Revisiting MAC Design for an 802.11-based Mesh Network

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http://www.cse.iitk.ac.in/users/braman/dgp.html
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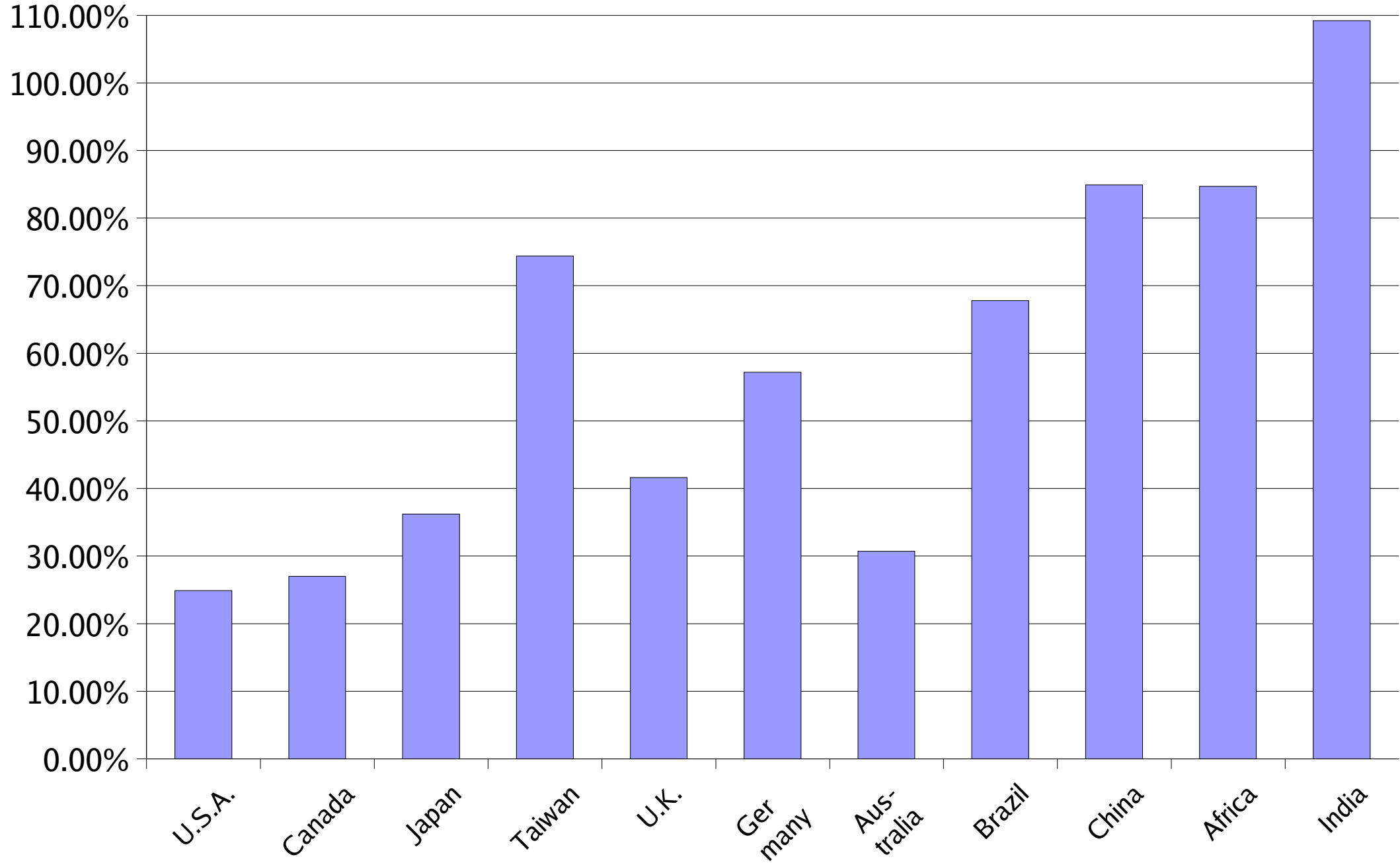
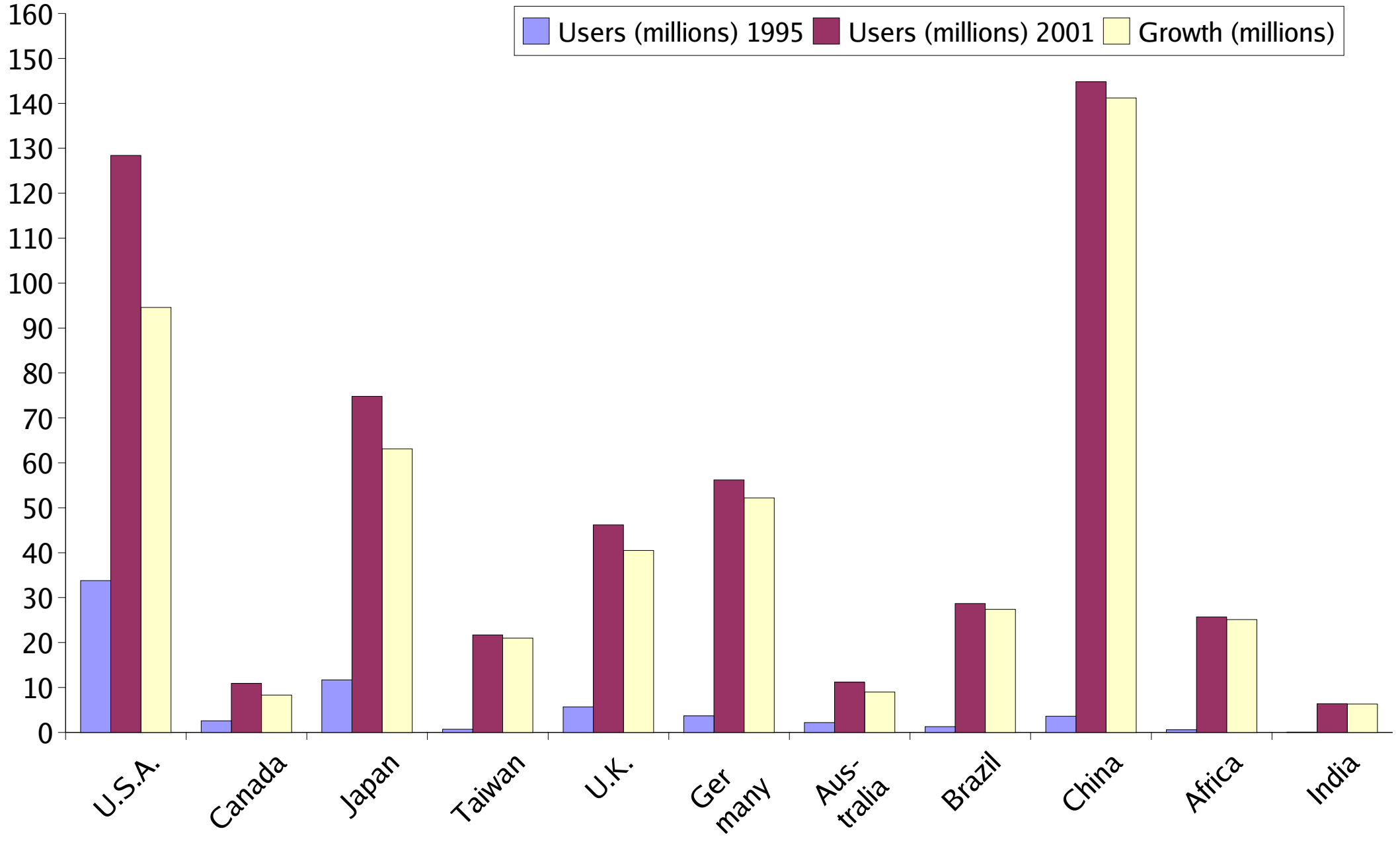
Cell Phones: CAGR 1995-2001



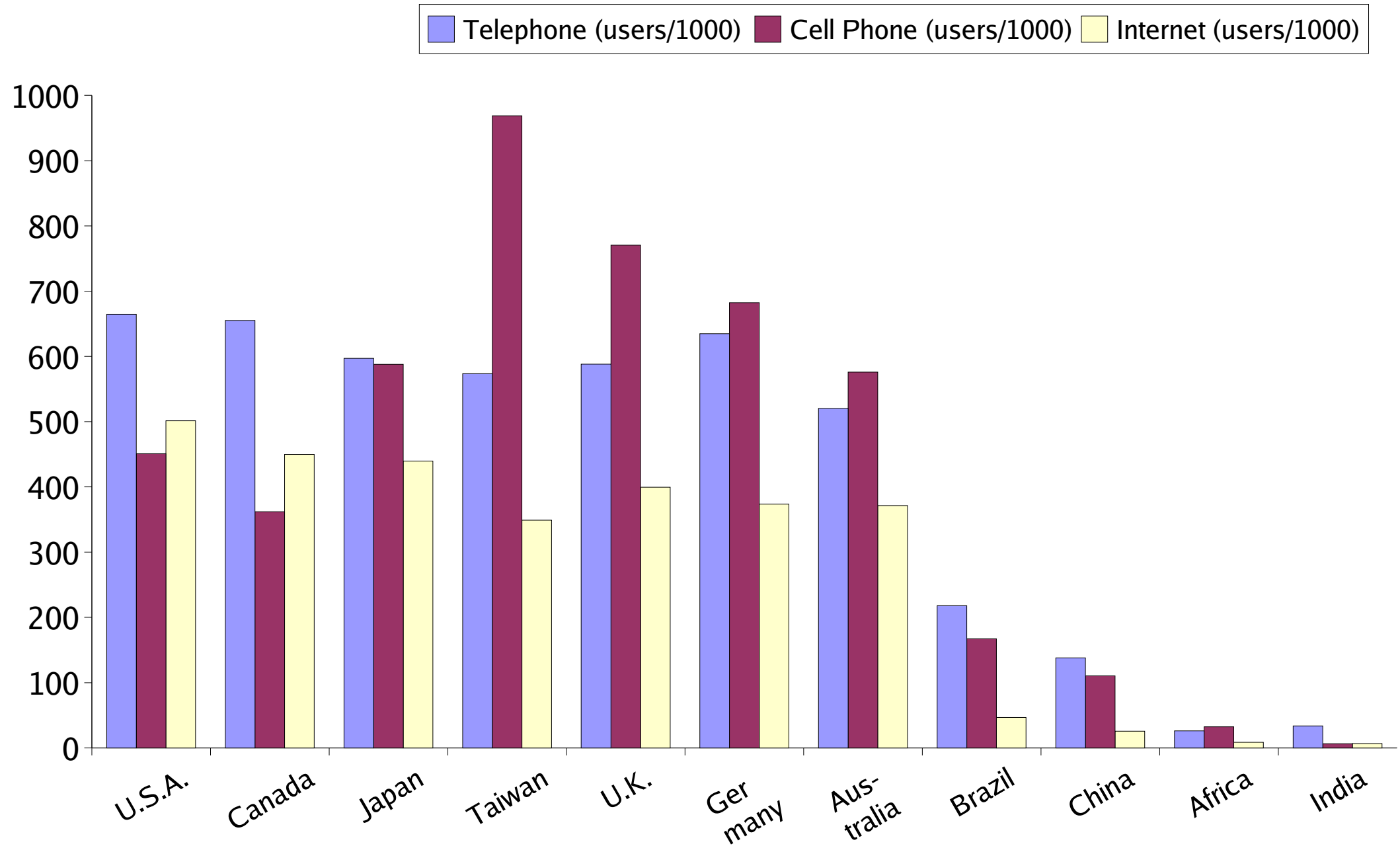
Source: ITU

Cell Phones: Absolute Growth



Source: ITU

Tele-density (2001)



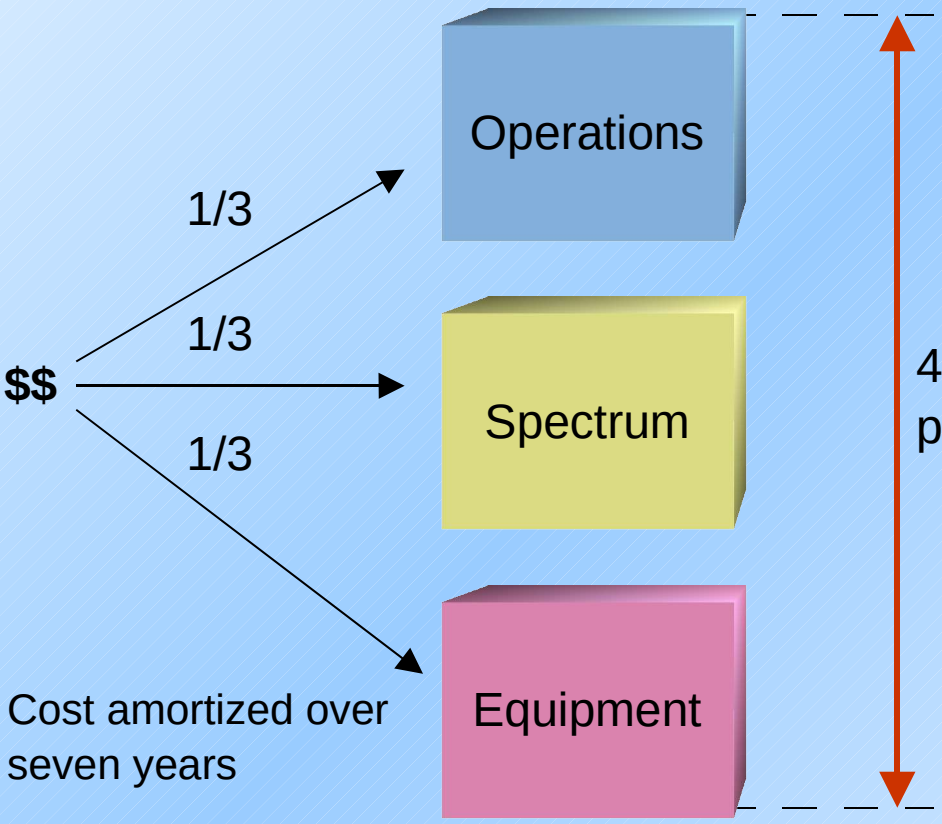
Source: ITU

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



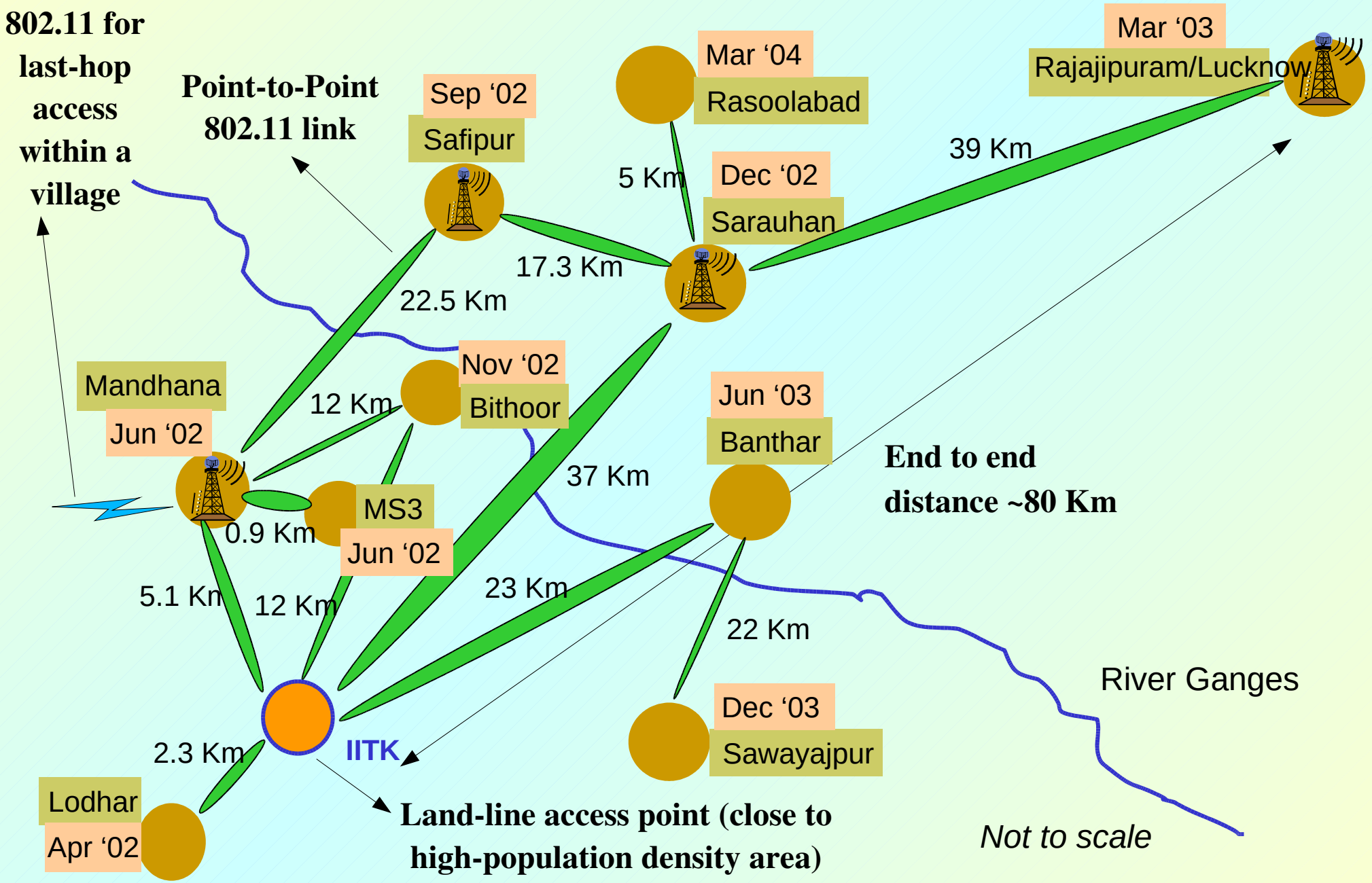
People in developed economies are willing to pay this price because voice is a very high value application

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

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)

Technical Issues

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

PHY issues

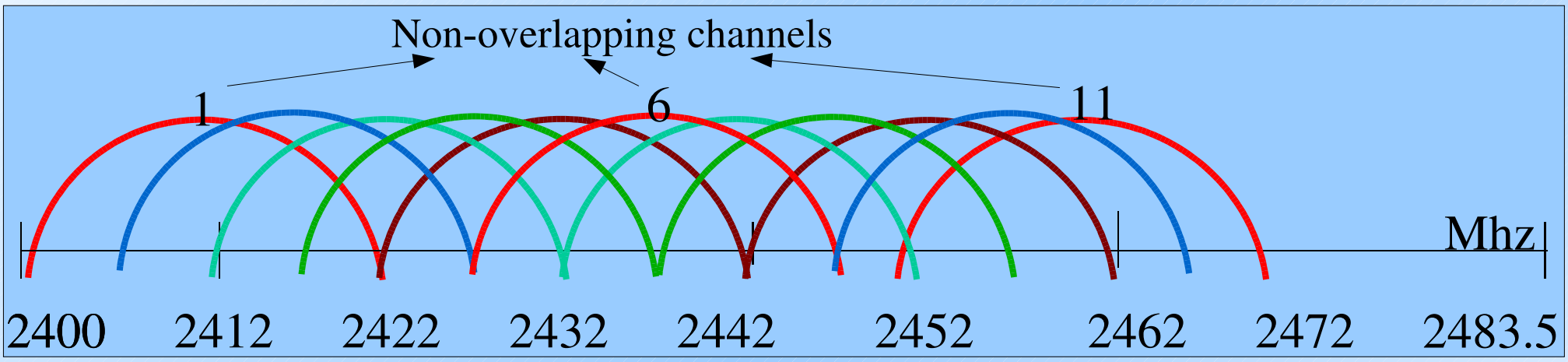
- Empirical path loss models
  - Free space model, with 4-6dB correction fits all the long-distance links
  - Further work: how much area can be lit in last hop?
- Performance under outdoor channel conditions
  - Design of equalizers to overcome multi-path
- Antenna design at low-cost
- Power savings 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

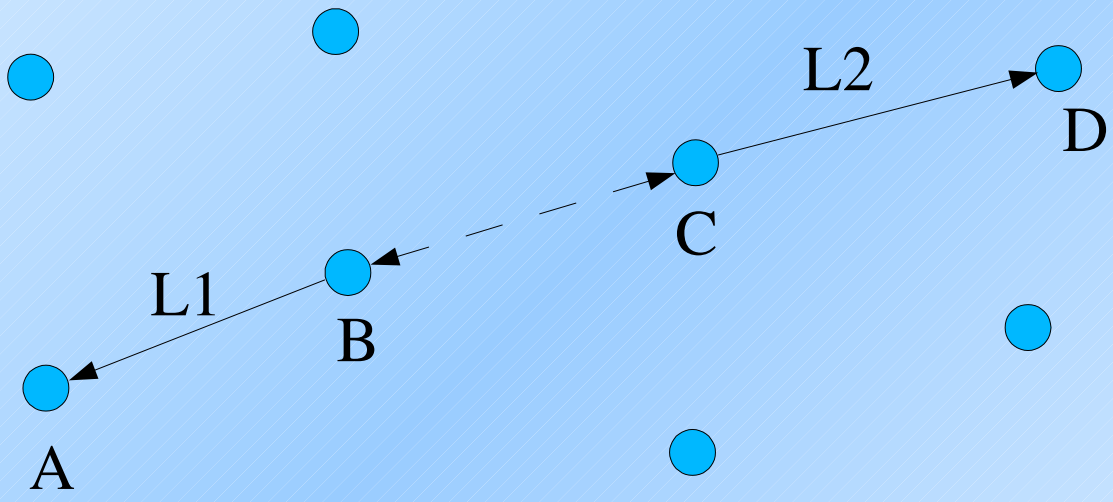


- Constraint: use min. #channels
  - Focus on the use of a single channel
  - Good if channels are licensed
  - Even otherwise, the approach is useful in parts of the mesh network

802.11 CSMA/CA-based MAC

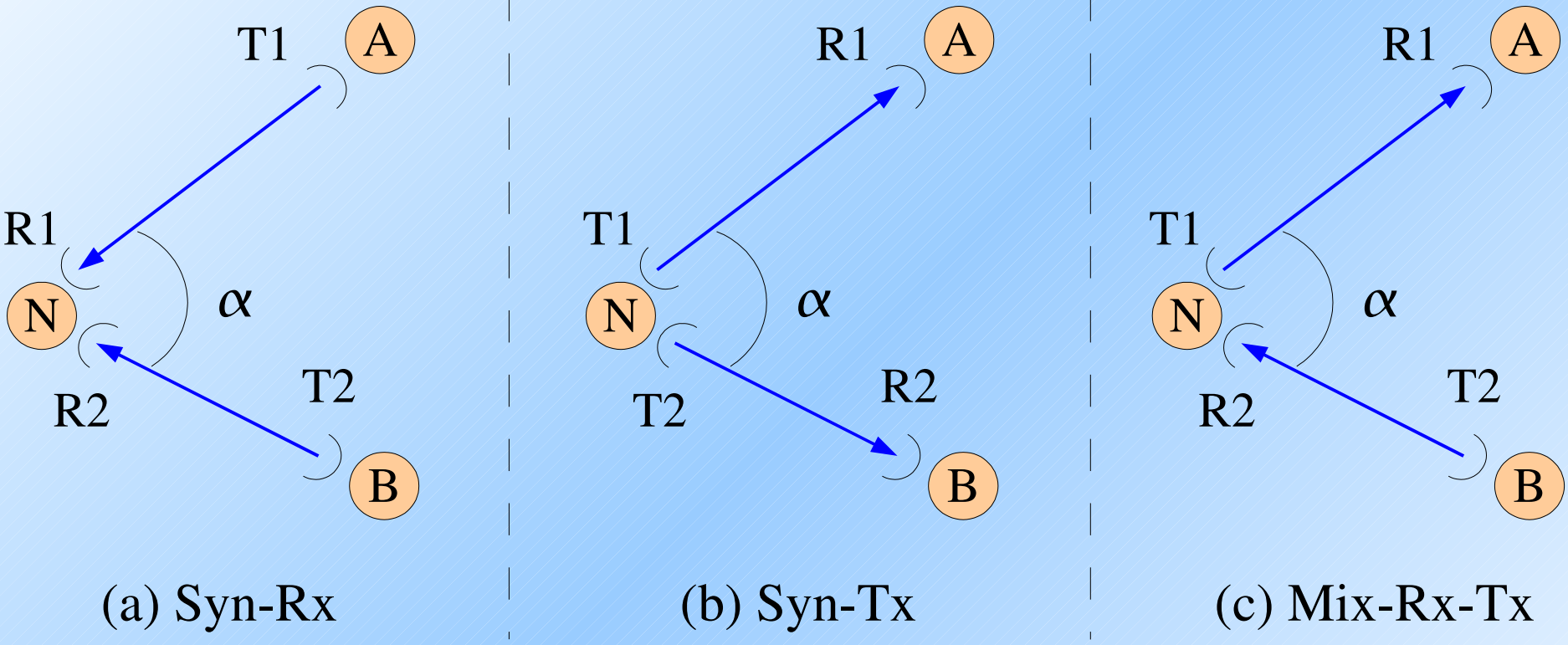
- CSMA/CA
  - Listen before transmit
  - Random backoff
  - RTS/CTS to address the hidden node problem
- Designed for indoor environments
  - Many nodes contending for the channel
  - Broadcast network
- How does it perform in a mesh-network?

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

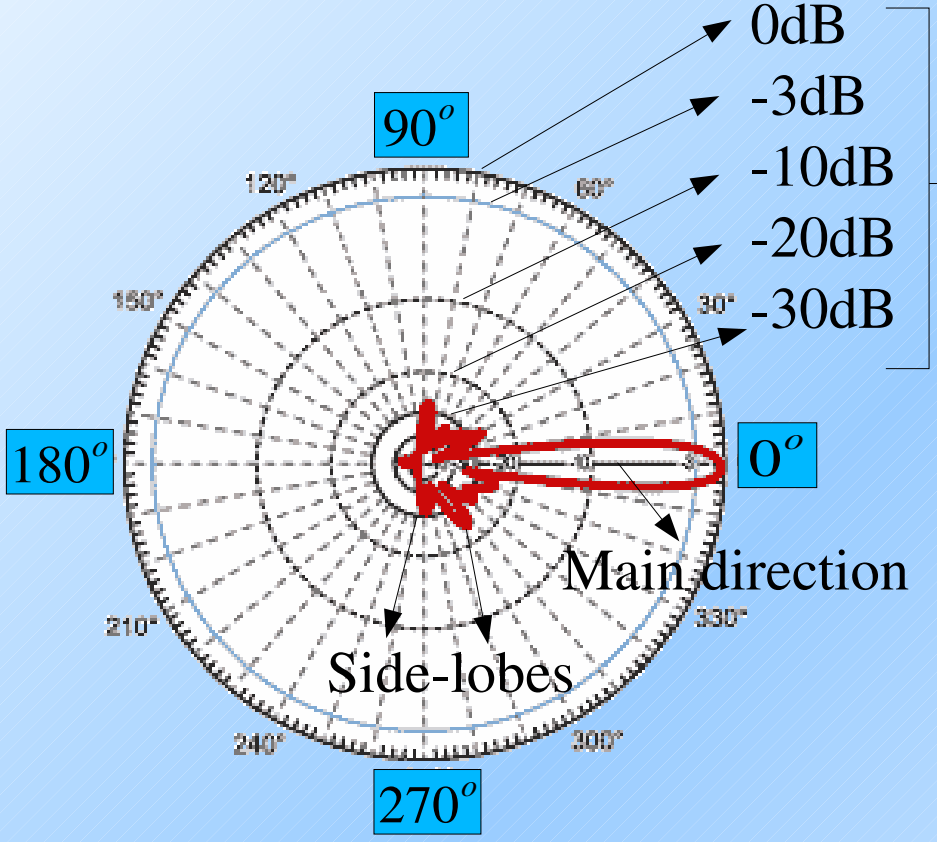
Antenna	RTS/CTS used?	1-hop (Mbps)	2-hop (Mbps)	3-hop (Mbps)
Omni	Yes	4.5	2.2	1.5
Omni	No	6.1	3	2
Dirnl.	Yes	4.5	2	1.9
Dirnl.	No	6.1	2.8	2.7

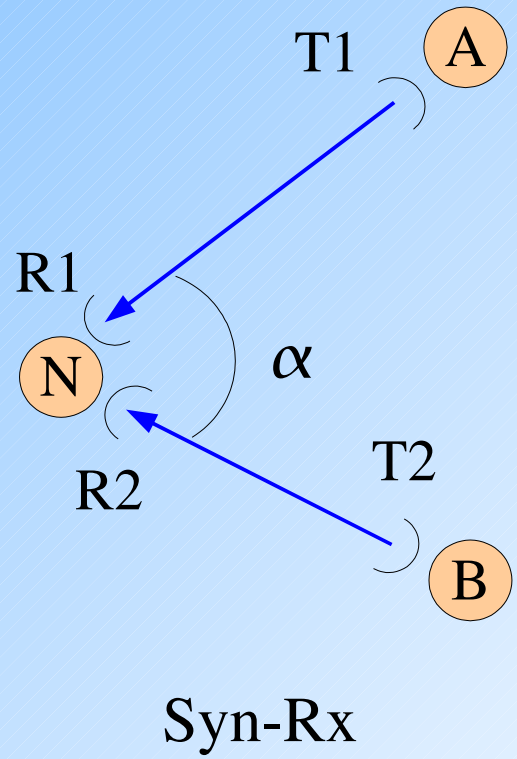
- Throughput of saturating UDP traffic
- Simulations using ns-2 (S. Roy and Ashwini)
- 3-hop shows exposed node problem (omni)
- Exposed *interface* problem with directional antennae

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

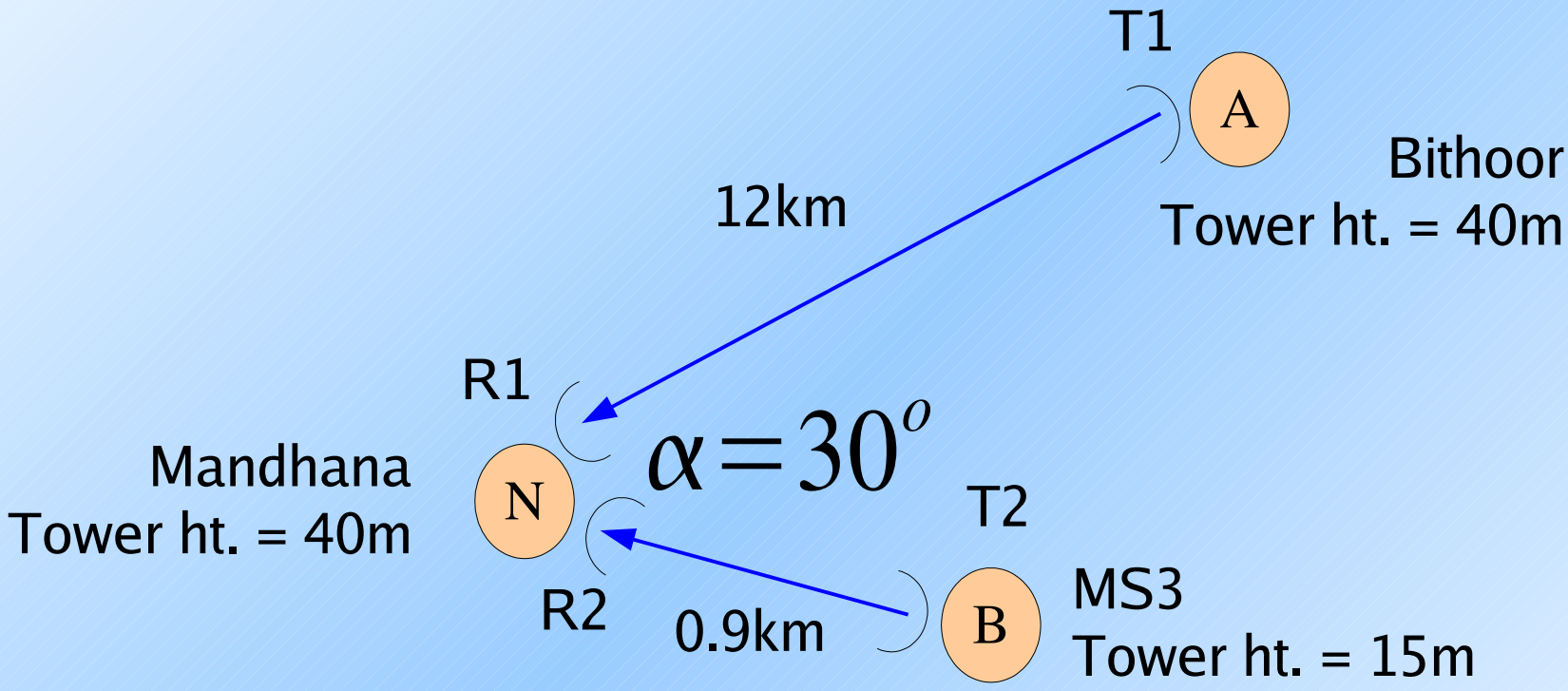
SynOp Feasibility





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

SynRx: Experimental Verification



Used *broadcast* packets on both links

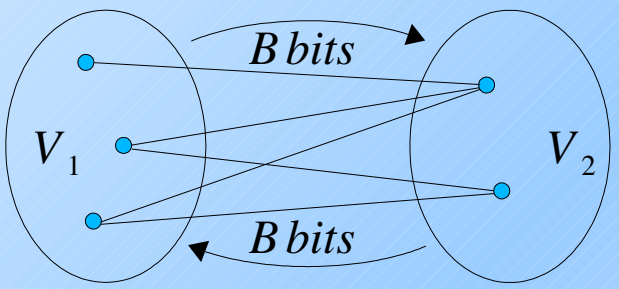
6.5 Mbps with and without simultaneous operation

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

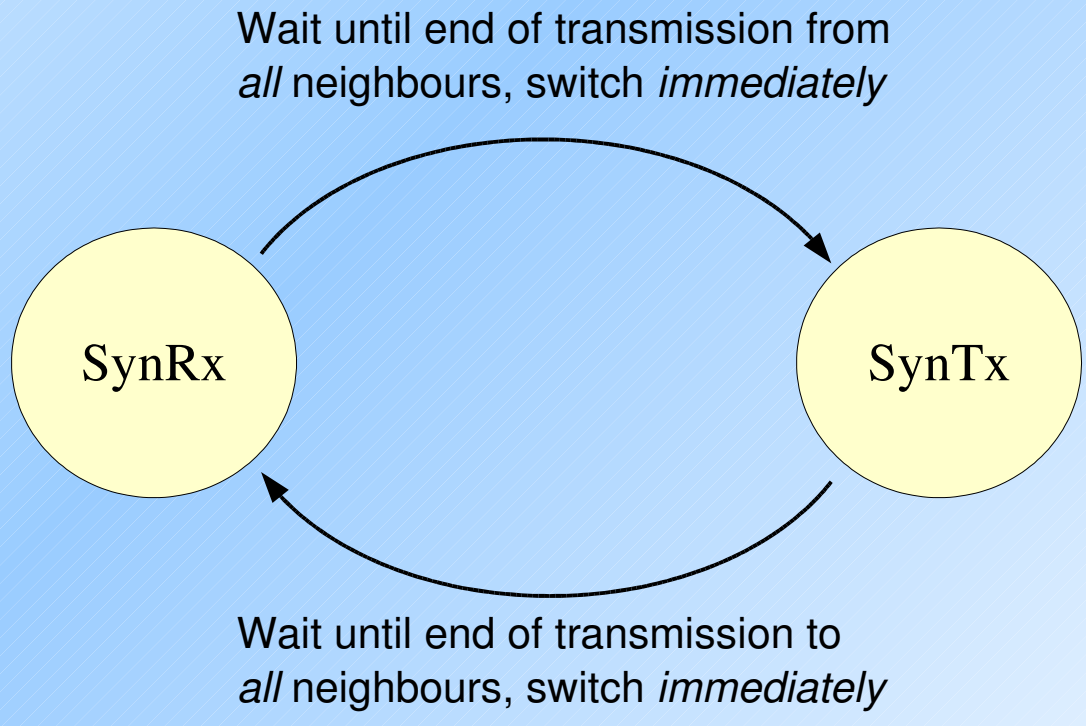
- 2-P: each node switches between SynRx and SynTx
- When a node is in SynRx, its neighbours are in SynTx, and vice versa



- 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

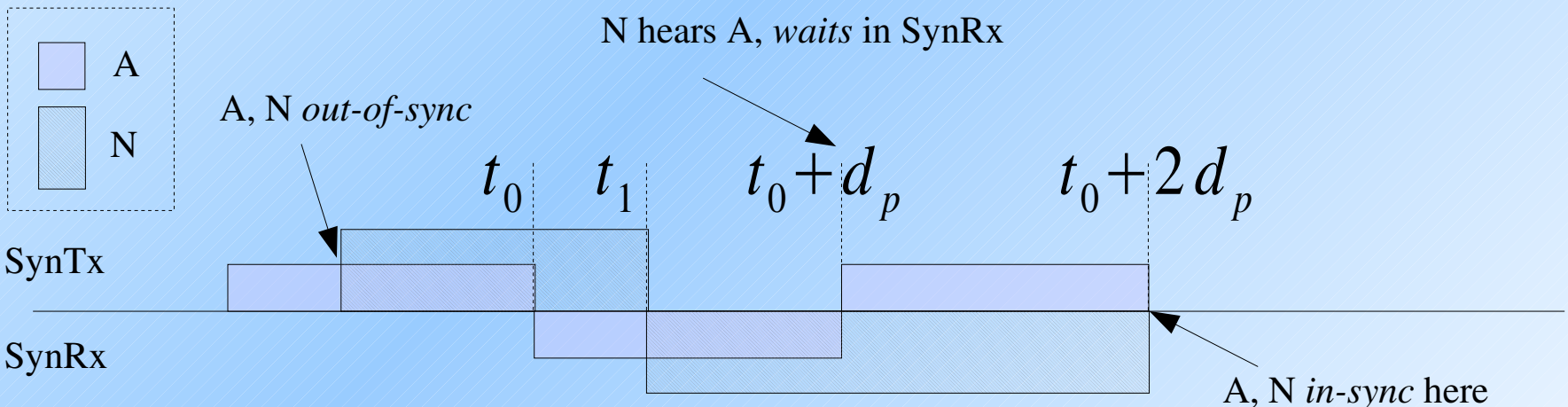
- Not necessary that all nodes in a partition are in the same phase
  - Does not matter
- Robust to packet CRC errors
- What about packet loss?
  - Timeout mechanism needed

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

Summary and 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?
- MAC design:
  - Mesh network performs like a wired network
  - **2-P/SynOp** applicable in other scenarios as well