The SRAWAN MAC Protocol to support Real-Time Services in Long Distance 802.11 Networks

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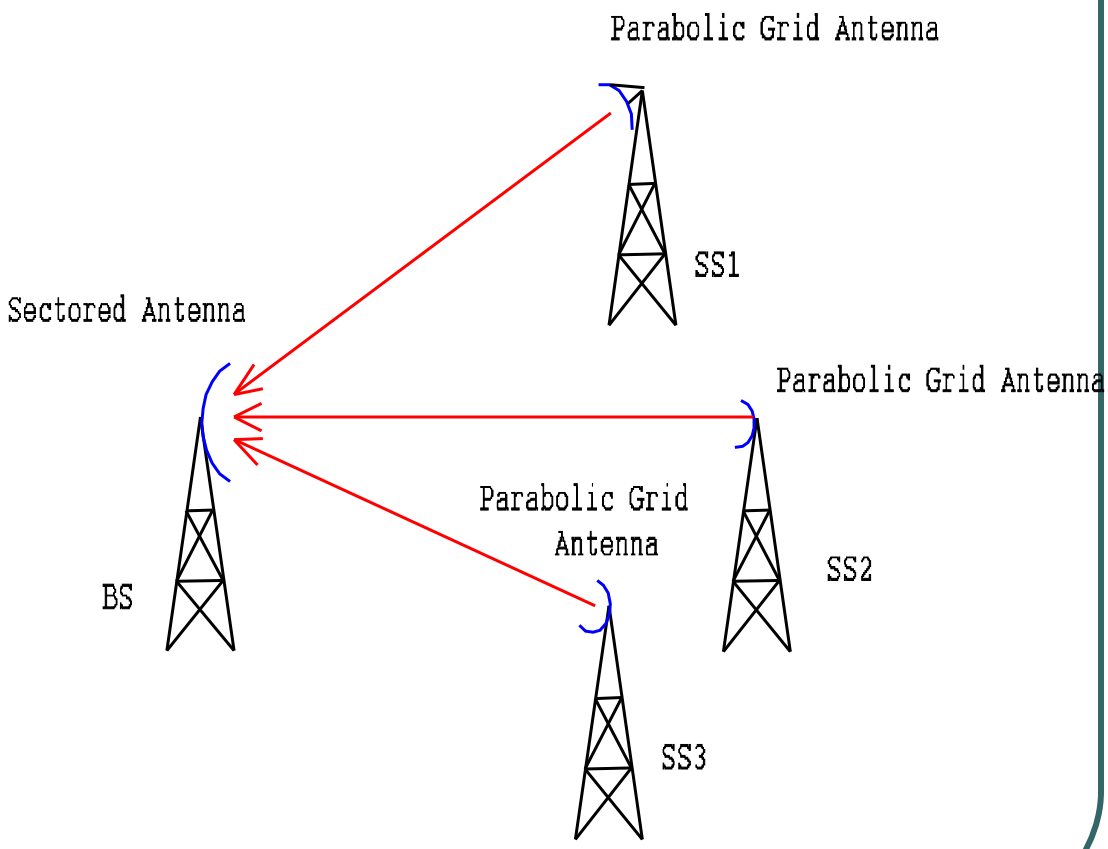
Problem Statement – Network Model

- Point to multipoint network (P2MP)
- BS – Base station
- SS – Subscriber station
- Single point of landline Internet connectivity
- Long distance links of tens of kilometers
- High-gain sectorized /directional antennae.
- Height Towers

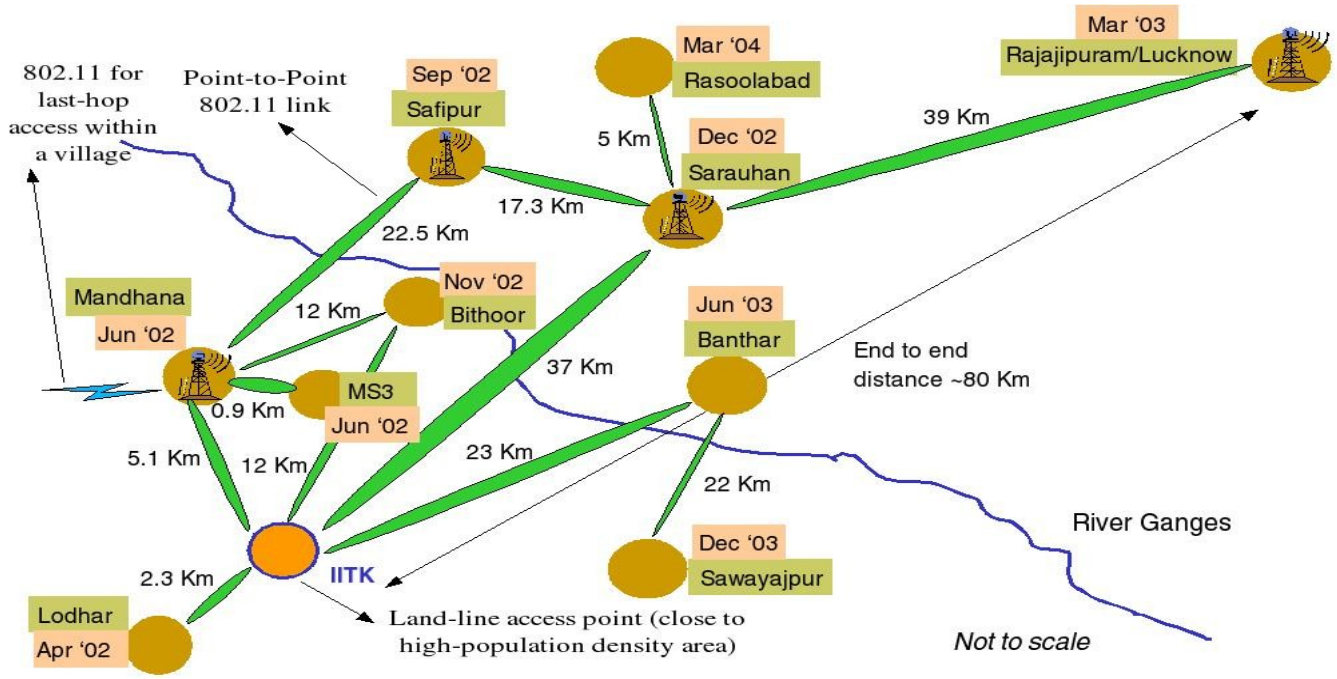


Problem Statement – Functionalities

- Develop a TDMA MAC protocol for a P2MP wireless network
- On top of the off-the-shelf 802.11 hardware to preserve cost-benefits
- Named as SRAWAN – Sectorized Rural Area Wireless Access Network
- Should solve the main problems in legacy 802.11 MAC like:
  - Hidden node problem
  - Huge overheads
- Improve throughput performance over CSMA/CA
- Provide QoS to real-time multimedia services like Voice/Video

Motivation

- Low cost Internet connectivity to rural villages
- Digital Gangetic Plains (DGP) project -

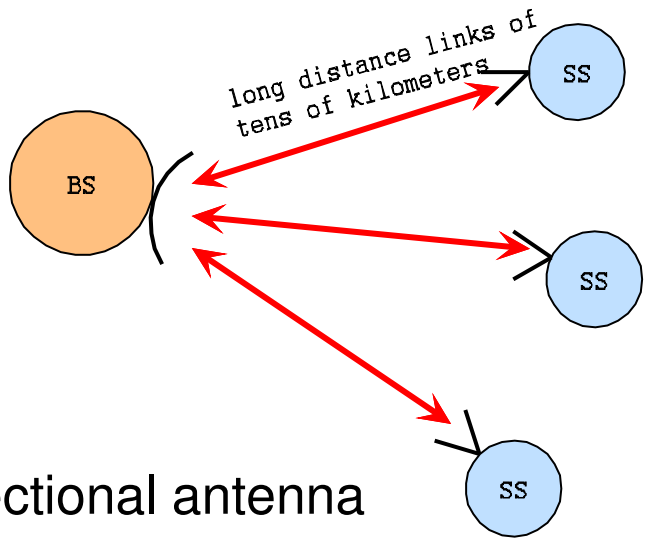


Motivation contd….

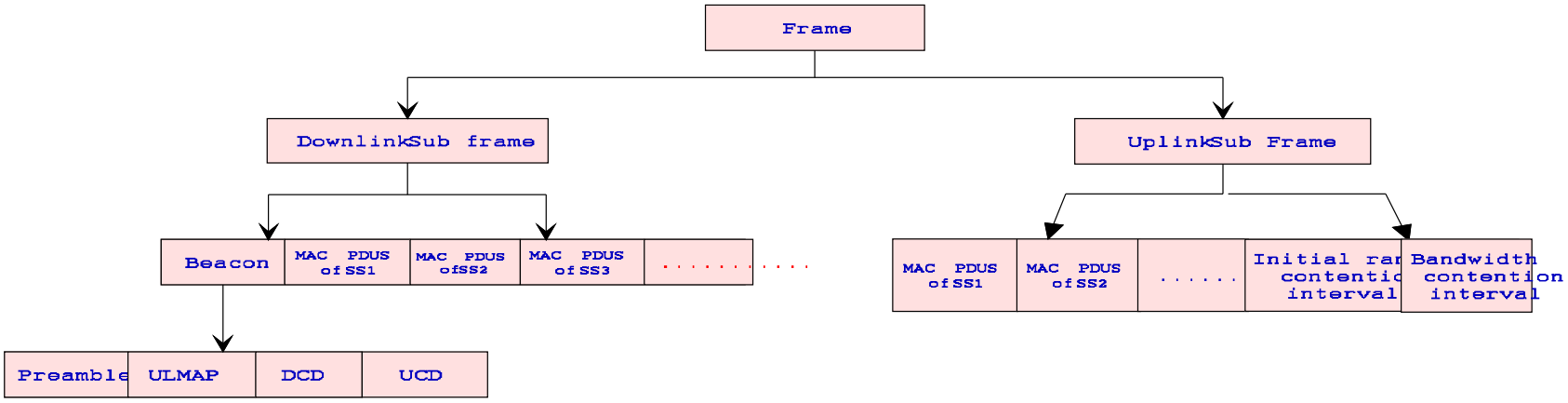
- No tested results exists for outdoor long distance links at higher data rates
- VoIP behavior with normal 802.11
  - Poor VoIP capacity in terms of no. of conversations
  - Poor VoIP performance with any TCP traffic flow
- Large portion of the world use 802.11 hardware
- Due to huge mass of production 802.11 hardware costs have tremendously come down

SRAWAN MAC Protocol - Architecture

- Supports P2MP networks
- Two types of entities in the network
  - BS
  - SS
- BS equipped with sectorized antenna
- SS equipped with parabolic grid directional antenna facing towards the direction of BS
- BS, SS communicates through a single shared channel using TDMA access mechanism
- Channel access time by all SSs is centrally decided by BS



SRAWAN MAC Protocol – Frame Structure



- Frame is a duration of time period during which BS and SS communicate each other
- Frame starts with a beacon packet broadcasted by BS to inform its presence of network.

SRAWAN MAC Protocol – Frame Structure

- Frame is divided into:
  - Downlink subframe (DL) – Traffic flow from BS to SS
  - Uplink subframe (UL) – Traffic flow from SS to BS
- Downlink subframe contains:
  - Beacon Packet
    - BSSID, timestamp
    - UL and DL channel descriptors
    - Uplink Map – Uplink transmission time periods for SSs scheduled by BS
  - DL MAC PDUs
- Uplink subframe contains:
  - Ranging contention slots – described later
  - Bandwidth contention slots – described later
  - UL MAC PDUs

SRAWAN MAC Protocol – Functional Description

- Network initialization
  - BS starts the network by broadcasting the beacon packet for every frame
  - SS enter into the BS network by going through a sequence of management phases with BS.
- SS joining into BS's network should go through the following management phases:
  - BS identification – beacon packet synchronization
  - Ranging – Tight time synchronization
  - Registration
  - Connection establishment

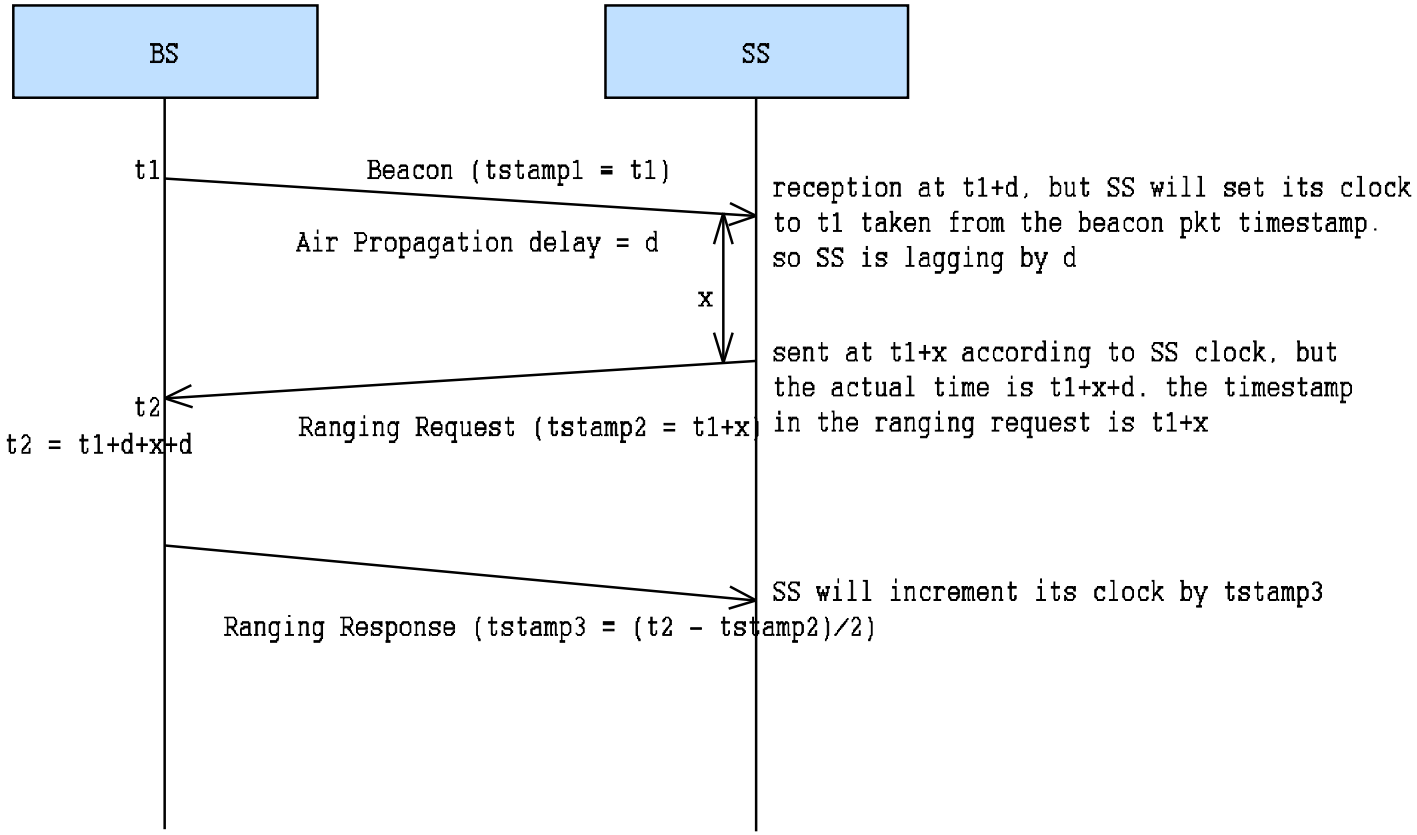
SRAWAN MAC Protocol – BS identification phase

- Once SS boots up, it enters into sniffing mode to detect beacon packets (having predefined preamble) from any BS
- Immediately after identifying the beacon packet from any BS, SS stores the following fields from beacon packet:
  - **BSSID** – used to join BS network
  - **Timestamp** – used for time synchronization
  - **UCD** – used for uplink channel specifications
  - **UL-MAP** – ranging contention slot boundaries are noted
- After identifying some BS, SS enters into **ranging phase**.

SRAWAN MAC Protocol – Ranging Phase

- **Ranging phase** – During this phase SS adjusts its clock to be in tight sync with BS's clock based on:
  - Adjustment values obtained from BS
- Initially SS sends a ranging request message in ranging contention interval
- BS replies with ranging response message containing timing adjustment values
- Entities in a TDMA based network should be in tight time synchronization all the time
- All the SSs should be in sync with BS to prevent any deviations in sharing the single communication channel

SRAWAN MAC Protocol – Time Synchronization

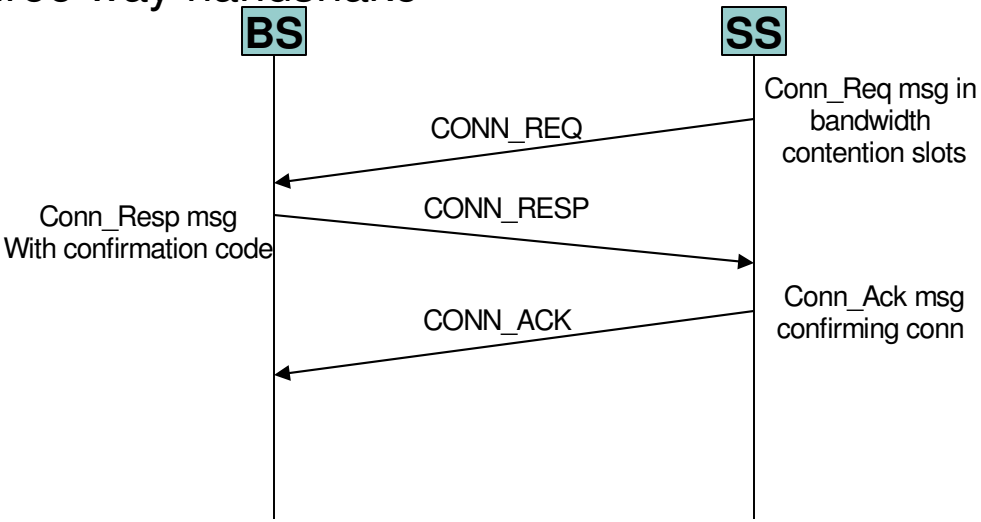


SRAWAN MAC Protocol – Registration Phase

- **Registration phase** – After successful completion of ranging phase, SS registers to the BS network
- In order to establish any new connections between SS and BS, SS has to be registered in prior.
- Two management messages are transmitted between SS and BS in this phase.
  - **REG_REQ** msg from SS to BS
  - **REG_RESP** msg from BS to SS is reply for REG_REQ
- BS gives SS an uplink slot to send REG-REQ

SRAWAN MAC Protocol – Connection Establishment

- Three way handshake



- Request for a new connection for every new traffic flow
- Bandwidth contention slots are used for connection request from SS… .why?

SRAWAN MAC Protocol – Connection Establishment

- Capability negotiation
  - ARQ enabled…?
  - Encryption enabled..?
  - Packing enabled.. …fixed packet size/variable packet size….?
- QoS parameters
  - Minimum reserved traffic rate, periodic interval, packet size
  - Scheduling service type
    - **UGS** (Unsolicited Grant Service): Fixed size packets at periodic intervals, Ex: VoIP
    - **rtPS** (real-time Polling Service): Variable size packets at periodic intervals, Ex: MPEG Video
    - **n-rtPS** (non-real time Polling Service): Variable size packets with minimum reserved bandwidth, Ex: FTP
    - **BE** (Best Effort): No such requirements, Ex: WWW

SRAWAN MAC Protocol – More features

- **Periodic Ranging**
  - If nodes in the network might slide out of sync in the middle of operation they can be brought back to synchronization in a small period of time
- **Authentication and Security**
  - SRAWAN does not define any new authentication on security mechanism
  - 802.1x security mechanisms can be used in SRAWAN for authentication
- **Packing**
  - Overhead of PHY preamble and MAC header can be reduced
  - Improves throughput efficiency
- **ARQ acknowledgment**
  - Reliable data transmission at MAC layer
  - MAC level selective ARQ mechanism with cumulative acknowledgements

SRAWAN MAC Protocol – Round Robin Scheduling

- Implemented only in uplink direction
- Each SS is given fixed amount of uplink interval in a round-robin fashion
- Advantages
  - Simple to implement
  - Provides equal share of bandwidth among all the connections
- Disadvantages
  - With increase in number of connections, inter-packet delay increases
  - Cannot provide guaranteed delay bounds for real-time traffic like voice/video

SRAWAN MAC Protocol – WFQ Scheduling

- Implemented in both downlink and uplink direction
- Each traffic flow is given a weight at the time of connection establishment
- Need to specify the service type and QoS parameters required for the specified service type
- Advantages
  - Provides ***guaranteed bandwidth/delay*** performance bounds
  - Each traffic flow obtains its own QoS performance values
  - Voice/Video/FTP traffic flows can co-exist harmoniously
- Disadvantages
  - Complex for implementation
  - Need high processing power
  - Iterated round number calculation is complex to implement

Implementation Details

- SRAWAN is developed on Atheros AR5212 Chipsets
- MADWIFI (Multiband Atheros Driver for Wi-FI) driver is taken as base code in building SRAWAN MAC
- MADWIFI provides the functionality of totally by passing the existing MAC layer and using the PHY layer functionality
- So, our new MAC protocol is built using MADWIFI with same PHY functionality.
- Features exploited from Atheros Madwifi driver:
  - Disable MAC level immediate acks.
  - Disable physical and virtual carrier sensing

Implementation Details contd….

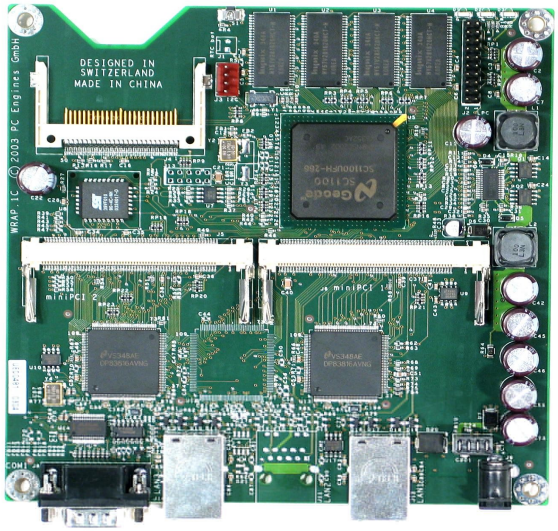
- Disable exponential backoff
- Nullifying SIFS, DIFS, EIFS and slot time
- Microsecond granularity timer used at various pointsS by both SS and BS
  - To start uplink transmission by SS
  - BS to trigger packet queuing for next downlink frame
- Beacon is sent at lowest possible rate in different modes:
  - 1Mbps – 11b, 6Mbps – 11a/g
- Transmit power is set to maximum value
- Transmit rate is also fixed: Rate control module has to be incorporated
- Uplink slot allocation:
  - Round Robin scheduling – fixed amount of slots
  - WFQ (Weighted Fair Queuing) scheduling – based on queue information at SS side which are informed to BS in their uplink packet transmissions

Contributions of thesis work

- A new ***TDMA MAC*** protocol to provide QoS for real-time multimedia services in a point-to-multipoint wireless network
- Performance analysis of ***WFQ*** scheduling on SRAWAN MAC
- Well tested in ***indoor*** environments and partially done some ***outdoor*** experiments
- Efficient ***throughput*** performance in comparison with legacy 802.11 MAC
- Protocol ***tested at scale*** of 20-25 simultaneous traffic flows.

Hardware Used – Wireless Equipment

WRAP Board



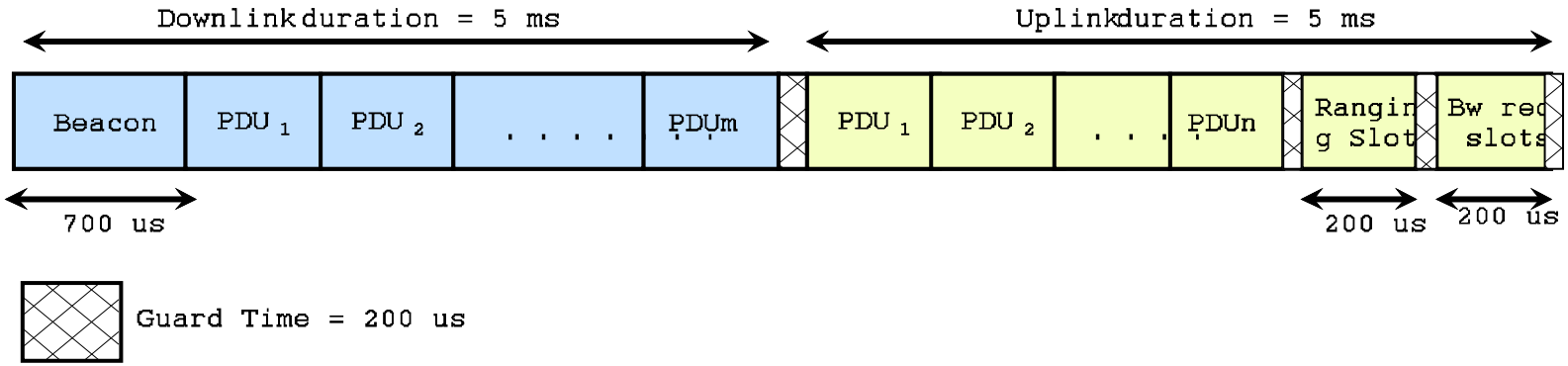
Ubiquiti SR5 card

Wistron CM9 card

Ubiquiti SR2 card

Performance Analysis – Implementation Parameters

- The following implementation parameters shown in figure below are common for all experiments



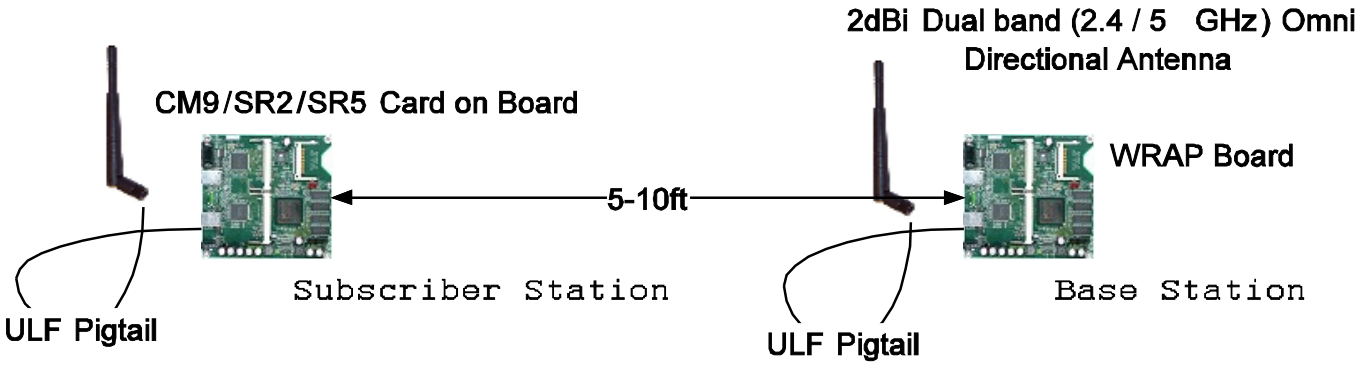
- Frame length of 10msec
- Downlink subframe : Uplink subframe = 1 : 1
- So, DL and UL subframes are 5msec each

Performance Analysis – Implementation Parameters

- Guard time of 200usecs between end of DL subframe and start of UL subframe
- Ranging and bandwidth contention intervals of 200usecs each.
- Guard time of 200usecs between ranging and bandwidth contention intervals
- There is also a guard period of 200 usecs at the end of UL subframe and start of next DL subframe
- ARQ Retry Limit – 4

Performance Analysis – Round Robin scheduling

- In round robin mechanism, each connection is provided with 500usecs in each round of its occurrence
- Indoor experiment on a P2P link:
  - Experimental setup



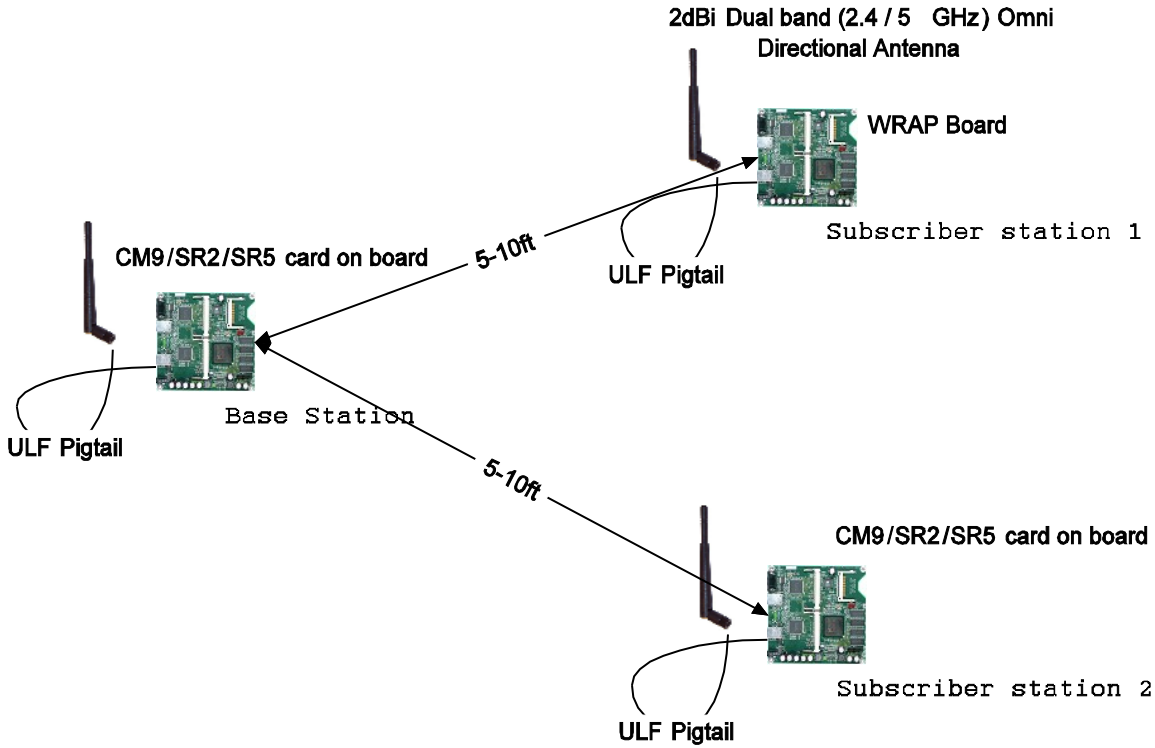
Performance Analysis – RR / Indoor / P2P link test

- Experimental Results :
  - For normal 802.11, madwifi driver is tested
  - Tests were conducted with all types of minipci cards – **CM9/SR2/SR5**
  - Achieved same amount of performance in all experimental setups

PHY	Effective UDP throughput of SRAWAN MAC	Effective UDP throughput in legacy 802.11
11b (11 Mbps)	7.92 Mbps	7.70 Mbps
11g (54 Mbps)	40.33 (21.67, 18.66) Mbps	34 – 37 Mbps
11a (54 Mbps)	39.87 (21.66, 18.21) Mbps	30 – 34 Mbps

Performance Analysis – RR / Indoor / P2MP link test

- Experiment is conducted with one BS and two SSs. This test is also conducted using all the types of minipci cards – CM9 / SR2 / SR5



Performance Analysis – RR / Indoor / P2MP link test

- Experimental Results :
  - For normal 802.11 comparison, Madwifi driver is tested
  - Tests were conducted with all types of minipci cards – CM9/SR2/SR5
  - Achieved same amount of performance in all different cards on board

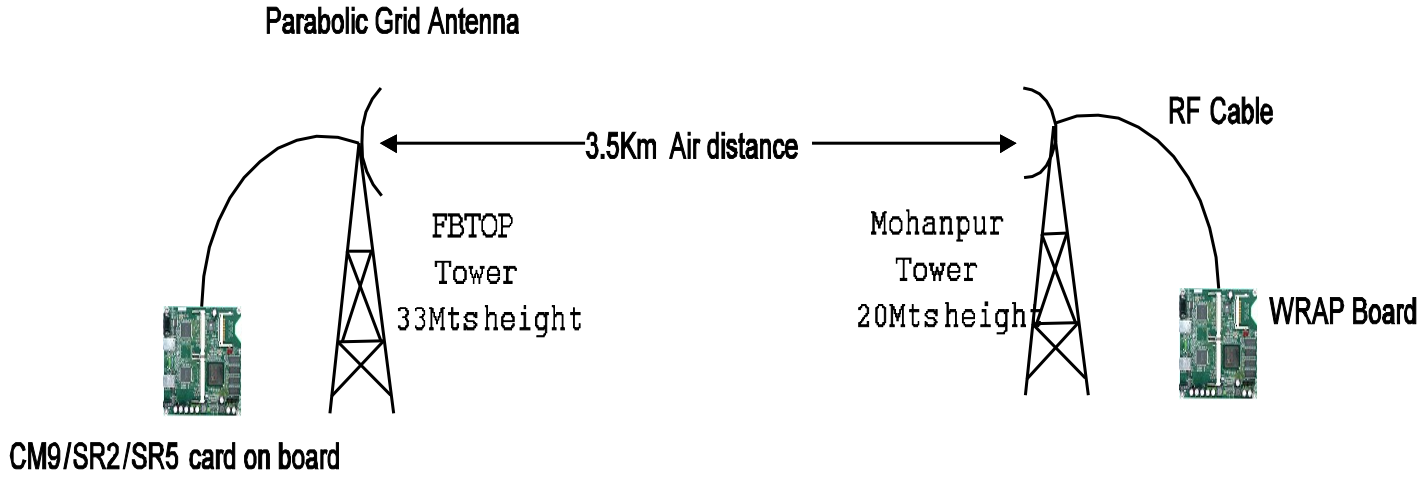
PHY	Effective UDP throughput of SRAWAN MAC	Effective UDP throughput in legacy 802.11
11b (11Mbps)	5.78 Mbps (2.95, 2.83)	5.7 Mbps (3.2, 2.5)
11g (54 Mbps)	41.80 Mbps (20.88, 20.92)	33 – 36 Mbps
11a (54 Mbps)	41.81 Mbps (20.88, 20.93)	30 – 33 Mbps

Performance Analysis – RR / Indoor Conclusion

- Round Robin scheduled SRAWAN performs efficiently than normal 802.11 MAC
- Throughput improvement is more in 11g/11a at 54Mbps
- Each of the SS is given equal amount of share of uplink bandwidth

Performance Analysis – RR / Outdoor / P2P test

- In this experiment instead of rubber duck antenna, high gain directional antennas are used which are placed on top of height towers
- Minipci external connectors are connected to MMCX pigtail which then connected to RF cable.
- RF Cable goes till the external antenna on top of the tower.



Performance Analysis – RR / Outdoor / P2P link test

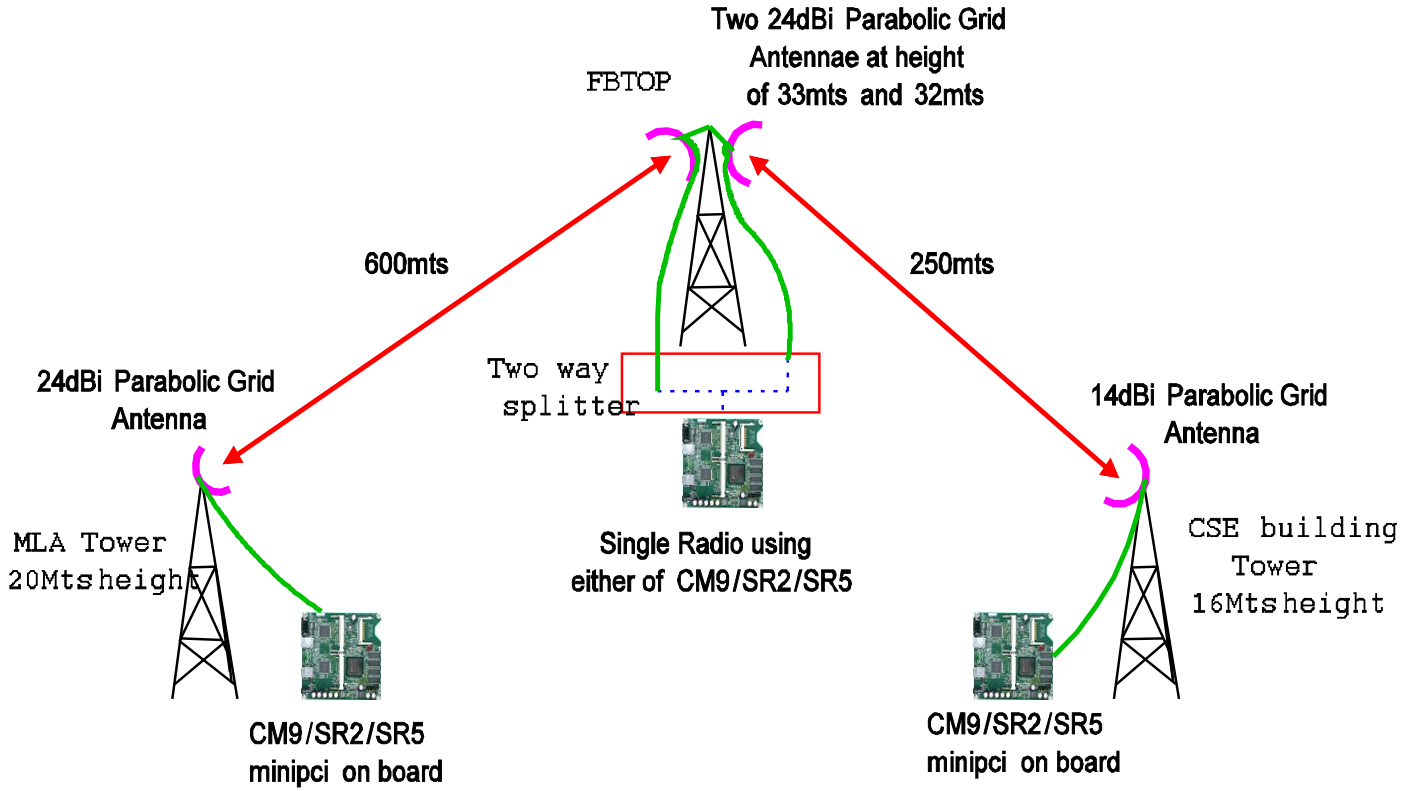
- Experimental Results :
  - For normal 802.11 comparison, Madwifi driver is tested
  - Tested only in 11b, have some issues in 11g/11a in outdoor at higher rates

PHY	Effective TCP throughput of SRAWAN MAC	Effective TCP throughput in legacy 802.11
11b (11Mbps)	5.95 Mbps	7.42 Mbps

  - Throughput reduction compared to indoor setup is due to fixed data rate and disabled ARQ mechanism.

Performance Analysis – RR / Outdoor / P2MP test

- Experimental setup



Performance Analysis – RR/Outdoor/P2MP link test

- Experimental Results : Taken from Pavan's thesis work
  - For normal 802.11 comparison, Madwifi driver is tested
  - Tested only in 11b, have some issues in 11g/11a in outdoor at higher rates

PHY	Effective TCP throughput of SRAWAN MAC	Effective TCP throughput in legacy 802.11
11b (11Mbps)	5.70 Mbps	5.7 Mbps

Performance Analysis – RR/Outdoor Conclusion

- Table below shows the comparison of throughput performance for SRAWAN and 802.11 MAC in outdoor environment tested at 11Mbps in 11b mode.

Environment	Effective TCP throughput of SRAWAN MAC	Effective TCP throughput in legacy 802.11
Outdoor P2P	5.95 Mbps	7.42 Mbps
Outdoor P2MP	5.70 Mbps	5.7 Mbps

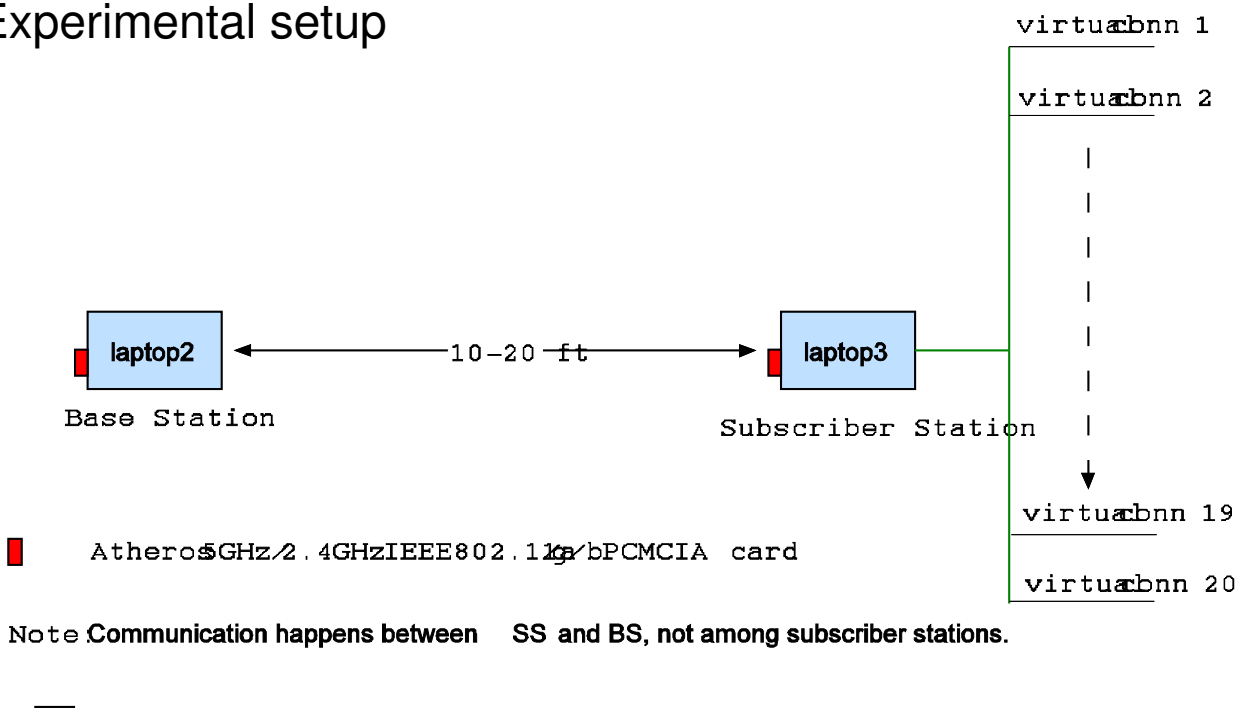
- SRAWAN MAC is performing a little poorer in outdoor environment
  - Reason is due to fixed data rate and ARQ is disabled.

Performance Analysis – WFQ Scheduling

- WFQ packet scheduling algorithm is tested only in indoor environment
- Fixed weights of 1 : 10 : 100 are given for TCP, Video and Voice traffic flows.
- Voice/Video/FTP traffic flows behavior on WFQ is tested by generating different combinations of traffic types each of different number.
- Maximum of 20 traffic flows totally are tested in the following combinations:
  - 20 Voice traffic flows with all standard voice codec parameters
  - 4 Video traffic flows
  - 17 Voice flows and 3 Video flows
  - 19 voice flows and 1 TCP traffic flow
  - 3 / 4 video flows and 1 TCP flow
- All the tests are done in 11a at 54Mbps data rate.

Performance Analysis – WFQ / Voice / Indoor test

- Experimental setup



Performance Analysis – WFQ / 20-Voice test

- Experimental Results :
  - Voice data is generated from the codec attributes
  - Results taken for all standard codecs shown in table below.

Voice codec	Expected Bit rate	Avg bit rate for each of 20 voice flow in DL direction (BS -> SS)	Avg bit rate for each of 20 voice flow in UL direction (SS -> BS)
GSM 6.10	13.2	13.18	13.165
G. 711	64	64.095	63.793
G. 723.1	6.3	6.402	6.378
G.726 -32	32	31.914	31.948
G.729	8	7.976	7.98

Performance Analysis – WFQ / 3 - Video test

- Experimental Results :
  - 3 Video flows are generated simultaneously from SS to BS direction
  - In order to generate three flows, 3 virtual connections are established between SS and BS.
  - All three are of 256Kbps data rate
  - Below are the bandwidth values of the video flows received at BS

    - SS-v1 -> BS – 0.254060 Mbps
    - SS-v2 -> BS -- 0.252953 Mbps
    - SS-v3 -> BS -- 0.253119 Mbps

Performance Analysis – WFQ/3-Video/17-voice test

- Experimental Results :
  - 3 Video and 17 voice flows are generated simultaneously from SS to BS direction
  - In order to generate these flows, 20 virtual connections are established between SS and BS.
  - All the three video flows and 17 voice flows got their expected bandwidth values when received at BS

Performance Analysis – WFQ/19-voice/1-TCP test

- Experimental Results :
  - This is the experiment of our interest. Because in normal 802.11, VoIP connections degrade their performance even with a single TCP traffic flow.
  - 19 voice flows are carried from SS to BS and one TCP flow is carried from BS to SS direction.

Voice Codec	No. of Voice flows	No. of TCP flows	Expected Bit rate	Avg bit-rate of all 19 voice flows	TCP bandwidth
GSM 6.10	19	1	13.2 Kbps	13.86 Kbps	0.652Mbps
G.723-1	19	1	6.3 Kbps	6.369 Kbps	1.919Mbps
G.726-32	19	1	32 Kbps	31.867 Kbps	0.319Mbps
G.729	19	1	8 Kbps	7.987 Kbps	1.078Mbps

Performance Analysis – WFQ/3-video/1-TCP test

- Experimental setup & results :
  - This experiment is also of our interest to know how well does multimedia applications behave with TCP traffic in WFQ.
  - 3 video flows are carried from SS to BS and one TCP flow is carried from SS to BS direction.
  - All the three video traffic flows are of 256Kbps bit rate ones

- Output results when received at BS:
  - Video stream 1 -> 253.343Kbps
  - Video stream 2 -> 252.129Kbps
  - Video stream 3 -> 228.326Kbps
  - Throughput achieved by the single TCP flow is: 0.245Mbps

Performance Analysis – WFQ Conclusions

- Voice flows are existing smoothly with TCP traffic flows unlike normal 802.11
- Video flows are also working fine, but to a small extent getting lower performance bounds (bandwidth)
- As of now, the weight values are taken random
- Perfect weight factors might give good QoS to all kinds of traffic flows

Applications – Hot spots

- Broadband Wireless Network
  - A similar kind of WiMAX broadband wireless service provision can be established.
  - Huge cost benefits due to fast deployment and low-cost hardware
  - Users are provided the service quality (bandwidth or delay) based on their requirements

Applications – Rural Internet Connectivity

- Rural Connectivity
  - Can bring Internet technology to rural villages by providing the following services
  - Internet connectivity at very low costs
  - Tele-Conference service using VoIP application
  - Tele-Education / Tele-Medicine services can be provided with Video over IP (Video conferencing)

Conclusions & Future work

- Conclusions
  - SRAWAN MAC protocol is giving good throughput values
  - Solved many problems of 802.11 networks like
    - Hidden node problem
    - Huge overheads were nullified
  - Multimedia and TCP traffic flows can co-exist harmoniously.
  - Provides more number of VoIP conversations - analytical results
  - Maximum throughput values of 42Mbps at 54Mbps in 11g/11a and 7.92Mbps at 11Mbps in 11b are achieved.
  - Protocol working well between laptops

Conclusions & Future work

- Future Work
  - Need rigorous testing, there are few instabilities in the driver
  - Issues related to 11g/11a at higher rates (54Mbps) have to be resolved
  - Periodic ranging, rate control module and packing have to be incorporated
  - Delay/Jitter calculations of voice/video traffic flows need to be done
  - Much more outdoor testing has to be done on long distance links

Thank You!