Topology Planning for Long Distance Wireless Mesh Networks

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Under Guidance of Dr. Bhaskaran Raman

Outline

- Motivation & Background
- Problem statement, Uniqueness
- Problem formulation
  - Definitions, dependences
- Solution approach
- Evaluation
- Conclusions

Rural Connectivity

- Goal:
  - Provide 100% connectivity to rural India, as 74% Indian population rural.
- What Technology to use ?

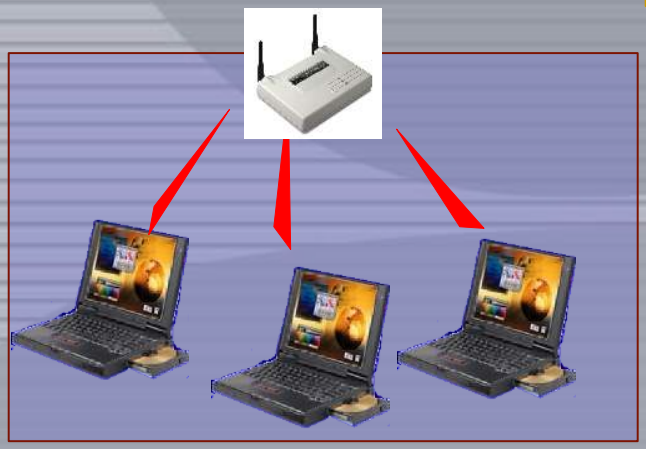
WiFi-based Rural Networks

Cost of land-line telephony: $400 per line --> $200 per line

400 million lines for India ==> $80 billion

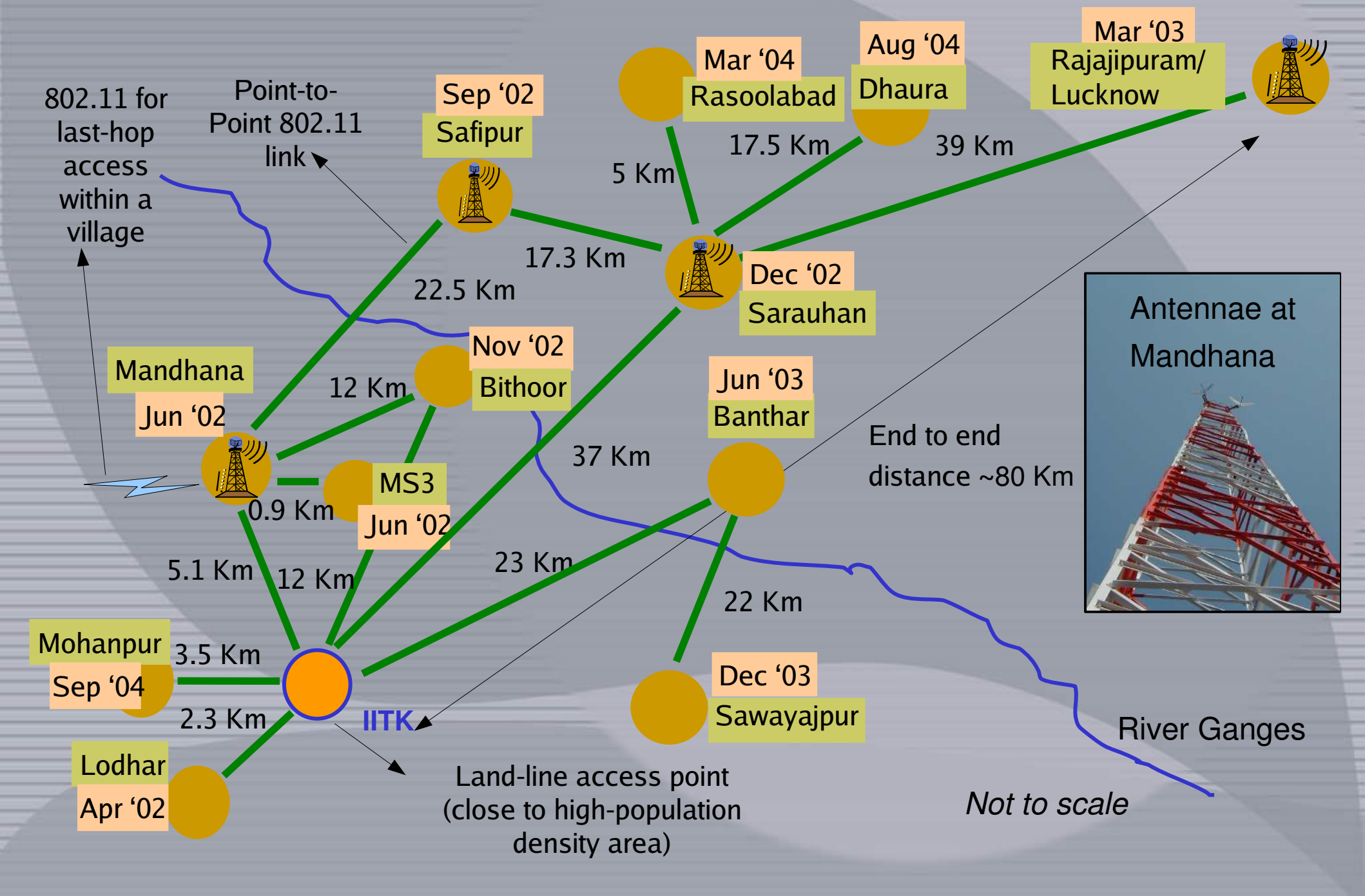
Cellular technology is *value-priced*
(expensive for rural deployment)

WiMAX (IEEE 802.16) yet to hit the market
Unclear if it will be inexpensive enough for rural areas

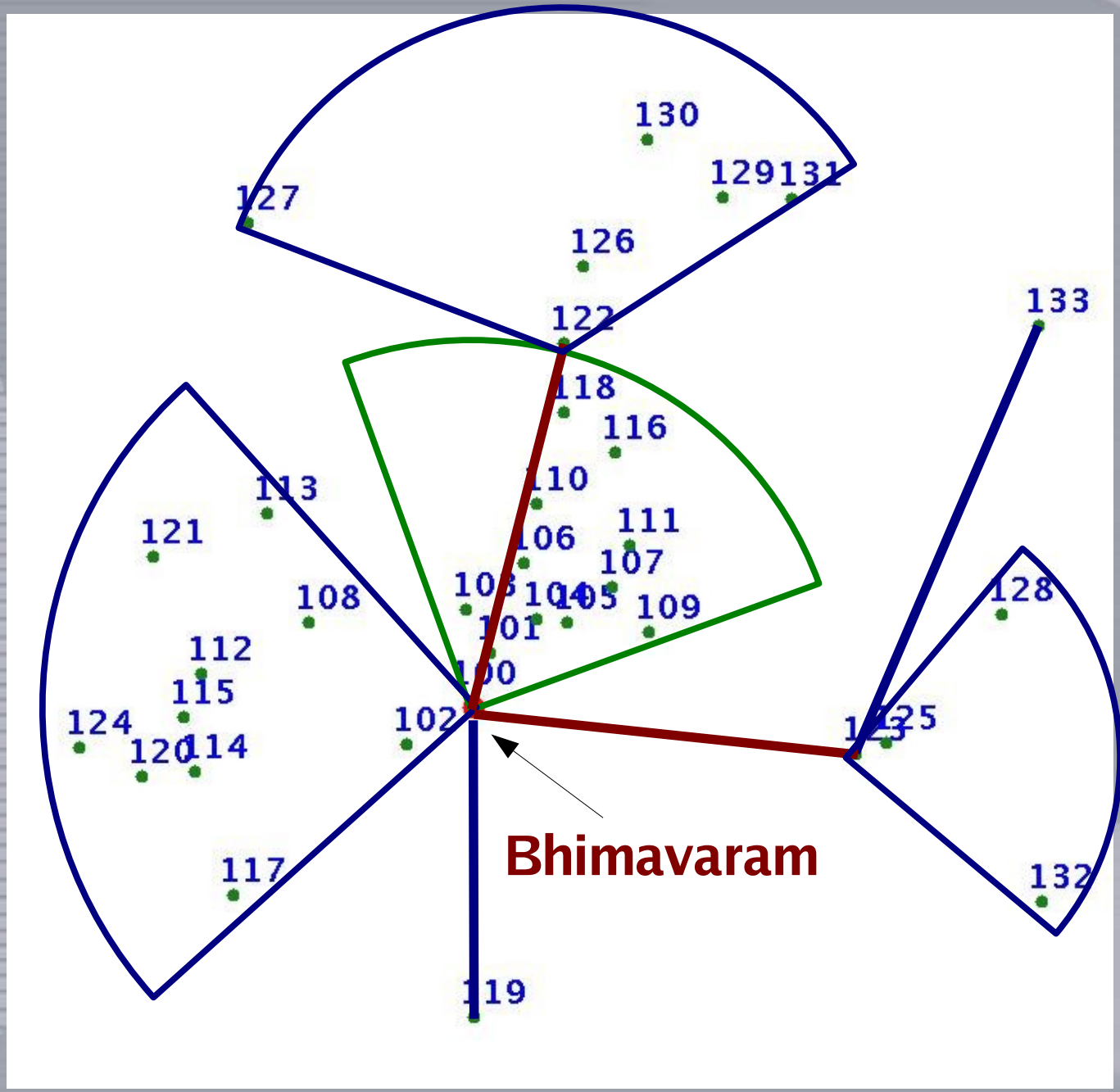


In contrast: WiFi equipment *cost-priced*
Rs 2-5K per WiFi radio
Inexpensive enough for rural deployment

Digital Gangetic Plains: Testbed



The Ashwini Project



- Byrraju foundation, West Godavari, Andhra Pradesh
- To connect 34 villages
- Video-based health, education services

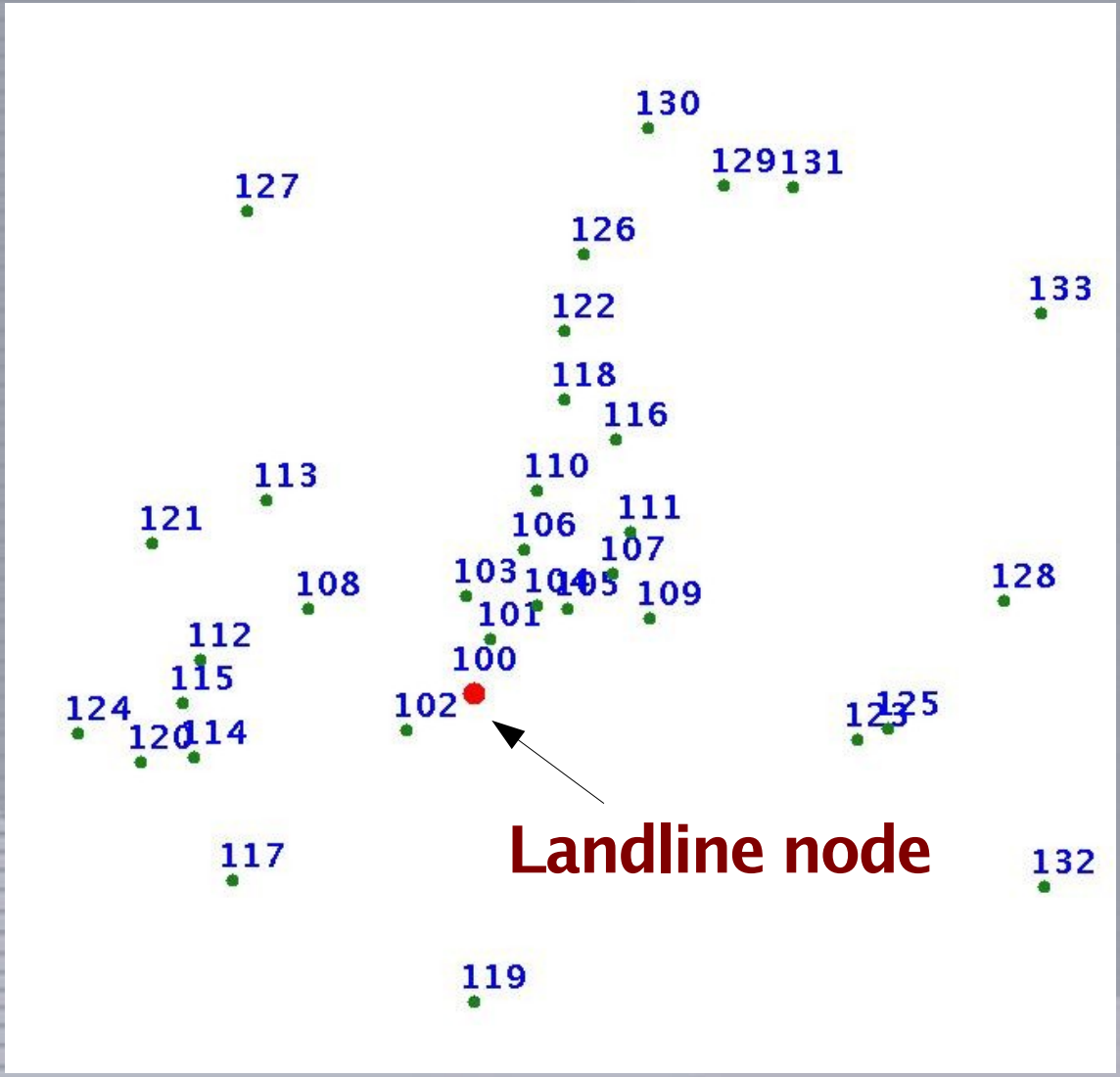
A WiFi Network in Djurslands, Denmark

www.DjurslandS.net

Problem Statement Motivation

- Problem:
  - India has order of 6 lakh villages.
  - No automated method exists to plan such networks.
  - Current methods highly cost inefficient and ad-hoc.
- Last Mile Connectivity problem:
  - 85% of the villages are within 20 Km radius of a fiber Point-of-Presence (PoP).
    (source:A. Jhunjhunwala et. al, Role of Wireless technologies in connecting rural India, Indian Journal of Radio & Space Physics'05)

Problem Statement

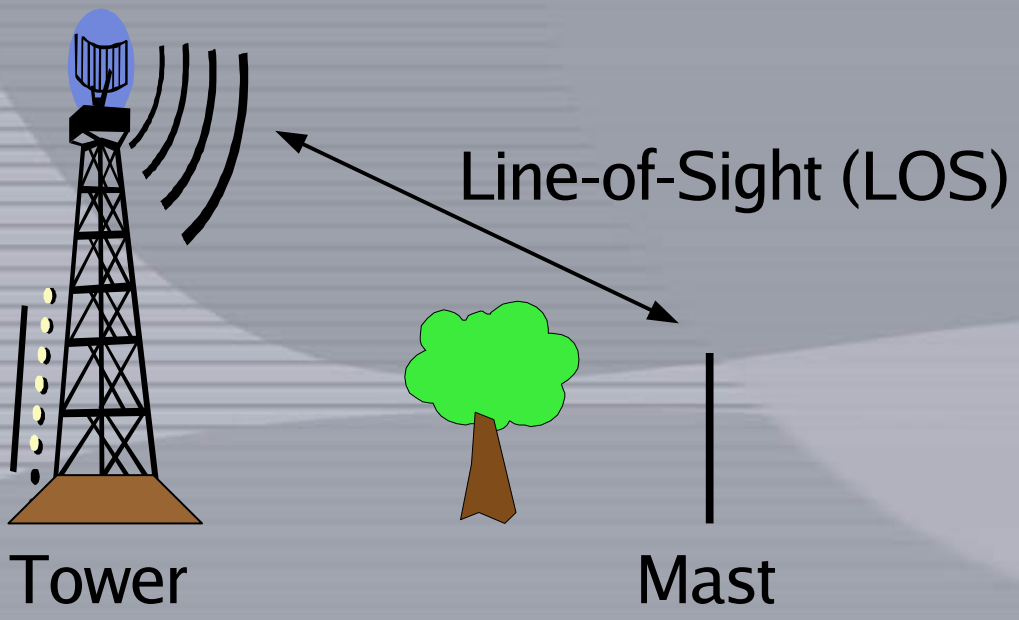


- Given: a set of village nodes, a single landline node
- Requirement: connect all villages to the landline in a network

- Primary concern: cost and bandwidth guarantees.

Problem Uniqueness

- Coverage only at village nodes (unlike cellular coverage)
- Line-of-Sight requirement
- Focus on cost optimality
  - Cost dominated by towers



Tower/mast height (m)	Cost (x1000 Rs.)
10	4
15	6
21	36
24	41
27	48
30	82

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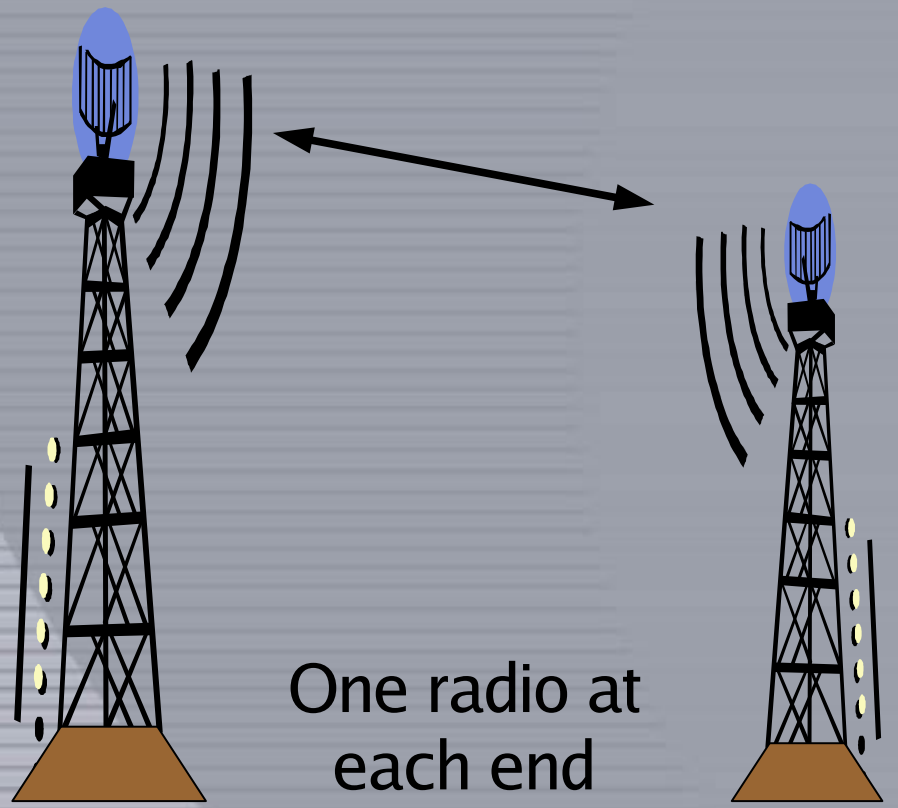
Problem Formulation

- Assumptions:
  - Antenna towers to be placed only at villages
  - Tree topology
- Application requirement:
  - Throughput per village: say, 384Kbps (for video)
- Definitions...
- Dependences...

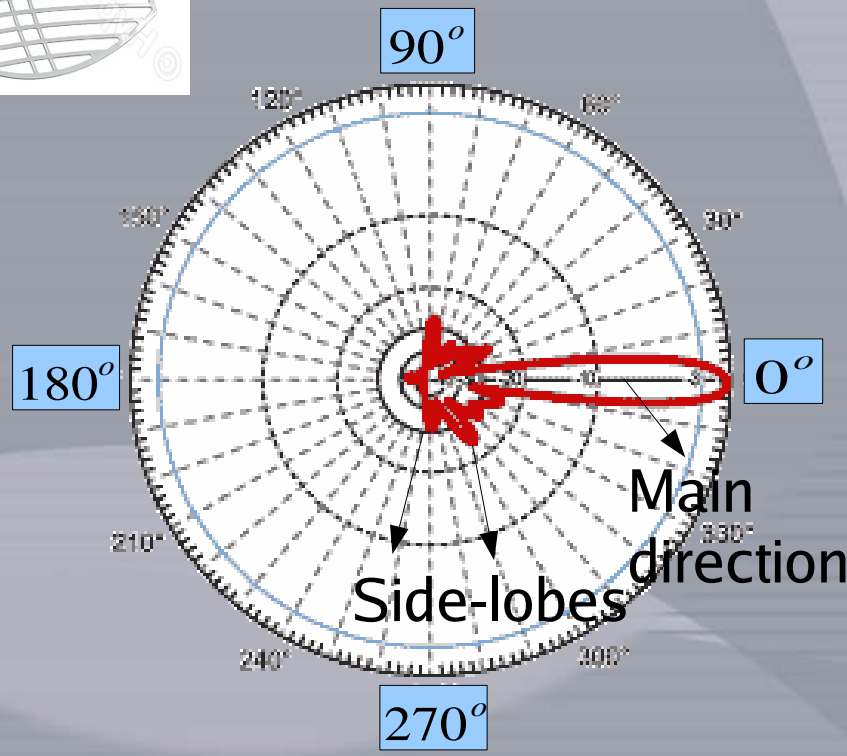
Definition: Point-to-Point Link



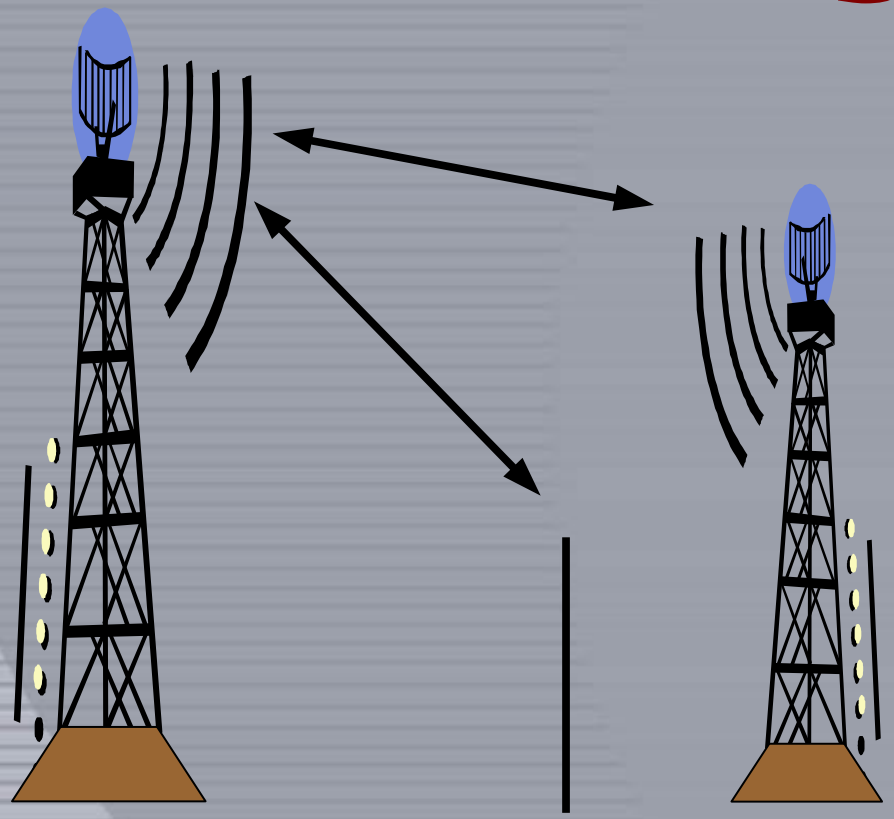
One radio at each end

Parabolic Grid Antenna

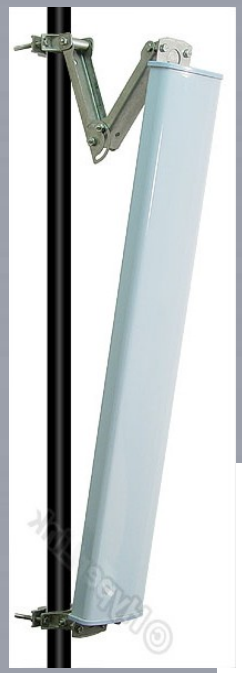
Antenna Radiation Pattern



Definition: Point-to-MultiPoint Link Set

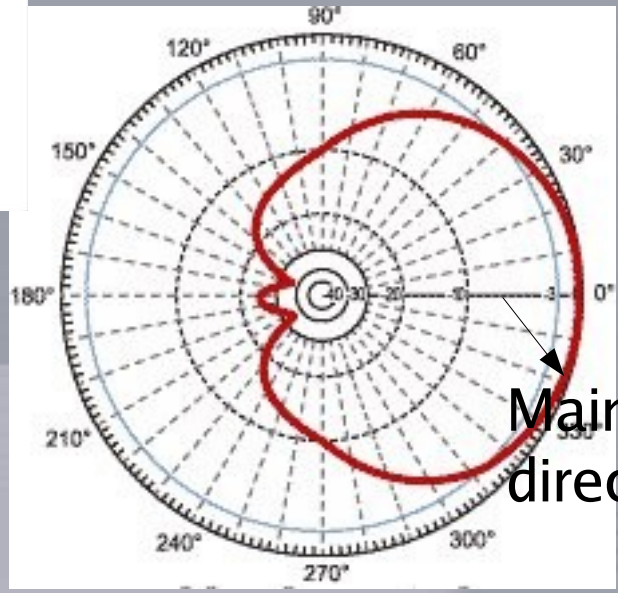


Single radio for both links

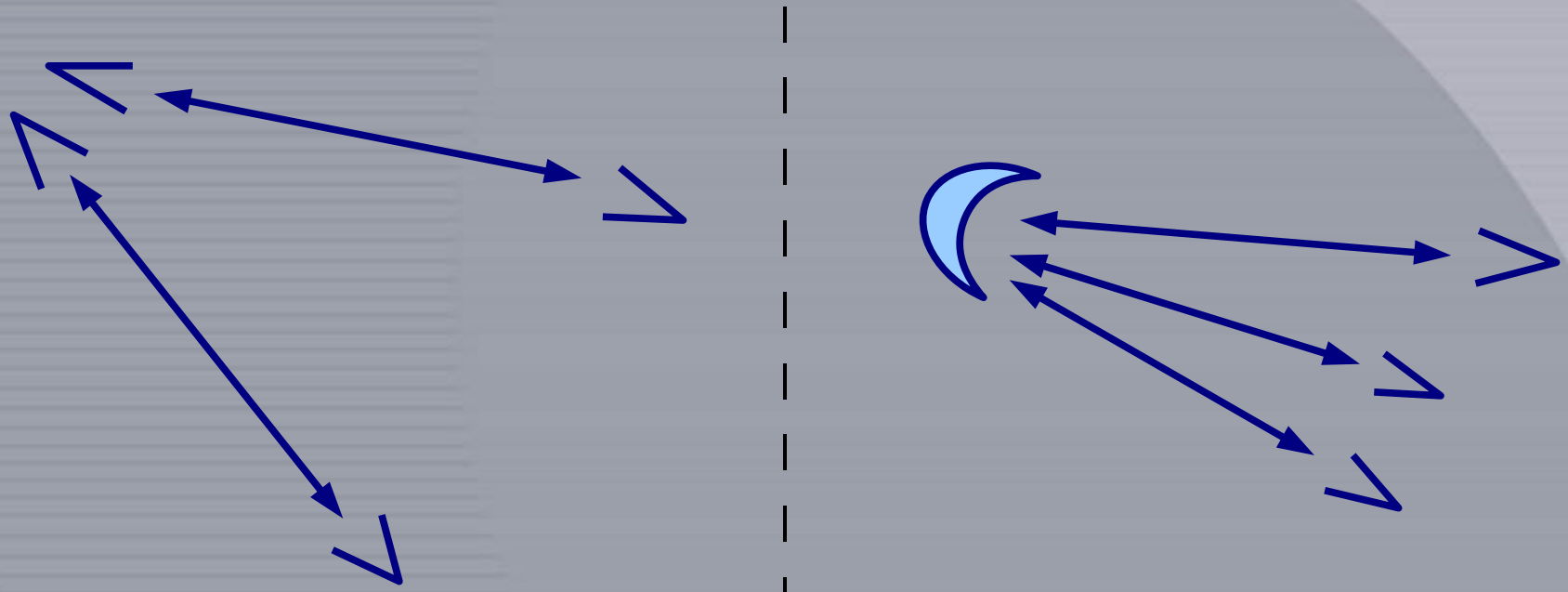


Sector Antenna

Antenna Radiation Pattern



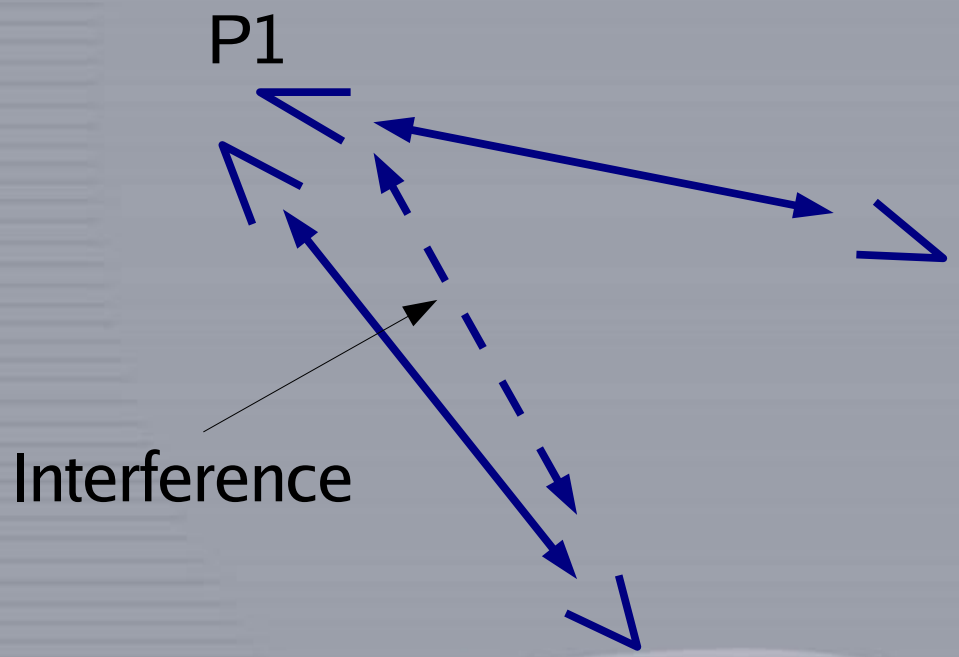
Notation: Top View



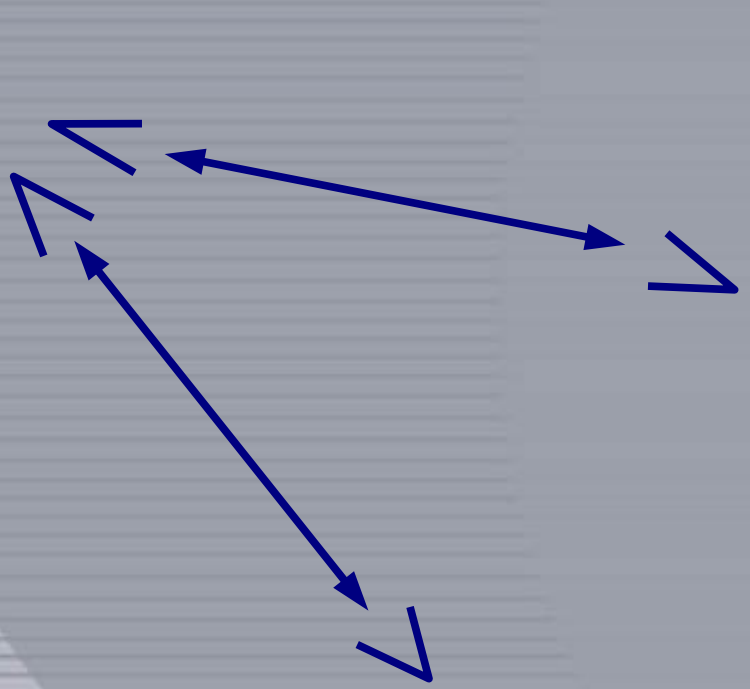
Point-to-Point (P2P) links

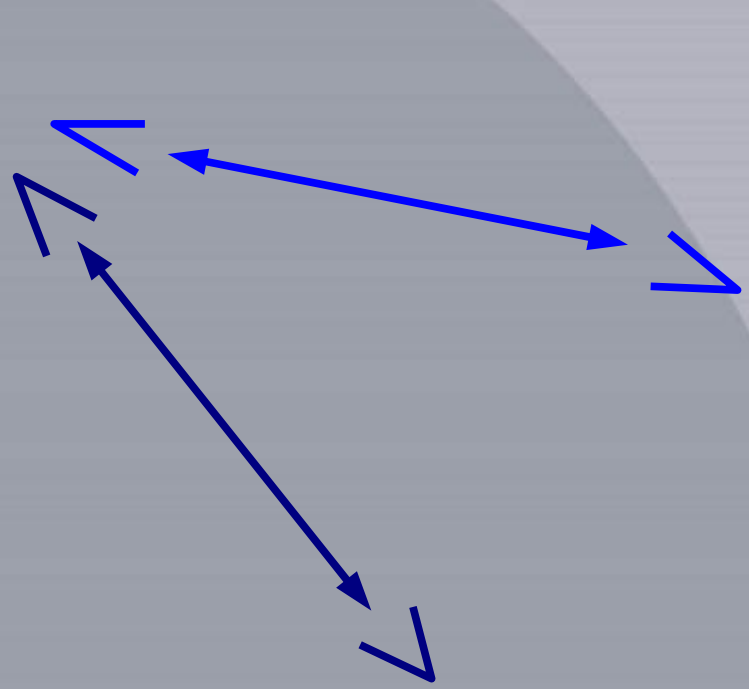
Point-to-MultiPoint (P2MP) link

Definitions: Transmit Power & Interference



Definitions: 2P and TDMA MAC

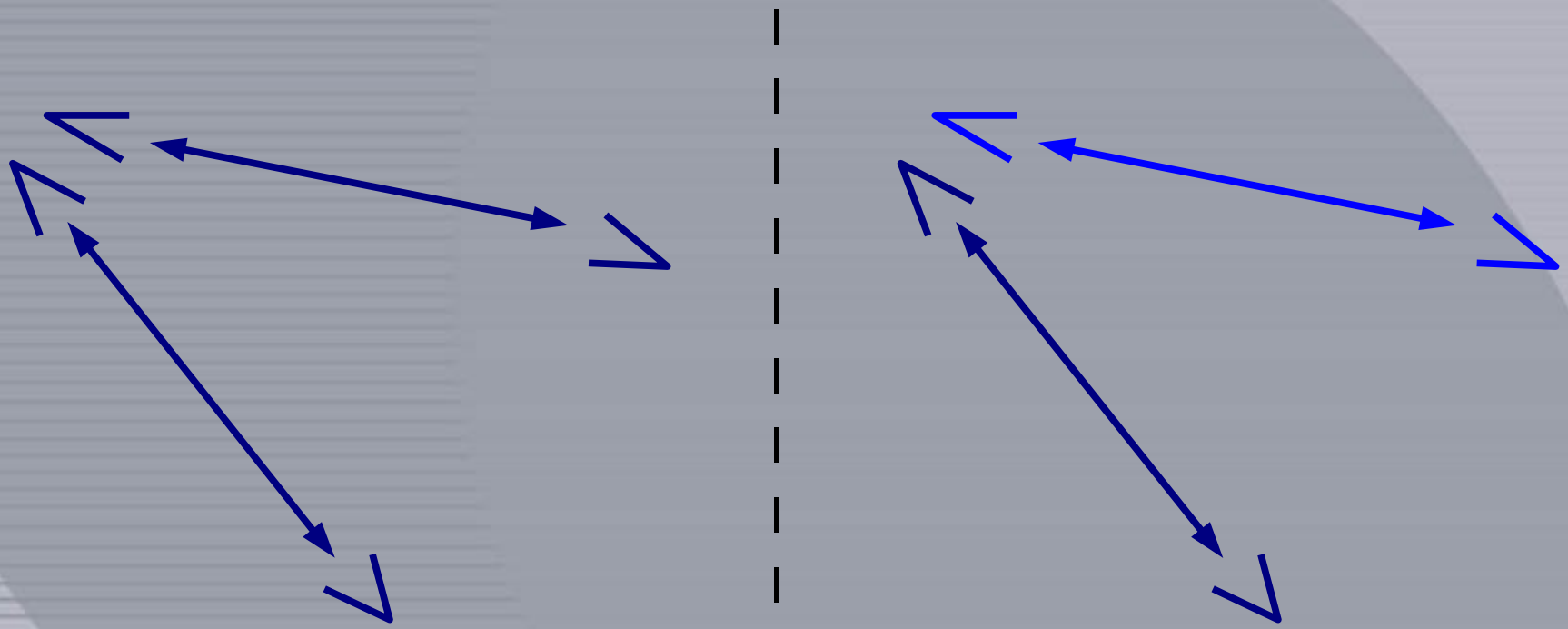




2P: The two links can operate simultaneously

TDMA: The two links operate in turns

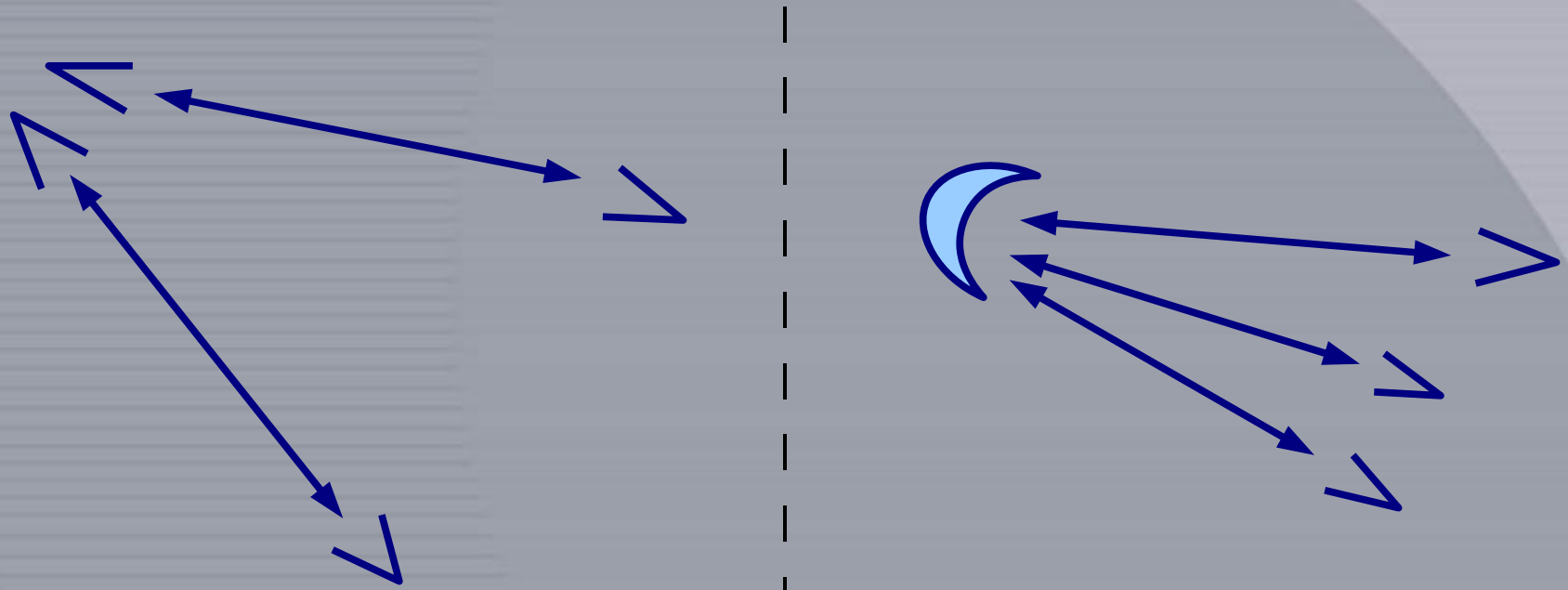
Dependence: Throughput depends on the MAC



2P: The two links can operate simultaneously

TDMA: The two links operate in turns

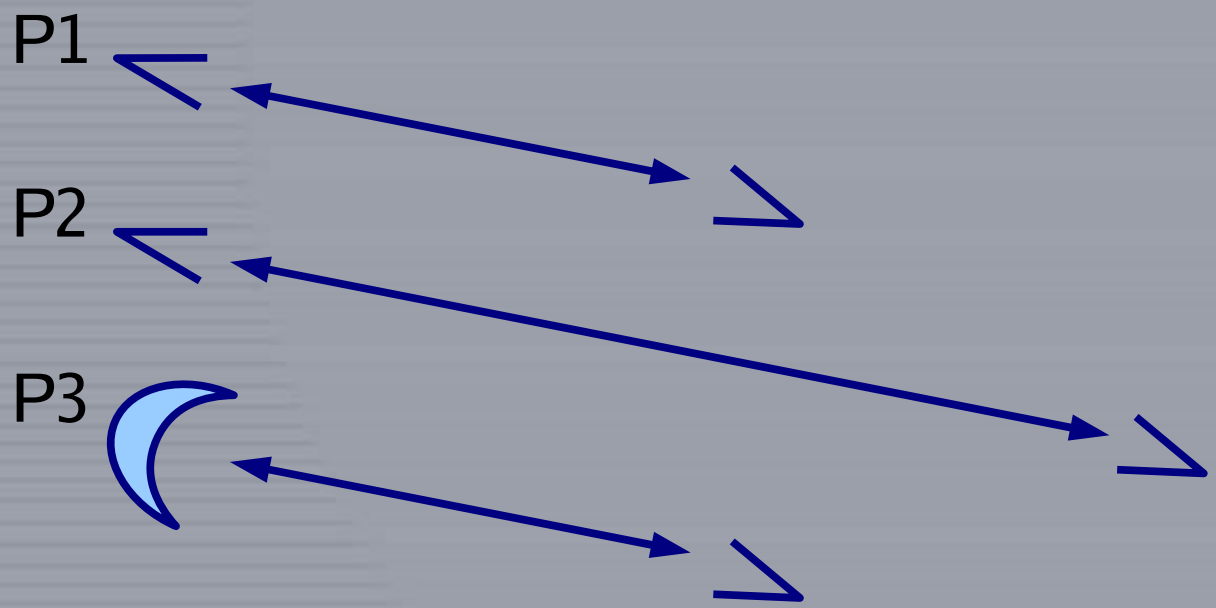
Dependence: Throughput depends on Link/Antenna Type



Point-to-Point (P2P) links

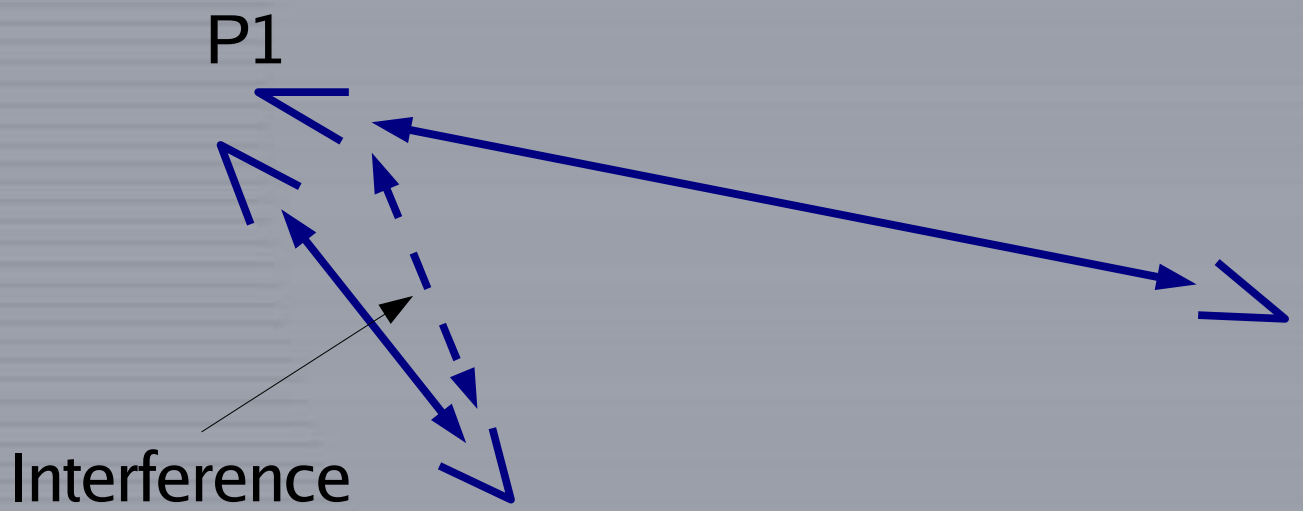
Point-to-MultiPoint (P2MP) link

Dependence: Transmit Power (required) depends on Link (length) & Antenna Type



P2 > P1
P3 > P1

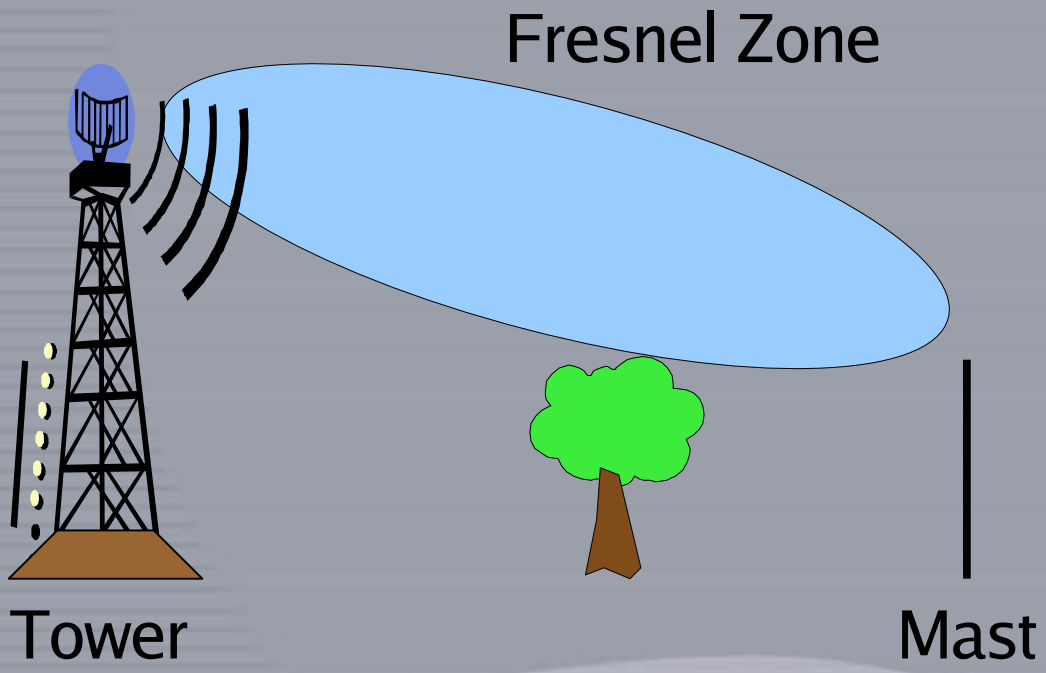
Dependence: MAC (feasibility) depends on the Transmit Powers



Signal to Interference Ratio should be above threshold

$$\frac{P_R}{I_R} \geq SIR_{reqd}$$

Dependence: Tower Height(s) (required) depends on Link (length)

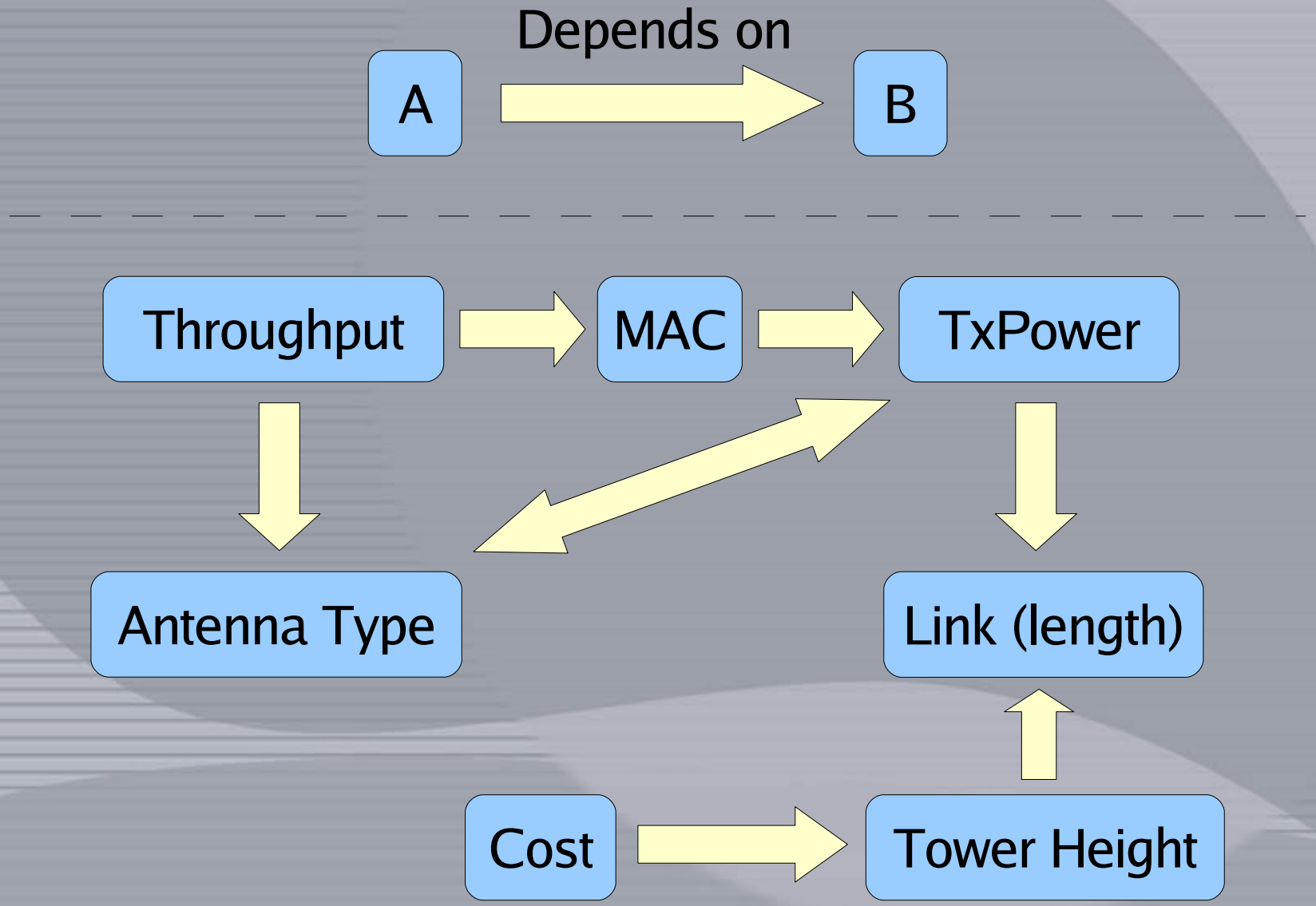


Dependence: Cost depends on Tower Height

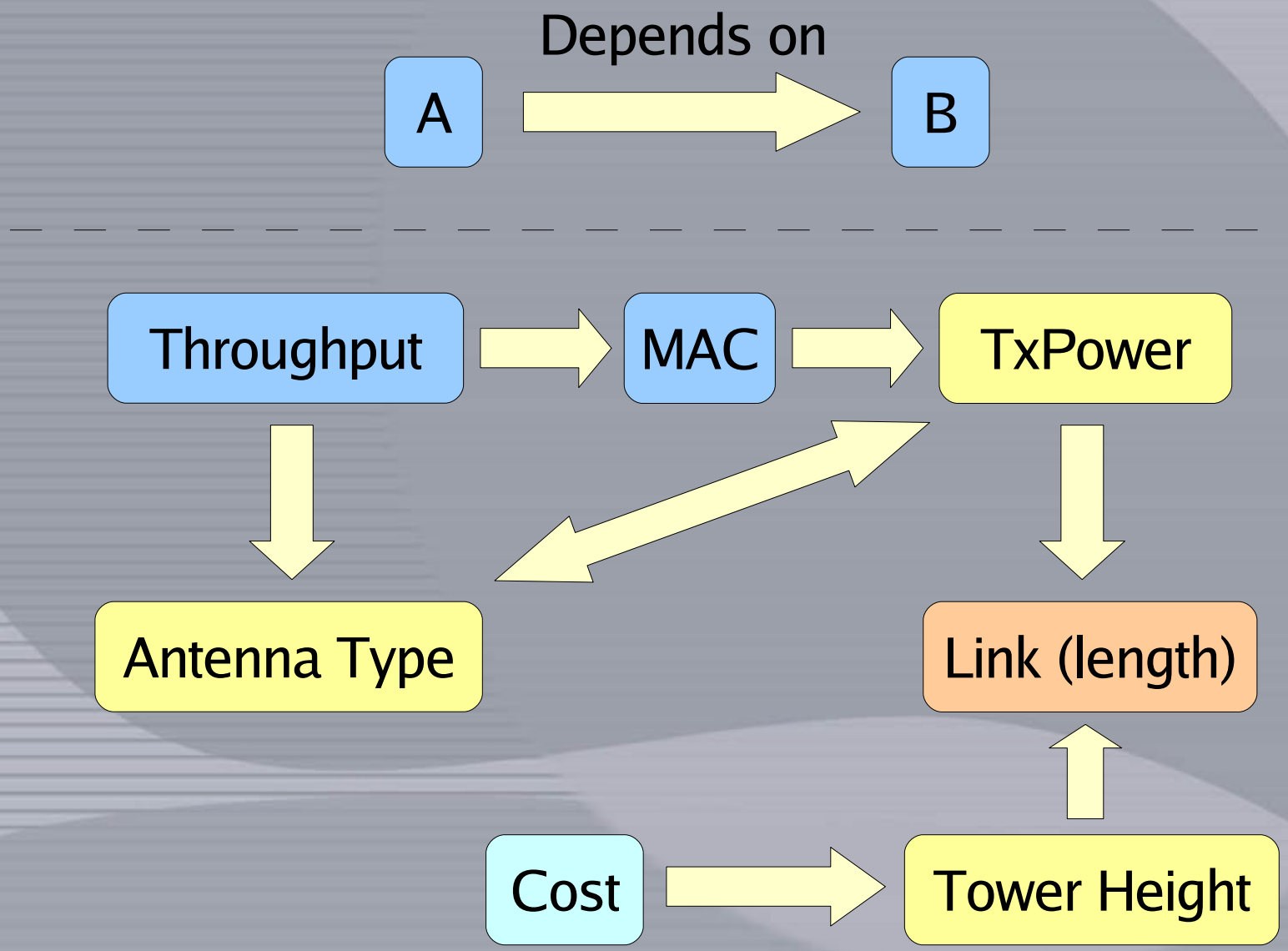
- Cost takes quantum jumps due to change in underlying tower design
  - Increases super-linearly with height

Tower/mast height (m)	Cost (x1000 Rs.)
10	4
15	6
21	36
24	41
27	48
30	82
45	220

Dependences: Summary



Problem Statement



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  - Overview
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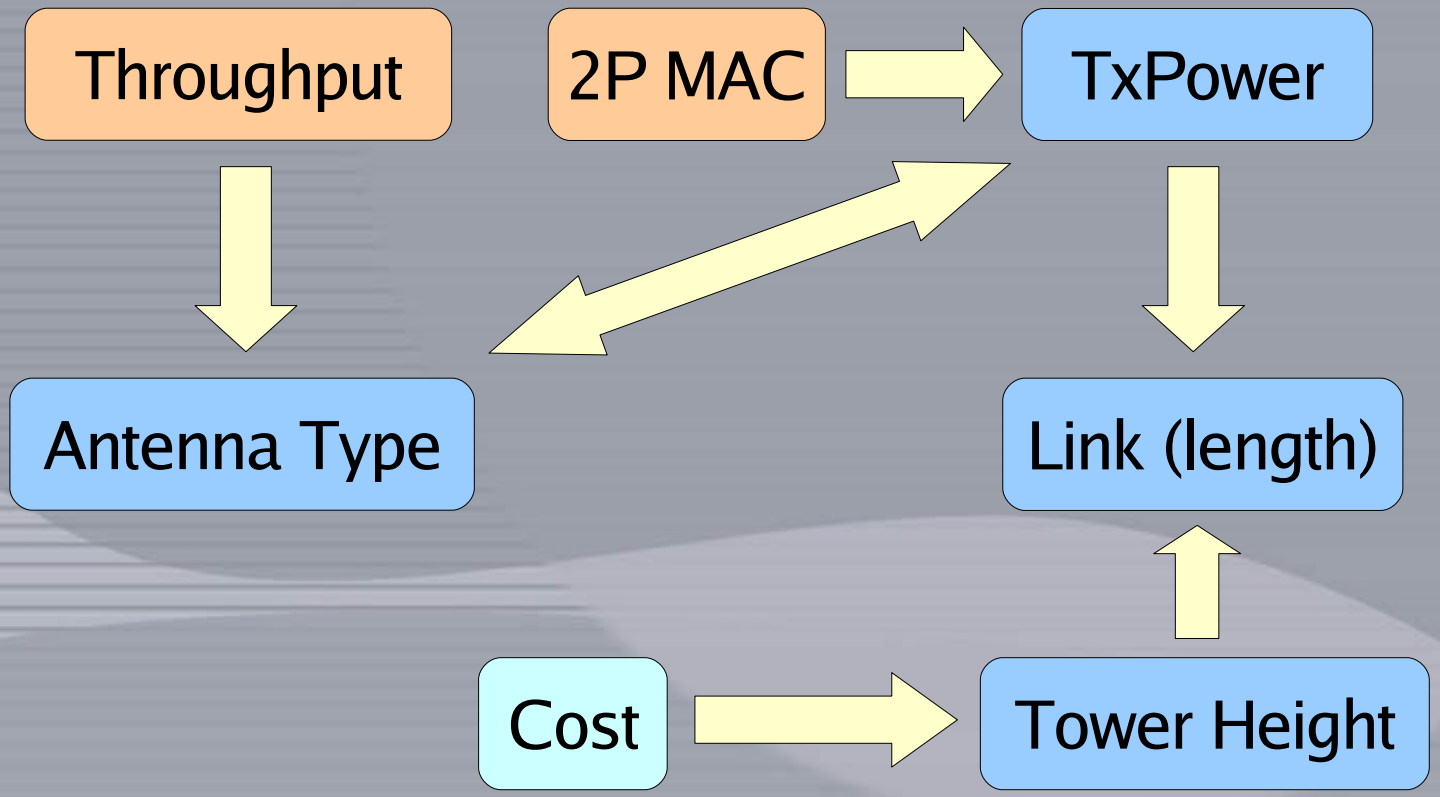
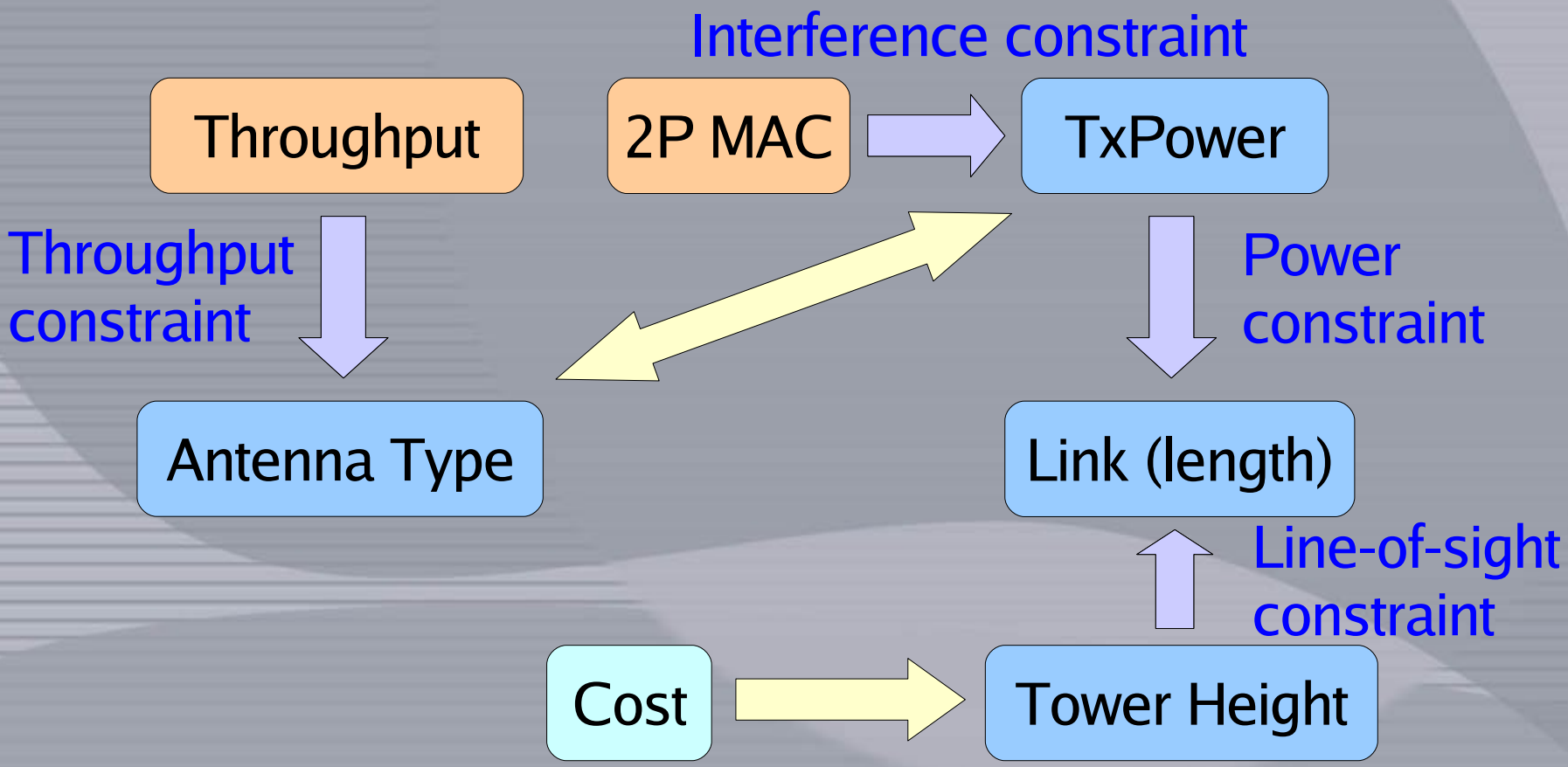
Solution Approach (Overview)

- Fix 2P MAC: more efficient
- Throughput, 2P MAC feasibility are constraints
- Cost minimization is an objective



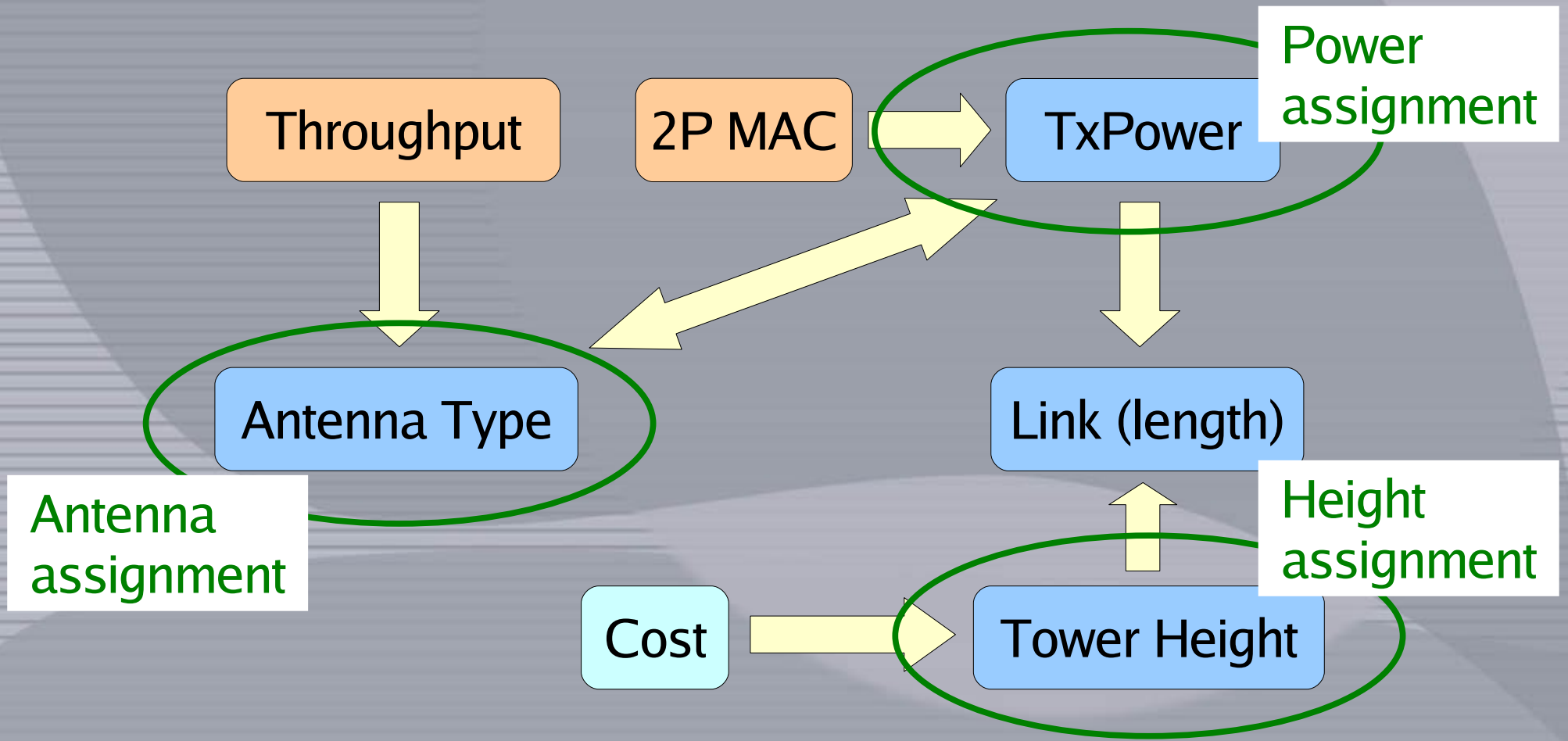
Solution Approach (continued)

- Constraints:
  - Throughput constraint, Interference constraint, Power constraint, Line-of-sight constraint



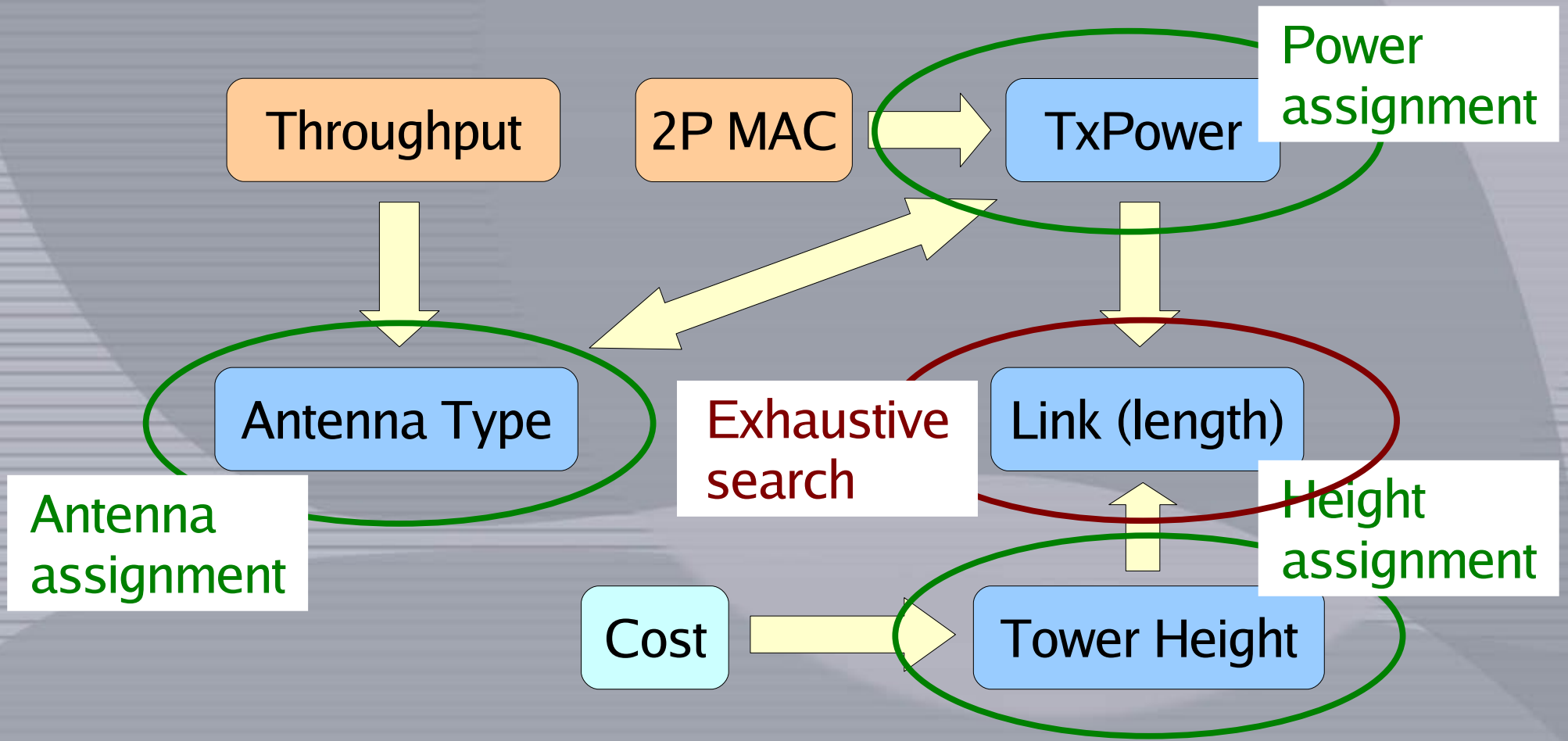
Solution Approach (continued)

- Sub-problems
  - Height assignment, Antenna assignment, Power assignment

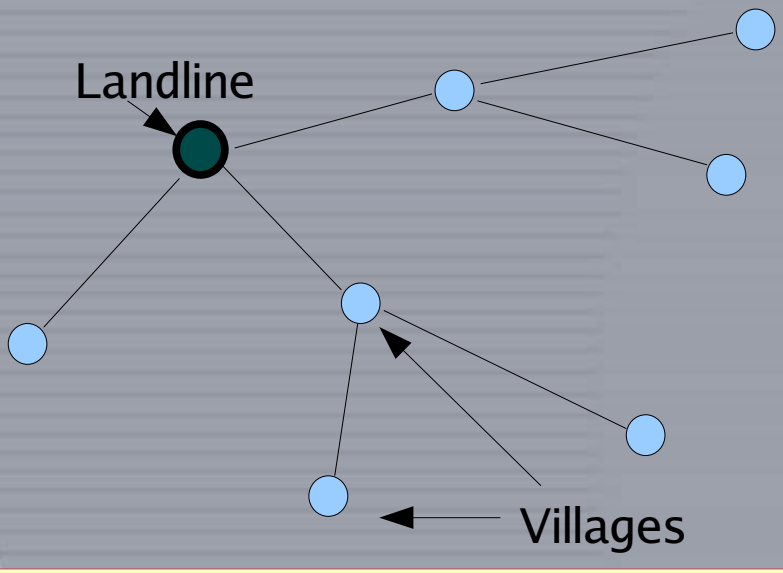


Solution Approach (continued)

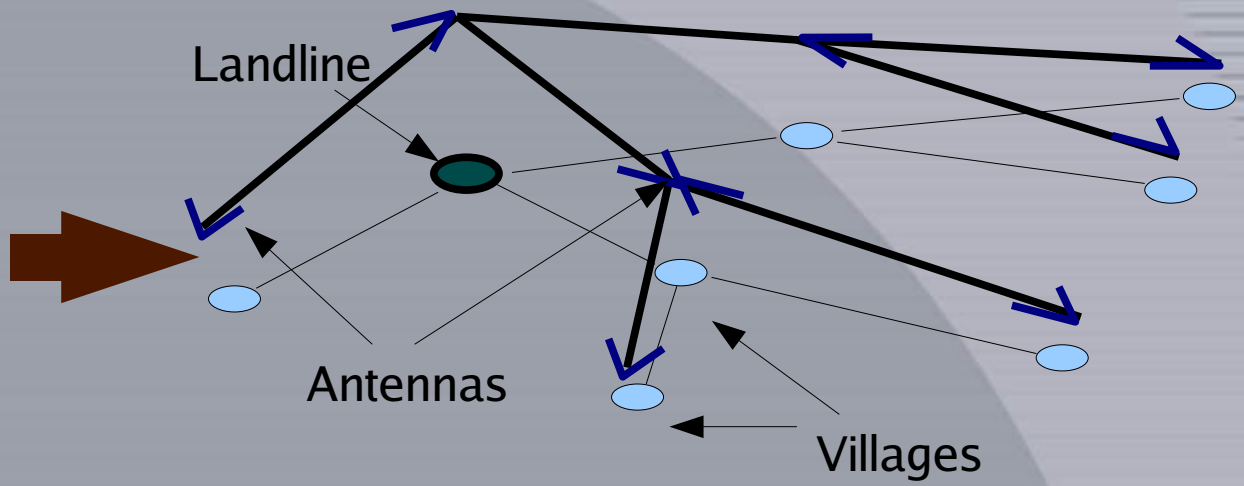
- Exhaustive search of all spanning trees
  - Determine who is the parent of each node



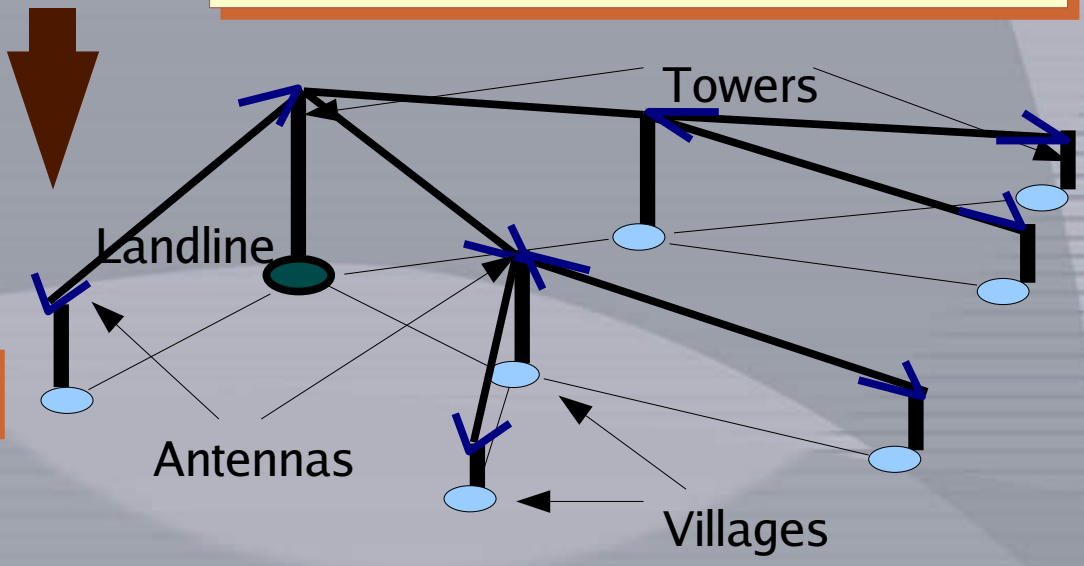
Solution Methodology



STEP 1: Tree Enumeration



STEP 2: Antenna + Power Assignment



STEP 3: Tower Height Assignment

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  - Tree Enumeration
- Evaluation
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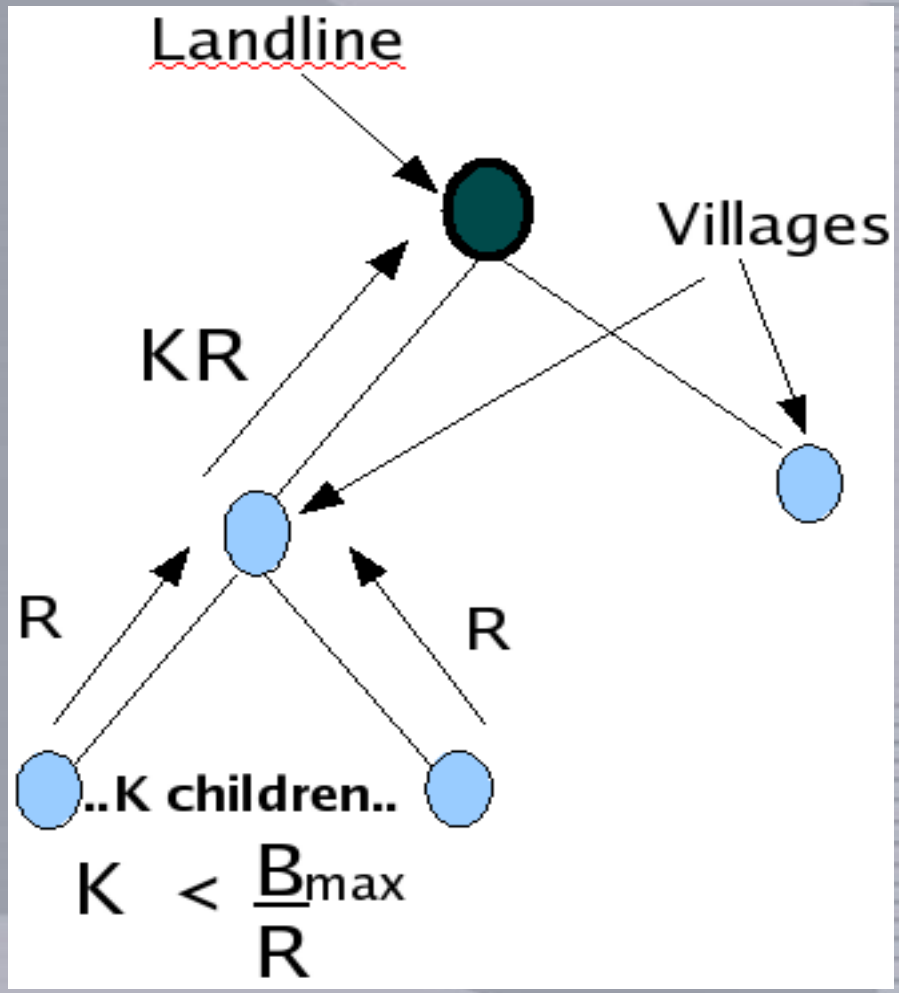
Tree Enumeration

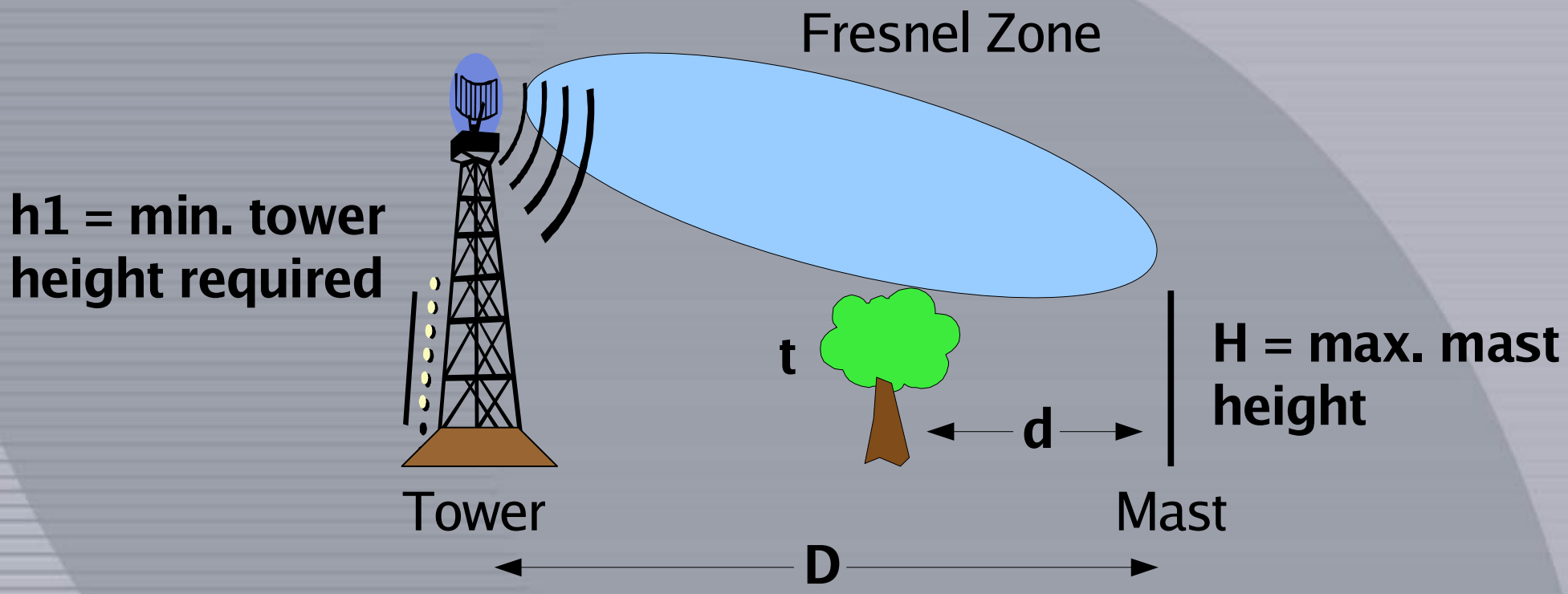
- Exhaustive Enumeration of all spanning trees
  - Throughput check: MAC dependant
  - Other domain based relaxations



Optimizations on Exhaustive Search

- Domain-knowledge based optimizations
  - Eliminate “long” links to begin with
  - Tree depth restriction
  - Dynamic cost bounding

Dynamic Cost Bounding



- Observation-1: height of level-2 tower determined by children set
- Observation-2: given a link-length, can lower-bound tower height
- Implication: can lower-bound the cost of a sub-tree
  - Can pre-compute lower-bounds for efficiency

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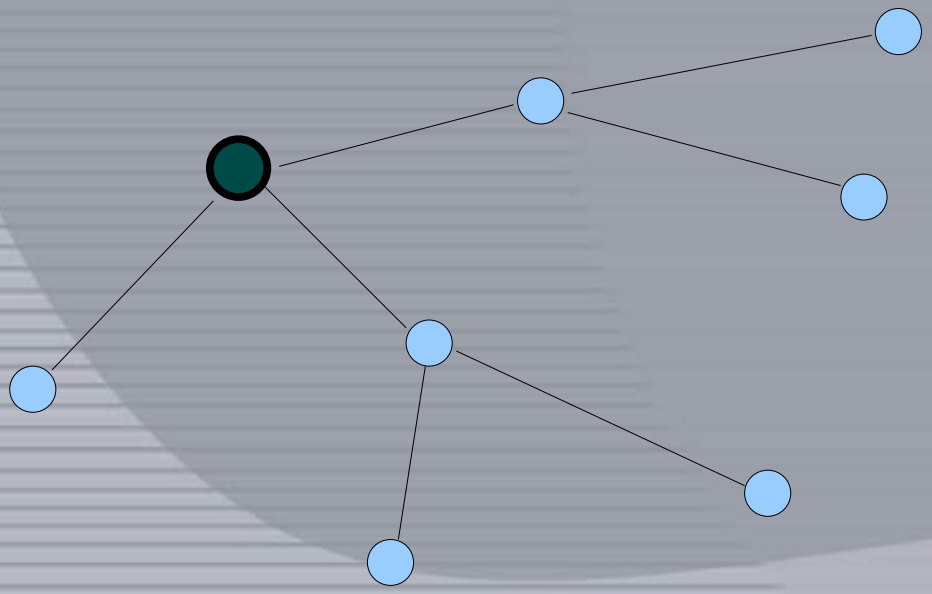
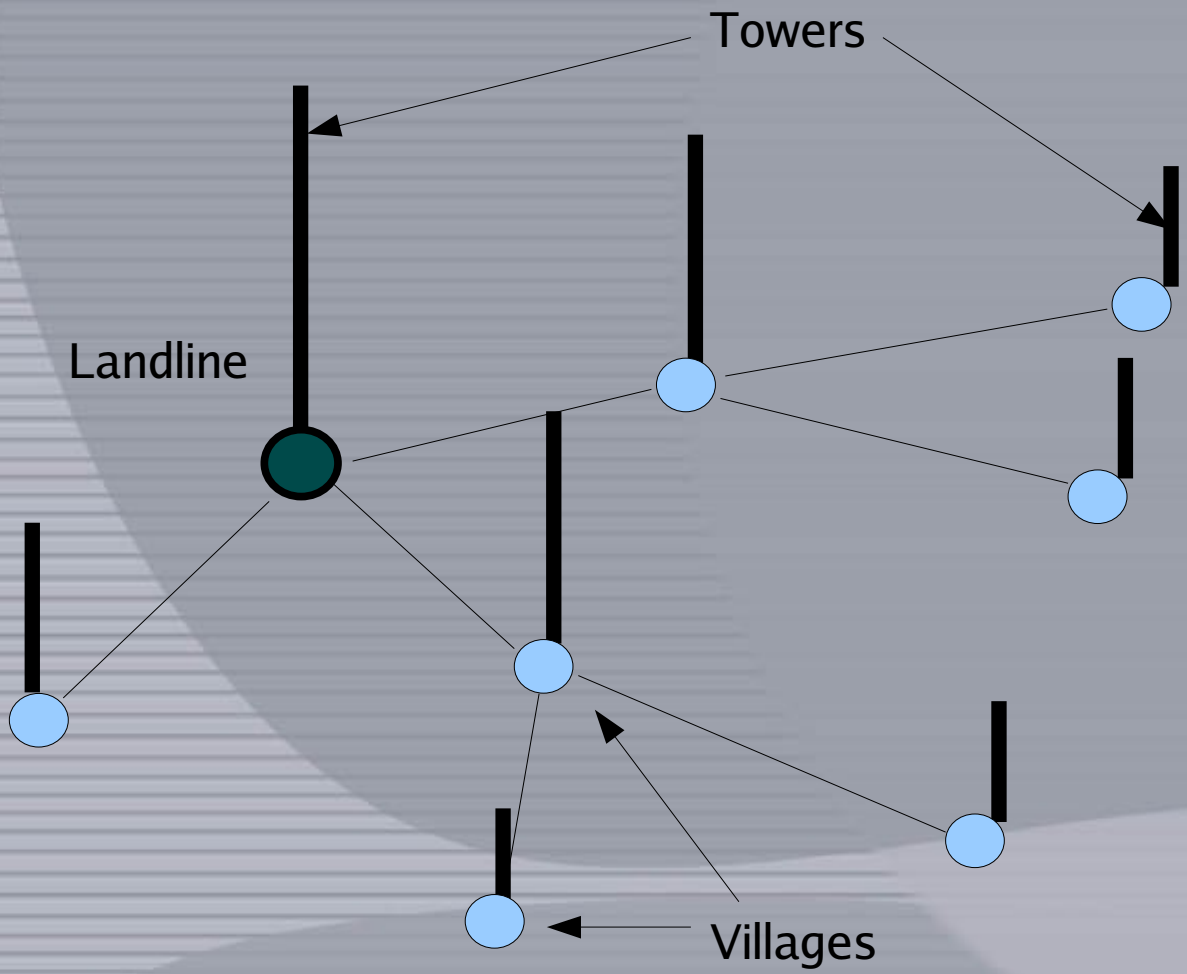
Height Assignment: Problem Statement



- Given: a topology (parent-child relationships)

Height Assignment: Problem Statement



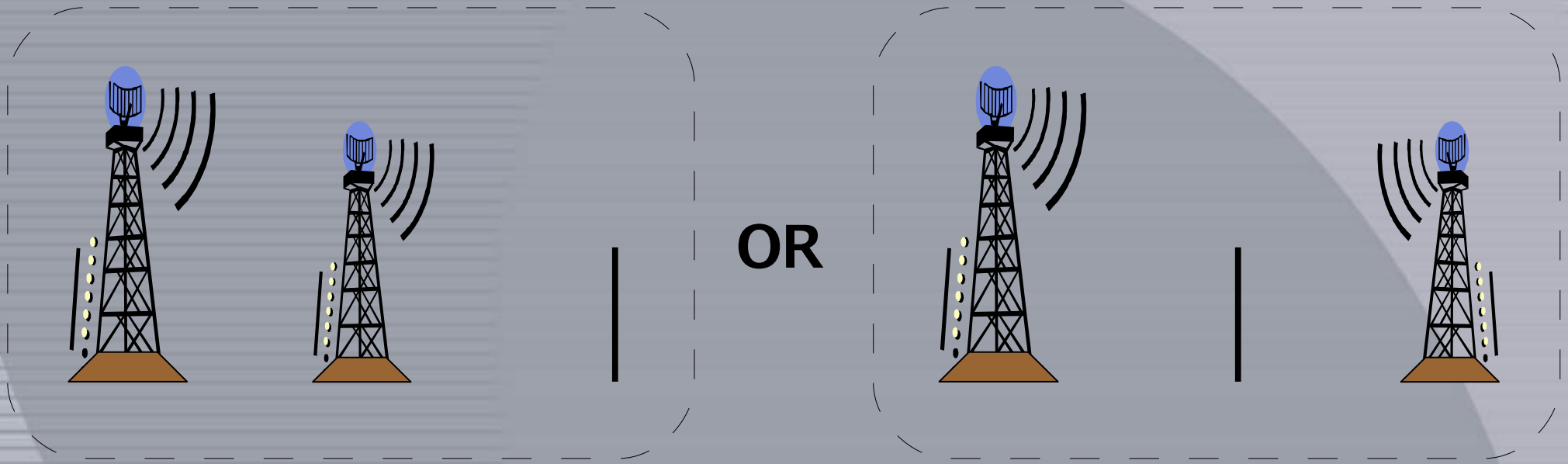
- Given: a topology (parent-child relationships)

- To determine: optimal tower/mast heights, satisfying LOS criteria

Height Assignment: Simplifications

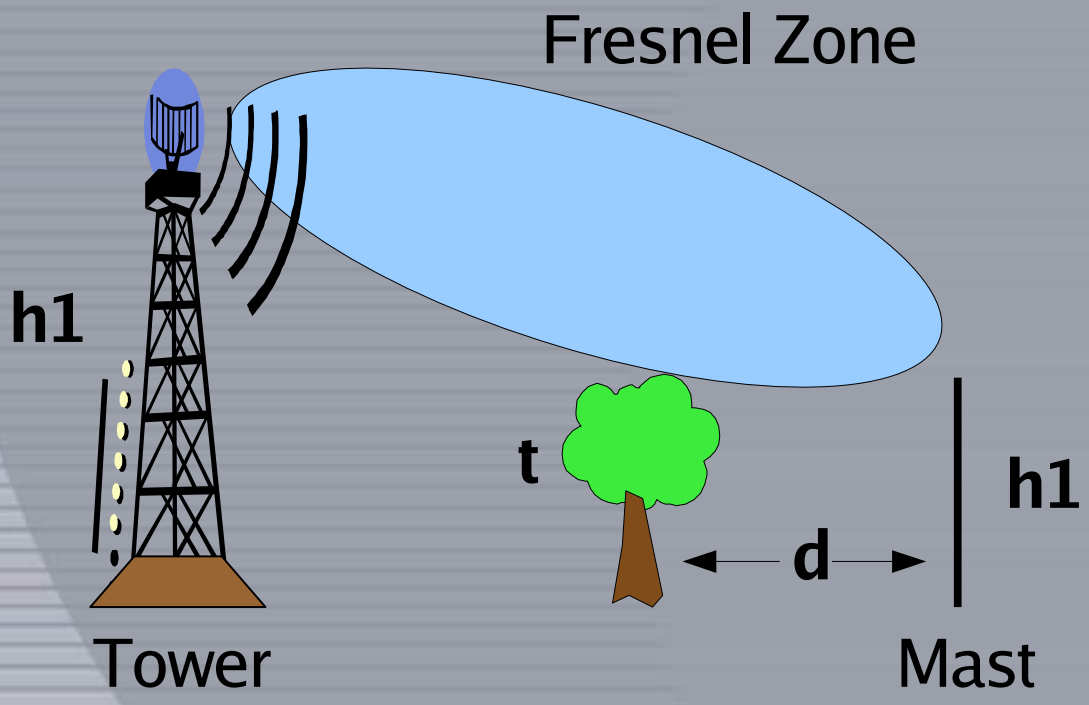
- 2-hop topology only
  - One hop ~ 10km ==> 20km radius ==> 40km dia
  - Accommodates significant # practical scenarios
- Tower at central location: say 50m
  - Typically in a town with reasonably tall buildings
- Assumption: No link between two masts (tree obstructions)
- Assumption: tower cost is linear in height
  - But we distinguish between towers and masts
  - Cost is a piece-wise linear function of height

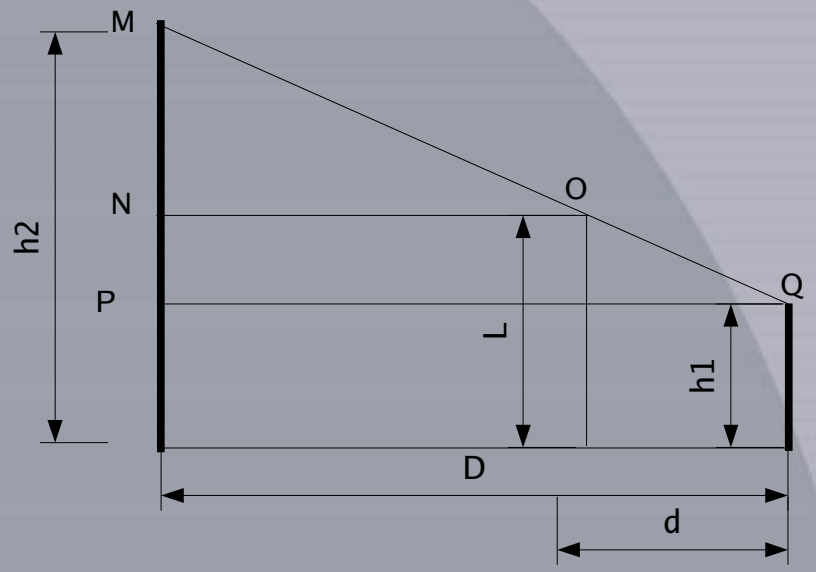
Tower at Level-2 or Level-3 ?



- Observation-1: tower heights can be interchanged in a link, retaining the same cost
  - Note: does not hold if terrain uncertainties are considered
- Observation-2: # level-3 nodes (leaves) > # level-2 nodes
- Implication: towers at level-2 and masts at level-3

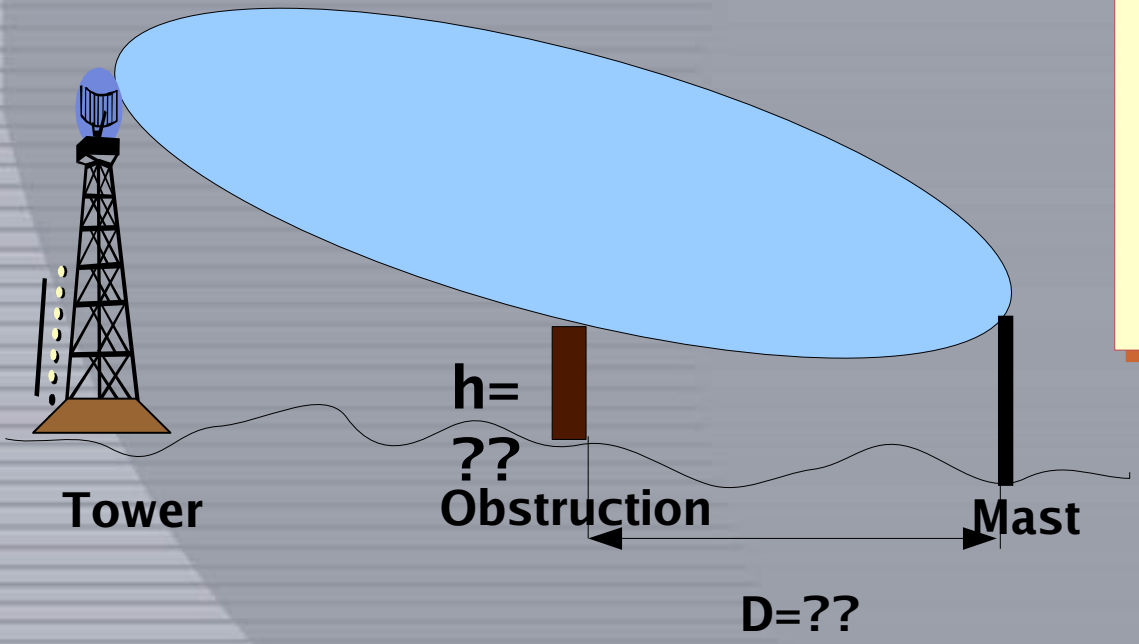
The LP Formulation





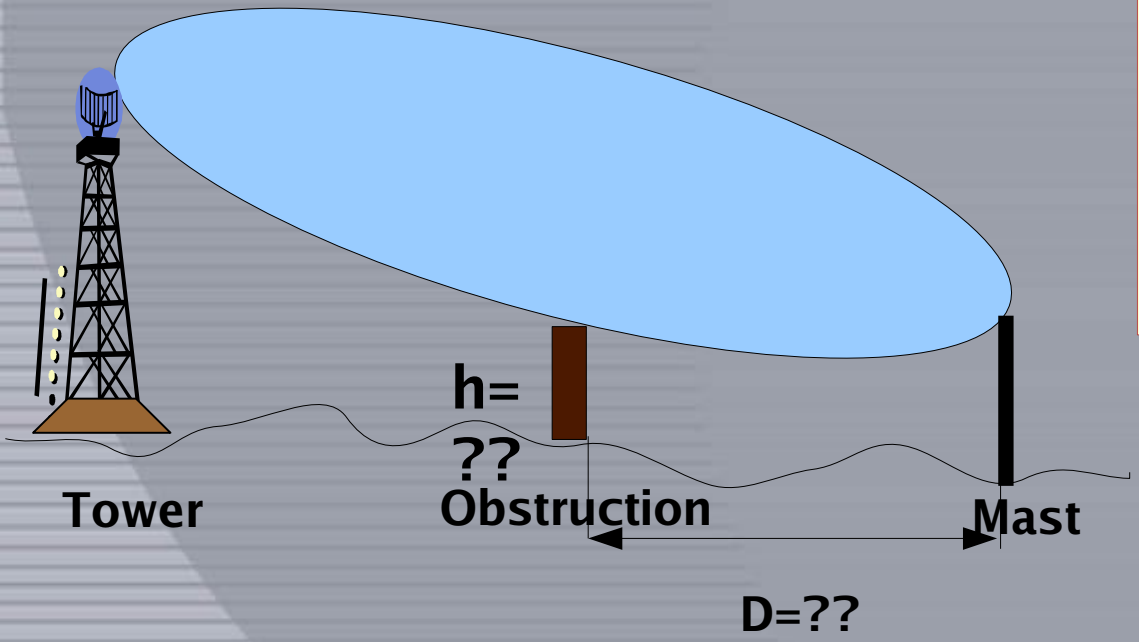
- Linear equations for obstruction clearance
- Linear cost optimization function

Finding Obstruction Height



- How to estimate the
  - Maximum Obstruction Height
  - And it's location ?

Finding Obstruction Height



- How to estimate the
  - Maximum Obstruction Height
  - And it's location ?

- Use freely available Satellite data (ftp://e0srp01u.ecs.nasa.gov)
- Interpolate to estimate.

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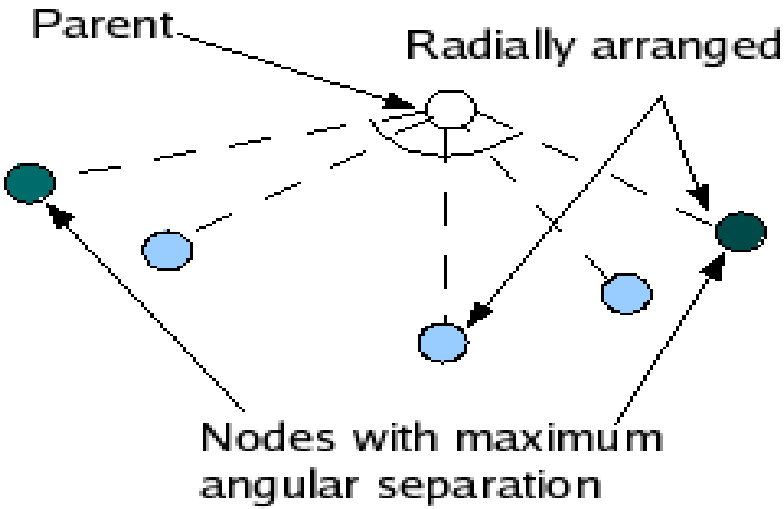
Antenna Assignment

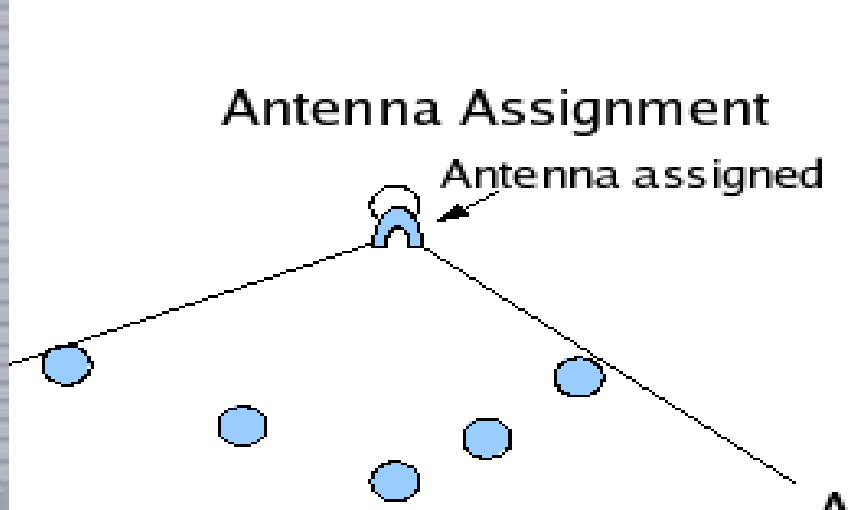
- Problem Statement:
  - Given a node and its children
    - What antenna types?
    - How many?, and
    - In which directions to use?
    - So that interference is minimised.

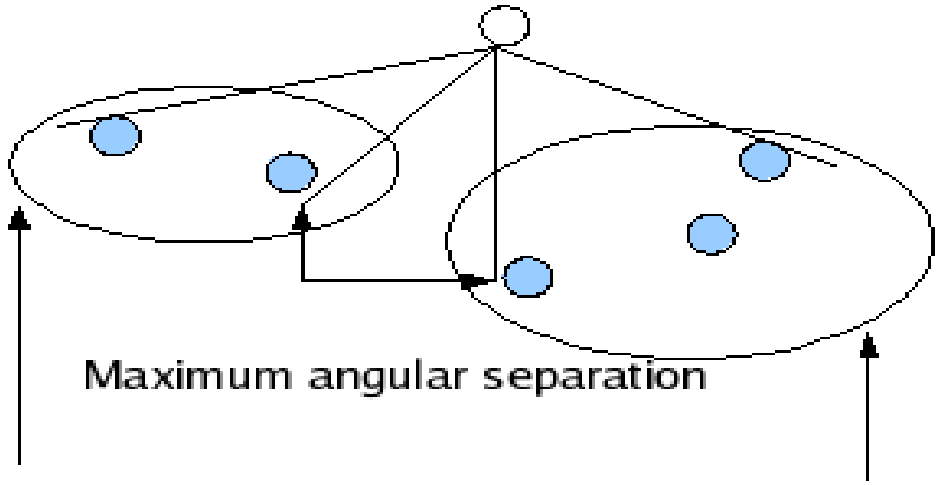
- Similar to the minimum set-cover problem
- Solved locally: For a node and its child set
  - Chicken egg problem
  - Power assignment takes care that all the links are working anyway
- Child always has a high gain directional antenna

Heuristic Antenna Assignment Algorithm

INPUT:







Algorithm called on these point sets recursively

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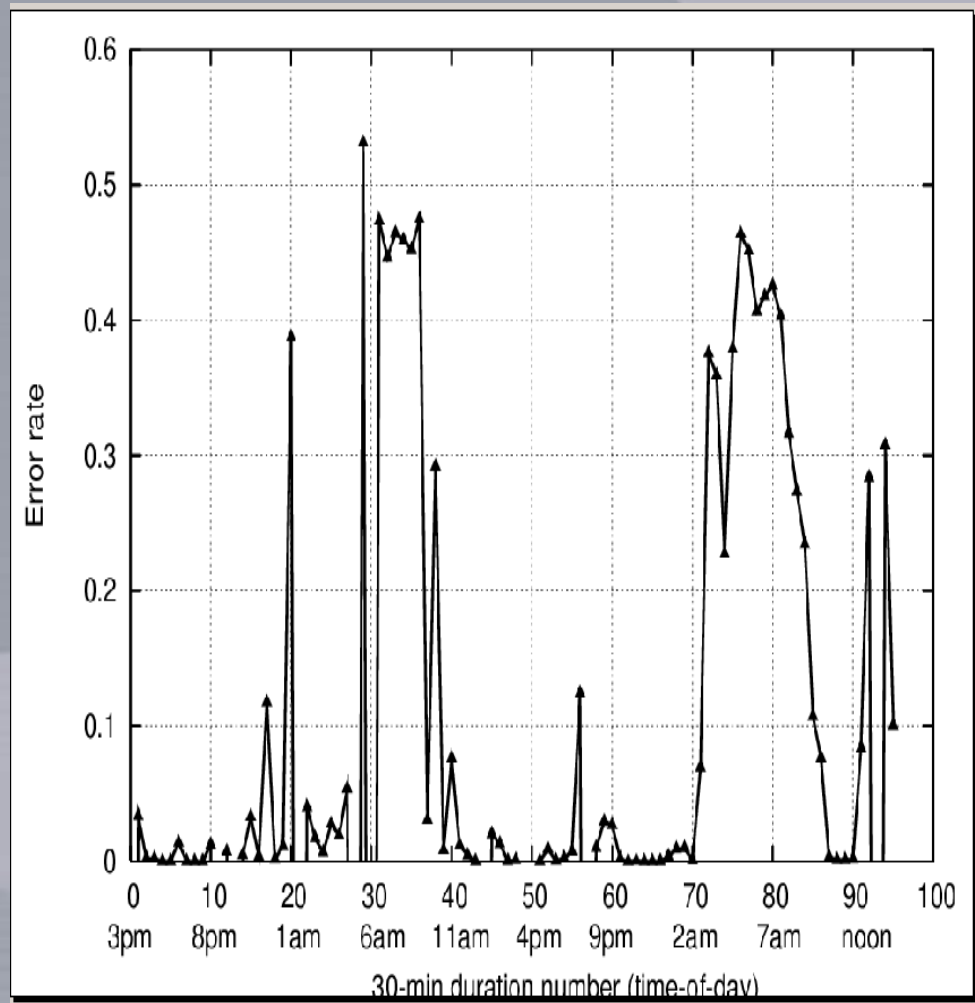
Power Assignment: Motivation

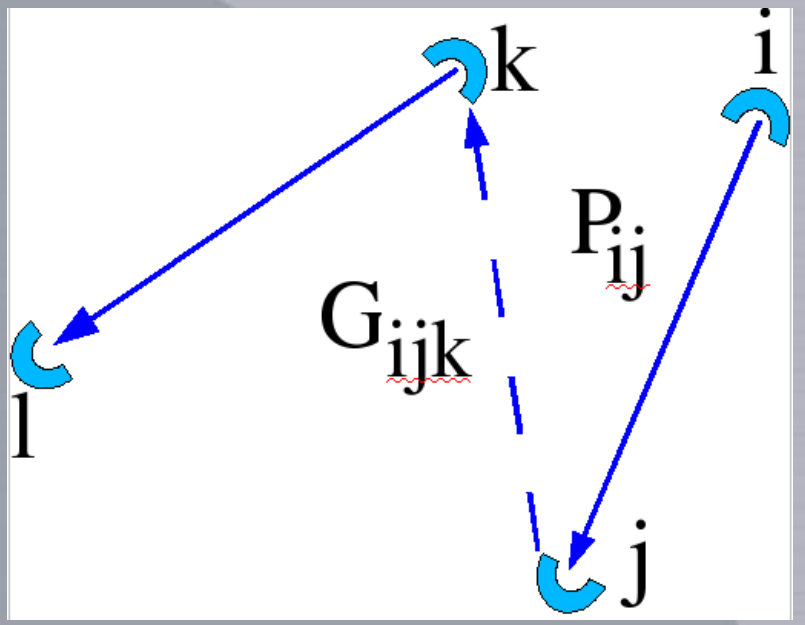
- Given: topology, antennas at nodes
- To determine: transmit powers for each radio

- Motivation: Direct cause-effect relationship between interference & packet error rate
  - Error rate as high as 50 %.
  - RTS/CTS not a remedy.



Power Assignment

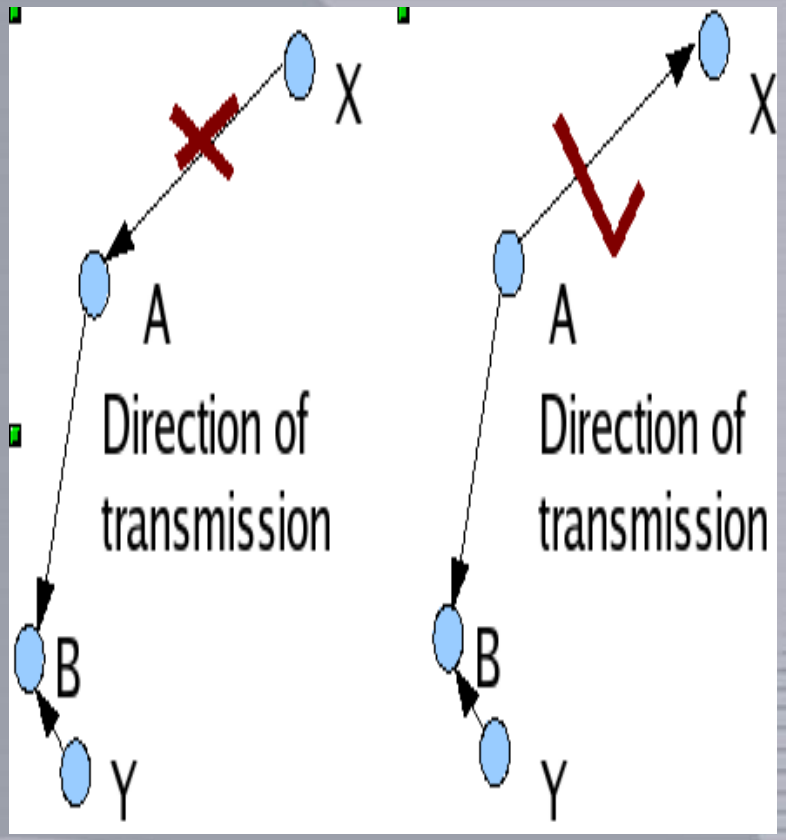
- P_{ij} = power transmitted by antenna at i for j, towards j.
- G_{ijk} = gain of antenna at i for j, towards k.
- PL_{ij} = pathloss from i to j.



- Maximum broadcast power criteria: $P_{ij} * G_{ijj} \leq P_{max}$
- Minimum received power criteria: $P_{ij} * G_{ijj} * G_{jii} / PL_{ij} \geq P_{min}$
- SIR criteria: $P_{ij} * G_{ijj} * G_{jii} / PL_{ij} \geq SIR_{reqd} * \Sigma_{(k,l) \in R} P_{kl} * G_{jik} * G_{klj} / PL_{kj}$
  - R is the set of interfering links

Interfering links (for 2P)

- Denote by A⇨B,
  A transmitting towards B
- For 2P:
  - X⇨A, does not interfere
  - A⇨X and antenna different from A⇨B, interferes
  - Y⇨B, interferes
  - B⇨Y, interfers
  - If none of above satisfied, C⇨D interferes



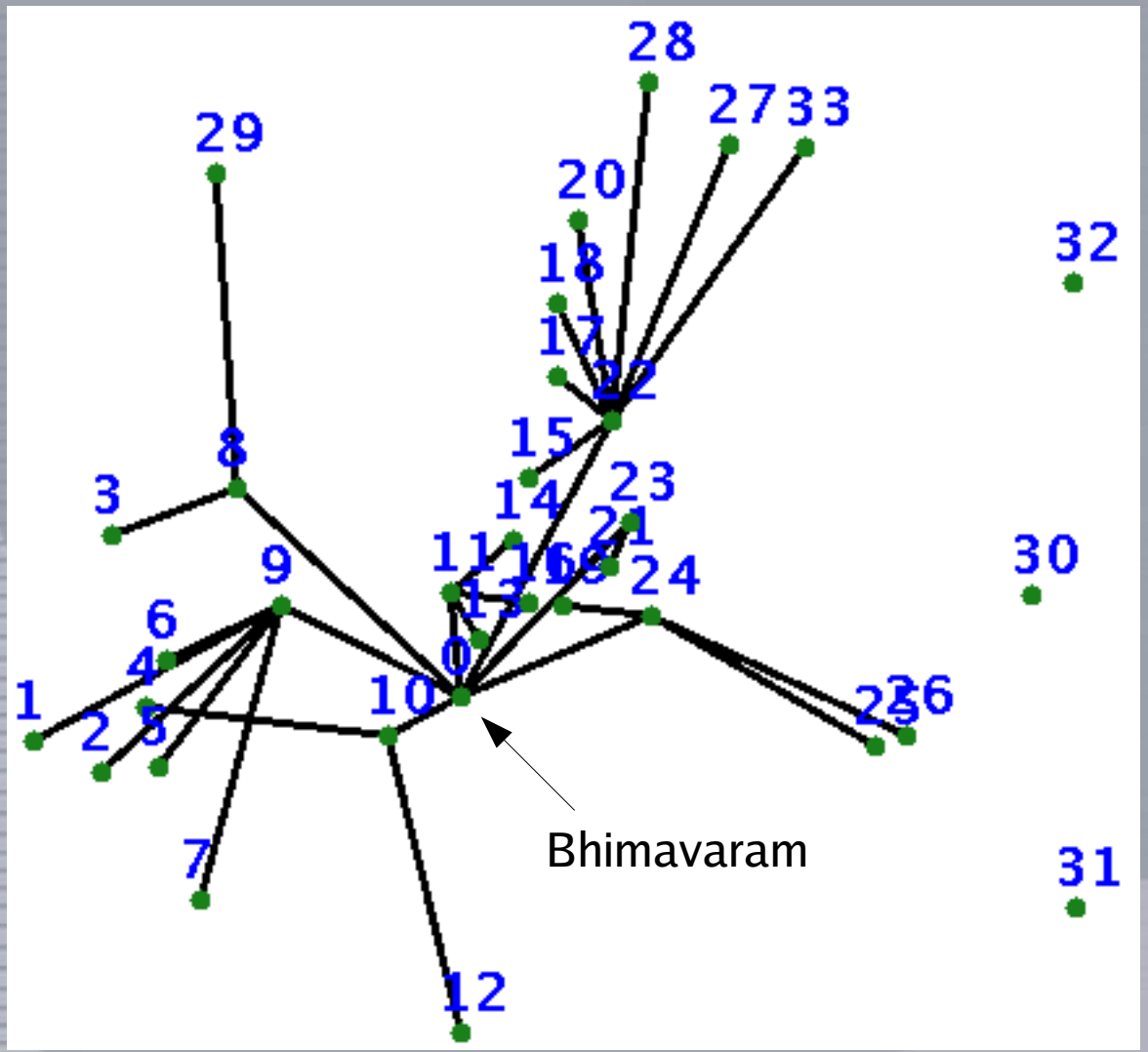
Putting it All Together

- Exhaustive enumeration of all spanning trees
  - Connected sub-trees at each stage
  - BFS-based enumeration
  - Eliminate “long” edges before starting enumeration
- For each sub-tree during enumeration:
  - Depth restriction check
  - Throughput check
  - Dynamic Cost Bounding
- For each spanning tree formed:
  - Height, antenna, power assignment

Outline

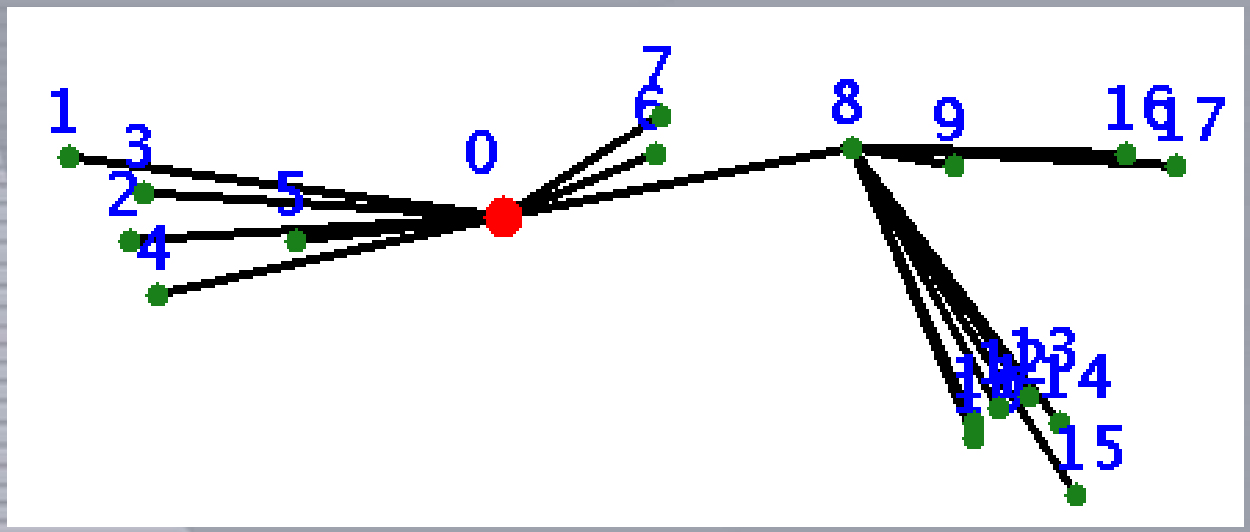
- Motivation & Background
- Problem statement, Uniqueness
- Problem formulation
  - Definitions, dependences
- Solution approach
- Evaluation
- Conclusions

Evaluation: Bhimavaram topology



- Ashwini Project: Byrraju foundation, West Godavari, Andhra Pradesh
- To connect 34 villages (result only for 31 nodes)
- Uses ONE wireless channel compared to THREE by current deployment.
- Careful topology planning led to 21% cost savings.
- Careful height assignment led to 15 times cost benefit over current deployment (undergoing tests).

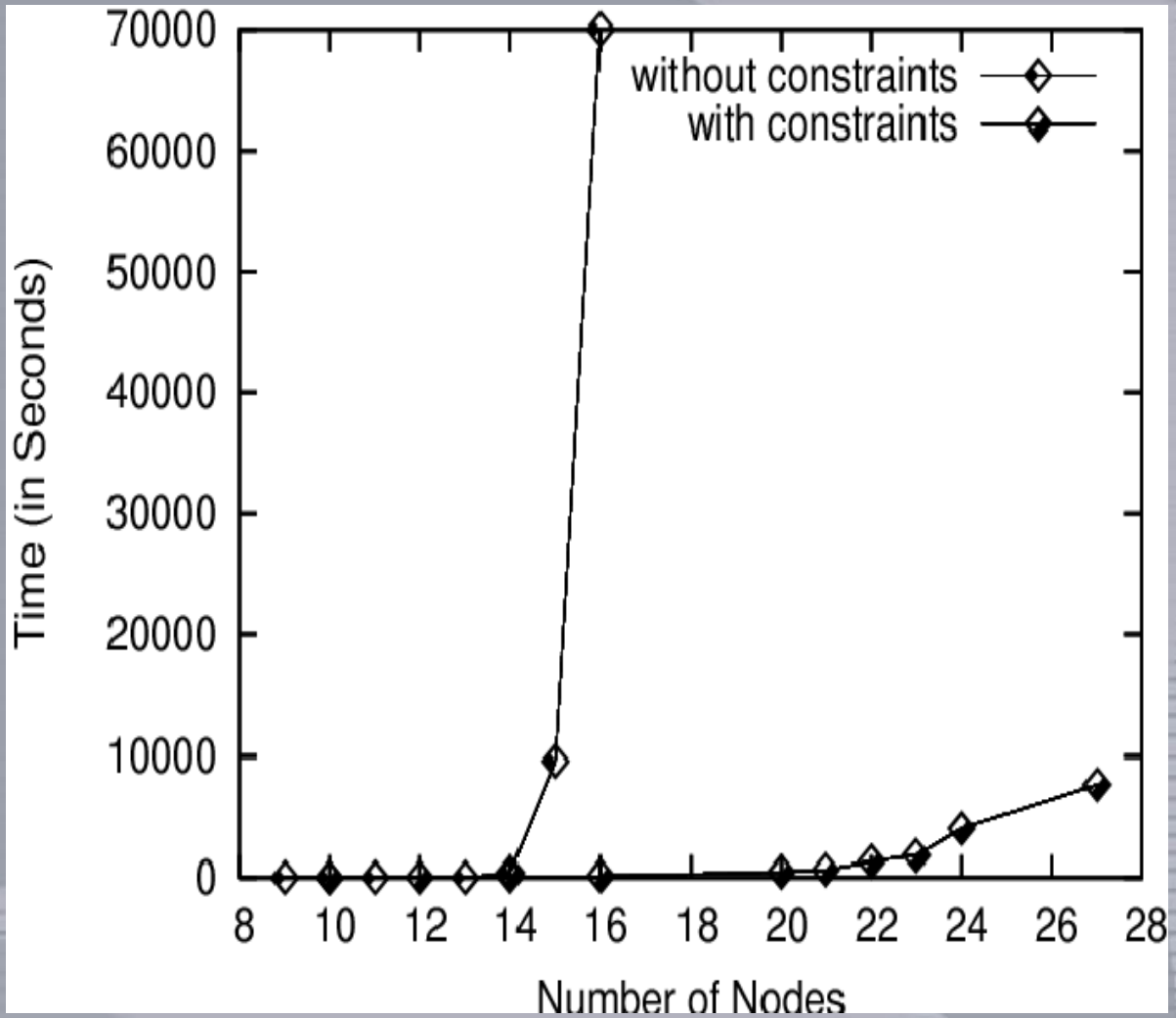
Evaluation: Amalapuram topology



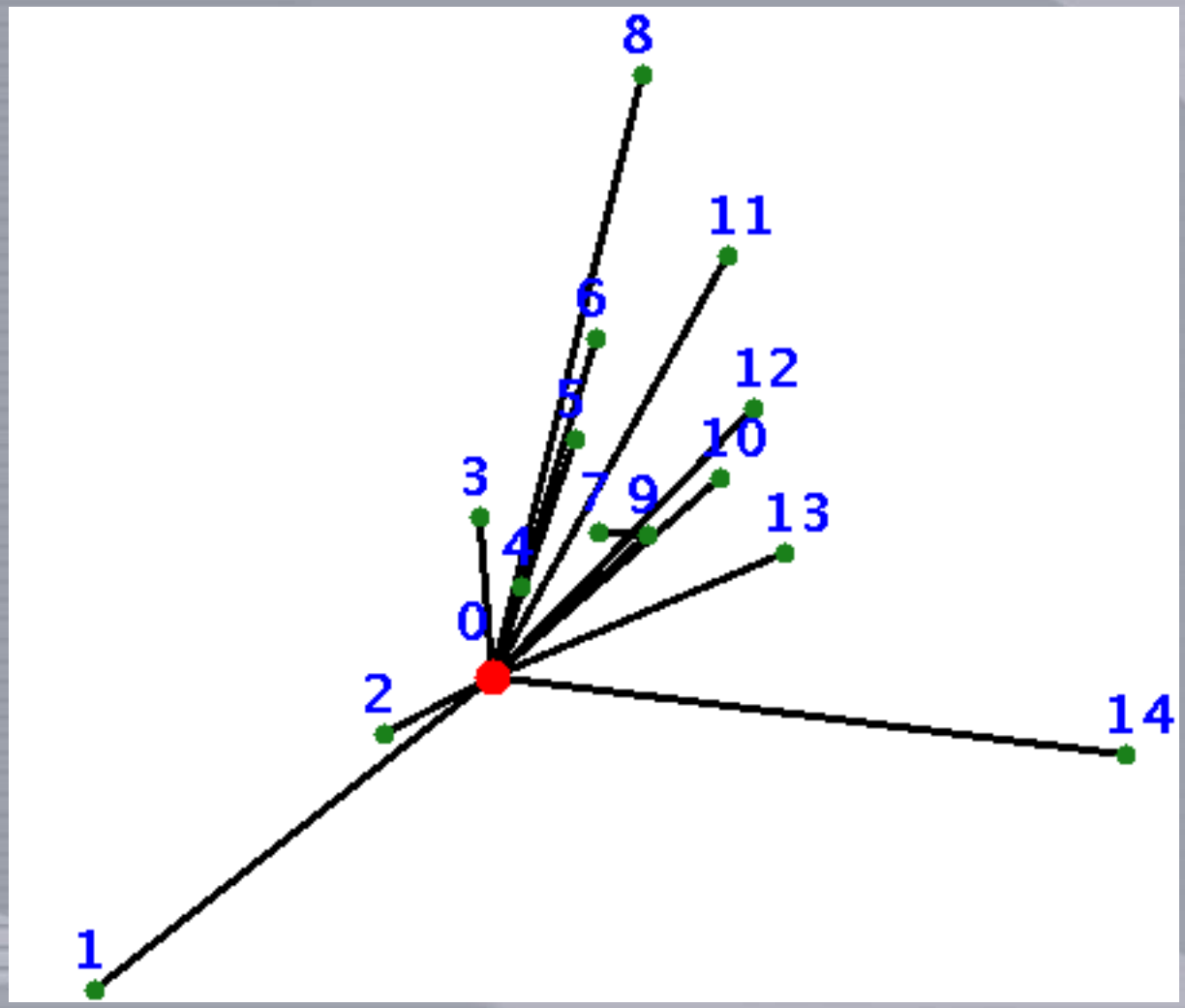
- Ashwini Project: Byrraju foundation, East Godavari, Andhra Pradesh
- To connect 18 villages
- Uses ONE wireless channel.

Evaluation

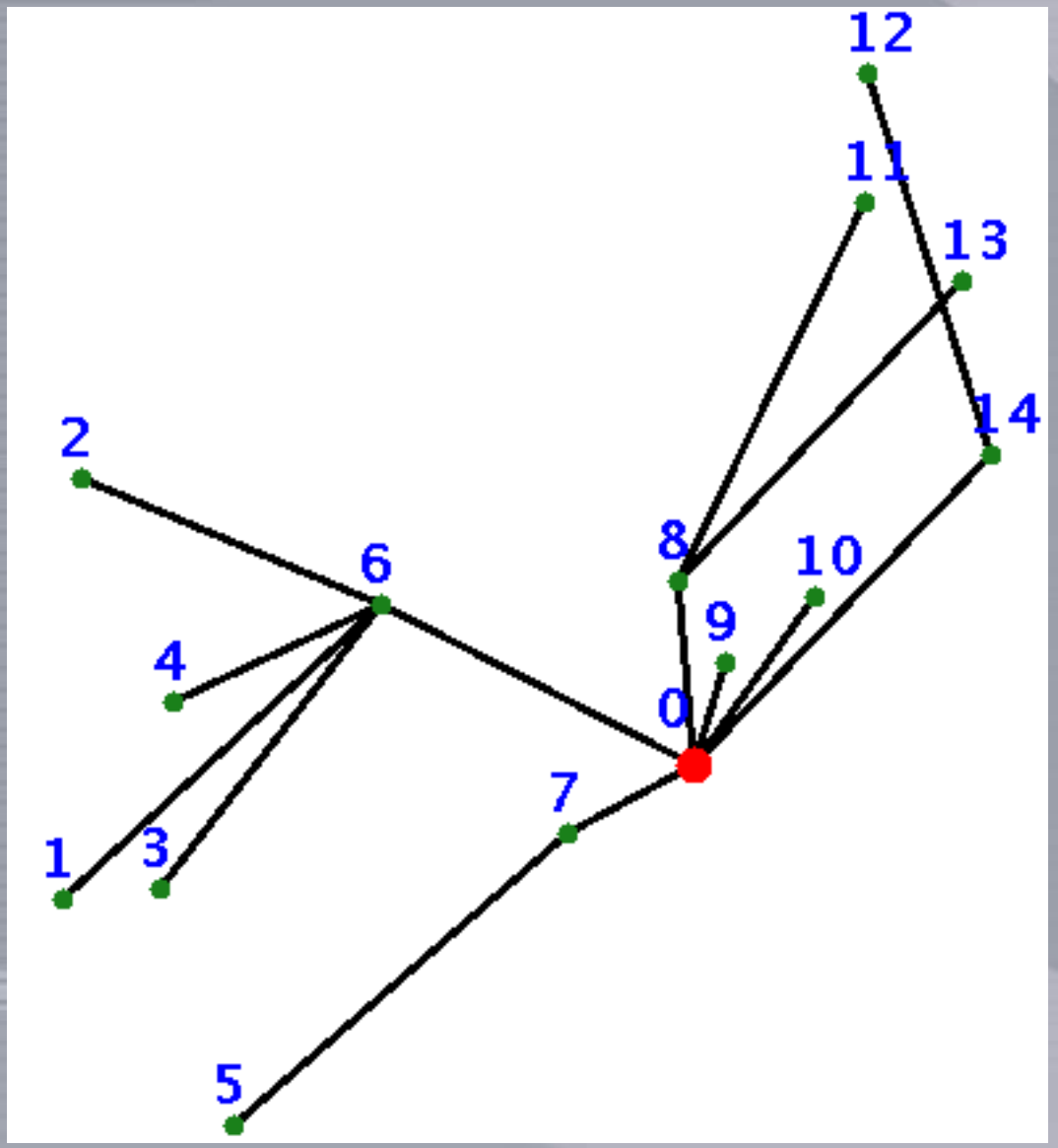
- Runtime Plot
- Observations
  - Antennas of max half power beamwidth 30 degree.
  - The two ends of a link are assigned same power values
  - Linearity of tower cost holds



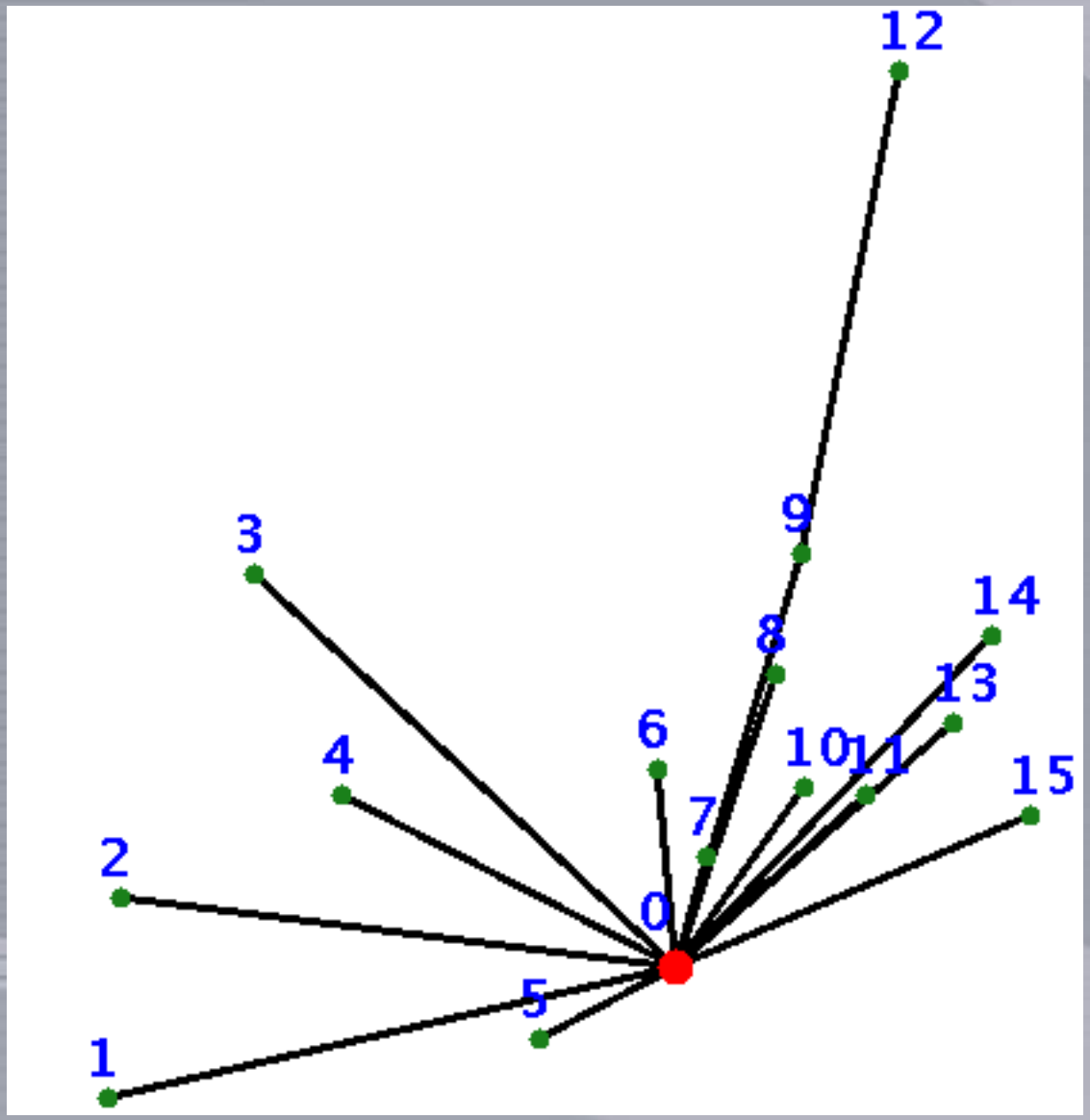
Evaluation: Random Topologies



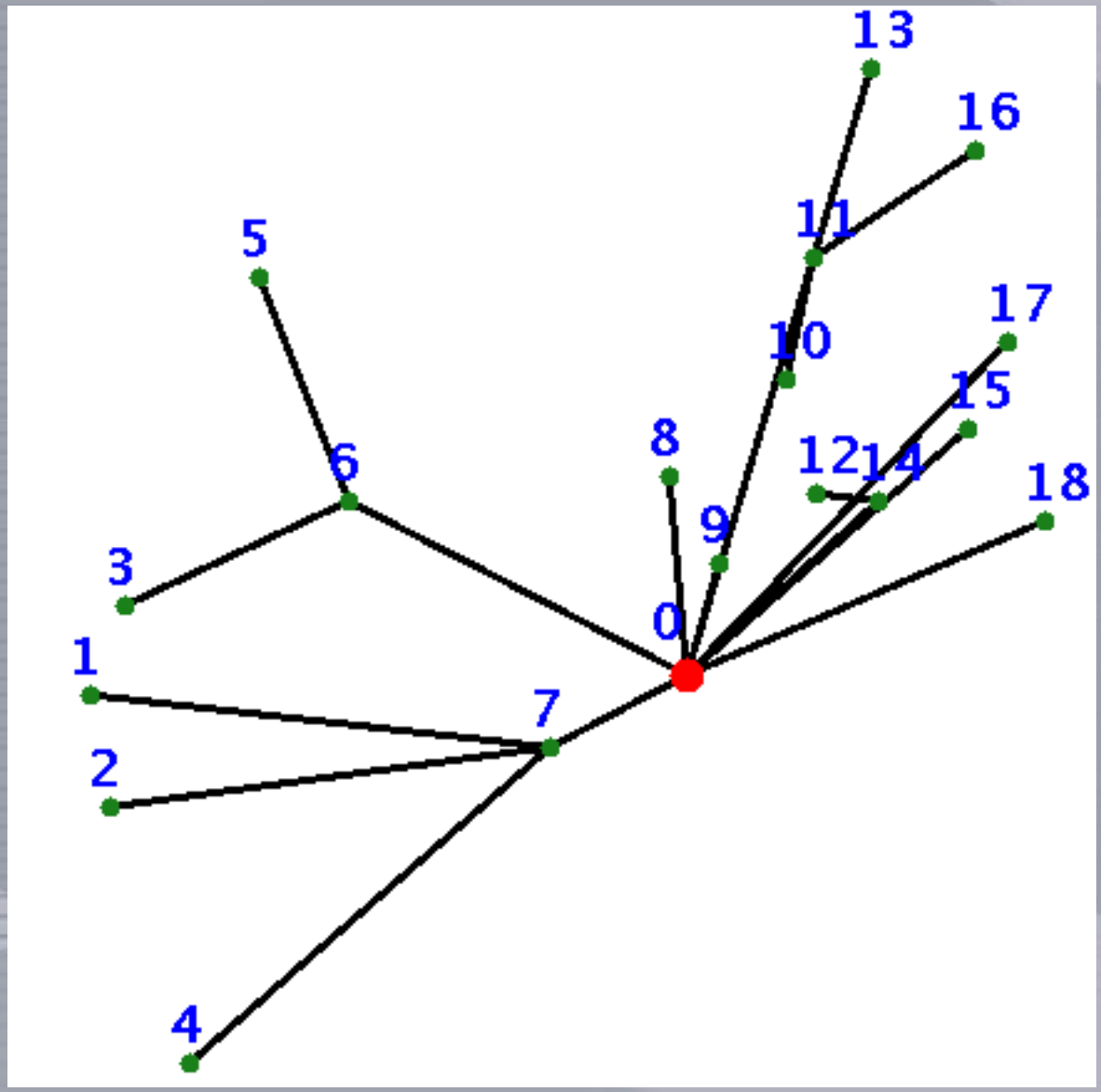
Evaluation: Random Topologies



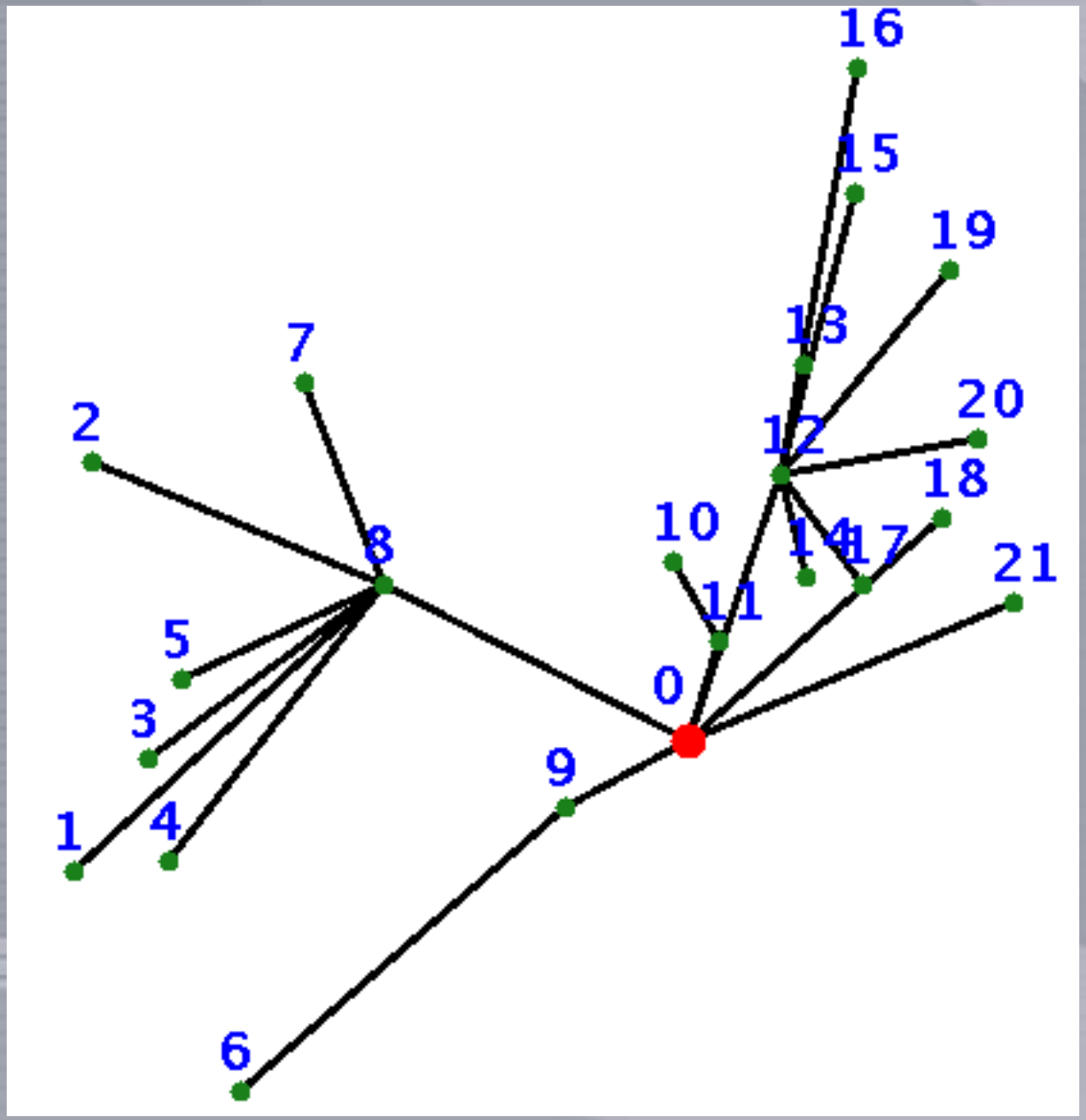
Evaluation: Random Topologies



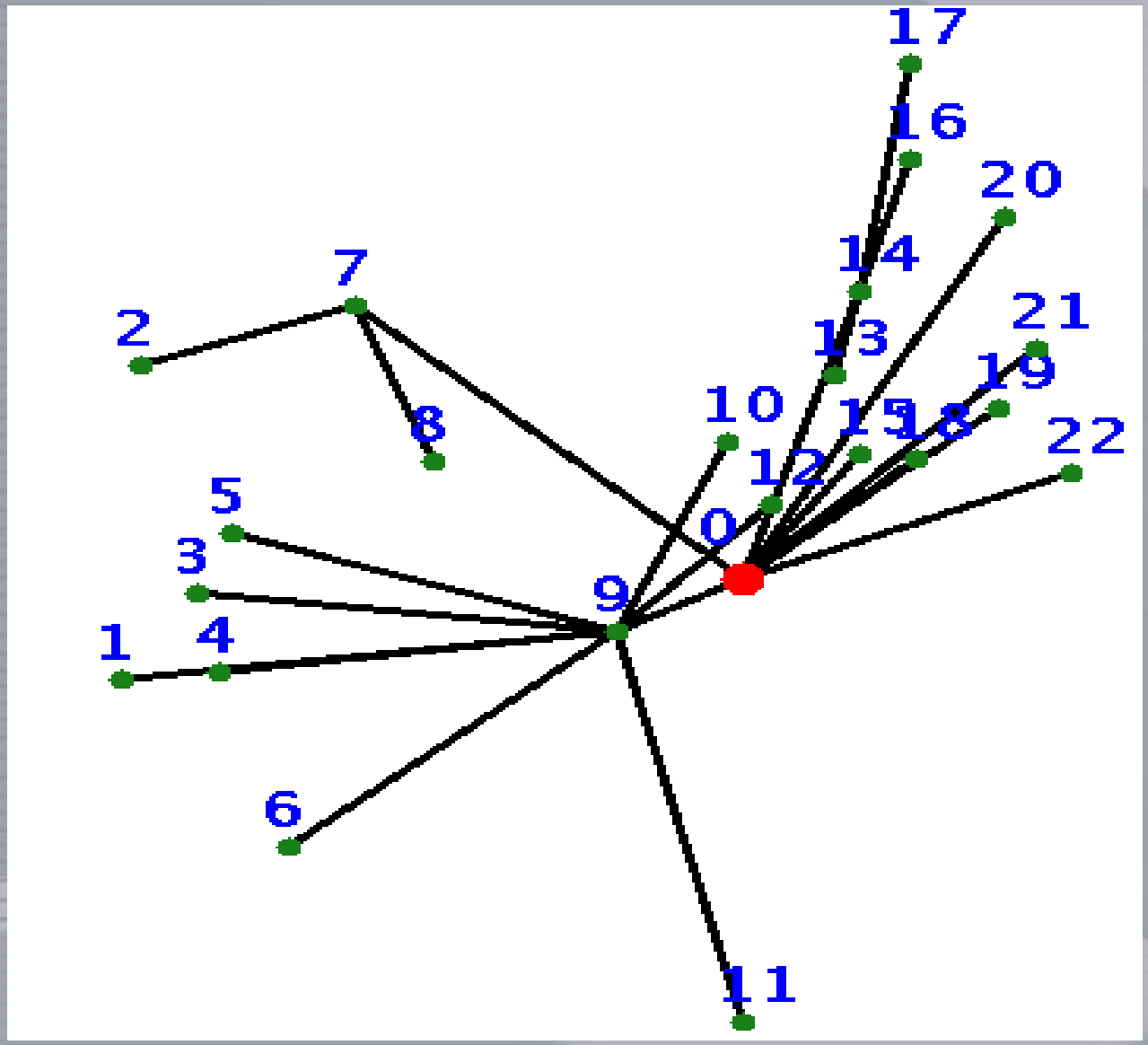
Evaluation: Random Topologies



Evaluation: Random Topologies



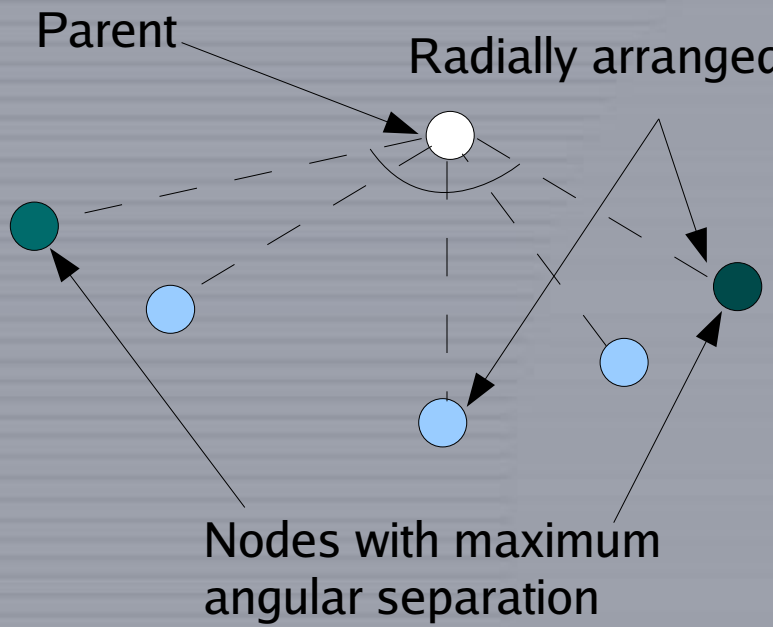
Evaluation: Random Topologies



Conclusions

- Topology construction an important problem
- Unique problem thus far
- Challenging to formulate
- Our contributions:
  - Problem formulation
  - Overall approach
  - First-cut solution
- Lots of scope for further in-depth work

INPUT:



Antenna Assignment