RuralNet (Digital Gangetic Plains): WiFi-Based Low-Cost Rural Networking

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Keynote Presentation
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University of Philippines

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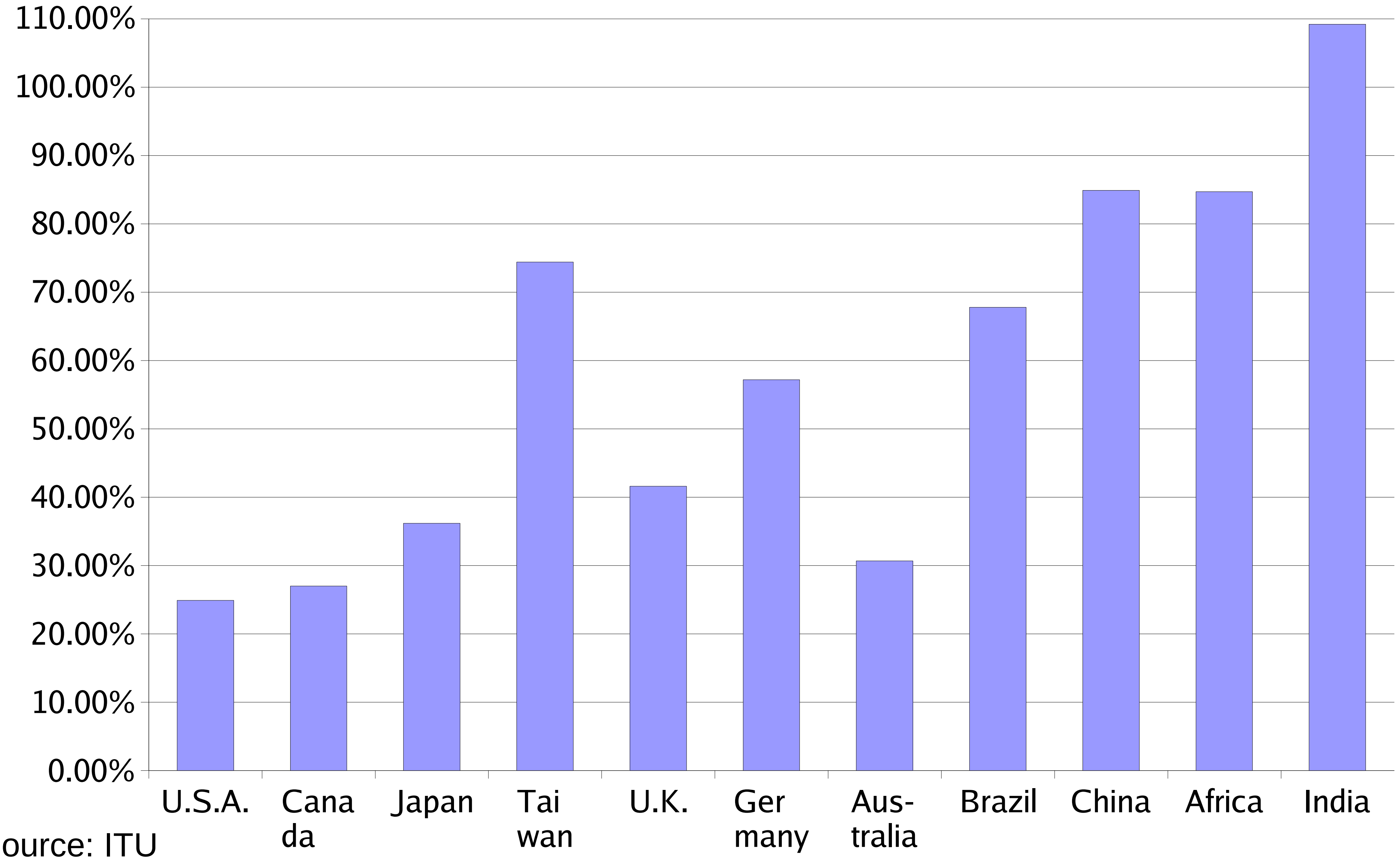
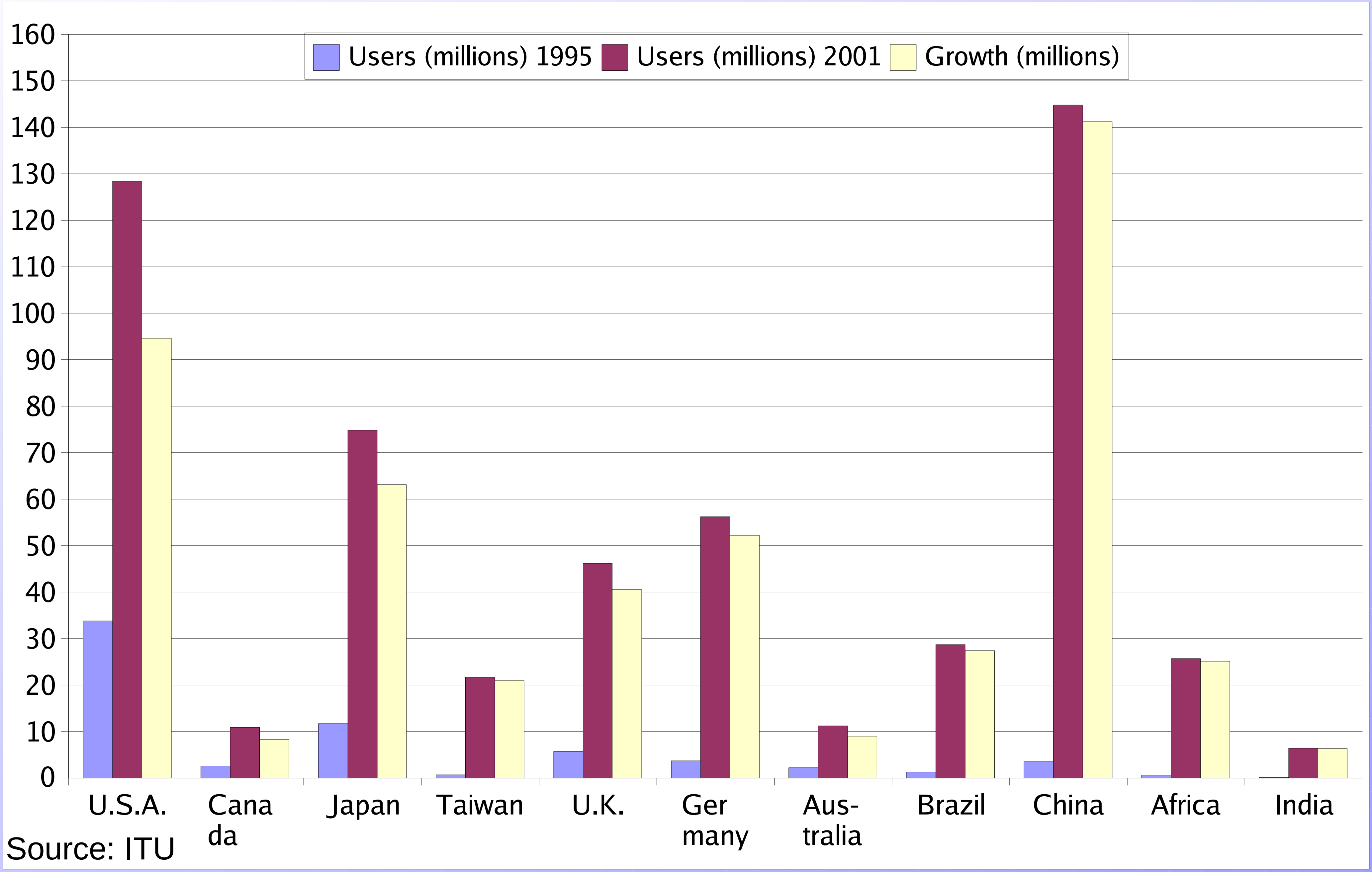
Cell Phones: CAGR 1995-2001

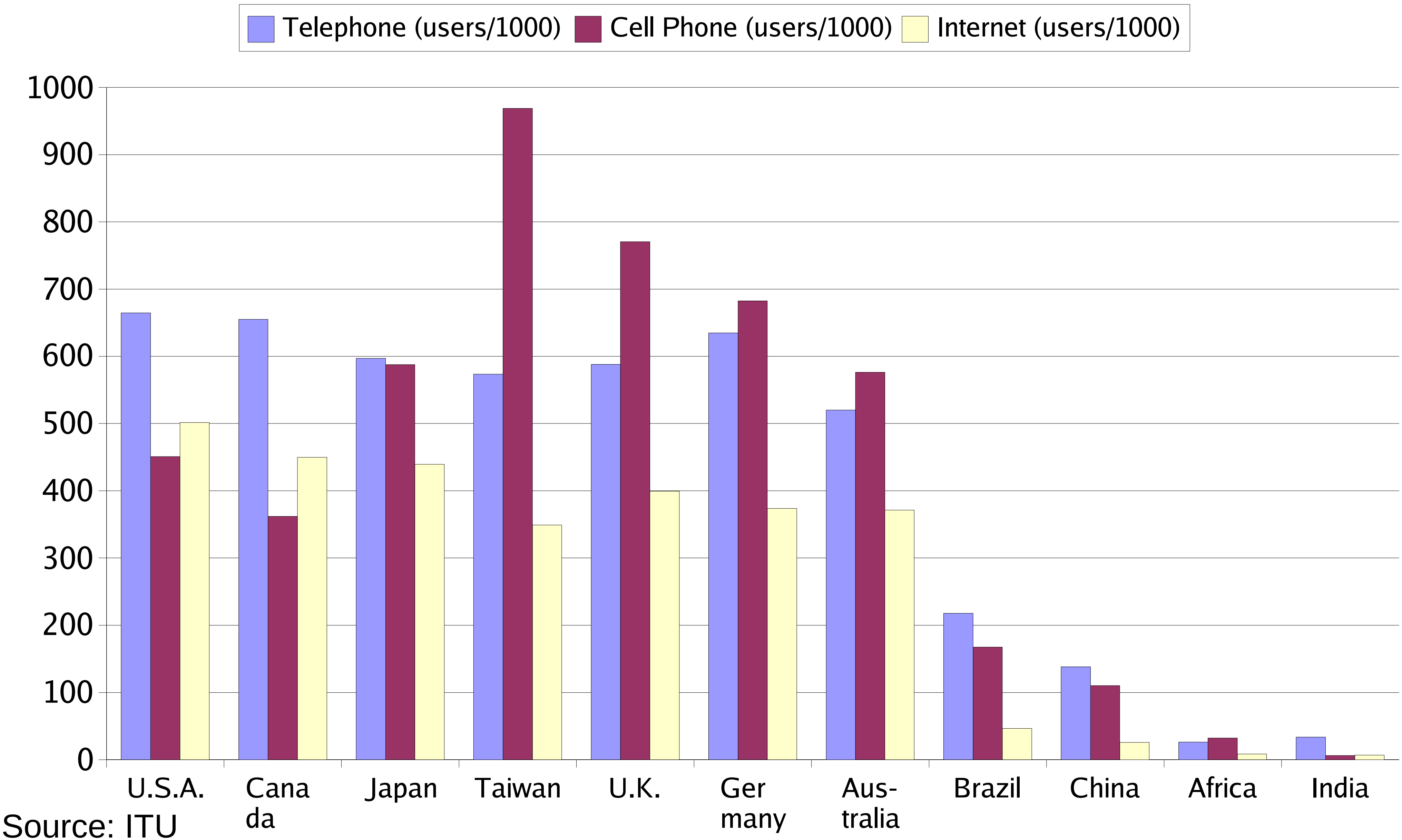


Source: ITU

Cell Phones: Absolute Growth



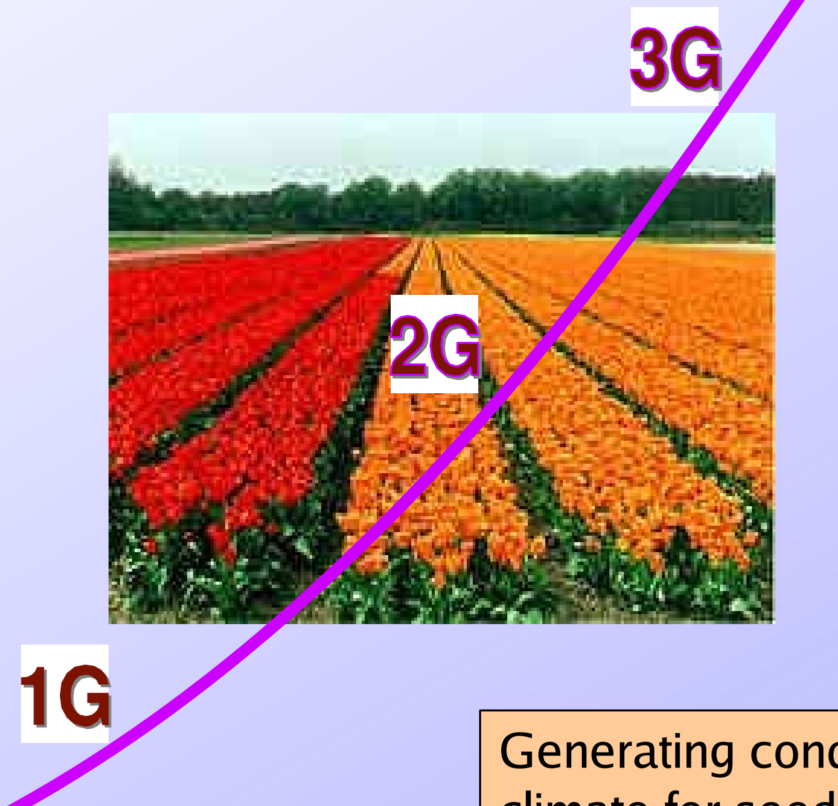
Tele-density (2001)



Source: ITU

Can Tulips grow in Hot Climate?

Mobile Telephony evolution has been shaped by technical innovations and market forces in the west



This business model can thrive when average per capita income is high ($20K)

Wireless systems being deployed in India are successful in Metro pockets, but providing cost effective voice and data services to the masses will remain a challenge for many years to come.

Generating conducive climate for seeds of innovation & entrepreneurship to take root

Achieving necessary cost reduction for mass market penetration

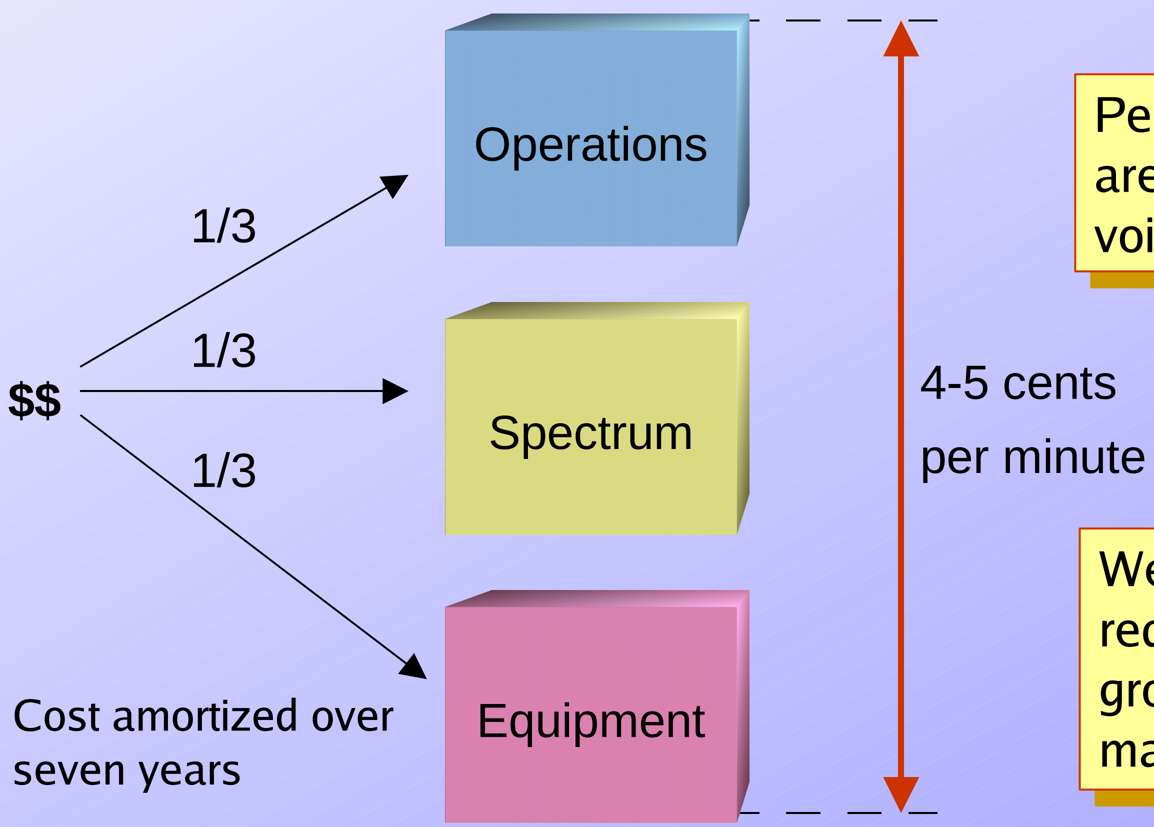
Reaching out to the remaining 83% of the world market

Barriers to Digital Empowerment

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

400 million lines ==> $80 billion

Value Pricing of Cellular Technology



People in developed economies are willing to pay this price because voice is a very high value application

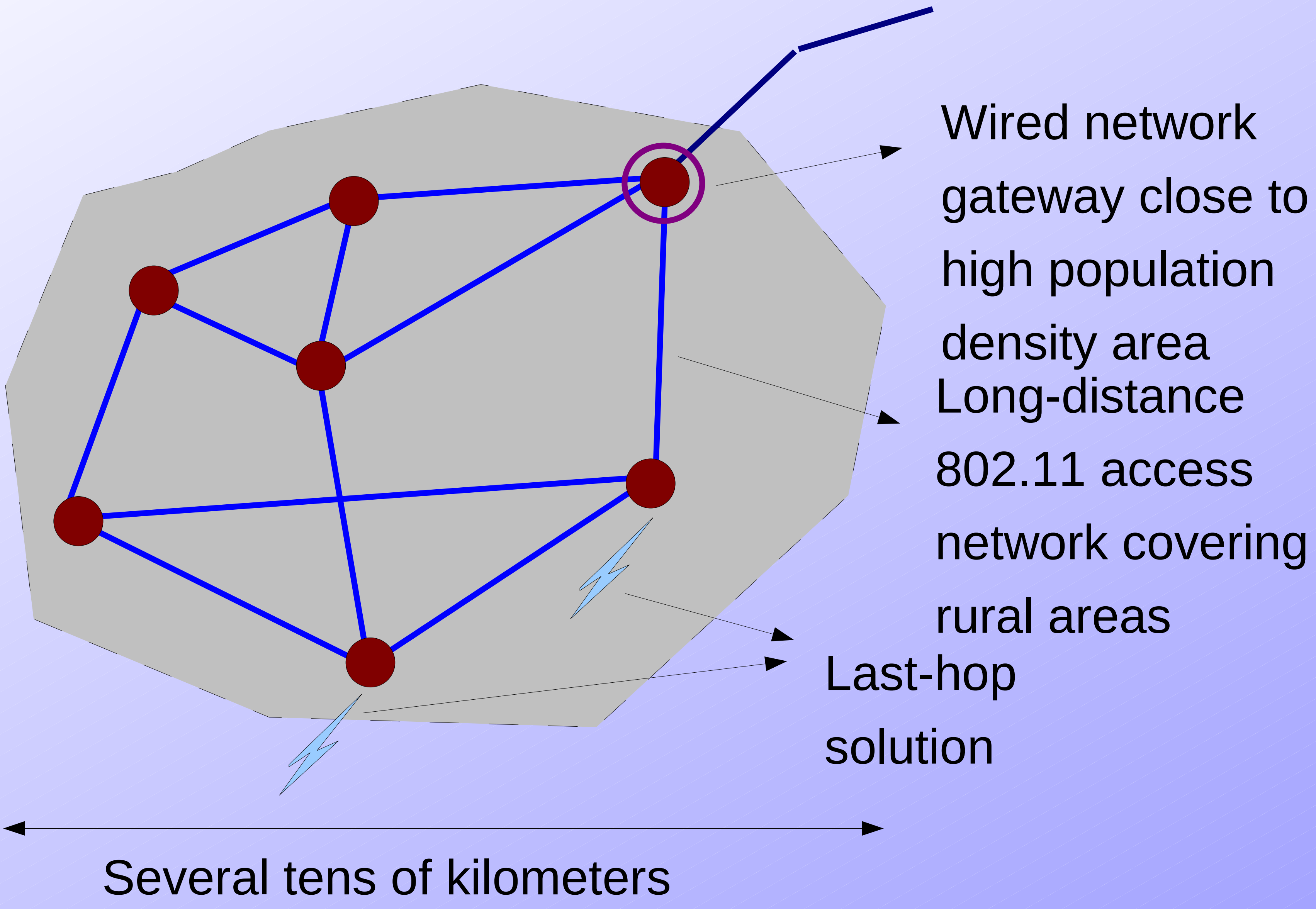
We cannot peg our hopes for price reduction on continued market growth since price elasticity in this market has already been maximized

Promising Technology: 802.11

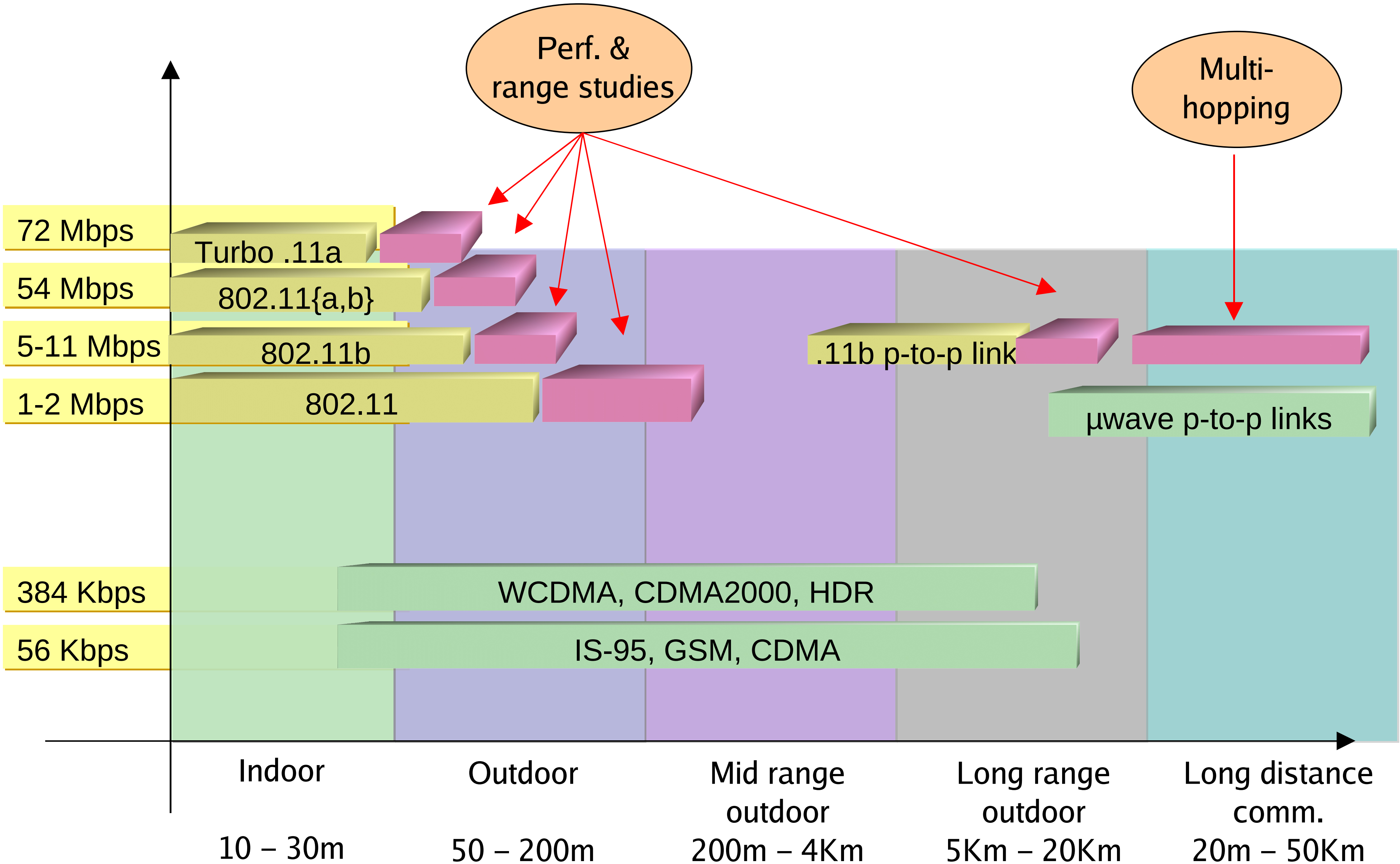
- Equipment: cost priced
  - Open, inter-operable standard
  - Competitive mass production
  - Chip-sets: \$25-30, Access-Points: \$120-700, PCMCIA cards: \$60-110

- Tremendous growth and acceptance in US/Europe markets
- Designed for last-hop indoor (office/home) use

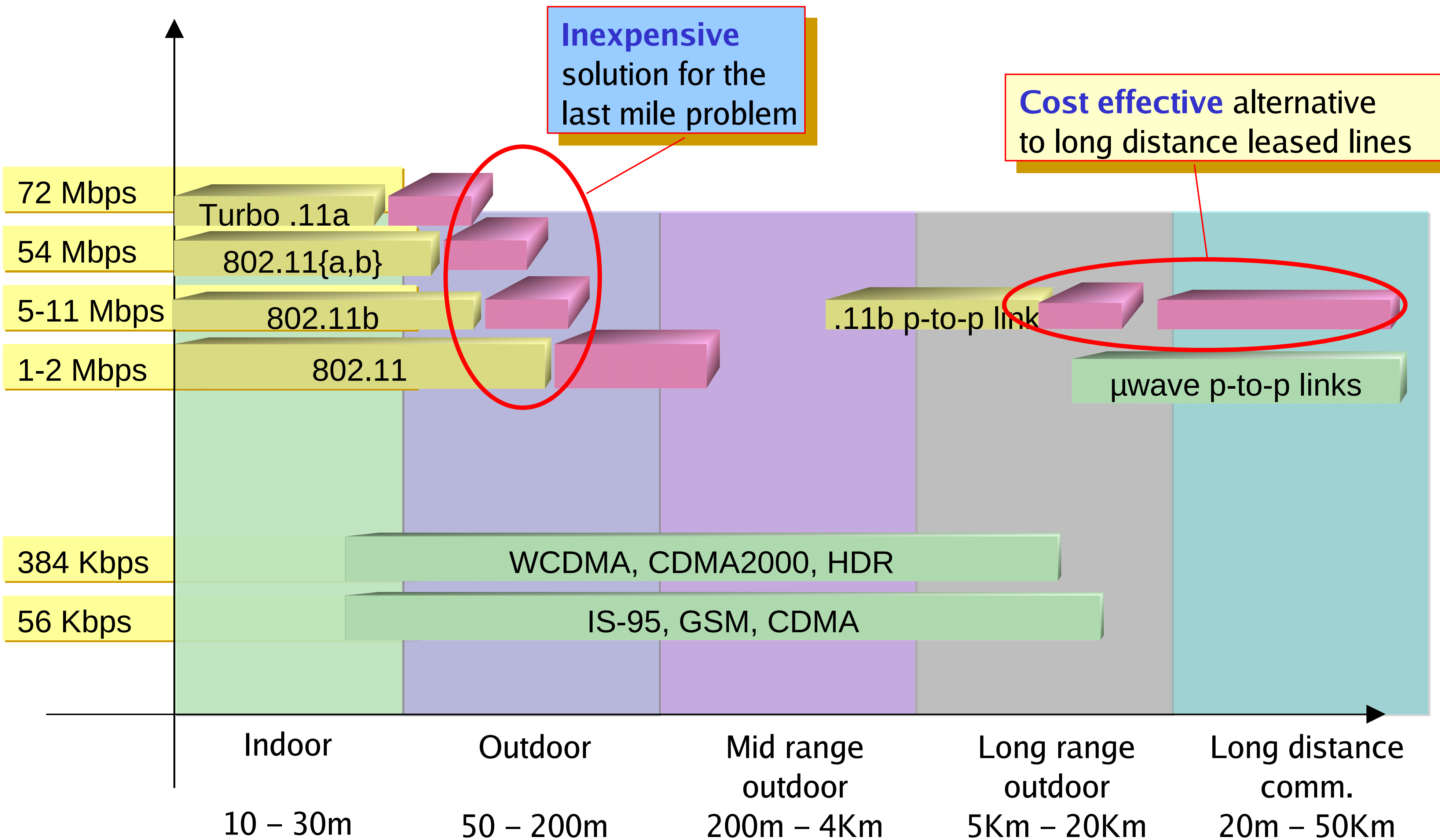
Envisioned use of 802.11



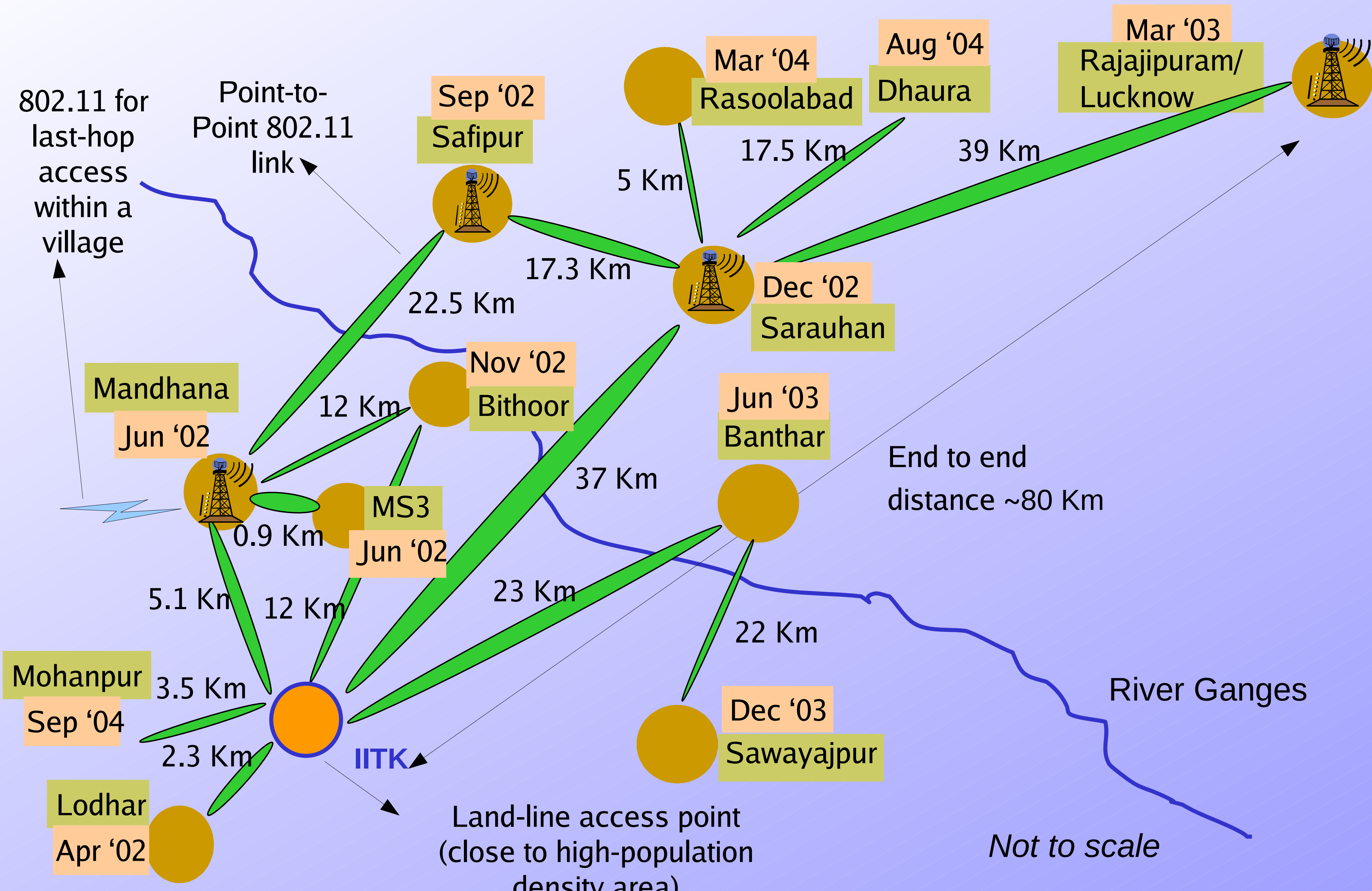
Digital Gangetic Plains: Goals



Value Propositions



Digital Gangetic Plains: Testbed



Testbed Equipment

- Off-the-shelf equipment
  - 802.11b Access Points
  - PCMCIA cards
  - Parabolic-grid antennae
- Pre-existing towers, high-rise buildings, masts, makeshift towers for setting up antennae: 15-40 metres

Some Pictures

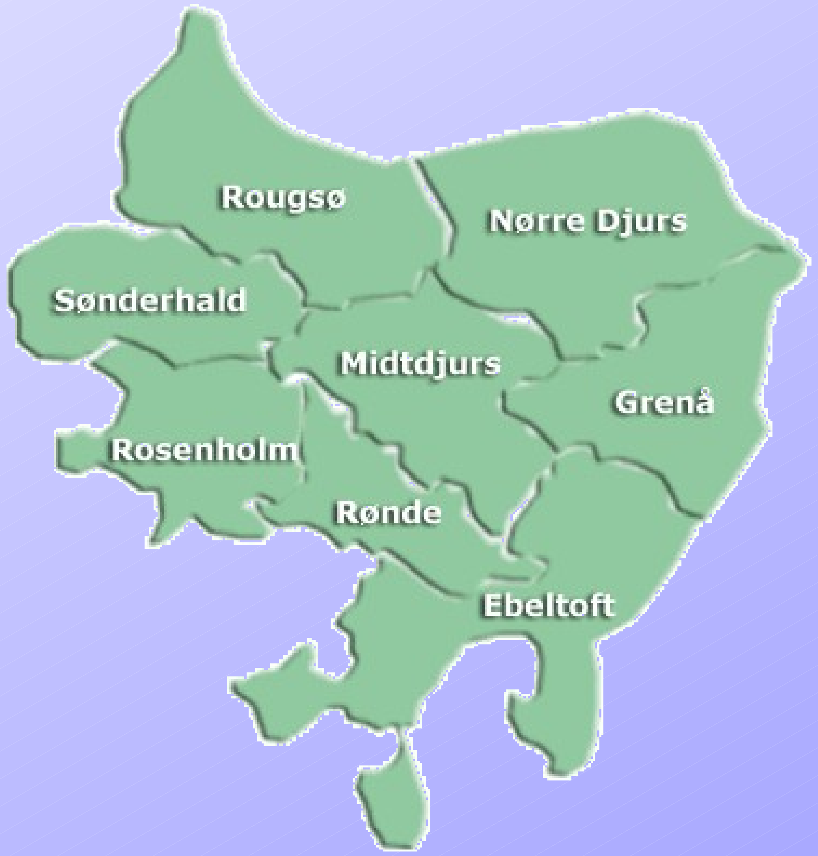
Antennae at Mandhana

Hello from Saroha

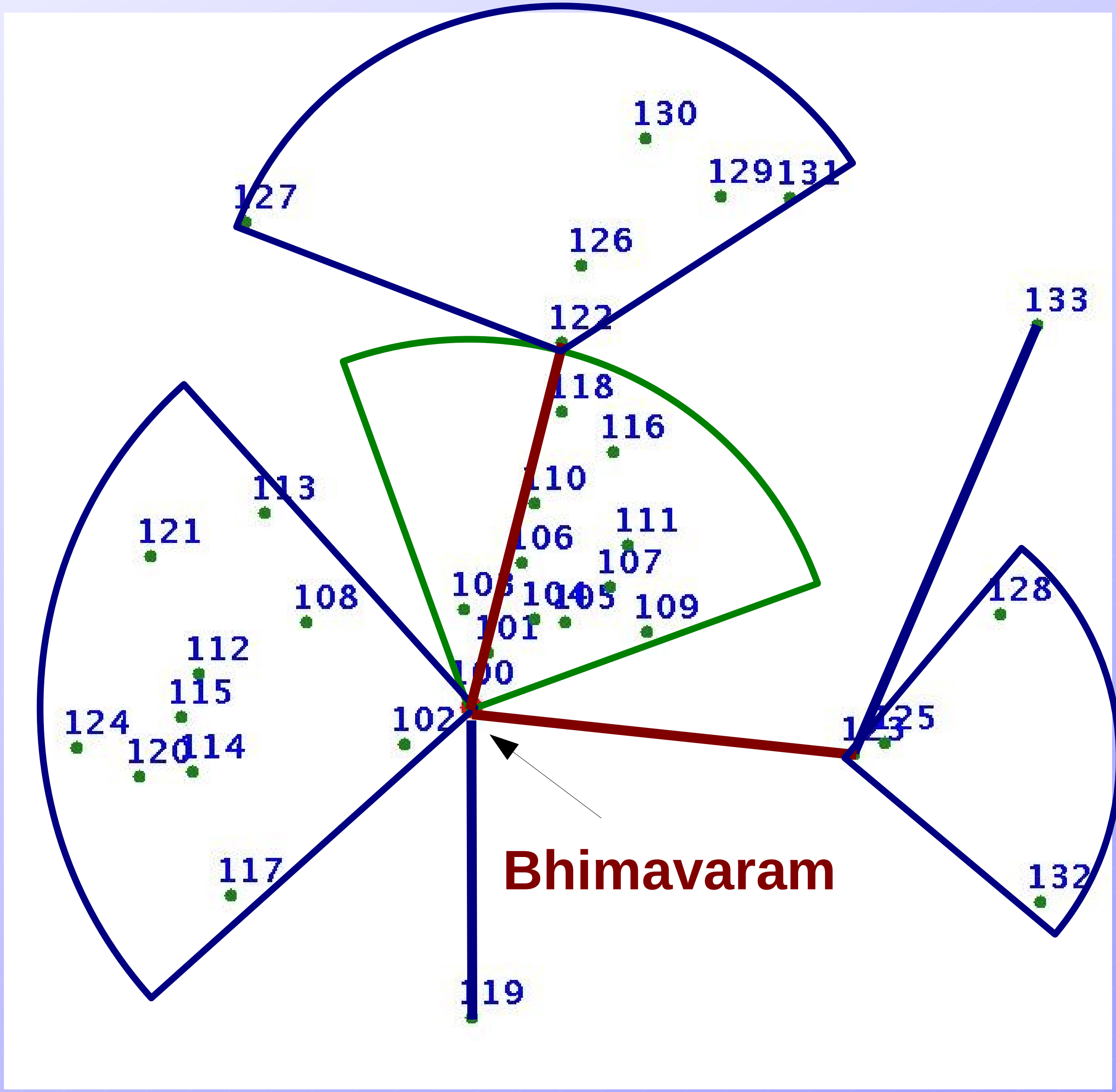
Testbed Contributors (subset)

A WiFi Network in Djurslands, Denmark

www.DjurslandS.net



The Ashwini Deployment (Planned) West Godavari, A.P., India



Outline

- Motivation: why WiFi for rural networking
- Technical issues:
  - PHY
  - MAC
- Future directions
- Conclusions

Technical Issues

- Two categories:
  - Specific to long distance use of 802.11
  - More general issues
- PHY, MAC/LLC, Routing, Other system-level issues

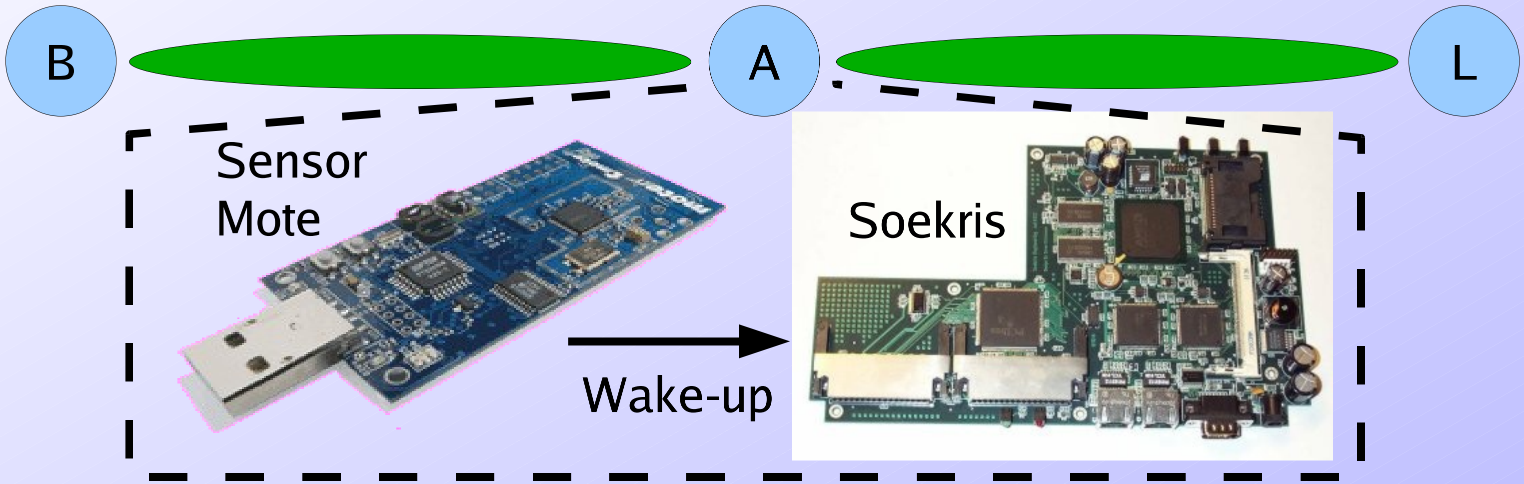
PHY issues: Outdoor Performance

- Empirical path loss models
  - Free space model, with 4-6dB correction fits all the long-distance links
  - Further work: how much area can be lit in last hop?
- Performance under outdoor channel conditions
  - Link very sensitive to multi-path
    - Effect seen in IITK-MS3 link
  - Equalizers, modulation designed for indoor delay spreads (~100ns max)
  - Outdoor multi-path ==> ~1 micro-sec delay spread
  - Design of equalizers to overcome these is required

PHY issues: Power Efficiency

- Power efficiency: a new perspective
  - So far: power efficiency for client
  - There is value in power efficient APs/Routers
  - Solar panel ($200)
    - 35W at peak, average efficiency of ~0.7 ==> 25W
    - 7-8 hours of sunshine per day ==> ~8W average
  - In testbed, APs consume about 10-30W each
  - Soekris power consumption: 6-8W

Power Efficiency: Ongoing Work



- Upstream station is off by default
  - Remotely switch on upstream station on-demand
  - Wake-on-WLAN
- Use sensor motes:
  - Readily available, low power consumption
  - Can sense 802.11b/g at 2.4GHz (tested: Nilesh Mishra)

PHY issues: Spectral Efficiency

- Spectral efficiency versus cost trade-off
  - Spectrum is very valuable in western markets
  - Hence lot of effort in spectral efficiency
    - Complex channel encoding, modulation methods
    - Throw more signal processing power
  - System cost reduction more important than spectral efficiency in rural settings

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- Technical issues: MAC
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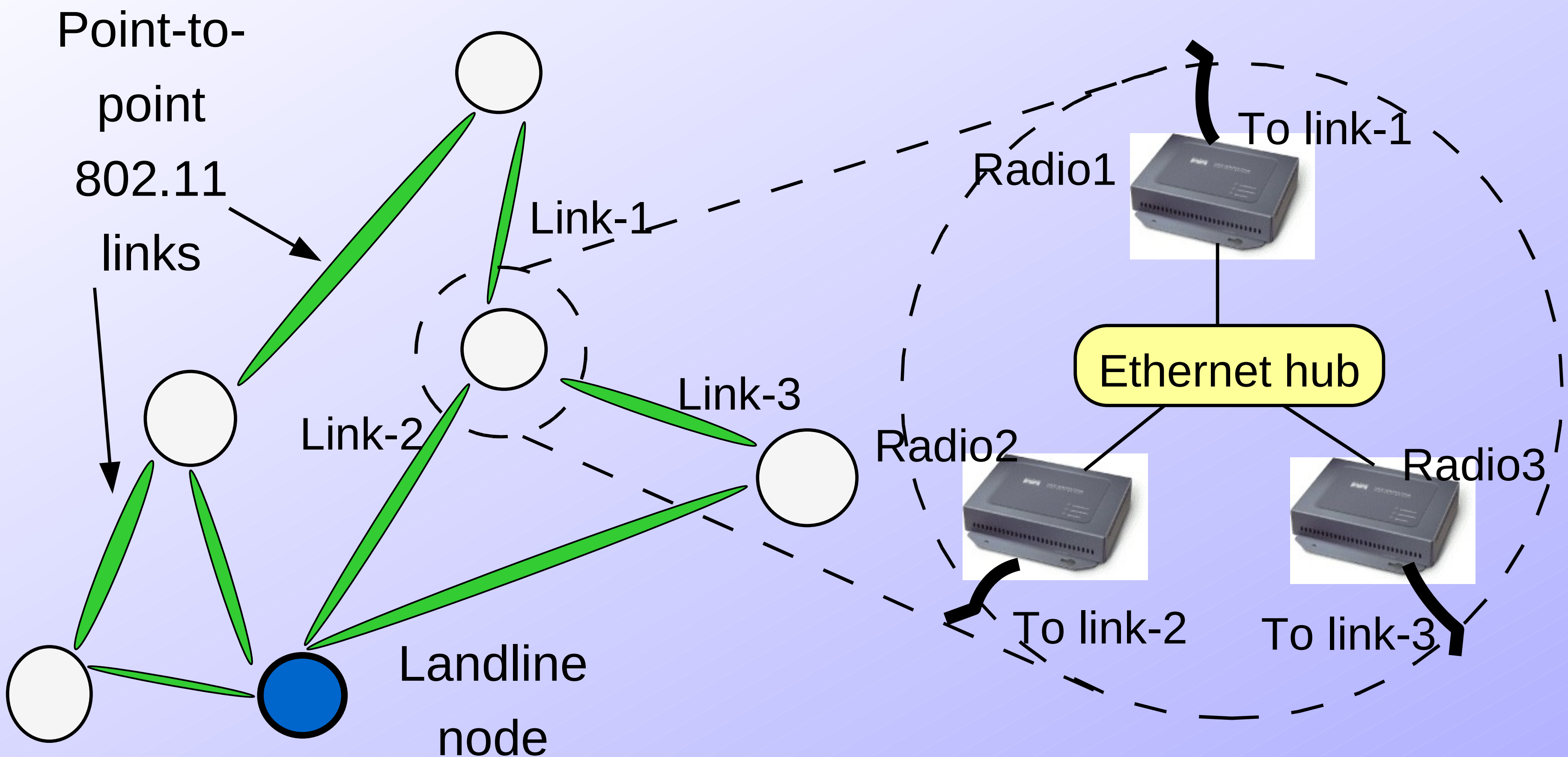
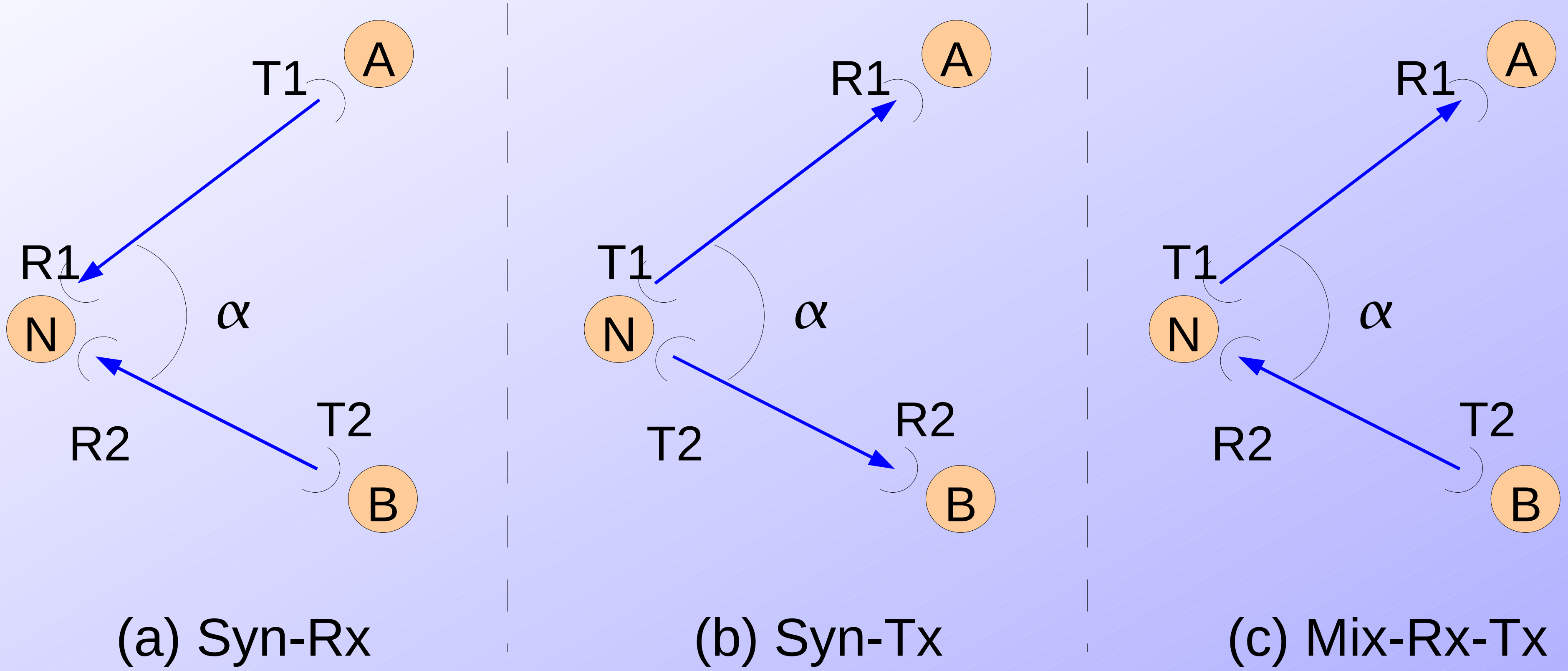
MAC Issues: Network Model



- Point-to-point links
- Multiple interfaces (radios) per node
- One directional antenna per link
- Single channel operation

SynRx, SynTx, and Mix-Rx-Tx

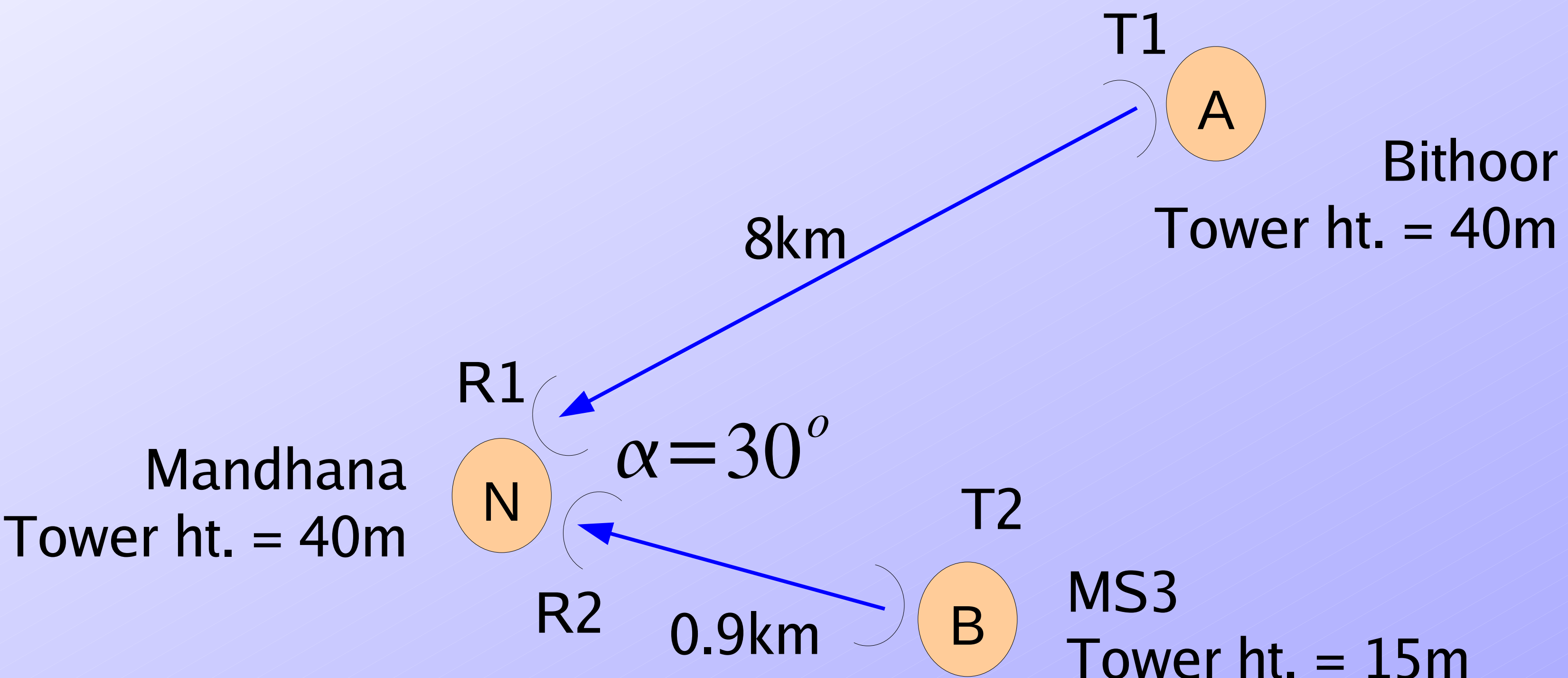


Exposed interface problem within a node:

CSMA/CA (802.11 DCF) inherently allows only one link operation per node

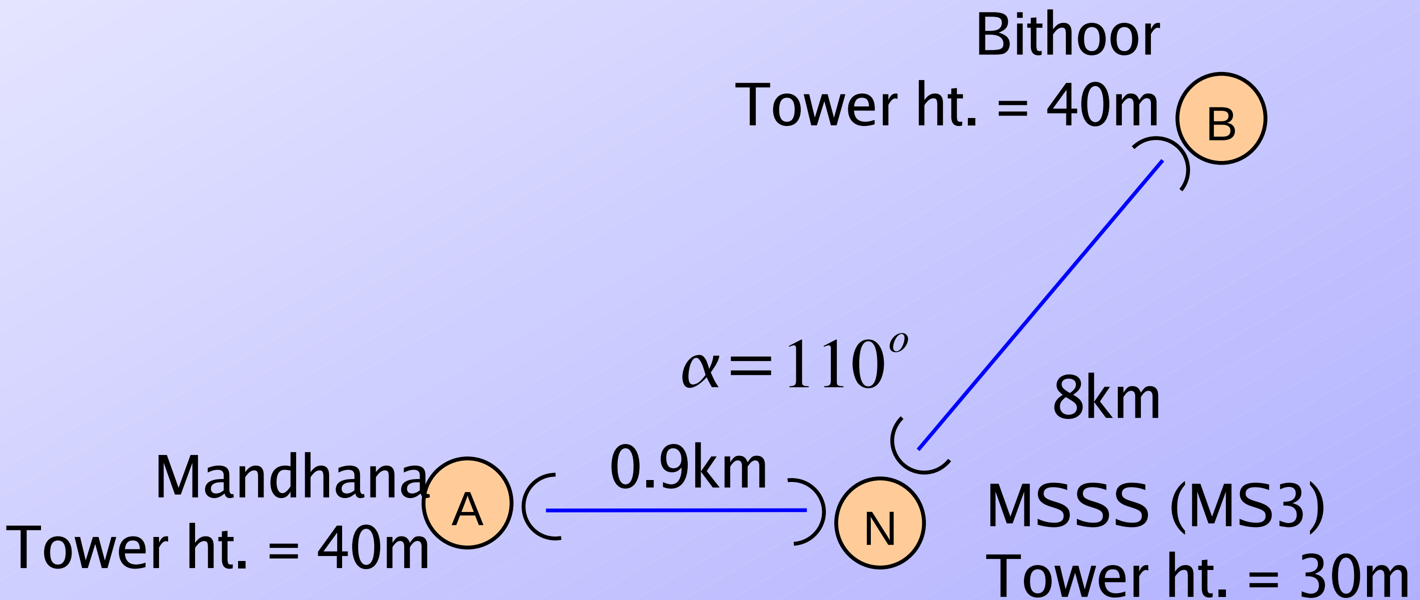
Problems: (a) Immediate ACK, (2) CS back-off

SynOp: SynTx + SynRx Experimental Verification (1 of 2)



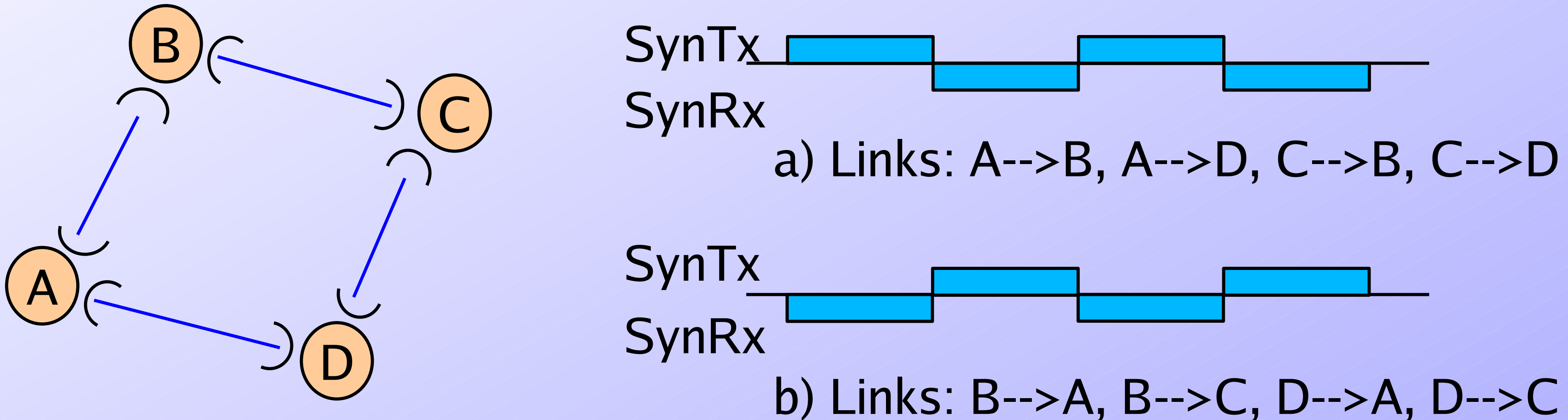
Experiments along with: A. R. Harish & Sreekanth Garigala

SynOp: SynTx + SynRx Experimental Verification (2 of 2)



The 2P MAC Protocol

- Two phases: each node switches between SynRx and SynTx
- Topology has to be bipartite



Note: diagram ignores system and propogation delays

- How to achieve 2P on off-the-shelf hardware?
- Can 2P work without tight time synchronization?
- Relation between 2P and network topology
- 2P performance versus CSMA/CA

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- Motivation: why WiFi for rural networking
- Technical issues: PHY
- Technical issues: MAC
- Technical issues: PHY+MAC
- Future directions
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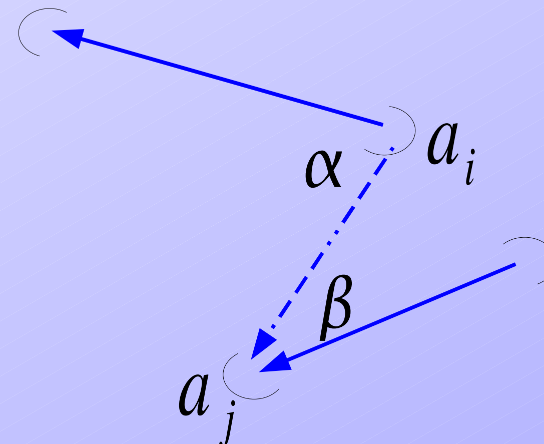
PHY+MAC: Topology Constraints

- 2P has two main constraints:
  - Topology should be bipartite
  - Power constraints
- Write a set of linear equations with variables P_i
  - SIR >= SIR_{reqd}
- Simple set of heuristics for topology formation



$$\textit{Overall gain from } a_i \textit{ to } a_j =$$

$$(\textit{Gain of } a_i\textit{'s Tx in } a_j\textit{'s dirn}) \times$$

$$(\textit{Gain of } a_j\textit{'s Rx in } a_i\textit{'s dirn}) =$$

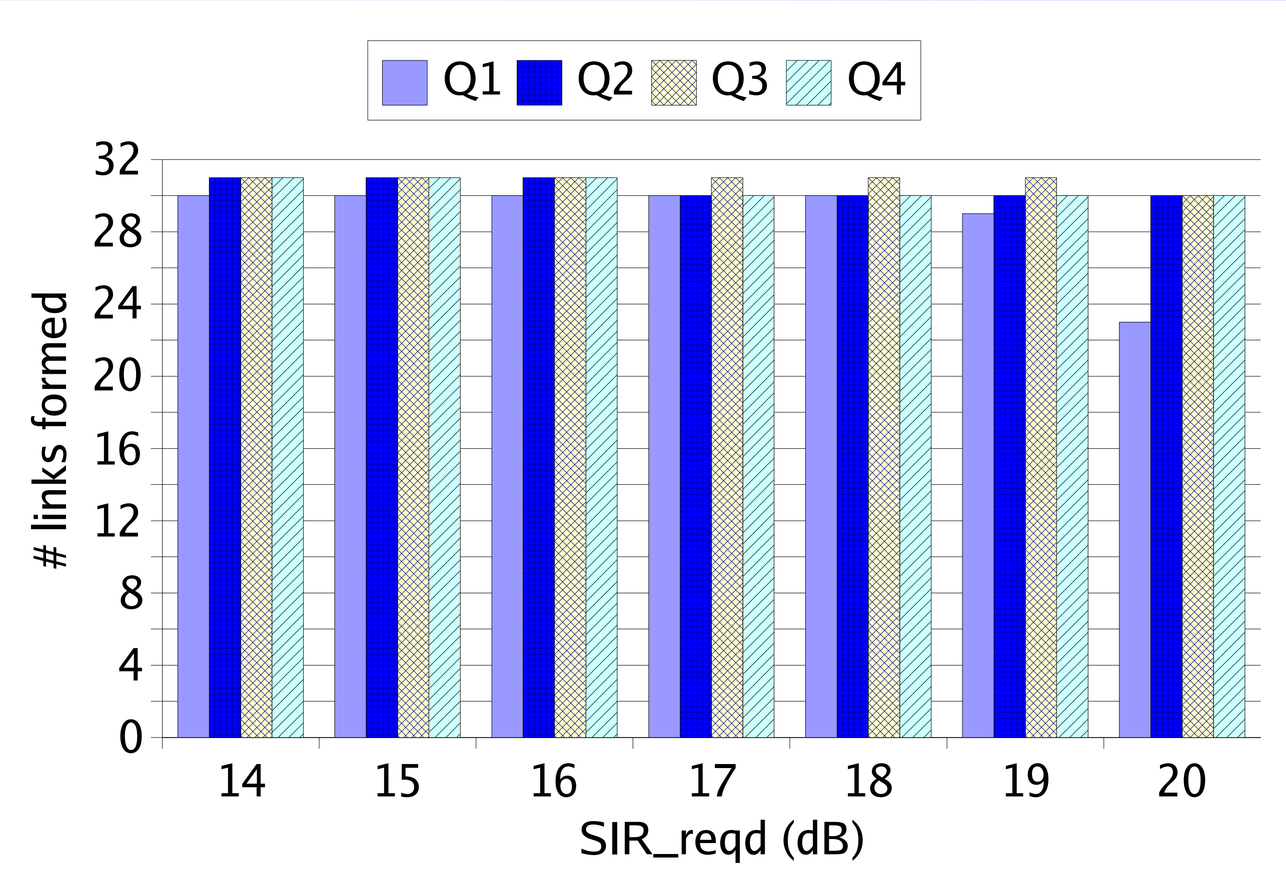
$$\textit{Gain at angle } \alpha \times \textit{Gain at angle } \beta$$

Evaluation of Topology Creation

- Aspects of interest:
  - How well does the algorithm scale?
  - How much head-room in SIR_{reqd} is possible?
- Evaluation:
  - Using parts of the map of Durg district, Chattisgarh, India
  - Using random topologies

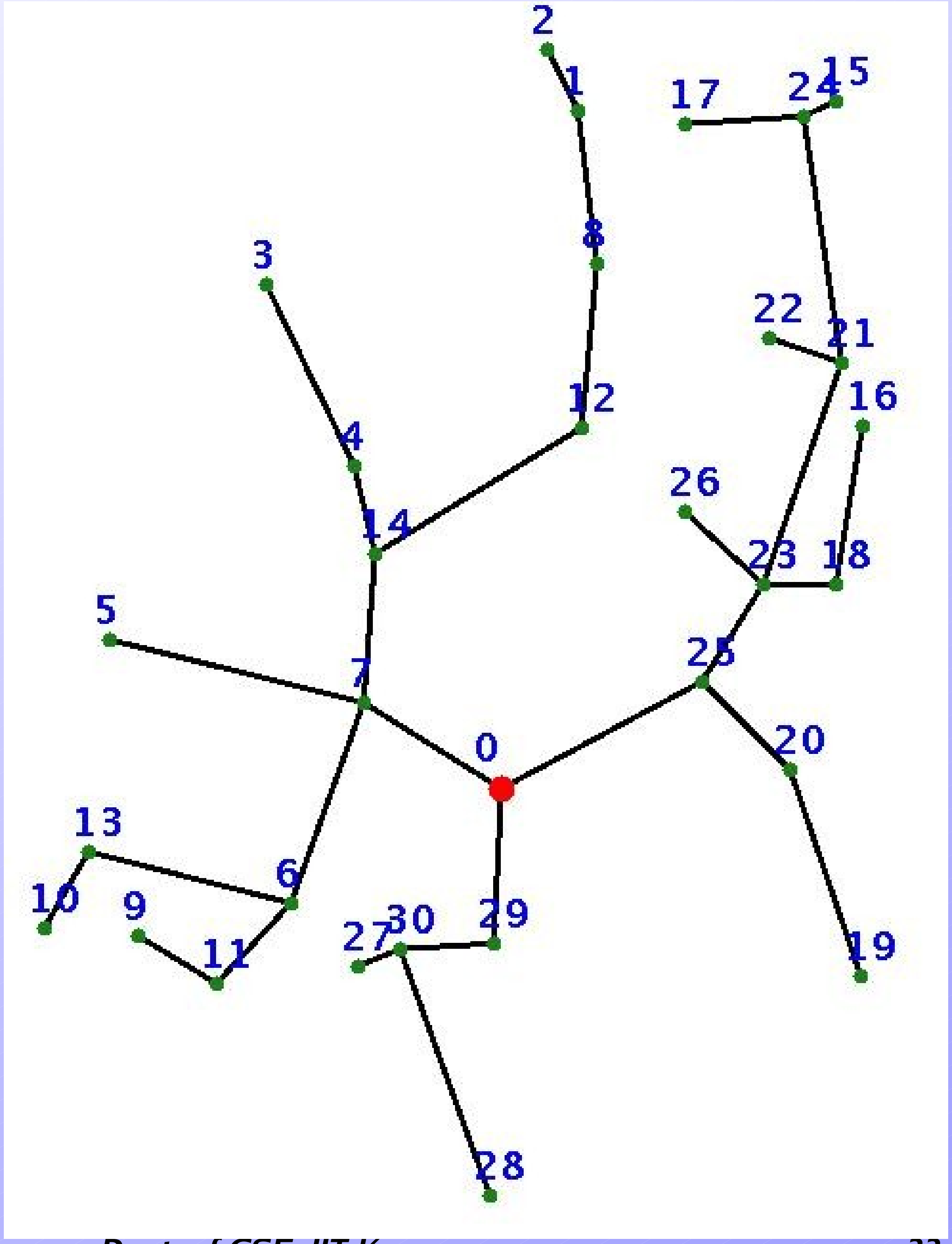
Topology Creation on Durg District

- Four clusters of villages
  - Q_i (i=1..4) 31, 32, 32, and 32 villages each



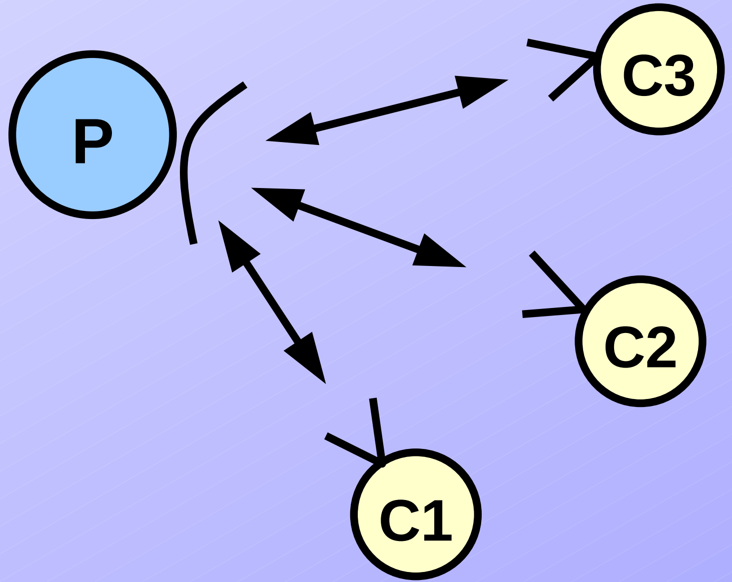
SIR_{reqd} of 18-20dB easily possible

The Topology on Q_1



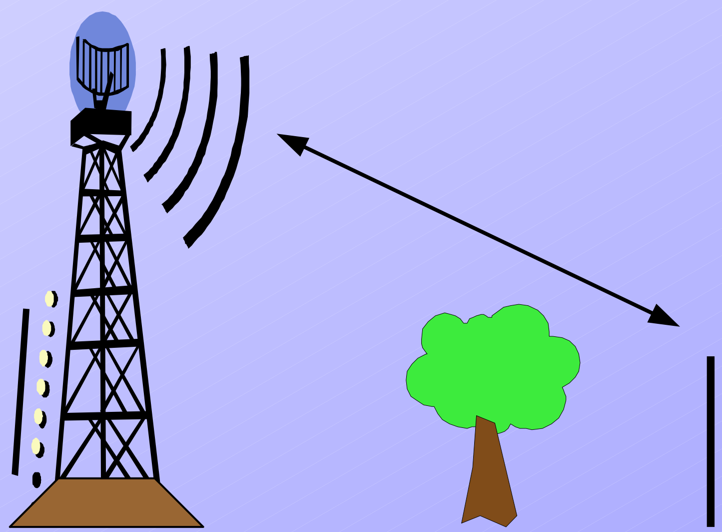
Lessons Learnt

- Full-mesh is generally not a good idea
  - Too many hops ==> reliability is a problem
  - High degree ==> too many antennas on a tower
  - Need flexibility to have point-to-multipoint (p2mp) links

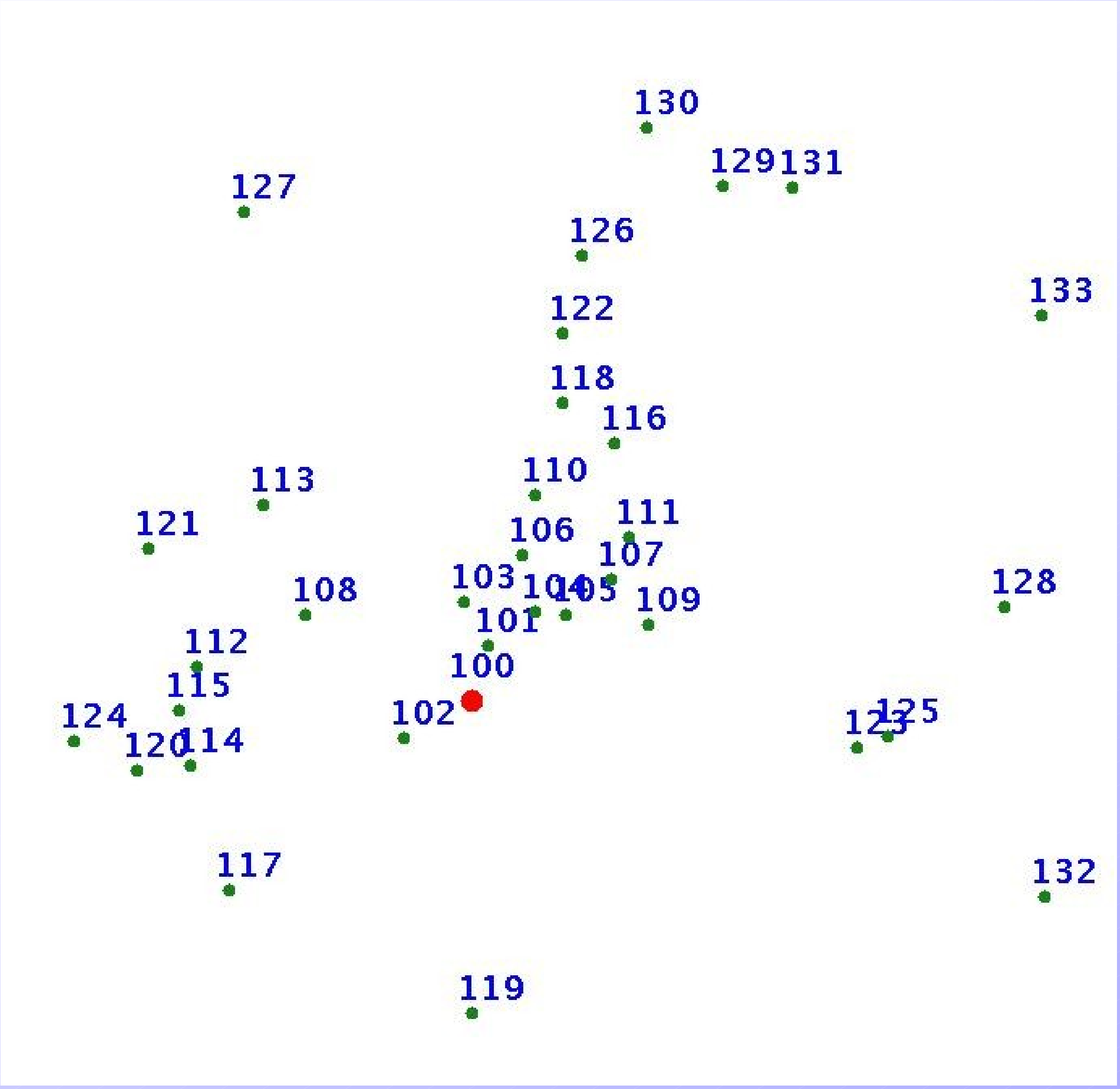


Topology Construction: The Cost Factor

- Antenna towers are expensive
  - For 15m and above
  - Cost proportional to steel weight
  - 30m tower: O($1,000)
- Antenna masts are cheap
  - Upto 12-15m, cost: O($20)
  - Water pipes (GI) are sufficient
- Insight from TENET group (IITM):
  - A tall tower can cover several short masts



Topo. Construction: Ongoing Work



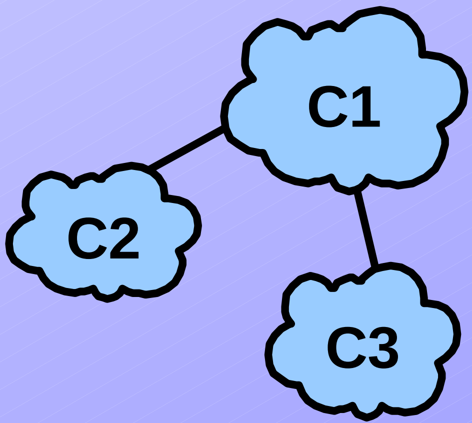
- Problem stmt.:
  - Given N points
  - And a desired bandwidth requirement (e.g. 384 Kbps two-way video)
  - What should be the topology?
  - Work by: Sayandeep Sen

Topo. Construction: Approach

- Focus on tree construction for now
- Break down the problem into two parts:
  - Decide on parent-child relationship: tree construction
  - Decide on antennae to use at each node: antenna assignment
- Constraints: capacity, power, interference
- Optimization metric: cost of the system

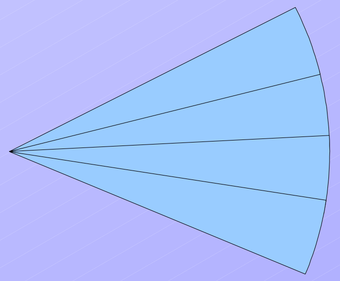
The Tree Construction Problem

- Finding optimal solution seems combinatorial
- Restrict the solution space under consideration
  - Not more than k (2 or 3) hops
- Clustering approach:
  - Exhaustive search within each cluster
  - Cluster merging (non-optimal)



The Antenna Assignment Problem

- Can be formulated as an LP optimization problem
- Consider 360 1-degree sectors at a node
  - What antenna to use to cover each sector?
  - Only sectors which encompass a child node matter
  - Parabolic grid antenna assumed with parent



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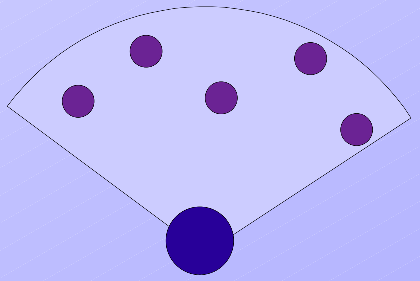
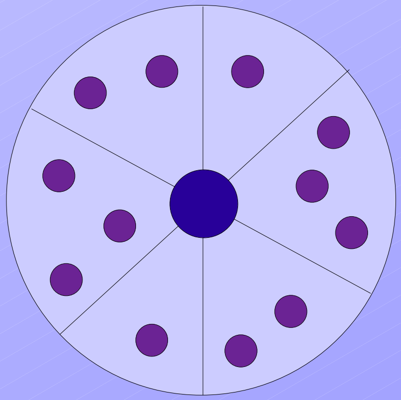
Standardization Efforts: SRAWAN, WiFiRe

- Commercial 802.11 products for outdoors
  - Non-inter-operable
  - Performance implications?
  - Expensive!
- SRAWAN: Sectorized Rural Access Wide Area Network
  - Single sector solution: IIT-Kanpur
- WiFiRe: WiFi Rural Extension
  - Multi-sector: IITB, IITK, IITM, IISc





A Place for WiMAX?

- WiMAX is designed from the ground-up for long-distance wireless
  - Spectrally efficient,unlike WiFi
  - MAC protocol is also efficient
  - But, how about cost?
  - And all the (free) software?
- Current approach: squeeze the best possible performance from WiFi
  - A bird in hand versus...

Concluding Remarks

- Low-cost is crucial for rural networking
  - To bridge the digital divide
- RuralNet (DGP): exploring WiFi in this context
- Our focus so far:
  - Technology demonstration
  - MAC protocol design
  - Topology construction algorithm
- Further technical issues:
  - In PHY, MAC, Topology construction, Routing, Application performance