Long Distance Wireless Mesh Network Planning: Problem Formulation and Solution

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Outline

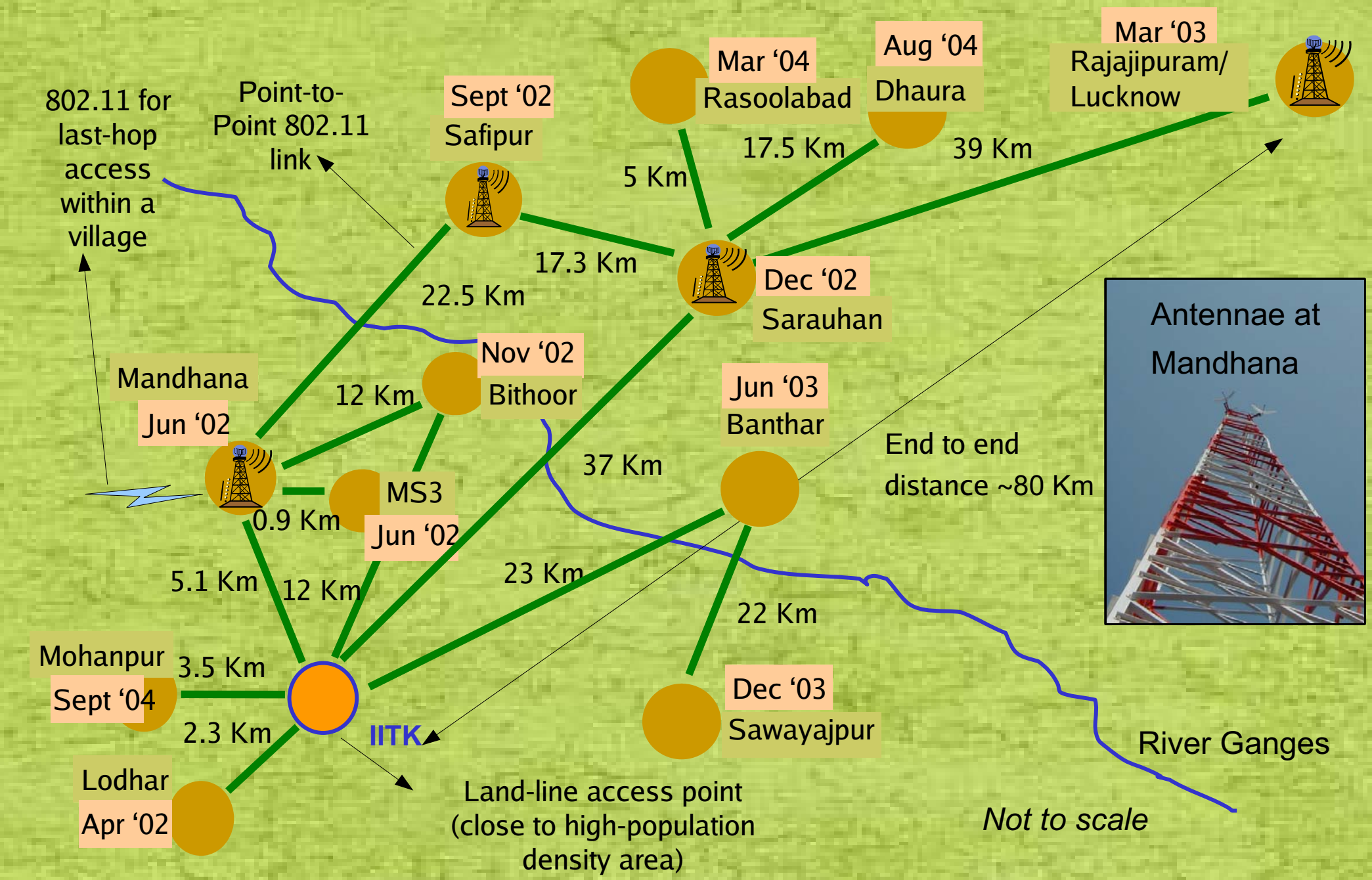
- Motivation & Background
- Problem statement, Uniqueness
- Solution Preliminaries
  - Definitions, dependences
- Solution approach
  - Overview
  - Brief Details
- Evaluation
- Conclusions

802.11 to Bridge the Digital Divide

- Benefits:
  - Existence of low cost equipments.
  - Free Spectrum

- Example Deployments:
  - Akshaya, Kerala, India
  - Digital Gangetic Plains, Uttar Pradesh, India
  - Djursland.net, Denmark
  - Nepal Wireless

Digital Gangetic Plains: Testbed



The Ashwini Project

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

A WiFi Network in Djurslands, Denmark

www.DjurslandS.net

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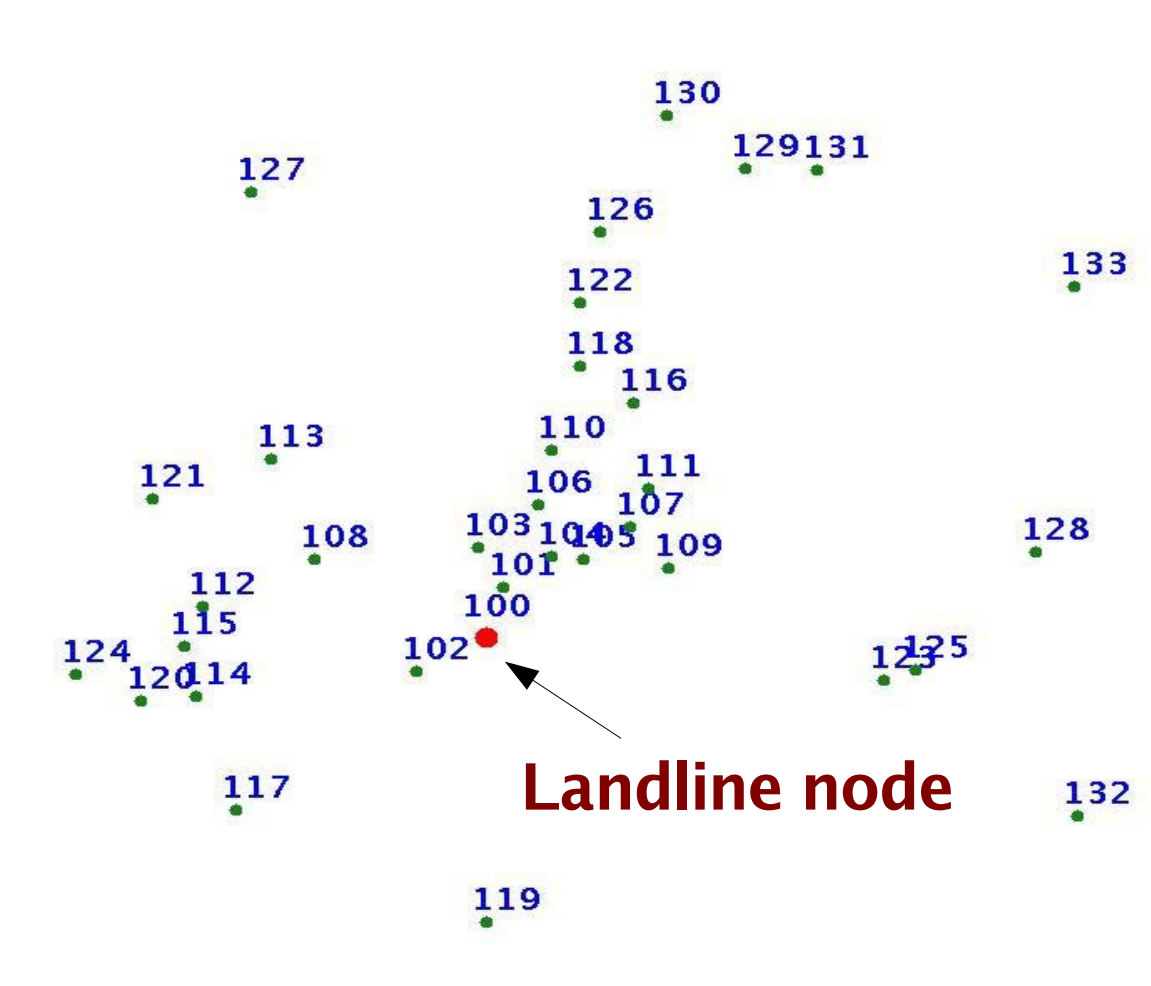
Problem Statement Motivation

- Problem:
  - India has order of 600,000 villages.
  - India has order of 600 districts.
  - Africa has order of 100,000 sparse settlements.
  - Long Distance WiFi network deployments envisaged
  - No automated method exists to plan such networks.
  - Current methods highly cost inefficient and ad-hoc.

Problem Statement

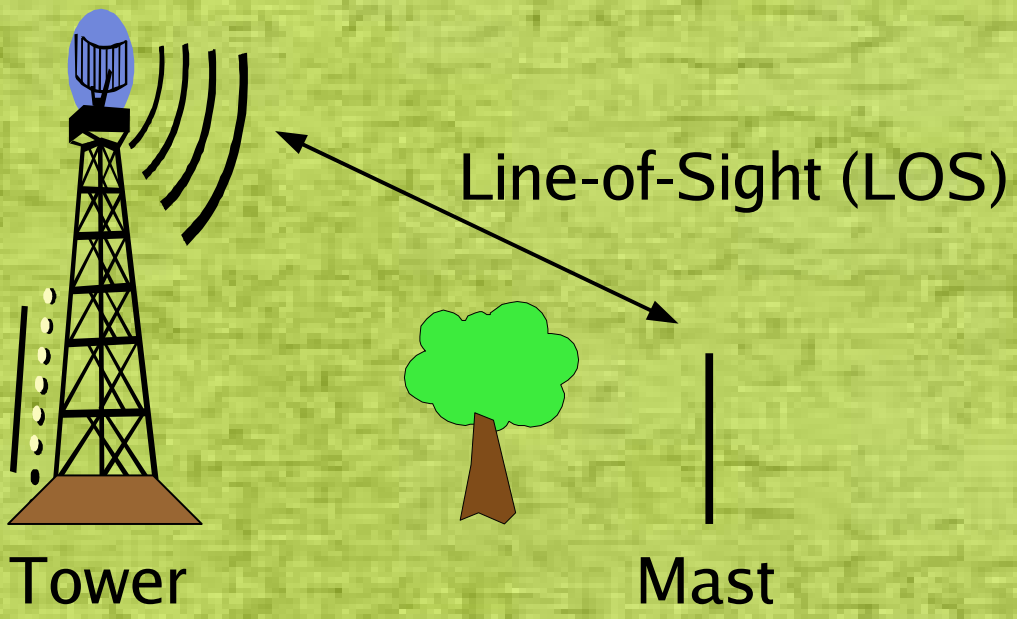


- Given: a set of village nodes, a single landline node
- Requirement: connect all villages to the landline in a network

- 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 (around 80% of total costs)



Tower/mast height (m)	Cost (x1000 Rs.)	Cost (U.S $)
10	4	90
15	6	140
21	36	850
24	41	980
27	48	1200
30	82	1950
45	220	5240

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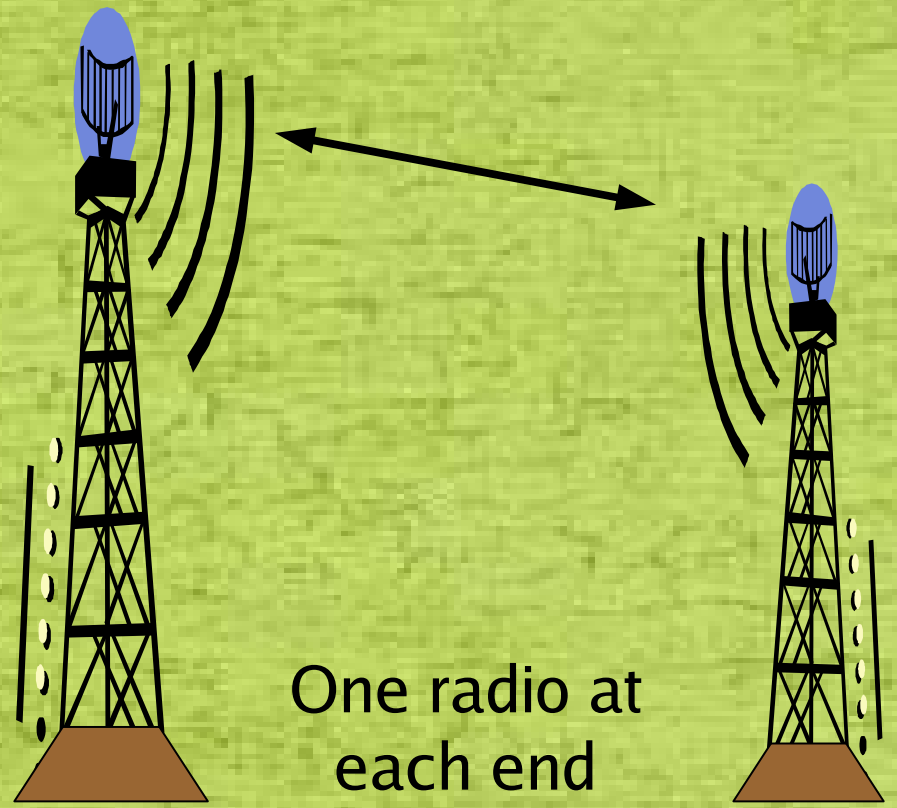
Preliminaries

- Assumptions:
  - Antenna towers to be placed only at villages
  - Tree topology
  - 2P MAC [1] to be deployed
    - Other MACs: Minor modifications
- Application requirement:
  - Throughput requirement specified per village
    - E.g. 384Kbps/ village (for video)
- Definitions...
- Dependences...

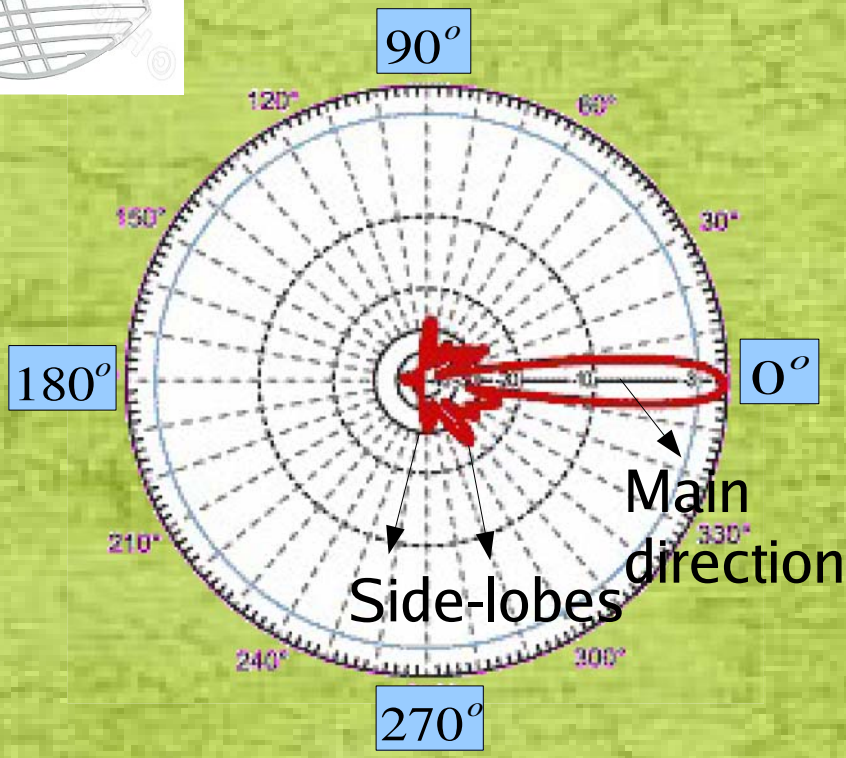
Definition: Point-to-Point Link



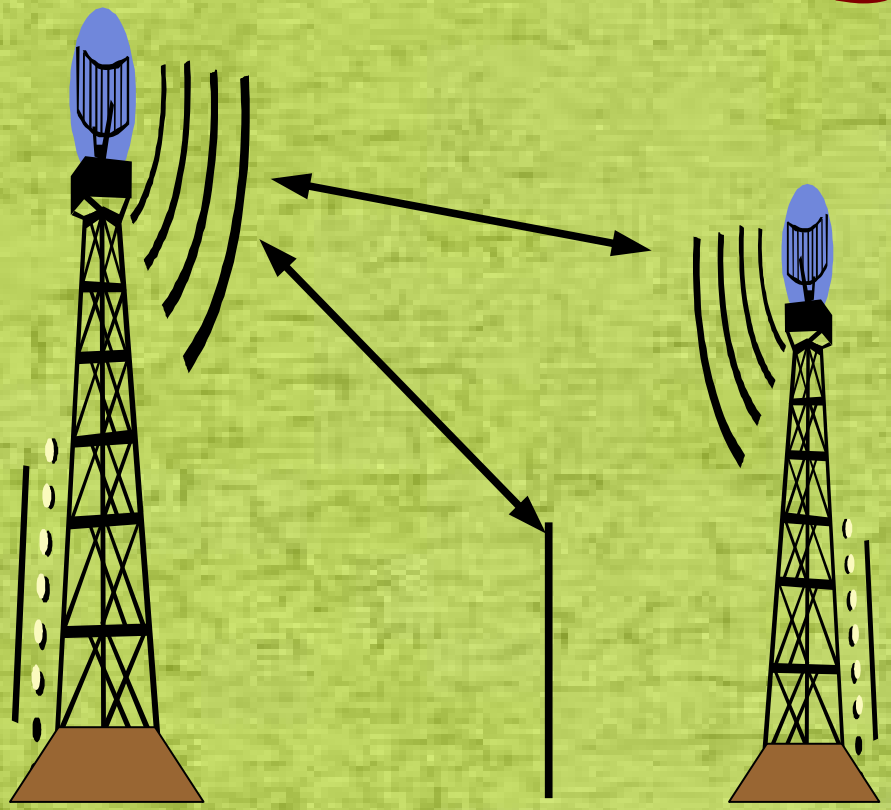
One radio at each end

Parabolic Grid Antenna

Antenna Radiation Pattern

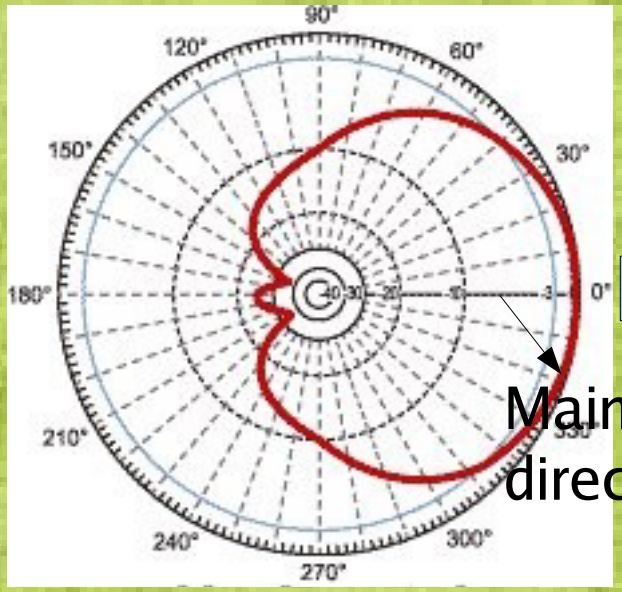


Definition: Point-to-MultiPoint Link Set



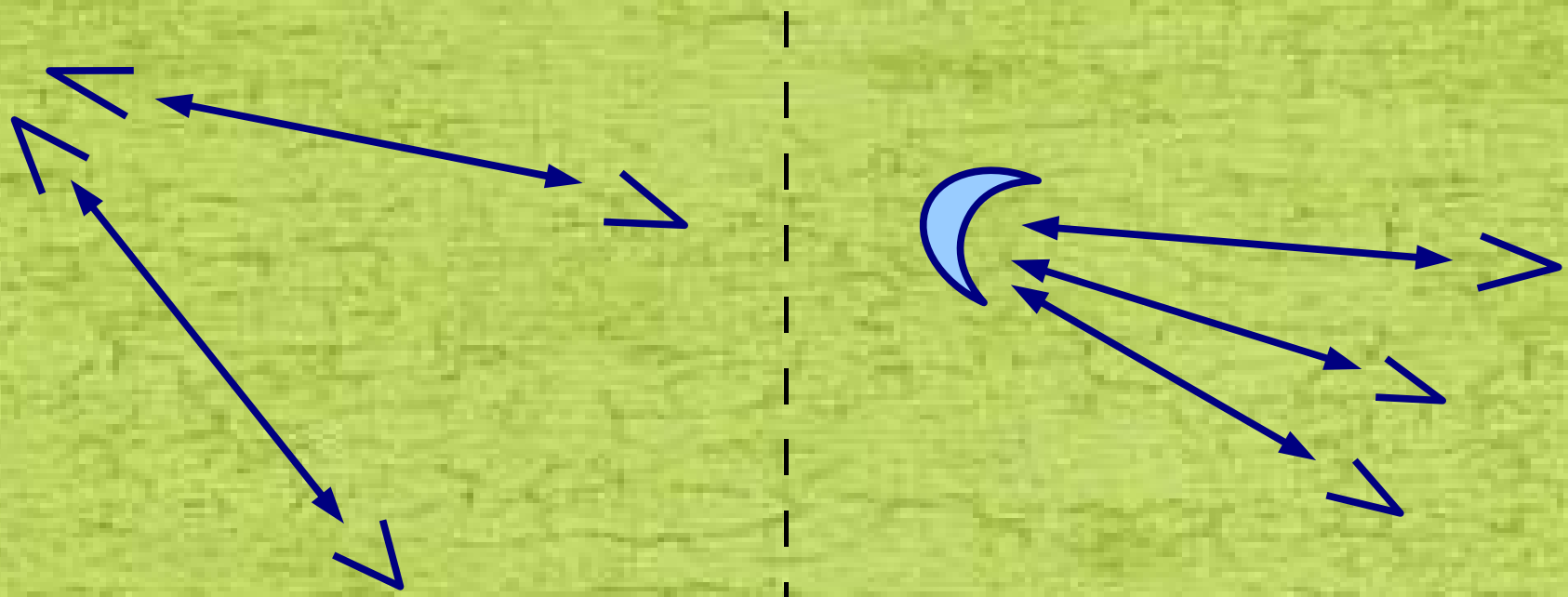
Sector Antenna

Antenna Radiation Pattern



Single radio for both links

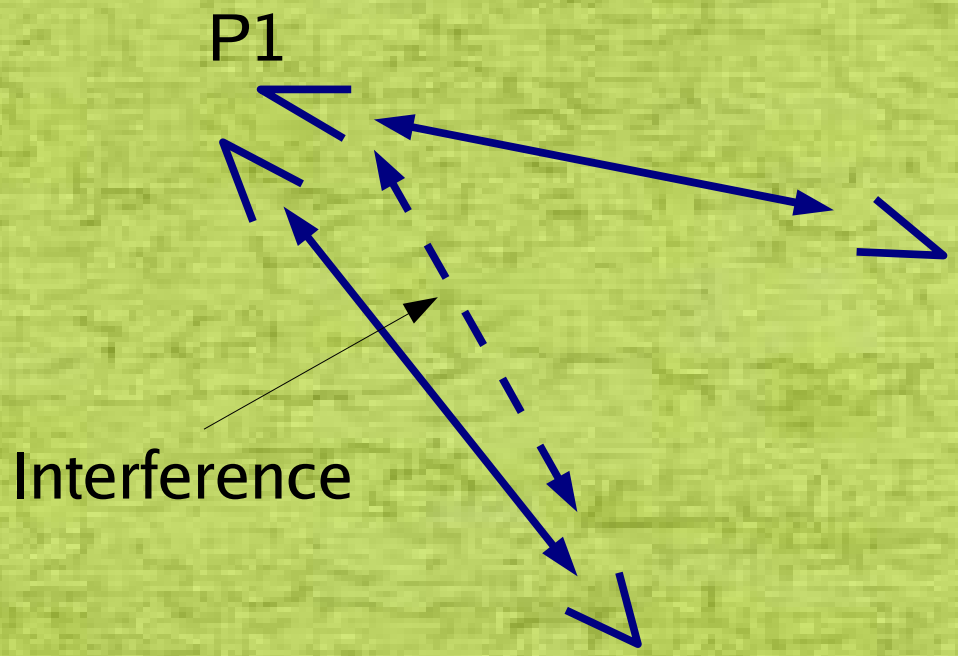
Notation: Top View



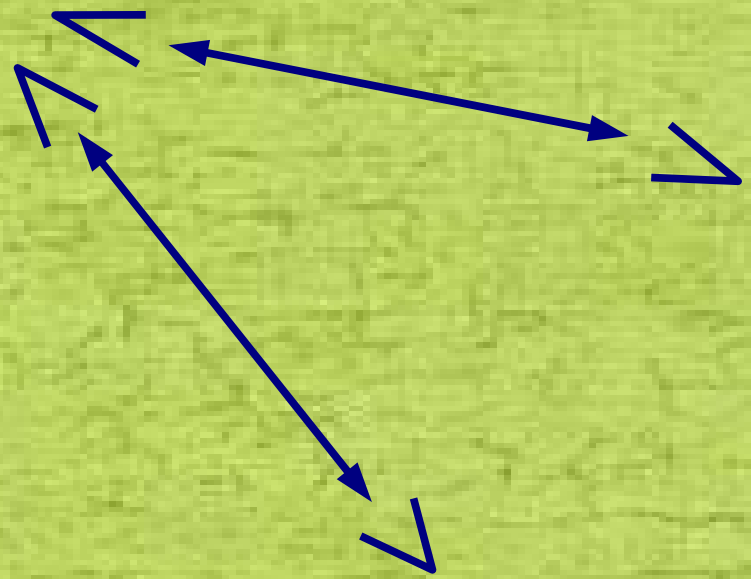
Point-to-Point (P2P) links

Point-to-MultiPoint (P2MP) link

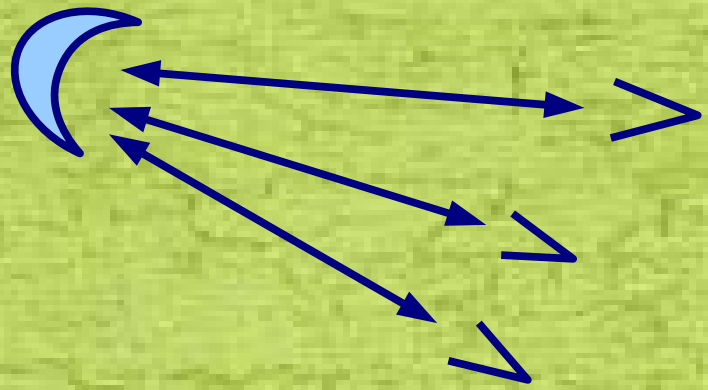
Definitions: Transmit Power & Interference



Dependence: Throughput depends on Link/Antenna Type

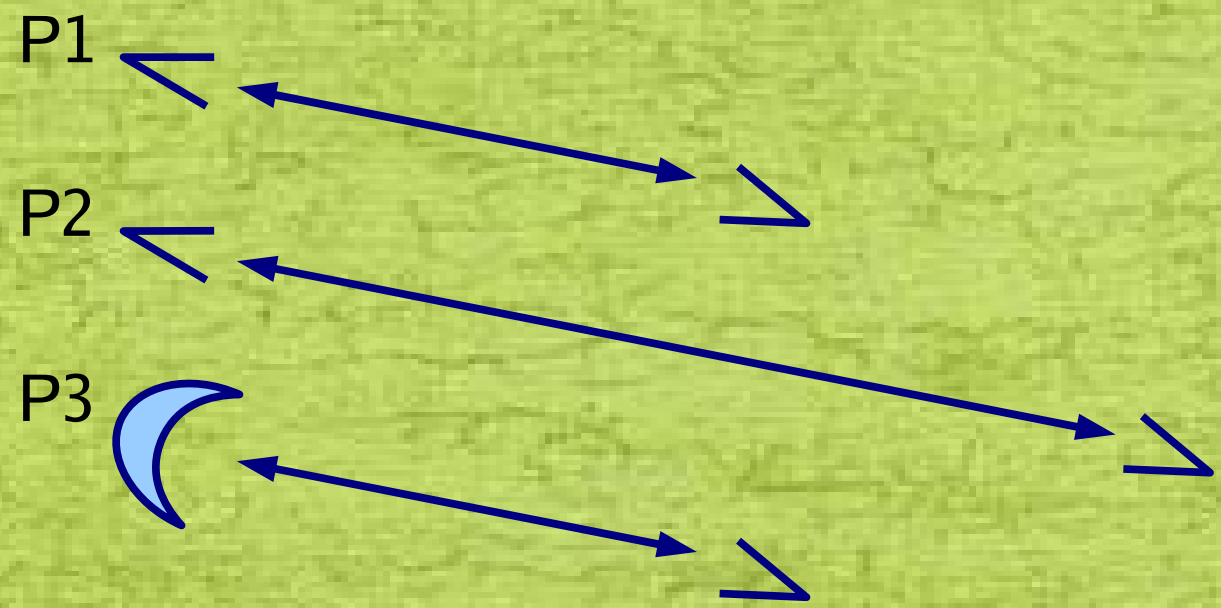


Point-to-Point (P2P) links



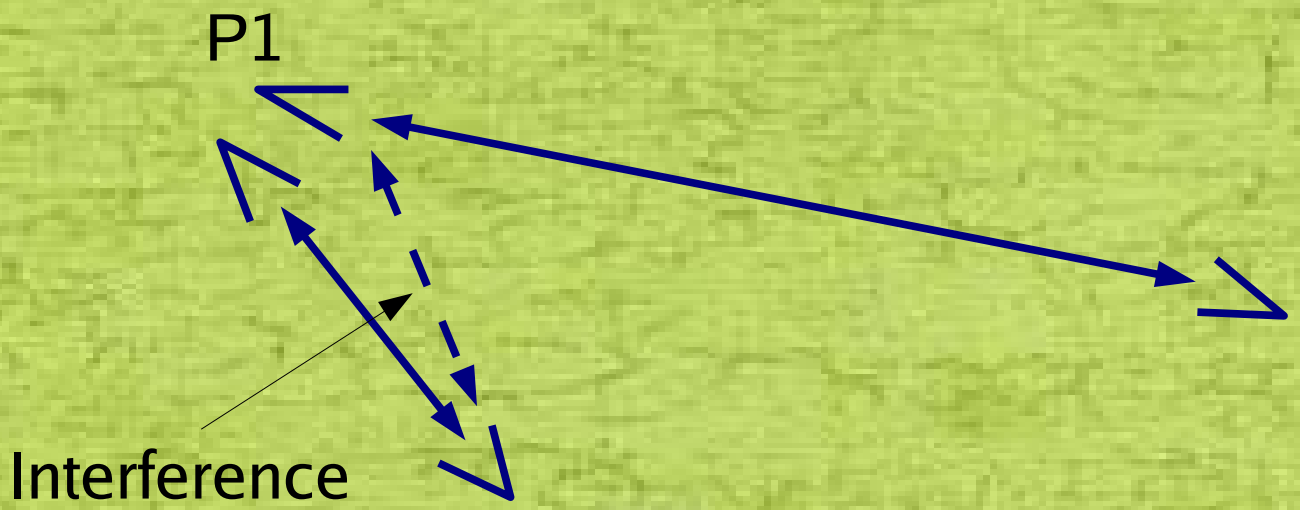
Point-to-MultiPoint (P2MP) link

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



P2 > P1 & P3 > P1

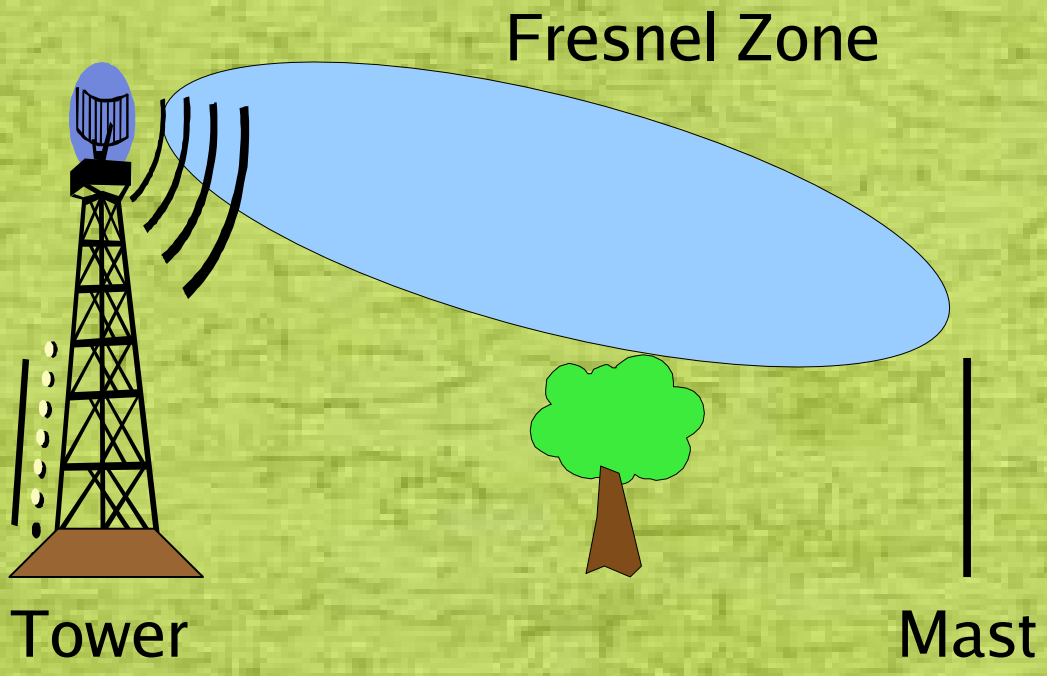
Dependence: MAC (feasibility) depends on the Transmit Powers



Signal to Interference Ratio should be above threshold

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

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



Dependence: Cost depends on Tower Height

Tower/mast height (m)	Cost (x1000 Rs.)	Cost (U.S $)
10	4	90
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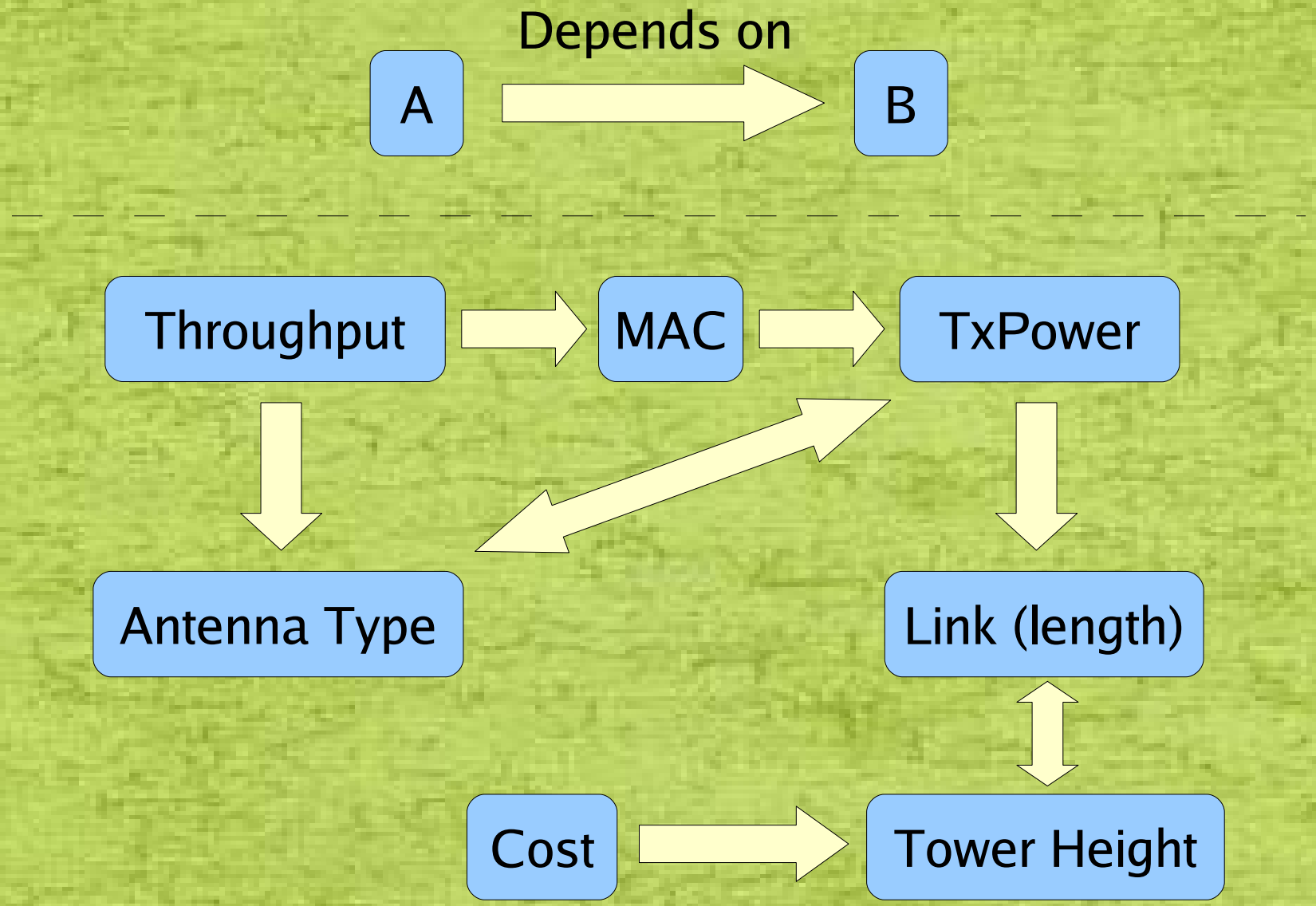
MASTS

- Cost takes quantum jumps due to change in underlying tower design
  - Super-linear function of height
  - Masts are extremely cheap

Dependences: Summary



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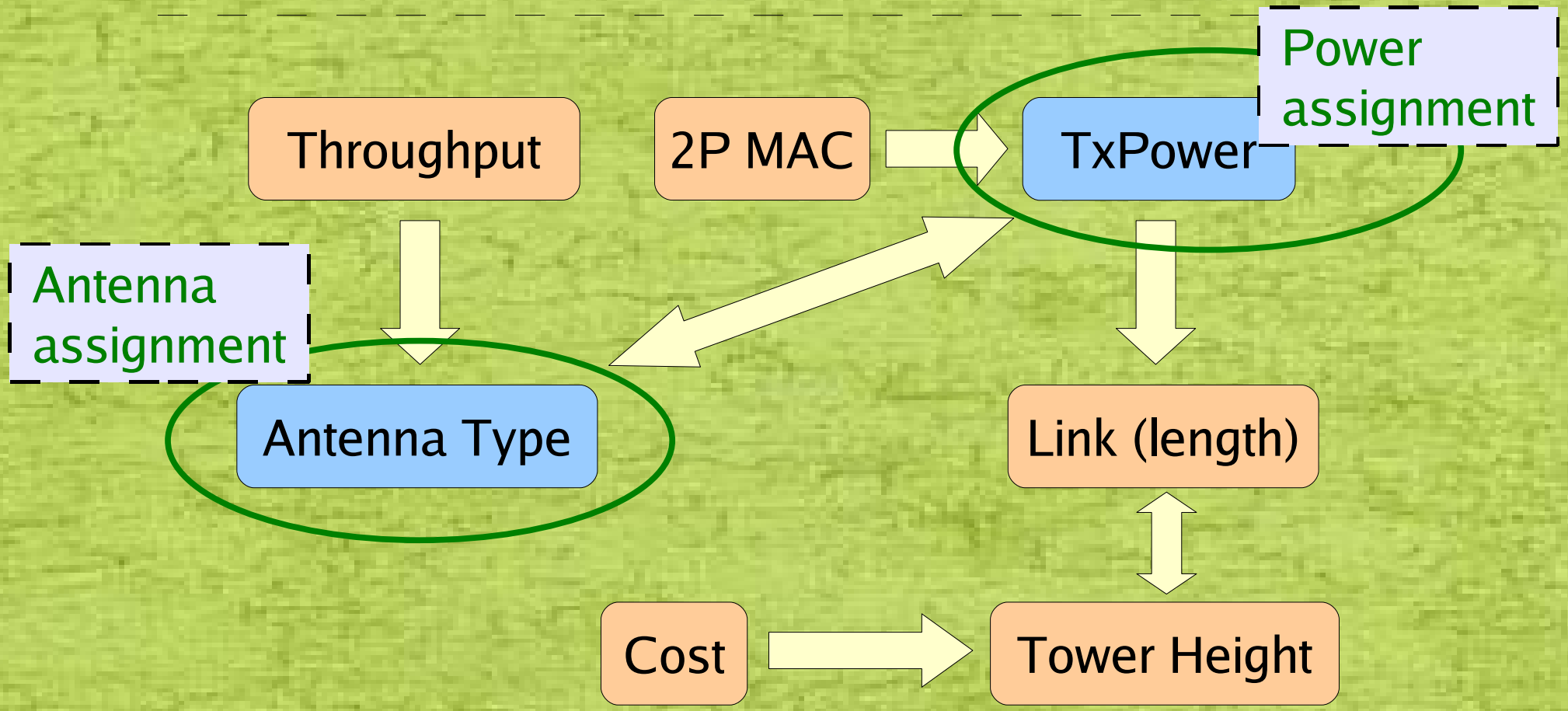
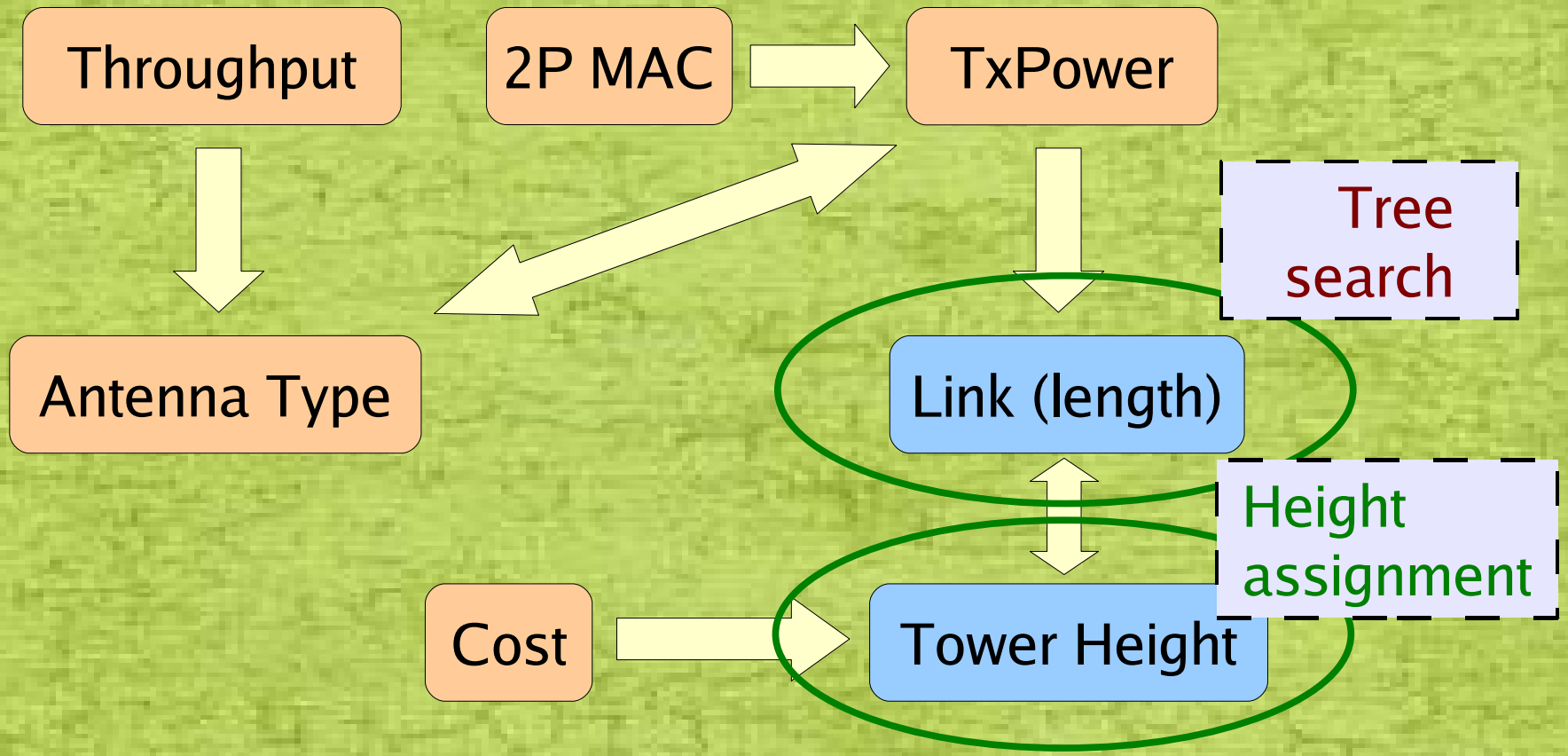
Dependence Resolution

- Antenna assignment to be done before TxPower
  - LP formulation of power assignment possible



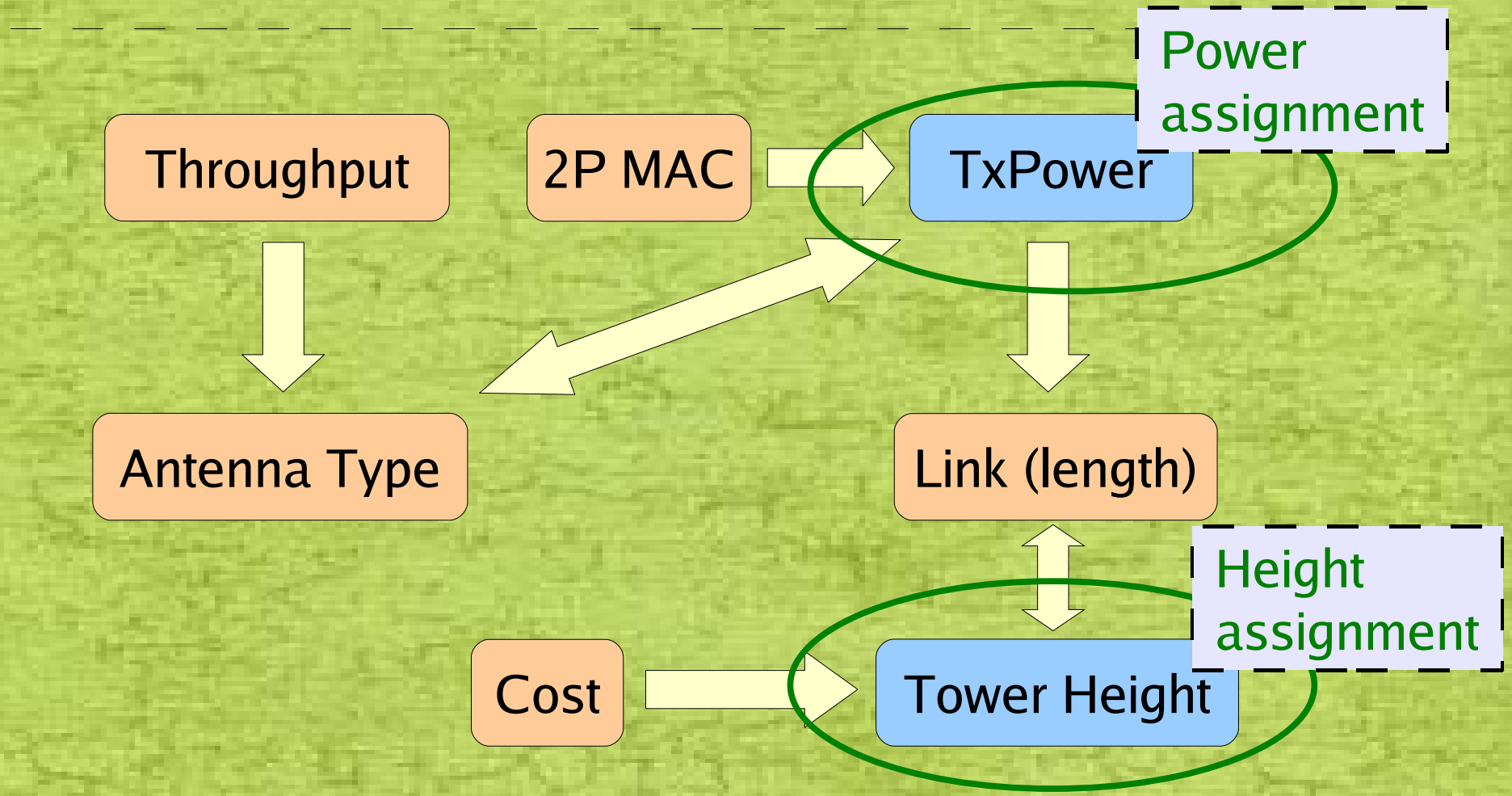
Solution Approach (continued)

- Spanning tree to be formed before assigning heights
  - LP formulation of height assignment if possible

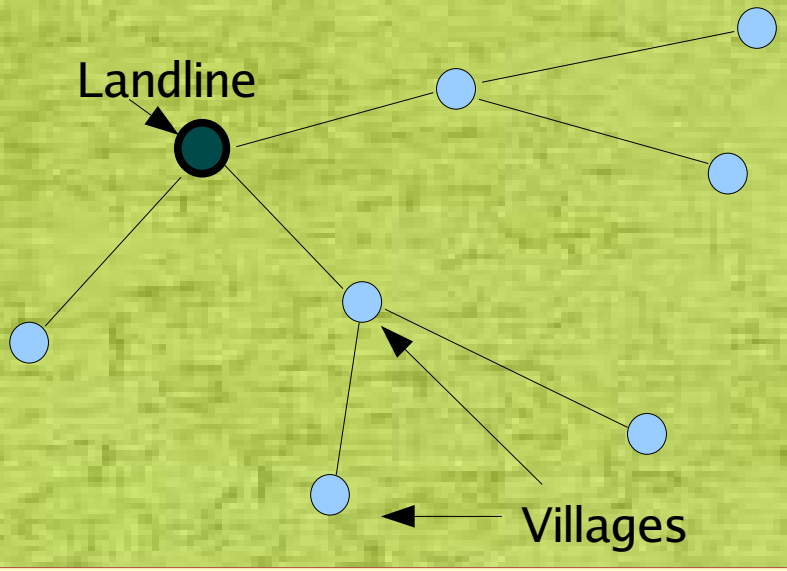


Solution Approach (continued)

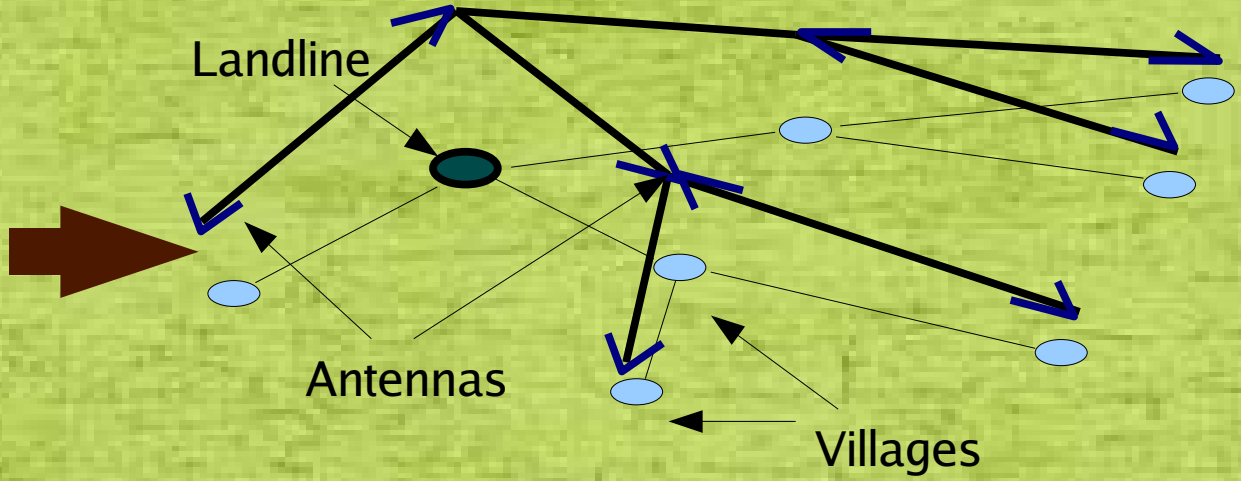
- Power Assignment & Height Assignment
  - mutually independent



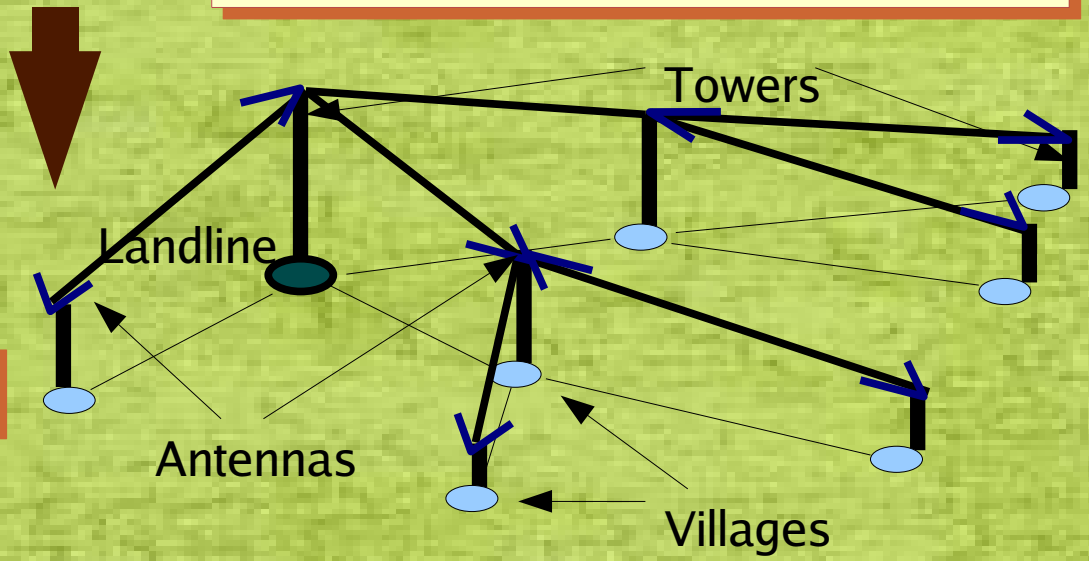
Solution Methodology



STEP 1: Tree Enumeration



STEP 2: Antenna + Power Assignment



STEP 3: Tower Height Assignment

Contributions

- For Tree enumeration:
  - Branch-and-Bound based algorithm with domain knowledge based pruning strategies.
- For Height Assignment:
  - Linear Programming (LP) formulation.
- For Antenna + Power Assignment:
  - Heuristic Algorithm for antenna assignment.
  - LP formulation for power assignment based on results from previous work [2].

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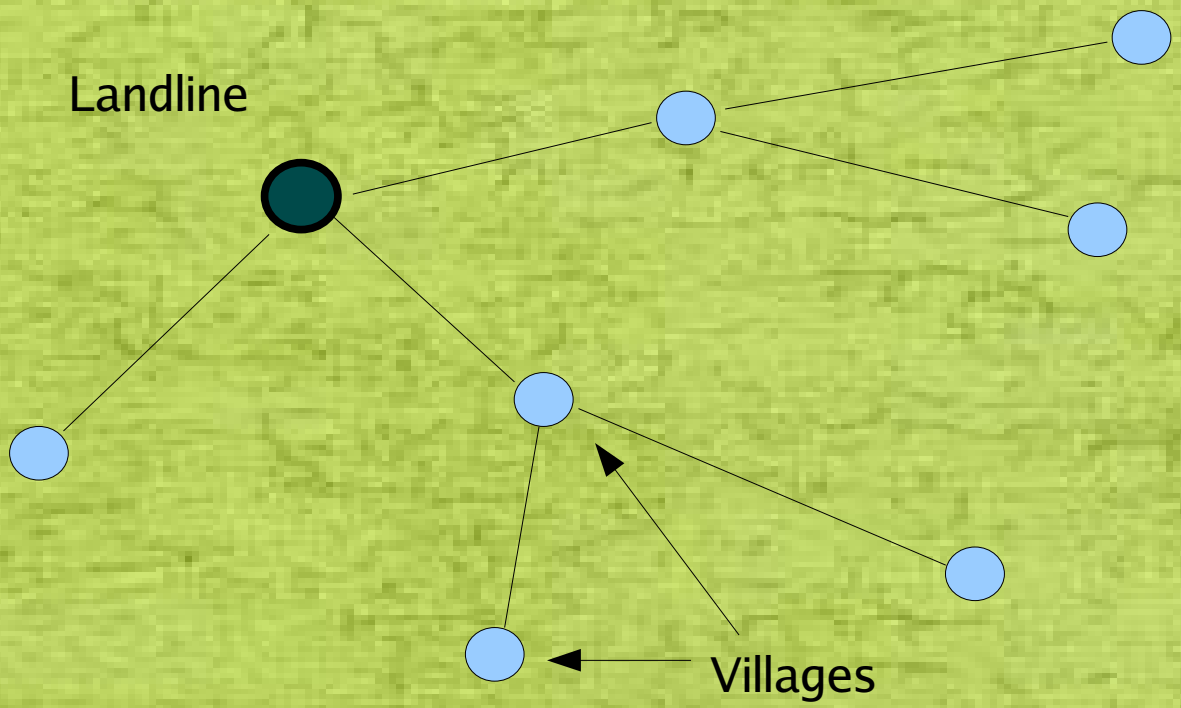
- Solution approach
  - Tree Search and Height Assignment
- Evaluation
- Conclusions

Optimized Tree Enumeration

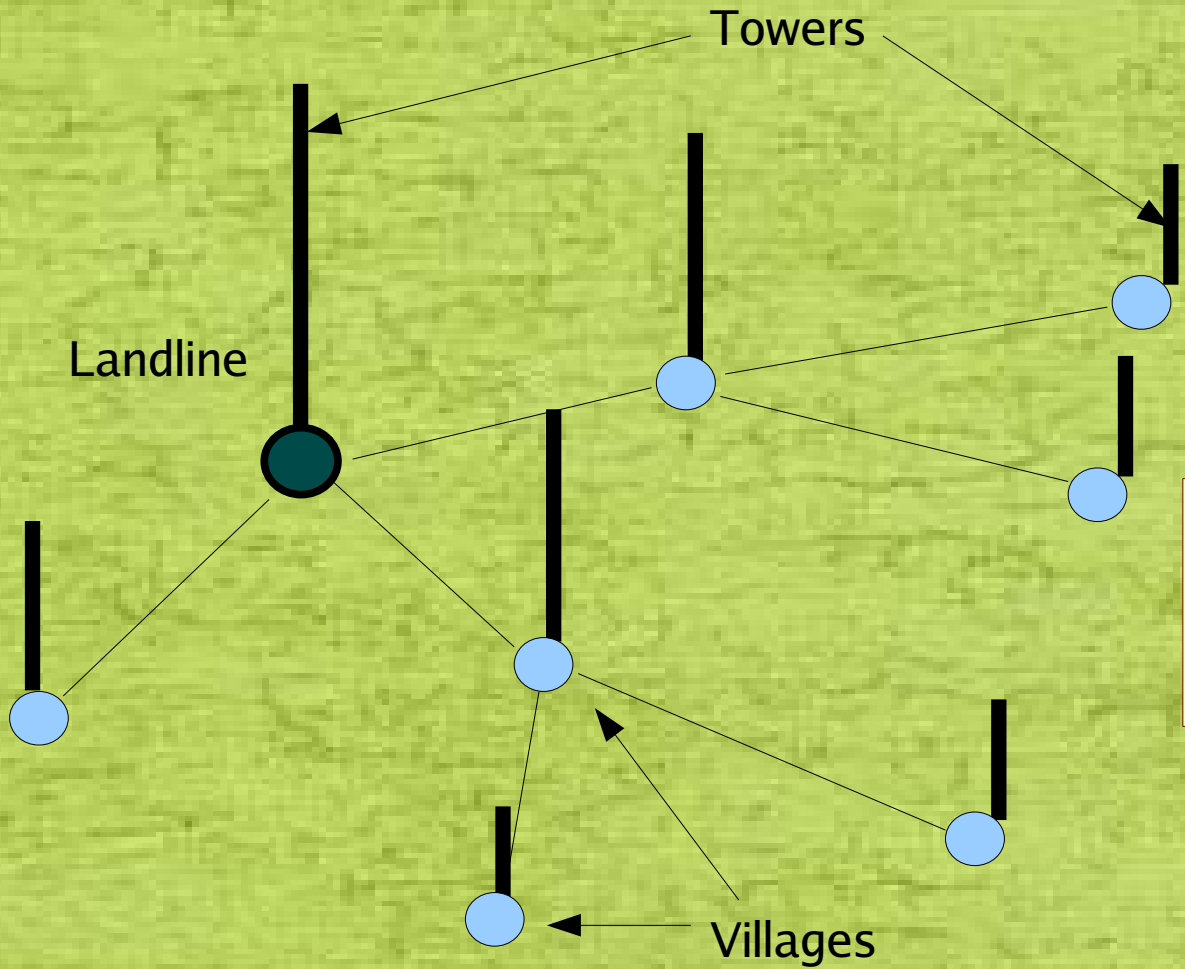
- Domain-knowledge based optimizations
  - Eliminate "long" links to begin with: > 15 km (say)
    - Trade-off between run time and search space
  - Tree depth restriction: 2 hop topologies only
    - Accommodates significant # practical scenarios
  - Dynamic cost bounding: throw out "costly" subtrees
    - Cyclic dependence on height assignment (to be explained).

Height Assignment: Problem Statement

- Given: a topology (parent-child relationships)



Height Assignment: Problem Statement

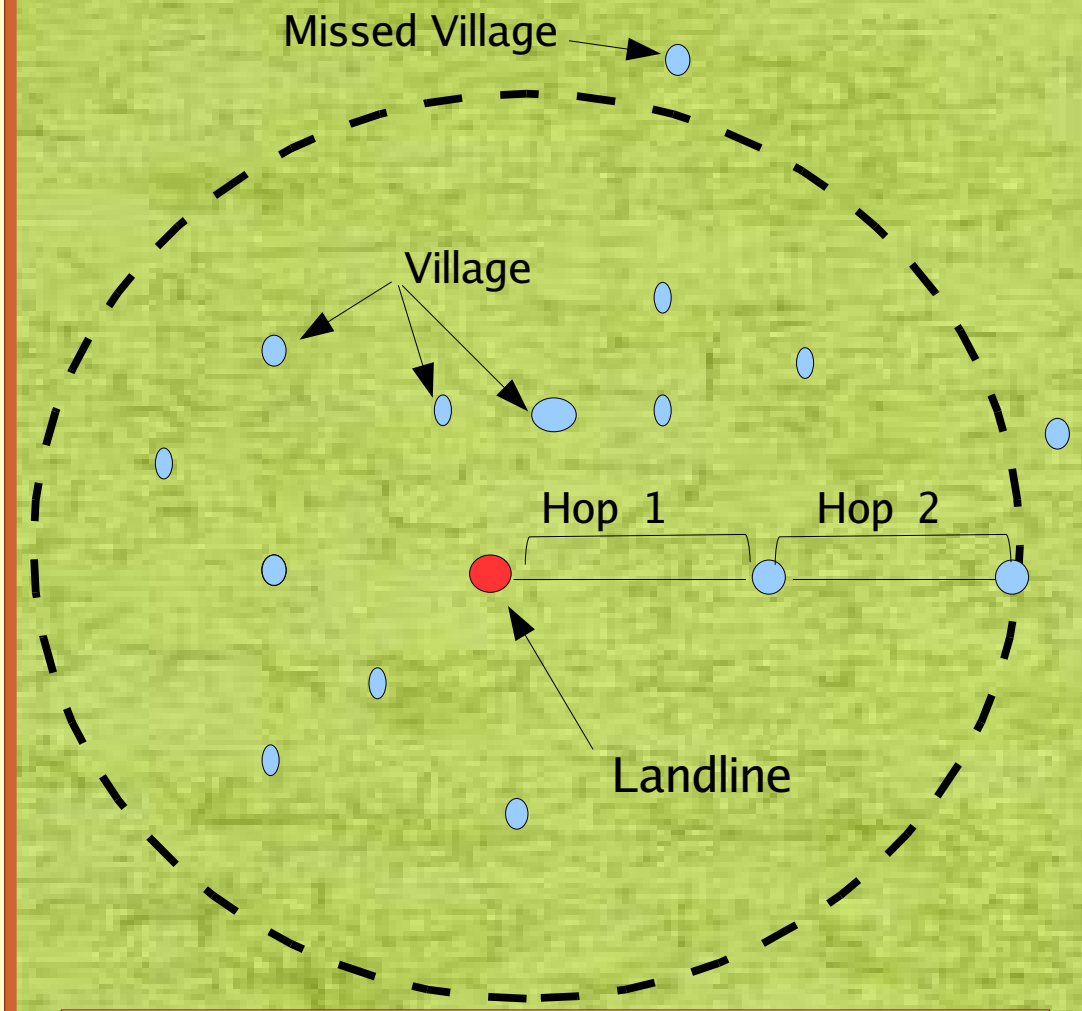


- Given: a topology (parent-child relationships)

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

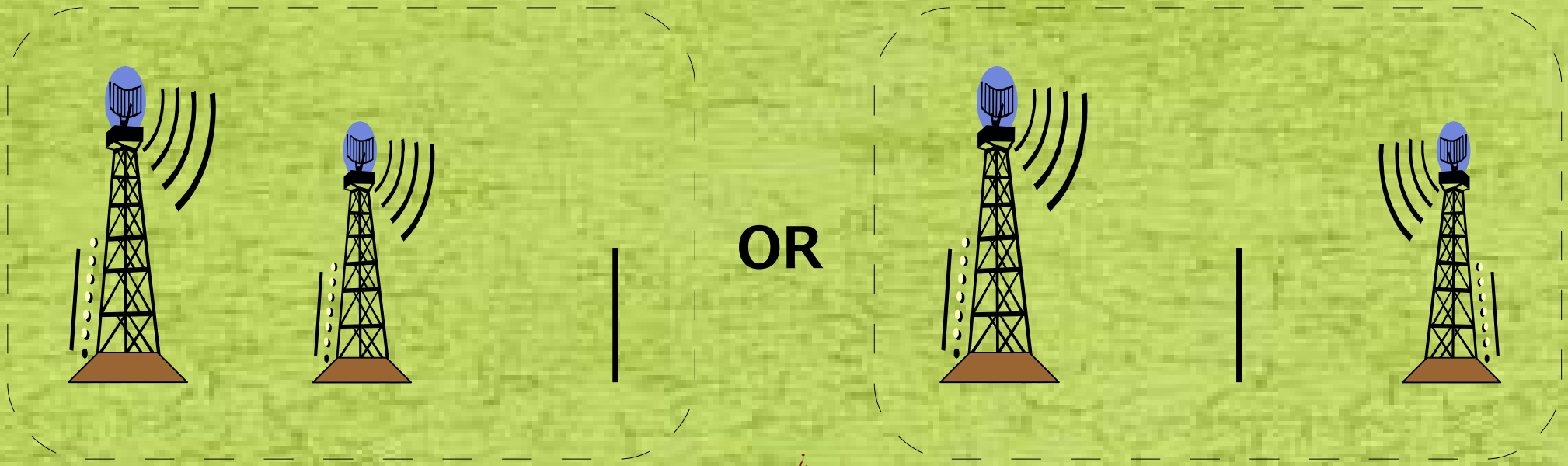
Height Assignment: Insights

- Insight 1: 2-hop topology only
  - Trade off between Runtime and Search Space
  - In India 85% of the villages are within 20 Km radius of a fiber Point-of-Presence (PoP) [3].
  - One hop ~ 10km ==> 20km radius ==> 40km dia
- Insight 2: Tower at central location say 50m
  - Common in a town with tall buildings



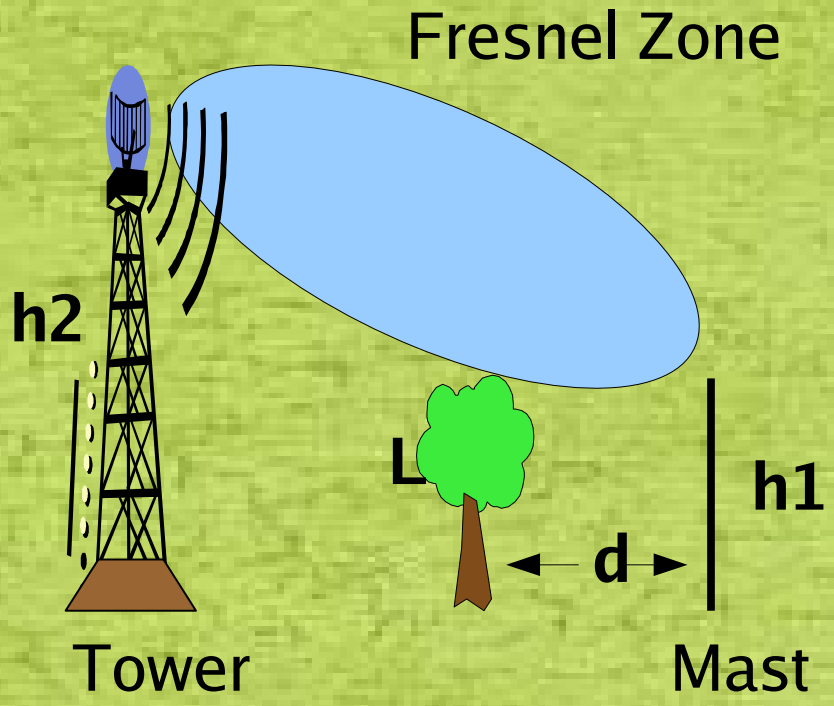
- Insight 3: link between two masts infeasible
  - Obstructions (trees etc.)

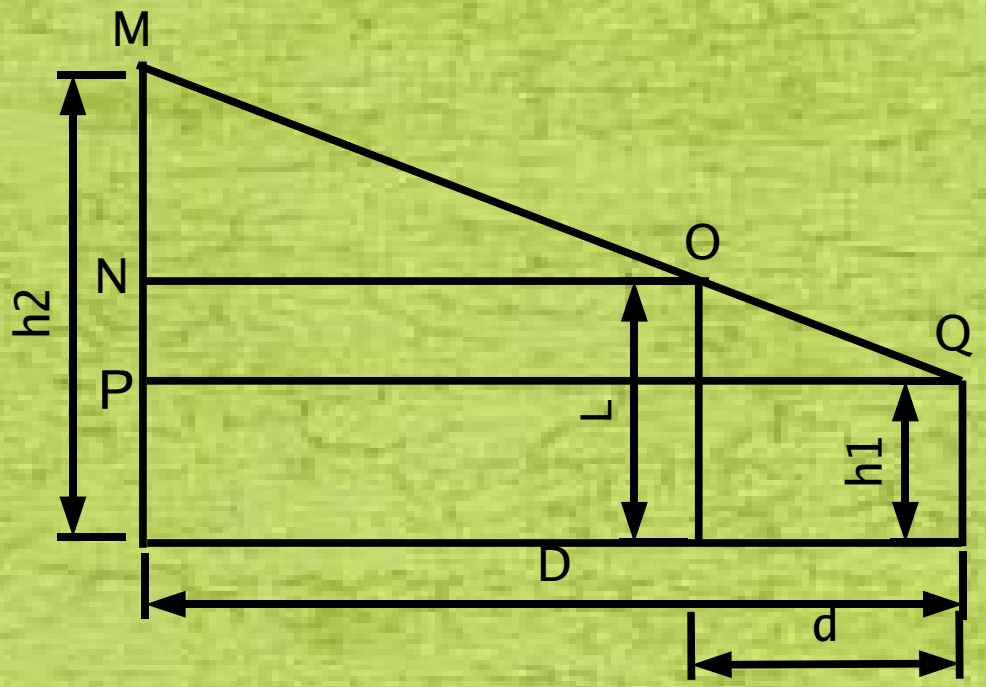
Tower at Level-2 or Level-3 ?



- 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

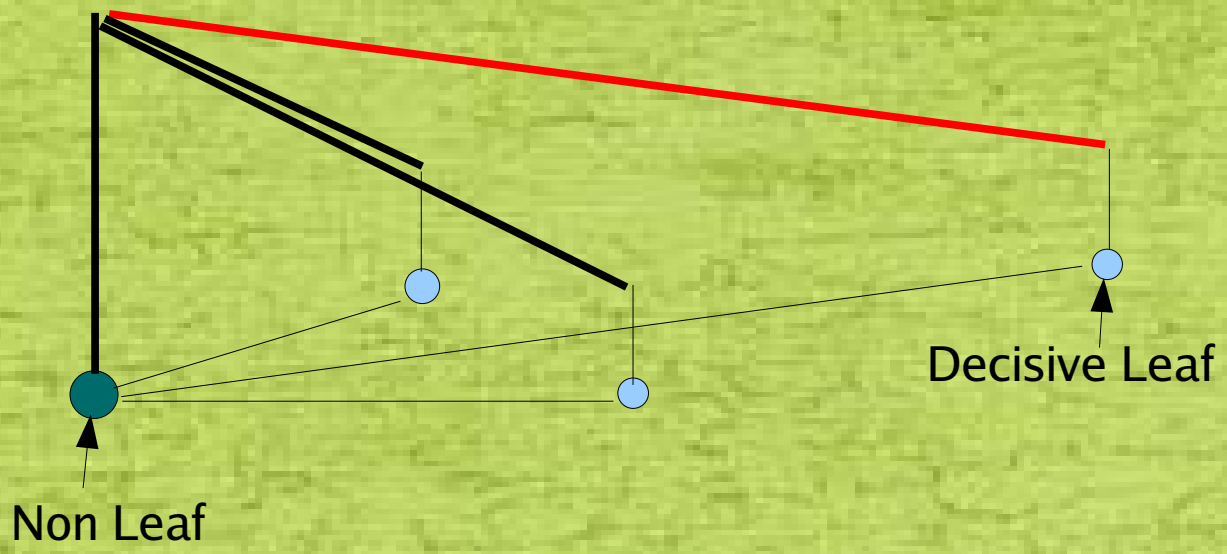
The LP Formulation





- Linear equations for obstruction clearance
- Linear cost optimization function (forced)
  - Use tower cost coefficient for level-2 and mast cost coefficient for level-3.

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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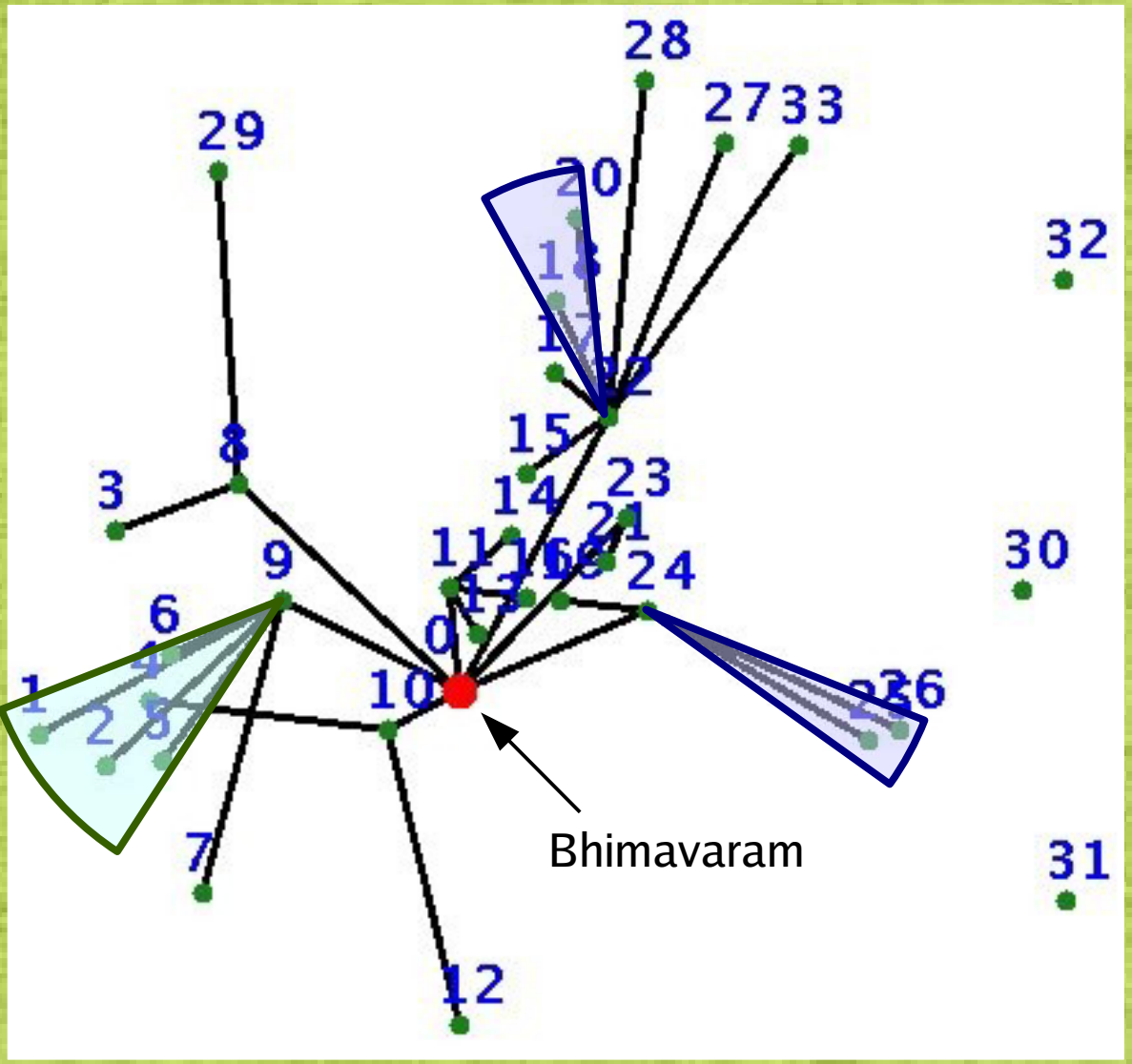
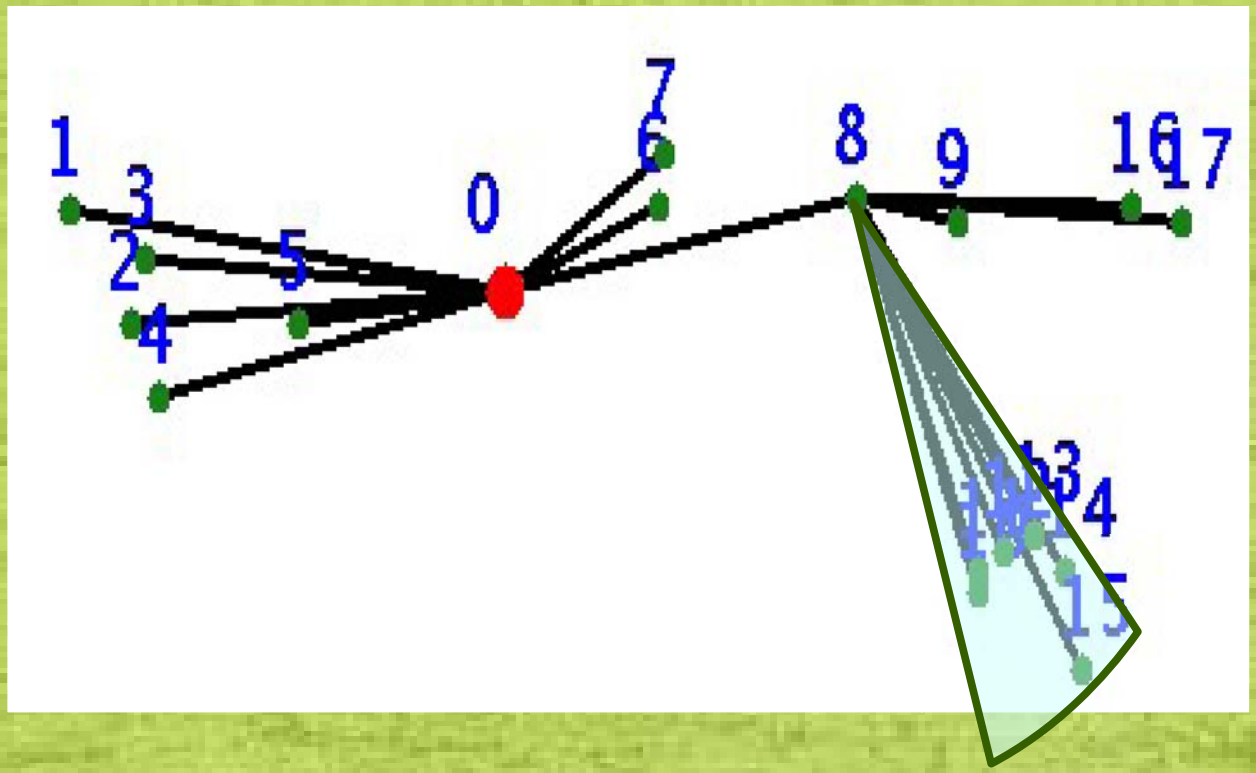
Evaluation: Bhimavaram topology



- 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.

Evaluation: Amalapuram topology



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

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
  - Details in the paper

Bibliography

- [1] Design and Evaluation of a new MAC Protocol for Long-Distance 802.11 Mesh Networks, B. Raman, K. Chebrolu, MOBICOM'05

- [2] Long-Distance 802.11b Links: Performance Measurements and Experience, K. Chebrolu, B. Raman, S. Sen, MOBICOM'06

- [3] A. Jhunjhunwala et. al, Role of Wireless technologies in connecting rural India, IJR&SP'05