Revisiting MAC Design for an 802.11-based Mesh Network

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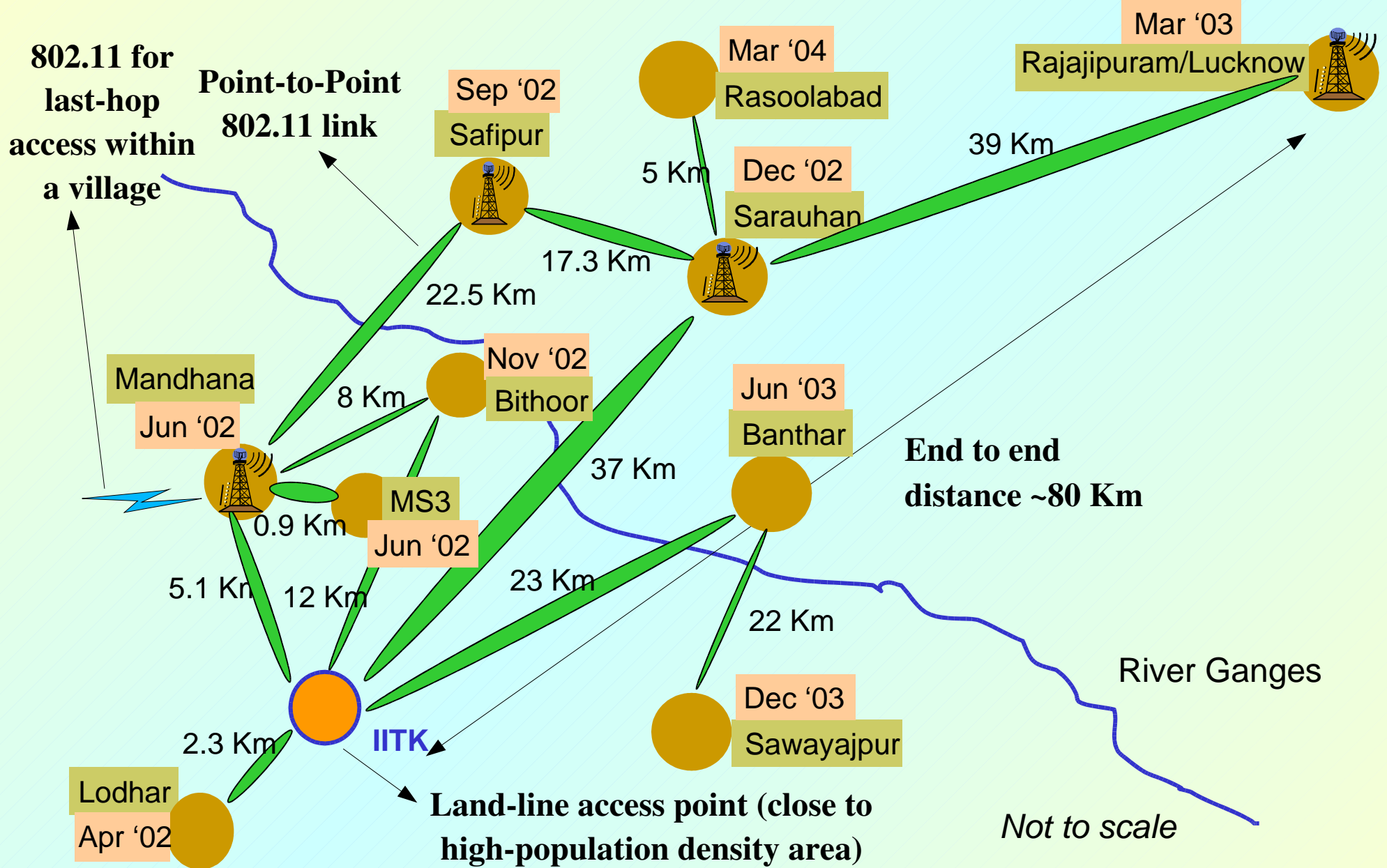http://www.iitk.ac.in/mladgp/

HotNets-III, 16 Nov 2004, San Diego, CA, USA
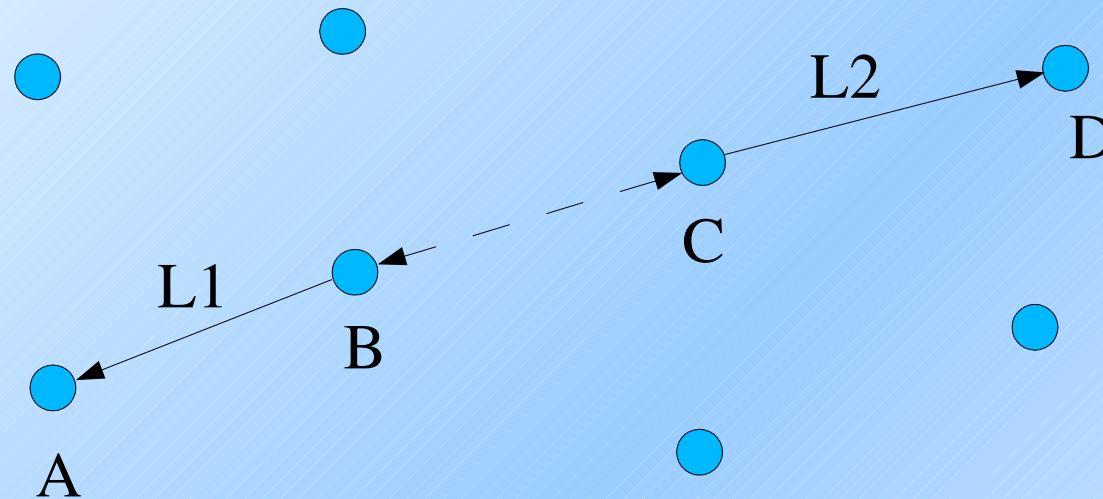
802.11 Mesh Networks

- Community networks

- Campus networks

- Rural access networks

  – Using 802.11 for *low-cost* long-distance access

  – Examples:

    - Djurslands, Denmark: http://www.djurslands.net

    - Berkeley TIER project

    - Digital Gangetic Plains, IIT Kanpur

Digital Gangetic Plains

802.11 for last-hop access within a village

Point-to-Point 802.11 link

Mar '04
Rasoolabad

Mar '03
Rajajipuram/Lucknow

Sep '02
Safipur

Dec '02
Sarauhan

5 Km

39 Km

17.3 Km

22.5 Km

Nov '02
Bithoor

Jun '03
Banthar

Mandhana
Jun '02

8 Km

MS3
Jun '02

0.9 Km

37 Km

End to end distance ~80 Km

5.1 Km   12 Km

23 Km

22 Km

IITK

River Ganges

2.3 Km

Dec '03
Sawayajpur

Lodhar
Apr '02

Land-line access point (close to high-population density area)

Not to scale

*(1) Long-distance, Point-to-Point links; (2) Multiple interfaces per node*

802.11 MAC Performance

- *Exposed node* problem prevents parallel transmissions

- (1) Long-distance links:
  - Slot-time, DIFS, ACK timeout have to be scaled
  - Immediate ACK, RTS/CTS are inefficient

- (2) When there are multiple interfaces per node?

Using Multiple Channels
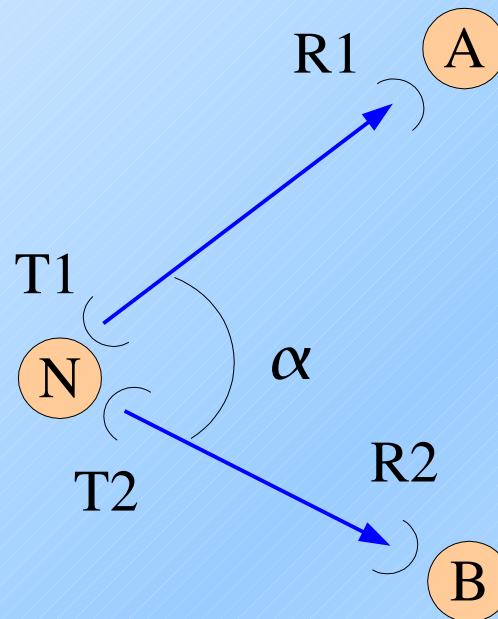
– 802.11b has three non-overlapping channels
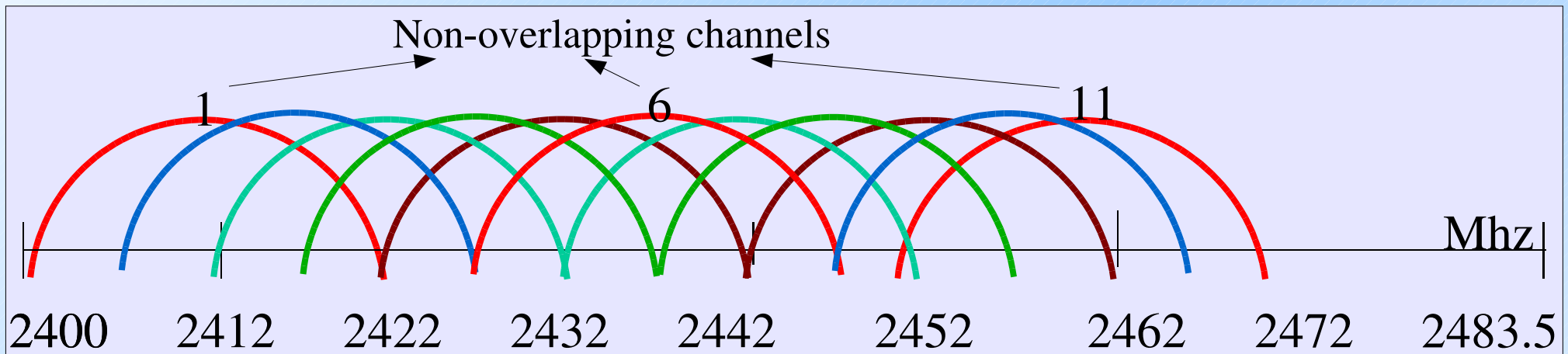
– If spectrum is licensed, using just one channel is better

– Even otherwise:

- May want to use just one channel for the back-haul links, and rest for local access

- Even if 2 (3) channels are available, graph may not be 2-edge (3-edge) colourable
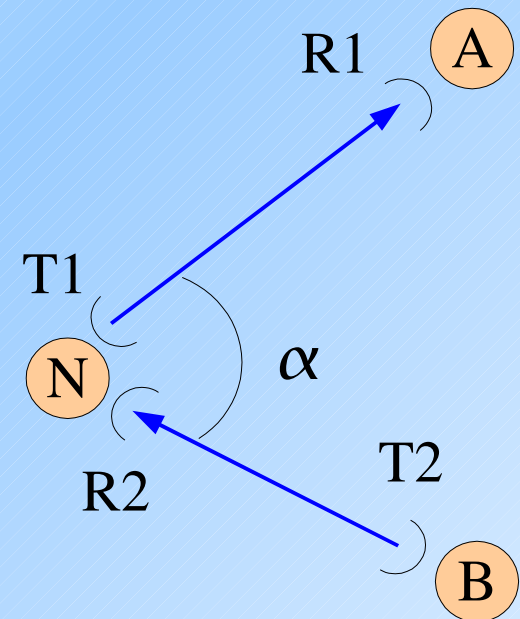
Do Multiple Interfaces Help?
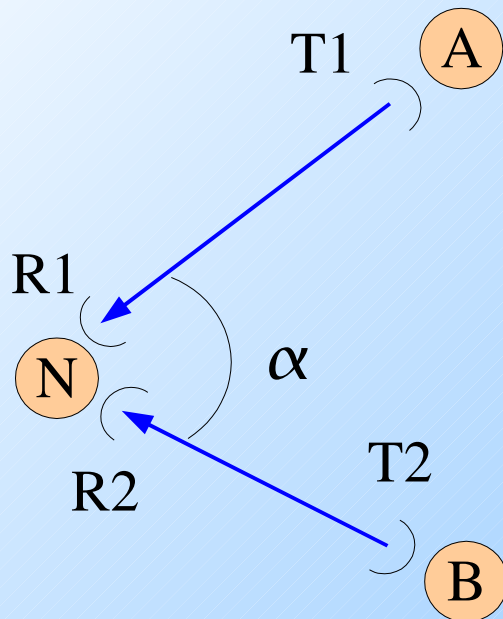
(a) Syn-Rx   (b) Syn-Tx   (c) Mix-Rx-Tx

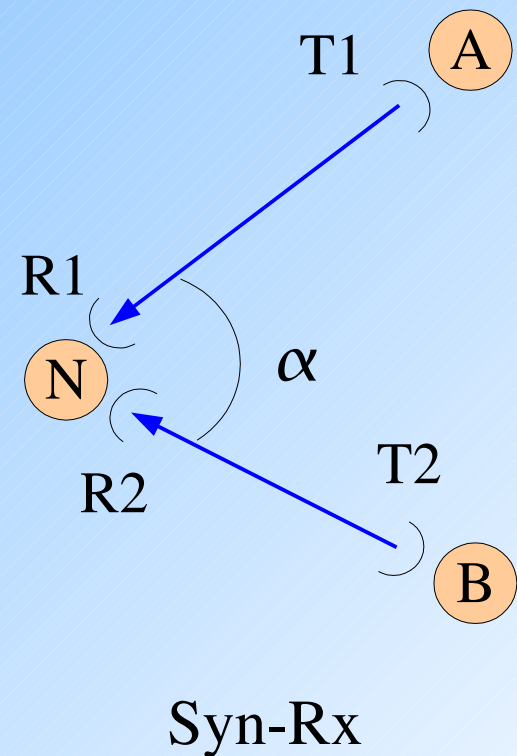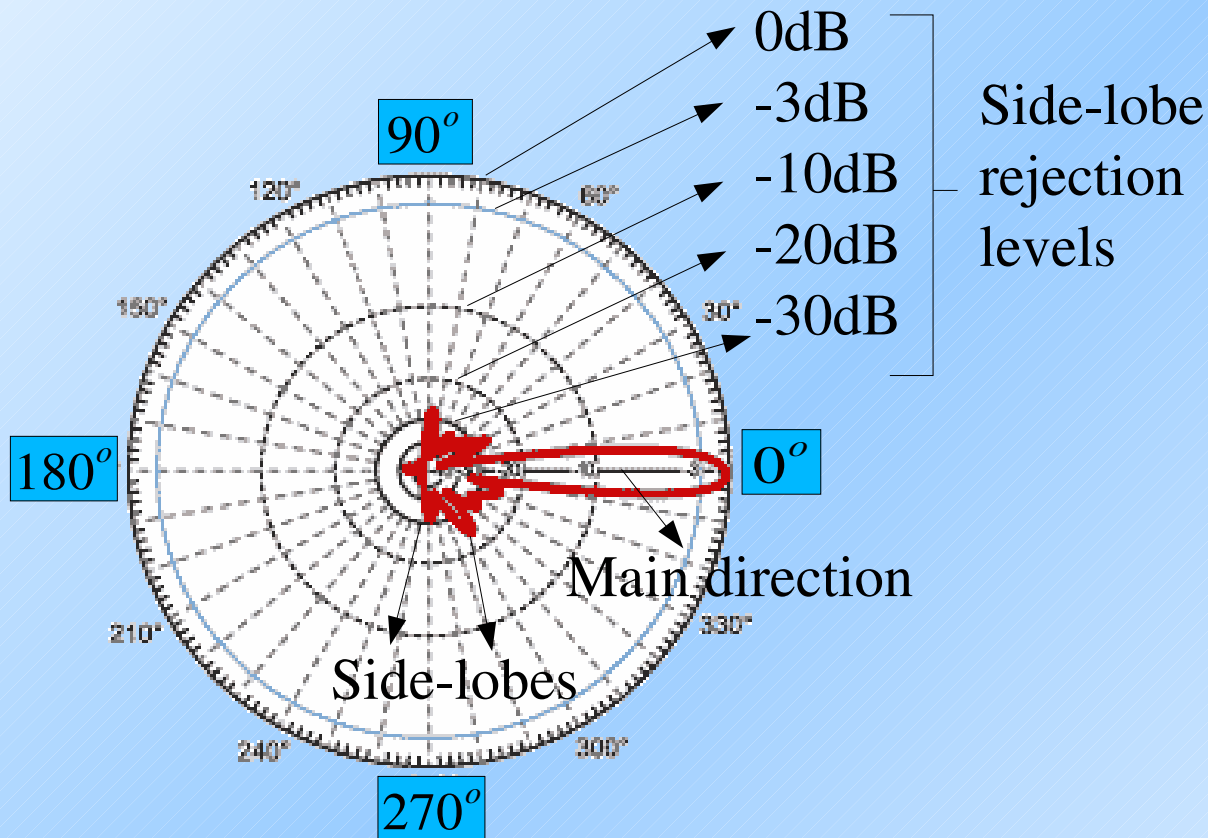Exposed *interface* problem still persists, within a node!

Ideally, links at a node should operate independently

CSMA/CA inherently allows only one link operation per node

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

0dB
-3dB
-10dB
-20dB
-30dB

Side-lobe rejection levels

90°

120°

150°

180°

210°

240°

270°

300°

330°

0°

Main direction

Side-lobes

T1

A

R1

N

α

R2

T2

B

Syn-Rx

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

SynOp: Experimental Verification

T1

A

Bithoor
Tower ht. = 40m

8km

R1

Mandhana
Tower ht. = 40m

N

$\alpha = 30^o$

T2

R2

0.9km

B

MS3
Tower ht. = 15m
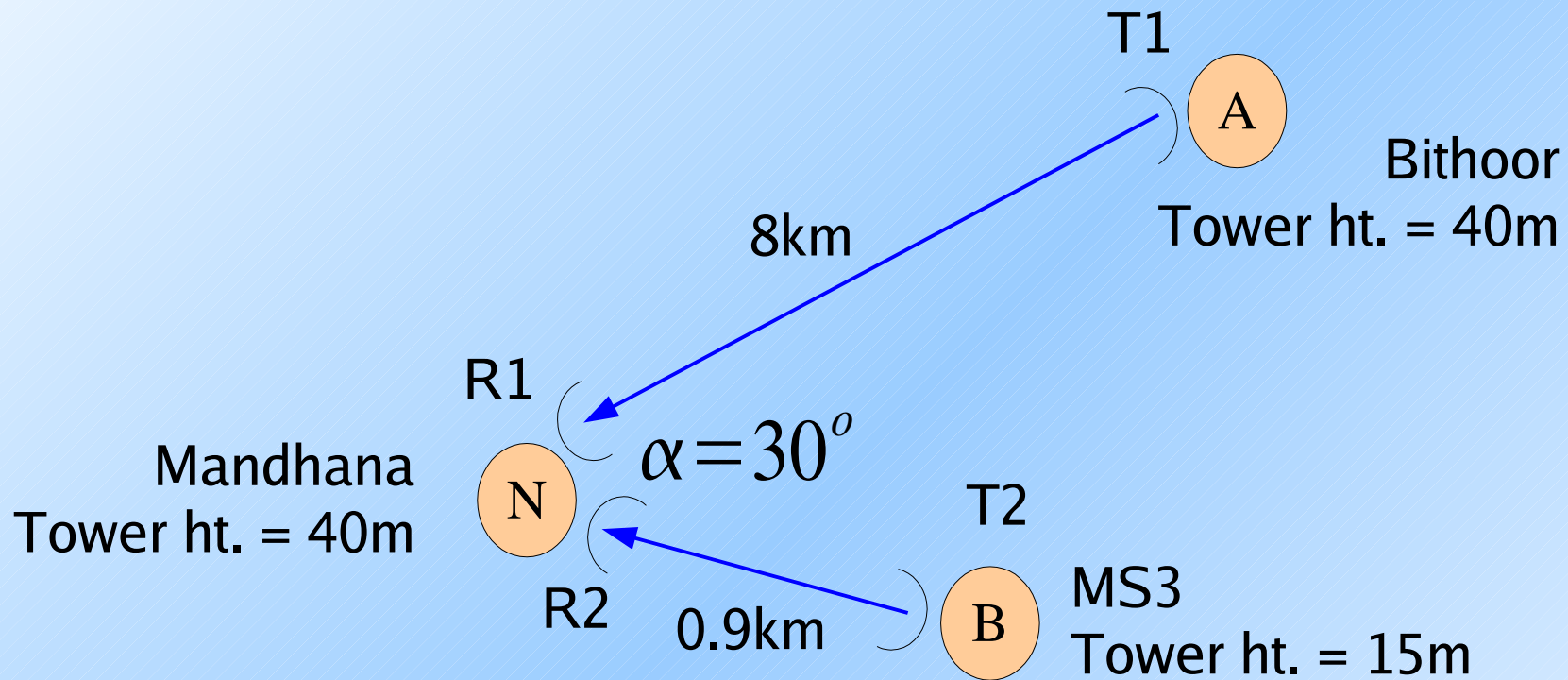
Used broadcast packets on both links (SynRx, SynTx)

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

2-P: A MAC on top of SynOp
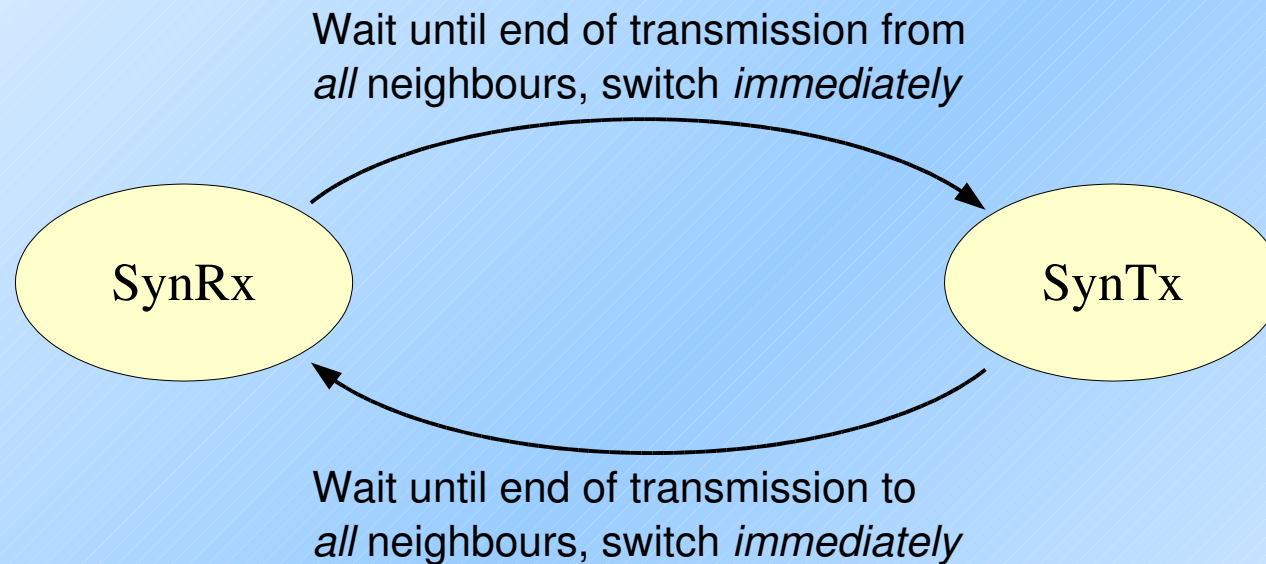
- 2-P: each node switches between SynRx and SynTx

- When a node is in SynRx, its neighbours are in SynTx, and vice versa

V_1 — *B bits* → V_2

V_1 ← *B bits* — V_2
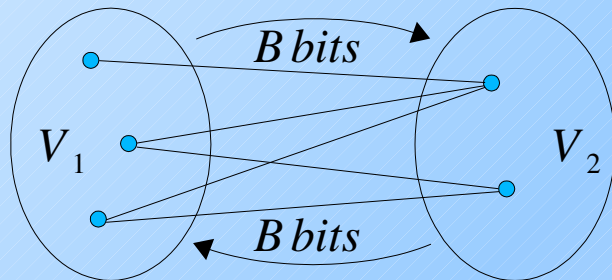
- SynRx + SynTx = 1 *round*

- Require a bipartite topology

Some Remarks on 2-P

– 2-P can be implemented without tight global synchronization!

Wait until end of transmission from *all* neighbours, switch *immediately*

SynRx

SynTx

Wait until end of transmission to *all* neighbours, switch *immediately*

– Timeout mechanism to deal with packet losses

– Firmware, proprietary driver software (e.g. Atheros), or driver-level implementation possible

  • Host-AP modifications tested for single-link

– Other issues: topology, TCP performance

Summary and Conclusions

- 802.11 mesh networks are popular
  - Attractive option for low-cost rural networking
- 802.11 MAC not good for long-distance, point-to-point links
- 2-P achieves maximal efficiency
  - Can be used in any wireless back-haul network
  - Dependence on PHY is minimal
- Can be implemented with firmware/driver modifications
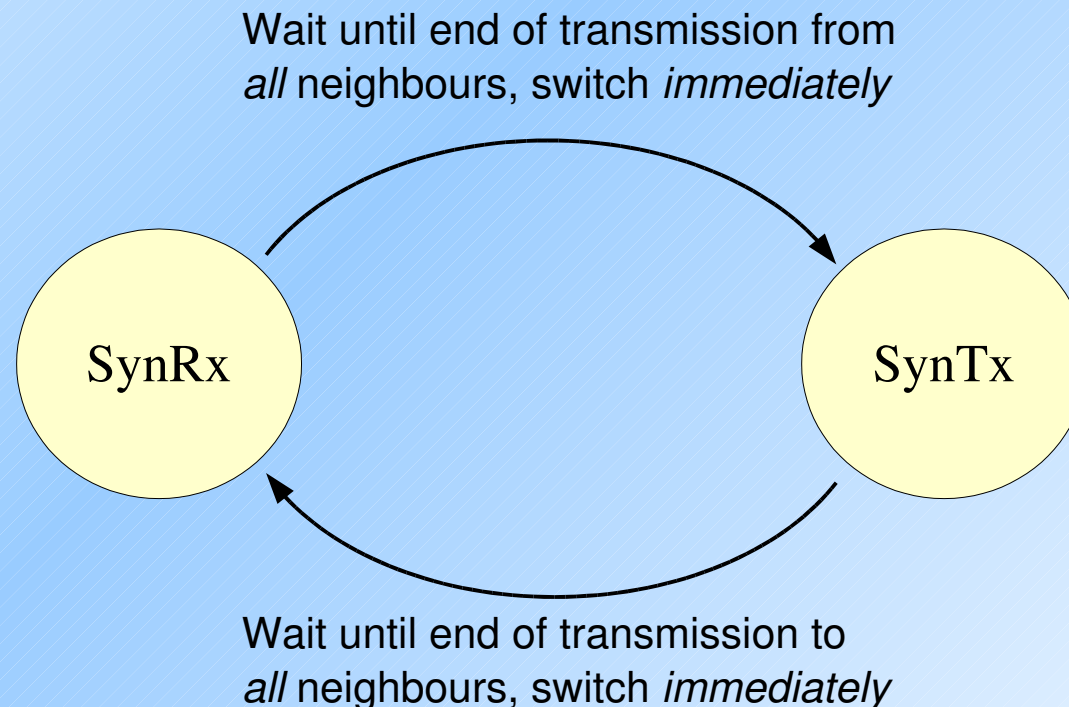 - Preserves low-cost of 802.11

Backup Slides

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

2-P without Synchronization

- 2-P can be implemented without global time synchronization!

  – Local (loose) synchronization is sufficient, and efficient

Wait until end of transmission from *all* neighbours, switch *immediately*

SynRx ⟶ SynTx

Wait until end of transmission to *all* neighbours, switch *immediately*
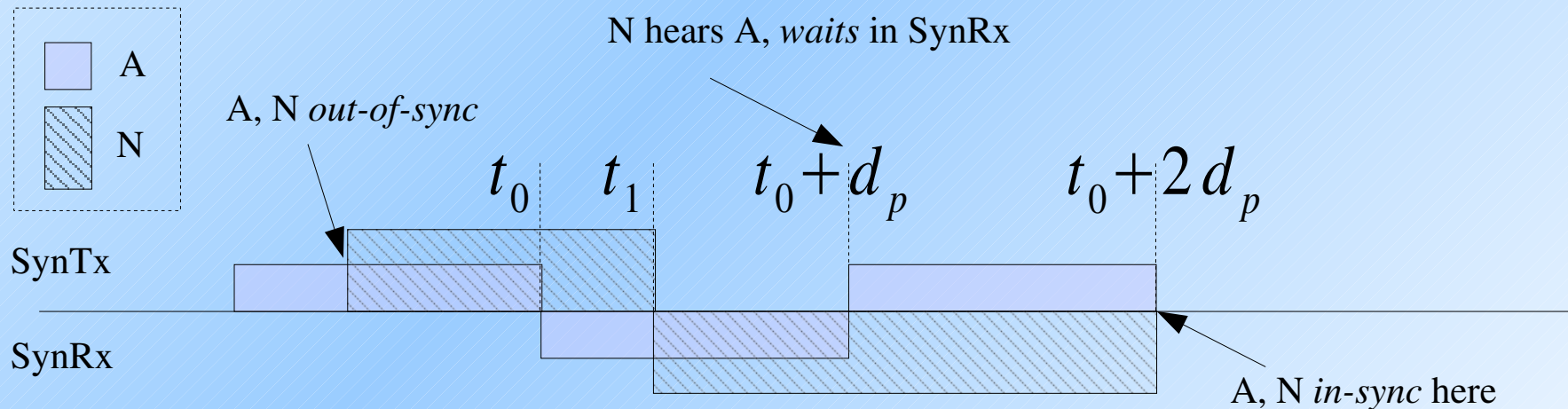
Loose Synchronization in 2-P

- 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

N hears A, *waits* in SynRx

A, N *out-of-sync*

t_0 t_1 $t_0 + d_p$ $t_0 + 2 d_p$

SynTx

SynRx

A, N *in-sync* here

A

N

Note: diagram ignores system/propagation delays

2-P Implementation

- How to implement on off-the-shelf 802.11?
- Minimal changes required
    - Get rid of MAC-level ACK
    - Do away with CSMA/CA backoffs
- Firmware, or proprietary driver software (e.g. Atheros), or driver-level
    - Host-AP modifications tested for single-link
- Some other issues:
    - Topology construction
    - TCP over 2-P