Digital Gangetic Plains (DGP): 802.11-based Low-Cost Networking for Rural India

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http://www.cse.iitk.ac.in/users/braman/dgp.html
http://www.iitk.ac.in/mladgp/

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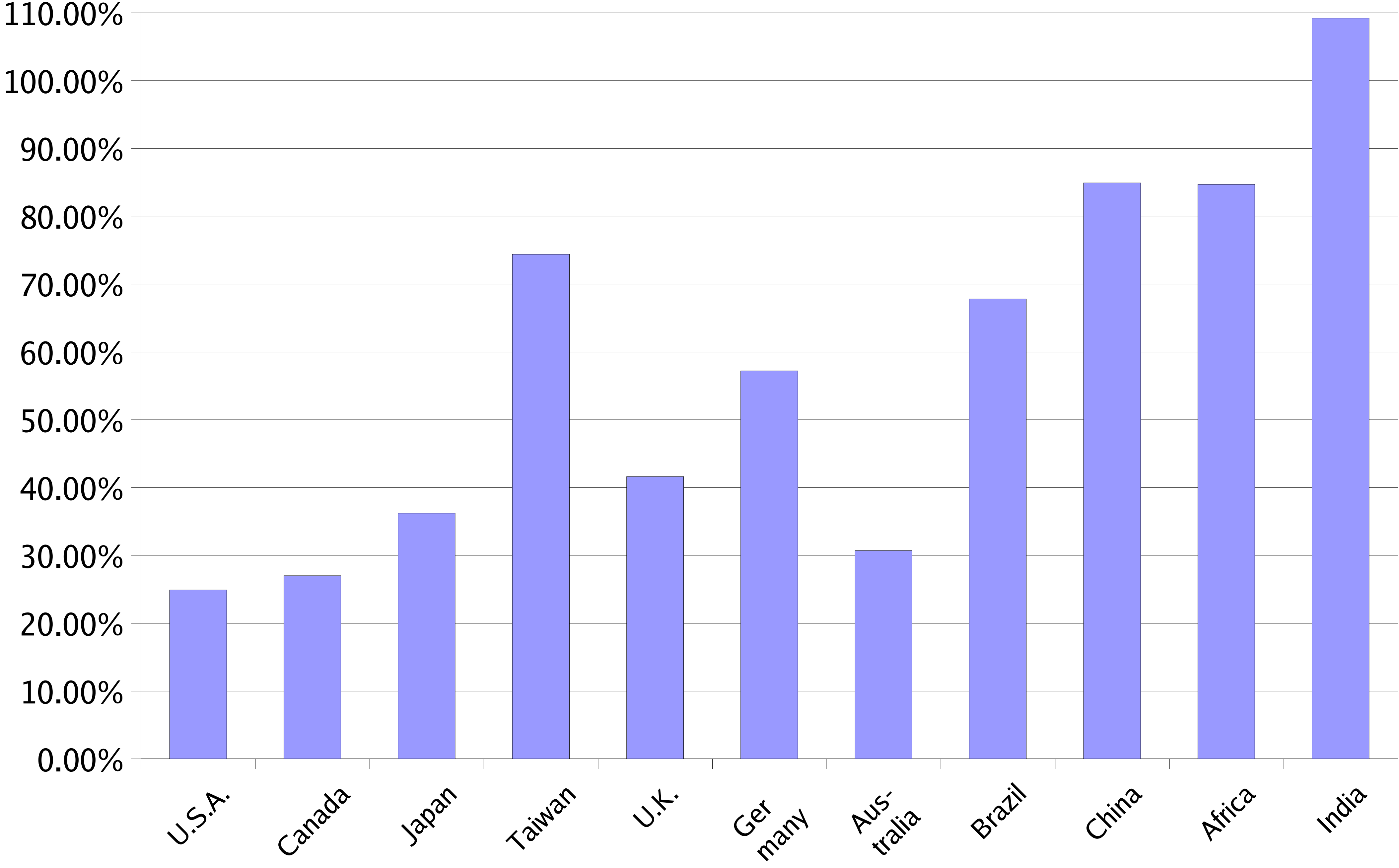
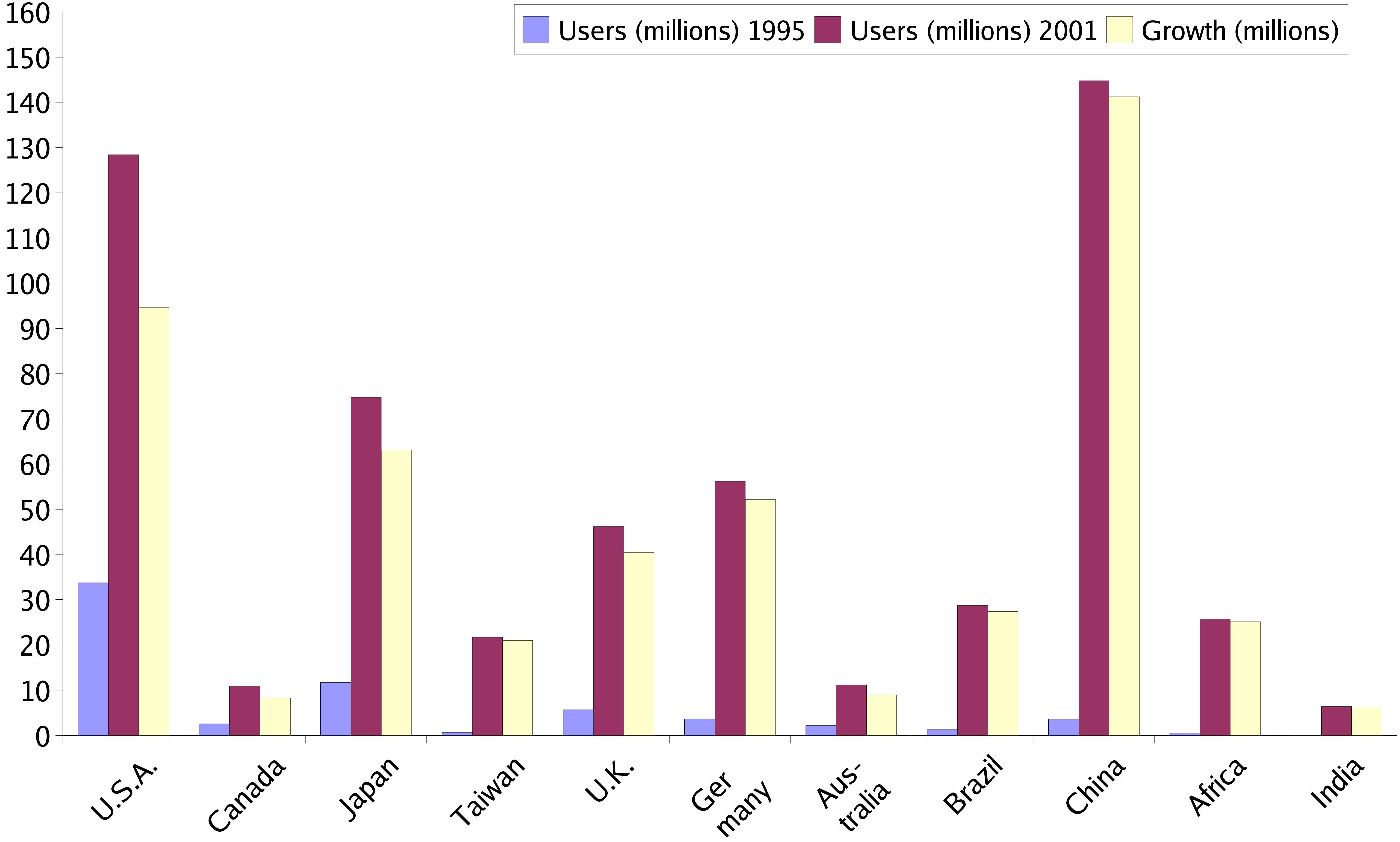
Wireless for Development, Denmark, September 2004

Cell Phones: CAGR 1995-2001



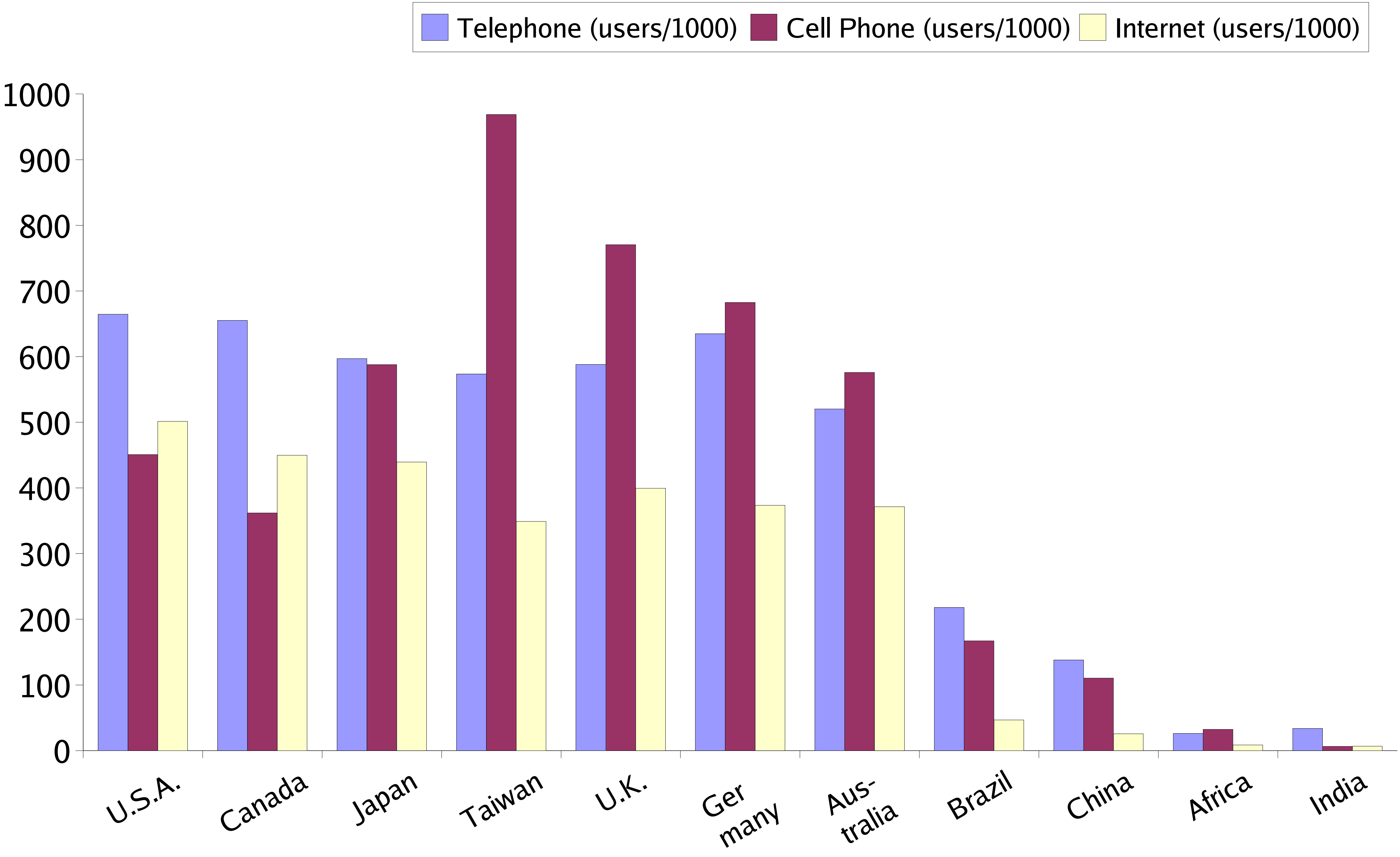
Source: ITU

Cell Phones: Absolute Growth



Source: ITU

Tele-density (2001)



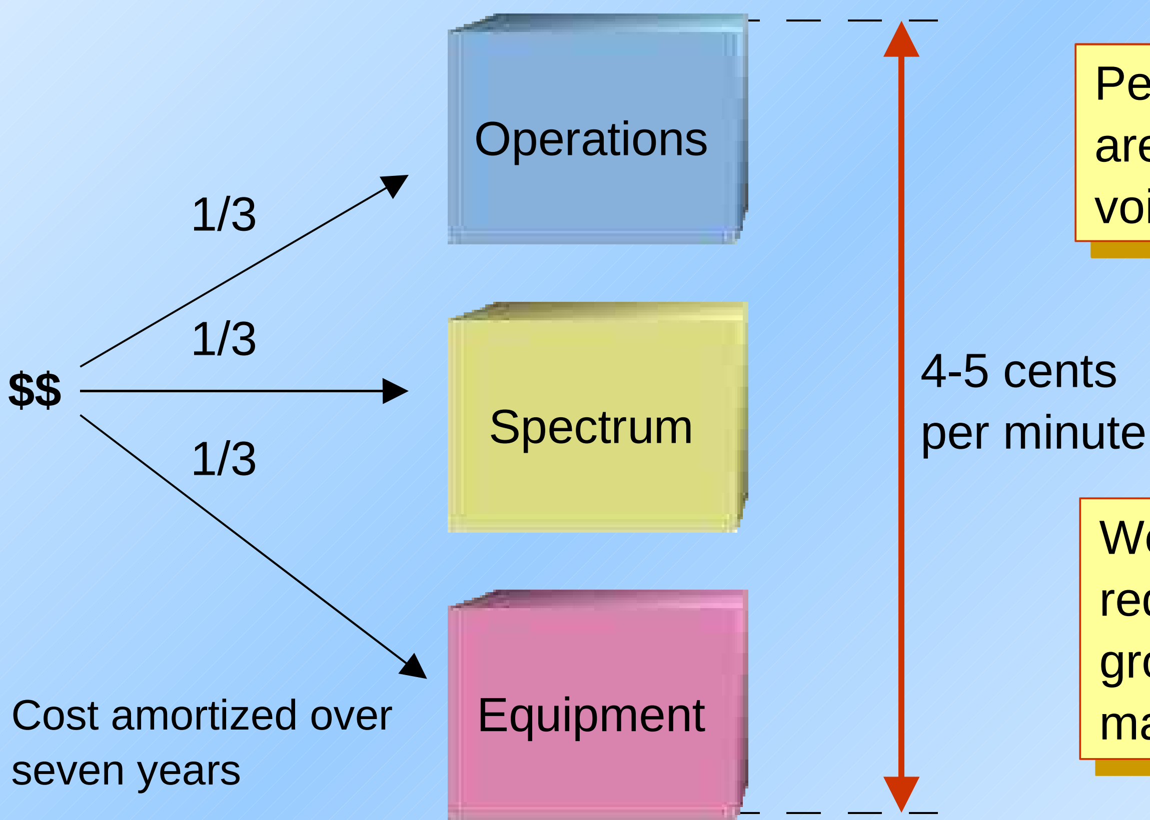
Source: ITU

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

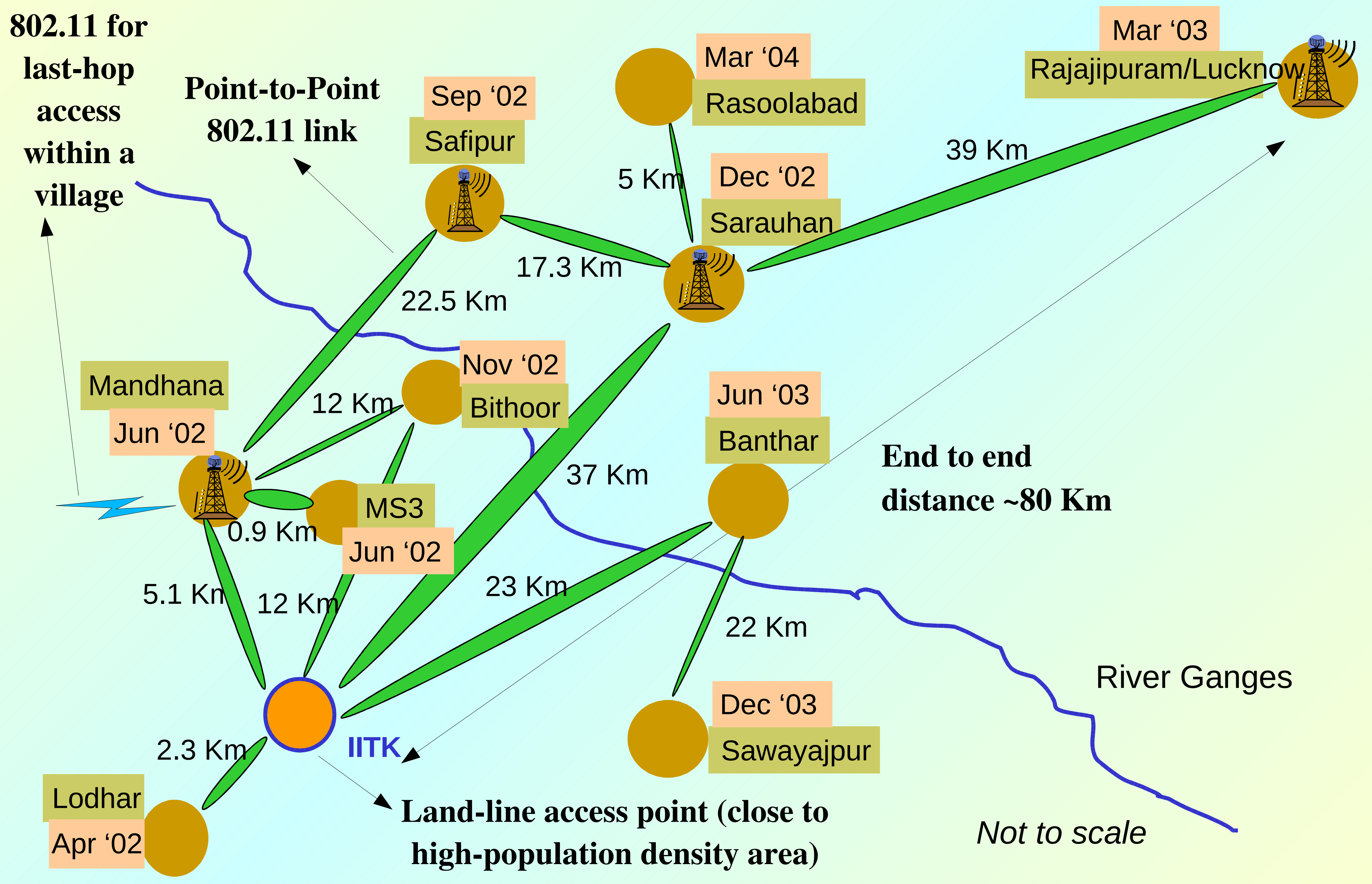
Promising Technology: 802.11b

- 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

DGP: Central Goal

How to use 802.11 for cost-effective rural networking?

Digital Gangetic Plains



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)

DGP: Issues Addressed

Operational issues

Application issues

Technical issues

Operational Issues

- How to setup an *outdoor* 802.11 network with *long-distance, point-to-point* links?
  - Antenna alignment, weather proof casing
- Which off-the-shelf equipments work under the above conditions?
  - Interoperability issues, configuration and running
- What are the various **costs** involved in the network setup?

Costs Involved

Antenna tower (15m)	Rs. 70K
Antenna tower (25m)	Rs. 105K
Antenna tower (40m)	Rs. 265K
Antenna mast (10m)	Rs. 4K
Antenna mast (15m)	Rs. 6K
Antenna mast (20m)	Rs. 8K

Per-node costs

Dominant

Bridges	U.S. $100-$1,000
Access Points	U.S. $100-$1,000
Client devices	U.S. $20-$120
Directional antennae	U.S. $50-$100

Per-link costs

Technical Issues Addressed

- Understanding of *path-loss* in the long-distance links
- SynOp: how to operate the mesh network using a single 802.11 channel?
  - Current understanding: poor performance in a mesh network
  - Not true with protocol redesign
  - Design done, implementation in progress
- TeNs: The Enhanced Network Simulator
  - Sabyasachi Roy, Ashwini Kumar (BTech project)
  - Software release; >200 downloads to date

Technical Issues (Details)

- Physical layer (PHY) issues
- MAC performance issues
  - SynOp: a novel flexibility
  - Design of a new MAC: 2-P
- Several other issues…

PHY issues

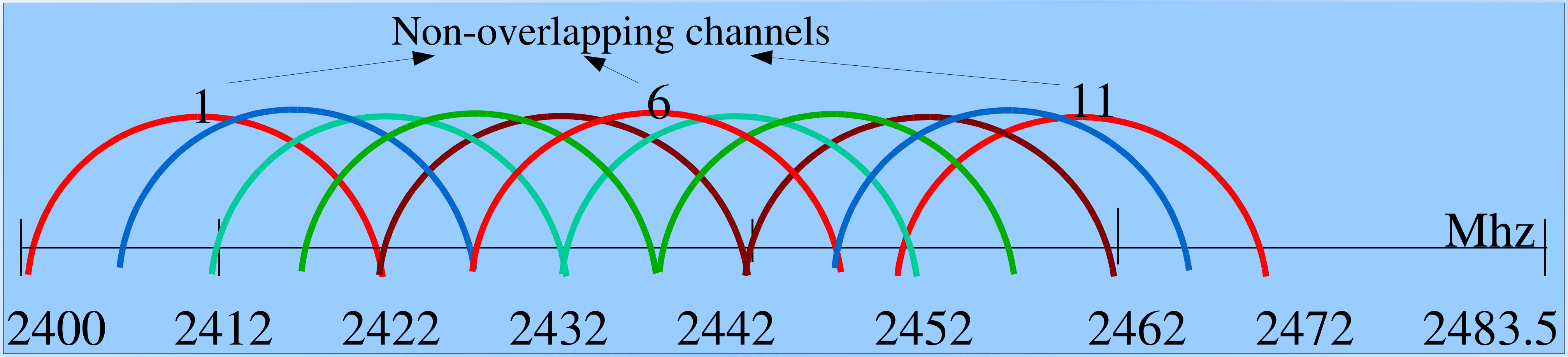
- Empirical path loss models
  - Free space model, with 4-6dB correction fits all the long-distance links
  - Further work: how much area can be lit in last hop?
- Performance under outdoor channel conditions
  - Design of equalizers to overcome multi-path
- Antenna design at low-cost
- Power savings in APs/Routers
  - Enable operation using solar panels
- Low cost vs. spectral efficiency

Design of a MAC

- Focus on the mesh network: *outdoor, long-distance, point-to-point* links
- Our mesh network is different
  - Interested mainly in “points of connectivity”
  - Use of directional antennae
  - Multiple radio devices per node

Design of MAC (continued)

- Goal: bandwidth efficiency

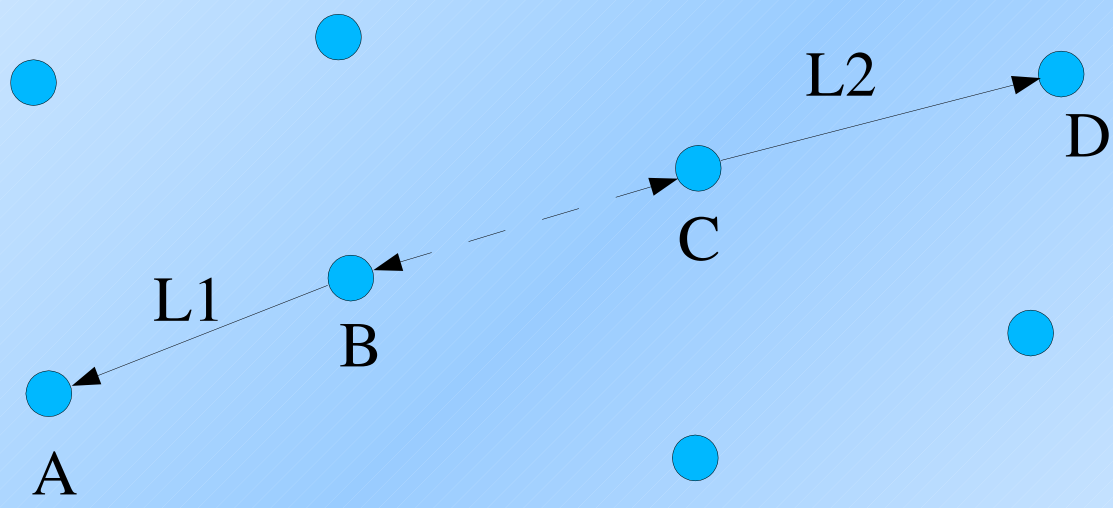


- Constraint: use min. #channels
  - Focus on the use of a single channel
  - Good if channels are licensed
  - Even otherwise, the approach is useful in parts of the mesh network

802.11 CSMA/CA-based MAC

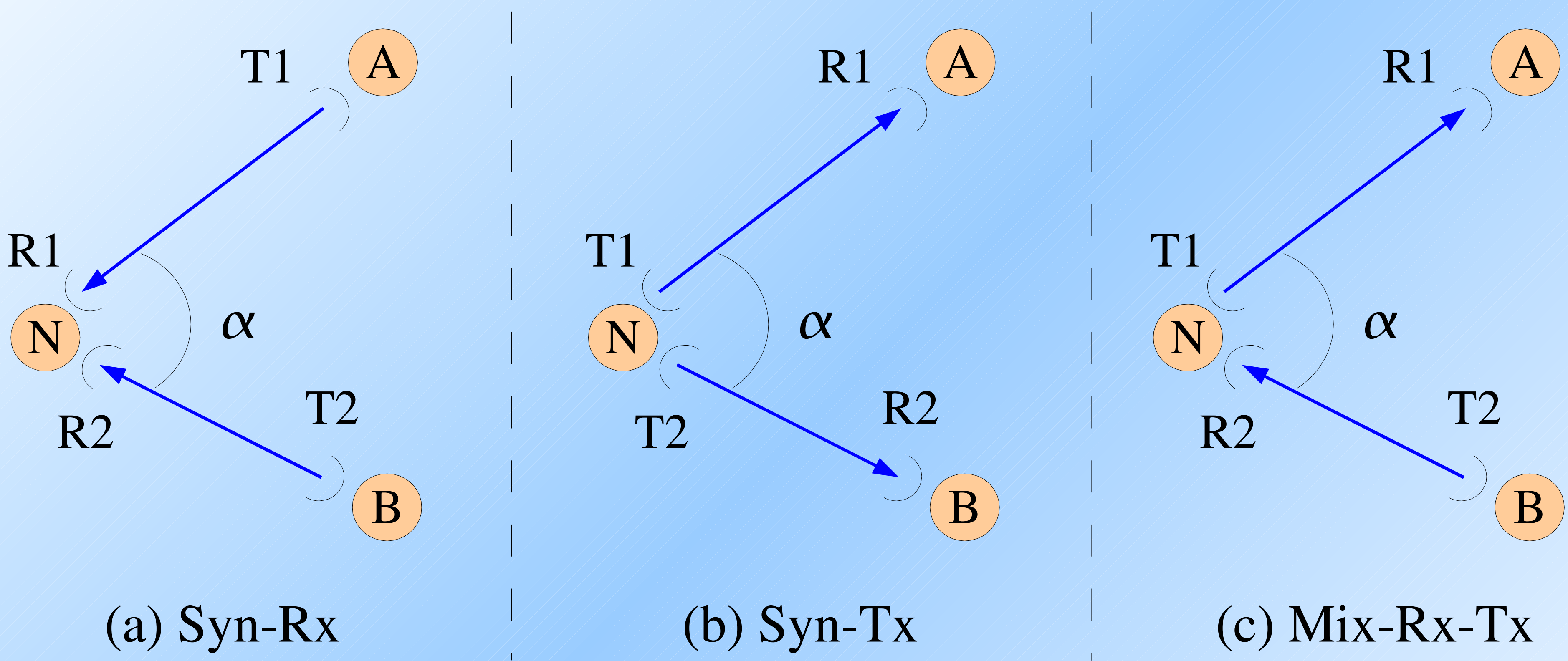
- CSMA/CA
  - Listen before transmit
  - Random backoff
  - RTS/CTS to address the hidden node problem
- Designed for indoor environments
  - Many nodes contending for the channel
  - Broadcast network
- How does it perform in a mesh-network?

Multi-Hop CSMA/CA in a Mesh Network



- Too much interference
- Exposed node problem prevents parallel transmissions

Do Directional Antennae Help?



Exposed *interface* problem still persists, within a node!

Ideally, links at a node should operate independently

CSMA/CA inherently allows only one link operation per node

Some Numbers

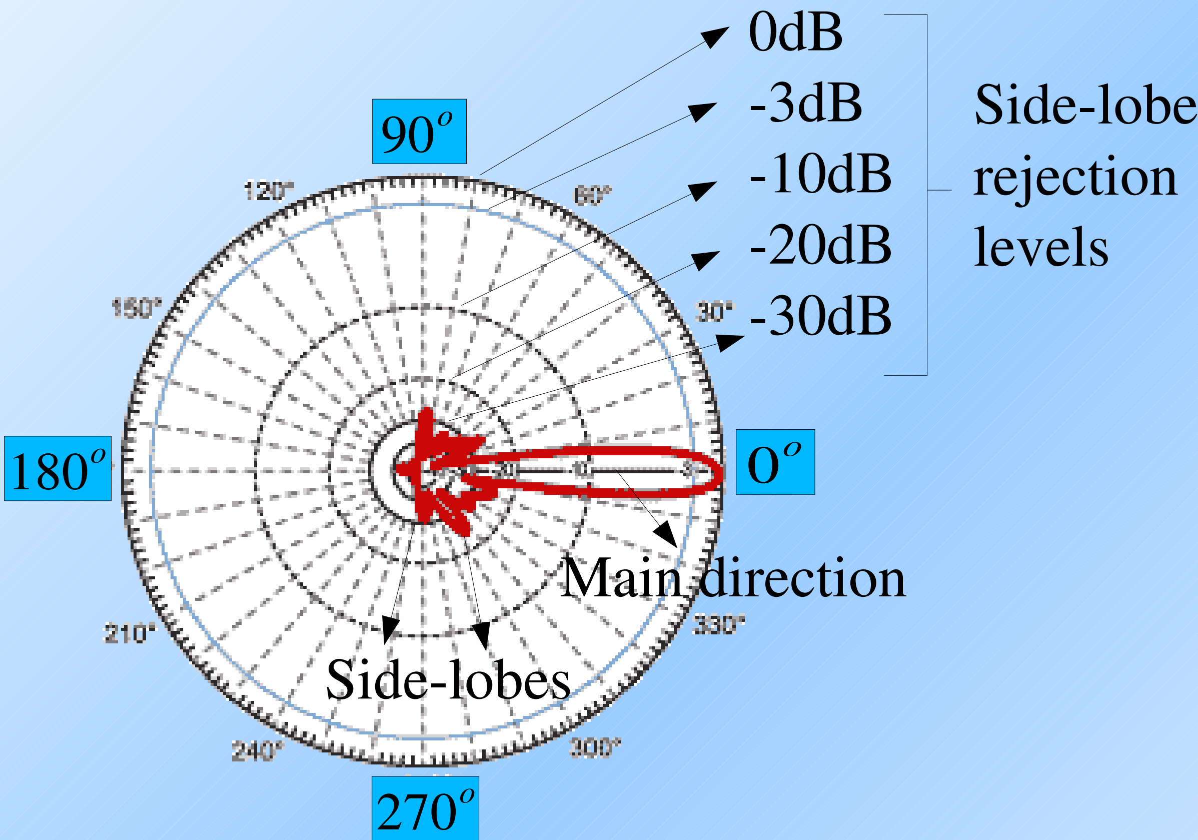
Antenna	RTS/CTS used?	1-hop (Mbps)	2-hop (Mbps)	3-hop (Mbps)
Omni	Yes	4.5	2.2	1.5
Omni	No	6.1	3	2
Dirnl.	Yes	4.5	2	1.9
Dirnl.	No	6.1	2.8	2.7

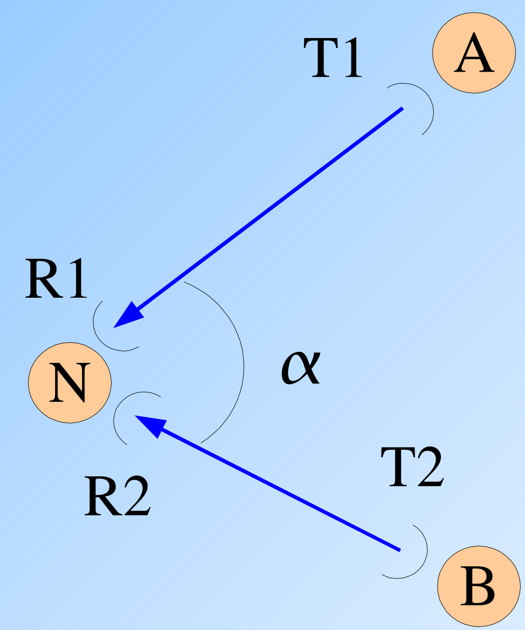
- Throughput of saturating UDP traffic
- Simulations using ns-2 (S. Roy and Ashwini)
- 3-hop shows exposed node problem (omni)
- Exposed *interface* problem with directional antennae

SynOp: Simultaneous Synchronous Operation

- SynOp: SynRx + SynTx
  - Links at a node operating simultaneously, synchronously (on the same channel)
- Is this feasible?
  - Yes, under certain conditions

SynOp Feasibility

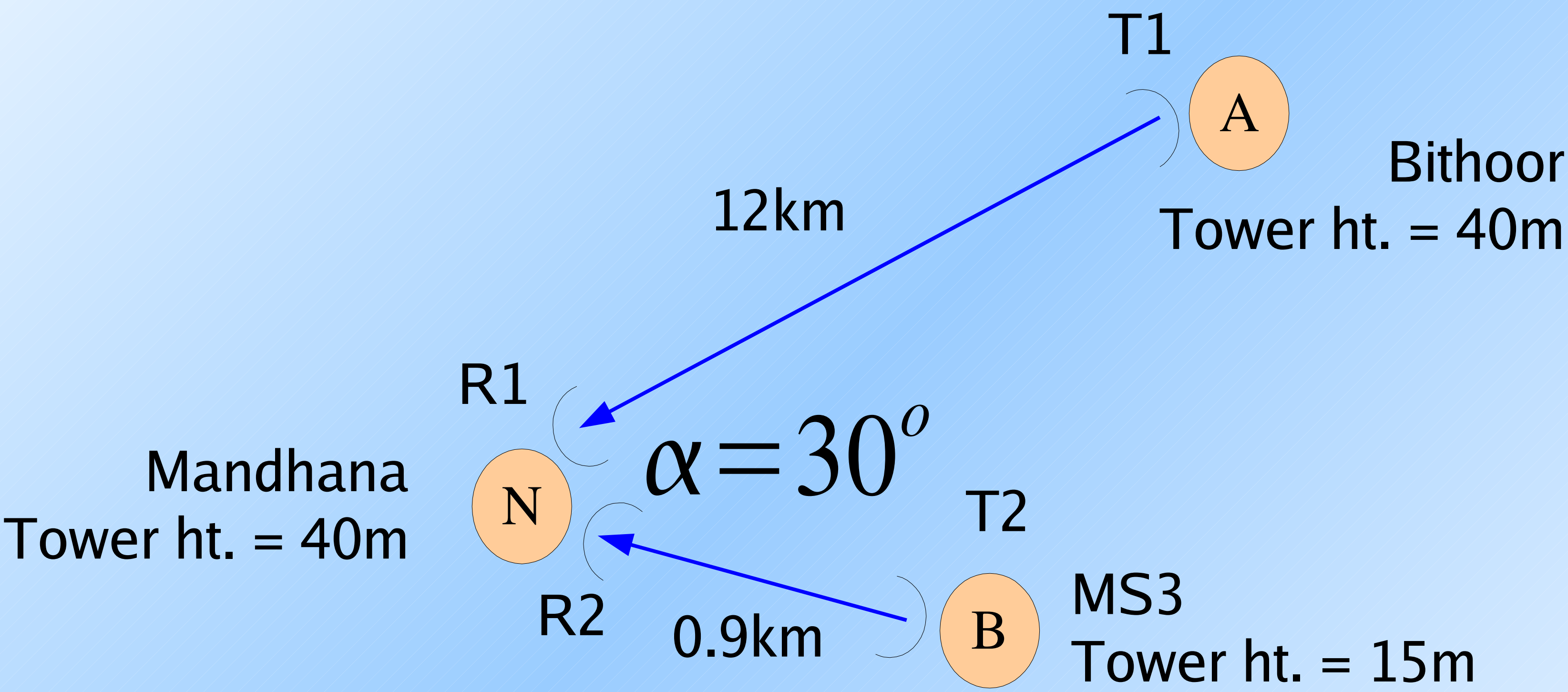




Syn-Rx

$$\left| P_{R_1} - P_{R_2} \right| \leqslant SL_{\alpha} - SIR_{reqd}$$

SynRx: Experimental Verification



Used *broadcast* packets on both links

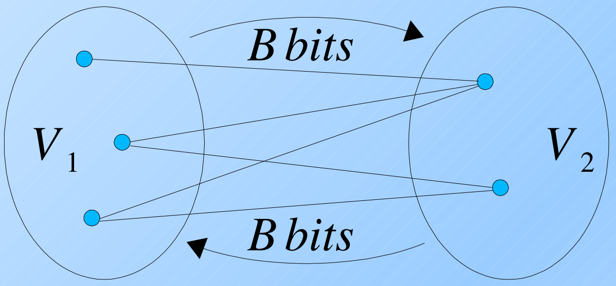
6.5 Mbps with and without simultaneous operation

SynTx also verified – using antenna diversity for the setup

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

2-P: A MAC on top of SynOp

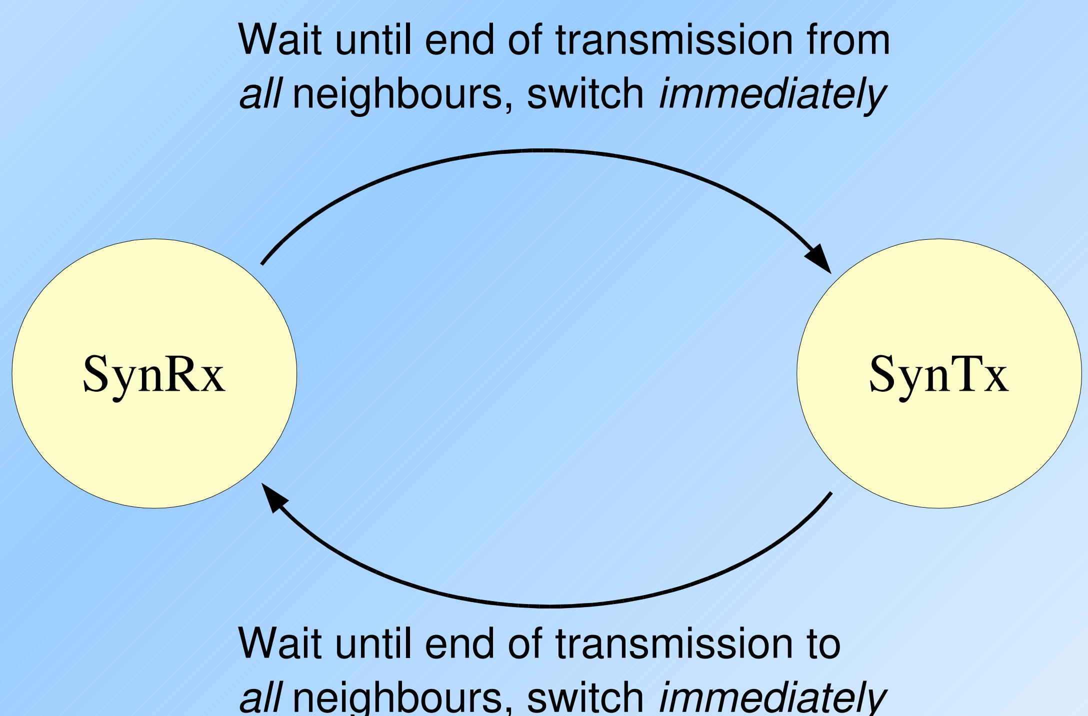
- 2-P: each node switches between SynRx and SynTx
- When a node is in SynRx, its neighbours are in SynTx, and vice versa



- SynRx + SynTx = 1 *round*
- Require a bipartite topology

2-P without Synchronization

- 2-P can be implemented without global time synchronization!
  - Local (loose) synchronization is sufficient, and efficient



Loose Synchronization in 2-P

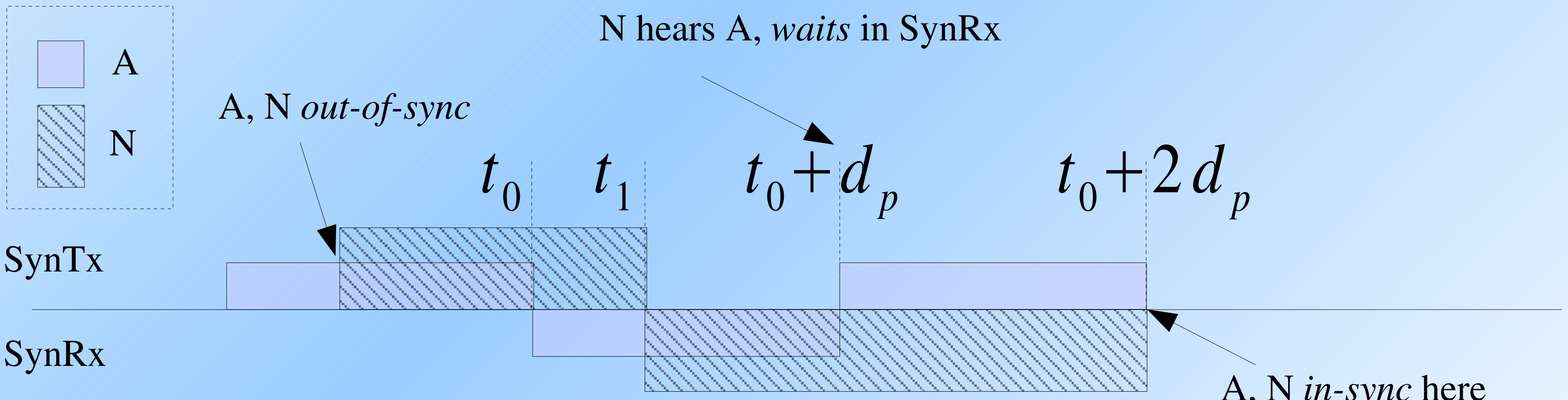
- Not necessary that all nodes in a partition are in the same phase
  - Does not matter
- Robust to packet CRC errors
- What about packet loss?
  - Timeout mechanism needed

Timeout Mechanism in 2-P

- Timer started at a node on entering SynRx
  - On timer expiry, enter SynTx anyway
  - Cancel timer if signal received from *all* neighbours
- Timeout value?
  - Larger than propagation+system delays

Self-Synchronization in 2-P

- Arbitrary possibilities of simultaneous timeouts, loss of synchrony, etc.
- Resync within 1 round



Note: diagram ignores system/propagation delays

2-P Implementation

- How to implement on off-the-shelf 802.11?
- Can be done through firmware-level control
- Conjecture: minimal changes required
  - Get rid of MAC-level ACK
  - Do away with CSMA/CA backoffs
- Some other issues:
  - Topology construction
    - Enable 2-P, fault-tolerance, low-cost
  - TCP over 2-P

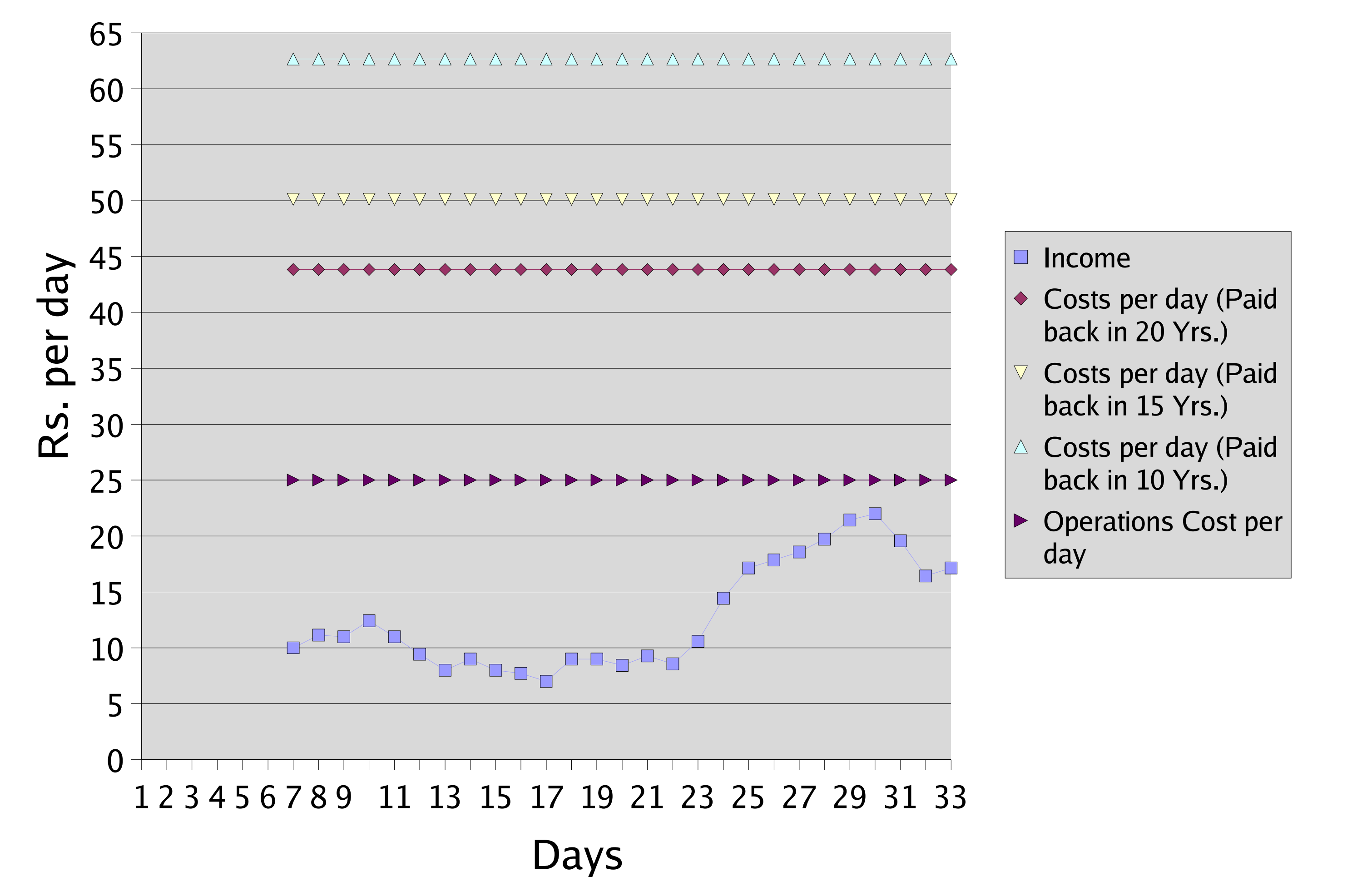
Applications for DGP

Applications for DGP

- Infothela uses DGP for last-hop connectivity
- Telemedicine group for video application
-
- Any rural application requiring connectivity could use DGP

Application Issues

- Voice-over-IP
  - Sarauhan PCO setup using 802.11 in last-hop
  - Experiment in economic viability (Jan/Feb 2004)



Going Forward...

- Implementation and experience with SynOp
  - To operate network under *single* 802.11 channel
  - Collaboration with UCSD/Cal-IT2 for implementation
  - Potential for production after prototyping
- Network monitoring tools
- Experimenting with low-cost antenna towers
- Experience with 802.11g

Going Forward... (continued)

- For commercialization of technology
  - Need lowering of licensing fee
    - Presently about few thousand rupees per 25KHz for long-distance links (higher if above 5km)
  - Or, delicensing, with power restrictions
  - For at least one 802.11 channel

Summary of Contributions

- Establishing technical feasibility of 802.11 for long-distance wireless networking to villages
- Understanding of various costs involved
- Development of simulator for performance studies
- Protocol enhancement for better performance using a single 802.11 channel
- Experiments with applications
- Detailed report at: http://www.cse.iitk.ac.in/users/braman/dgp.html

Conclusions

- >75% of world remains to be networked
  - Optimization point changes
  - Cost reduction is primary concern
  - Power efficiency in various aspects
- Digital Gangetic Plains
  - 802.11 is cost-priced
  - How to tighten the nuts and bolts to adapt the technology for outdoor setting?
- Need lowering of licensing costs, or delicensing for commercialization

Backup Slides

802.11 versus CorDECT

- 802.11 is fundamentally data-based
  - Telecomm. world moving towards a data-centric model
  - Can leverage protocols, standards, applications
- 802.11 can provide up to 54Mbps (at least 11Mbps)
  - CorDECT only a max of 70 Kbps
- Growing popularity of 802.11
  - Falling prices; trend likely to be stronger than for CorDECT

802.11b Channels