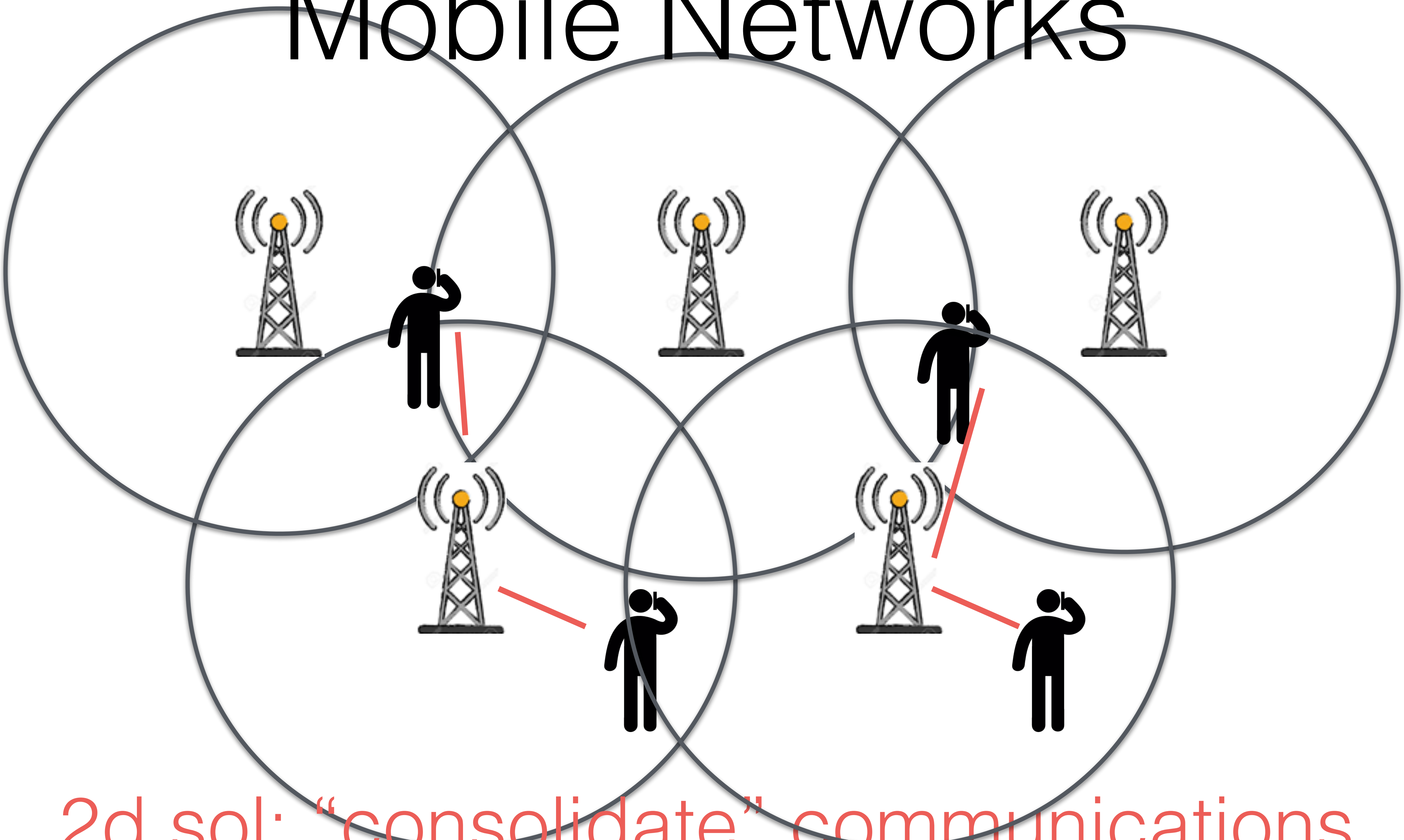
Mobile Networks



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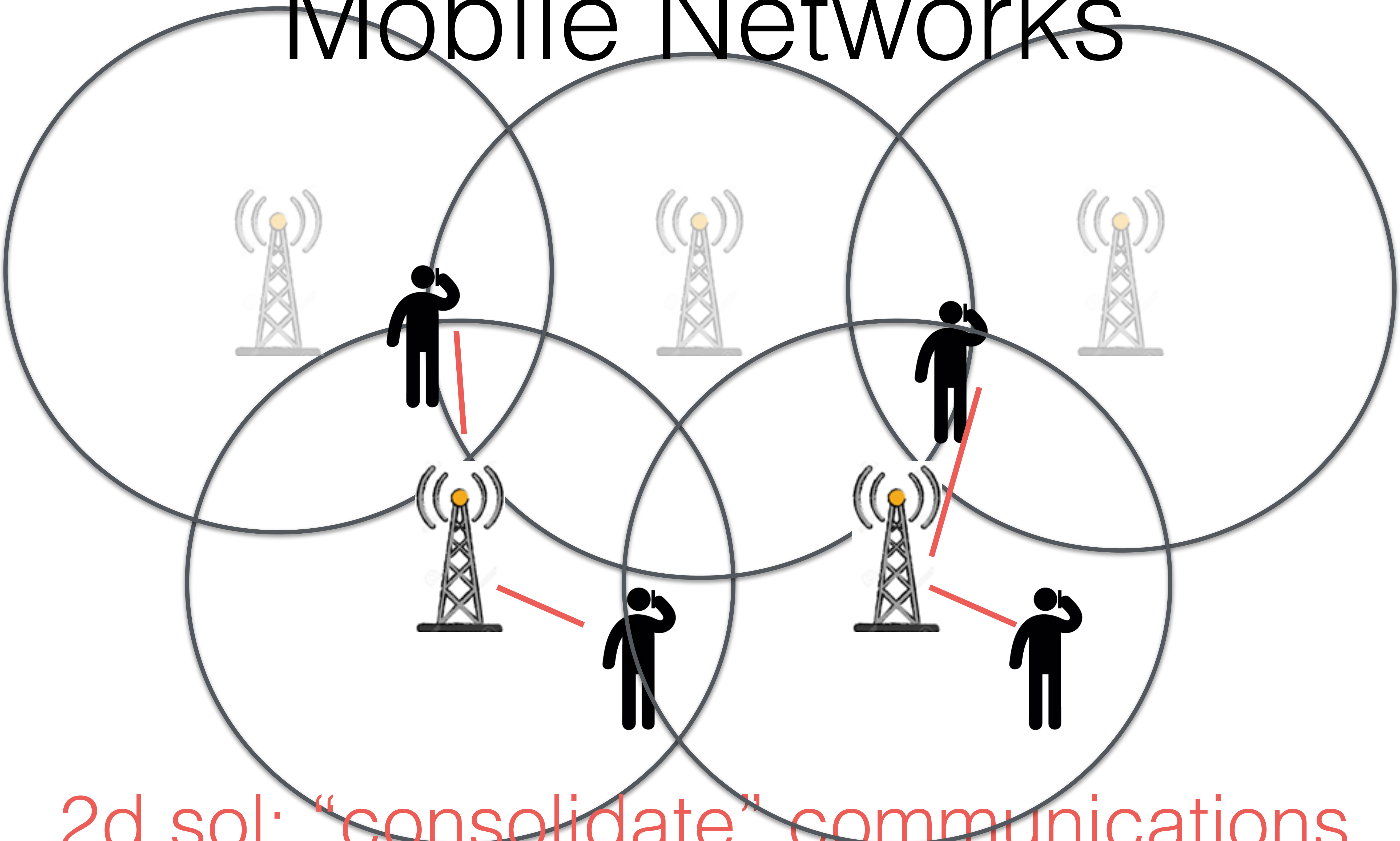
Mobile Networks



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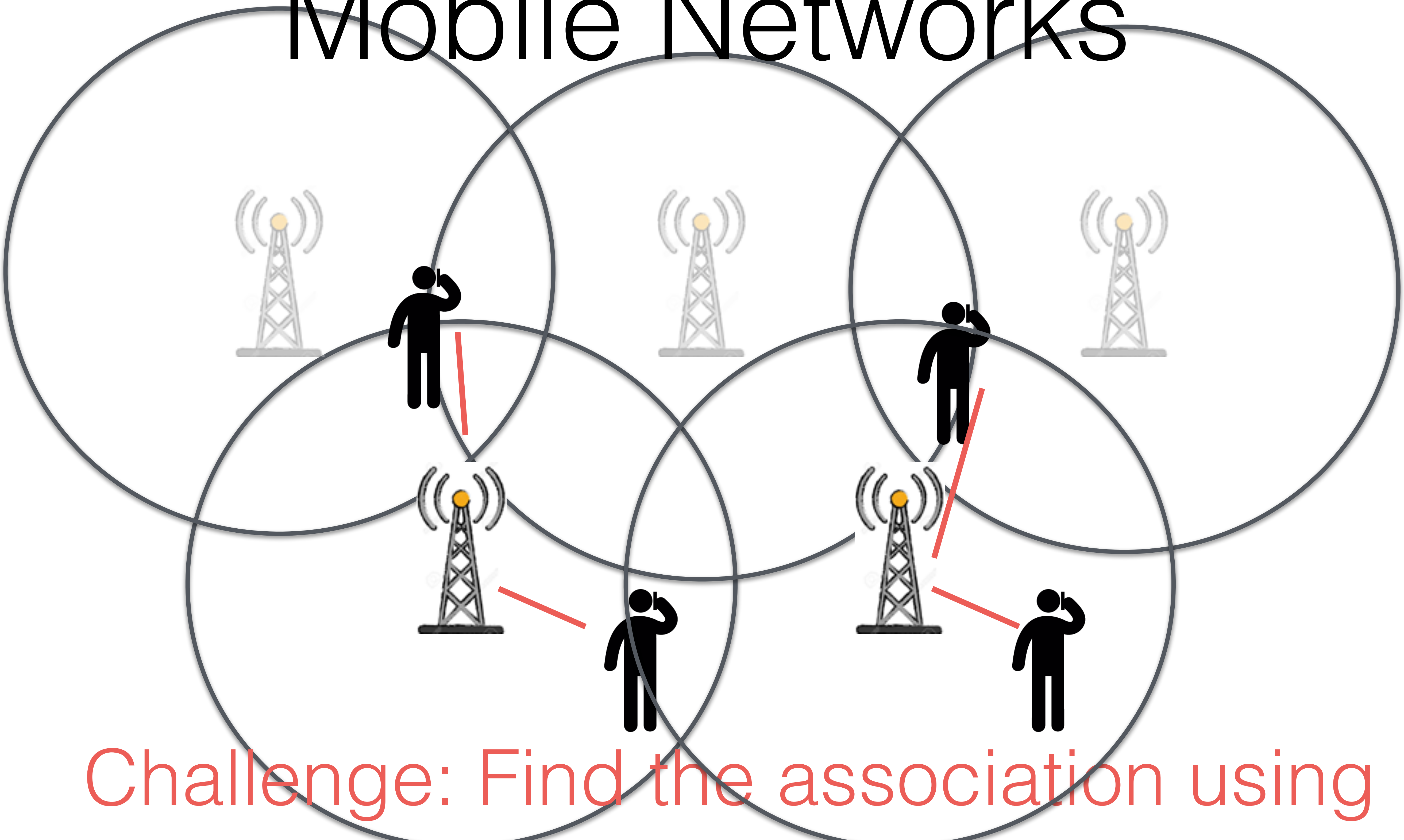
Mobile Networks



Challenge: Find the association using the minimum number of antennas.

Combinatorial Optimization Problem

- Minimum Set Cover Problem

Problem: Given a universe U of n elements, a collection of subsets of U, $\mathscr{S} = S_1, ..., S_k$, and a cost function $c : S \rightarrow Q^+$, find a minimum cost subcollection of S that covers all elements of U.

- Here, we consider that the cost of all Si is uniform c=1.

Exercise

- Ex1. Solve the minimum set cover problem for the following instance: U={1,2,3,4,5,6} S1={1} S2={5,6} S3={3,4,5} S4={2,6} S5={1,3}

Algorithm

- Greedy approximation algorithm:
  - at each stage, choose the set that contains the largest number of uncovered elements.

- Algorithmic complexity: This method can be implemented in time linear in the sum of sizes of the input sets, using a bucket queue to prioritize the sets.

- Achieves an approximation ratio of H(s) (s-th harmonic number), where s is the size of the set to be covered. In other words, it finds a covering that may be H(s) times as large as the minimum one.

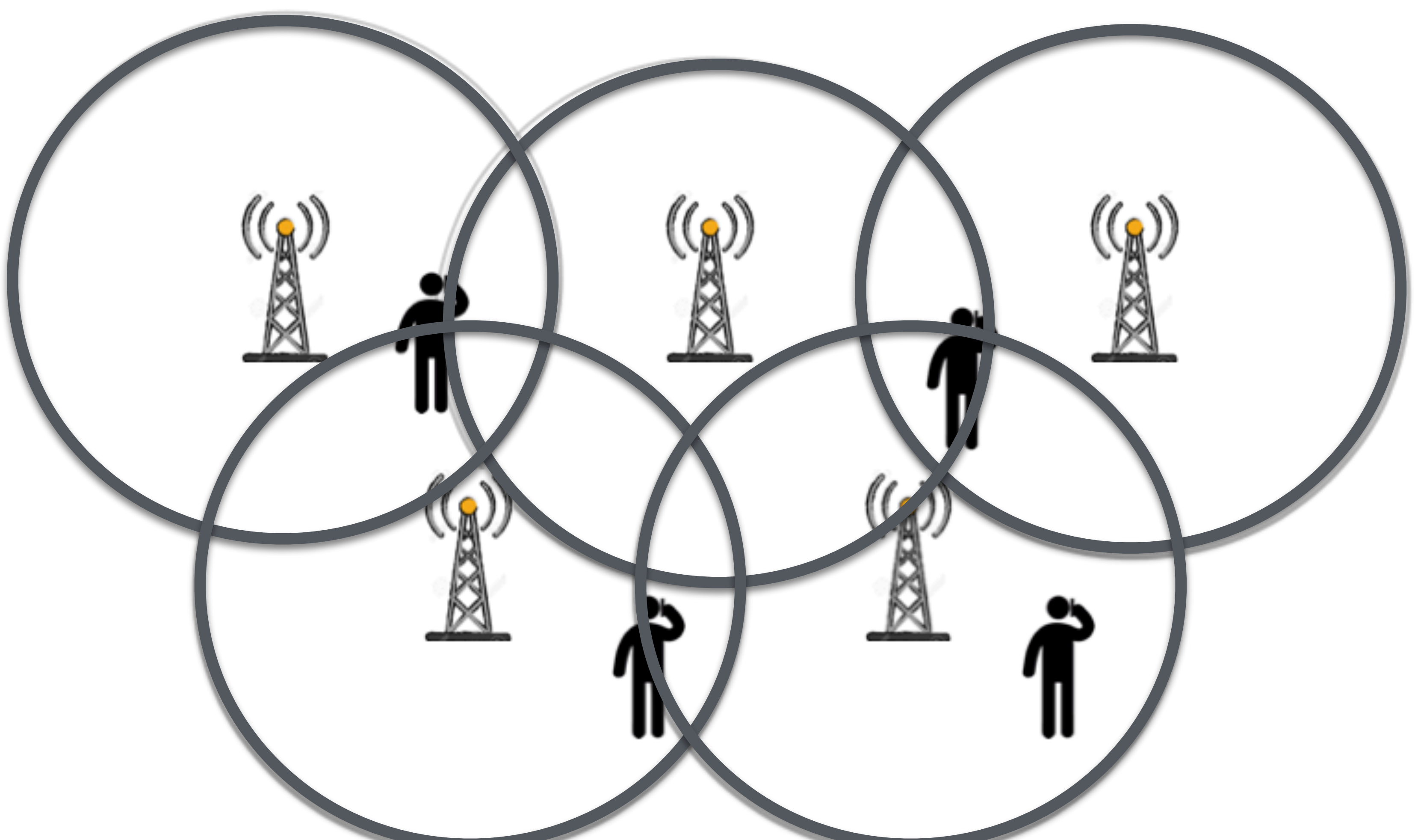
$$H(n) = \sum_{k=1}^{n} \frac{1}{k} \leq \ln n + 1$$

Exercises

- Ex2. Apply the greedy algorithm for the following instances:
  - U={1,2,3,4,5,6} S1={2,3,5} S2={1,3} S2={2,3,6} S3={1,4} S4={5,6}
  - U = {1,..,6} S1={3,4} S2={1,3,5} S3={5,6} S4={1,2}

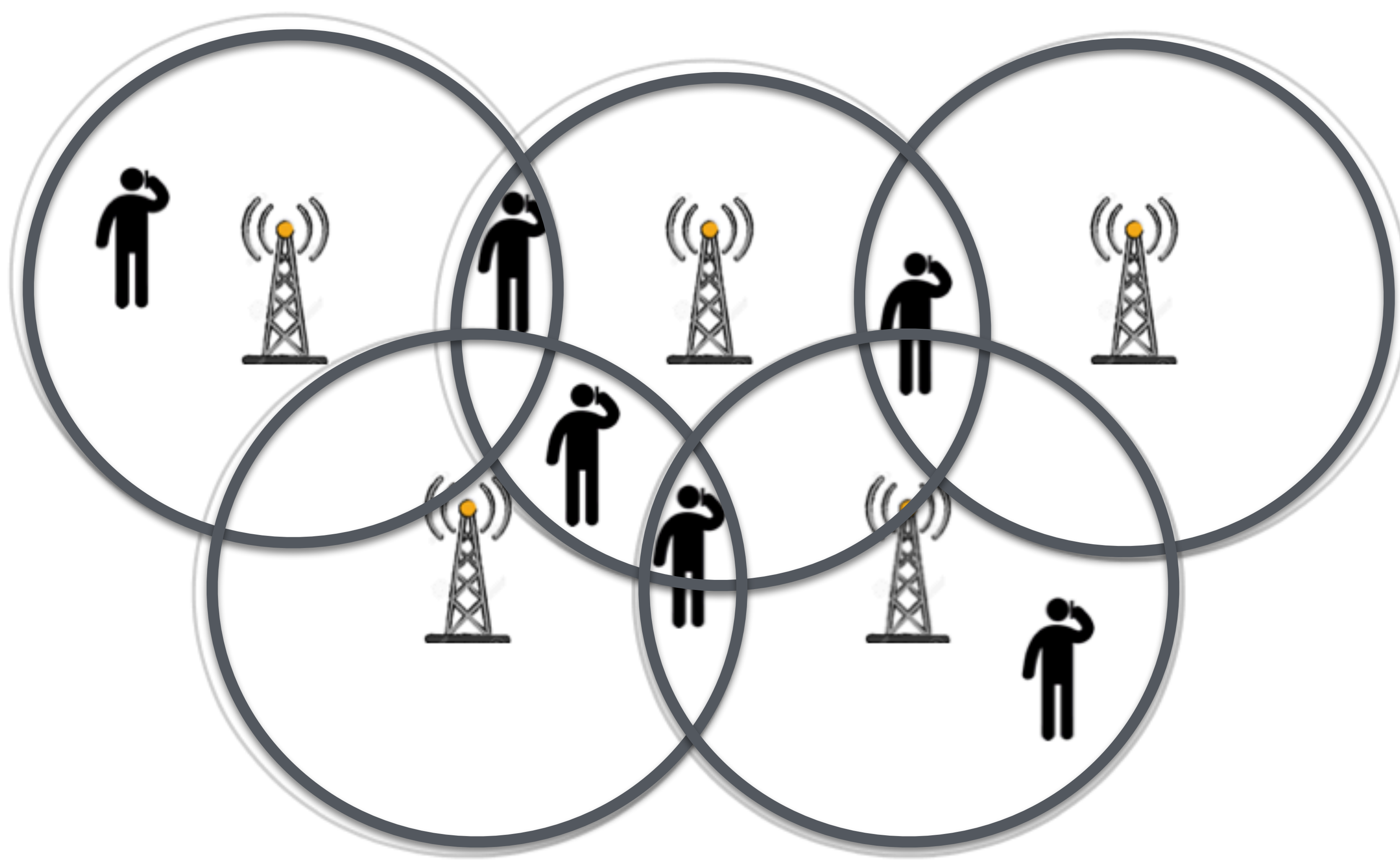
Exercise

- Ex3. Apply the greedy algorithm for the following instance (if a person touches a disk or circle of an antenna, he can use it to communicate)



Exercise

- Ex4. Apply the greedy algorithm for the following instance (if a person touches a disk or circle of an antenna, he can use it to communicate)



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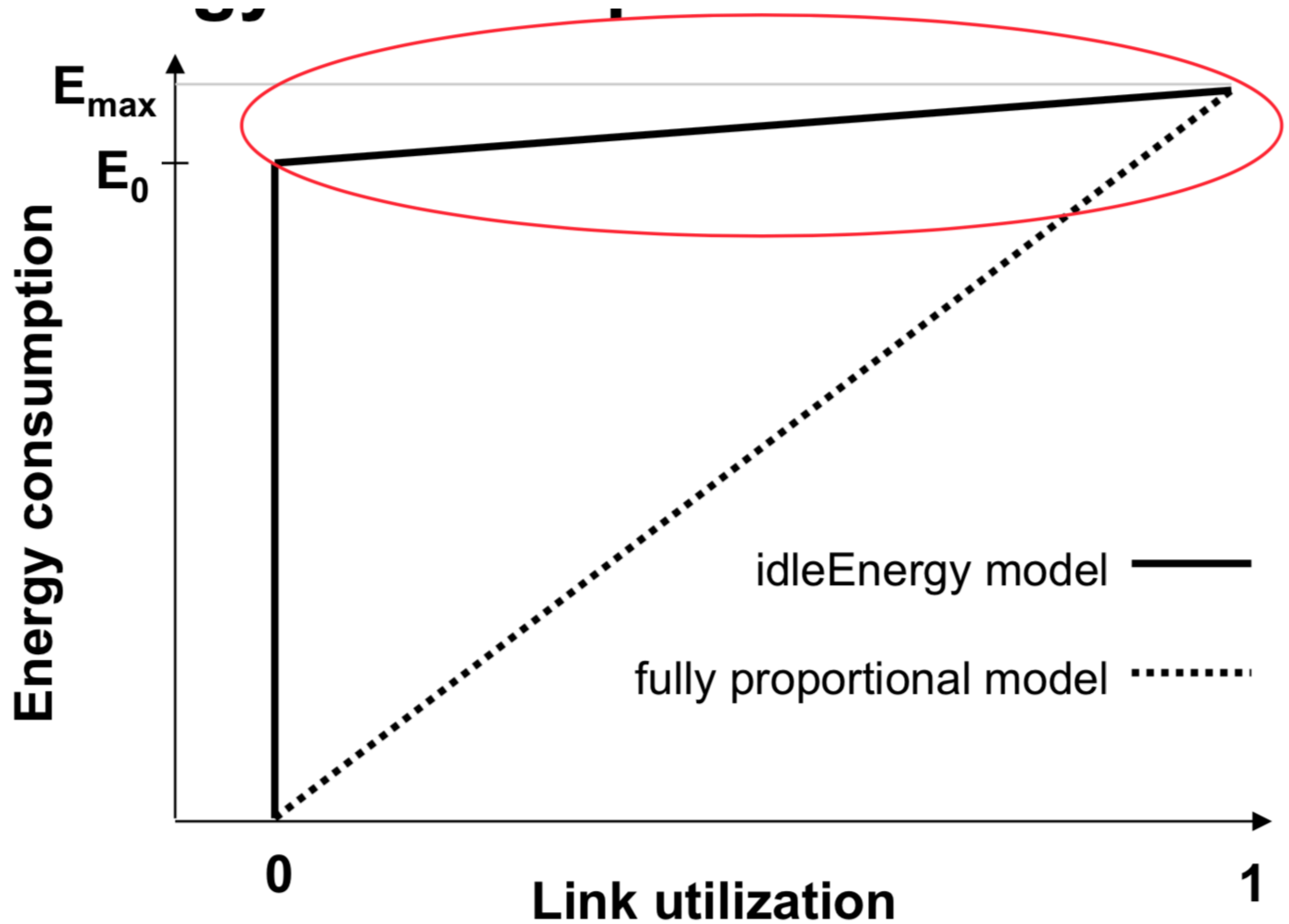
Energy Efficiency of Wired Networks

- Measurement on energy consumption on routers:

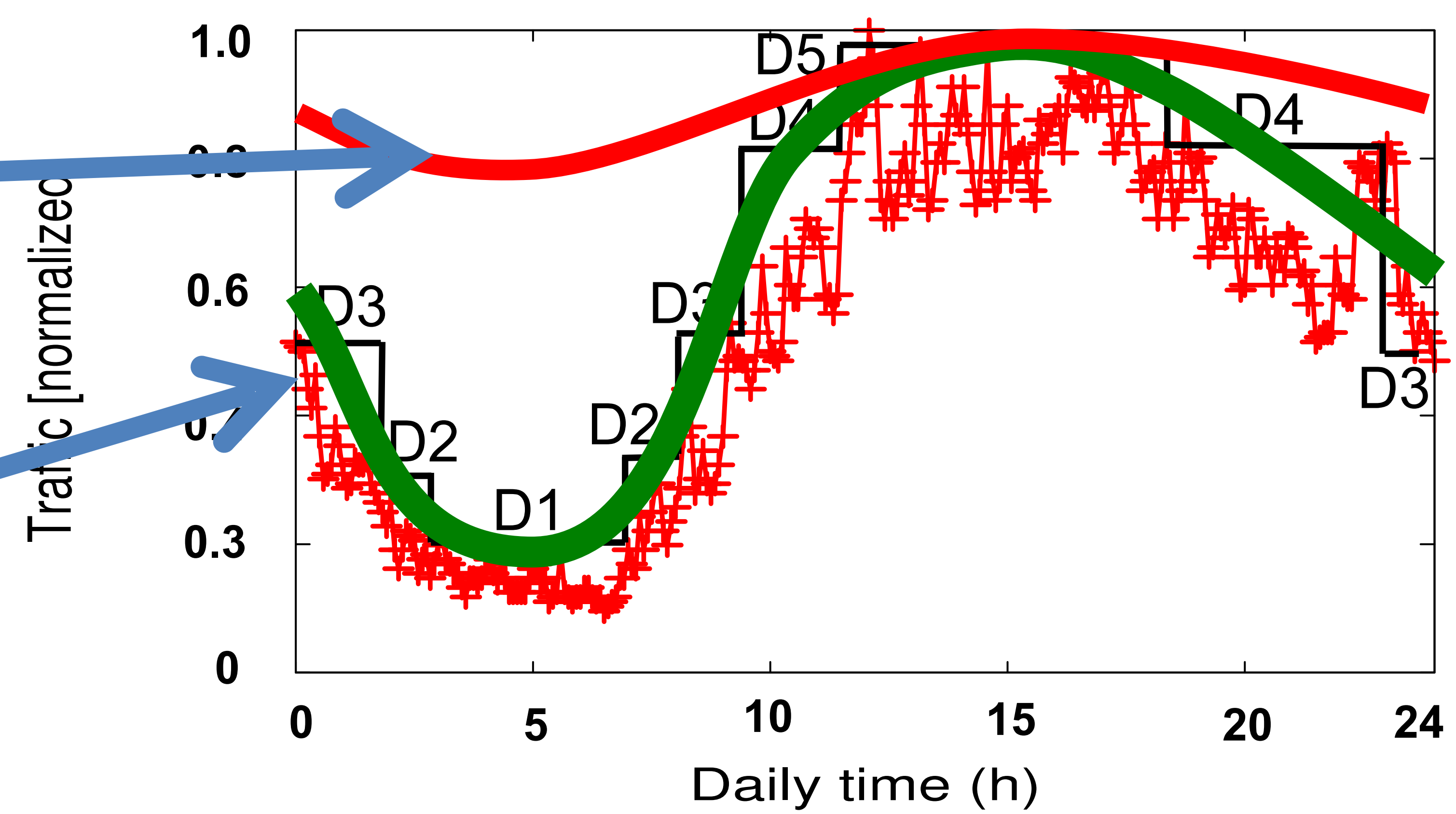


Small influence of traffic load
To save energy switch off interfaces and chassis

Energy Efficiency of Wired Networks

Current power consumption

Ideal power consumption



Energy Aware Routing (EAR)

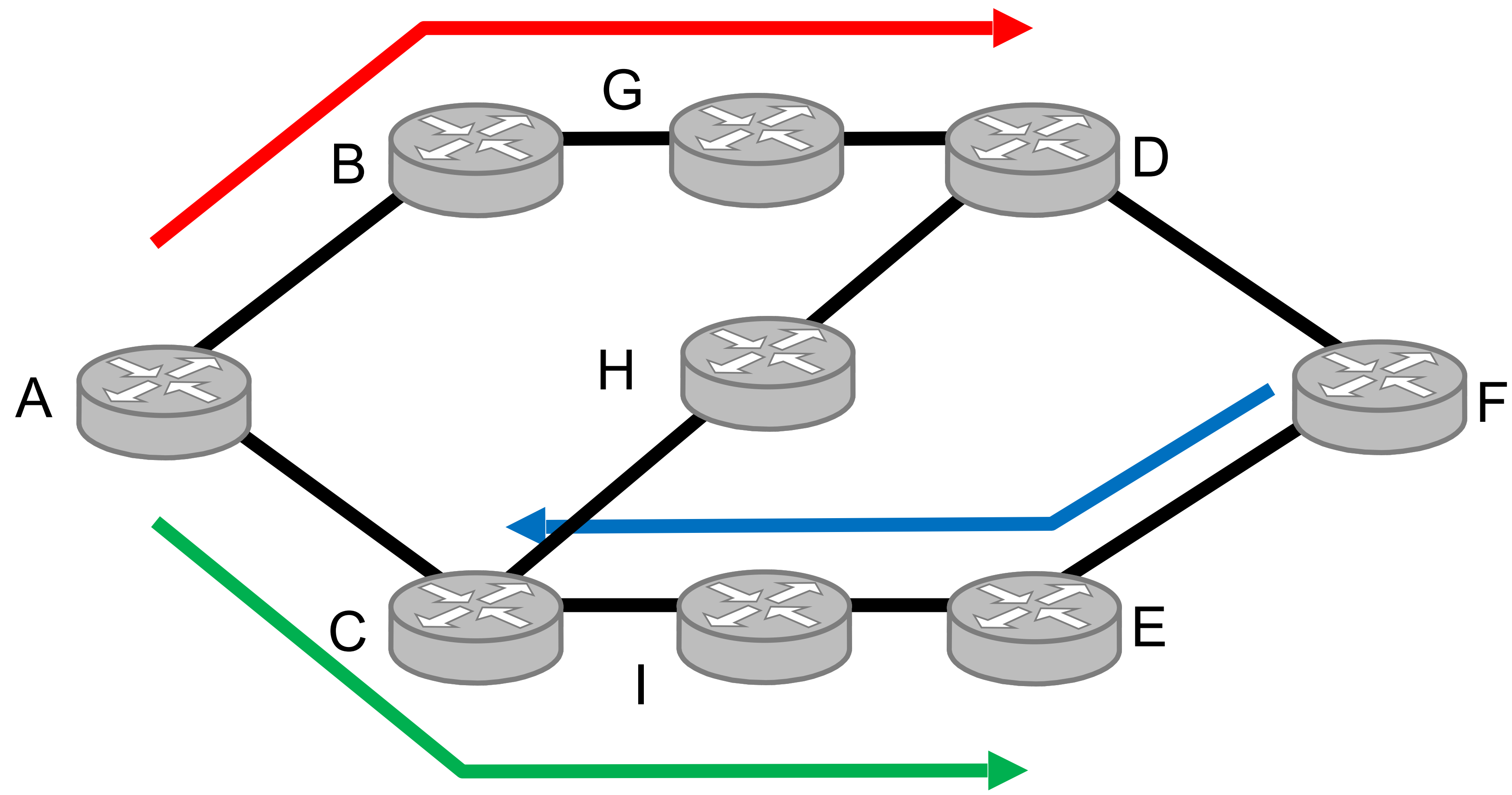
Link Capacity = 2

Path between:

A et D

F et C

A et E



Routing request while minimizing the number of active devices (routers and/or links)

Energy Aware Routing (EAR)

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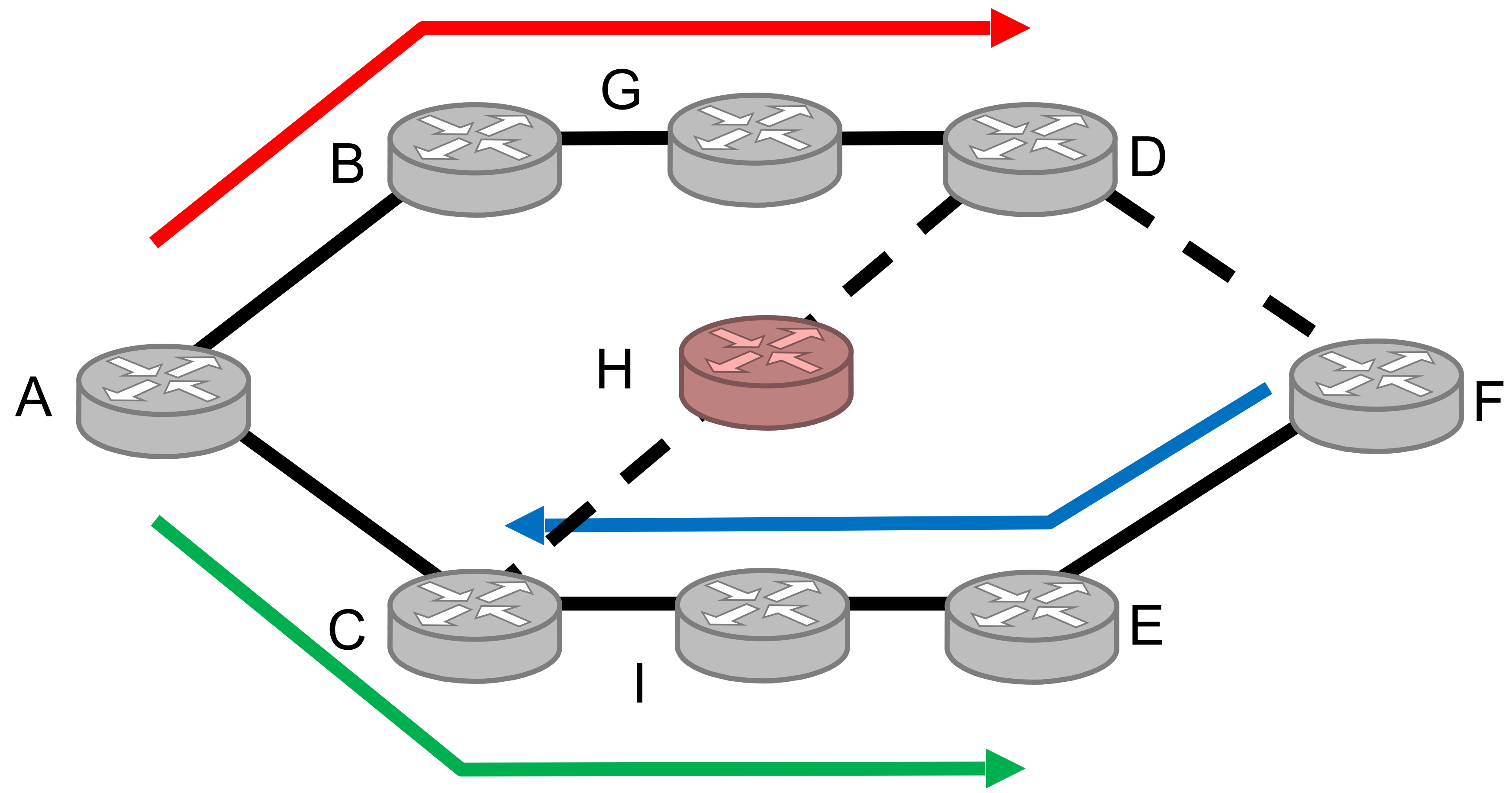


Shortest path routing

Routing request while minimizing the number of active devices (routers and/or links)

Energy Aware Routing (EAR)

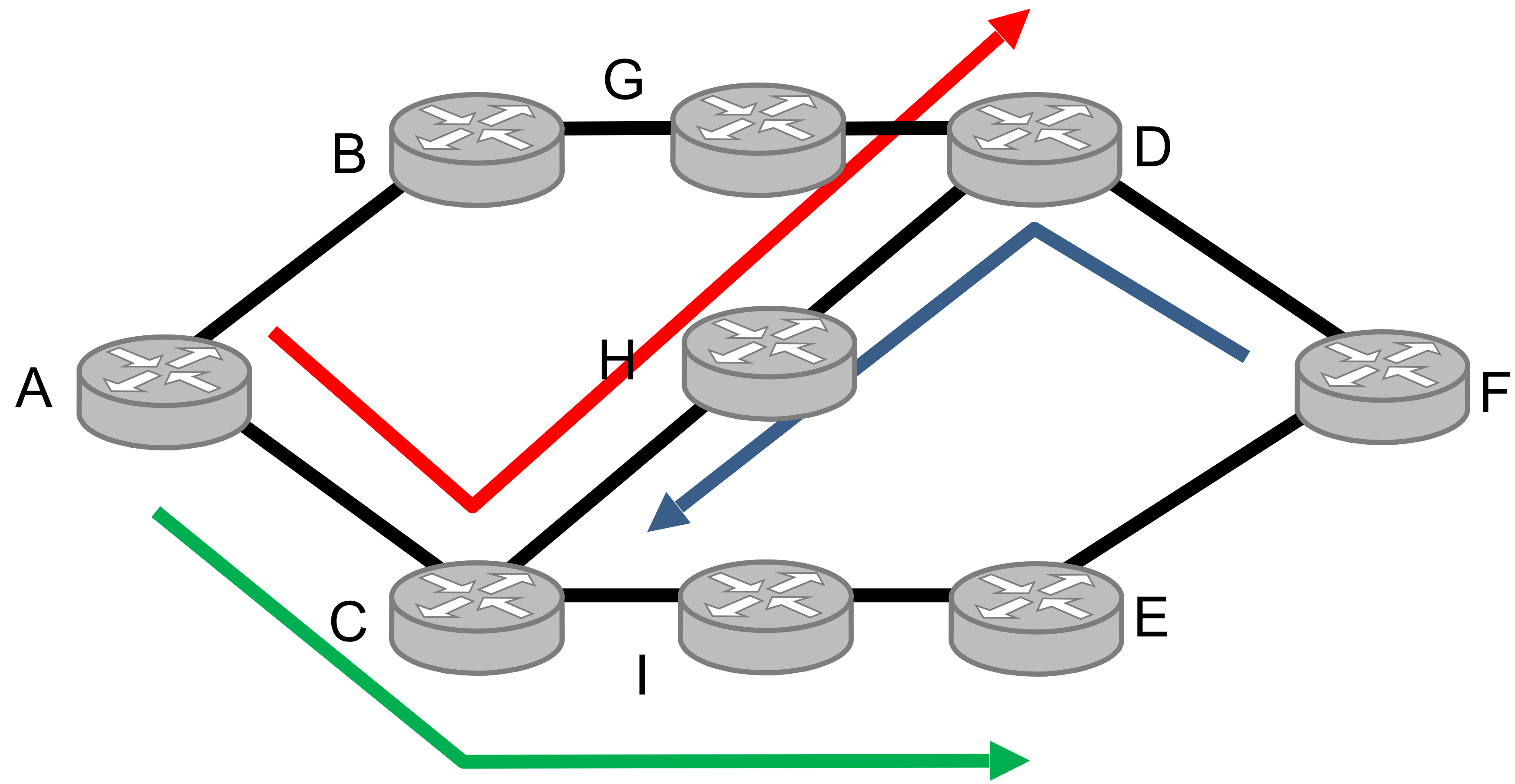
Link Capacity = 2

Path between:

A et D

F et C

A et E



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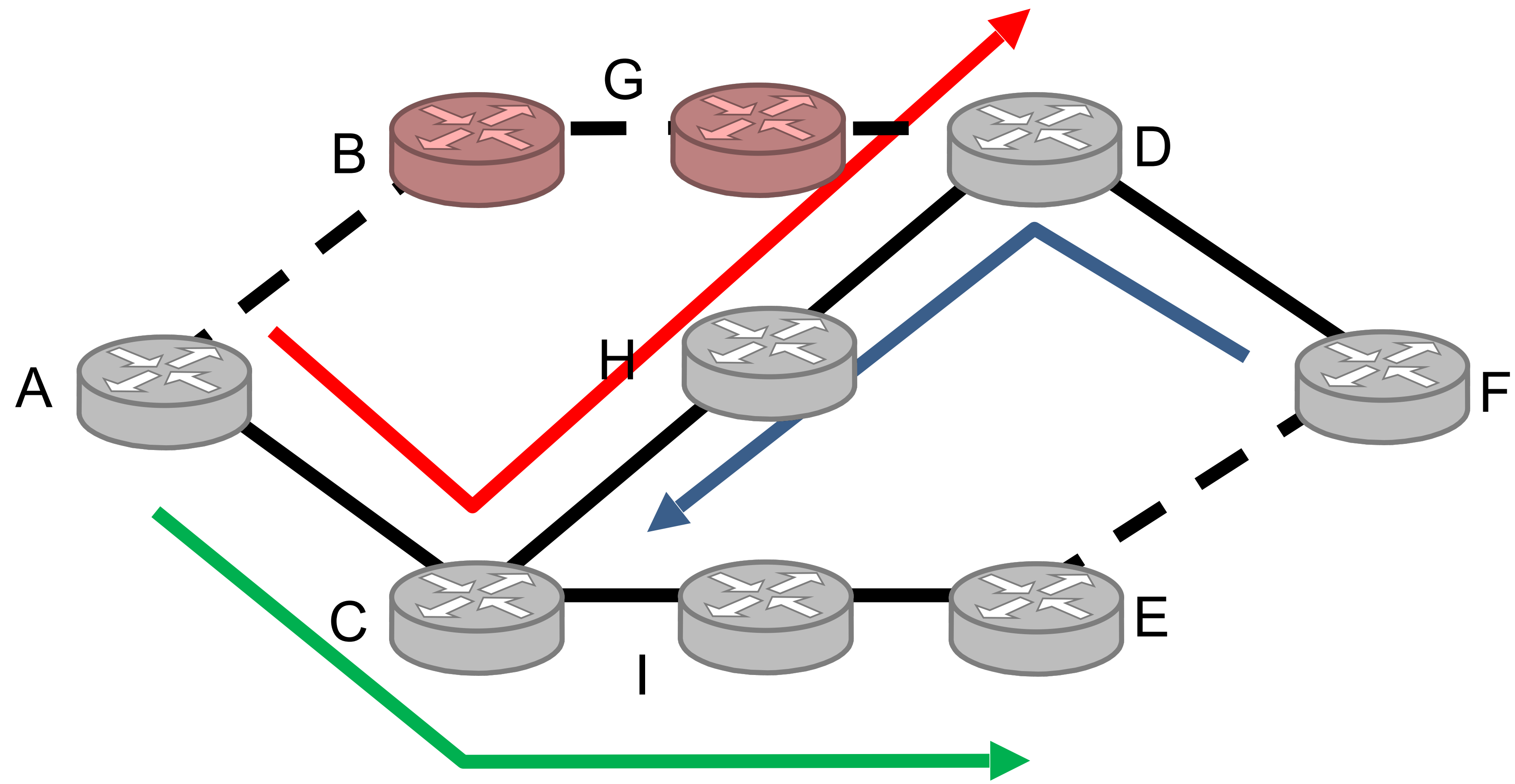


Energy Aware Routing

Routing request while minimizing the number of active devices (routers and/or links)

Solving the Problem

- **Complexity:** NP-complete, Not-approximable.
- Modeling the problem as Mixed Integer Linear Program (MILP) and use solvers.
- **Heuristic algorithms.**
  - Least loaded + shortest path (LL-SP): try to put into sleep the least loaded ressource.

Algorithms

Algorithm: Least loaded + shortest path (LL-SP)
L = V
While (L not empty):
  Select the least loaded node *lln* in L
  Try to put *lln* to sleep.
  Route all demands using SPs
  If routing NOT feasible
    Put *lln* back ON
    Go back to previous routing
  remove *lln* from L.

Exercise

- Apply LL-SP to the following instance:

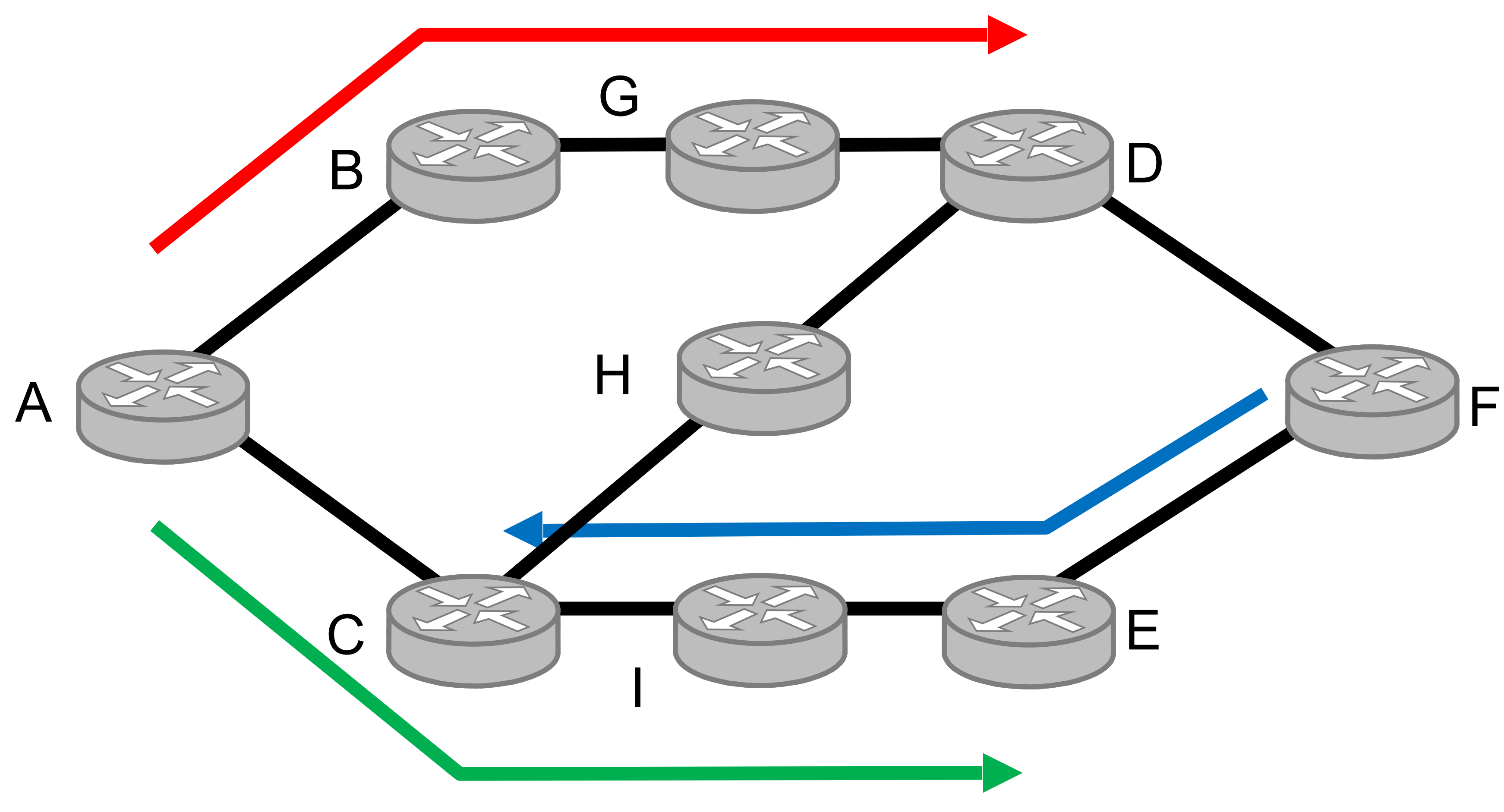
Link Capacity = 2

Paths between:

A et D

F et C

A et E



Take-aways

- In data centers.
    - VM consolidation
    - Bin packing problem
    - Classic algorithms

*

*This is not a tree

Take-aways

- In mobile networks
  - Putting to sleep antennas
  - Set cover problem
  - Greedy approximation algorithm

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Take-aways

- In core networks
  - Energy aware routing
  - LL-SP heuristic

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Take-aways

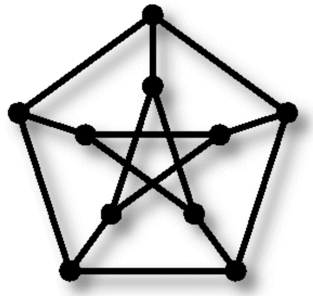
- A lot proposed since 2008.
- A lot remains to be put into reality (good for us :-)

*

*This is not a tree

Who we are?

- Working in the **team COATI** at Sophia Antipolis (Inria and I3S/CNRS/University of Nice Sophia Antipolis)



- **Expertise:**
  - **In General:** Algorithmics, combinatorics and optimization for telecommunication networks.
  - **On Energy Efficiency**: mostly **networks and data centers.**

Conclusions

- Encouraging technology advances and challenges:
  - More energy efficient hardwares
  - SDN revolution and virtualisation
  - Ubiquitous networking and multiple joint optimization

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Conclusions

* Encouraging technology advances and challenges:
  * More energy efficient hardwares
  * SDN revolution and virtualisation
  * Ubiquitous networking and multiple joint optimization

*

Thanks for your attention!!!

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Credits due to:

- **Surveys:**
  - Bolla, R., Bruschi, R., Davoli, F., & Cucchietti, F. (2011). Energy efficiency in the future internet: a survey of existing approaches and trends in energy-aware fixed network infrastructures. *Communications Surveys & Tutorials*, IEEE, 13(2), 223-244.
- **Slides:**
  - F. Davoli. Green Networking and Network Programmability: A Paradigm for the Future Internet? 22d ITC Specialist Seminar. 2013
  - Christensen, K., & Nordman, B. Reducing the energy consumption of networked devices. IEEE 802.3 tutorial.
  - D. Kilper, Tutorial: Energy Efficient Networks.
  - D. Lopez & F. Giroire, Green Networks, Master Course, University Nice-Sophia Antipolis, 2016.
  - Design and Management of Networks with Low Power Consumption, Truong Khoa Phan, *PhD Defense*, Sophia Antipolis, 2014
  - Slides from presentations from J. Moulierac, N. Huin and M. Rifai.
  - F. Hermenier, Resource management in IaaS cloud
- **Reports:**
  - Global e-Sustainability Initiative. (2012). GeSI SMARTer 2020: the role of ICT in driving a sustainable future. *Global e-Sustainability Initiative*, Brussels, Belgium.