A MAC for WiFi Mesh Networks

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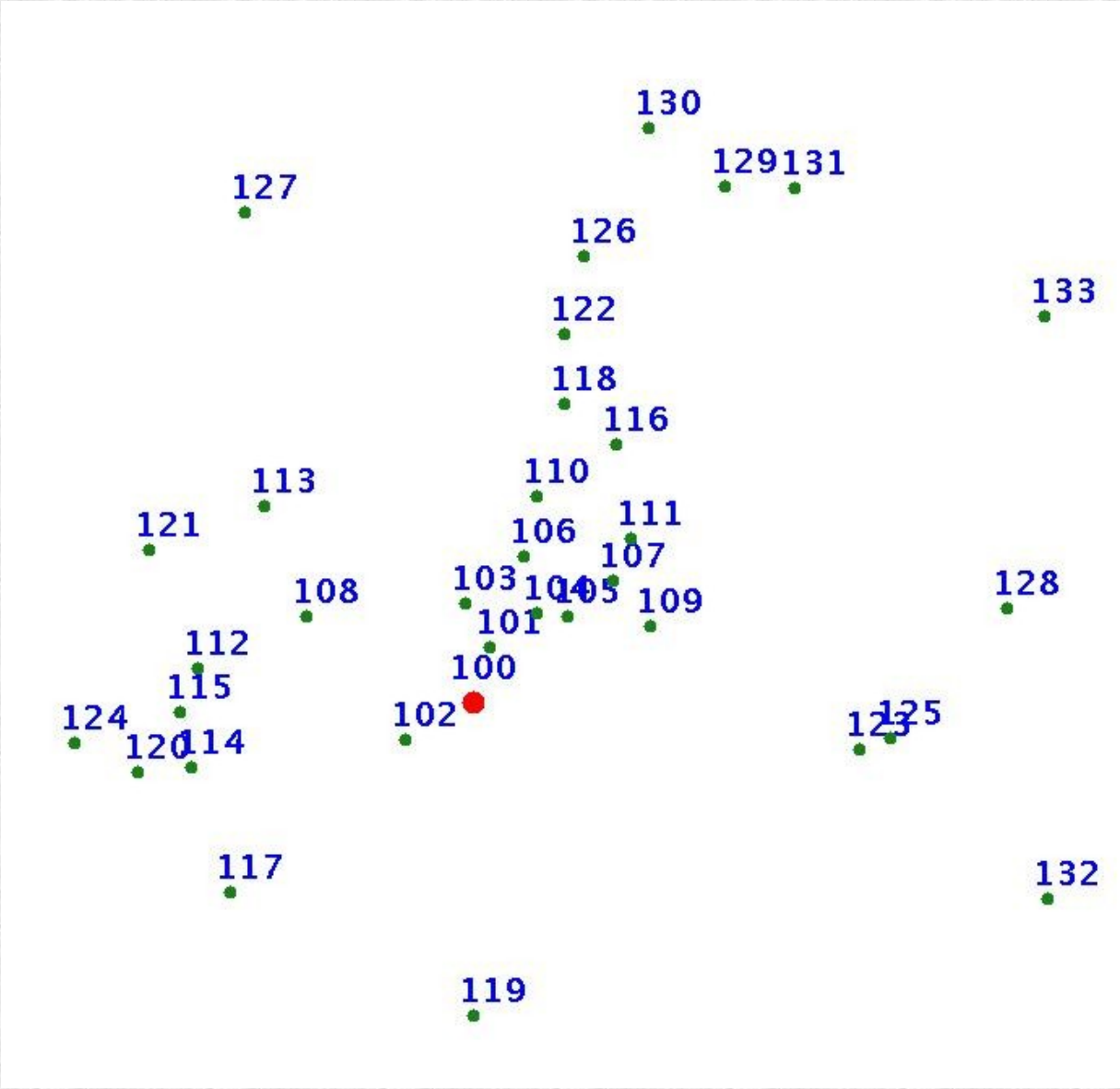
IEEE 802.11 (WiFi)

- Originally designed as a replacement (extension) for wired LANs
- Multi-hop mesh networks are very popular
  - Wireless community networks in cities
    - Share wired Internet broadband connections
    - Replacement for last-hop telephony?
  - Wireless Internet in rural areas
    - Developed as well as developing countries

A WiFi Network in Djurslands, Denmark

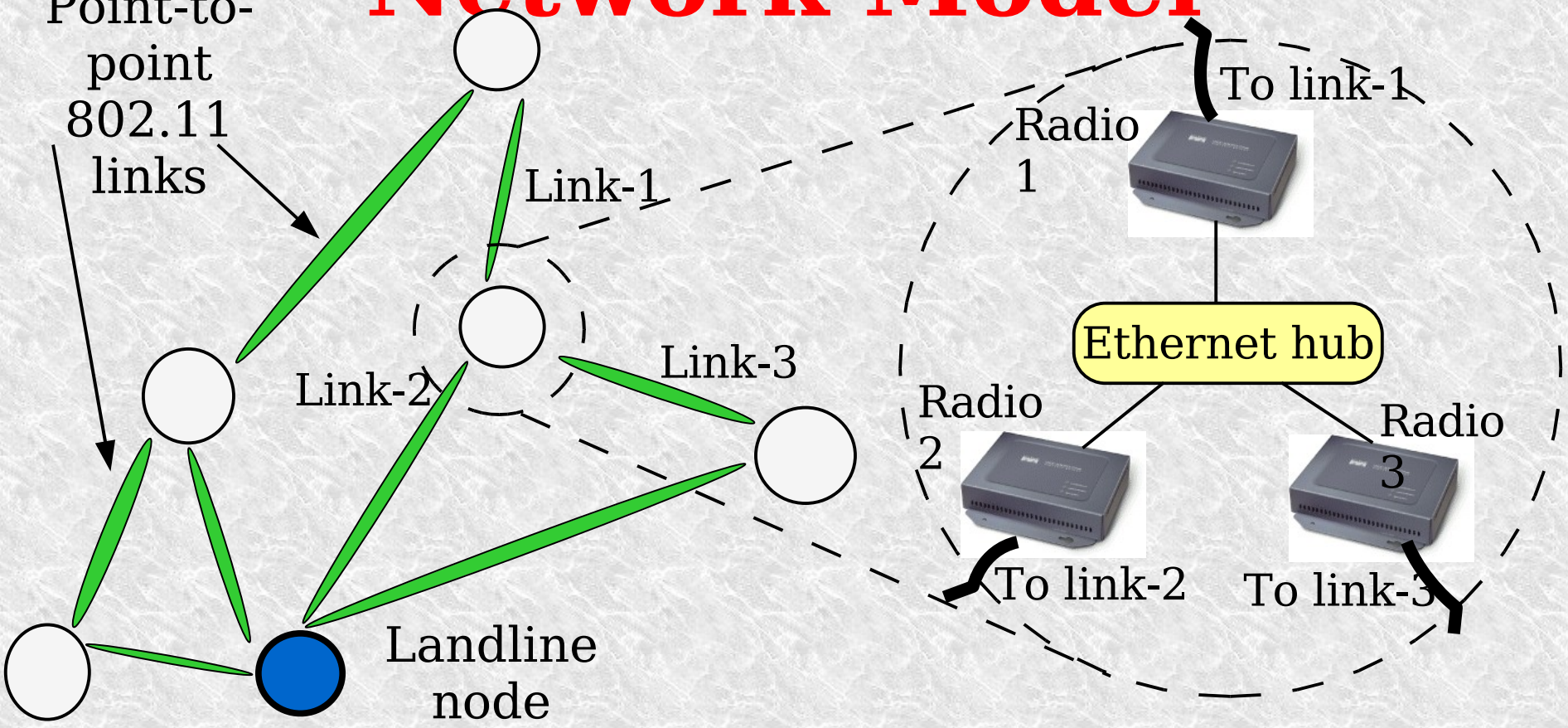
- www.DjurslandS.net
- Remote area of Denmark
  - No broadband
  - Operators do not see returns to investment
  - 802.11 mesh network used for broadband connectivity

A WiFi Network (planned) for Bhimavaram, A.P., India



- Requirements:
  - Need 384 Kbps video for telemedicine and educational apps
    - This is the requirement per-village
  - Cost should be as low as possible
    - So that the network model is replicable
- WiFi is the only serious option

Network Model

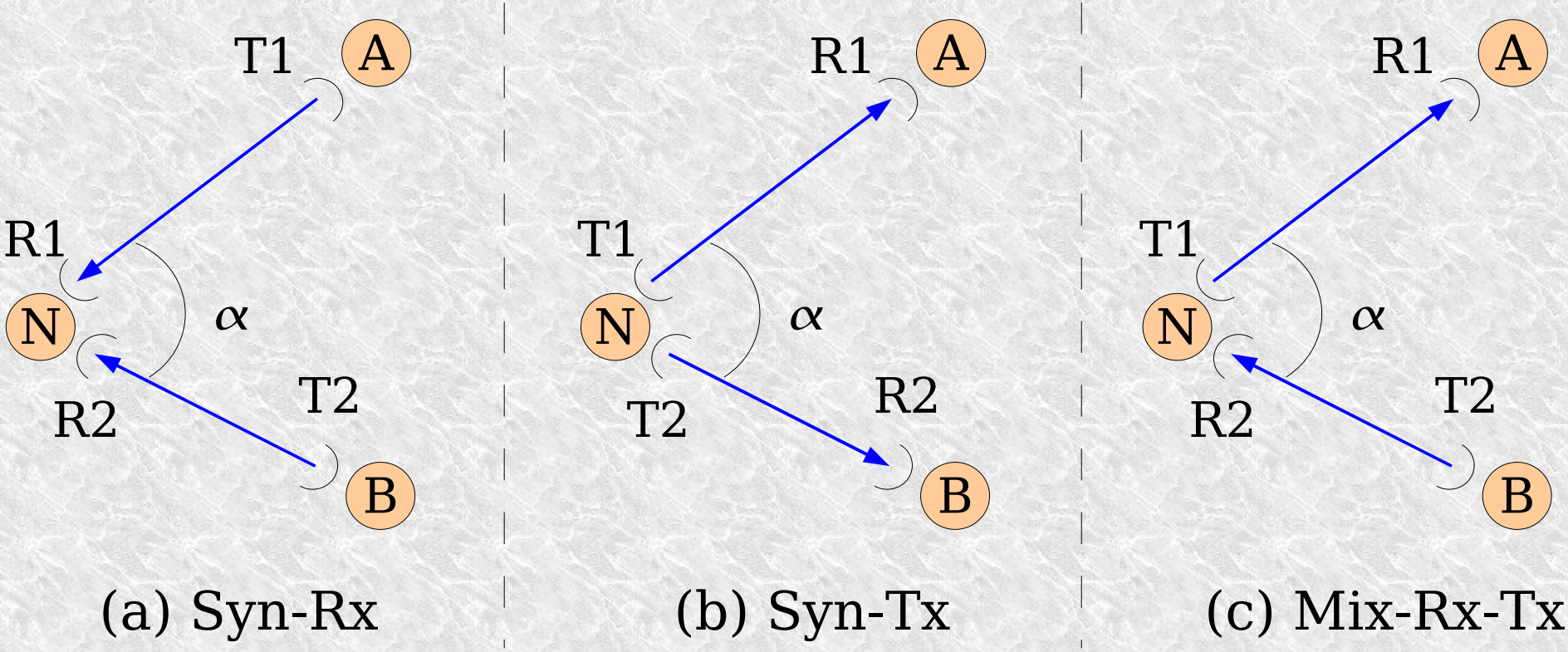


- Point-to-point links
- Multiple interfaces (radios) per node
- One directional antenna per link

Single Channel Operation

- 802.11b has only three independent channels
- 802.11a has twelve independent channels
  - Four are meant for outdoor use
- Why only a single channel for the mesh?
  - Mitigation of “RF pollution”
  - The mesh may not be 3-edge-colourable
  - If the frequency is licensed, more channels could imply more cost

SynRx, SynTx, and Mix-Rx-Tx



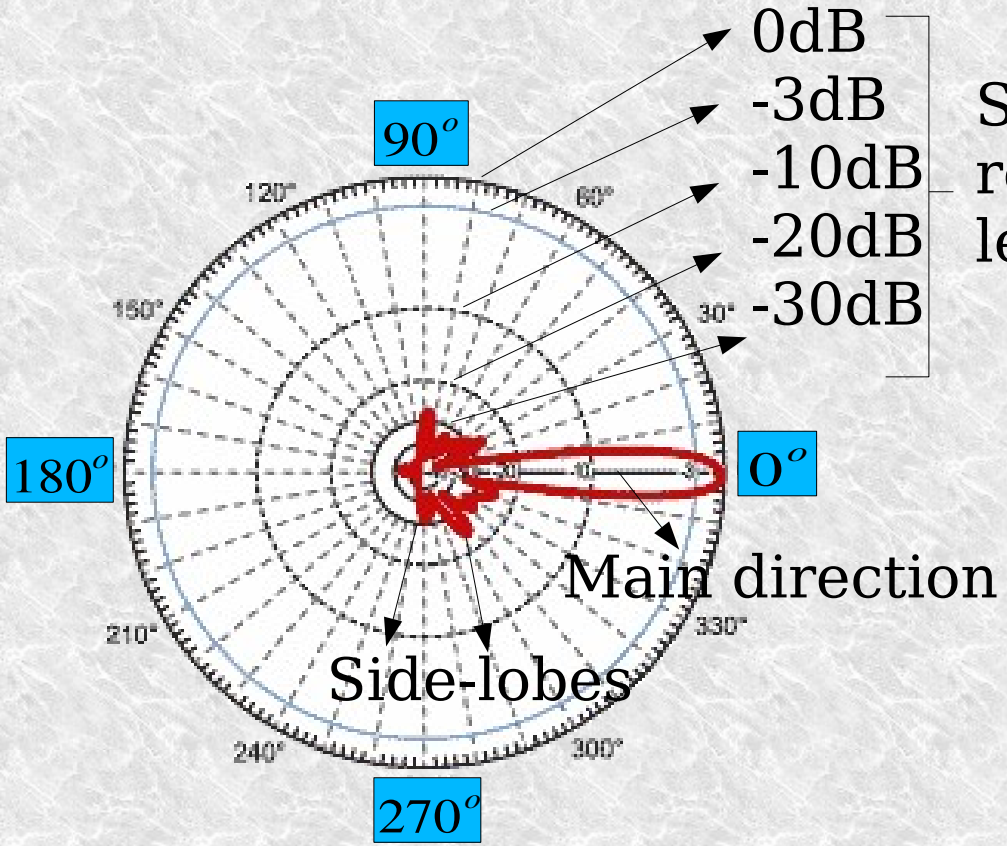
Exposed interface problem within a node:

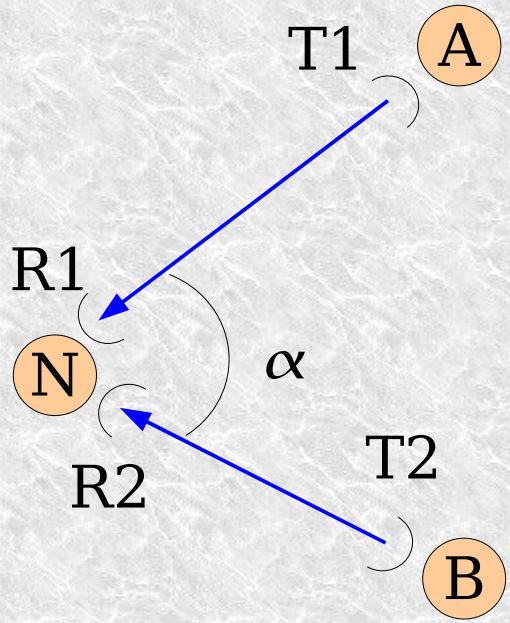
CSMA/CA (802.11 DCF) inherently allows only one link operation per node

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

SynOp: SynRx + SynTx

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

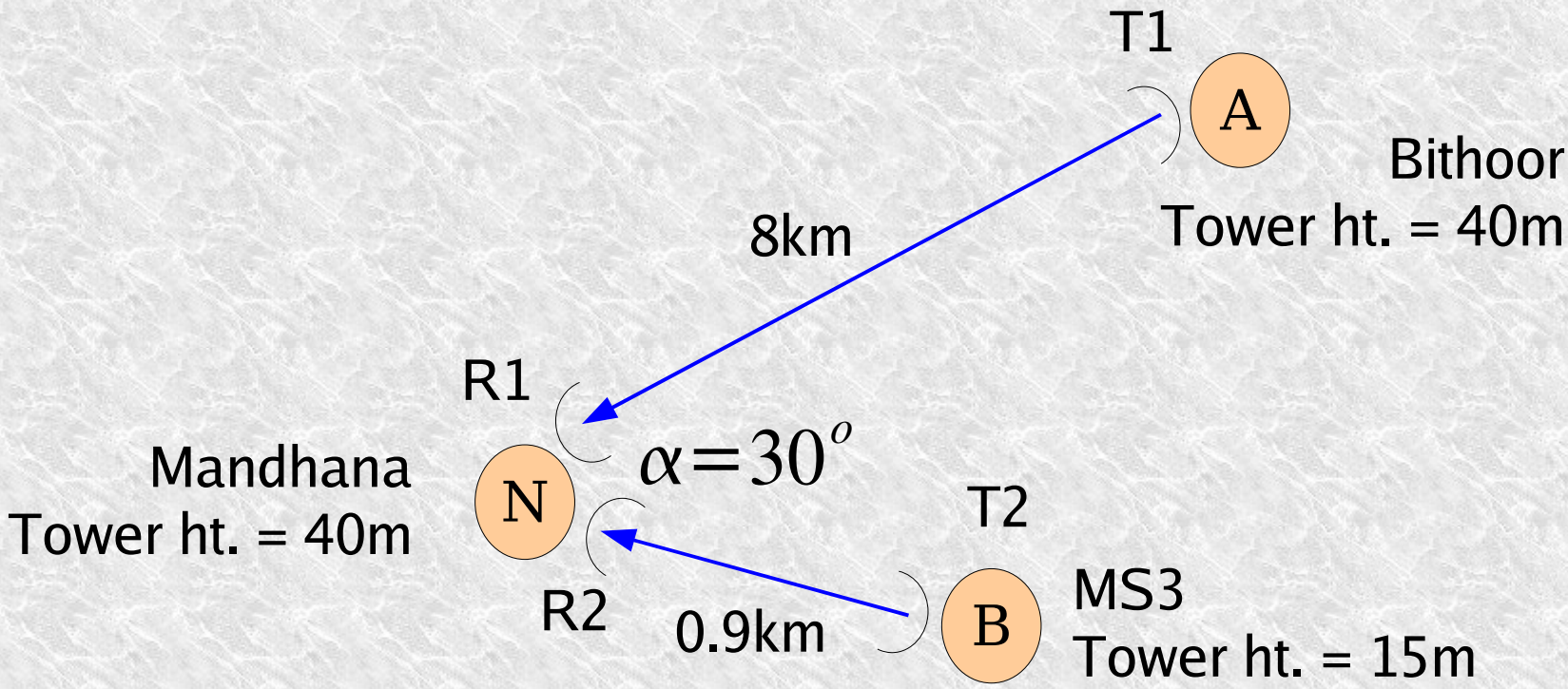




Syn-Rx

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

SynOp: Experimental Verification



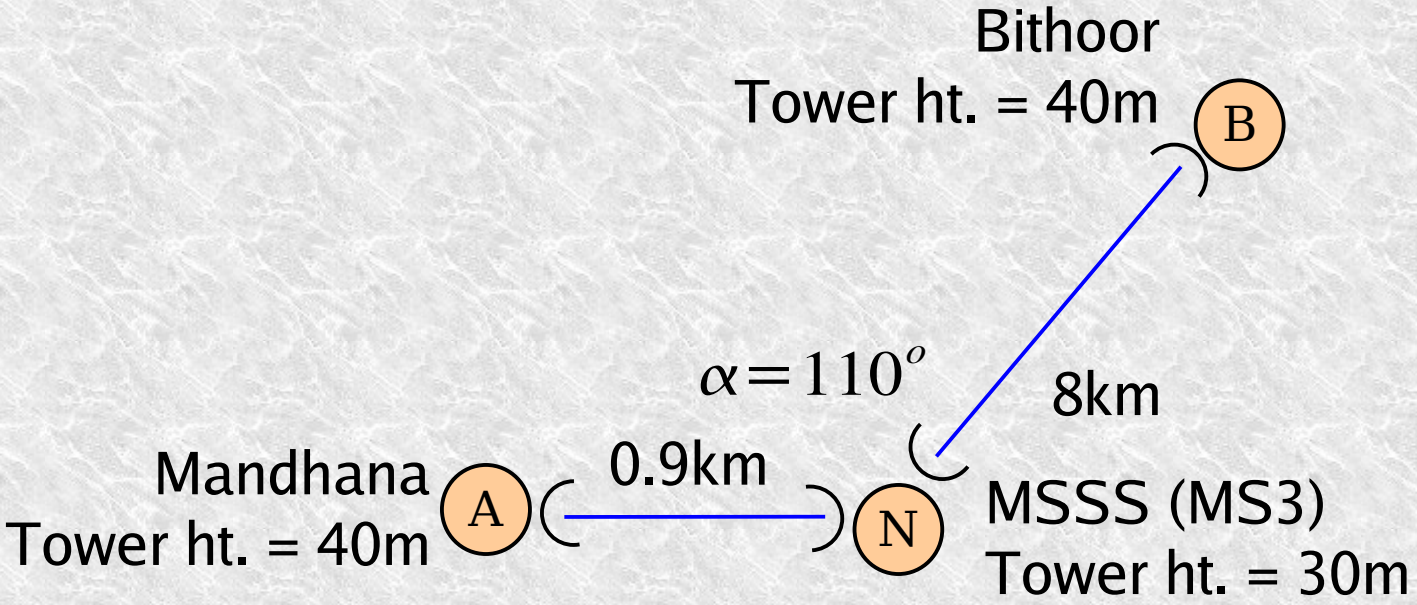
Used broadcast packets on both links (SynRx, SynTx)

6.5 Mbps with and without simultaneous operation

SynTx also verified – using antenna diversity for the setup

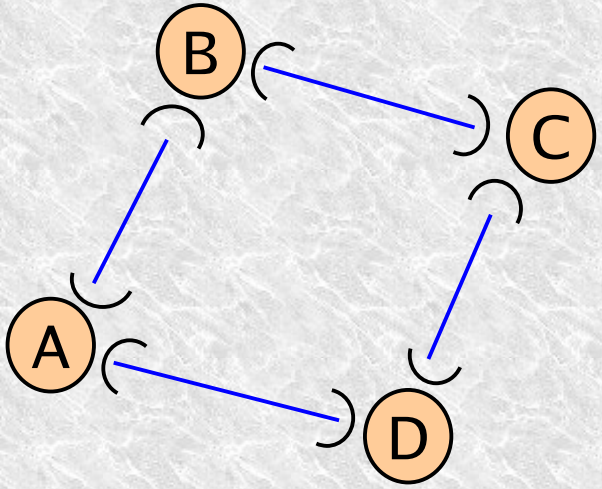
Experiments along with: A. R. Harish & Sreekanth Garigala

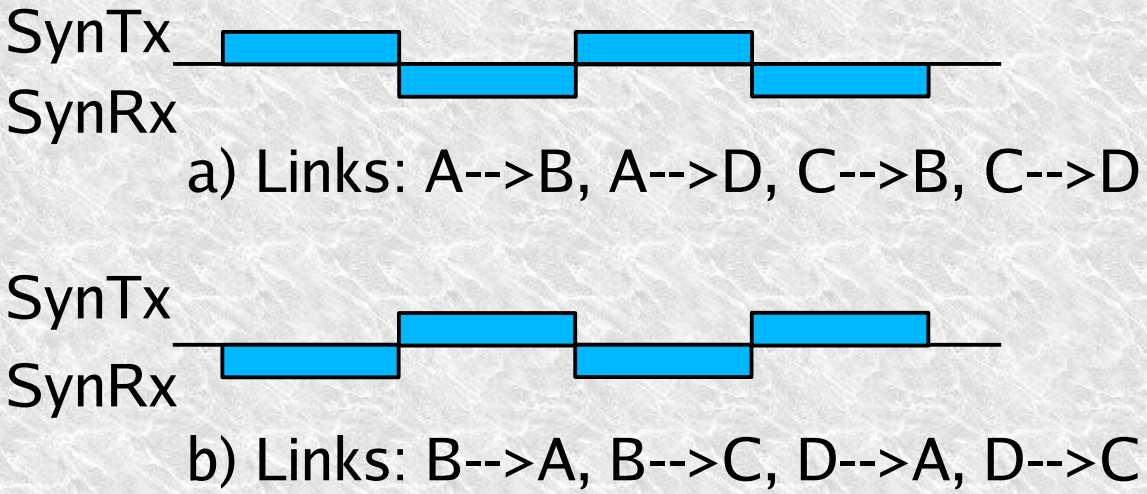
SynOp: Another Experiment



The 2P MAC Protocol

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



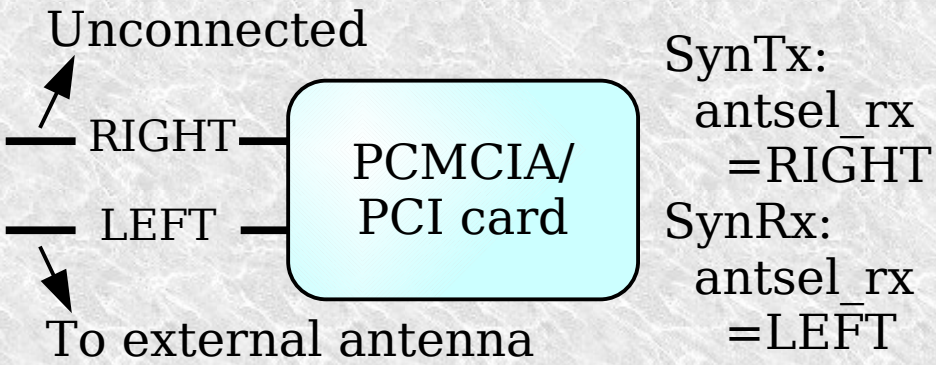


Note: diagram ignores system and propogation delays

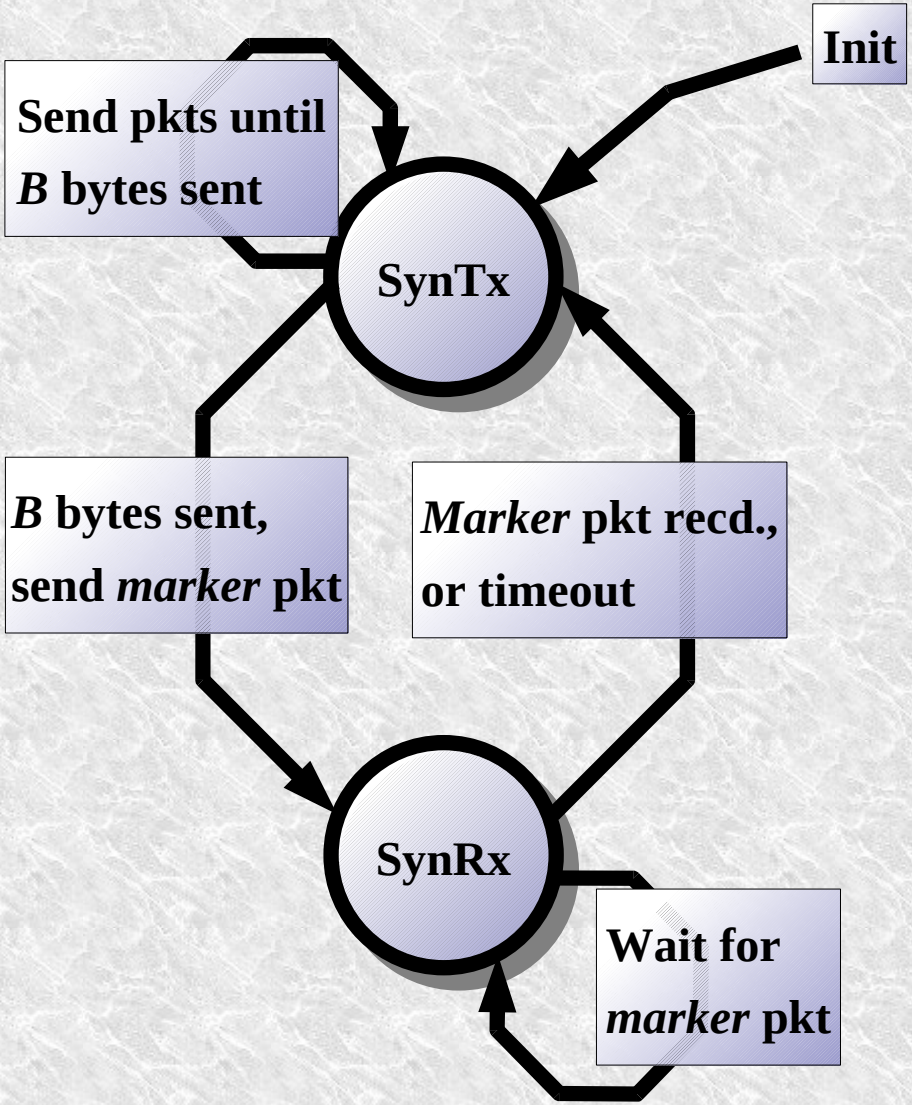
- How to achieve 2P on off-the-shelf hardware?
- Can 2P work without tight time synchronization?
- Relation between 2P and network topology
- 2P performance versus CSMA/CA

Achieving SynOp

- Goal: bypass DCF to achieve SynOp
- Two offending factors: immediate ACKs, CSMA backoff
- Avoiding immediate ACKs:
  - Use IBSS mode
  - IP unicast to/from MAC broadcast
- Avoiding CSMA backoff:
  - Make use of diversity antenna
  - Change antsel_rx to the unconnected antenna before transmitting

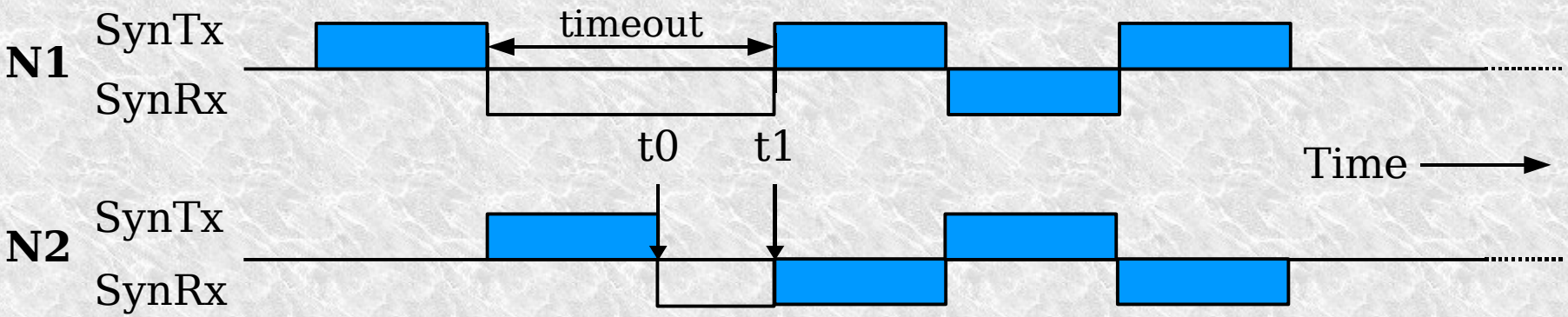


2P on a Single P2P Link



- B bytes in each phase
- SynTx+SynRx = one round
- Marker packet acts as a “token”
- The two ends of the link are in loose-synchrony
- How do we handle:
  - Temporary loss of synchrony?
  - Link recovery or initialization?

The 2P Timeout Mechanism

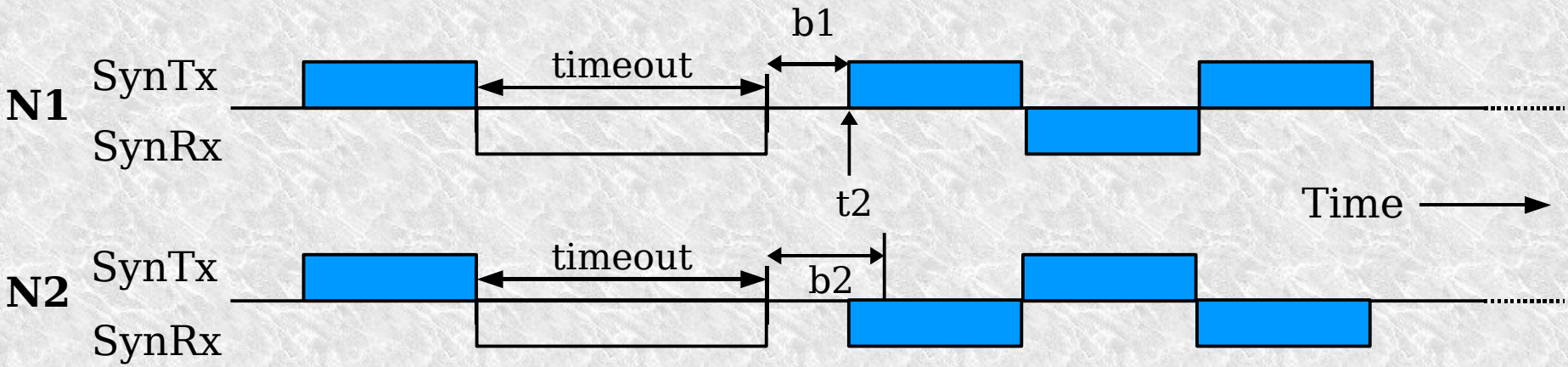


Note: diagram ignores system and propagation delays

- Timer started on entering SynRx
- Put on hold on starting to hear
- Link-resync takes only one round
- CRC errors of non-marker pkts immaterial

Bumping to Avoid Repeated Timeouts

- If SynTx phases coincide, repeated timeouts occur
- Use random delay bumping to avoid this

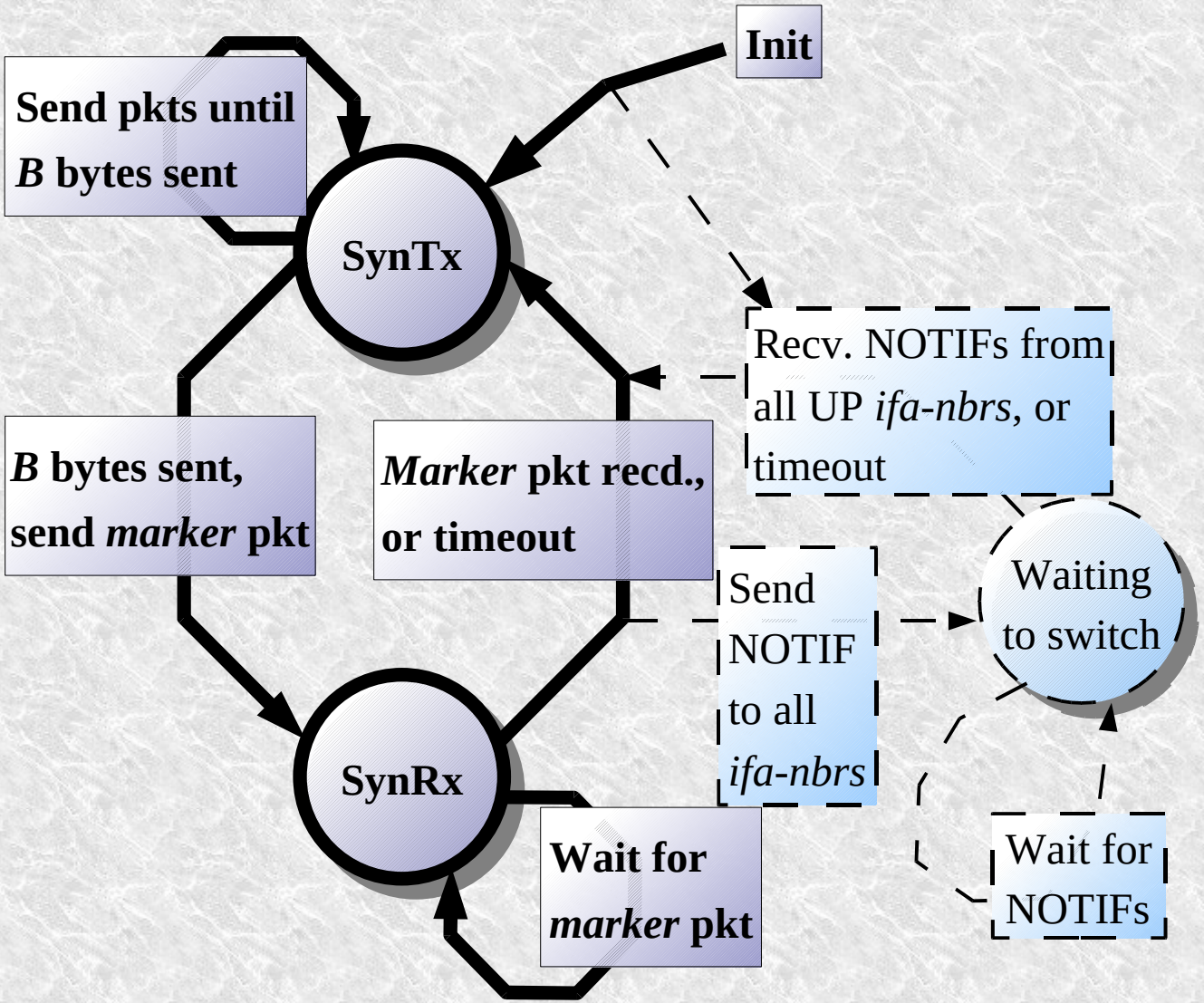


Note: diagram ignores system and propagation delays

Parameters in 2P

- Phase duration: B bytes
  - Large B implies lower % overhead, but higher latency
  - For B=10KB, 6% overhead, 13ms latency
  - For B=4.5KB, 11% overhead, 6ms latency
- Timeout:
  - Lower bound: one phase duration
  - Simulation: 1.25 times the phase duration
  - Implementation: 25ms (kernel jitter ~ 10ms)

Communication Across Interface-Neighbours



- NOTIF msgs to indicate end of SynRx
- Wait for NOTIF msgs from all ifa-nbrs before SynTx
- UP/DOWN state w.r.t. each ifa-nbr
- Communication through shared-memory, or ethernet

Some Remarks on 2P

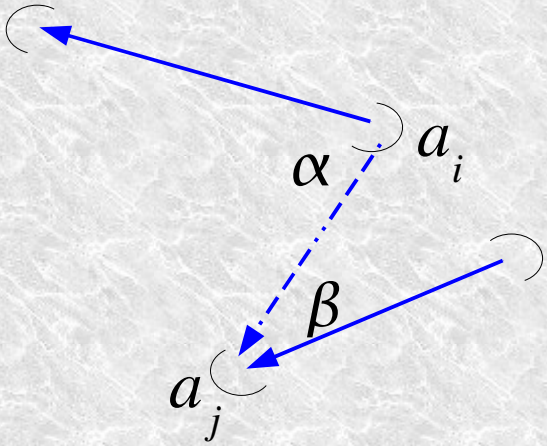
- Dummy bytes sent when no IP data
  - Power consumption not a major concern
  - Embedded platform ~ 4-6W at least 802.11 radio ~ 0.1-0.2W only
- Unequal phase durations possible
  - But not really useful for more than a single hop network
- RF leakages: not too many interfaces can be placed close to each other

Topology Constraints

- 2P has two main constraints:
  - Topology should be bipartite
  - Power constraints

Power Constraints

- Denote by P_i, the txpower at antenna A_i
- Each transmission acts as interference to all other transmissions
- Write a set of linear equations with variables Pi
  - SIR >= SIR_{reqd}
  - Probably should have some head-room too
  - Feasibility of a solution to this implies that the topology is 2P-compatible



$$Overall\ gain\ from\ a_i\ to\ a_j =$$

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

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

$$Gain\ at\ angle\ \alpha \times Gain\ at\ angle\ \beta$$

Topology Formation

- Tree topology:
  - Trivially bipartite
  - Only one landline ==> tree is natural
    - Only a tree is active at any time
- Heuristics:
  - H1: use short links
  - H2: avoid short angles between links
  - H3: minimize the number of hops
- Mimic a natural deployment pattern
  - Nodes close to landline connected first, then the next level

Evaluation of 2P

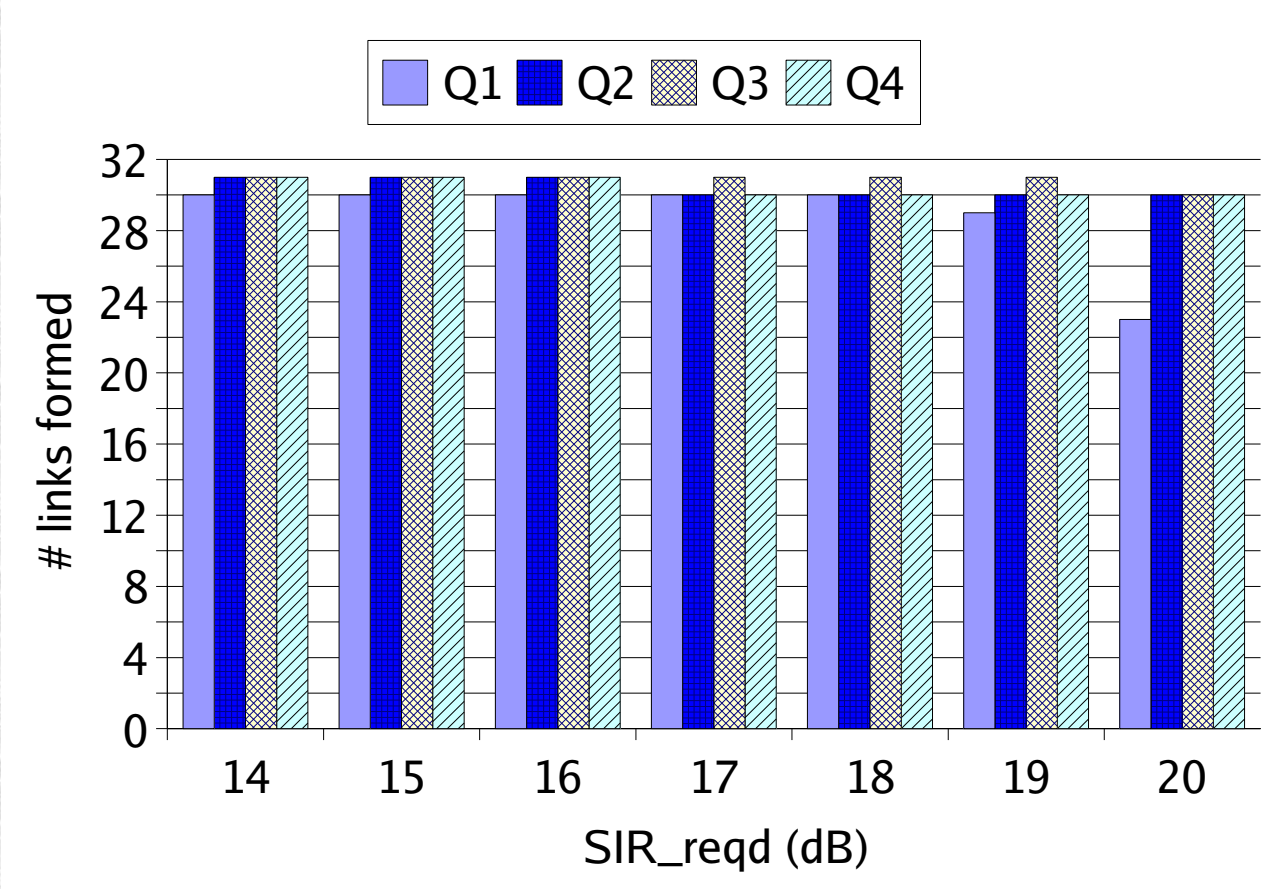
- Topology formation
- Simulation studies
- Implementation

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, U.P.
  - Using random topologies

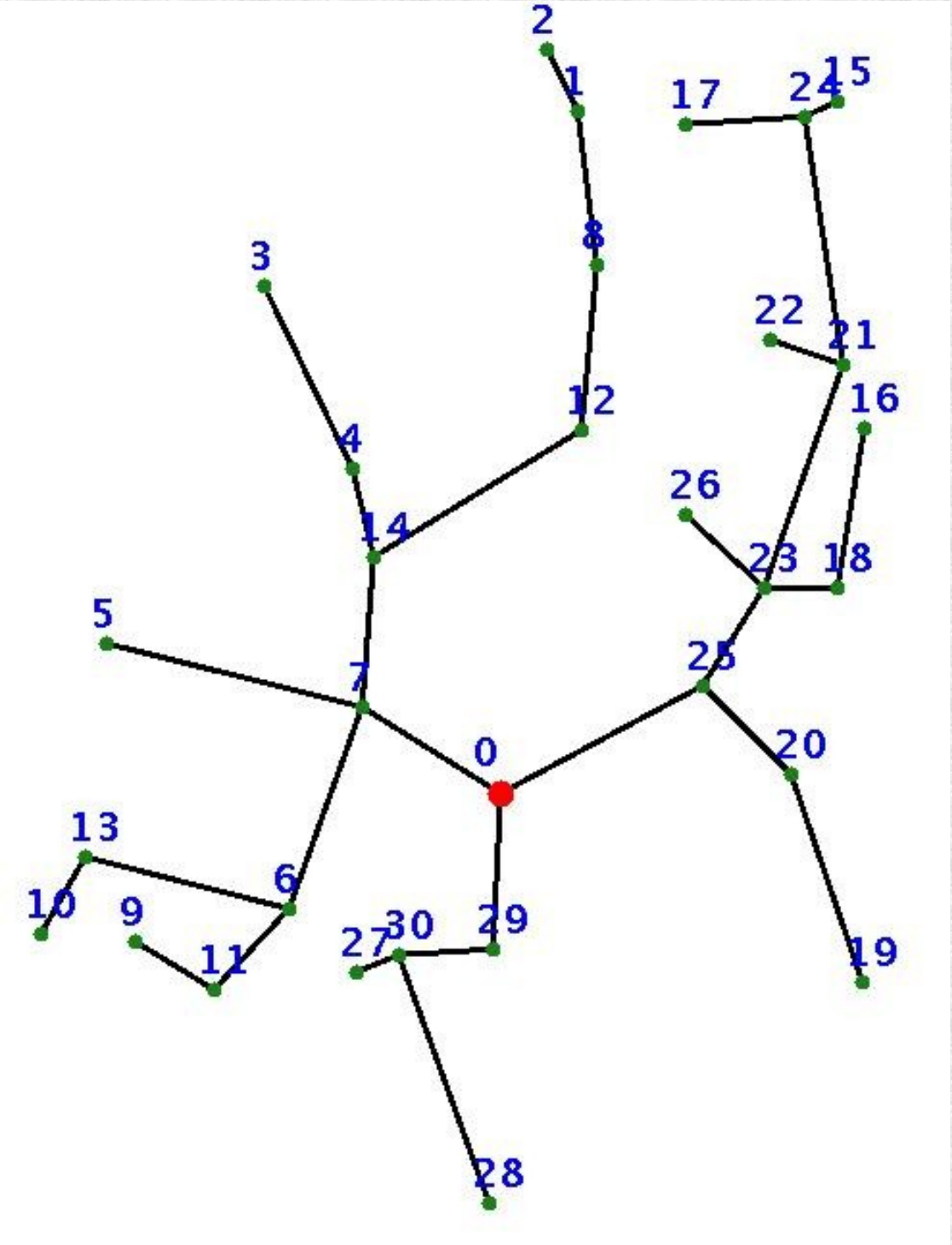
Topology Creation on Durg District

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

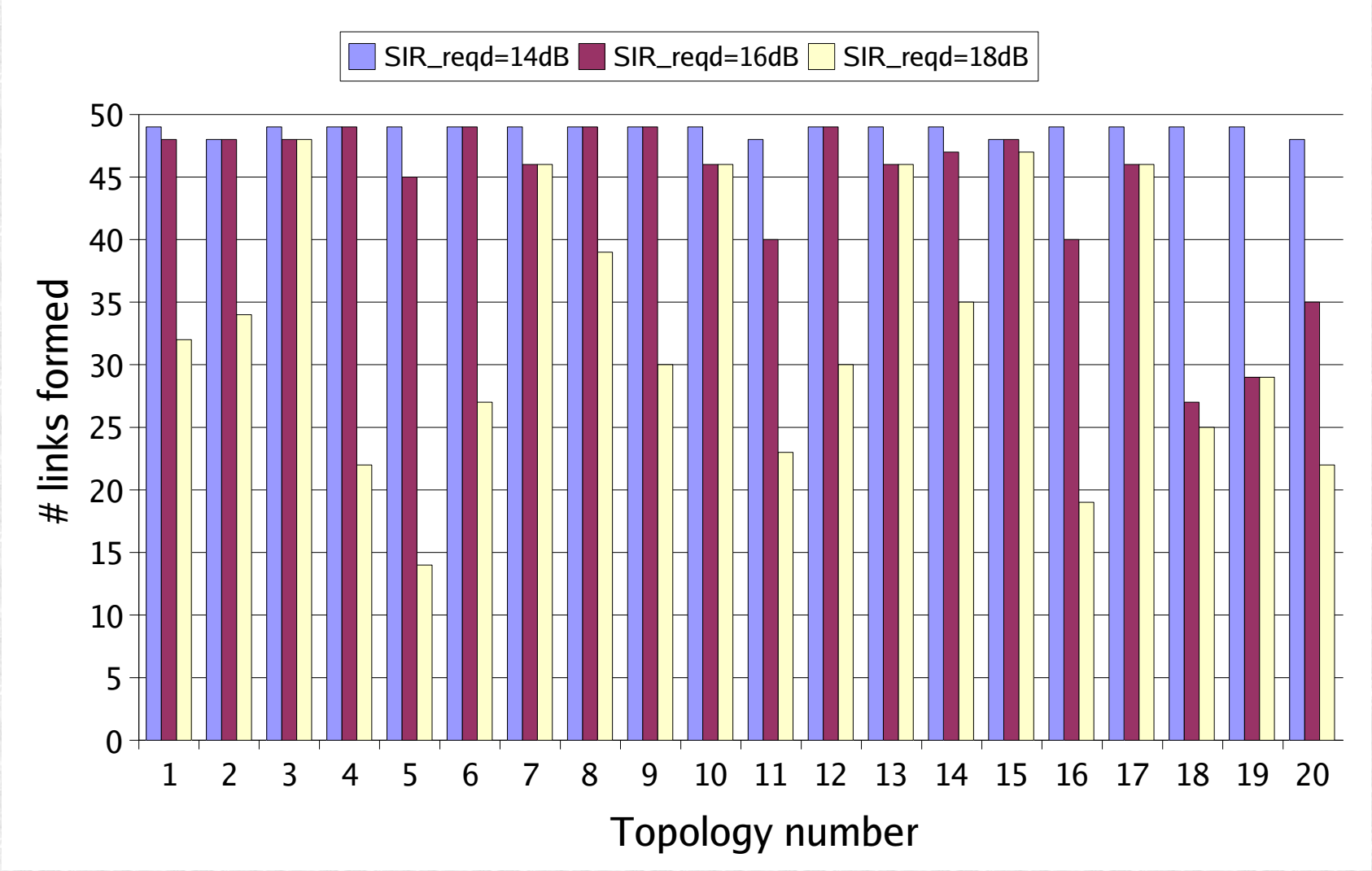


SIR_{reqd} of 18-20dB easily possible

The Topology on Q_1



Topology Creation on Random Scenarios



SIR_{reqd} of 16-18dB mostly possible for up to 30-50 node topologies

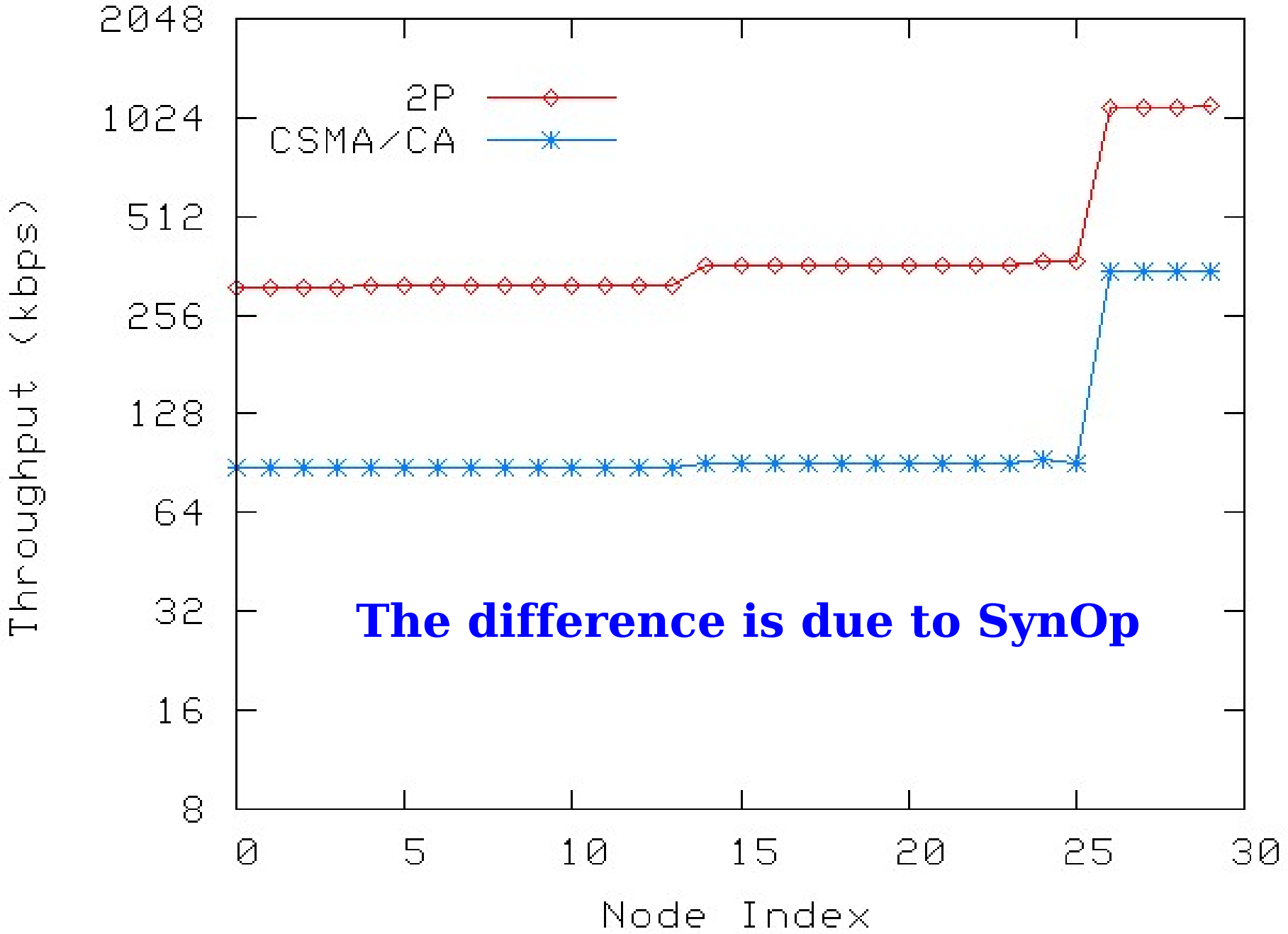
Simulation-based Evaluation

- TeNs:
  - http://www.cse.iitk.ac.in/~bhaskar/tens/
  - Channel interference, grey regions, multiple interface support, directional antennas
- Further extensions:
  - Populating the ARP table appropriately
  - 24dBi directional antenna support
  - MAC modifications: air propagation delay, ACK timeout
  - LLC: sliding-window protocol

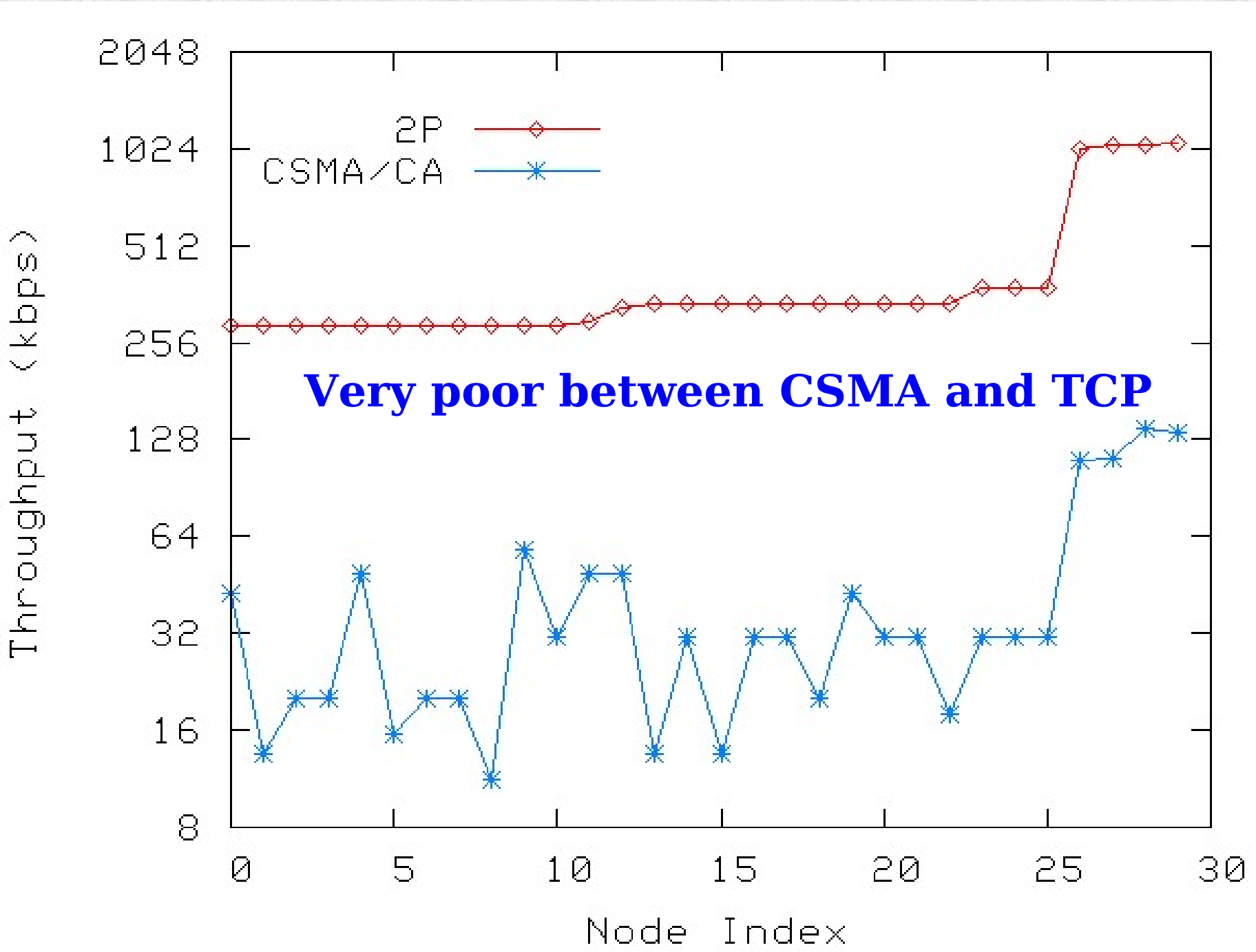
Simulation Parameters

- Q_1's 31-node topology used
- UDP or TCP traffic
  - Packet size: 1400 bytes
  - UDP: saturating CBR traffic (every 2ms)
  - TCP: NewReno used
- Simulated time duration: 10sec

Saturation Throughput (UDP)



TCP Performance



Implementation-based Evaluation

- Implementation using HostAP v0.2.4, Linux 2.4 (also works on Linux 2.6)
- 2P on a single link: 6.1Mbps
  - Less than the max. possible 6.5Mbps
  - Overhead in antsel_rx, marker pkt, CW_{min} being 32
- 2P performance on a pair of links:
  - A <--> N1, N2 <--> B, UDP traffic

	Avg (SD) thrpt at A (Mbps)	Avg (SD) thrpt at N1 (Mbps)	Avg (SD) thrpt at N2 (Mbps)	Avg (SD) thrpt at B (Mbps)
2P	2.70 (0.31)	2.06 (0.24)	2.81 (0.15)	2.81 (0.10)
CSMA	2.07 (0.13)	1.13 (0.22)	1.90 (0.15)	3.11 (0.14)

Concluding Remarks

- 2P good for 802.11 mesh networks
  - Reuse of spectrum for max. throughput
  - Applicable in a wide-range of deployments
- Can be extended to P2MP scenarios as well
  - Provided the antenna is suitable
- Topology creation is an interesting aspect of study