Implementation of WiFiRe PHY Sectorization in OPNET

P Sreedhar Reddy
Roll No. 06305024

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Under the Guidance Of
Prof. Sridhar Iyer

Department Of Computer Science and Engineering
Indian Institute Of Technology, Bombay

Outline

- WiFiRe overview.
- WiFiRe model design in OPNET
- Simulation results of WiFiRe model design.
- Conclusion and future work.

System Architecture

- WiFiRe adopts star network topology.
- System is designed to cover cell with radius 15-20Km
- Cell is divided in to sectors.
- System S consists of set of BSs
- ST antenna is directional which minimizes co-channel interference

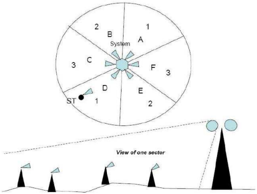


Figure: WiFiRe Network Configuration

Sectorization and frame structure

- Downlink and Uplink transmissions in a sector.
- WiFiRe employs TDD-MSTDM scheduling of slots
- Time is divided in to Frames

Protocol phases

- Network entry and initialization
  - Ranging
  - Registration

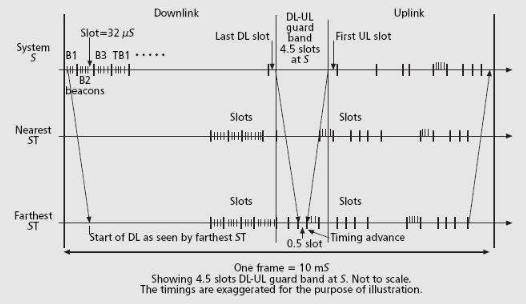


Figure: Uplink Downlink frame timings

MAC services

- UGS, pre-allocates periodic transmission opportunities to the STs, which eliminates the overhead involved in the bandwidth request-grant process. Used for fixed size periodic transmission such as VoIP.
- rtPS, ensures that STs get periodic bandwidth request opportunities. The STs can then request bandwidth from the BS.
- nrtPS, designed to support high bandwidth connections and not delay sensitive, which require variable size data grant slots on a regular basis, such as high bandwidth FTP.
- Best Effort service targets best effort traffic where no throughput or delay guarantees are necessary. These flows served in contention slots.

Prior work done on WiFiRe

Initial contributions 1

- Implemented some Base station, Subscriber station specific functionalities like processing control packets, beacon processing etc.
- Greedy hueristic scheduler at Base station with optimization parameter of UGS grant size of subscriber station.

Initial contributions 2

- Implemented WiMAX MAC model modifying for WiFiRe
- Modelled Polling, Bandwidth request mechanisms to simulate rtPS and nrtPS flows
- Modelled Round robin scheduler to accept various flows.

WiFiRe model design

Overview of work done earlier

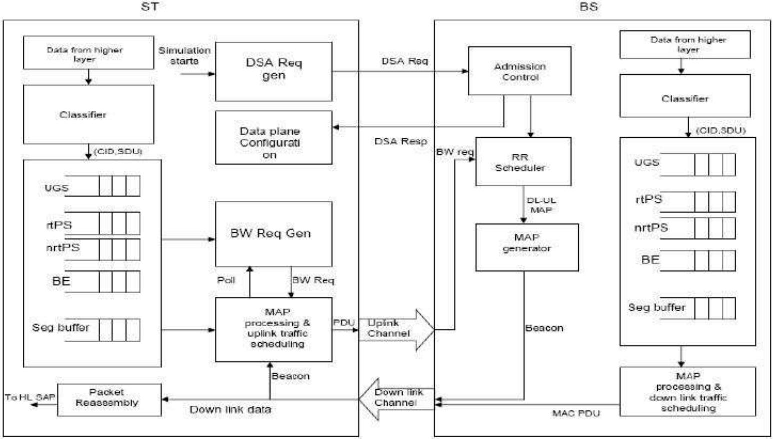


Figure: WiFiR model design

WiFiRe Common MAC process model

Common functionalities to ST and BS

- segmentation and reassembly
- Beacon processing
- packet classification

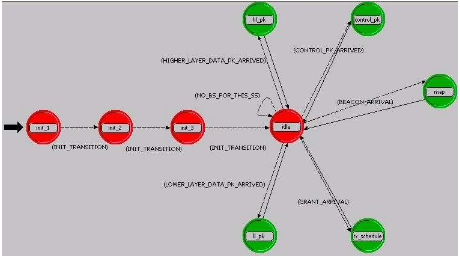


Figure: WiFiRe common MAC process

ST child control process

- ST child control process responsible for, DSA req, DSA response

Base child control process

- sending beacon periodically
- Processing DSA request
- Sending DSA response
- Scheduling downlink traffic

Present Work

Subscriber node model

- All STs have same MAC process
- MAC process responsible for defining service flows, processing beacons
- Each ST is modelled with directional antenna pointed towards system S

Base station node model

- BS node model consists of 6 WiFiRe interfaces, each WiFiRe interface represents a sector.
- Each WiFiRe interface is connected to antenna through transmitter and receiver.

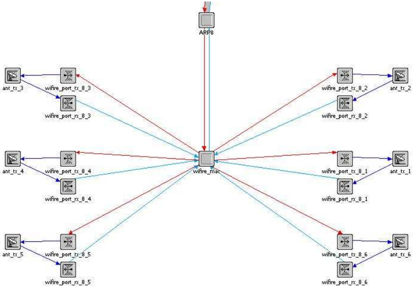


Figure: WiFiRe BS Node Model

Antenna object with transmitter and receiver

- Radio receiver and Radio trasmitter are entry and exit points of packets through wireless environment via antenna object
- Antennas are used for modeling radio transmission
- Antenna pattern editor allow modeling of directional gain at radio receivers and transmitters

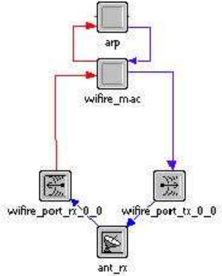


Figure: Antenna object with Tx and Rx

Antenna pattern

- Antenna pattern is defined in terms of spherical angle phi and theta
- Phi is horizontal angle
    - If phi = 0 then the point is on the positive z-axis
    - If phi = pi / 2 then the point is in the xy-plane
    - if phi = 180 then the point is on the negative z-axis
- Theta measures the angle from the positive xz-plane to the point.
- 3D antenna pattern is collection of 2D slices.
- Slices used for defining gain pattern

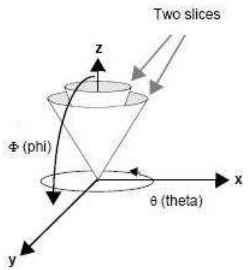


Figure: Antenna pattern using spherical angle phi and theta

Antenna pattern editor

- Antenna pattern editor is used for antenna pattern
- For each 2D slice, absicca is theta and ordinate is associated gain
- Gain tables are created for 2D slices by sample points
- For n slices there are 2n sample points

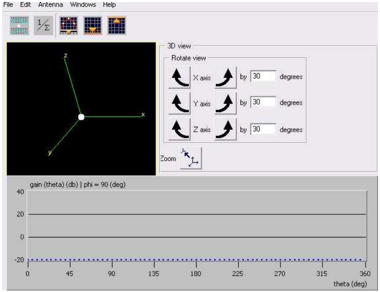


Figure: Antenna pattern editor for creating antenna pattern

Antenna Pointing processor module

- Each antenna is associated with processor module.
- Calculates the information that antenna needs to point at target.
- Convert node's position in to subnet
- Associates receiver node with tranmitter in the subnet through antenna object
- Processor module makes calculation using Kernal procedures.

```
/* op_topo_parent() uses the processor object ID to determine the
/* processor's parent object ID. */

rx_node_id = op_topo_parent (op_id_self ());
subnet_id = op_topo_parent (rx_node_id);
tx_node_id = op_id_from_name (subnet_id, OPC_OBJTYPE_NDFIX, "tx");
comp_code = op_ima_obj_pos_get (tx_node_id, &latitude, &longitude,
&altitude, &x_pos, &y_pos, &z_pos);
rx_ant_id = op_id_from_name (rx_node_id, OPC_OBJTYPE_ANT, "ant_rx");
```

Figure: Processor module code snippet

Pipeline stages

- Exists between radio transmitter and radio receiver.
- Implements physical layer characteristics of wireless medium.
- Executed once for each packet transmission.
- TDA's for communication between pipeline stages

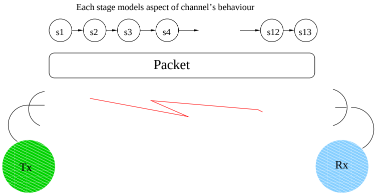


Figure: Transmission of packet

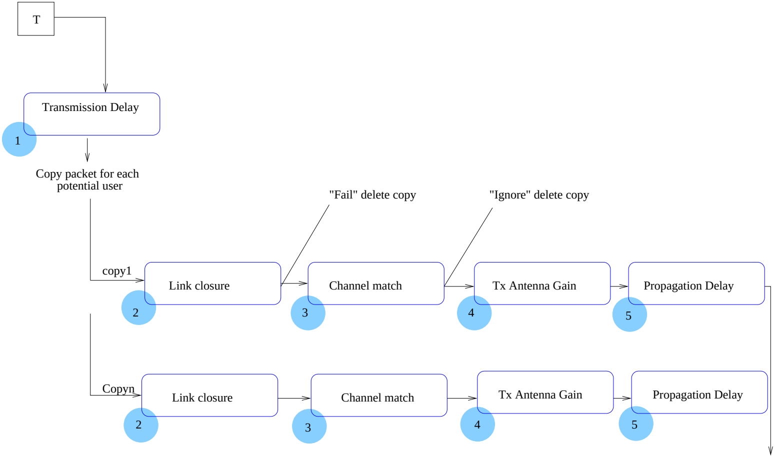


Figure: Transmitter pipeline stages

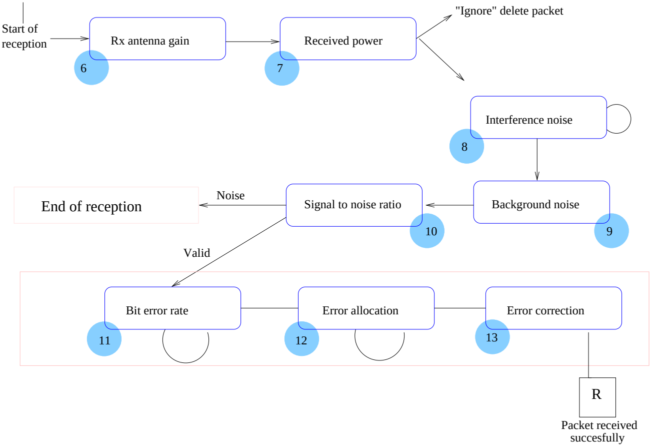


Figure: Receiver pipeline stages

Transmission delay

- Calculate the time for the entire packet transmission
- Active the trace to check the labelled break point is achieved
- Get transmission data rate from the packet using KP
- Place the result in Transmission data attributes for use of latter stages

```
if (op_prg_odb_ltrace_active ("sree"))
    op_prg_odb_print_minor ("reached transmission delay", OPC_NIL);
op_prg_odb_bkpt ("sree_test_bk_pt");
/*code by sree*/
op_pk_nfd_get_dbl (pkptr, "Tx Data Rate", &tx_drate);
/* Obtain length of packet.                                */
pklen = op_pk_total_size_get (pkptr);
/* Compute time required to complete transmission of packet */
    tx_delay = pklen / tx_drate;
op_td_set_dbl (pkptr, OPC_TDA_RA_TX_DELAY, tx_delay)
```

Figure: Transmission delay code snippet

Channel match stage

- Active the trace to check labelled break point is acheived.
- Check for non overlapping bands for classification.
- Place the result in Transmission data attributes for use of latter stages

```
if (op_prg_odb_ltrace_active ("sree_test"))
    op_prg_odb_print_minor ("reached channel match pipeline stage", OPC_NIL);
op_prg_odb_bkpt ("sree_test_bk_pt");
/* Obtain transmitting channel attributes. */
tx_freq      = op_td_get_dbl (pkptr, OPC_TDA_RA_TX_FREQ);
tx_bw        = op_td_get_dbl (pkptr, OPC_TDA_RA_TX_BW);
/* Obtain receiving channel attributes. */
rx_freq      = op_td_get_dbl (pkptr, OPC_TDA_RA_RX_FREQ);
rx_bw        = op_td_get_dbl (pkptr, OPC_TDA_RA_RX_BW);
if ((tx_freq >= rx_freq + rx_bw) || (tx_freq + tx_bw <= rx_freq))
op_td_set_int (pkptr, OPC_TDA_RA_MATCH_STATUS, OPC_TDA_RA_MATCH_IGNORE);
if ((tx_freq != rx_freq) || (tx_bw != rx_bw))
op_td_set_int (pkptr, OPC_TDA_RA_MATCH_STATUS, OPC_TDA_RA_MATCH_NOISE);
```

Figure: Channel match stage code snippet

Transmitter antenna gain

- Compute the gain associated with the transmitter's antenna.
- Get all the transmitter geocentric coordinates of transmitter.
- perform difference vector from the transmitter to receiver.
- Place the result in Transmission data attributes for use of latter stages

```
/** Compute the gain associated with the transmitter's antenna. */
/* Obtain the geocentric coordinates of the transmitter. */
tx_x = op_td_get_dbl (pkptr, OPC_TDA_RA_TX_GEO_X);
tx_y = op_td_get_dbl (pkptr, OPC_TDA_RA_TX_GEO_Y);
tx_z = op_td_get_dbl (pkptr, OPC_TDA_RA_TX_GEO_Z);
/* Compute the vector from the transmitter to the receiver. */
    dif_x = rx_x - tx_x;
    dif_y = rx_y - tx_y;
    dif_z = rx_z - tx_z;
/* converts antenna direction to gain value corresponding to that direction*/
 gain = op_tbl_pat_gain (pattern_table, rx_phi, rx_theta);
/* Set the tx antenna gain in the packet's transmission data attribute. */
op_td_set_dbl (pkptr, OPC_TDA_RA_TX_GAIN, gain);
```

Figure: Transmitter antenna gain code snippet

Propagation delay

- Get distance between transmitter and receiver using TDA
- Propagation velocity is set to propagation velocity of raido signal.
- Calculate propagation delay using propagation velocity and propagation distance
- The result is placed in the propagation delay TDA

```
/** Compute the propagation delay between the transmitter and receiver**/
/* Get the distance between transmitter and receiver.    */
prop_distance = op_td_get_dbl (pkptr, OPC_TDA_RA_START_DIST);
/* Compute propagation delay to start of reception.      */
prop_delay = prop_distance / PROP_VELOCITY;
op_td_set_dbl (pkptr, OPC_TDA_RA_START_PROPDEL, prop_delay)
```

Figure: Propagation delay code snippet

Received power

- Compute the received power of the arriving packet
- Correct reception of packet is determined by channel match.
- Depends on path loss, transmission frequency, transmitter and receiver antenna gain.
- Result is placed in TDA for use of latter stages.

Interference noise

- Account for the situation that two packets arrive concurrently at the same receiver channel
- Increment the number of collisions for two packets
- Interference of previous packet on arriving one is calculated and placed in TDA.

Signal to noise ratio

- Receive the rcvd power and interference noise from previous stages
- Calculated snr using received power and noise in db

```
/** Compute the signal-to-noise ratio for the given packet. **/
 /* Get the packet's received power level. */
 rcvd_power = op_td_get_dbl (pkptr, OPC_TDA_RA_RCVD_POWER);
 if (op_prg_odb_ltrace_active ("sree"))
     op_prg_odb_print_minor ("reached snr", OPC_NIL);
 op_prg_odb_bkpt ("sree_test_bk_pt");
 /*code by sree*/
 /* Get the interference noise from previous stage */
 accum_noise = op_td_get_dbl (pkptr, OPC_TDA_RA_NOISE_ACCUM);
 /*Assign Snr in dB */
 op_td_set_dbl (pkptr, OPC_TDA_RA_SNR, 10*log10(rcvd_power/(accum_noise)))
```

Figure: Signal to noise ratio code snippet

Bit error rate

- From Modulation scheme of Bit rate and SNR it calculates bit error rate
- Bit error rate is placed in BER Transmission date attribute
- Determine whether or not the arriving packet can be accepted

```
/* Determine current value of Signal-to-Noise-Ratio (SNR). */
    if (op_prg_odb_ltrace_active ("sree"))
    op_prg_odb_print_minor ("reached ber", OPC_NIL);
op_prg_odb_bkpt ("sree_test_bk_pt");
snr = op_td_get_dbl (pkptr, OPC_TDA_RA_SNR);
/* Derive expected BER from effective SNR. */
ber = op_tbl_mod_ber (modulation_table, snr);
/* Place the BER in the packet's transmission data. */
op_td_set_dbl (pkptr, OPC_TDA_RA_BER, ber);
```

Figure: Bit error rate code snippet

Experiments

- Building WiFiRe model in OPNET.
- Setup a sector using directional antenna.
- Setup STs in six sectored system with VoIP configuration
- Experiment to simulate VoIP and Video scenario

S.No	Parameter	Value
1	Data Rate	11 Mbps
2	Control packet data rate	2 Mbps
3	Frame Duration	10 ms
4	Slot duration	32μsec
5	DL-UL ratio	2:1
7	Service class	UGS

Table: System setup parameters

S.No	Parameter	Value
1	Frequency Channel	2.4 GHz
2	Bandwidth	22 MHz
3.	Duplexing technique	TDD
4.	PHY overhead	96μsec
5.	Number of symbols/frame	220000
6.	Symbol duration	0.045μsec

Table: PHY profile setup parameters

Setup to perform range of sectorization using directional antennas

Purpose of this experiment to show the sectorization works

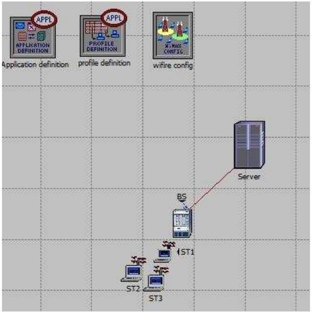


Figure: Scenario 1 with unit distance of 5Km

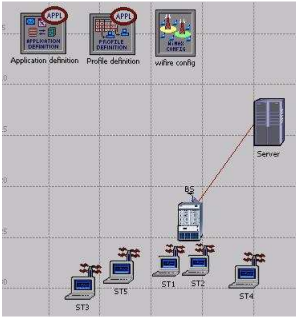


Figure: Scenario 2 with unit distance of 5Km

Above scenarios has setup of 60 degrees sectorized antenna at base station

Performance plots for range of sectorization

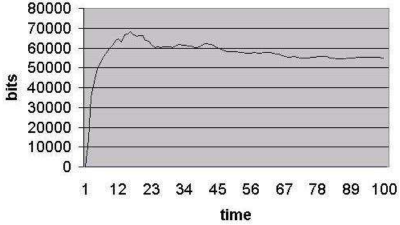


Figure: Load for scenario 1

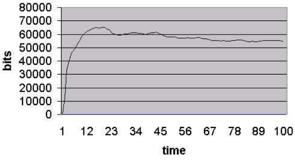


Figure: Throughput for scenario 1

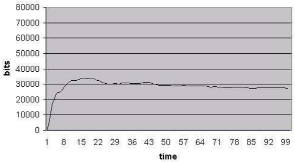
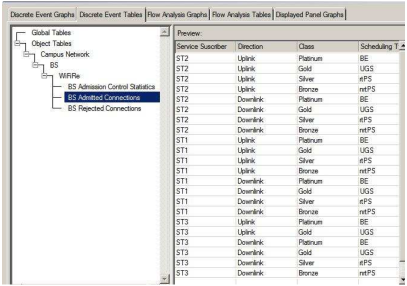


Figure: Throughput for scenario 2

Throughput of sectorization using directional antennas

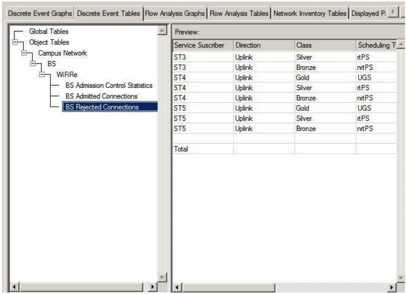
- Each ST is requested with 20Kbps
- The total load offered with first scenario is 60Kbps.
- The total load offered with second scenario is 100Kbps.
- Throughput for first scenario with 3 STs is same as load due to proper sectorization of BS with respect to directionality of ST.
- The load offered for scenario 2 is 100Kbps.
- Throughput for Scenario 2 is less compared with load as some STs in this scenario are out of range in the sector.

Sectorized deployed in a sector using antenna pattern



Service Suscriber	Direction	Class	Scheduling T
ST2	Uplink	Platinum	BE
ST2	Uplink	Gold	UGS
ST2	Uplink	Silver	rtPS
ST2	Uplink	Bronze	nrtPS
ST2	Downlink	Platinum	BE
ST2	Downlink	Gold	UGS
ST2	Downlink	Silver	rtPS
ST2	Downlink	Bronze	nrtPS
ST1	Uplink	Platinum	BE
ST1	Uplink	Gold	UGS
ST1	Uplink	Silver	rtPS
ST1	Uplink	Bronze	nrtPS
ST1	Downlink	Platinum	BE
ST1	Downlink	Gold	UGS
ST1	Downlink	Silver	rtPS
ST1	Downlink	Bronze	nrtPS
ST3	Uplink	Platinum	BE
ST3	Uplink	Gold	UGS
ST3	Downlink	Platinum	BE
ST3	Downlink	Gold	UGS
ST3	Downlink	Silver	rtPS
ST3	Downlink	Bronze	nrtPS

Figure: Admitted connections for scenario 1



Service Suscriber	Direction	Class	Scheduling T
ST3	Uplink	Silver	rtPS
ST3	Uplink	Bronze	nrtPS
ST4	Uplink	Gold	UGS
ST4	Uplink	Silver	rtPS
ST4	Uplink	Bronze	nrtPS
ST5	Uplink	Gold	UGS
ST5	Uplink	Silver	rtPS
ST5	Uplink	Bronze	nrtPS
Total			

Figure: Rejected connections for scenario 2

Some connections are rejected in scenario 2 due to out of range in the sector

Experiment to simulate VoIP calls

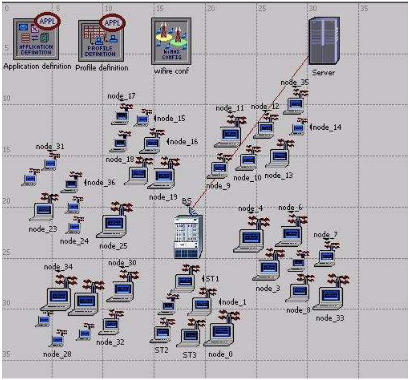


Figure: Scenario with 40 STs and unit distance of 5 Km

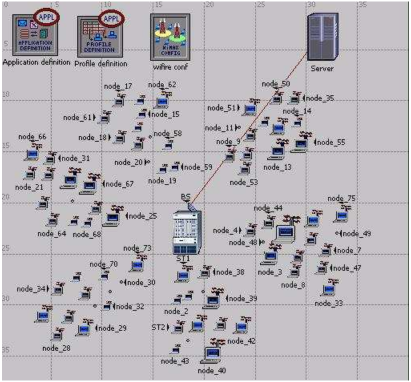


Figure: Scenario with 120 STs and unit distance of 5 Km

Performance plots for experiment to simulate VoIP calls

- Each ST requesting Bandwidth of 120Kbps
- Requested rate with MACoverhead is 130Kbps
- Load is 120Kbps, Actual traffic sent is 130Kbps

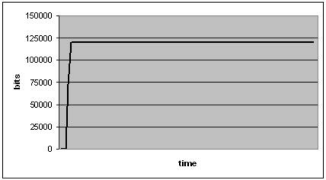


Figure: Load of the system

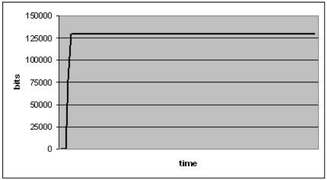


Figure: Actual traffic sent

Theoritical number of VoIP calls supported

Original Bandwidth request from ST = 120Kbps

$$\text{Requested rate with MACoverhead} = rate \times \left(\frac{avg\_pkt\_size + WiFiRe\_header}{avg\_pkt\_size}\right)$$

$$= (120 \times 10^3) \times \left(\frac{60+5}{60}\right) = 130 Kbps$$

Requested rate in symbols per second =

$$rate\_mac \times \left(\frac{1}{number\_of\_bits\_persymbol \times coding\_rate}\right)$$

$$= (130 \times 10^3) \times \left(\frac{1}{1 \times \frac{1}{2}}\right) = 260 \times 10^3$$

Number of symbols required per frame = (req rate in sps)× (frame duration)

symbols per frame = $260 \times 10^3 \times 10 \times 0.001$ =2600 symbols

$$\text{symbols per slot} = \frac{32}{0.045} = 711 \text{ symbols}$$

WiFiRe PHY overhead = 96 micro sec

Number of symbols with WiFiRe PHY overhead =

$$\frac{PHY\_overhead\_duration}{Symbol\_duration} = 2133 symbols.$$

Total number of symbols required is sum of PHY overhead and requested rate

= PHY overhead + Number of symbols requested

= 2133+2600=4733 symbols

$$\text{Total number of slots} = \frac{Total\_number\_of\_slots}{symbols\_for\_slot}$$

$$= \frac{4733}{711} = 6$$

$$\text{Down link bandwidth} = \frac{66}{100} \times 11 * 10^6 = 7.26 \times 10^6$$

With 40 ST's ratio each ST has 323 Kbps if voice packet server in two frames

$$= \frac{7260Kbps}{40} \times 2 = 323\text{Kbps}$$

similarly with 120 STs it is around 119 Kbps which is close to requested bandwith

Traffic received and Throughput for 40 STs

- All STs got Bandwidth alloted with theoritical calculation of 66 percentage DL Bandwidth
- Throughput is equal to traffic sent
- Each ST has 3 data slots and 3 phy slots
- Three VoIP calls are supported by each ST

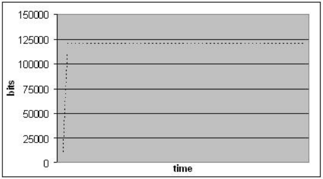


Figure: Traffic received for 40 STs

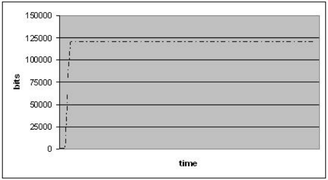


Figure: Throughput for 40 STs

Queuing dealy and datadropped for 40 STs

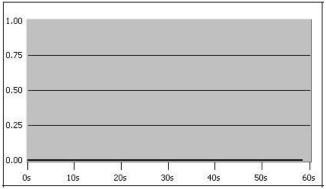


Figure: Data drop for 40 STs

- Arrival rate is equal to service rate
- Queuing delay is constant
- No traffic dropped

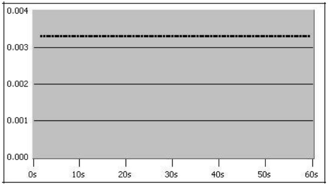


Figure: Queuing delay for 40 STs

Data dropped and queuing delay for 120 STs

- No sufficeint bandwidth alloted to STs
- Queuing delay varies
- Queue will be filled packets are dropped

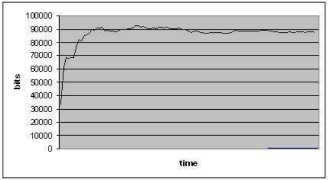


Figure: Data drop for 120 STs

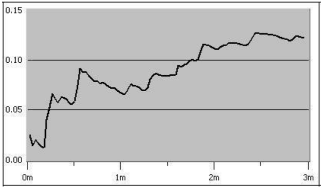


Figure: Queuing delay for 120 STs

Throughput for 120 STs

- Bandwidth not sufficent for STs
- Throughput is less compared to traffic sent

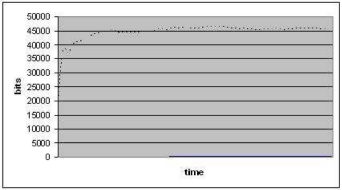


Figure: Throughput for 120 STs

Experiment to simulate VoIP and Video scenario

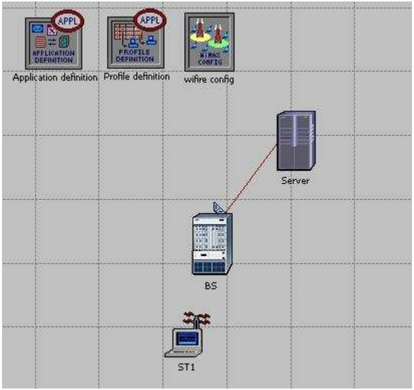


Figure: Scenario with ST and unit distance of 5Km

End to End delay for UGS

- This experiment is based on earlier model to simulate VoIP and Video Scenario by changing parameters
- The type of scheduling used is round robin
  - BS first allocates admitted number of slots for UGS flows.
  - Allocates requested number of slots for rtPS, if the requested number of slots are less than the admitted number of slots.
- UGS requesting 120Kbps serving smoothly
- BS allocates requested no of slots to UGS

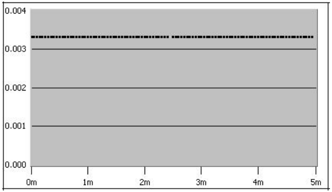


Figure: End to end delay for UGS

End to End delay for rtPS

- rtPS connection requesting 120Kbps
- End to end delay is intially high, as BS allocates admitted slots to UGS
- End to end delay gradually reduces to constant after getting requested number of slots

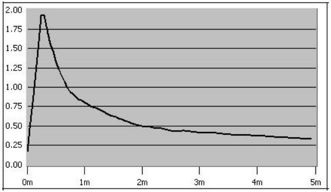


Figure: End to end delay for rtPS

Throughput for UGS and rtPS

- Throughput of UGS connection is high intially compared to rtPS
- As BS first allocates admitted number of slots to UGS
- Throughput of rtPS reaches 120Kbps after some time with requested rate

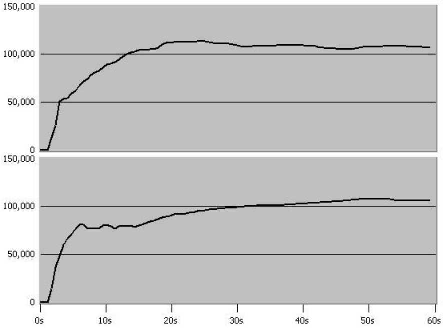


Figure: Throughput of UGS and rtPS

Conclusion

- Implemented WiFiRe model in OPNET
- Directional Antennas are modelled
- Pipeline stages are implemented to simulate physical behaviour of wireless link
- Results shows the model is working as expected

Future Work

- More experiments need to be performed in order to check performance of WiFiRe.
- The Performance questions are to be answered based upon different parameters are
  - What is the maximum number of users per sector and throughput in the sector which depends up on maximum throughput that channel can achieve
  - Number of packets dropped which depends on number of service flows and number of active users in the sector
  - Maximum number of allowed connections per ST

Thank You