Turning 802.11 Inside-Out

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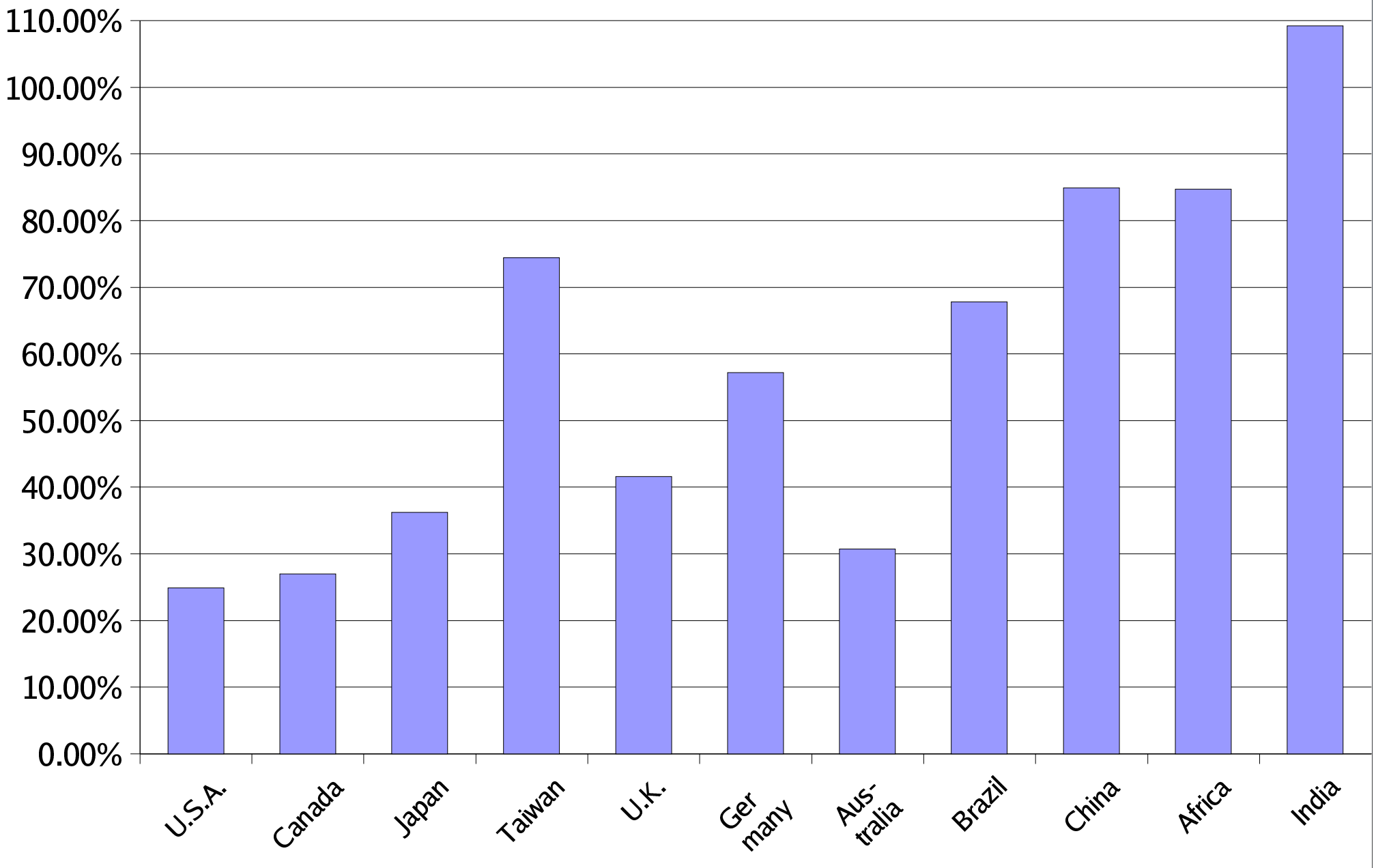
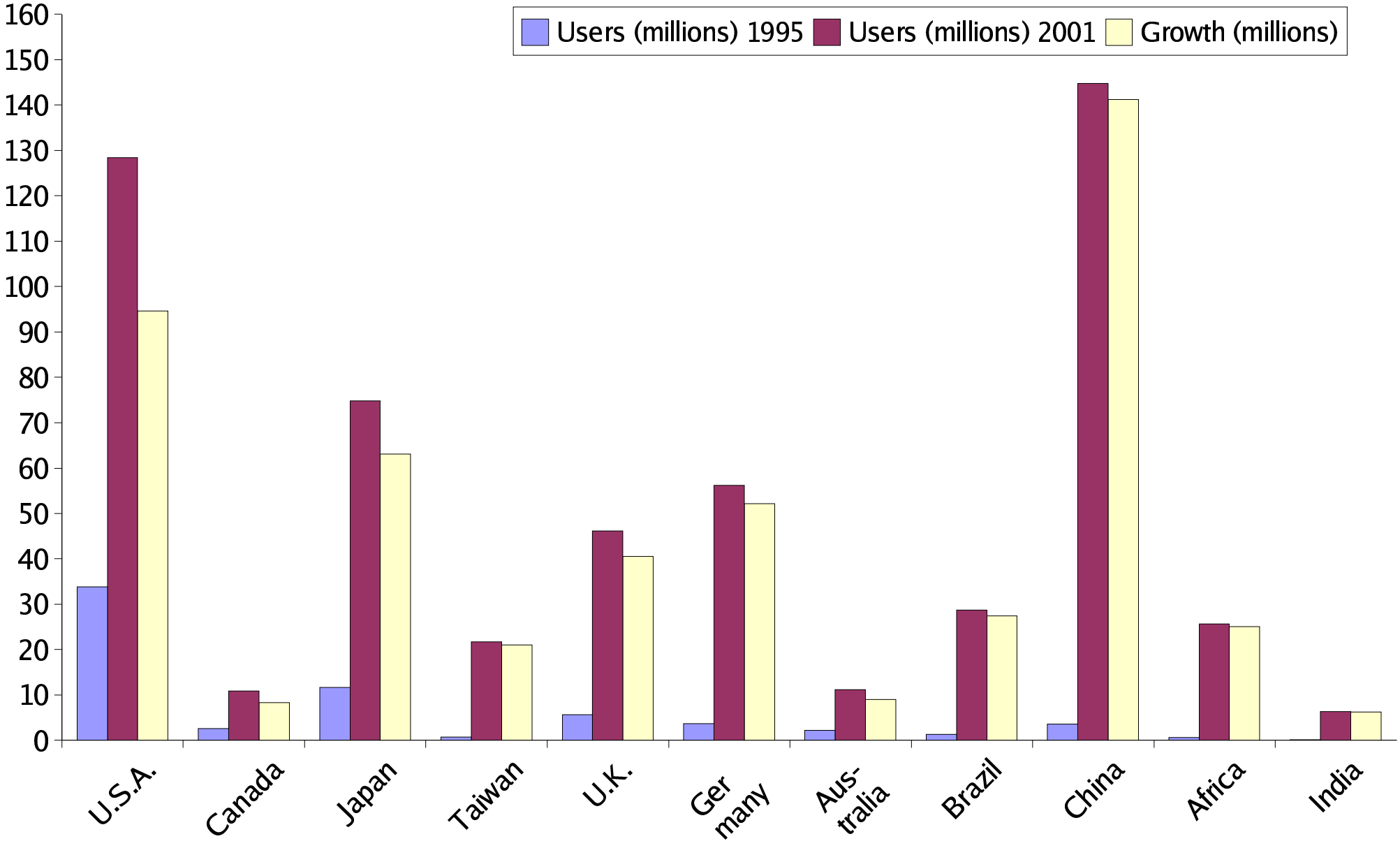
Cell Phones: CAGR 1995-2001



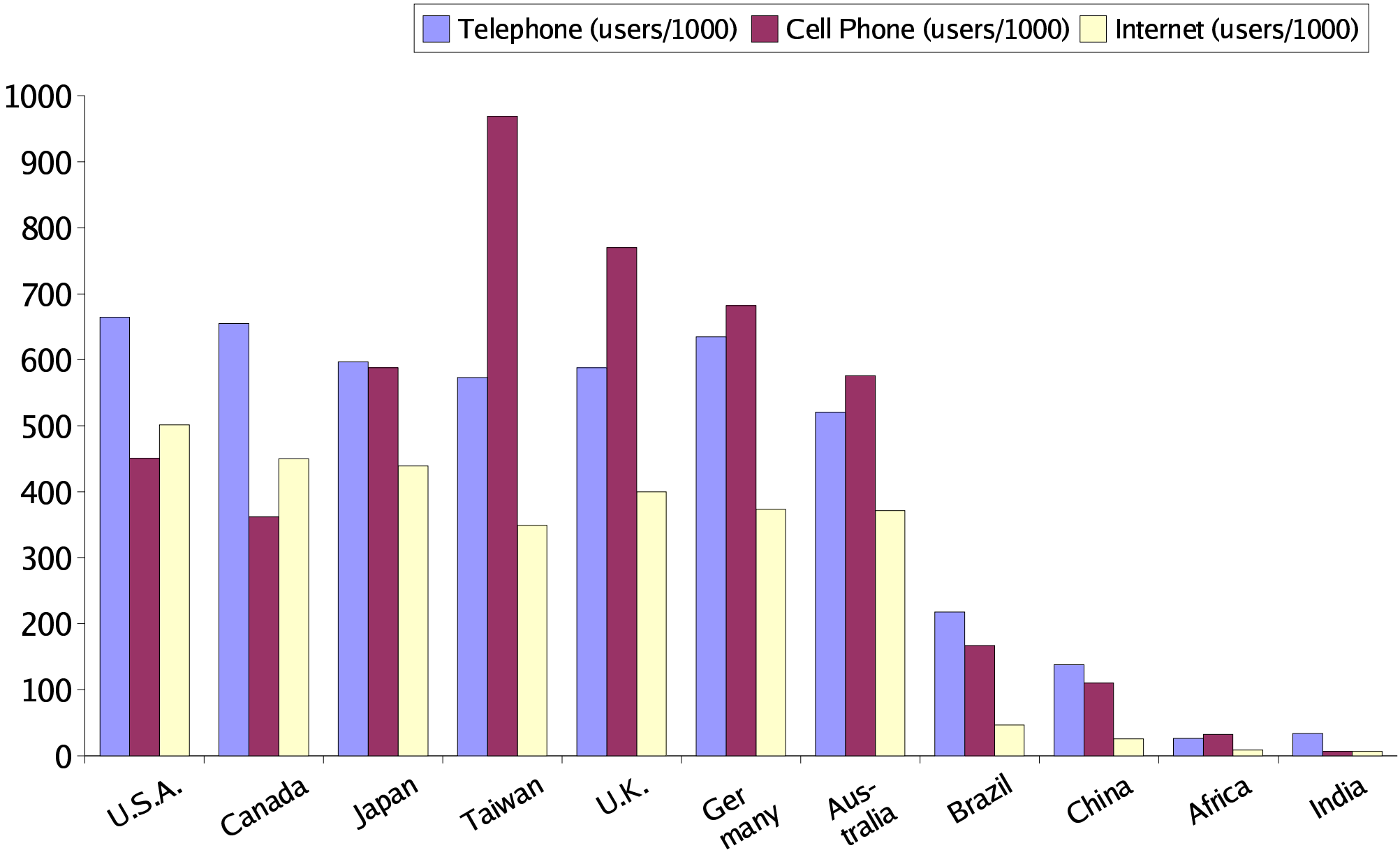
Source: ITU

Cell Phones: Absolute Growth



Source: ITU

Tele-density (2001)



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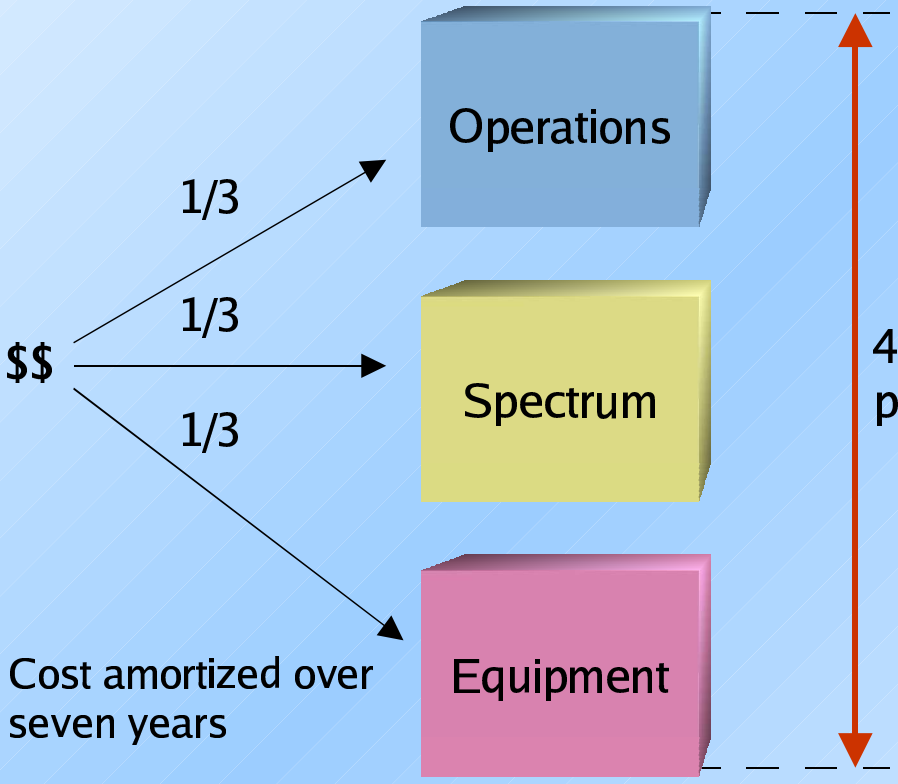
Barriers to Digital Empowerment

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

400 million lines ==> $80 billion

Value Pricing of Cellular Technology



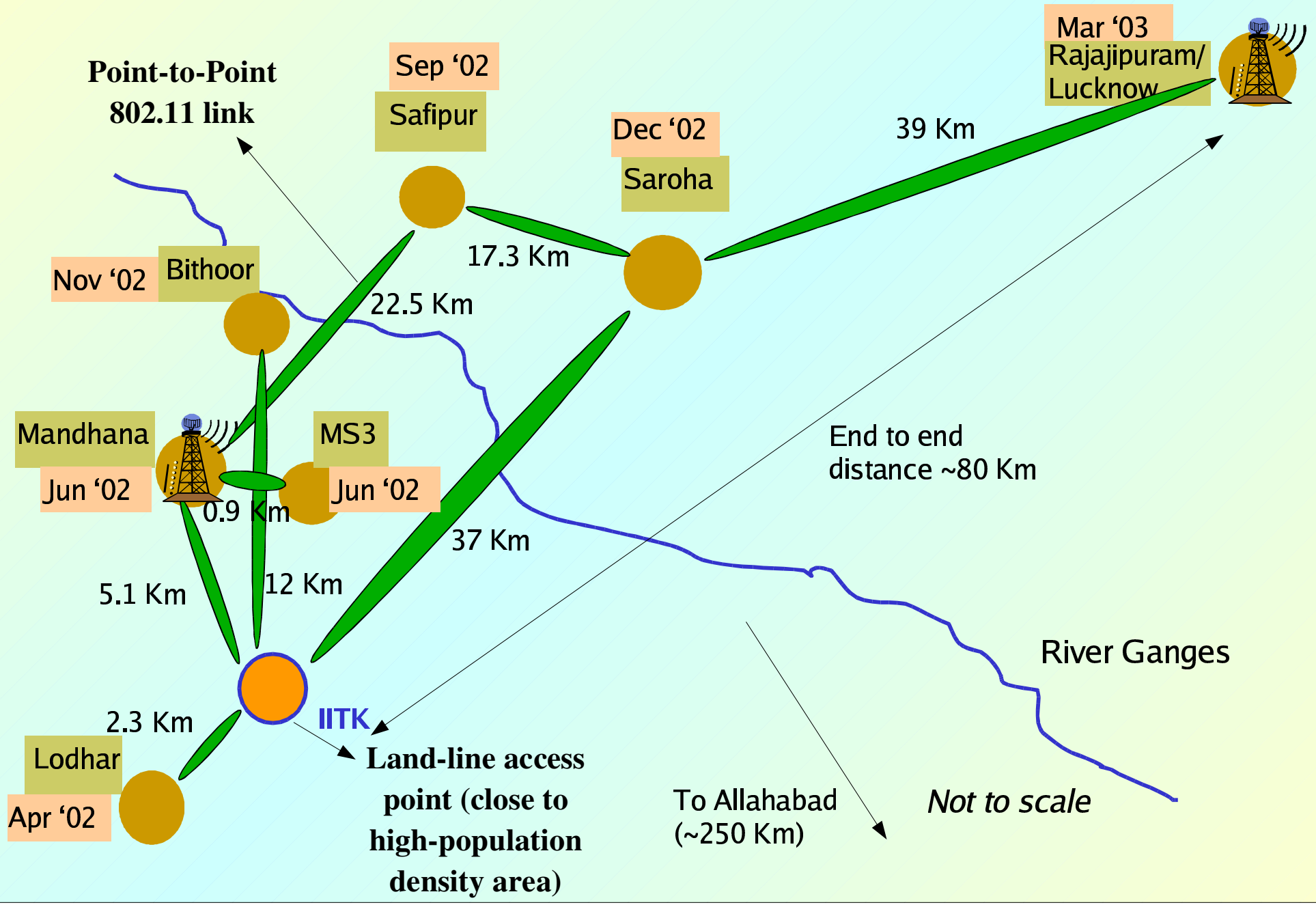
People in developed economies are willing to pay this price because voice is a very high value application

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

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

PHY issues (1 of 3)

- 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 (2 of 3)

- 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 30W each

PHY issues (3 of 3)

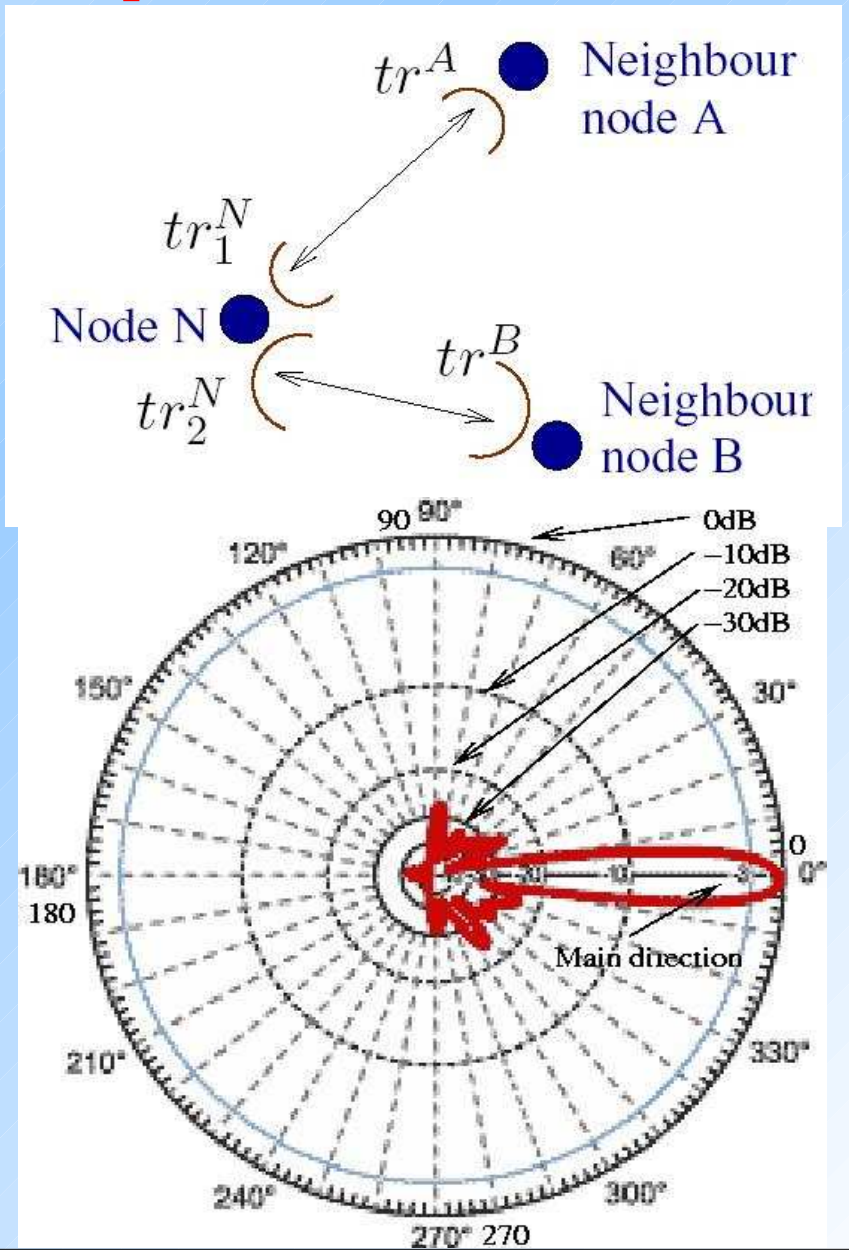
- Spectral efficiency versus cost trade-off
  - Spectrum is very valuable in western markets
  - Hence lot of effort in spectral efficiency
    - Complex channel encoding, modulation methods
    - Throw more signal processing power
  - System cost reduction more important than spectral efficiency in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

MAC for Long-Distance Links

- Contention-based MAC not suited
  - Slot time, ack timeouts should be larger
  - Use of RTS/CTS wastes round-trip
    - 30km round-trip ==> 100 micro-sec
    - 1000 byte transmission at 11Mbps ==> 700 micro-sec
- No arbitrary contention resolution required
- Spatial-reuse Time-Division Multiple Access (STDMA)

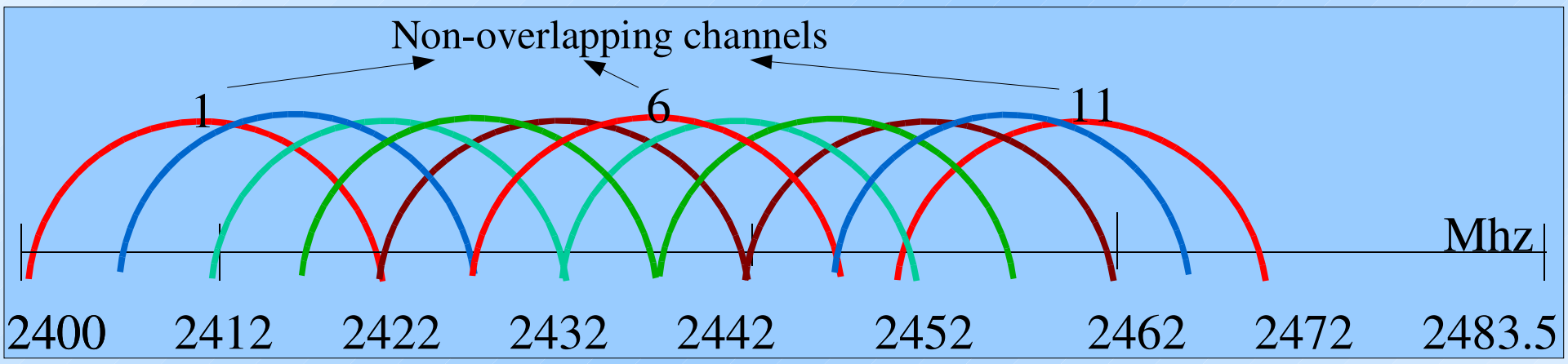
SymOp: Simultaneous Synchronous Operation

- System characteristics: fixed topology, directional antennae
- Can links at a node operate independently?
  - Not really, side-lobe and back-lobe leakages
- But, simultaneous reception (transmission) possible
  - With careful power engineering
  - And, sufficient angular separation



Data Link Layer: Further Issues

- Scheduling based on SymOp
- Channel allocation for links



- Power allocation for transmitters
- Link-Layer Control:
  - Packet aggregation
  - ARQ window size of > 1

Routing Issues

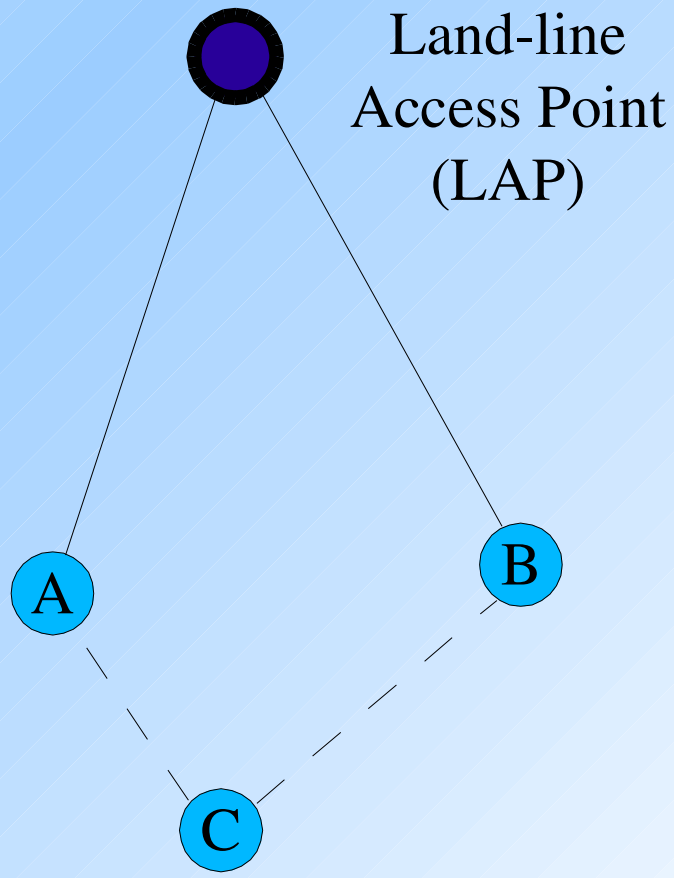
- Routing:
  - Conveying reachability information
  - Routing around congestion/failure
- 802.11 mesh network
  - *Dynamically configurable, at will*
  - Presence of links, and
  - Their capacities

Routing and Reconfigurability

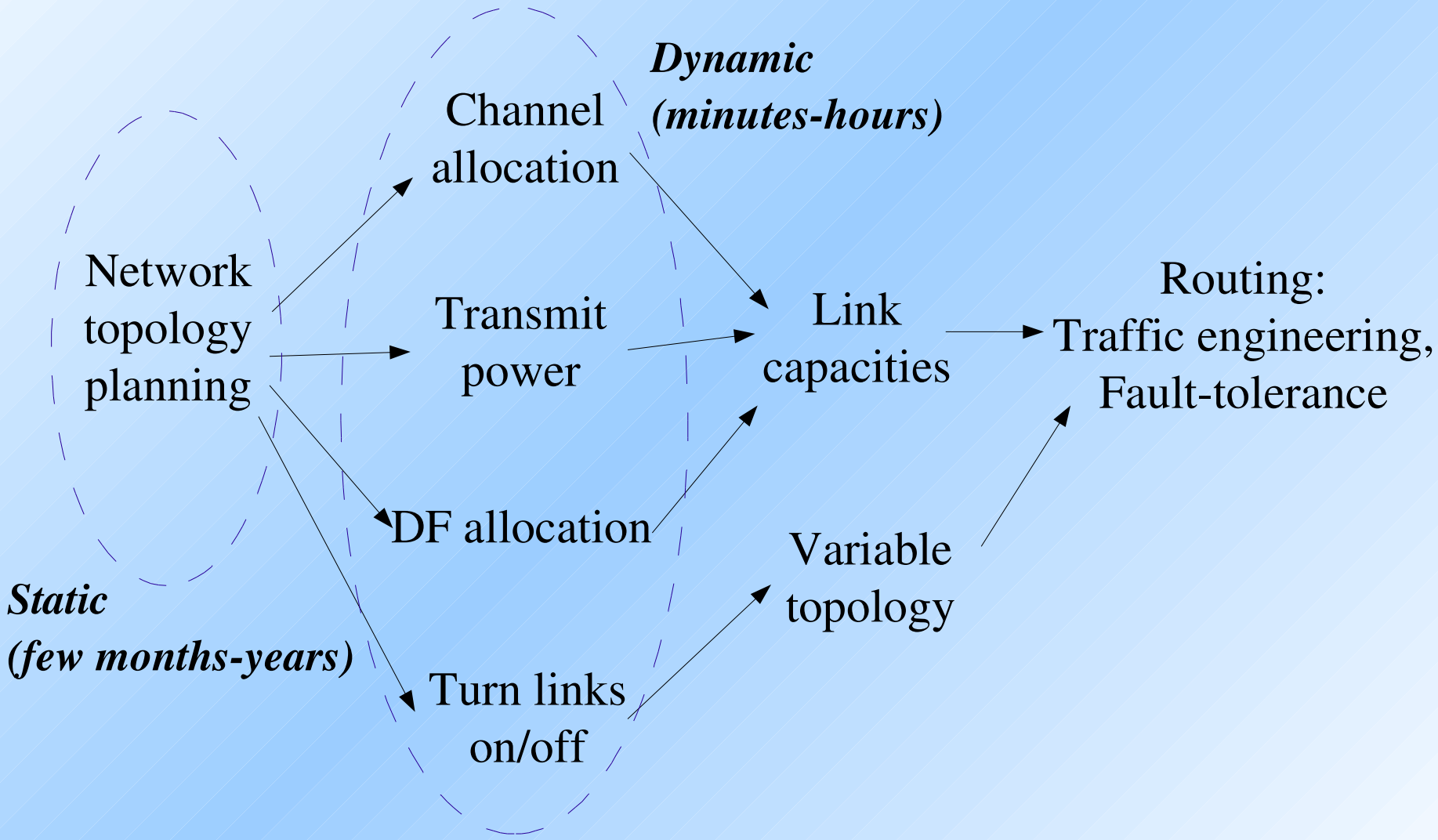
- Half-duplex link: how much in what direction?
  - *Desired Fraction (DF)* in a particular direction
- Channel allocation for a link
  - Decides DF dependence across links
- Power allocation for a link
  - 11Mbps, 5.5Mbps, 2Mbps, 1Mbps

Routing and Topology Creation

- Topology itself can be variable
- Need to provision APs and antennae appropriately
  - For fault-tolerance
- Very different from wired networks



Topology Construction and Reconfiguration: Morphing



Other issues

- TCP over multi-hop wireless
  - Currently a lot of attention in ad-hoc community
  - Our network is not ad-hoc
  - Directional links
  - MAC likely different from 802.11 MAC
- Operational issues
  - What is the right regulatory framework?

Summary and Conclusions

- >75% of world remains to be networked
- Optimization point changes
  - Cost reduction is primary concern
  - Power efficiency in various aspects
  - Different business models likely (than western markets)
- Digital Gangetic Plains
  - 802.11 is cost-priced
  - How to tighten the nuts and bolts to adapt the technology for outdoor setting?
  - Two issues under study: **SymOp, Morphing**