
WLAN Planning: Detailed Performance Evaluation Along the Pareto Front

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Andreas Eisenblätter

atesio GmbH

Zuse Institute Berlin (ZIB)

DFG Research Center MATHEON:
Mathematics for Key Technologies

joint work with:

Hans-Florian Geerdes
Booz & Co., formerly ZIB, MATHEON

Jonas Schweiger
ZIB

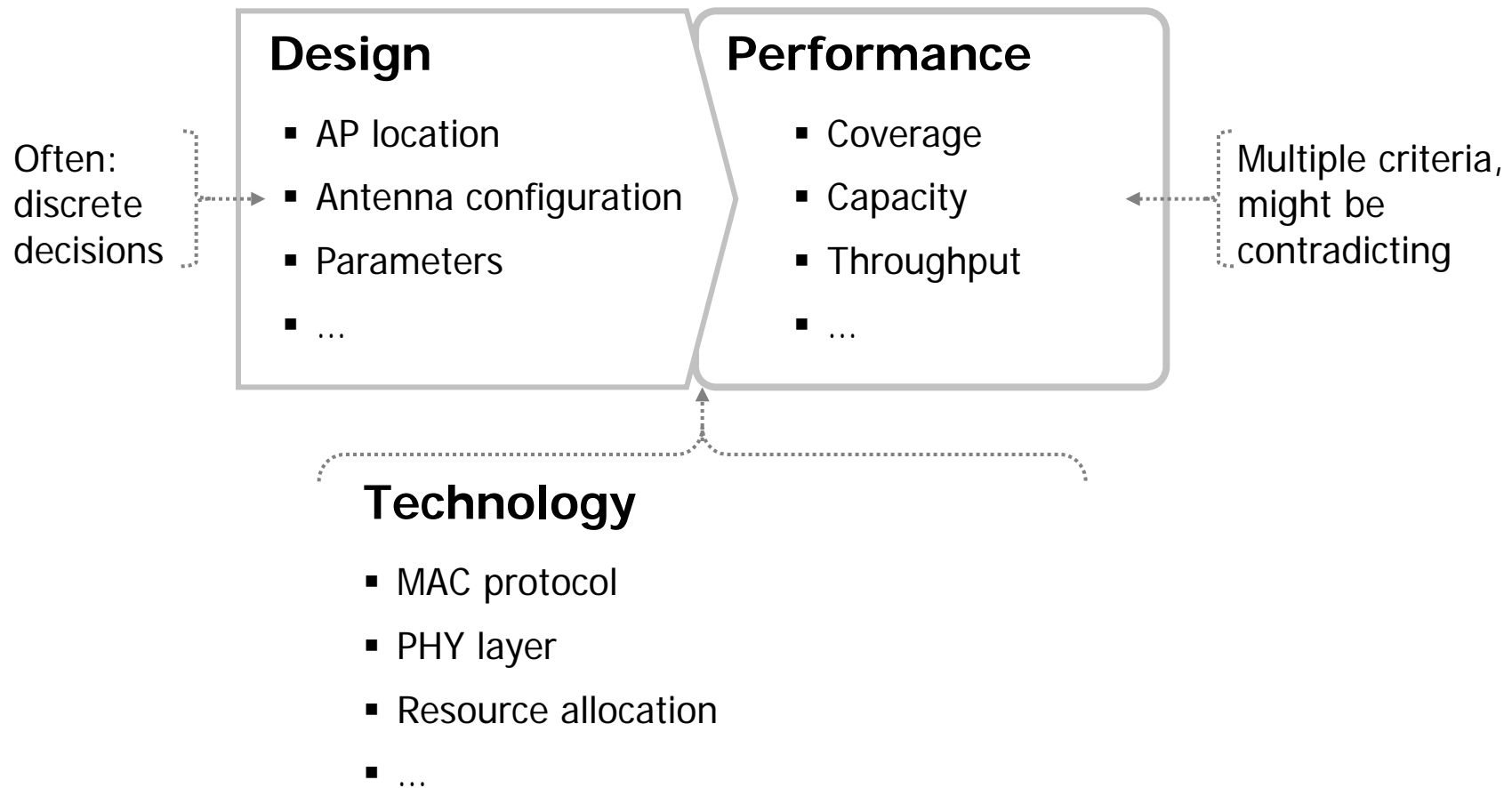
James Groß, Oscar Punal
Mobile Network Performance Group, UMIC
Research Centre, RWTH Aachen University

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Radio Network Planning

Goal: Find the network design that delivers best performance



Detailed Evaluation vs. Optimization

Detailed Evaluation

Model in detail

- Stochastics
- Traffic
- PHY
- MAC
- Propagation
- ...

Accurate account
of system behavior

(but takes too much
time)

Mathematical Optimization

Simple structure

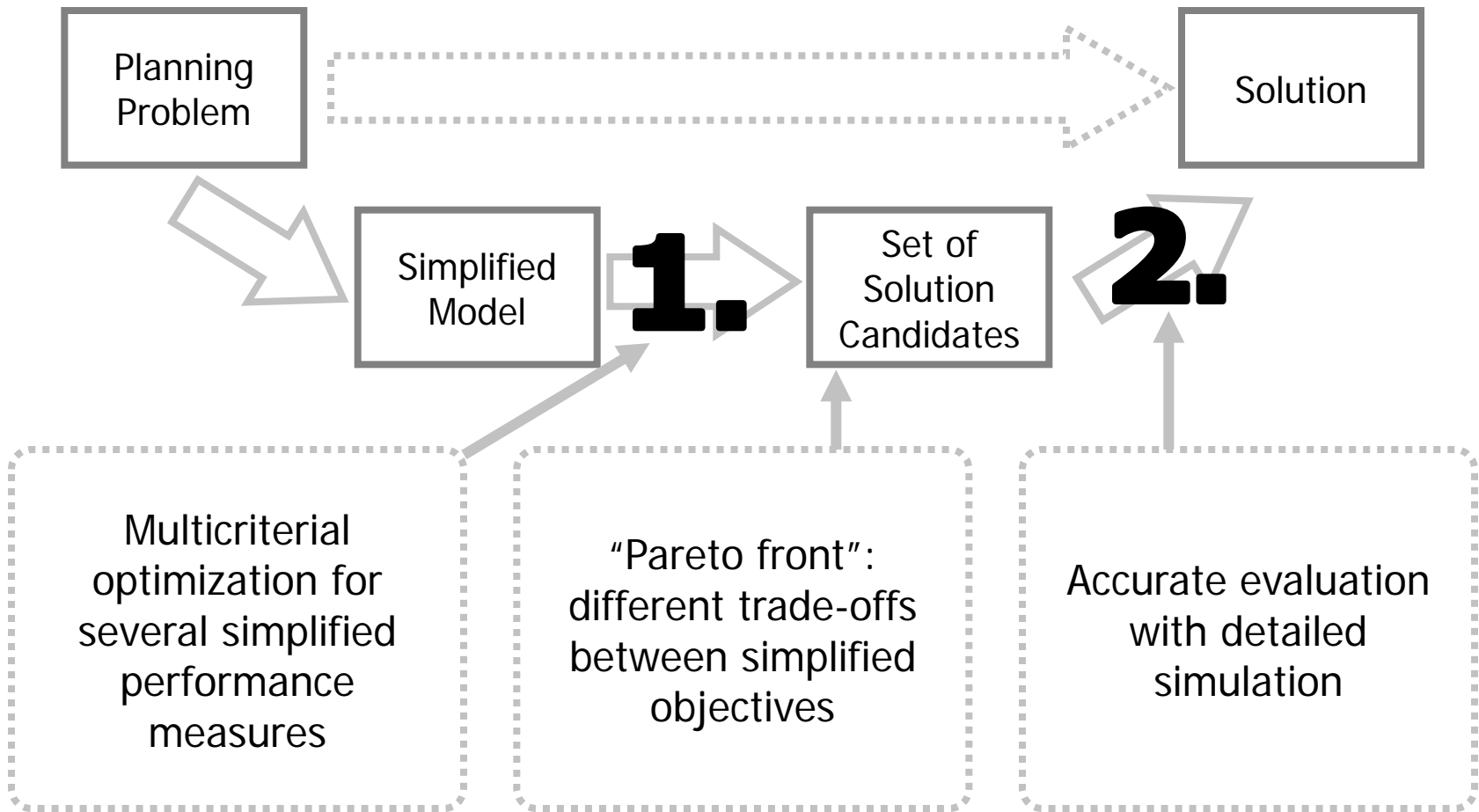
- Linear functions/
convex function
 - few variables
- + software
- linear programming
 - integer programming
- + heuristics

Good solutions

(but for
"unrealistic" model)

How to combine?

Two-Stage Approach

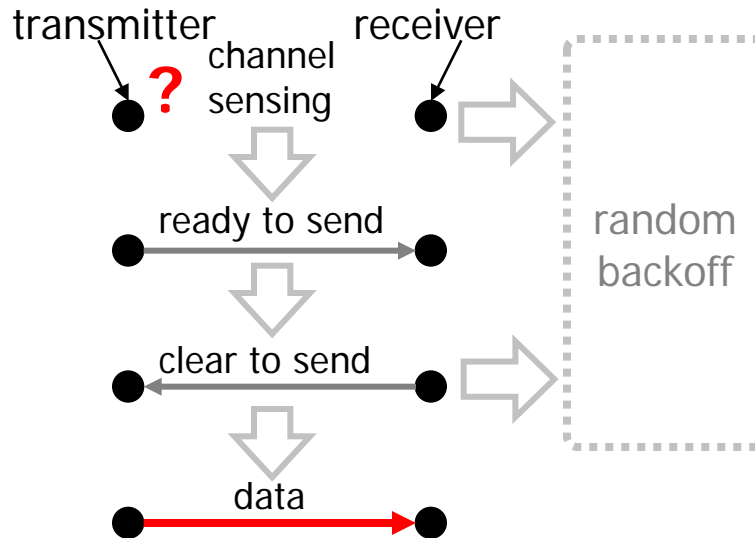


The IEEE 802.11 Standard

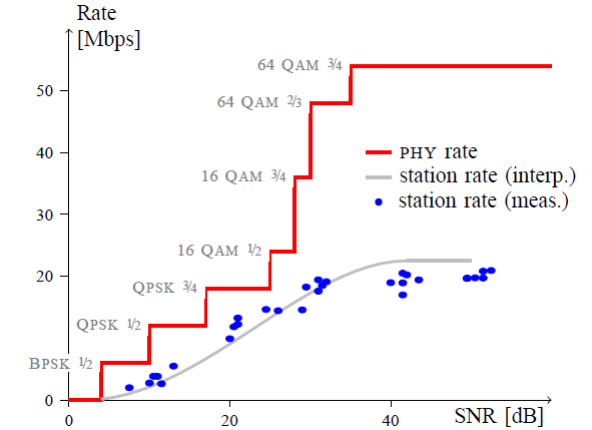
Versions

- Original: 1997, amendments IEEE 802.11b/g/n...
- Current: IEEE 802.11-2007
- This talk: IEEE 802.11g, infrastructure mode, DCF

CSMA/CA Protocol



Automatic rate selection



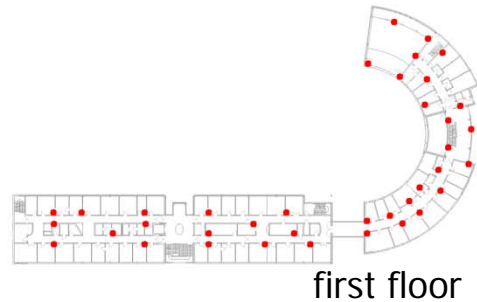
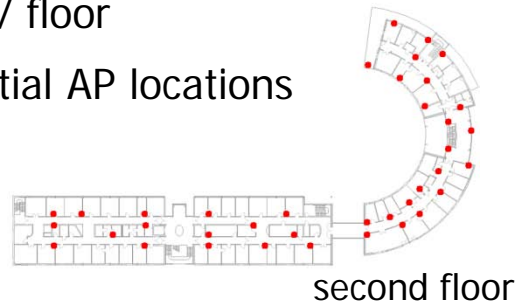
Performance Drivers

- Data rates
- Contention with other users
- "Performance Anomaly"

Case Study: ZIB Building

Scenario

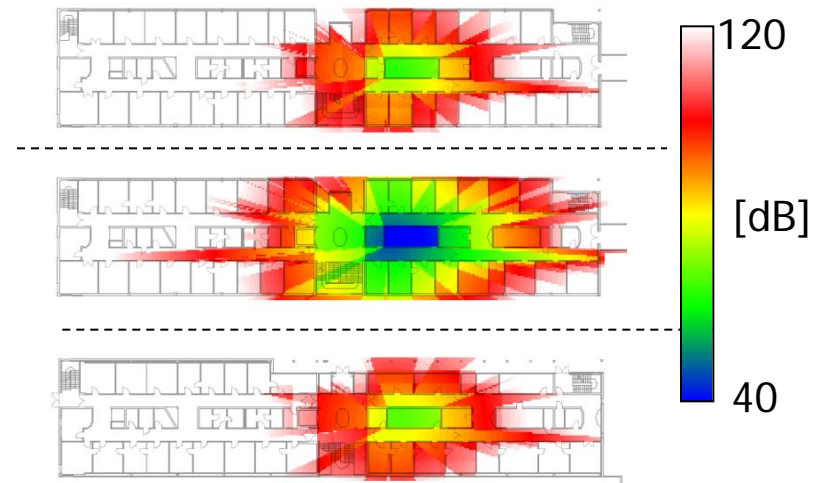
- 3 floors
- 2.663 m² / floor
- 144 potential AP locations



Propagation Prediction

- Cost 231 Multi-Wall model

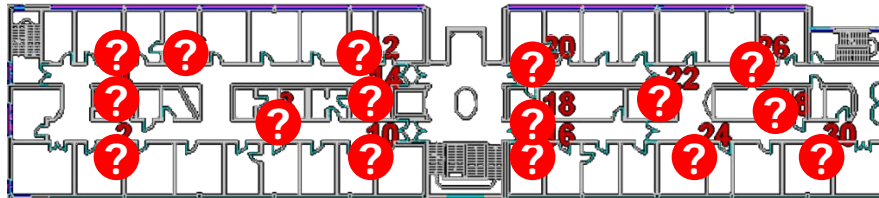
$$pl(p, q) := \ell_{\text{const}} + c_{\text{eu}}d(p, q) + c_{\text{multi}}^{|\mathcal{O}|-1} \sum_{o \in \mathcal{O}} \ell_o + \ell_{\text{floor}}f,$$



Planning Decisions

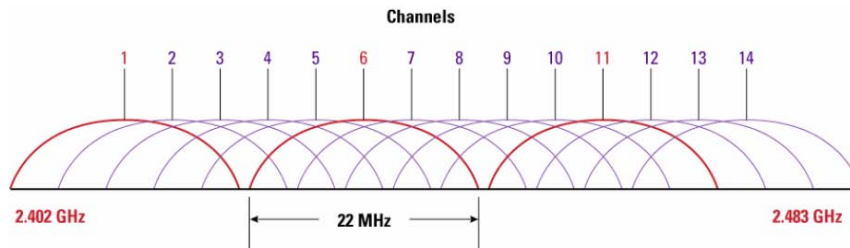
AP Locations

Ⓜ Potential AP Location



- Choose 21 AP locations
- Assign one of three non-overlapping channels

Channel Assignment



Case Study

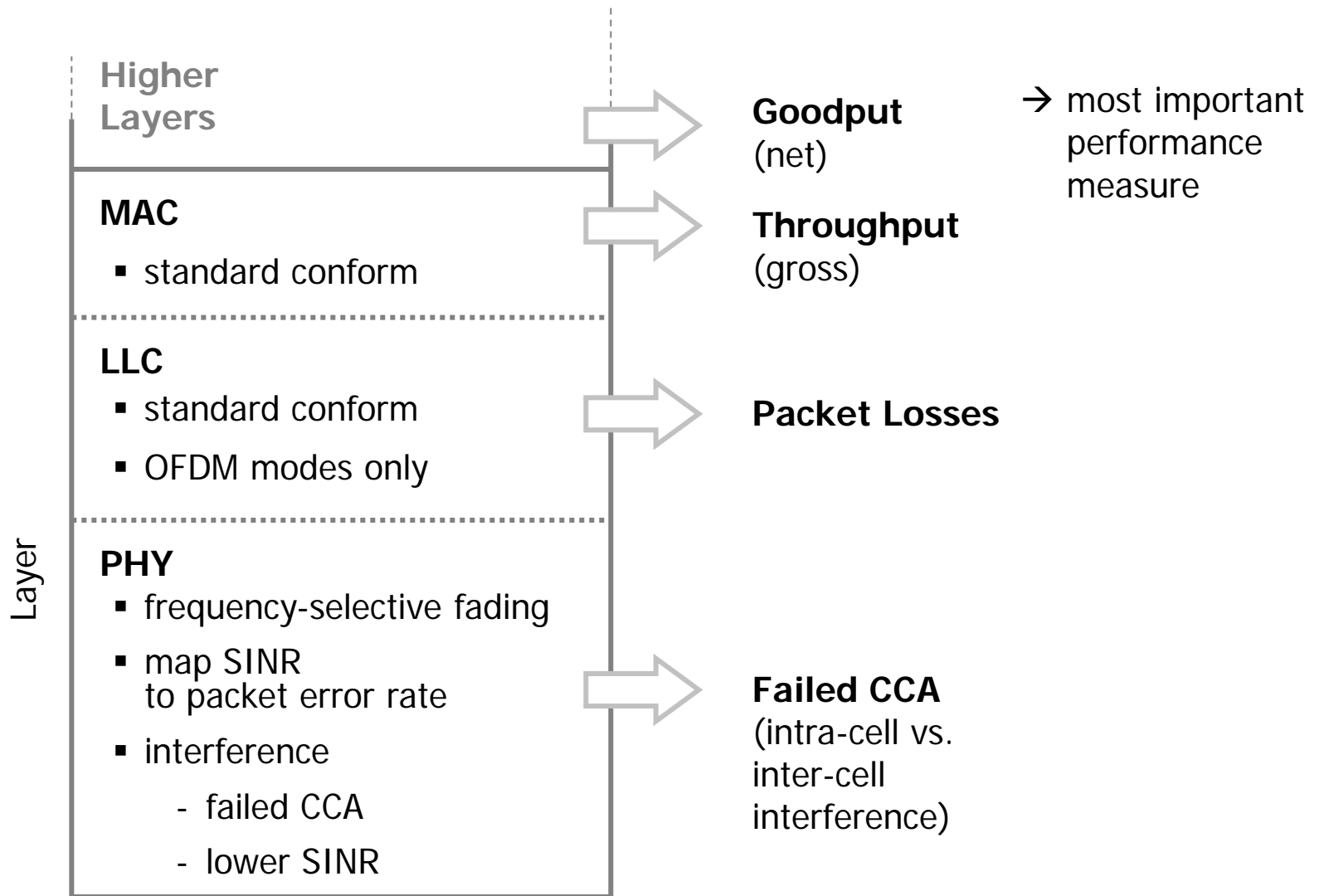
Select 21 from 144 locations:

channel assignments:
 $3^{21} = 10.460.353.203$

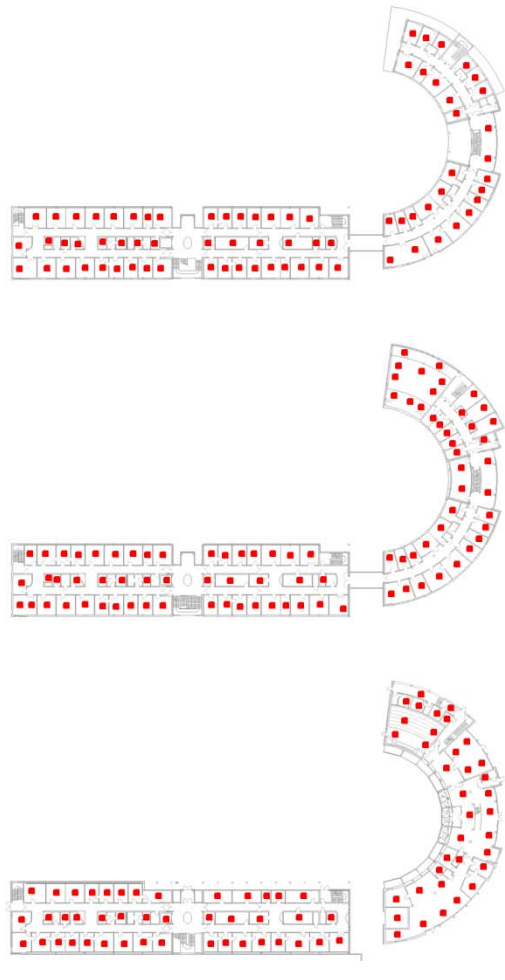
X AP placements:
 $144!/123! = 8.9439e+24$

= Total configurations:
 $8.2830e+28$

Simulation: Lower Layers and Performance Metrics

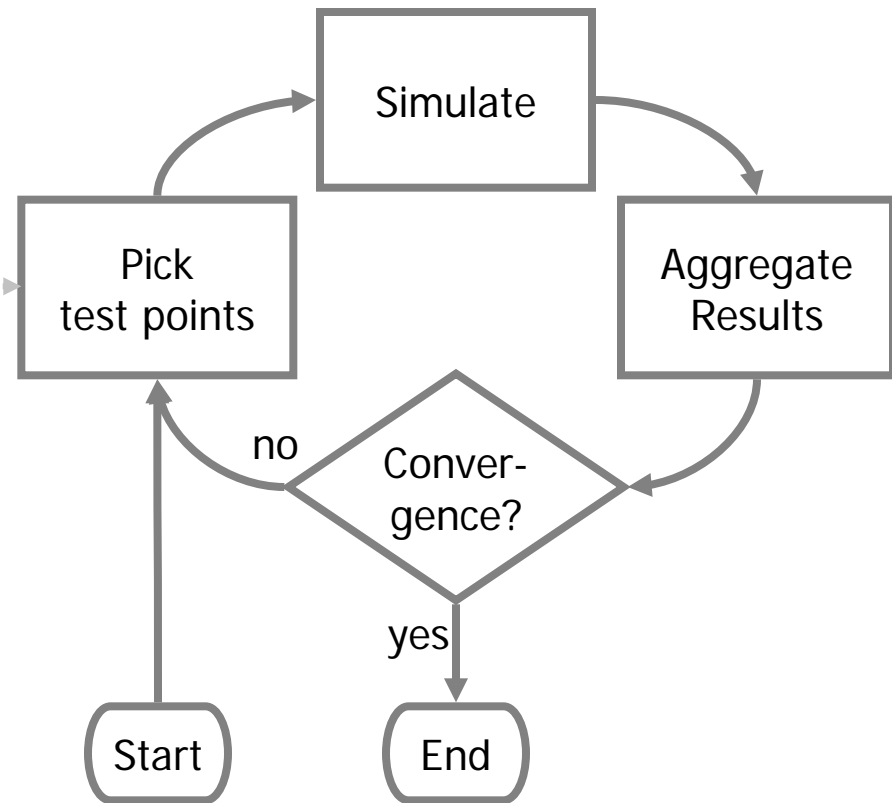


Expected Performance: Monte-Carlo Simulation

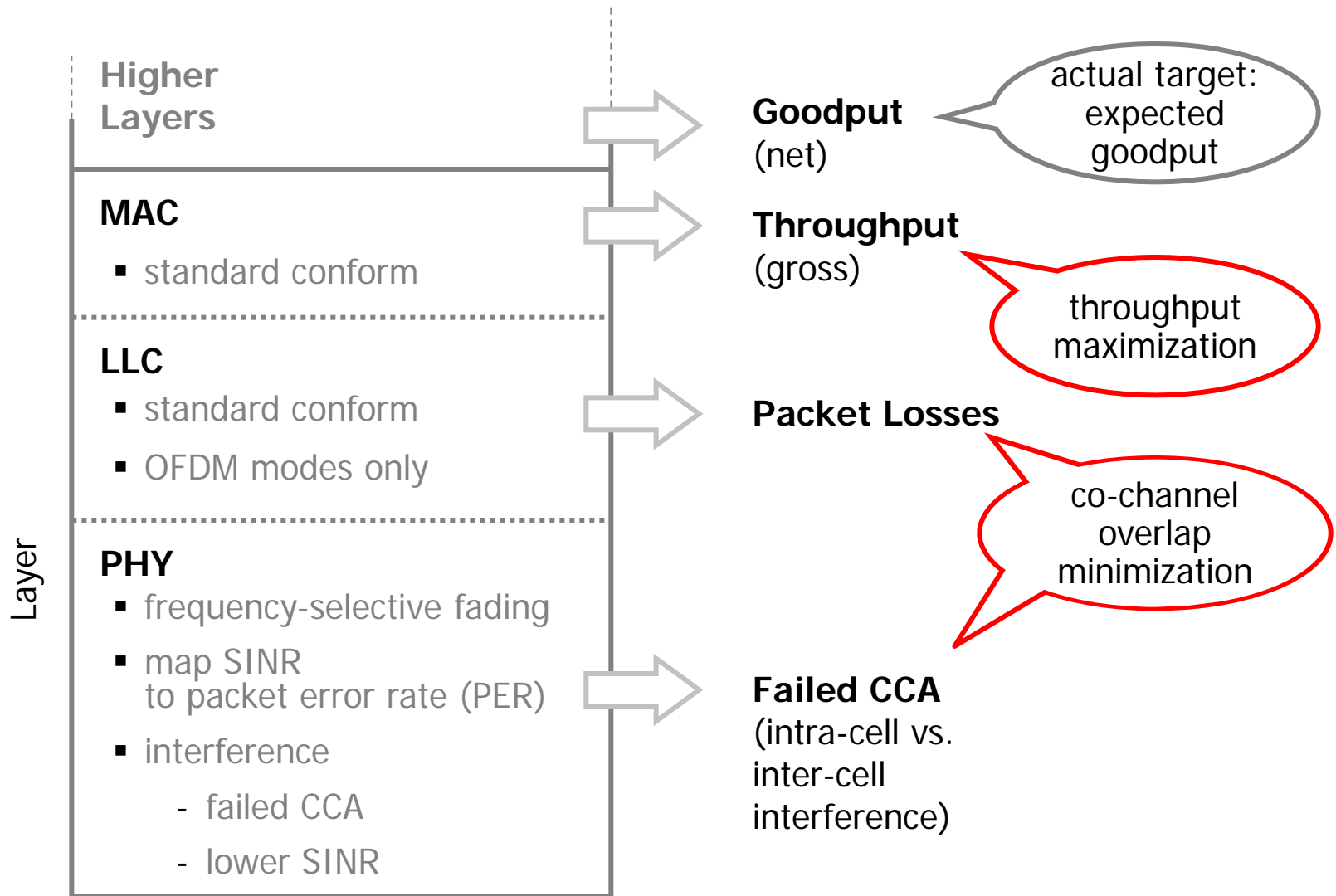


Analyze all
241 available test points.

- Saturation mode (TCP), or
- VoIP



Simplified Performance Measures

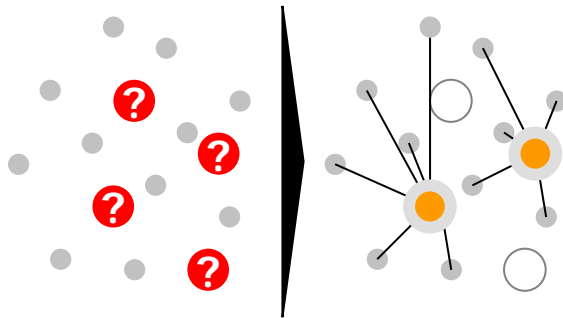


Simple Performance Measures

Throughput

Place APs such that the average minimum (radio) distance to users is minimized / average throughput is maximized.

→ **Facility location**

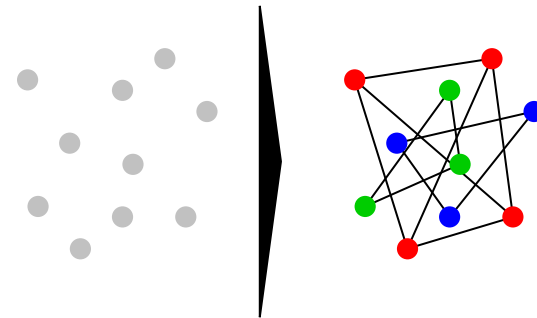


Ideally, APs are *densely* placed.

Overlap

Determine overlap coefficient w_{ab} for every pair of APs; color APs with 3 colors such that the sum of coefficients on edges between the same color is minimized.

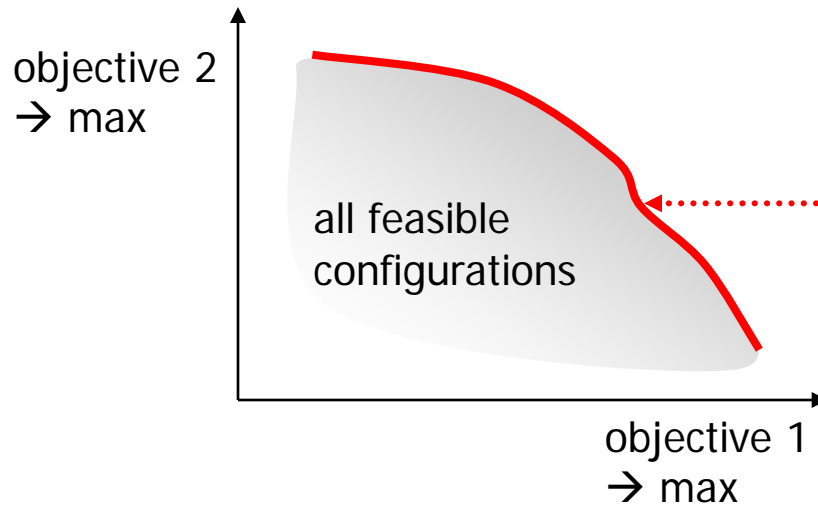
→ **Graph Coloring**



Ideally, APs (of same color) are *sparse* placed.

Tradeoff

Multi-criteria Optimization

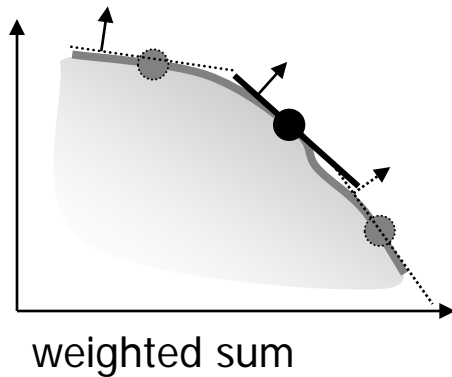


Pareto Front

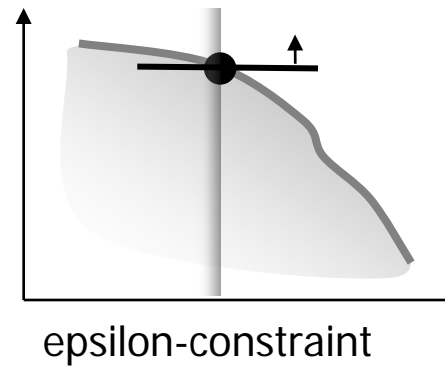
No objective can be improved without sacrificing another.

Solution to optimization problem: present complete Pareto Front to a "decision maker".

Scalarization Methods



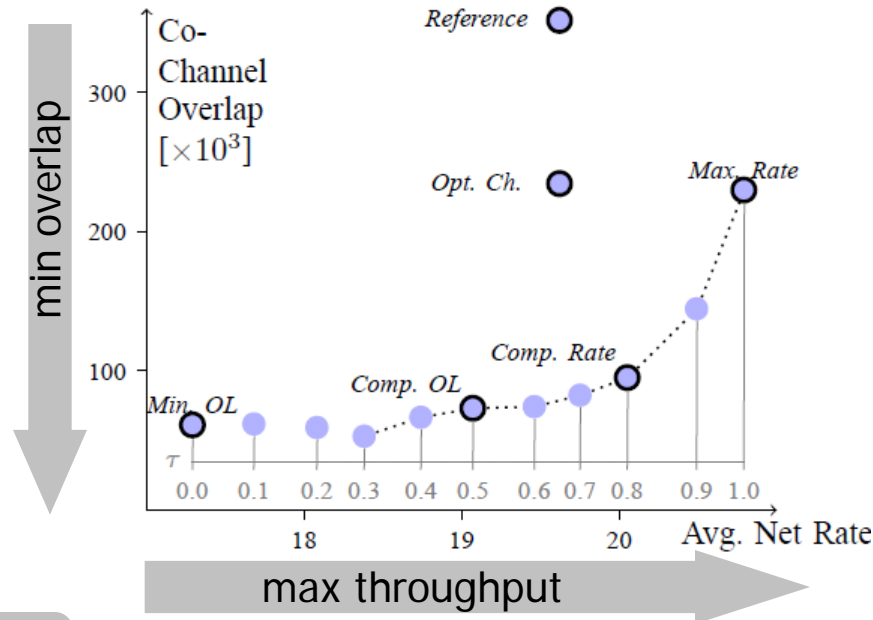
weighted sum



epsilon-constraint

- Produce some solution from the Pareto front
- Concrete choice depends on parameters

Multi-Criteria Optimization Model for Placing APs and Choosing Channels



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Throughput model

$$\begin{aligned} \max \quad & \sum_{ta} c_{ta} y_{ta} \\ \text{s. t.} \quad & \sum_a y_{ta} \leq 1 \quad \forall t \\ & y_{ta} \leq x_a \quad \forall t, a \\ & \sum_a x_a \leq M \\ & x \in \{0, 1\}^{|A|} \\ & y \in \{0, 1\}^{|A \times T|} \end{aligned}$$

Overlap model

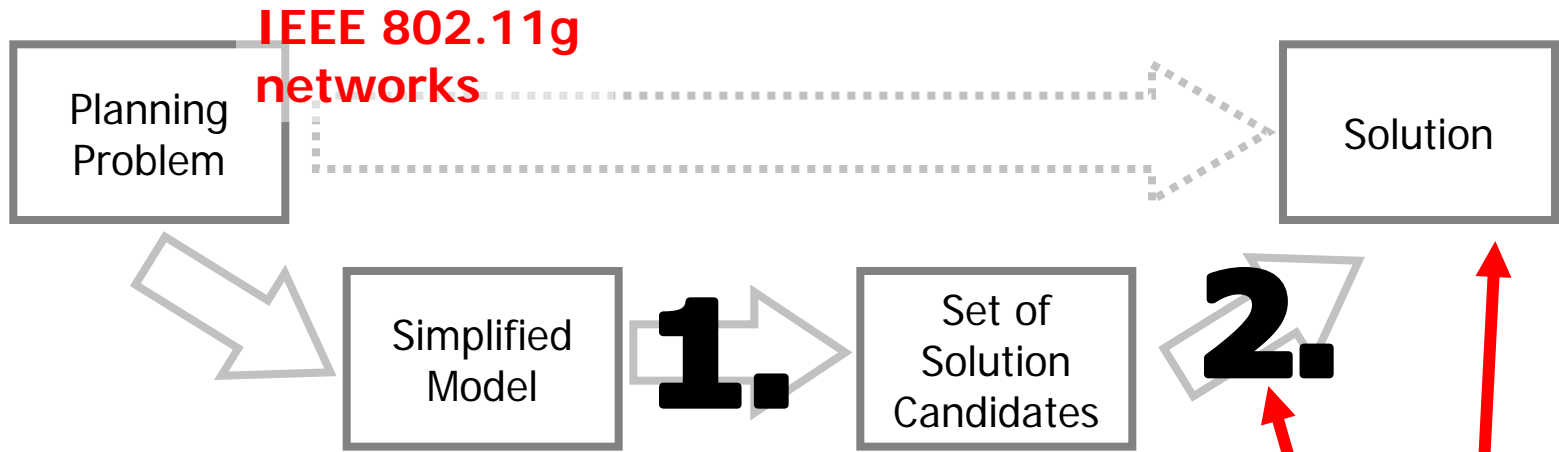
$$\begin{aligned} \min \quad & \sum_{a,b} l_{ab} w_{ab} \\ \text{s. t.} \quad & \sum_{ab \in E(H)} w_{ab} \geq 1 \quad \forall H : K_4, C \subset G \\ & w_{ab} + w_{bc} \leq 1 + w_{ac} \quad \forall \{a, b, c\} \subset A \\ & w \in \{0, 1\}^{|A \times A|} \end{aligned}$$

Integrated Model

- Mixed Integer Program (MIP)
- Trade-off parameter **alpha**

$$\begin{aligned} \max \quad & (1 - \alpha) \sum_{ta} c_{ta} y_{ta} - \alpha \sum_{a,b} l_{ab} w_{ab} \\ \text{s. t.} \quad & \sum_a y_{ta} \leq 1 \quad \forall t \\ & y_{ta} \leq x_a \quad \forall t, a \\ & \sum_a x_a \leq M \\ & \sum_{ab \in E(H)} w_{ab} \geq \sum_{c \in V(H)} x_c - 3 \quad \forall H : K_4, C \subset G \\ & w_{ab} + w_{bc} \leq 1 + w_{ac} \quad \forall \{i, j, k\} \subset A \\ & x \in \{0, 1\}^{|A|} \\ & y \in \{0, 1\}^{|A \times T|} \\ & w \in \{0, 1\}^{|A \times A|} \end{aligned}$$

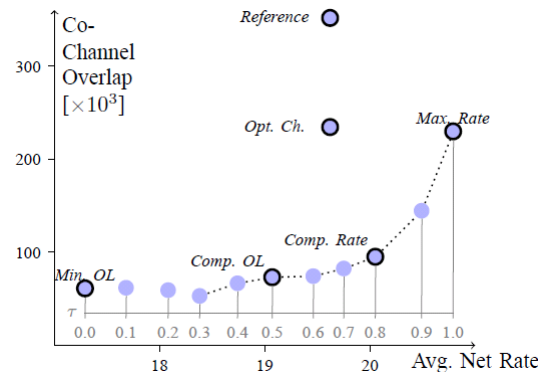
Two-Stage Approach



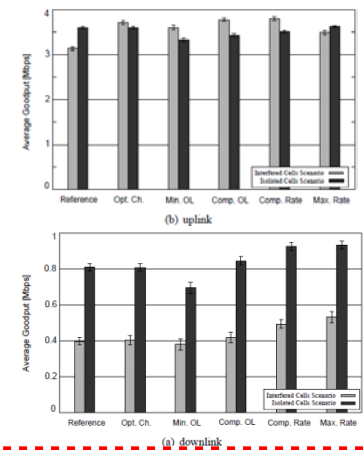
Multicriterial optimization: throughput vs. overlap

$$\begin{aligned}
 \max \quad & (1 - \alpha) \sum_{ta} c_{ta} y_{ta} - \alpha \sum_{a,b} l_{ab} w_{ab} \\
 \text{s. t.} \quad & \sum_a y_{ta} \leq 1 \quad \forall t \\
 & y_{ta} \leq x_a \quad \forall t, a \\
 & \sum_a x_a \leq M \\
 & \sum_{ab \in B(H)} w_{ab} \geq \sum_{c \in V(H)} x_c - 3 \quad \forall H: K_4, C \subset G \\
 & w_{ab} + w_{bc} \leq 1 + w_{ac} \quad \forall \{i, j, k\} \subset A \\
 & x \in \{0, 1\}^{|A|} \\
 & y \in \{0, 1\}^{|A \times T|} \\
 & w \in \{0, 1\}^{|A \times A|}
 \end{aligned}$$

Pareto Front



Simulation



Conclusion & Outlook

Two-Phase Approach

- Combine powerful mathematics with detailed evaluation
- Use simulation to where you are not sure of the quality of the optimization model
- Focus on the promising candidate designs

Results

- Validation of optimization scheme
- Insights into behavior/relevance of simplified performance measures
- Metrics in optimization and system model differ noticeably, nonetheless, two-stage approach proves very effective

Future

- Find best split between optimization and simulation
- Planning vs. Dynamic Management
 - Does intelligent resource management render planning obsolete? or
 - Is planning more important?

Thank You!

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