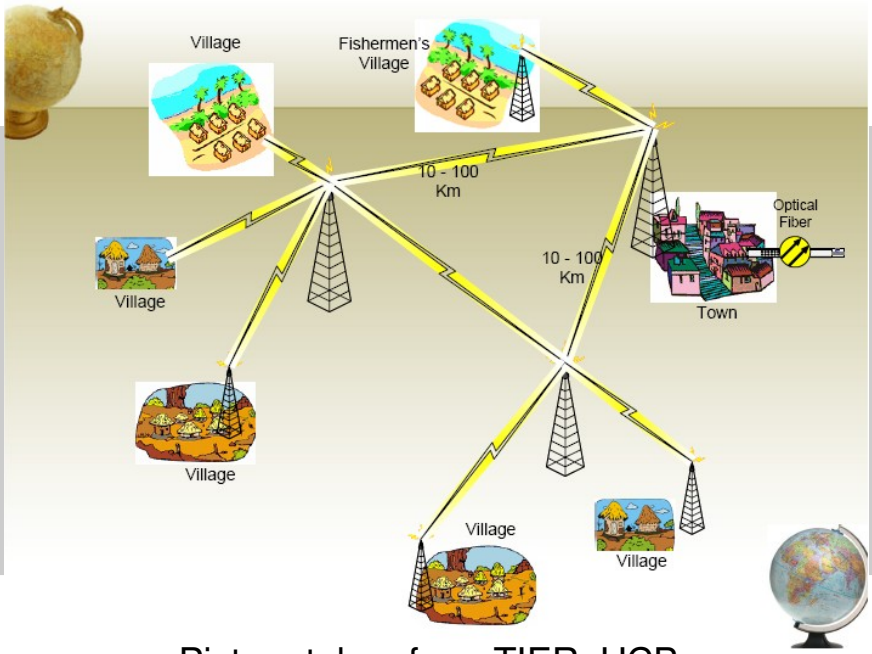
Design, Implementation, and Evaluation of new MAC Protocols for Long Distance 802.11 Networks



Picture taken from TIER, UCB

by

S Pavan Kumar

under the supervision of

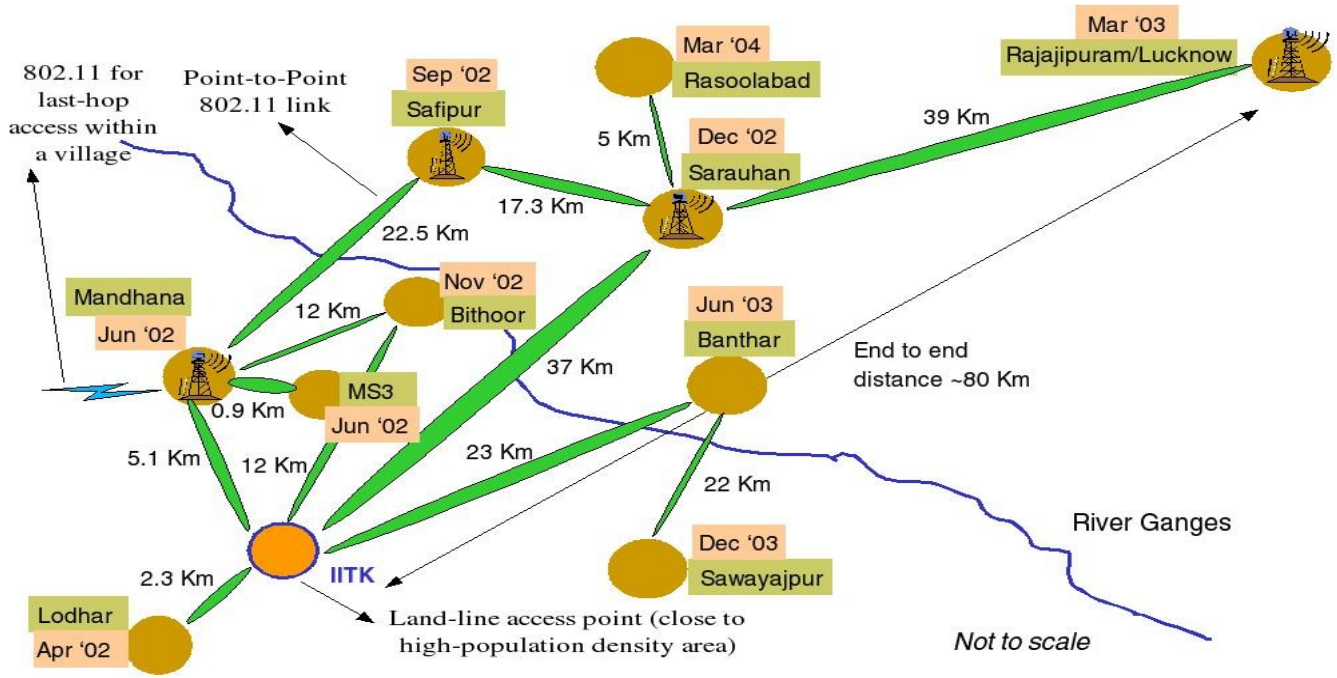
Dr. Bhaskaran Raman

Motivation

- Low cost Internet Access for remote rural villages
- Applications
  - Telephone service through Voice over IP
  - Telemedicine service through Video over IP
- How to go about it?
  - Network Infrastructure
    - Wired, Cellular, VSAT – Prohibitively expensive
    - Wireless (802.11) – inexpensive hardware, unlicensed spectrum, widely accepted and employed

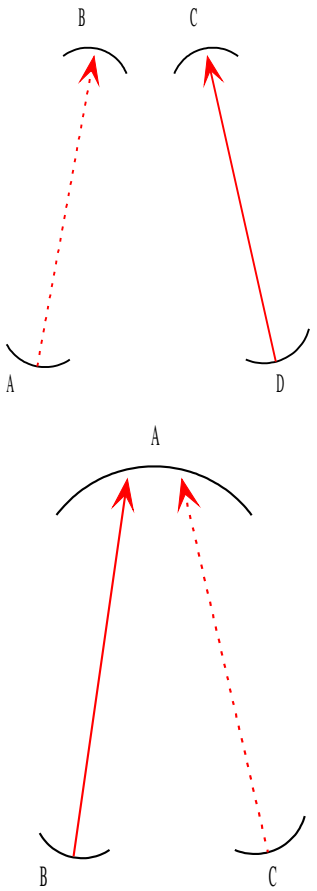
Motivation and Introduction

- Digital Gangetic Plains Project, IIT Kanpur
  - Single point of wired connectivity
  - Use of high gain directional and sector antennae
  - Long distance point-to-point and point-to-multipoint links



Motivation and Introduction

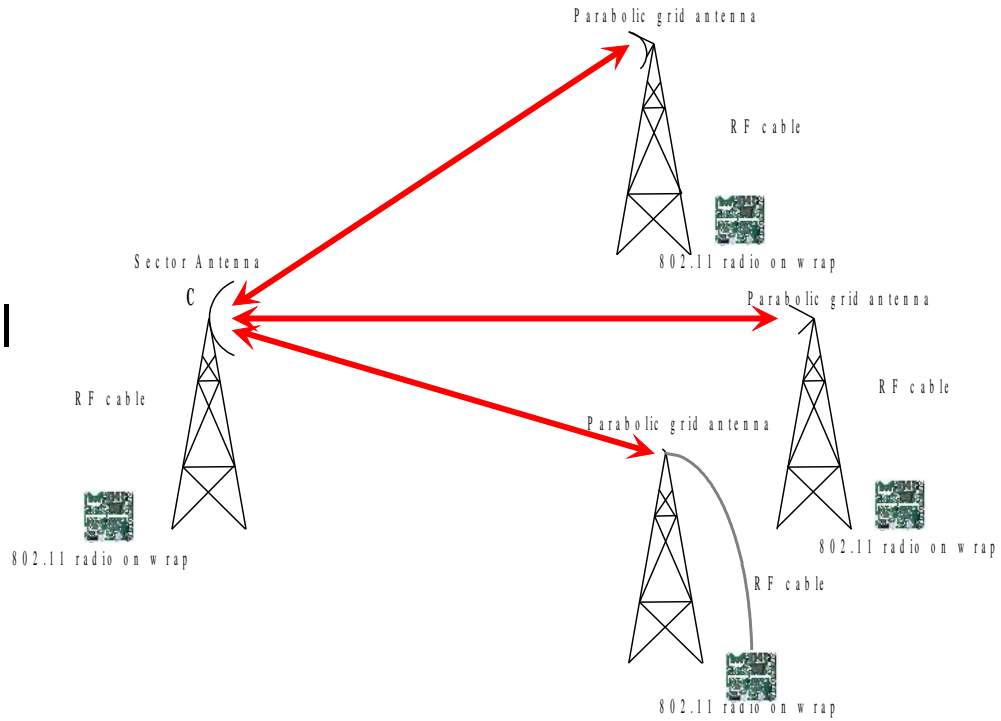
- CSMA/CA
  - –Standard MAC protocol for 802.11 networks
  - –Suitable for indoors (WLAN) and not outdoors
    - •Huge RTT
    - •Hidden node problem (RTS/CTS – large overhead)
    - •Contention is not arbitrary
  - –Not suitable for applications in question



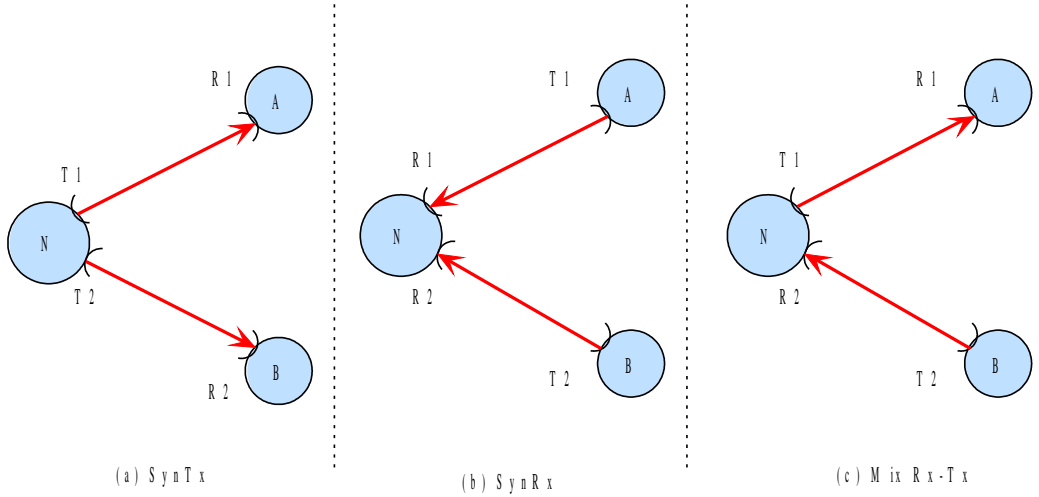
- Need for new MAC protocols suitable for long distance links – 2P and SRAWAN

New MAC Protocols

- 2P (2 Phase) for point-to-point links
  - TDMA based
- SRAWAN (Sectorized Rural Area Wireless Access Networks) for point-to-multipoint links
  - TDMA-TDD based

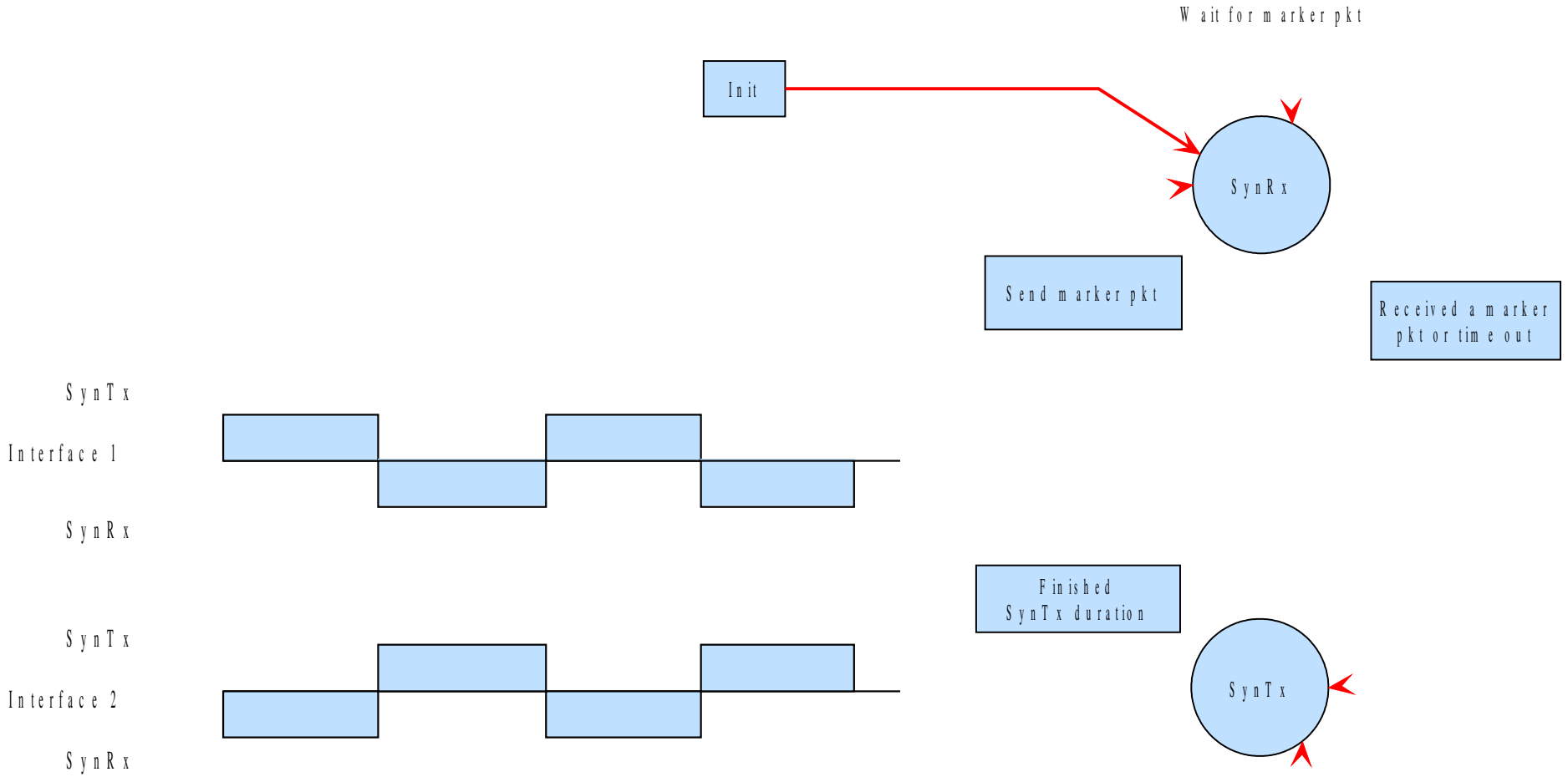


2P MAC – Background

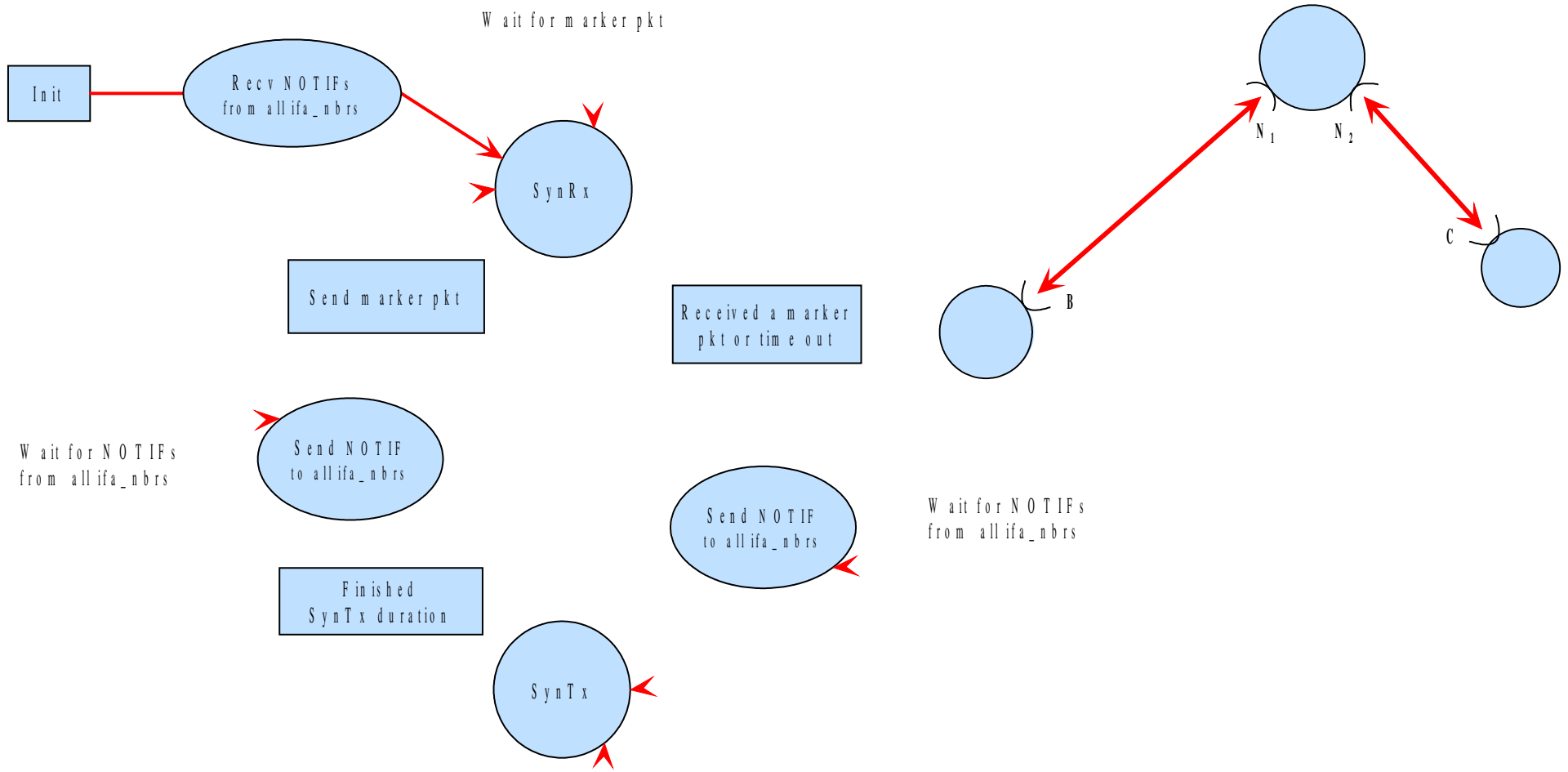


- Synchronous Operation by Sreekanth Garigala – SynTx/SynRx
- CSMA/CA performs poorly
  - Immediate acks
  - Carrier sensing
- STDMA based MAC by Dr. Bhaskaran Raman and Dr. Kameswari Chebrolu

2P operation on single link



2P operation on two links



2P MAC Operation

- Single link operation
  - Synchronization through marker packet
- Two link operation
  - Synchronization
    - With link-nbr through marker packet
    - With ifa-nbr through shared memory or ethernet messages
      - When the ifa switches from SynRx to SynTx
      - When the ifa switches from SynTx to SynRx before transmitting marker packet

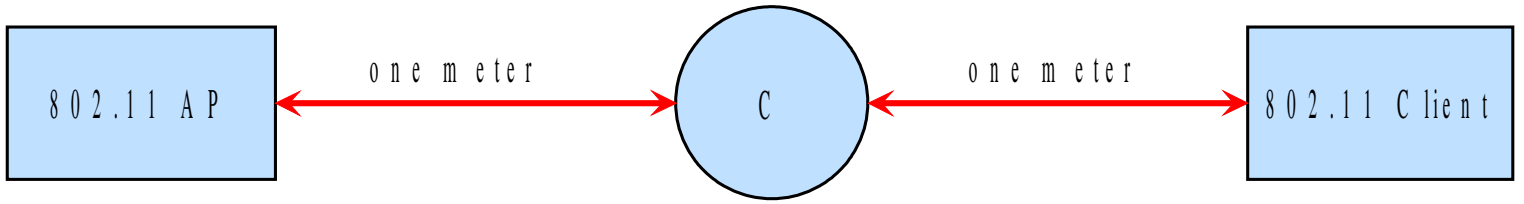
Significant Questions we seek to answer

- How to achieve 2P on the top of off-the-shelf 802.11 hardware to preserve cost benefits?
- Is 2P feasible outdoors?
- What is the performance of 2P in comparison to CSMA/CA?

2P MAC - Implementation

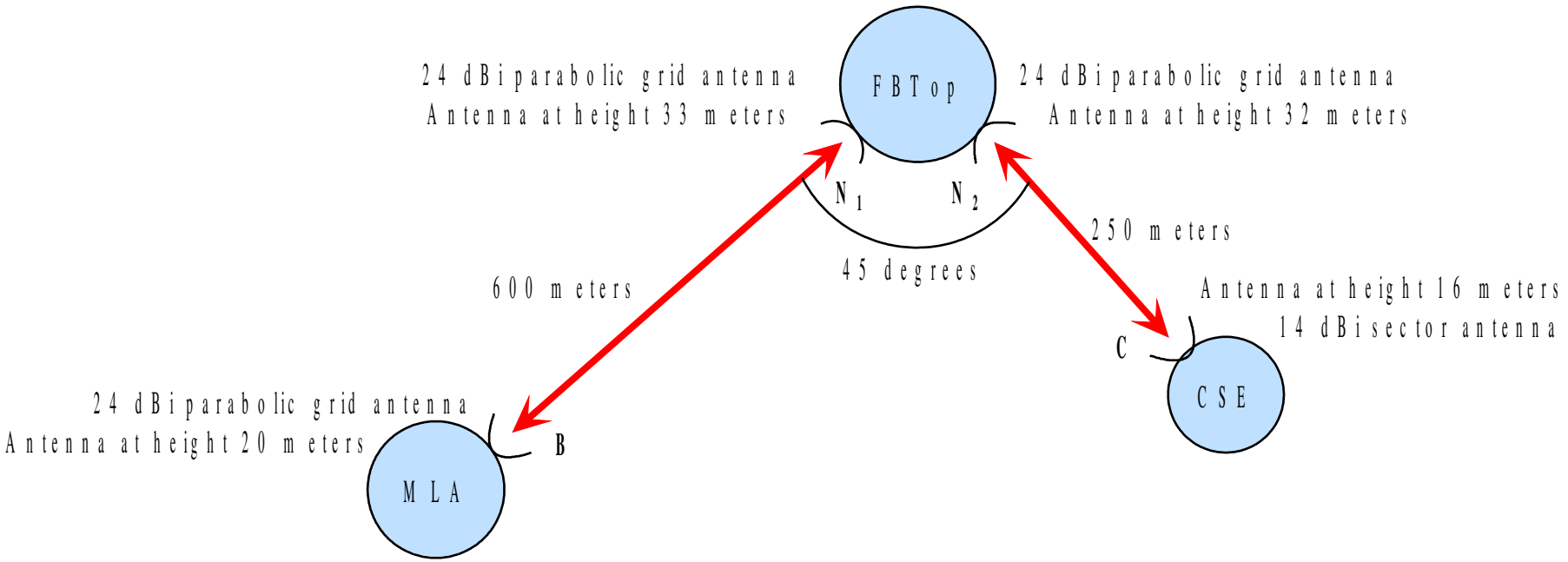
- Older implementation
  - IBSS mode and IP unicast packets to MAC broadcast
  - *antsel_rx*
- Drawbacks
  - Backoff, antenna switching overhead
- Newer implementation for Atheros AR5212 chipsets in Madwifi driver
  - Disable immediate MAC level acks
  - Disable CCA and NAV
  - Disable exponential backoff
  - Nullify SIFS, DIFS, EIFS and slot duration
  - Disable RTS/CTS

Effect of disabling CCA and NAV



Is C operating	NAV disabled at C	CCA disabled at C	SCP throughput from AP to client (KBPS)
No	No	No	850
Yes	No	No	450
Yes	Yes	No	235
Yes	No	Yes	200
Yes	Yes	Yes	185

2P – Experimental Setup

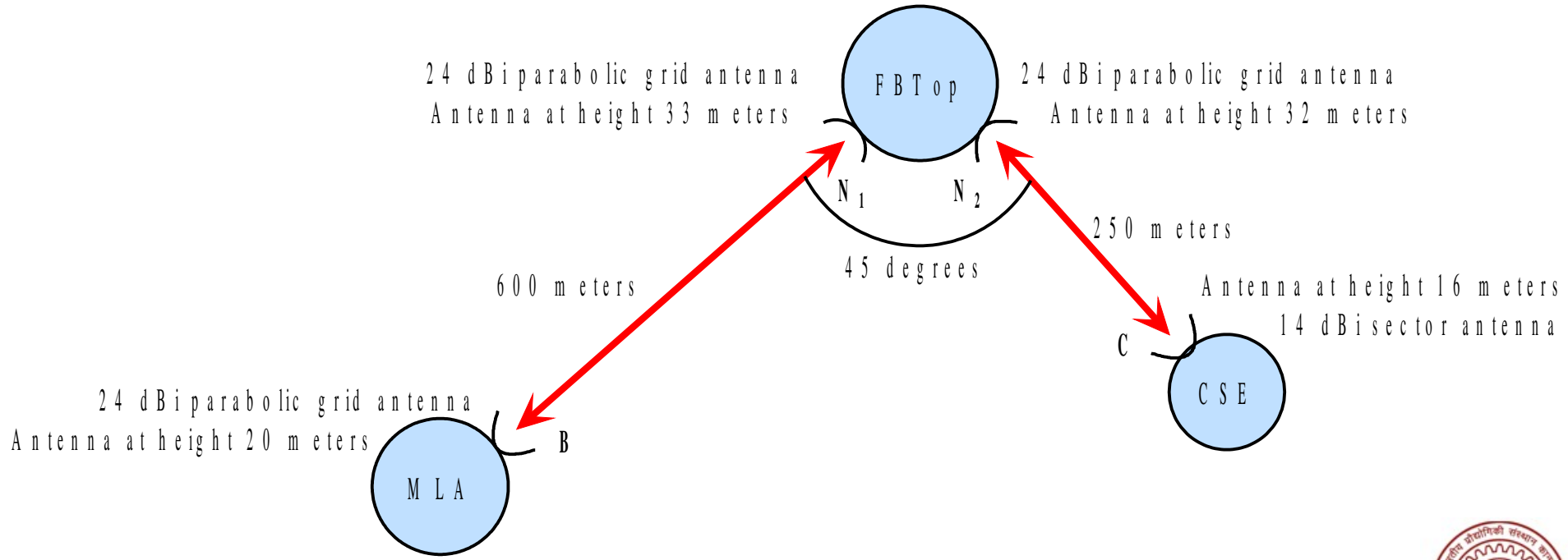


CSMA/CA and 2P – Performance Evaluation

MAC	Channels (MLA, CSE links)	Throughput MLA link (Mbps)	Throughput CSE link (Mbps)	Total (Mbps)
CSMA/CA Madwifi	1, 6	7.5	6.9	14.4
CSMA/CA HostAP	1, 6	6.1	5.8	11.9
2P	1, 6	6.3	6.2	12.5
CSMA/CA HostAP	6, 6	3.0	2.8	5.8
CSMA/CA Madwifi	6, 6	4.1	2.9	7.0
2P	6, 6	4.3	4.1	8.4

Problem during SynRx

Phase	Throughput on MLA link (Mbps)	Throughput on CSE link (Mbps)
SynTx	2.3	2.6
SynRx	2.0	1.5

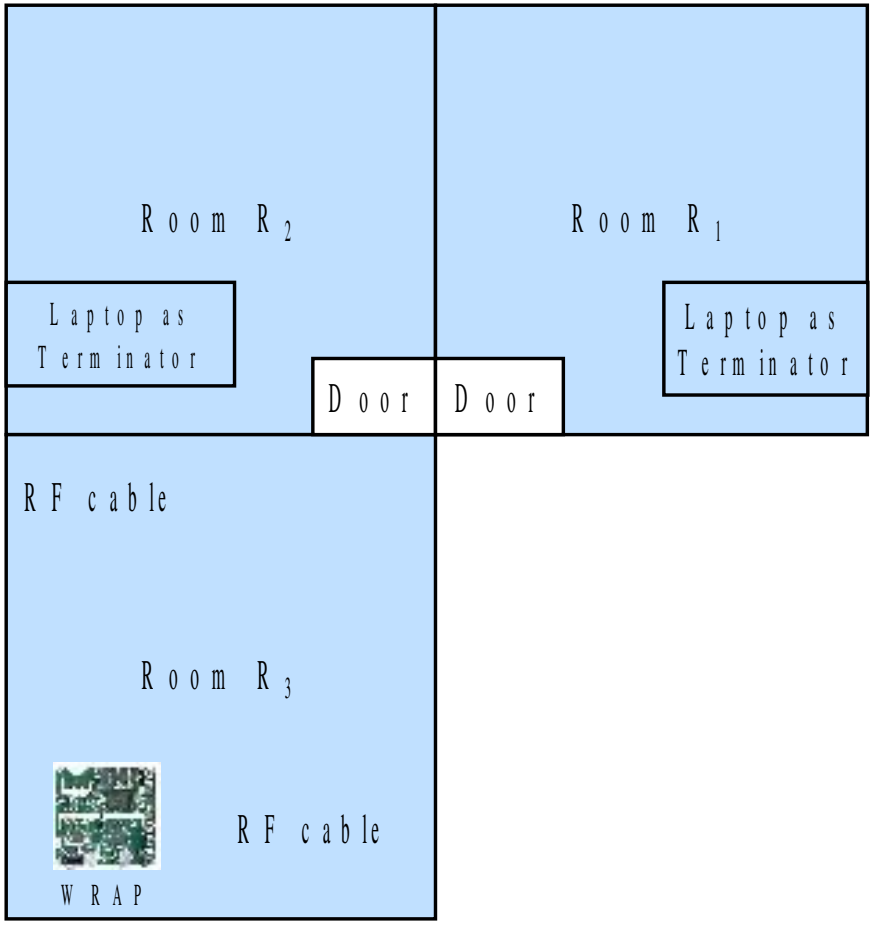


Overheads

- Time gap of 700us between NOTIF from *Master* and NOTIF_ACK from *Slave*
  - Net Filter hooks in Linux kernel for transmitting and receiving IP packets at MAC driver level
  - Low processing power of WRAP boards
- How to handle this?
  - Shared Memory coordination among interfaces: not possible

Experiment	Signal level at ifa1 because of ifa2	Signal level at ifa2 because of ifa1
Interfaces connected to no external antennae	-77 dBm	-75 dBm
Interfaces connected to external antennae with 3dBi gain	-33 dBm	-32 dBm
Interfaces connected to netgear pigtails	-30 dBm	-30 dBm

Shared Memory Experiment

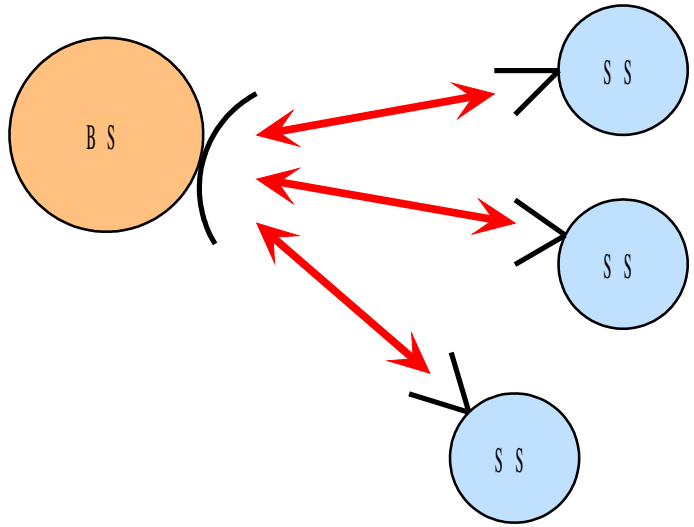


SRAWAN

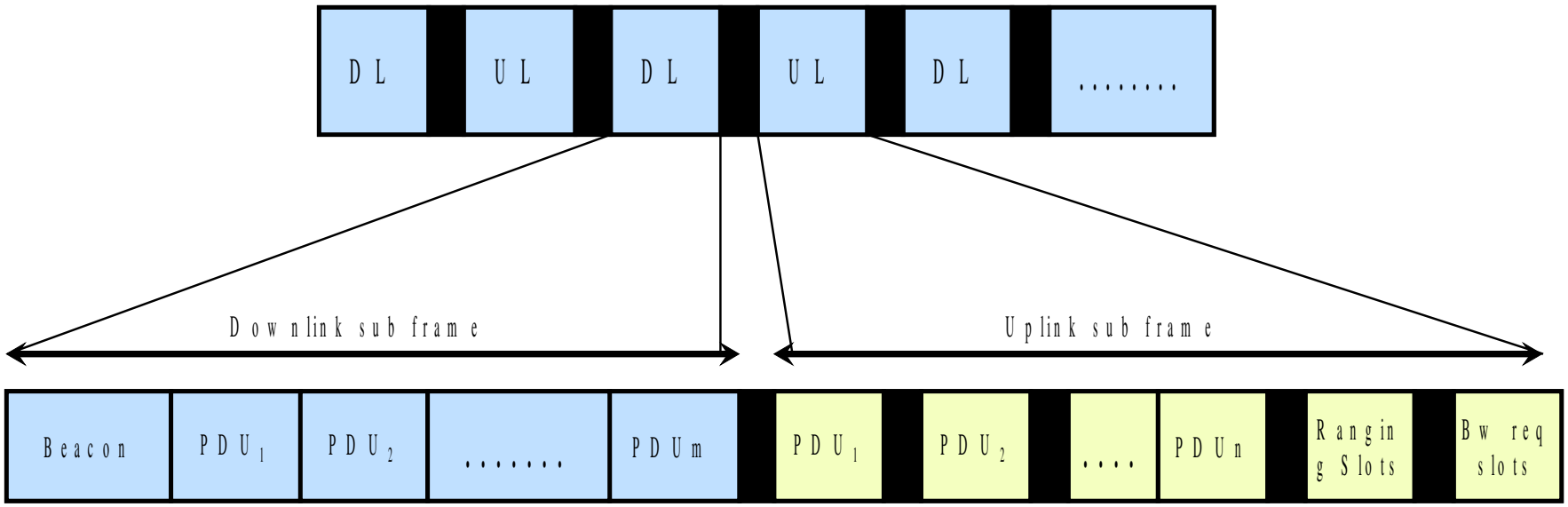
- SRAWAN – Sectorized Rural Area Wireless Access Network
  - Point-to-multipoint MAC protocol
  - TDMA-TDD based MAC based on WiMAX
  - Designed to operate on 802.11 PHY
  - Challenges
    - Intelligently select minimal functionality from WiMAX that will suit the applications for rural networks
    - Implementation on 802.11 PHY
- Design – Jointly done by Dr. Bhaskaran Raman, myself and Narasimha Puli Reddy of MTech 2004
- Implementation – Jointly done by myself, Narasimha Puli Reddy and Pratik Sinha of Zazu Networks.
- Evaluation – Done by me

SRAWAN – Architecture

- BS – Base Station (sector antenna)
- SS – Subscriber Station (directional antenna)
- SRAWAN specifies the communication between BS and SSs
- TDD – supports traffic from both sides
- TDMA – supports multiple SSs
- SRAWAN relies on tight time synchronization to support TDD and TDMA
- FDD is not possible. Why?



SRAWAN – Frame Structure



Guard Time

Guard Time present if PDU1 and PDU2 belong to different SSs

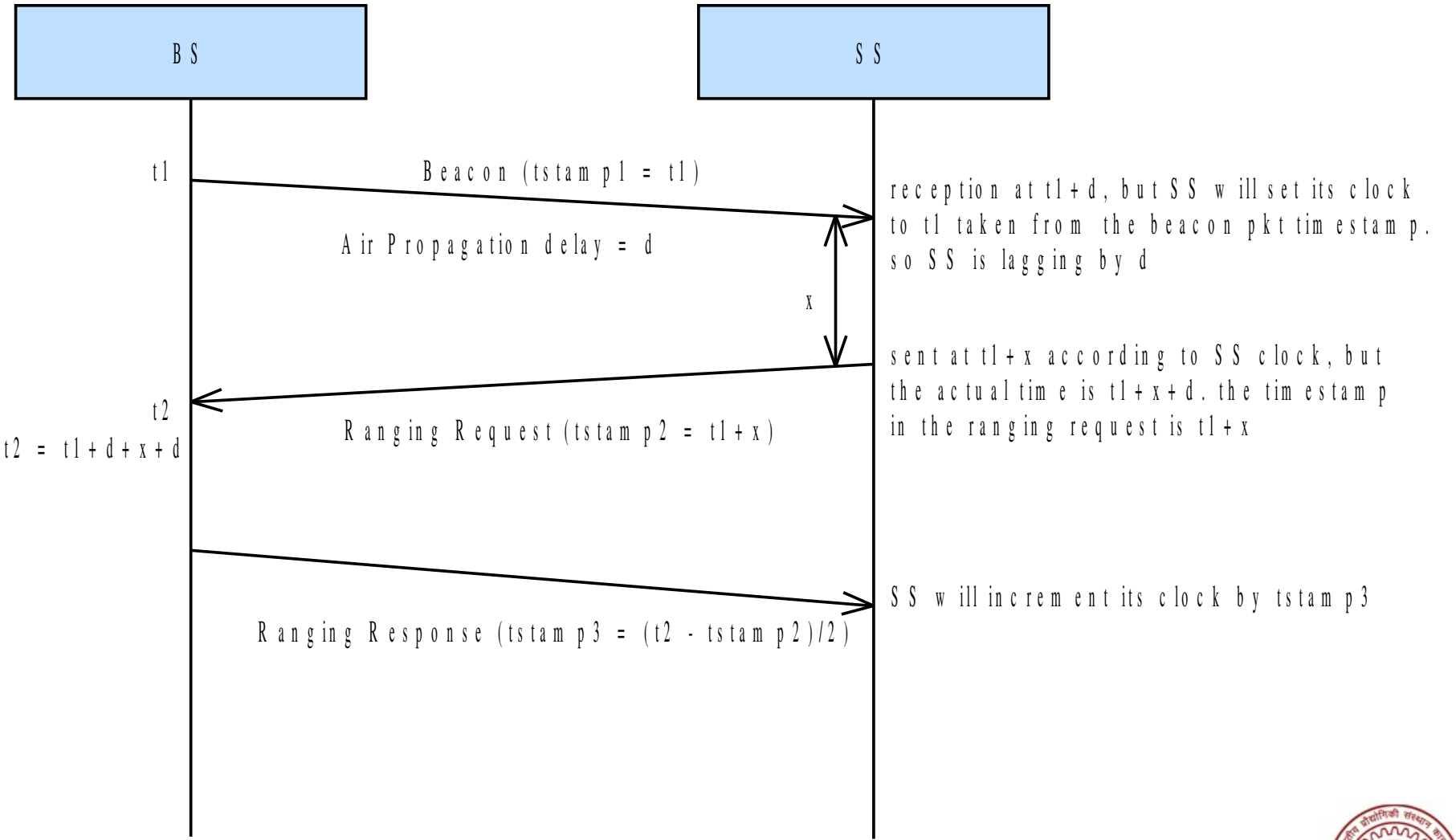
SRAWAN – Frame Structure

- Downlink – DL (BS to SSs)
  - Beacon: why is it the first PDU in DL?
    - FCH – UCD, DCD and ULMAP
    - No DLMAP. Why?
  - MPDUs (MAC Protocol Data Units)

- Uplink – UL (SSs to BS)
  - MPDUs
  - Contention based Ranging Slots
  - Contention based Bandwidth Request Slots

- Guard Time

Ranging


BS
SS
t1
Beacon (tstamp1 = t1)
reception at t1+d, but SS will set its clock to t1 taken from the beacon pkt timestamp. so SS is lagging by d
Air Propagation delay = d
x
sent at t1+x according to SS clock, but the actual time is t1+x+d. the timestamp in the ranging request is t1+x
t2
t2 = t1+d+x+d
Ranging Request (tstamp2 = t1+x)
SS will increment its clock by tstamp3
Ranging Response (tstamp3 = (t2 - tstamp2)/2)

Connection Establishment

- *Primary CID* – exchange of management messages except periodic ranging msgs
- *Basic CID* – exchange of periodic ranging msgs
- Connection establishment – 3 way handshake
- Multiple connections per SS

Other features of SRAWAN

- Authentication and Security – 802.1x
  - SRAWAN does not impose restrictions on what to send in pkts (payload) and how to send them (encryption etc)
  - 802.1x does not lay restrictions on when to send the pkts
- Packing
  - Multiple SDUs per PDU
  - No Packing of Multiple SDUs belonging to different CIDs as in WiMAX
- ARQ
  - Sliding window based
  - Retransmission granularity is MPDU
  - Cumulative ack (8 bits) with selective ack map (16 bits)

Significant questions we seek to answer

- How to achieve SRAWAN on the top of off-the-shelf 802.11 hardware?
- Is SRAWAN feasible outdoors? Is it possible to achieve tight time synchronization?
- What is the performance of SRAWAN in comparison to CSMA/CA?

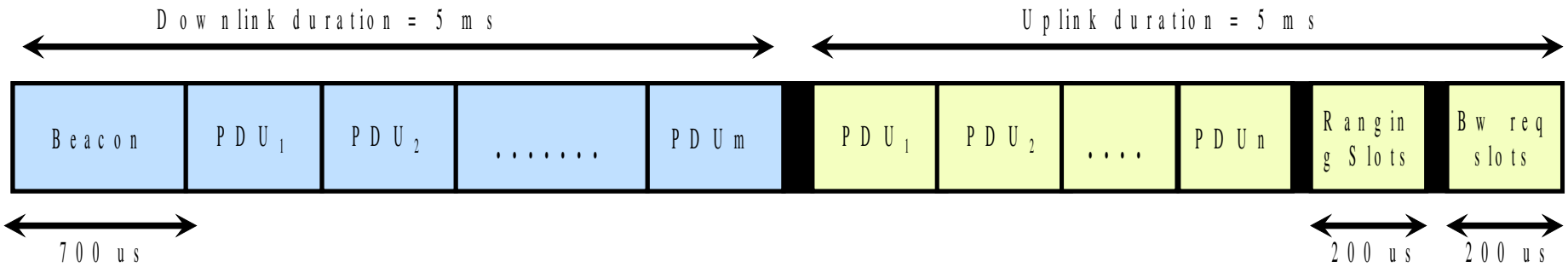
Implementation

- Atheros AR5212 chipsets (Ubiquiti SR2 and Wistron CM9 cards)
- Madwifi – Multiband Atheros Driver for WiFi
- Primary tasks required for SRAWAN
  - Overriding the 802.11 MAC PDU
  - Disabling immediate MAC level acks
  - Disable CCA and NAV
  - Disable exponential backoff
  - Eliminate SIFS, DIFS, EIFS, RTS/CTS and nullify slot
  - A micro second granular timer since the implementation is based on interrupt driven model

Features of the driver

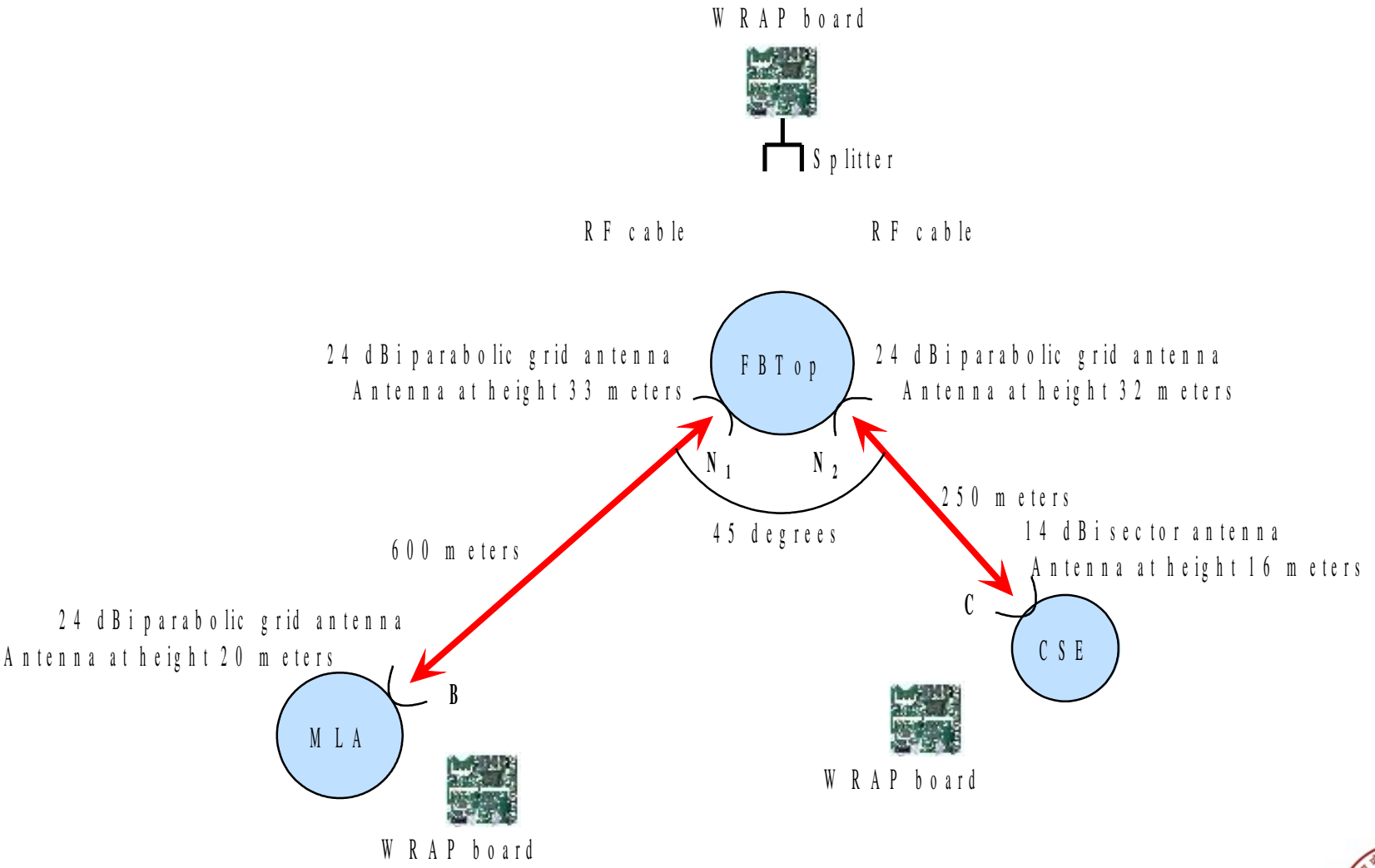
- Operates in 2 modes: BS and SS
- BS supports only UGS (CBR) flows
  - Bandwidth to be allocated for a CID is decided during connection establishment phase
  - Internet connectivity to subscribers who pay for a limited bandwidth support
  - Bandwidth requirements are not known apriori
- Beacon is sent at lowest possible rates
- Transmit power is set to maximum value
- Round robin scheduling
- ARQ
- No Packing

Implementation Parameters



- Frame duration = 10ms
- UL : DL = 1 : 1
- Guard time = 200 us
- Ranging slots = 200 us
- Connection request slots = 200us
- Num of ARQ retries = 4

Experimental Setup



CSMA/CA and SRAWAN – Performance Evaluation

MAC	Driver	RTS/CTS	Effective throughput (MLA link, CSE link in Mbps)
CSMA/CA	Madwifi	Disabled	6.3
CSMA/CA	Madwifi	Enabled	5.7
CSMA/CA	HostAP	Disabled	4.1
CSMA/CA	HostAP	Enabled	3.0
SRAWAN	Madwifi	Not applicable	6.0 (3, 3)

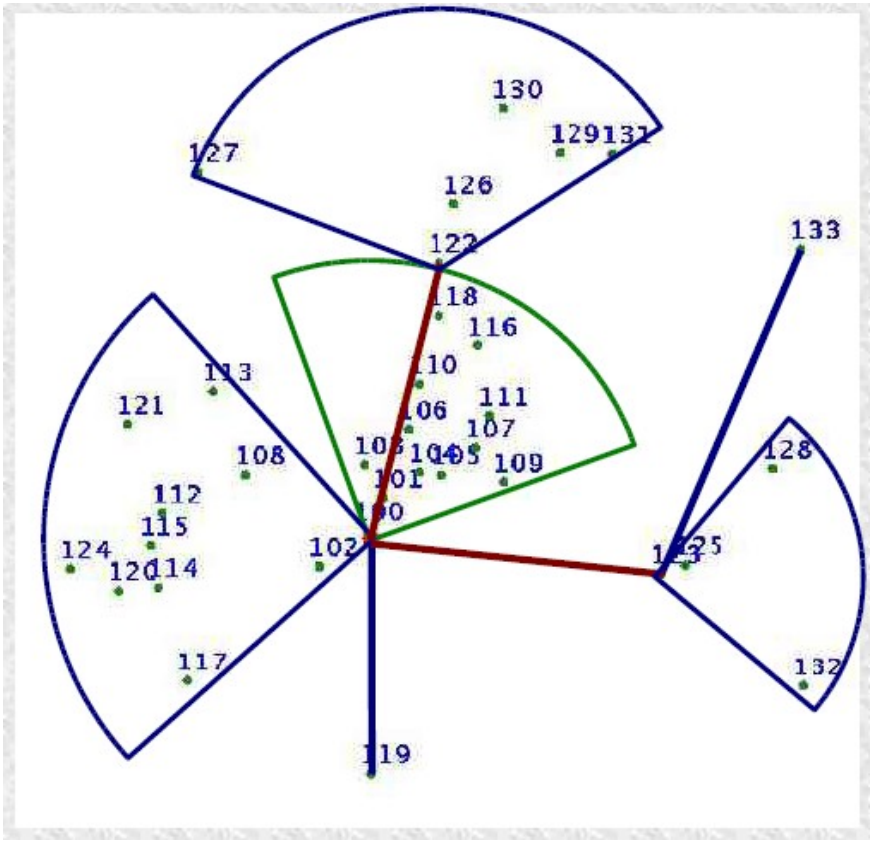
Single link performance evaluation of 2P, SRAWAN and CSMA/CA

MAC	Driver	Average throughput (Mbps)
CSMA/CA	Madwifi	7.42
CSMA/CA	HostAP	5.95
SRAWAN	NA	6.33 (7.40)
2P	NA	6.28

- Tight vs. loose time synchronization
- Lossy links – tight time synchronization is better
- Saturated traffic – TDMA MAC
- Bursty traffic – CSMA/CA

Applicability

- Rural Networks
  - *Ashwini* Network in Bhimavaram, AP (built by NGO *Byrraju* Foundation)
  - Estimated throughput support per village is 384 kbps (can support voice and video applications)



- Broadband connectivity in cities and hotspots
  - Deployment of SRAWAN in Paris by an ISP after further development by Zazu Networks, Bangalore

Conclusions

- 802.11 – cost effective solution for rural networks
- Voice and Video applications
- 2P and SRAWAN – performance effective MAC for point-to-point and point-to-multipoint links respectively
- Feasibility of 2P and SRAWAN outdoors
- Performance evaluation against CSMA/CA on DGP testbed
- Immediate applicability in *Ashwini* Network at Bhimavaram, AP built by *Byrraju Foundation*.

Questions?

Thank You