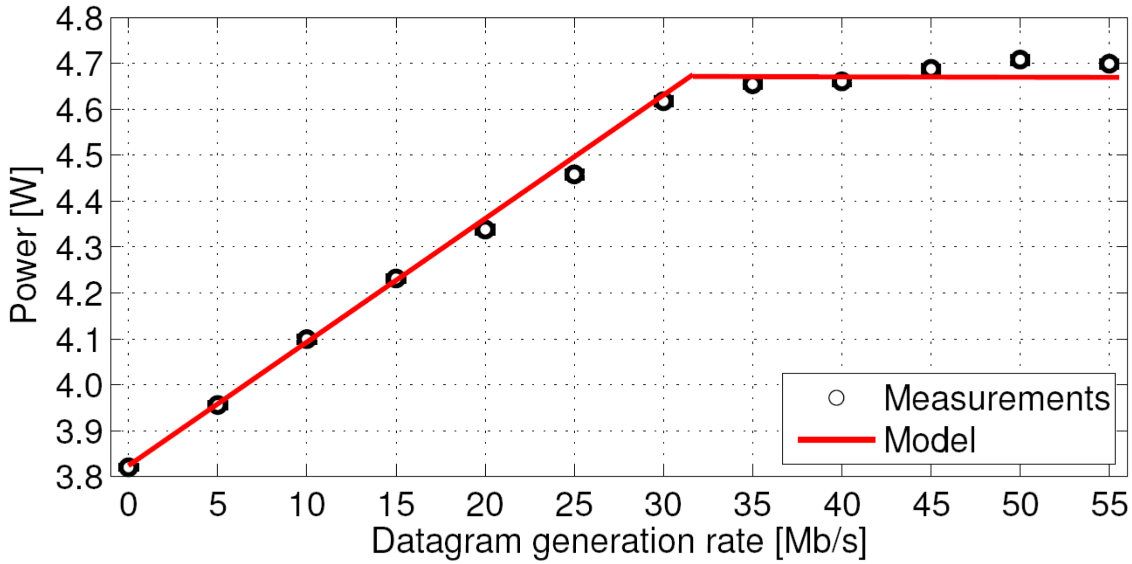
▪ ▪ ▪ Analysis of the Throughput/Energy ▪ ▪ ▪ Trade-off in Wireless Networks

ITG 5.2.4 Workshop/November 2012
“Green IT in Wireless Access Networks“

Peter Dely (Karlstad University, Sweden)

Problem Description

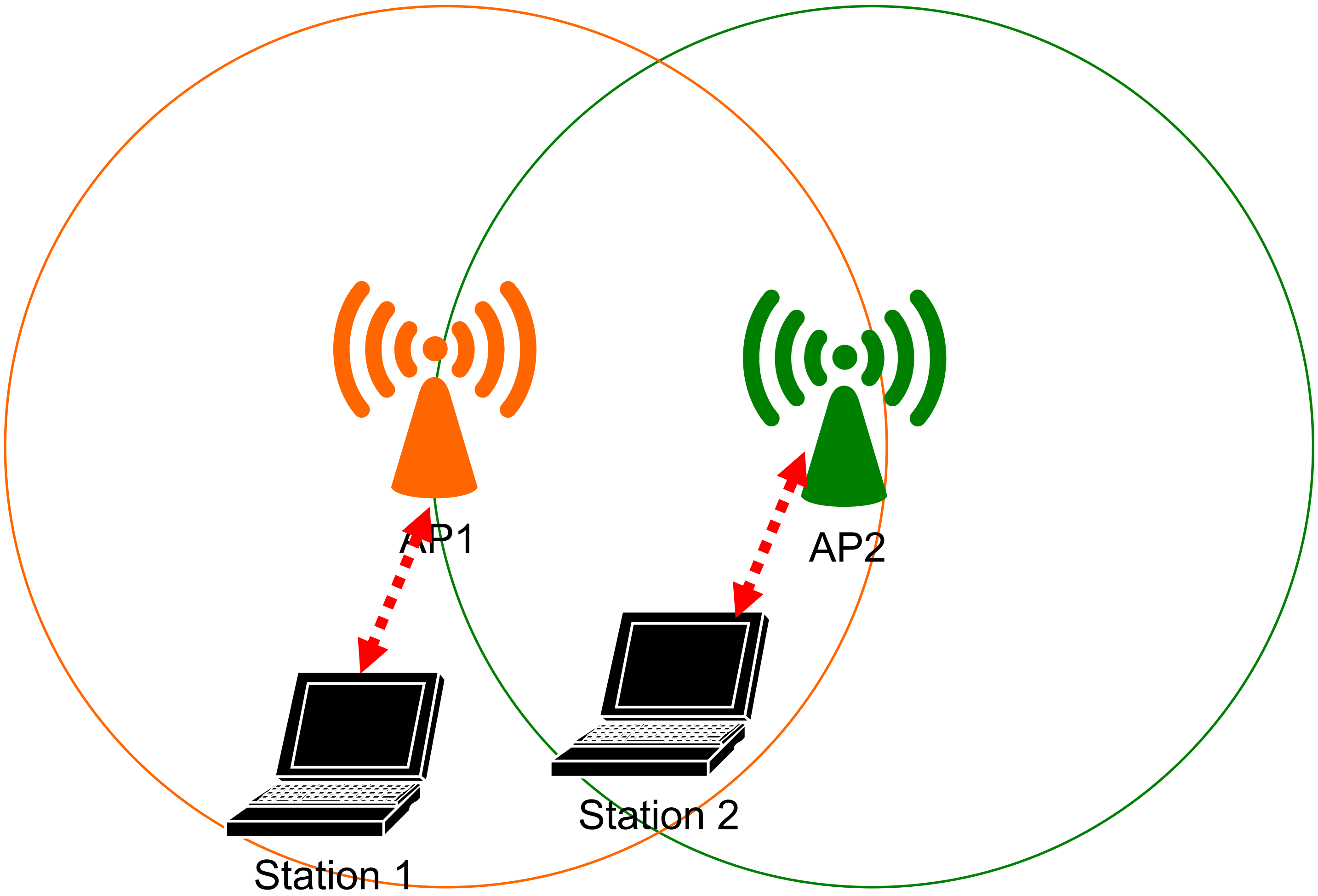
- Energy costs are increasing faster than operator revenues
- Base and peak consumption in WLAN APs are almost the same



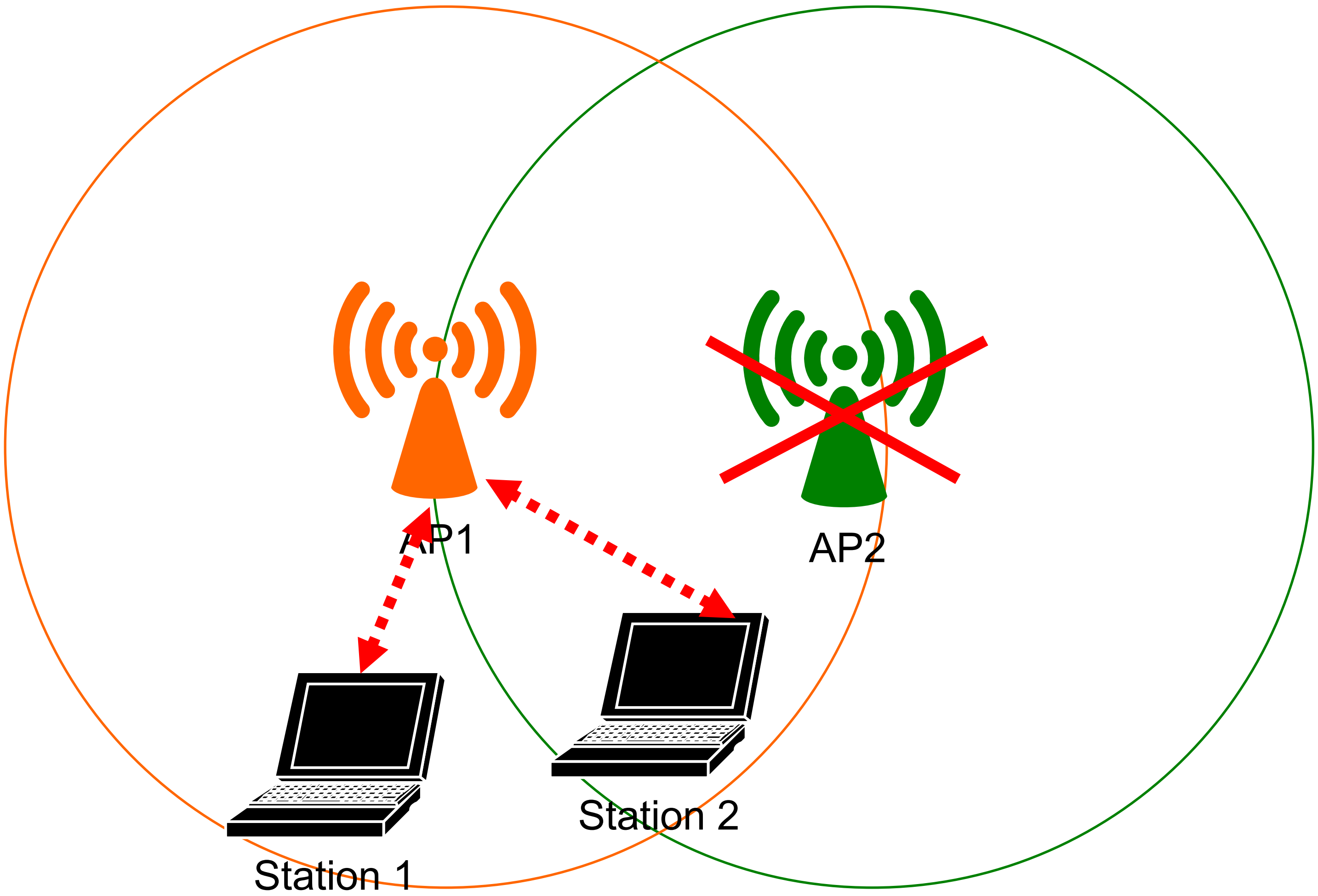
Source: "Energino: a Hardware and Software Solution for Energy Consumption Monitoring", Karina Gomez et al.

- If you want to save energy: switch off the AP!
- But: switching off APs reduces network coverage and impacts performance

Option 1 – High Performance



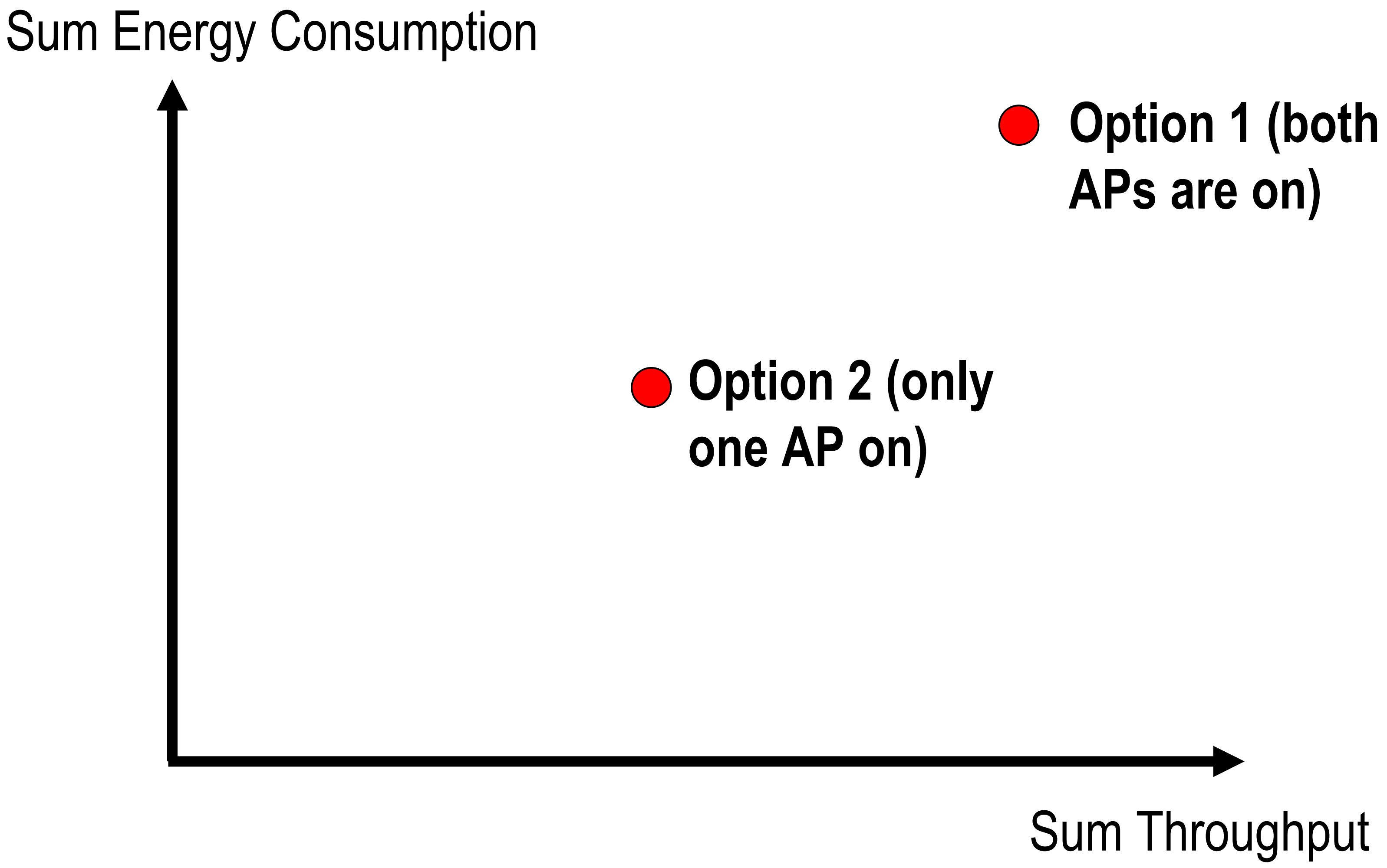
Option 2 – Low Energy



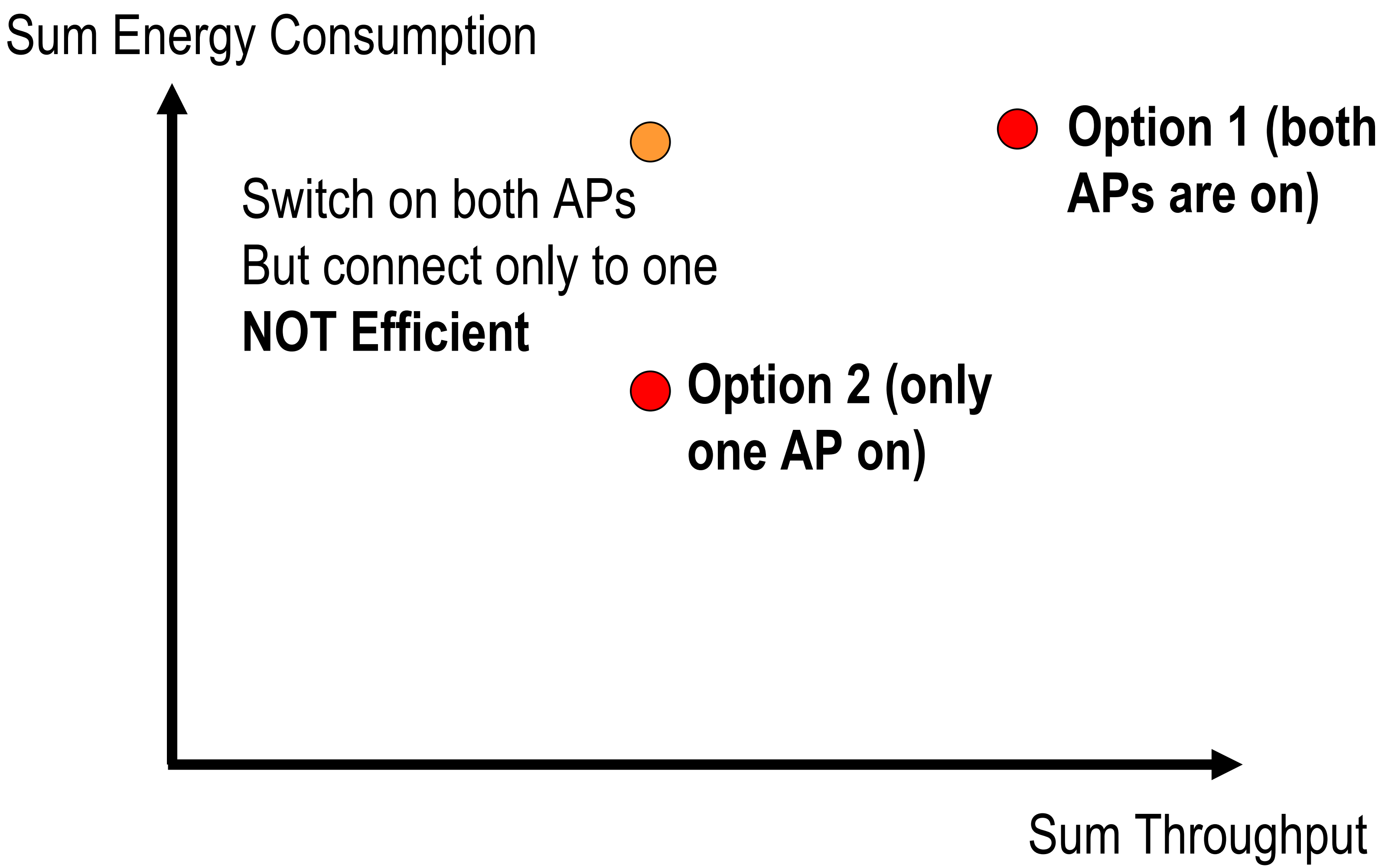
Comparison Option 1 and 2

	Throughput Station 1	Throughput Station 2	**Sum Throughput**	Energy Consumption AP1	Energy Consumption AP1	**Sum Energy Cons.**
Option 1	30 Mbit/s	30 Mbit/s	**60 Mbit/s**	4.7 W	4.7 W	**9.4 W**
Option 2	12 Mbit/s	10 Mbit/s	**22 Mbit/s**	4.7 W	0 W	**4.7 W**

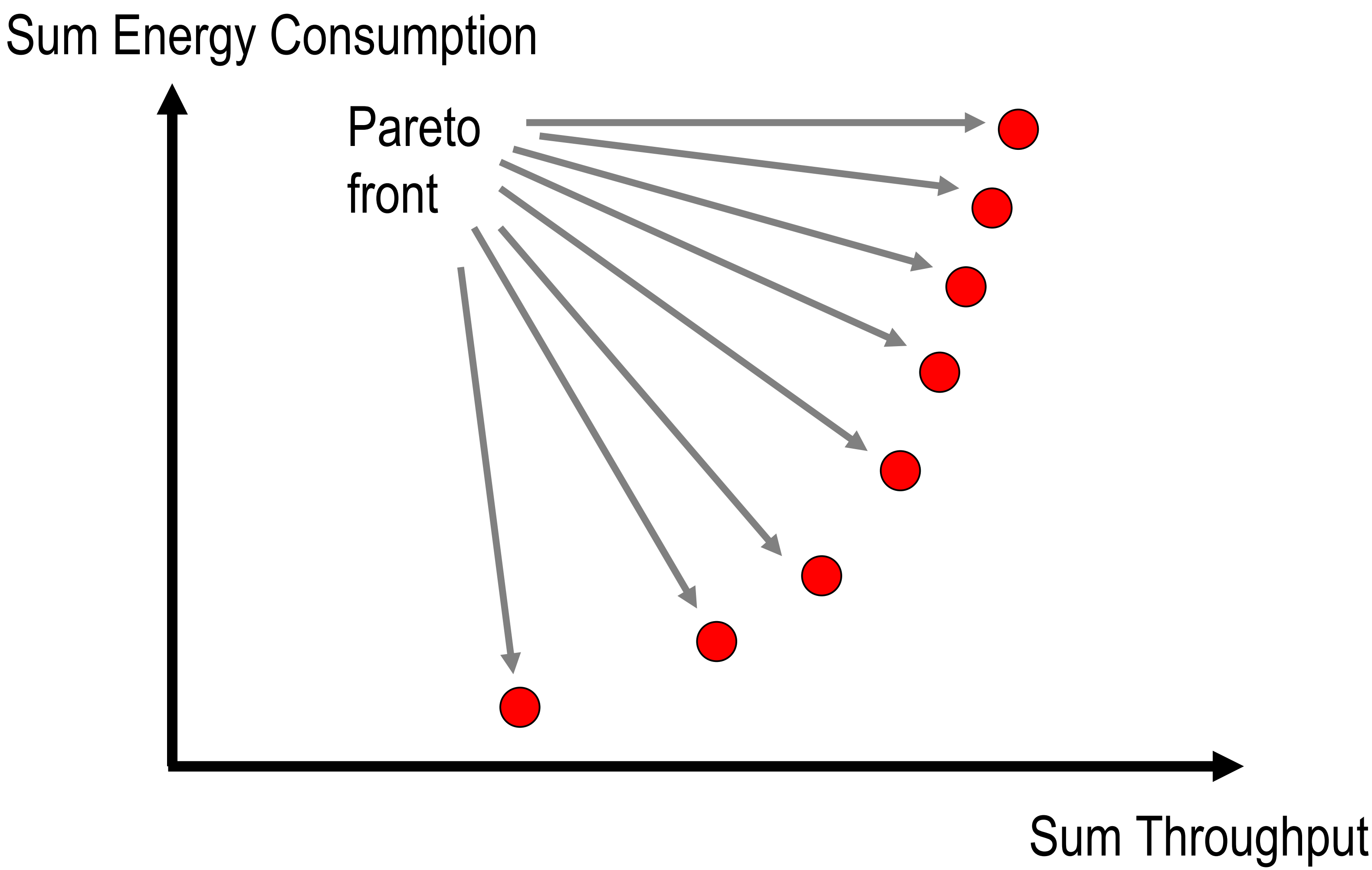
Throughput - Energy Tradeoff



Throughput - Energy Tradeoff



Energy – Throughput Tradeoff



Questions Discussed in this Presentation

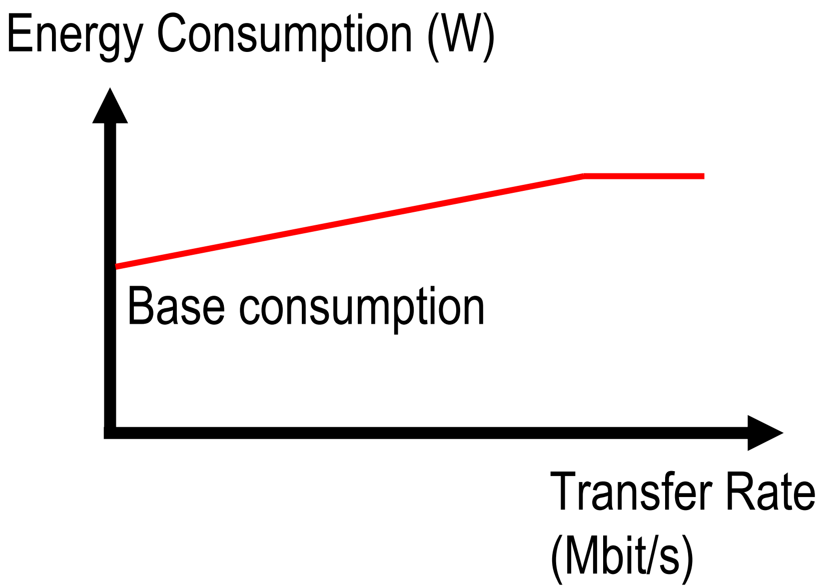
1. How to find points on the Pareto front?
2. Which point to choose?
3. What are the trade-offs in a WLAN deployment?

1. How to find points on the Pareto front?

Cost/Utility Functions

Network Energy Cost

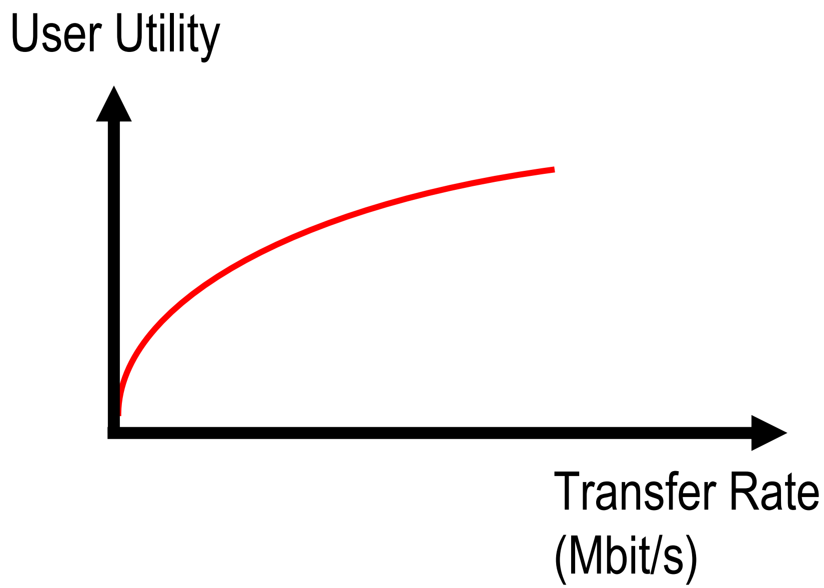
- Sum of energy consumption of all APs



- Base consumption + Energy per bit * transfer rate
- Utility = (-1) * Cost

Network Throughput Utility

- Network throughput utility is sum of user utilities



- User utility = **log**(Transfer Rate)
- Proportional fairness of user rates

Constraints

- Connection
  - Each STA must be connected to exactly one AP
  - STAs can only connect to powered-on APs
  - STAs can only connect to APs that exceed a minimum RSSI threshold
- Capacity
  - PHY rate depends on path loss, i.e. AP-STA distance
  - Transmissions occupy the channel for 1/PHYRate seconds per bit
  - Total channel occupation must be < 1 for all channels
- Coverage
  - Areas with STA need to be covered for sure
  - APs need to provide coverage for at least *k*% of the total area

Optimization Model Formulation

- Aim: Formulate the model as Mixed Integer Linear Program (MILP)
- MILPs can be solved efficiently to optimality
- MILP computes
  - Which AP to switch off
  - Which AP a STA should be connected to
  - What data rate the STA gets
- Requirements for a MILP:
  - One linear objective function
  - Linear (in)equalities as constraints
  - Variables are continuous or discrete

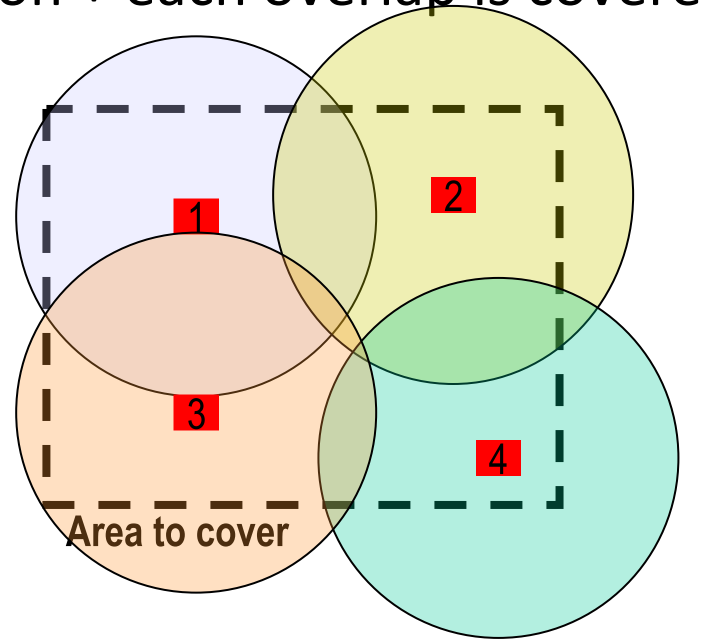
Optimization Model Formulation

- Problem 1:
  - Log function of user utility is not linear

  → Piece-wise linear approximation
- Problem 2:
  - Two objective functions
  - Weighted sum of scaled objective functions

Optimization Model Formulation

- Problem 3:
  - Constraint: Any point in the area to cover needs to be in communication distance of an powered-on AP
  - Find all areas that are only covered by one AP
  - Ensure that these APs are powered-on + each overlap is covered
- Variant of Problem 3:
  - *k*% of the total area need to be in communication distance of an powered-on AP
  - Compute area of each section that is only covered by one AP
  - Ensure that sum of covered areas is k% of total area



Generating the Pareto Front

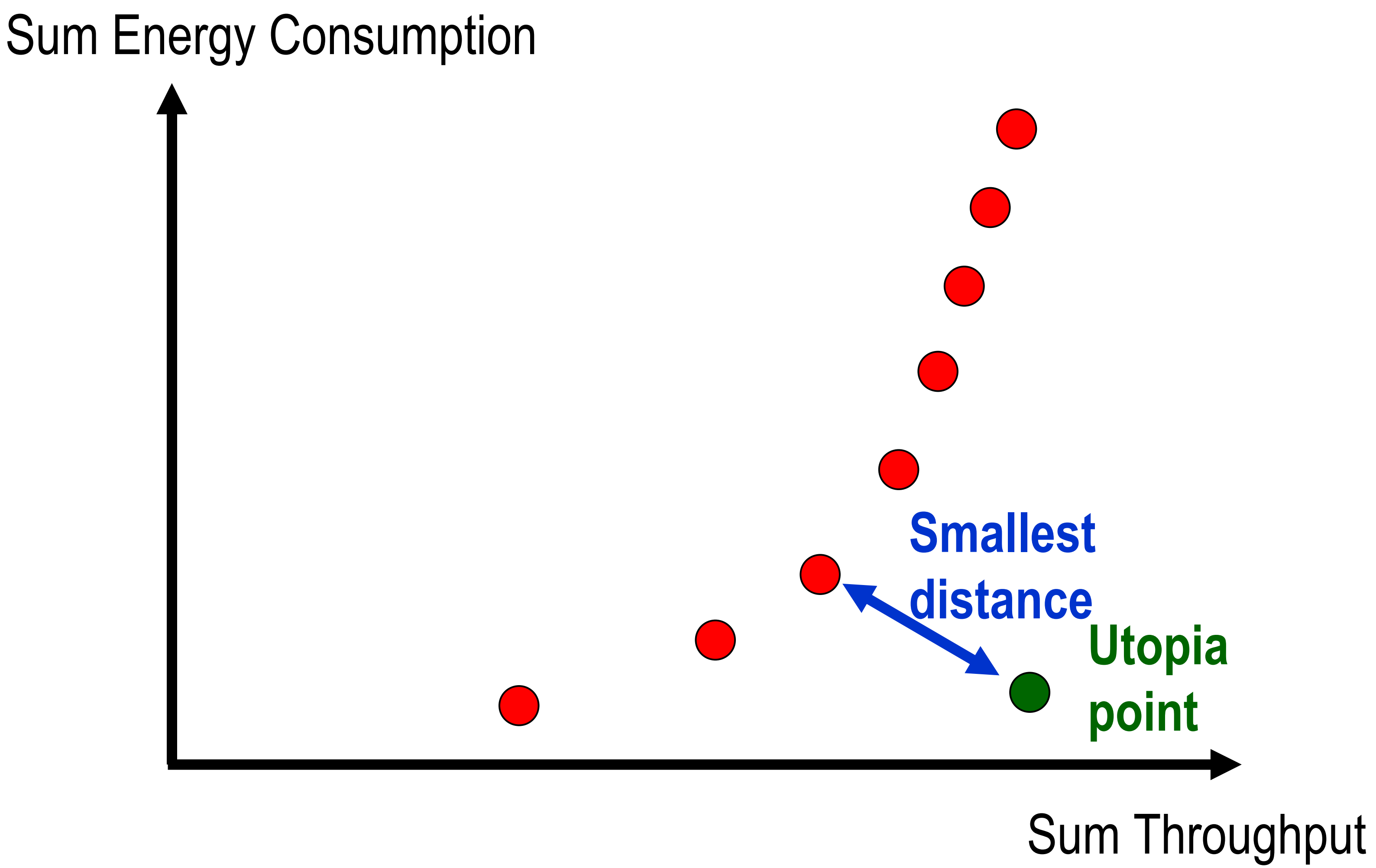
maximize $\alpha * U'_{Energy} + (1-\alpha) * U'_{Throughput}$

subject to the contraints described before

- Vary α to get points on the Pareto front
- However: with this approach we cannot find points on non-convex portions of the Pareto front
- Solution: Adaptively add new constraints such as
  - $U'_{Energy} \geq \beta_1$
  - $U'_{Throughput} \geq \beta_2$

2. Which point to choose?

Minimizing the Distance to the Goal

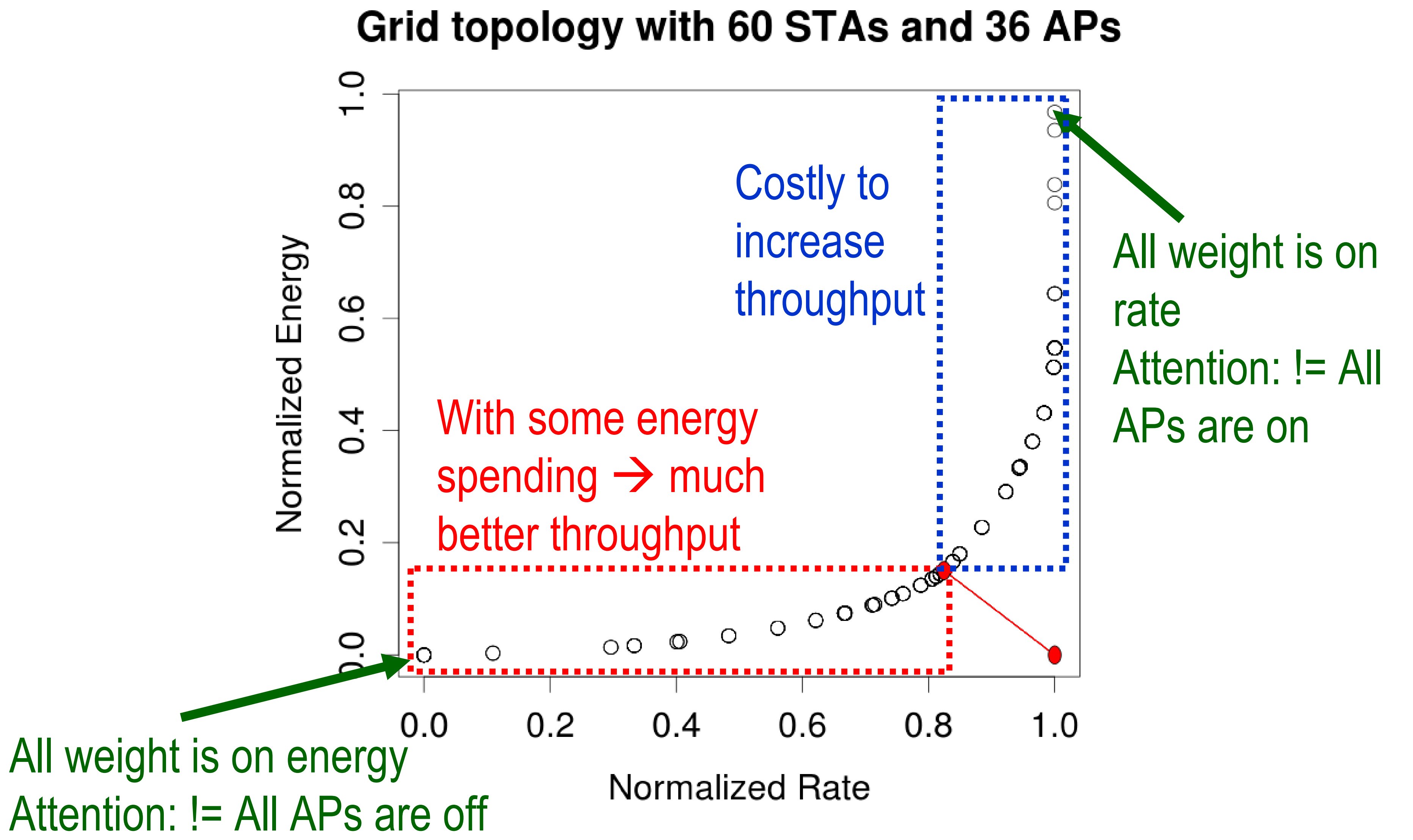


3. What are the trade-offs in a WLAN deployment?

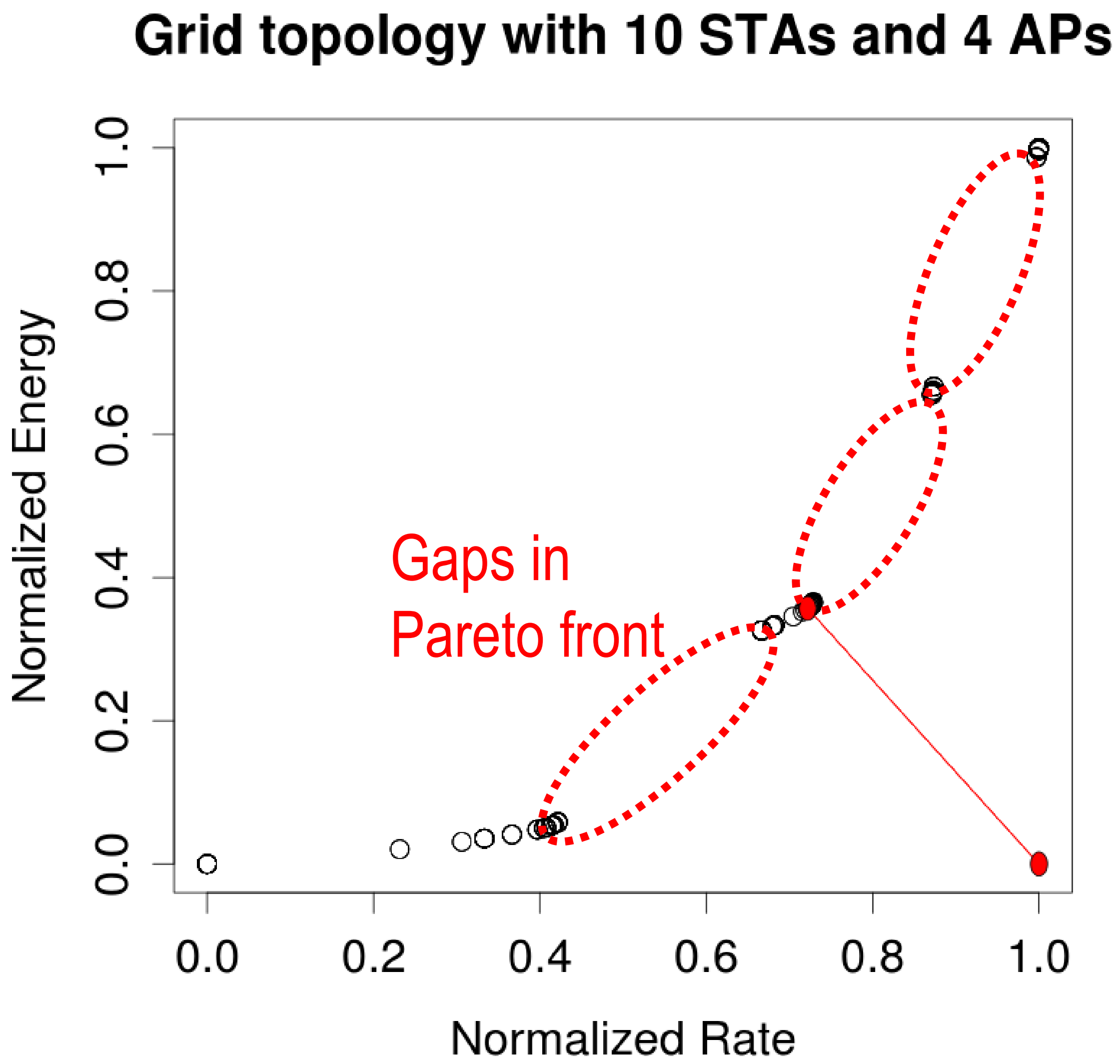
Numerical Simulation Settings

- Optimization model is implemented in CPLEX
- Exponential path loss with factor 4.5 (indoor/home environment)
- Receiver sensitivity for Atheros IEEE 802.11a cards
- APs are arranged in a grid so that all points are covered at least 24 Mbit/s PHY rate (if all APs are on)
- Stations are randomly and uniformly distributed in a rectangular area
- Orthogonal channel assignment

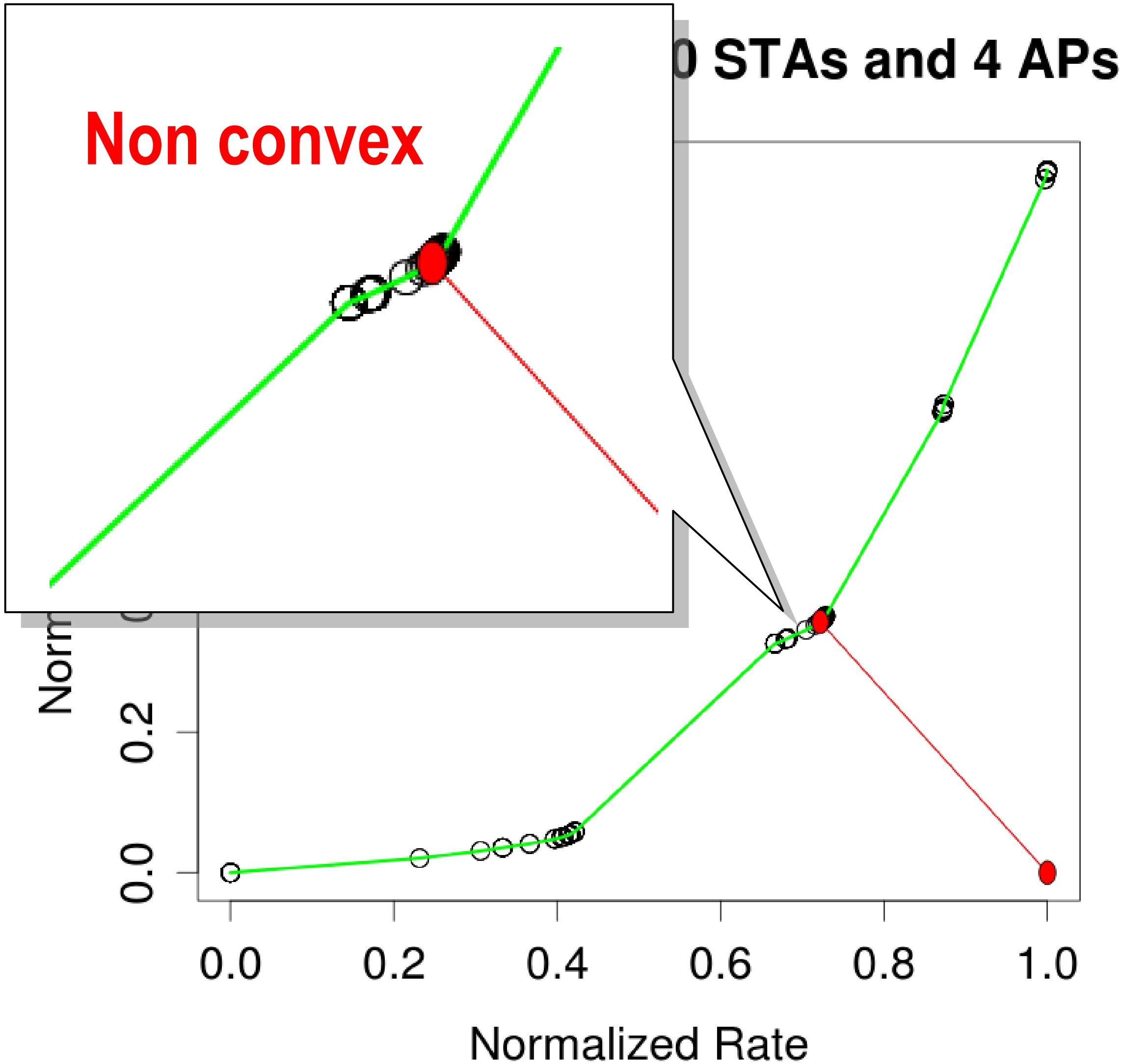
Throughput/Energy Trade-Off



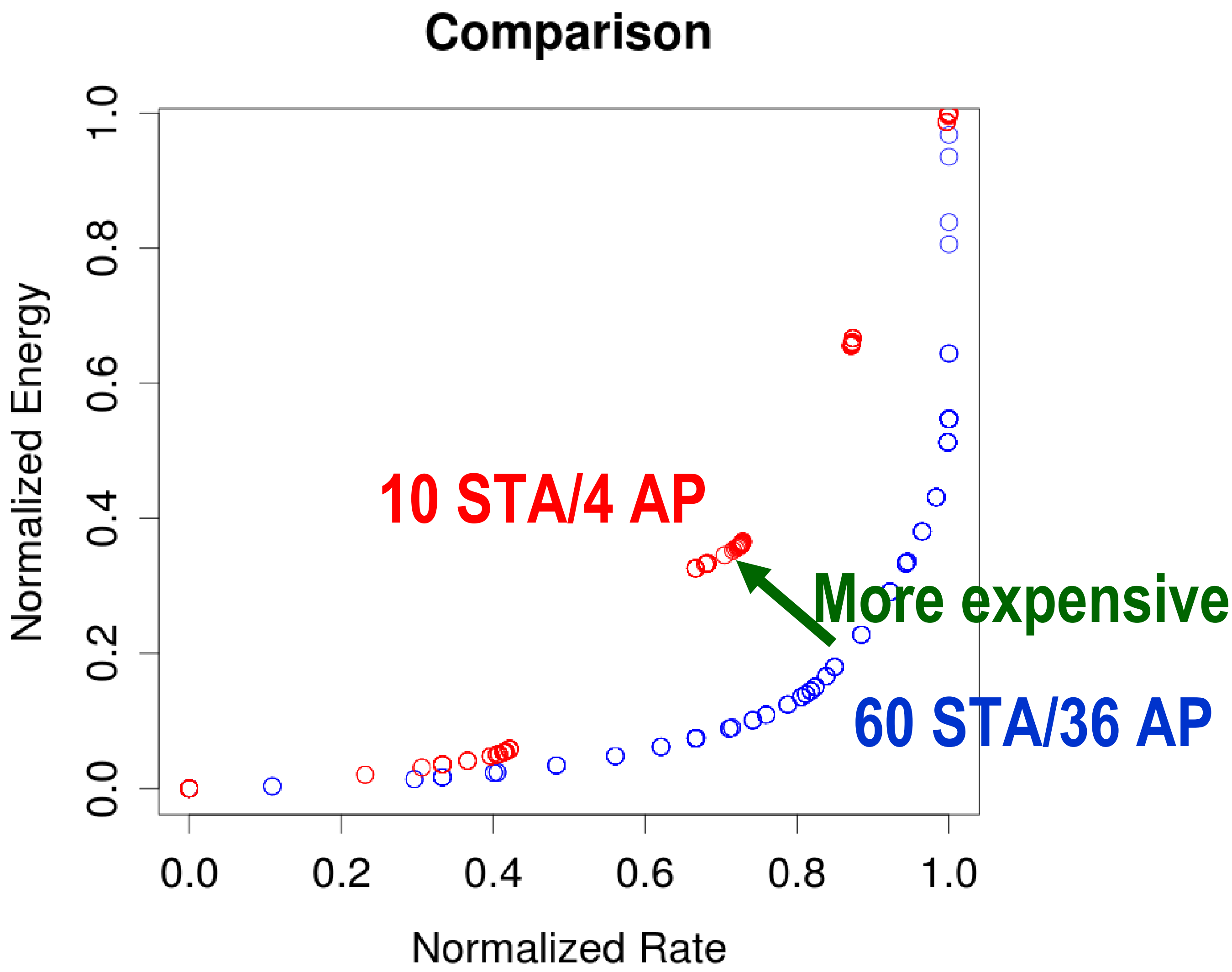
Throughput/Energy Trade-Off



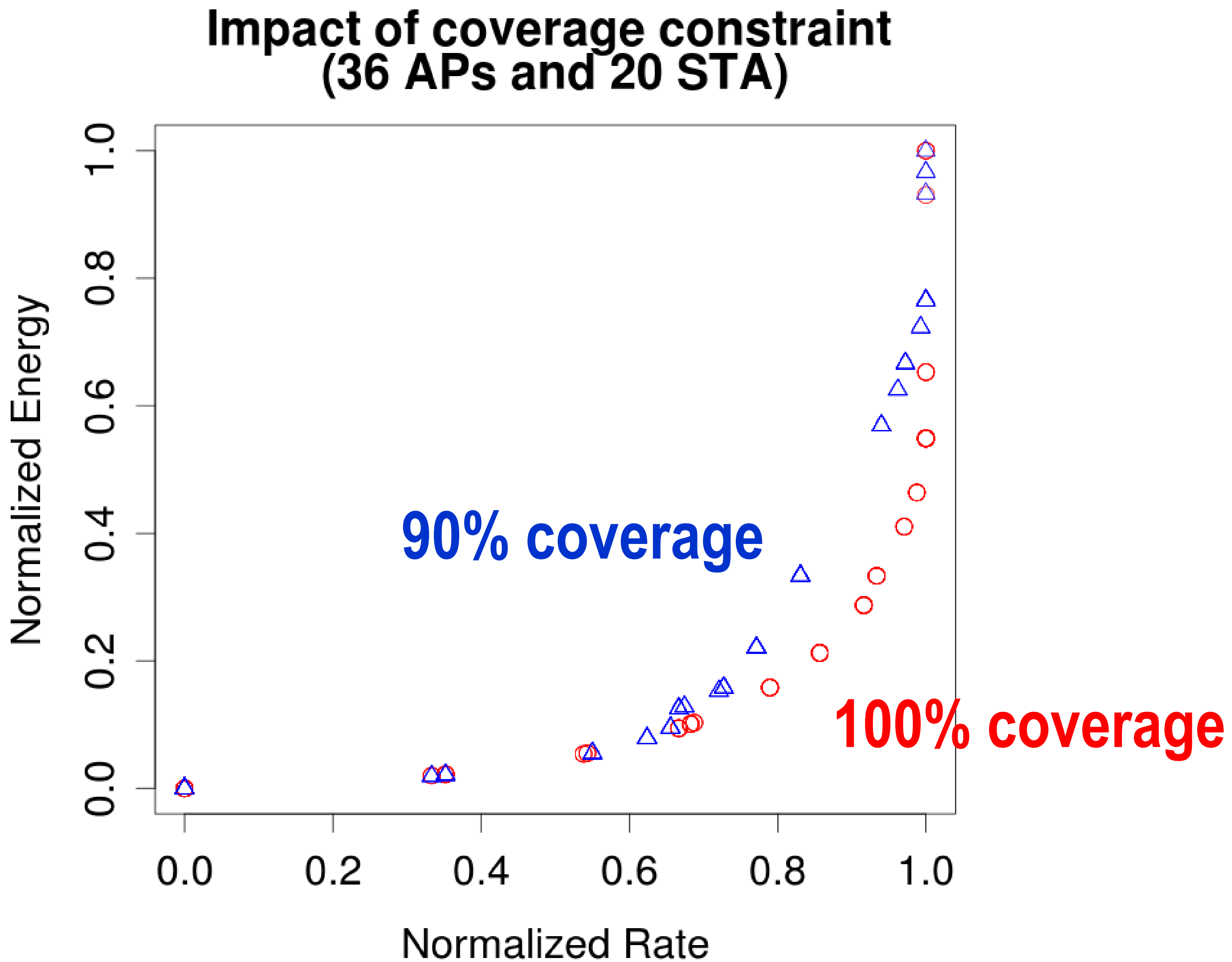
Throughput/Energy Trade-Off



Throughput/Energy Trade-Off



Impact of Coverage Constraint



Conclusions and Future Work

- Conclusions
  1. Major energy saving is possible with little throughput degradation
  2. Trade-off is in particular good when there are many stations in the network
  3. Pareto front can be non-convex → more difficult to generate
- Future work
  – Simulations on larger realistic instances
  – Consider dynamic users arrivals
  – Design of a heuristic that finds a good solution