NetSim™

Simulation Platform for Network R & D

Experiment Manual

TETCOS

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Contents

1. Introduction to NetSim

1.1 Introduction to network simulation through the NetSim simulation package

1.1.1 Theory:

- **What is NetSim?**

NetSim is a network simulation tool that allows you to create network scenarios, model traffic, and study performance metrics.

- **What is a network?**

A network is a set of hardware devices connected together, either physically or logically. This allows them to exchange information.

A network is a system that provides its users with unique capabilities, above and beyond what the individual machines and their software applications can provide.

- **What is simulation?**

A simulation is the imitation of the operation of a real-world process or system over time.

Network simulation is a technique where a program models the behavior of a network either by calculating the interaction between the different network entities (hosts/routers, data links, packets, etc) using mathematical formulae, or actually capturing and playing back observations from a production network. The behavior of the network and the various applications and services it supports can then be observed in a test lab; various attributes of the environment can also be modified in a controlled manner to assess how the network would behave under different conditions.

- **What does NetSim provide?**

Simulation: NetSim provides simulation of various protocols working in various networks as follows: **Internetworks, Legacy Networks**, **BGP Networks, Advanced Wireless Networks, Cellular Networks, Wireless Sensor Networks, Personal Area Networks, LTE/LTE-A Networks, Cognitive Radio Networks, and Internet of Things**. Users can open the experiments and save the experiments as desired. The different experiments can also be analyzed using the analytics option in the simulation menu.

Programming: NetSim covers various programming exercises along with concepts, algorithms, pseudo code and flowcharts. Users can also write their own source codes in C/C++ and can link them to NetSim.

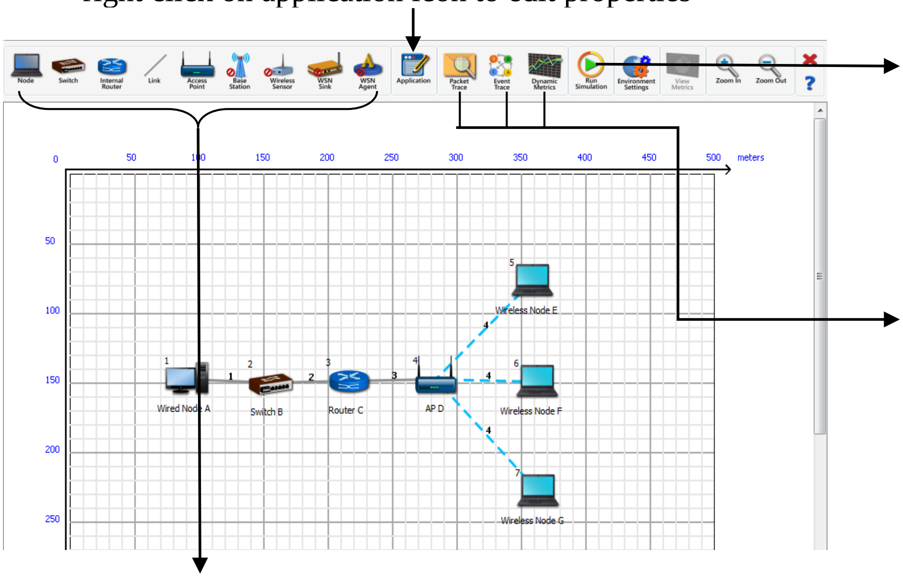
Some of the programming concepts are Address resolution protocol (ARP), Classless inter domain routing (CIDR), Cryptography, Distance vector routing, shortest path, Subnetting etc.

1.2 Design and configure a simple network model, collect statistics and analyze network performance.

1.2.1 Theory:

- **Network model:** A Network model is a flexible way of representing devices and their relationships. Networking devices like hubs, switches, routers, nodes, connecting wires etc. are used to create a network model.

Click here to drop the application icon to generate traffic. Then right click on application icon to edit properties



Click here to Run Simulation

Click here to enable the traces

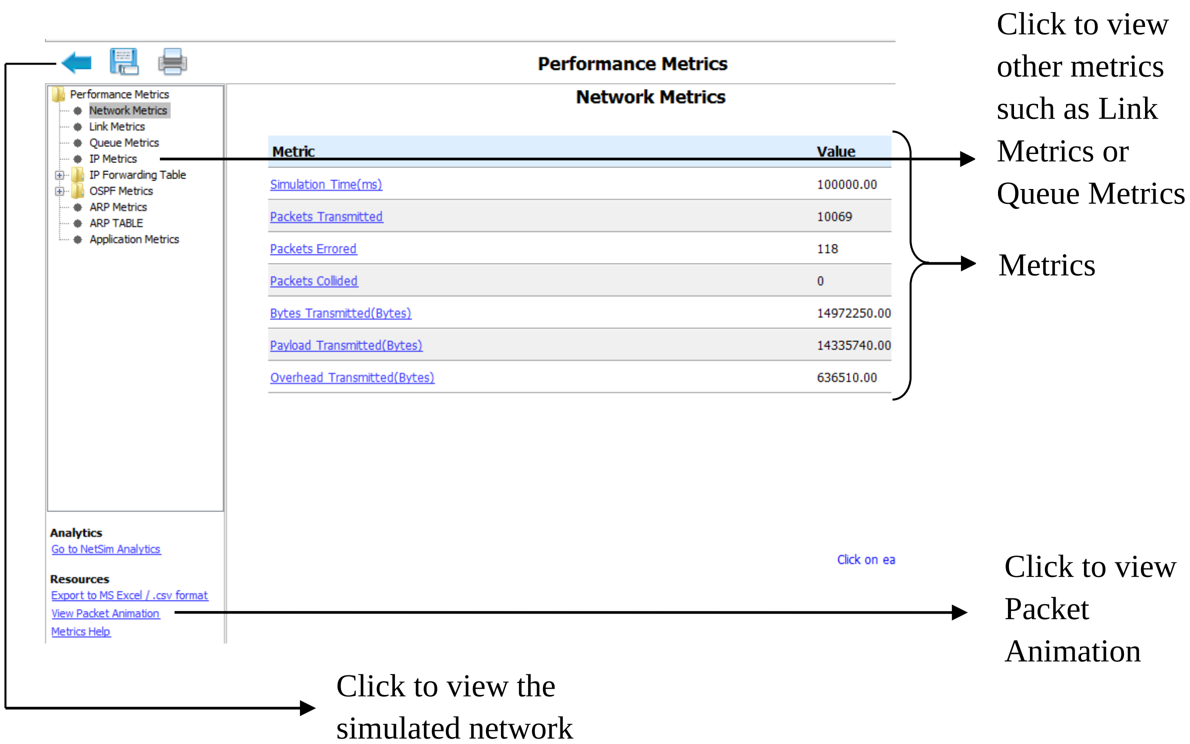
Click and drop network devices and right click to edit properties

- **Scenario:** A Scenario is a narrative describing foreseeable interactions of types of input data and its respective output data in the system.

- **Network performance:** To measure the performance of a network, performance metrics constitutes of Network Statistics.

- **What are network statistics?**

  Network statistics are network performance related **metrics** displayed after simulating a network. The report at the end of the completion of a simulation experiment include metrics like throughput, simulation time, frames generated, frames dropped, frames errored, collision counts etc, and their respective values.

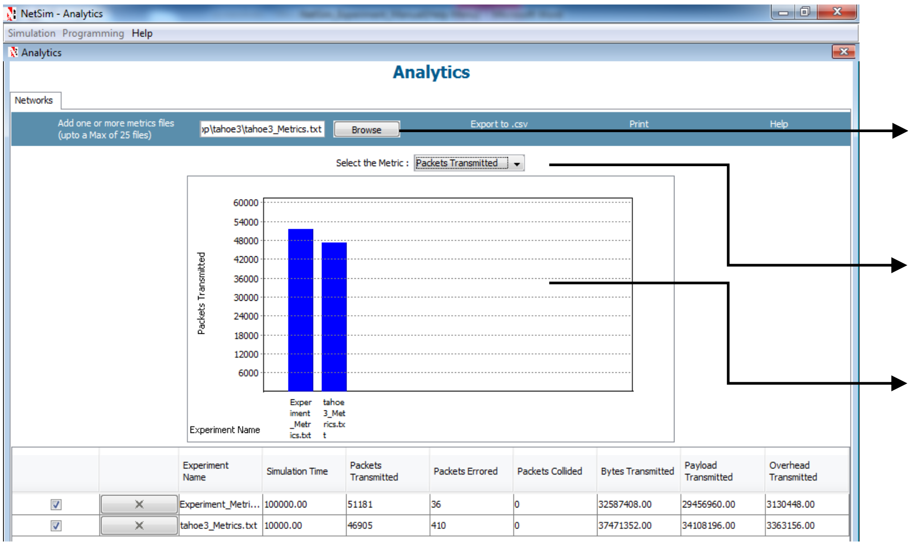


- **What is Packet Animation?**

  When running simulation, options are available to play and record animations which allow users to watch traffic flow through the network for in-depth visualization and analysis.

- **What is NetSim analytics used for?**

  It is used to compare and analyze various protocols scenarios under **Internetworks, Legacy Networks**, **BGP Networks, Advanced Wireless Networks – MANET and Wi-Max, Cellular Networks, Wireless Sensor Networks, Zigbee Networks, Internet of Things, LTE/LTE-A Networks** and **Cognitive Radio Networks**. Parameters like utilization, loss, queuing delay, transmission time etc of different sample experiments are compared with help of graphs.



Click on "Browse" to select the experiments

Click to select the metrics

Plot the chart here

2. Understand IP forwarding within a LAN and across a router

Note: NetSim Standard Version is required to run this experiment

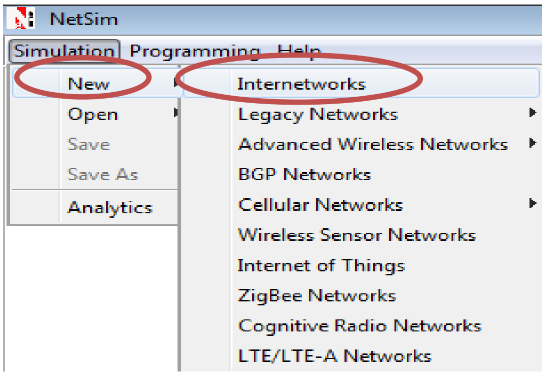
2.1 Theory:

Nodes in network need MAC Addresses in addition to IP address for communicating with other nodes. In this experiment we will see how IP-forwarding is done when a node wants to send data within a subnet and also when the destination node is outside the subnet.

2.2 Procedure

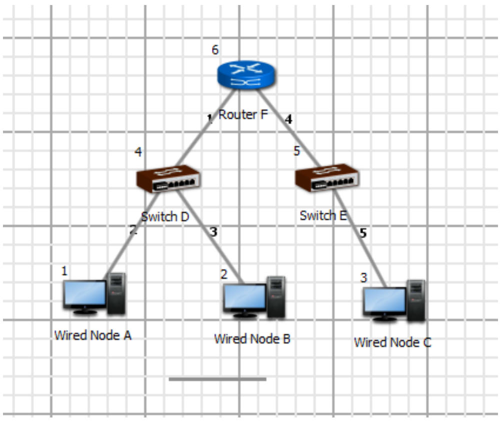
Step 1:

Go to Simulation → New → Internetworks

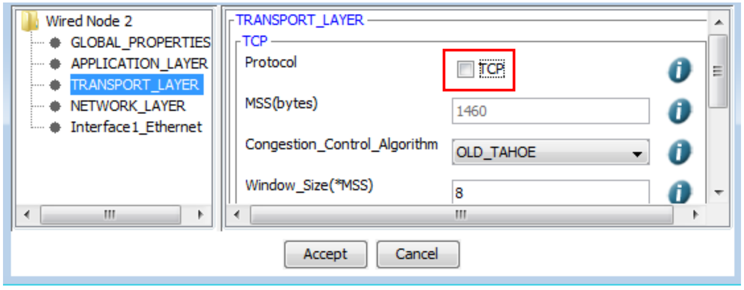


Step 2:

Click & drop Wired Nodes, Switches and Router onto the Simulation Environment as shown and link them.



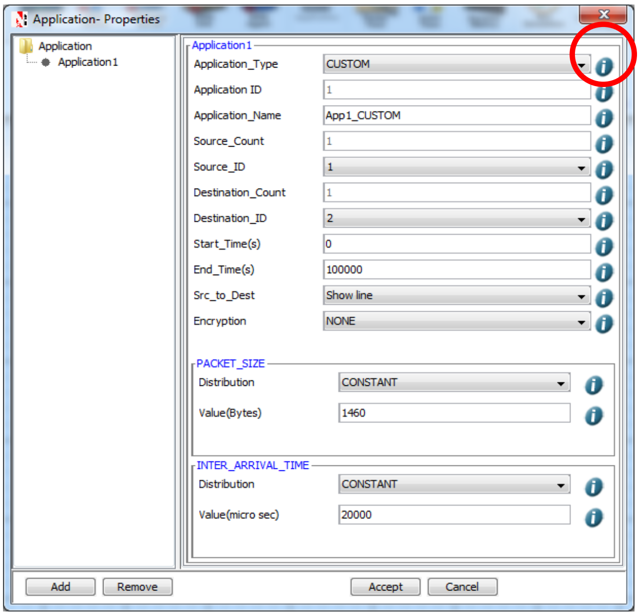
Node properties: Disable TCP in all nodes in Transport layer as follows:



Step 3: Create the Sample as follows:

Sample 1:

To run the simulation, drop the Application icon and set the Source_Id and Destination_Id as 1 and 2 respectively. Click on the ibutton as shown in the below figure for more information on the parameters



Enabling the packet trace:

- Click Packet Trace icon in the tool bar. This is used to log the packet details.
- Check "**All the Attributes**" button for Common Attributes, TCP and WLAN.
- And Click on Ok button. Once the simulation is completed, the file gets stored in the location specified.

Step 4:

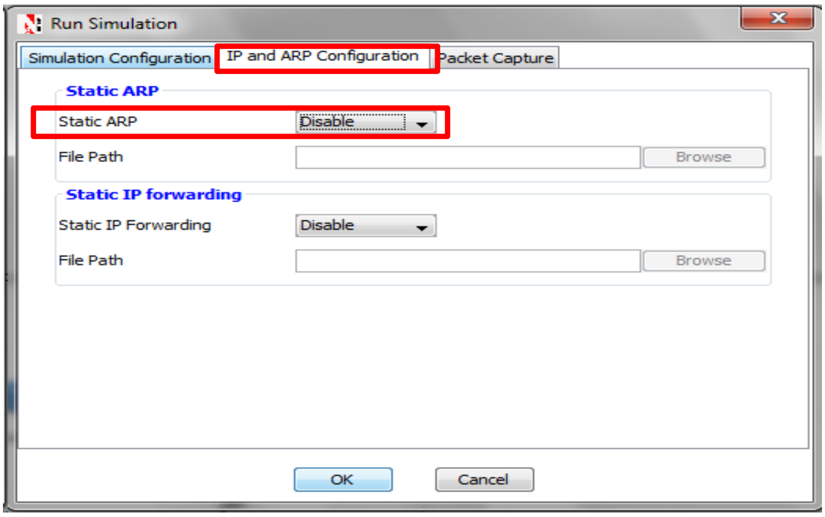
Simulation Time- 10 Seconds

Note: *The Simulation Time can be selected only after doing the following two tasks,*

- *Set the properties of Nodes*
- *Then click on the Run Simulation icon:*

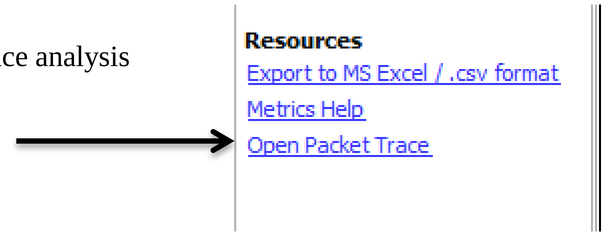
After clicking on Run Simulation, edit **IP and ARP Configuration** tab by setting Static ARP as Disable. If Static ARP is enabled then NetSim automatically creates the ARP table for each node. To see the working of the ARP protocol users should disable Static ARP. When disabled ARP request would be sent to the destination to find out the destinations MAC Address

Click on OK button to simulate.

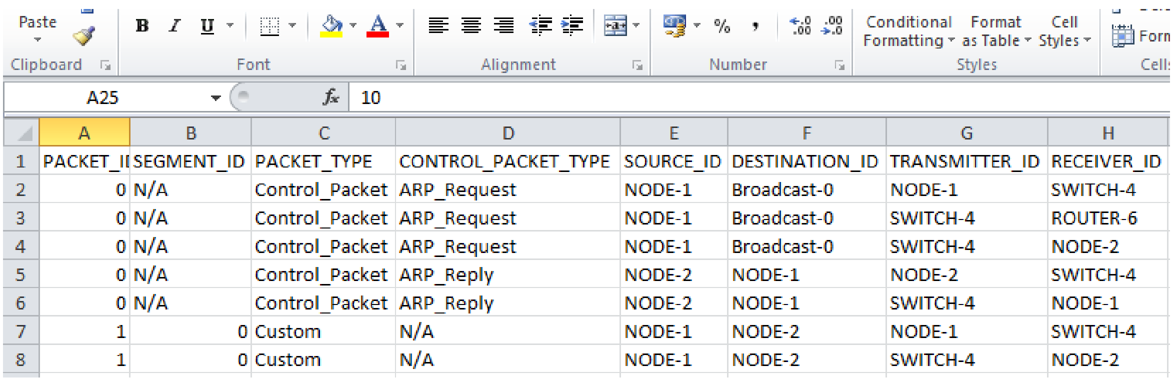


2.3 Output - I

Open Packet Trace for performing Packet Trace analysis



- **PACKET TRACE Analysis**

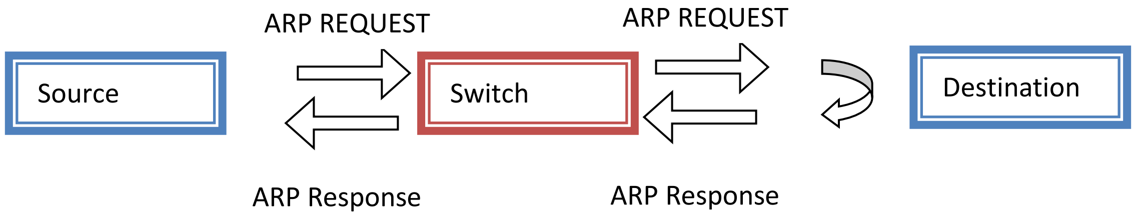


	A	B	C	D	E	F	G	H
1	PACKET_I	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID
2	0	N/A	Control_Packet	ARP_Request	NODE-1	Broadcast-0	NODE-1	SWITCH-4
3	0	N/A	Control_Packet	ARP_Request	NODE-1	Broadcast-0	SWITCH-4	ROUTER-6
4	0	N/A	Control_Packet	ARP_Request	NODE-1	Broadcast-0	SWITCH-4	NODE-2
5	0	N/A	Control_Packet	ARP_Reply	NODE-2	NODE-1	NODE-2	SWITCH-4
6	0	N/A	Control_Packet	ARP_Reply	NODE-2	NODE-1	SWITCH-4	NODE-1
7	1	0	Custom	N/A	NODE-1	NODE-2	NODE-1	SWITCH-4
8	1	0	Custom	N/A	NODE-1	NODE-2	SWITCH-4	NODE-2

2.4 Inference - I

Intra-LAN-IP-forwarding:

- **ARP PROTOCOL- WORKING**



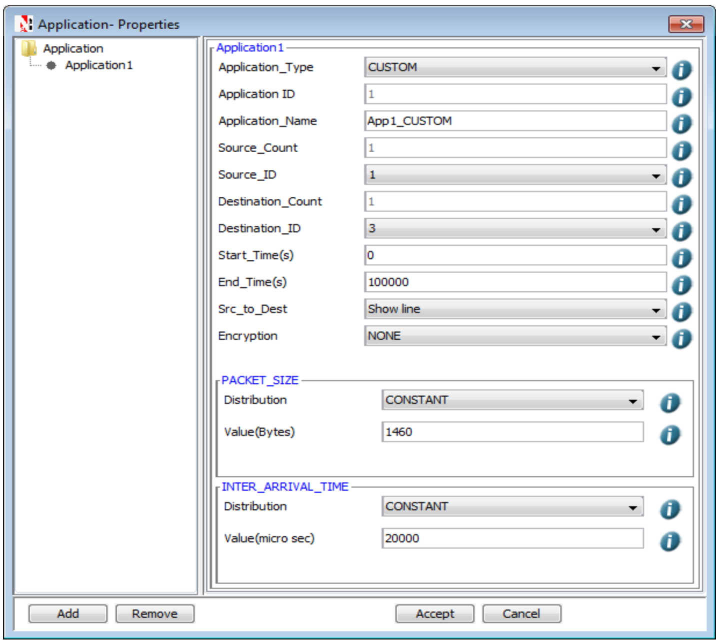
A Brief Explanation:

NODE-1 broadcasts ARP_Request which is then broadcasted by SWITCH-4. NODE -2 sends the ARP_Reply to NODE-1 via SWITCH-4. After this step, data is transmitted from NODE-1 to NODE-2. Notice the DESTINATION_ID column for ARP_Request type packets.

Step 5: Follow all the steps till Step 2 and perform the following sample:

Sample 2:

To run the simulation, drop the Application icon and set the Source_Id and Destination_Id as 1 and 3 respectively.



Enabling the packet trace:

- Click Packet Trace icon in the tool bar. This is used to log the packet details.
- Give a file name and check "**All the Attributes"** button for Common Attributes, TCP and WLAN.
- And Click on Ok button. Once the simulation is completed, the file gets stored in the specified location.

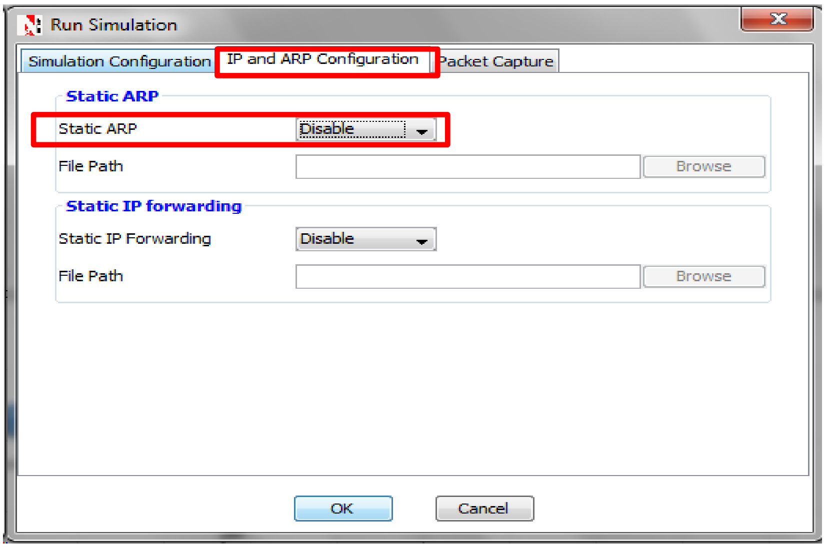
Step 6:

Simulation Time- 10 Seconds

Note: *The Simulation Time can be selected only after doing the following two tasks,*

- *Set the properties of Nodes*
- *Then click on the Run Simulation icon:*

After clicking on Run Simulation, edit **IP and ARP Configuration** tab by setting Static ARP as Disable. Click on OK button to simulate.

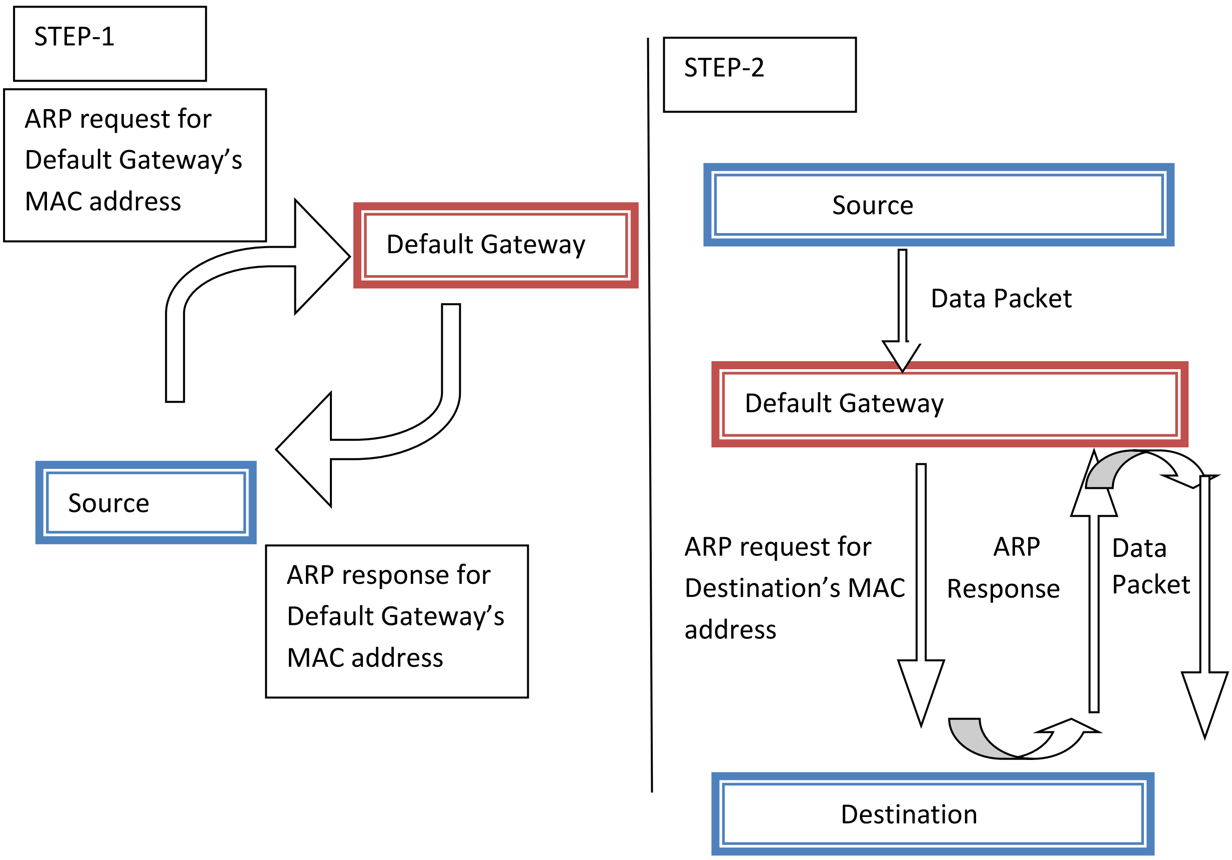


2.5 Output - II

- **PACKET TRACE Analysis**

PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID
0	N/A	Control_Packet	ARP_Request	NODE-1	Broadcast-0	NODE-1	SWITCH-4
0	N/A	Control_Packet	ARP_Request	NODE-1	Broadcast-0	SWITCH-4	ROUTER-6
0	N/A	Control_Packet	ARP_Request	NODE-1	Broadcast-0	SWITCH-4	NODE-2
0	N/A	Control_Packet	ARP_Reply	ROUTER-6	NODE-1	ROUTER-6	SWITCH-4
0	N/A	Control_Packet	ARP_Reply	ROUTER-6	NODE-1	SWITCH-4	NODE-1
1	0	Custom	N/A	NODE-1	NODE-3	NODE-1	SWITCH-4
1	0	Custom	N/A	NODE-1	NODE-3	SWITCH-4	ROUTER-6
0	N/A	Control_Packet	ARP_Request	ROUTER-6	Broadcast-0	ROUTER-6	SWITCH-5
0	N/A	Control_Packet	ARP_Request	ROUTER-6	Broadcast-0	SWITCH-5	NODE-3
0	N/A	Control_Packet	ARP_Reply	NODE-3	ROUTER-6	NODE-3	SWITCH-5
0	N/A	Control_Packet	ARP_Reply	NODE-3	ROUTER-6	SWITCH-5	ROUTER-6
1	0	Custom	N/A	NODE-1	NODE-3	ROUTER-6	SWITCH-5
1	0	Custom	N/A	NODE-1	NODE-3	SWITCH-5	NODE-3
2	0	Custom	N/A	NODE-1	NODE-3	NODE-1	SWITCH-4

Across-Router-IP-forwarding:



2.6 Inference -II

NODE-1 transmits ARP_Request which is further broadcasted by SWITCH-4. ROUTER-6 sends ARP_Reply to NODE-1 which goes through SWITCH-4. Then NODE-1 starts to send data to NODE-3.
If the router has the address of NODE-3 in its routing table, ARP protocol ends here and data transfer starts that is PACKET_ID 1 is being sent from NODE-1 to NODE-3. In other case, Router sends ARP_Request to appropriate subnet and after getting the MAC ADDRESS of the NODE-3, it forwards the packet which it has received from NODE-1.

When a node has to send data to a node with known IP address but unknown MAC address, it sends an ARP request. If destination is in same subnet as the source (found through subnet mask) then it sends the ARP (broadcast ARP message) request. Otherwise it forwards it to default gateway. Former case happens in case of intra-LAN communication. The destination node sends an ARP response which is then forwarded by the switch to the initial node. Then data transmission starts.

In latter case, a totally different approach is followed. Source sends the ARP request to the default gateway and gets back the MAC address of default gateway. (If it knows which router to send then it sends ARP request to the corresponding router and not to Default gateway) When source sends data to default gateway (a router in this case), the router broadcasts ARP request for the destined IP address in the appropriate subnet. On getting the ARP response from destination, router then sends the data packet to destination node.

PART 2: - Changing default Gateway

Do Sample 2 in PART 1 with the difference that in the **properties** of NODE-1, change the **default gateway** to some other value, for ex. "192.168.2.76" and click on Simulate button.

You will get error. Because NODE-1 will check the IP address of NODE-3 and then realize that it isn't in the same subnet. So it will forward it to default gateway. Since the default gateway's address doesn't exist in the network, error occurs.

3.Study the working of spanning tree algorithm by varying the priority among the switches.

3.1 Theory:

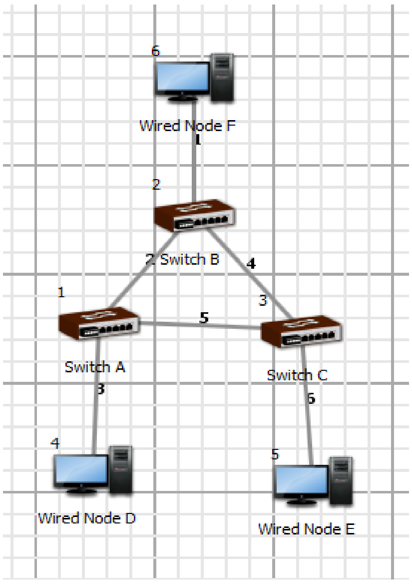
Spanning Tree Protocol (STP) is a link management protocol. Using the spanning tree algorithm, STP provides path redundancy while preventing undesirable loops in a network that are created by multiple active paths between stations. Loops occur when there are alternate routes between hosts. To establish path redundancy, STP creates a tree that spans all of the switches in an extended network, forcing redundant paths into a standby, or blocked state. STP allows only one active path at a time between any two network devices (this prevents the loops) but establishes the redundant links as a backup if the initial link should fail. Without spanning tree in place, it is possible that both connections may be simultaneously live, which could result in an endless loop of traffic on the LAN.

3.2 Procedure:

Please navigate through the below given path to,

Create Scenario: “Simulation → New → Internetworks”

Create the scenario as shown,



(Note: Minimum three switches are needed in the simulation to study about spanning tree formation.)

Sample Inputs:

Inputs for the Sample experiments are given below,

Sample 1:

Application properties:

<table>
<tr><td>Traffic Type</td><td colspan="2">Custom</td></tr>
<tr><td>Source_Id</td><td colspan="2">4</td></tr>
<tr><td>Destination_Id</td><td colspan="2">5</td></tr>
<tr><td rowspan="2">Packet Size</td><td>Distribution</td><td>Constant</td></tr>
<tr><td>Packet Size (bytes)</td><td>1460</td></tr>
<tr><td rowspan="2">Packet Inter Arrival Time</td><td>Distribution</td><td>Constant</td></tr>
<tr><td>Packet Inter Arrival Time (µs)</td><td>20000</td></tr>
</table>

Wired Node D is sending data to Wired Node E. The node properties are default.

(***Note***: Wired Node F is not generating **Traffic** to any other Wired Nodes)

Switch Properties	Switch A	Switch B	Switch C
Switch Priority	2	1	3

(***Note***: Switch Priority has to be changed for all the interfaces of Switch.)

Simulation Time - 10 Seconds

(*Note:* *The Simulation Time can be selected only after doing the following two tasks,*

- *Set the properties of Nodes and Switches*
- *Then click on Run Simulation button)***.**

Sample 2:

Set all properties as above and change properties of Switch as follows:

Switch Properties	Switch A	Switch B	Switch C
Switch Priority	1	2	3

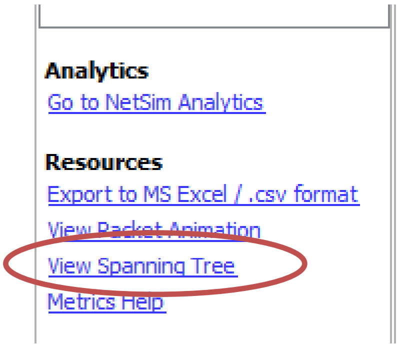
Simulation Time - 10 Seconds

(***Note:*** *The Simulation Time can be selected only after doing the following two tasks,*

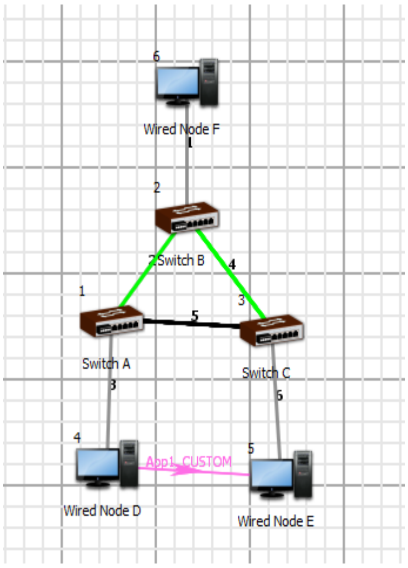
- *Set the properties of Nodes and Switches*
- *Then click on Run Simulation button***).**

3.3 Output:

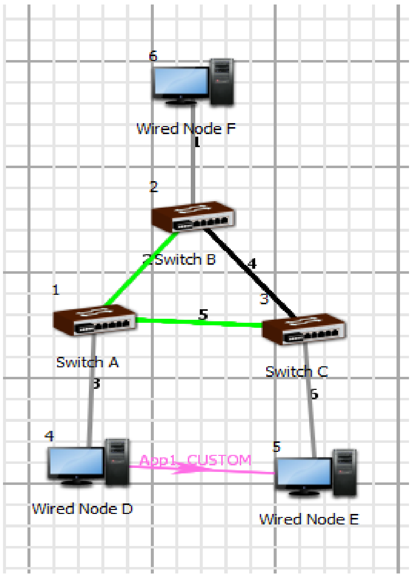
- To view the output, click the View Spanning Tree Link available on the Performance Metrics screen under Resources.



Sample 1:



Sample 2:



3.4 Inference:

In the Sample 1, Switch B was assigned least priority and was selected as a Root switch. The Green line indicates the forward path and the Black line indicates the blocked path. The frame from Wired Node D should take the path through the Switch B to reach the Wired Node E.

In the Sample 2, Switch A was assigned least priority and selected as a Root switch. In this case, the frame from Wired Node D can directly reach the destination Wired Node E.

4. Understand the working of "Connection Establishment" in TCP using NetSim.

Note: NetSim Standard Version is required to run this Experiment.

4.1 Theory

When two processes wish to communicate, their TCP's must first establish a connection i.e. initialize the status information on each side. Since connections must be established between unreliable hosts and over the unreliable internet communication system, a "three-way handshake" with clock based sequence numbers is the procedure used to establish a Connection. This procedure normally is initiated by one TCP and responded by another TCP. The procedure also works if two TCPs simultaneously initiate the procedure. When simultaneous attempt occurs, each TCP receives a "SYN" segment which carries no acknowledgement after it has sent a "SYN".

The simplest three-way handshake is shown in the following figure.

TCP A			TCP B
1. CLOSED			LISTEN
2. SYN-SENT	→	<A: SEQ=100><CTL=SYN>	→SYN-RECEIVED
3. ESTABLISHED	←`	<B: SEQ=300><ACK=101><CTL=SYN, ACK>	←SYN-RECEIVED
4. ESTABLISHED	→	<A: SEQ=101><ACK=301><CTL=ACK>	→ESTABLISHED
5. ESTABLISHED	→	<A: SEQ=101><ACK=301><CTL=ACK><DATA>	→ESTABLISHED

Fig: Basic 3-Way Handshake for Connection Synchronization

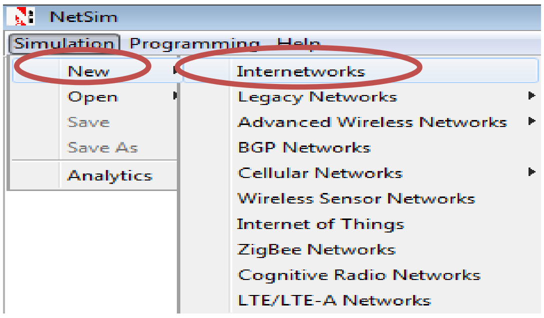
Explanation:

The above figure should be interpreted in the following way. Each line is numbered for reference purposes. Right arrows (→) indicates the departure of a TCP Segment from TCP A to TCP B, or arrival of a segment at B from A. Left arrows (←) indicates the reverse. TCP states represent the state AFTER the departure or arrival of the segment (whose contents are shown in the center of each line).Segment contents are shown in abbreviated form, with sequence number, control flags, and ACK field. In line2 of the above figure, TCP A begins by sending a SYN segment indicating that it will use sequence numbers starting with sequence number 100. In line 3, TCP B sends a SYN and acknowledges the SYN it received from TCP A. Note that the acknowledgment field indicates TCP B is now expecting to hear sequence 101, acknowledging the SYN which occupied sequence 100. At line 4, TCP A responds with an empty segment containing an ACK for TCP B's SYN; and in line 5, TCP A sends some data.

4.2 Procedure

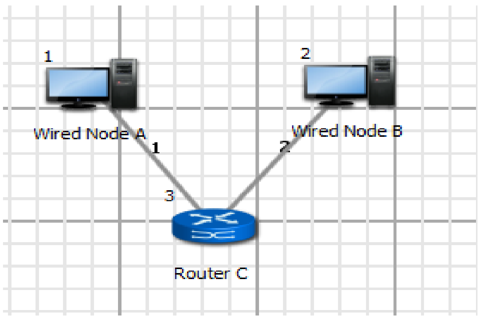
Step1:

Go to Simulation → New → Internetworks



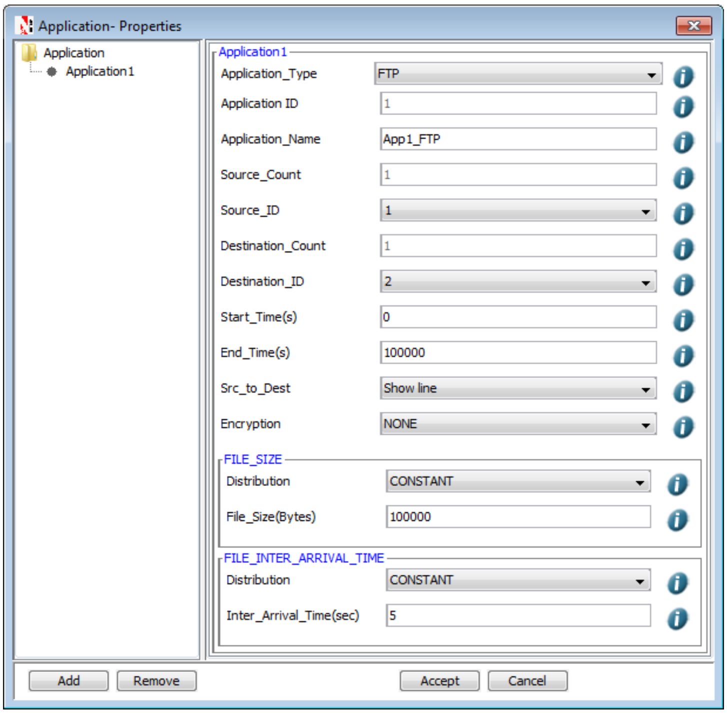
Step2:

Click & drop Wired Nodes and Router onto the Simulation Environment and link them as shown below.



Step3:

To run the simulation, drop the Application icon and change the Application_type to FTP. The Source_Id is 1 and Destination_Id is 2.



Router Properties: Accept default properties for Router.

Enabling the packet trace:

- Click Packet Trace icon in the tool bar. This is used to log the packet details.
- Select the required attributes and click OK. Once the simulation is completed, the file gets stored in the location specified.

Note: Make sure that after enabling the packet trace you select the **TCP option** in the **Internetworks** and then select the required attributes.

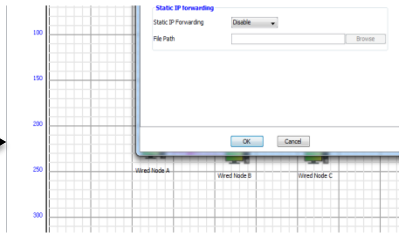
Simulation Time - 10 sec

After clicking on "Run Simulation", edit **IP and ARP Configuration** tab by setting Static ARP as **Disable**.

4.3 Output

The following results will be obtained:

Click on Open Packet Trace for performing Packet Trace analysis



PACKET _ID	SEGMENT _ID	PACKET_TYPE	CONTROL_PACKET_TYPE	SOURCE_ID	DESTINATION _ID	TRANSMITTER _ID	RECEIVER _ID
0	N/A	Control_Packet	ARP_Request	NODE-1	Broadcast-0	NODE-1	ROUTER-3
0	N/A	Control_Packet	ARP_Request	NODE-2	Broadcast-0	NODE-2	ROUTER-3
0	N/A	Control_Packet	ARP_Reply	ROUTER-3	NODE-1	ROUTER-3	NODE-1
0	N/A	Control_Packet	ARP_Reply	ROUTER-3	NODE-2	ROUTER-3	NODE-2
0	N/A	Control_Packet	ICMP_ECHO_REQUEST	NODE-1	ROUTER-3	NODE-1	ROUTER-3
0	N/A	Control_Packet	ICMP_ECHO_REQUEST	NODE-2	ROUTER-3	NODE-2	ROUTER-3
0	N/A	Control_Packet	ICMP_ECHO_REPLY	ROUTER-3	NODE-1	ROUTER-3	NODE-1
0	N/A	Control_Packet	ICMP_ECHO_REPLY	ROUTER-3	NODE-2	ROUTER-3	NODE-2
0	N/A	Control_Packet	TCP_SYN	NODE-1	NODE-2	NODE-1	ROUTER-3
0	N/A	Control_Packet	TCP_SYN	NODE-1	NODE-2	ROUTER-3	NODE-2
0	N/A	Control_Packet	TCP_SYN_ACK	NODE-2	NODE-1	NODE-2	ROUTER-3
0	N/A	Control_Packet	TCP_SYN_ACK	NODE-2	NODE-1	ROUTER-3	NODE-1
0	N/A	Control_Packet	TCP_ACK	NODE-1	NODE-2	NODE-1	ROUTER-3
1	1	FTP	N/A	NODE-1	NODE-2	NODE-1	ROUTER-3
0	N/A	Control_Packet	TCP_ACK	NODE-1	NODE-2	ROUTER-3	NODE-2
1	1	FTP	N/A	NODE-1	NODE-2	ROUTER-3	NODE-2

Fig: 3-way Handshake using packet trace.

4.4 Inference

In MS Excel go to DATA and select FILTER option to view only the desired rows and columns as shown in the figure

Line 1, 2, 3 and 4 of the above table are ARP related packets and not of interest to us in this experiment.

In line 9 of the above figure we can see that NODE-1 is sending a control packet of type TCP_SYN requesting the connection with the NODE-2, and this control packet is first sent to the ROUTER-3 (receiver ID). In line 10, the ROUTER-3 is sending the TCP_SYN packet that has been received from NODE-1 to the NODE-2. In line 11, NODE-2 is sending the control packet of type TCP_SYN_ACK to NODE-1, and this control packet is first sent to the ROUTER-3. This TCP_SYN_ACK is the ACK packet for the TCP_SYN packet. In line 12, ROUTER-3 is sending the TCP_SYN_ACK, (received from NODE-2) to the NODE-1. In line 13, NODE-1 is sending the TCP_ACK to NODE-2 via ROUTER-3 making the CONNECTION_STATE as TCP_ESTABLISHED.

Once the connection is established, we see that a packet type of type “FTP” is sent from the NODE-1 to the NODE-2 in line 14.

5. Study the throughputs of Slow start + Congestion avoidance (Old Tahoe) and Fast Retransmit (Tahoe) Congestion Control Algorithms.

5.1 Theory:

One of the important functions of a TCP Protocol is congestion control in the network. Given below is a description of how Old Tahoe and Tahoe variants (of TCP) control congestion.

Old Tahoe:

Congestion can occur when data arrives on a big pipe (i.e. a fast LAN) and gets sent out through a smaller pipe (i.e. a slower WAN). Congestion can also occur when multiple input streams arrive at a router whose output capacity is less than the sum of the inputs. Congestion avoidance is a way to deal with lost packets.

The assumption of the algorithm is that the packet loss caused by damaged is very small (much less than 1%), therefore the loss of a packet signals congestion somewhere in the network between the source and destination. There are two indications of packets loss: a timeout occurring and the receipt of duplicate ACKs

Congestion avoidance and slow start are independent algorithms with different objectives. But when congestion occurs TCP must slow down its transmission rate and then invoke slow start to get things going again. In practice they are implemented together.

Congestion avoidance and slow start requires two variables to be maintained for each connection: a Congestion Window (i.e. cwnd) and a Slow Start Threshold Size (i.e. ssthresh). Old Tahoe algorithm is the combination of slow start and congestion avoidance. The combined algorithm operates as follows,

1. Initialization for a given connection sets cwnd to one segment and ssthresh to 65535 bytes.

2. When congestion occurs (indicated by a timeout or the reception of duplicate ACKs), one-half of the current window size (the minimum of cwnd and the receiver's advertised window, but at least two segments) is saved in ssthresh. Additionally, if the congestion is indicated by a timeout, cwnd is set to one segment (i.e. slow start).
3. When new data is acknowledged by the other end, increase cwnd, but the way it increases depends on whether TCP is performing slow start or congestion avoidance.

If cwnd is less than or equal to ssthresh, TCP is in slow start. Else TCP is performing congestion avoidance. Slow start continues until TCP is halfway to where it was when congestion occurred (since it recorded half of the window size that caused the problem in step 2). Then congestion avoidance takes over.

Slow start has cwnd begins at one segment and be incremented by one segment every time an ACK is received. As mentioned earlier, this opens the window exponentially: send one segment, then two, then four, and so on. Congestion avoidance dictates that cwnd be incremented by 1/cwnd, compared to slow start's exponential growth. The increase in cwnd should be at most one segment in each round trip time (regardless of how many ACKs are received in that RTT), whereas slow start increments cwnd by the number of ACKs received in a round-trip time.

Tahoe (Fast Retransmit):

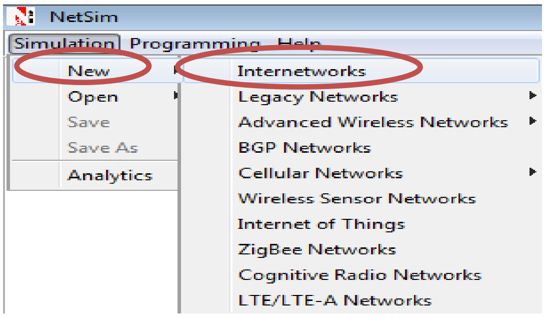
The Fast retransmit algorithms operating with Old Tahoe is known as the Tahoe variant.

TCP may generate an immediate acknowledgement (a duplicate ACK) when an out-of-order segment is received out-of-order, and to tell it what sequence number is expected.

Since TCP does not know whether a duplicate ACK is caused by a lost segment or just a re-ordering of segments, it waits for a small number of duplicate ACKs to be received. It is assumed that if there is just a reordering of the segments, there will be only one or two duplicate ACKs before the re-ordered segment is processed, which will then generate a new ACK. If three or more duplicate ACKs are received in a row, it is a strong indication that a segment has been lost. TCP then performs a retransmission of what appears to be the missing segment, without waiting for a re-transmission timer to expire.

5.2 Procedure:

Go to Simulation → New → Internetworks



Sample Inputs:

Follow the steps given in the different samples to arrive at the objective.

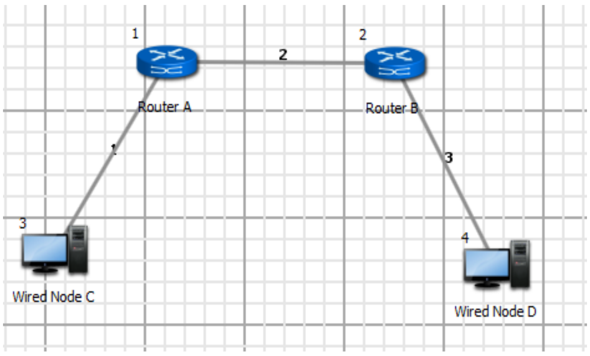
Sample 1.a: Old Tahoe (1 client and 1 server)

In this Sample,

- Total no of Node used: 2
- Total no of Routers used: 2

The devices are inter connected as given below,

- Wired Node C is connected with Router A by Link 1.
- Router A and Router B are connected by Link 2.
- Wired Node D is connected with Router B by Link 3.



Set the properties for each device by following the tables,

Application Properties	
Application Type	Custom
Source_Id	4(Wired Node D)
Destination_Id	3(Wired Node C)

Packet Size	
Distribution	Constant
Value (bytes)	1460
Inter Arrival Time	
Distribution	Constant
Value (micro secs)	1300

Node Properties: In Transport Layer properties, set

TCP Properties	
MSS(bytes)	1460
Congestion Control Algorithm	**Old Tahoe**
Window size(MSS)	8

Router Properties: Accept default properties for Router.

Link Properties	Link 1	Link 2	Link 3
Max Uplink Speed (Mbps)	8	10	8
Max Downlink Speed(Mbps)	8	10	8
Uplink BER	0.000001	0.000001	0.000001
Downlink BER	0.000001	0.000001	0.000001

Simulation Time - 10 Sec

Upon completion of simulation, “Save” the experiment.

(Note: *The Simulation Time can be selected only after doing the following two tasks,*

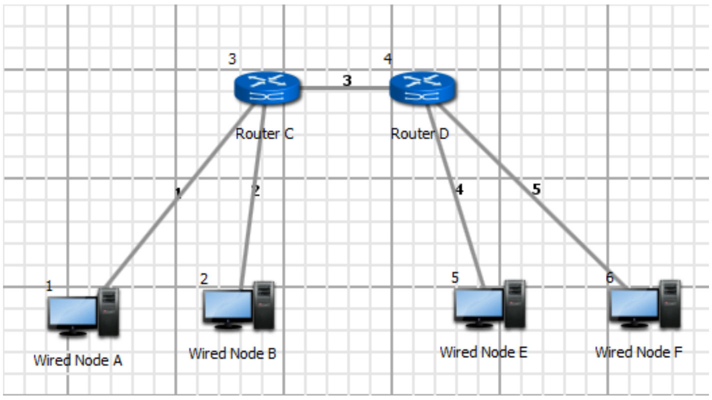
- *Set the properties of Node, Router& Link*
- *Then click on Run Simulation button)***.**

Sample 1.b: Tahoe (1 client and 1 server)

Open sample 1.a, and change the TCP congestion control algorithm to Tahoe (in Node Properties). Upon completion of simulation, “Save” the experiment as sample 1.b.

Sample 2.a: Old Tahoe (2 clients and 2 servers)

In this Sample,



- Total no of Wired Nodes used: 4
- Total no of Routers used: 2

The devices are inter connected as given below,

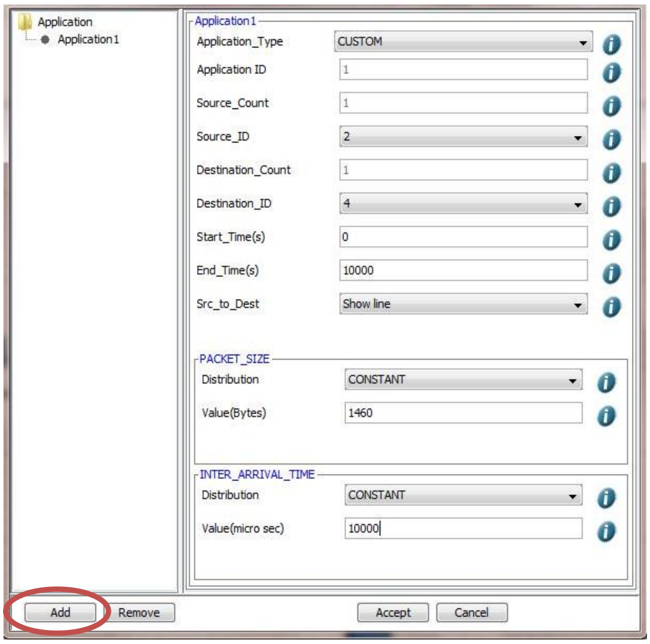
- Wired Node A and Wired Node B are connected with Router C by Link 1 and Link 2.
- Router C and Router D are connected by Link 3.
- Wired Node E and Wired Node F are connected with Router D by Link 4 and Link 5.
- Wired Node A and Wired Node B are not transmitting data in this sample.

Set the properties for each device by following the tables,

Application Properties	Application 1	Application 2
Application Type	Custom	
Source_Id	5	6
Destination_Id	1	2
Packet Size		
Distribution	Constant	Constant
Value (bytes)	1460	1460
Inter Arrival Time		
Distribution	Constant	Constant
Value (micro secs)	1300	1300

NOTE: The procedure to create multiple applications are as follows:

Step 1: Click on the ADD button present in the bottom left corner to add a new application.



Node Properties: In Transport Layer properties, set

TCP Properties	
MSS(bytes)	1460
Congestion Control Algorithm	**Old Tahoe**
Window size(MSS)	8

Router Properties: Accept default properties for Router.

Link Properties	Link 1	Link 2	Link 3	Link 4	Link 5
Max Uplink Speed (Mbps)	8	8	10	8	8
Max Downlink Speed (Mbps)	8	8	10	8	8

Uplink BER	0.000001	0.000001	0.000001	0.000001	0.000001
Downlink BER	0.000001	0.000001	0.000001	0.000001	0.000001

Simulation Time - 10 Sec

Upon completion of simulation, “Save” the experiment.

(Note: *The Simulation Time can be selected only after doing the following two tasks,*

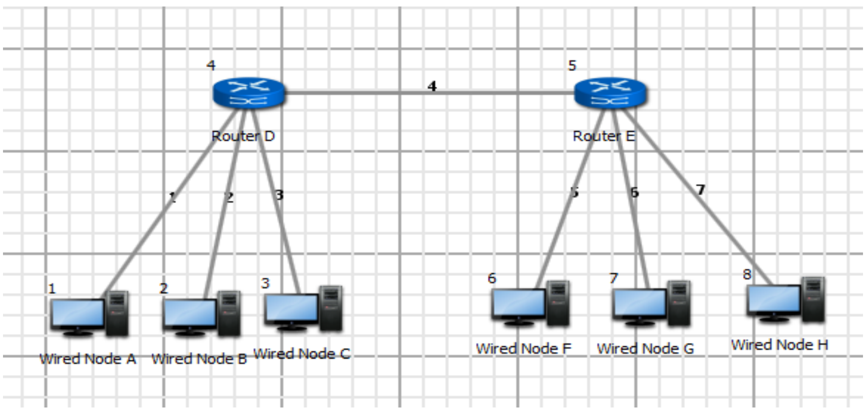
- *Set the properties of Node , Router & Link*
- *Then click on Run Simulation button)***.**

Sample 2.b: Tahoe (2 clients and 2 servers)

Do the experiment as sample 2.a, and change the congestion control algorithm to Tahoe. Upon completion of simulation, “Save” the experiment.

Sample 3.a: Old Tahoe (3 clients and 3 servers)

In this Sample,



- Total no of Nodes used: 6
- Total no of Routers used: 2

The devices are inter connected as given below,

- Wired Node A, Wired Node B & Wired Node C is connected with Router D by Link 1, Link 2 & Link 3.
- Router D and Router E are connected by Link 4.
- Wired Node F, Wired Node G & Wired Node H is connected with Router E by Link 5, Link 6 & Link 7.
- Wired Node A, Wired Node B and Wired Node C are not transmitting data in this sample.

Set the properties for each device by following the tables,

Application Properties	Application 1	Application 2	Application 3
Application Type	Custom		
Source_Id	6	7	8
Destination_Id	1	2	3
Packet Size			
Distribution	Constant	Constant	Constant
Value (bytes)	1460	1460	1460
Inter Arrival Time			
Distribution	Constant	Constant	Constant
Value (micro sec)	1300	1300	1300

Node Properties: In Transport Layer properties, set

TCP Properties			
MSS(bytes)	1460	1460	1460
Congestion Control Algorithm	**Old Tahoe**	**Old Tahoe**	**Old Tahoe**
Window size(MSS)	8	8	8

Router Properties: Accept default properties for Router.

Link Properties	Link 1	Link 2	Link 3	Link 4	Link 5	Link 6	Link 7
Max Uplink Speed (Mbps)	8	8	8	10	8	8	8
Max Downlink Speed(Mbps)	8	8	8	10	8	8	8
Uplink BER	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
Downlink BER	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001

Simulation Time- 10 Sec

Upon completion of simulation, “Save” the experiment.

(Note: *The Simulation Time can be selected only after doing the following two tasks,*

- *Set the properties of Node, Router & Link*
- *Then click on Run Simulation button)***.**

Sample 3.b: Tahoe (3 clients and 3 servers)

Do the experiment as sample 3.a, and change the TCP congestion algorithm to Tahoe. Upon completion of simulation, “Save” the experiment.

5.3 Output

Comparison Table:

TCP Downloads	Metrics	Slow start + Congestion avoidance	Fast Retransmit
1 client and 1 server	Throughput(Mbps)	5.926432	6.120320
	Segments Retransmitted + Seg Fast Retransmitted	195	200
2 clients and 2 servers	Throughput(Mbps)	8.796208	8.810224
	Segments Retransmitted + Seg Fast Retransmitted	343	378
3 clients and 3 servers	Throughput(Mbps)	9.144272	9.23304
	Segments Retransmitted + Seg Fast Retransmitted	401	434

Note: To calculate the "Throughput (Mbps)" for more than one application, add the individual application throughput which is available in Application Metrics (or Metrics.txt) of Performance Metrics screen. In the same way calculate the metrics for "Segments Retransmitted + Seg Fast Retransmitted" from TCP Metrics → Connection Metrics.

5.4 Inference:

User lever throughput: User lever throughput of Fast Retransmit is higher when compared then the Old Tahoe (SS + CA). This is because, if a segment is lost due to error, Old Tahoe waits until the RTO Timer expires to retransmit the lost segment, whereas Tahoe (FR) retransmits the lost segment immediately after getting three continuous duplicate ACK's. This results in the increased segment transmissions, and therefore throughput is higher in the case of Tahoe.

6. Study how the Data Rate of a Wireless LAN (IEEE 802.11b) network varies as the distance between the Access Point and the wireless nodes is varied

6.1 Theory:

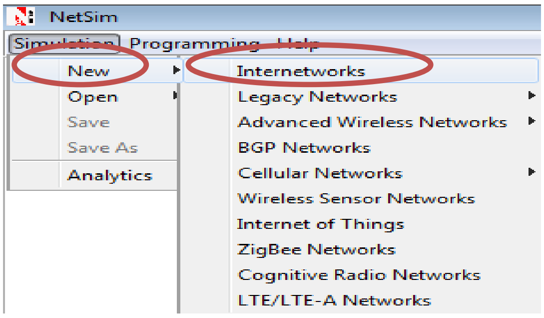
In most of the WLAN products on the market based on the IEEE 802.11b technology the transmitter is designed as a Direct Sequence Spread Spectrum Phase Shift Keying (DSSS PSK) modulator, which is capable of handling data rates of up to 11 Mbps. The system implements various modulation modes for every transmission rate, which are Different Binary Phase Shift Keying (DPSK) for 1 Mbps, Different Quaternary Phase Shift Keying (DQPSK) for 2 Mbps and Complementary Code Keying (CCK) for 5.5 Mbps and 11 Mbps.

Large Scale Fading represents Receiver Signal Strength or path loss over a large area as a function of distance. The statistics of large scale fading provides a way of computing estimated signal power or path loss as a function of distance and modulation modes vary depends on the Receiver Signal Strength.

6.2 Procedure:

Please navigate through the below given path to,

Go to Simulation → New → Internetworks



Sample Inputs:

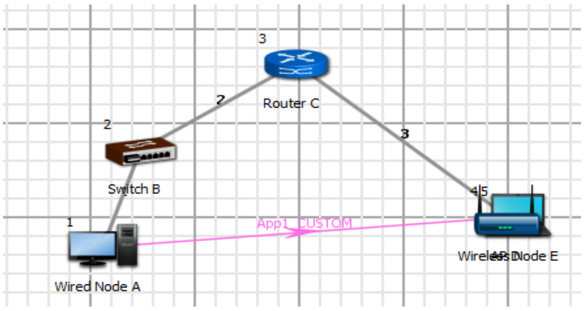
Follow the steps given in the different samples to arrive at the objective.

In Sample 1,

- Total no of APs (Access Points) used: 1
- Total no of Wireless Nodes used: 1
- Total no of Routers used: 1

- Total no of Switches used: 1
- Total no of Wired Nodes used: 1

The AP, Wireless Nodes, Router, Switch and Wired Nodes are interconnected as shown:



Also edit the following properties of Wireless Node E:

Wireless Node E Properties	
X/Lat	355
Y/Lon	150
Interface_Wireless properties	
RTS Threshold(bytes)	2347
Retry Limit(DataLink_Layer)	7
Rate _Adaptation	GENERIC

Edit all link properties as shown:

Wireless Link Properties	
Channel Characteristics	Fading only
Path Loss Exponent	2.5
Fading Figure	1.0

Wired Link Properties	
Uplink Speed (Mbps)	100
Downlink Speed (Mbps)	100
Uplink BER	0
Downlink BER	0

Also edit the following properties of Wired Node A:

Wired Node A Properties	
TCP	Disabled

Set the properties of Access Point as follows:

Access Point Properties	
X/Lat	350
Y/Lon	150
Interface_Wireless properties	
Buffer Size(MB)	5
RTS Threshold(bytes)	2347
Retry Limit	7

Click and drop the Application, set properties and run the simulation.

Application Properties	
Application Type	Custom
Source_Id	1
Destination_Id	5
Packet Size	
Distribution	Constant
Value (bytes)	1460
Packet Inter Arrival Time	
Distribution	Constant
Value (micro secs)	900

Simulation Time - 10 Sec

(**Note:** *The Simulation Time can be selected only after the following two tasks,*

- *Set the properties for all the devices and links.*
- *Click on Run Simulation button*.

Upon completion of the experiment, "Save" the metrics result for comparison by using Export to Excel . Save the excel file in any user defined location.

- **Sample 2**: Distance from Wireless Node E to Access Point is 10m.
- **Sample 3**: Distance from Wireless Node E to Access Point is 15m.

……. And so on till 55 meter distance.

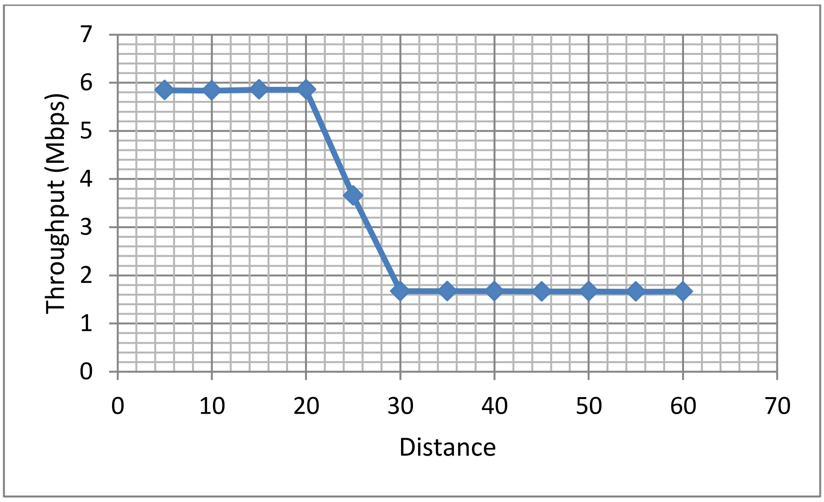
6.3 Output:

Go to Application Metrics and obtain Throughput value for all the samples from the saved Excel files and make a comparison chart as shown. Use Excel "Insert →Chart" option and then select chart type as "Line chart".

Comparison Chart:

Distance (m)	Throughput (Mbps)
5	5.843504
10	5.837664
15	5.85752
20	5.85635
25	3.65467
30	1.67024
35	1.69907
40	1.69907
45	1.66556
50	1.66790
55	1.65972
60	1.66323

6.4 Inference



*** All the above plots highly depend upon the placement of nodes in the simulation environment. So, note that even if the placement is slightly different, the same set of values will not be got but one would notice a similar trend.

We notice that as the distance increases, the throughput decreases. This is because the underlying data rate depends on the received power at the receiver. Received power is directly proportional to (1 / distance).

In 802.11b, four data rates, 1 Mbps, 2 Mbps, 5.5 Mbps, and 11 Mbps, are supported. The rate is decided based on the received power and the errors in the channel. Note a higher data rate does not necessarily yield a higher throughput since packets may get errored. Only when the channel conditions are good, does a higher data rate give a higher throughput. In a realistic WLAN environment, the channel condition can vary due to pathloss, fading, and shadowing. In NetSim to accommodate different channel conditions, rate adaptation is commonly employed. The **rate adaptation algorithms dynamically adjusts the modulation mode and data rate to optimize performance when channel condition changes**. So, when NetSim detects that the number of errors in the channels are high, it automatically drops down to a lower rate.

In addition, one must note that WLAN involves ACK packets after data transmission.. These additional packet transmission lead to reduced Application throughput of 5.5 Mbps (at 1 – 20 mts range) even though the PHY layer data rate is 11 Mbps.

7. Study the working and routing table formation of Interior routing protocols, i.e. Routing Information Protocol (RIP) and Open Shortest Path First (OSPF)

7.1 Theory:

RIP

RIP is intended to allow hosts and gateways to exchange information for computing routes through an IP-based network. RIP is a distance vector protocol which is based on Bellman-Ford algorithm. This algorithm has been used for routing computation in the network.

Distance vector algorithms are based on the exchange of only a small amount of information using RIP messages.

Each entity (router or host) that participates in the routing protocol is assumed to keep information about all of the destinations within the system. Generally, information about all entities connected to one network is summarized by a single entry, which describes the route to all destinations on that network. This summarization is possible because as far as IP is concerned, routing within a network is invisible. Each entry in this routing database includes the next router to which datagrams destined for the entity should be sent. In addition, it includes a "metric" measuring the total distance to the entity.

Distance is a somewhat generalized concept, which may cover the time delay in getting messages to the entity, the dollar cost of sending messages to it, etc. Distance vector algorithms get their name from the fact that it is possible to compute optimal routes when the only information exchanged is the list of these distances. Furthermore, information is only exchanged among entities that are adjacent, that is, entities that share a common network.

OSPF

In OSPF, the Packets are transmitted through the shortest path between the source and destination.

Shortest path:

OSPF allows administrator to assign a cost for passing through a link. The total cost of a particular route is equal to the sum of the costs of all links that comprise the route. A router chooses the route with the shortest (smallest) cost.

In OSPF, each router has a link state database which is tabular representation of the topology of the network (including cost). Using dijkstra algorithm each router finds the shortest path between source and destination.

Formation of OSPF Routing Table

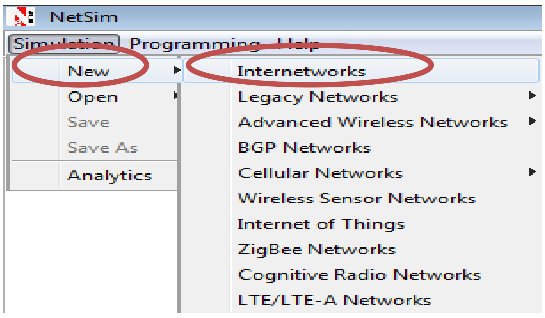
1. OSPF-speaking routers send Hello packets out all OSPF-enabled interfaces. If two routers sharing a common data link agree on certain parameters specified in their respective Hello packets, they will become neighbors.
2. Adjacencies, which can be thought of as virtual point-to-point links, are formed between some neighbors. OSPF defines several network types and several router types. The establishment of an adjacency is determined by the types of routers exchanging Hellos and the type of network over which the Hellos are exchanged.
3. Each router sends link-state advertisements (LSAs) over all adjacencies. The LSAs describe all of the router's links, or interfaces, the router's neighbors, and the state of the links. These links might be to stub networks (networks with no other router attached), to other OSPF routers, or to external networks (networks learned from another routing process). Because of the varying types of link-state information, OSPF defines multiple LSA types.
4. Each router receiving an LSA from a neighbor records the LSA in its link-state database and sends a copy of the LSA to all of its other neighbors.
5. By flooding LSAs throughout an area, all routers will build identical link-state databases.
6. When the databases are complete, each router uses the SPF algorithm to calculate a loop-free graph describing the shortest (lowest cost) path to every known destination, with itself as the root. This graph is the SPF tree.
7. Each router builds its route table from its SPF tree

7.2 Procedure

Sample 1:

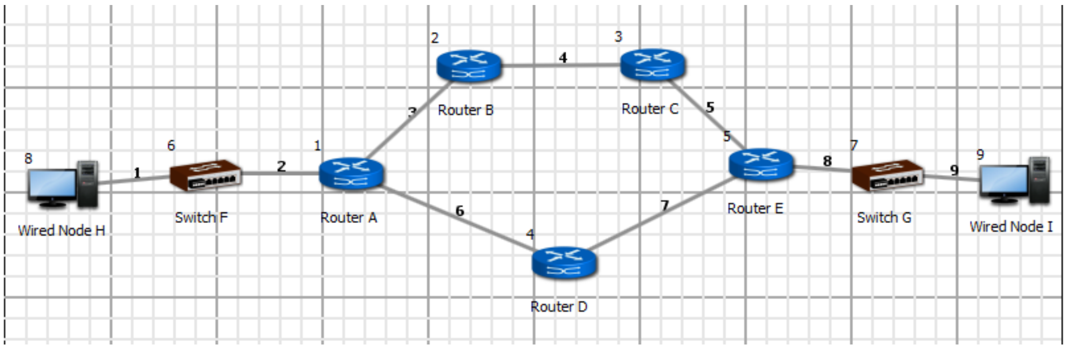
Step 1:

Go to Simulation → New → Internetworks



Step 2:

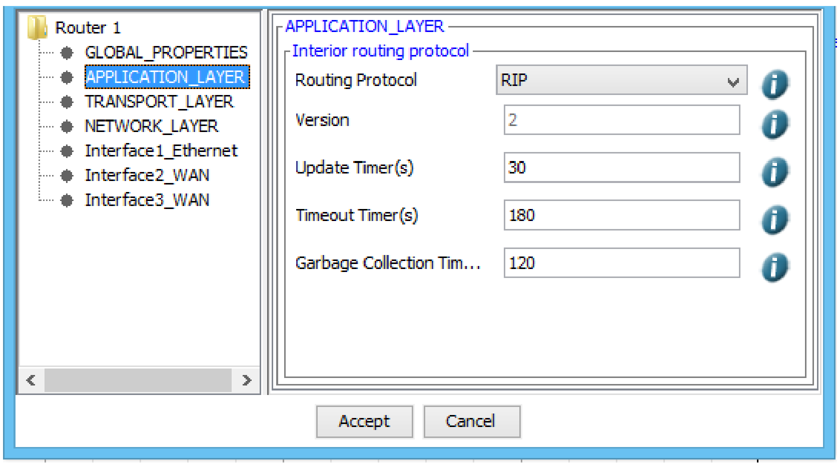
Click & drop Routers, Switches and Nodes onto the Simulation Environment and link them as shown:



Step 3:

These properties can be set only after devices are linked to each other as shown above.

Set the properties of the Router 1 as follows:

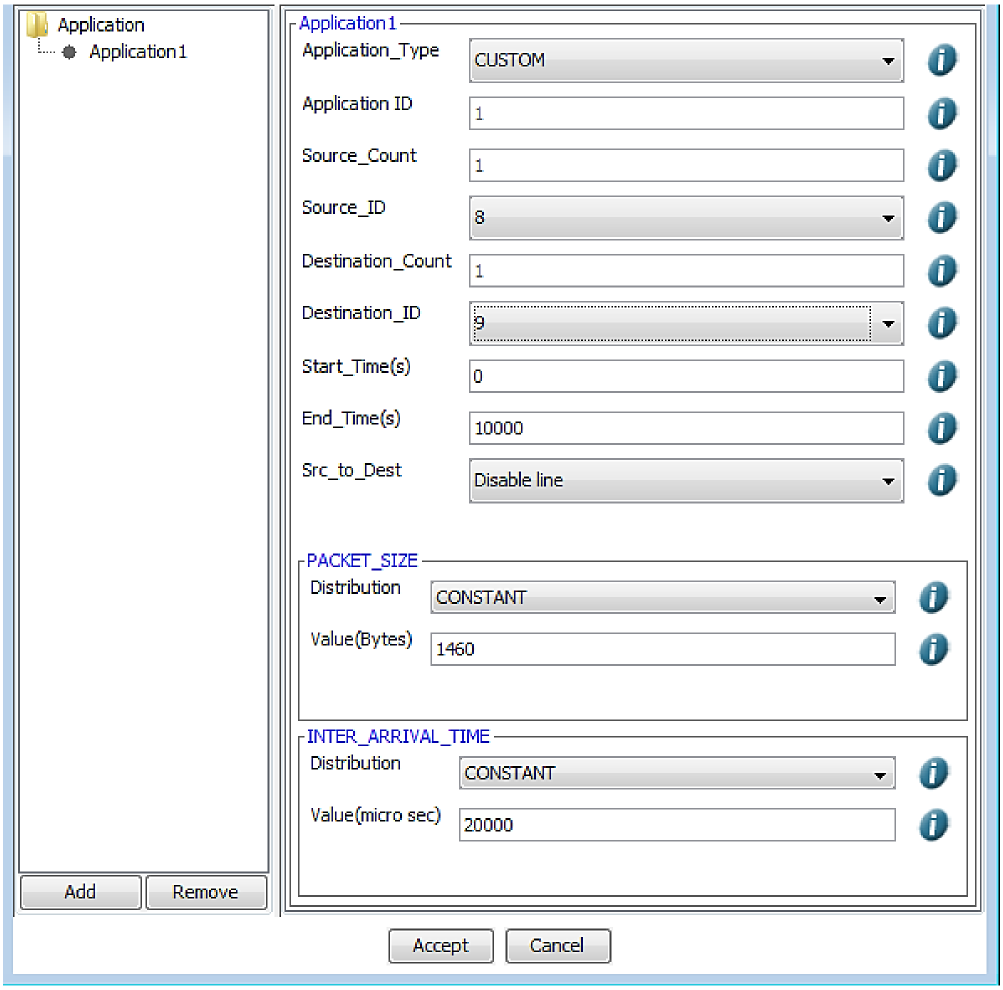


Node Properties: In Wired Node H, go to Transport Layer and set TCP as Disable

Switch Properties: Accept default properties for Switch.

Link Properties: Accept default properties for Link.

Application Properties: Click and drop the Application icon and set properties as follows:



Simulation Time - 100 Sec

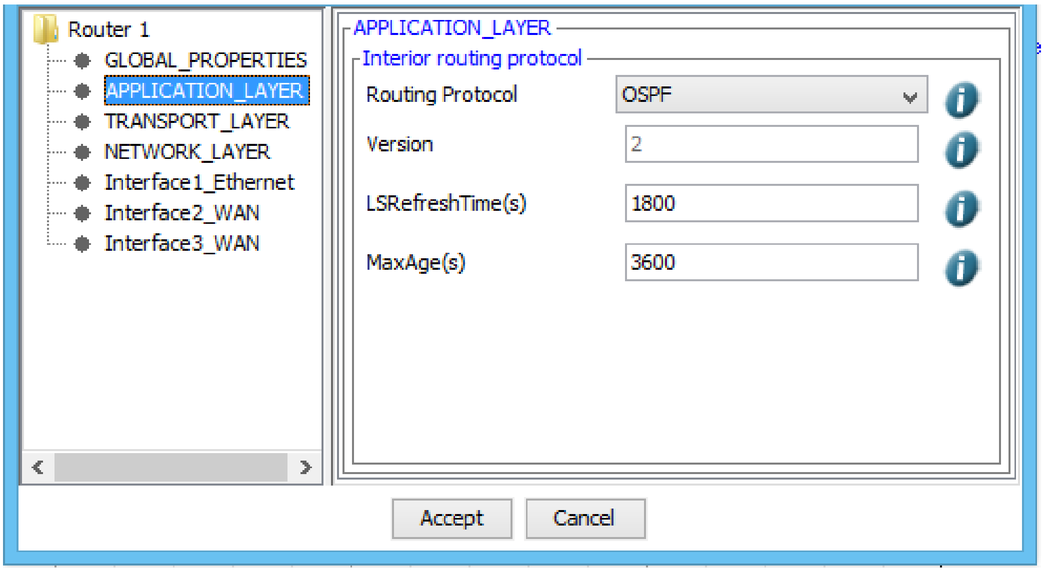
After Simulation is performed, save the experiment.

(**Note:** *The Simulation Time can be selected only after doing the following two tasks,*

- *Set the properties of Node, Switch, Router& Application*
- *Then click on Run Simulation button*).

Sample 2:

To model a scenario, follow the same steps as given in Sample1 and set the Router A properties as given below:



Link Properties:

Link Properties	Link 3	Link 4	Link 5	Link 6	Link 7
Uplink Speed	**100**	**100**	**100**	**10**	**10**
Downlink Speed	**100**	**100**	**100**	**10**	**10**

Node Properties: In Wired Node H, go to Transport Layer and set TCP as Disable

Switch Properties: Accept default properties for Switch.

Application Properties: Click and drop the Application icon and set properties as in Sample 1.

Simulation Time- 100 Sec

(Note: *The Simulation Time can be selected only after doing the following two tasks,*

- *Set the properties of Node, Switch, Router& Application*
- *Then click on Run Simulation button***).**

7.3 Output and Inference:

RIP

In Distance vector routing, each router periodically shares its knowledge about the entire network with its neighbors. The three keys for understanding the algorithm,

1. **Knowledge about the whole network**

Router sends all of its collected knowledge about the network to its neighbors

2. **Routing only to neighbors**

Each router periodically sends its knowledge about the network only to those routers to which it has direct links. It sends whatever knowledge it has about the whole network through all of its ports. This information is received and kept by each neighboring router and used to update that router's own information about the network.

3. **Information sharing at regular intervals**

For example, every 30 seconds, each router sends its information about the whole network to its neighbors. This sharing occurs whether or not the network has changed since the last time information was exchanged

In NetSim the Routing table Formation has 3 stages

Initial Table: This table will show the direct connections made by each Router.

Intermediate Table: The Intermediate table will have the updates of the Network in every 30 seconds

Final Table: This table is formed when there is no update in the Network.

The data should be forwarded using Routing Table with the shortest distance

The RIP table in NetSim

- After running Sample1, click RIP table in Performance Metrics screen. Then click the respective router to view the Routing table.
- We have shown the routing table for Router 1,

Performance Metrics

Router1

Initial

DestinationIP	Subnet mask	NextHopIP	Interface	Metric	Timer(Micro sec)
11.1.0.0	255.255.0.0	11.1.1.1	1	0	3000000.000000
11.2.0.0	255.255.0.0	11.2.1.1	2	0	3000000.000000
11.3.0.0	255.255.0.0	11.3.1.1	3	0	3000000.000000

Intermediate

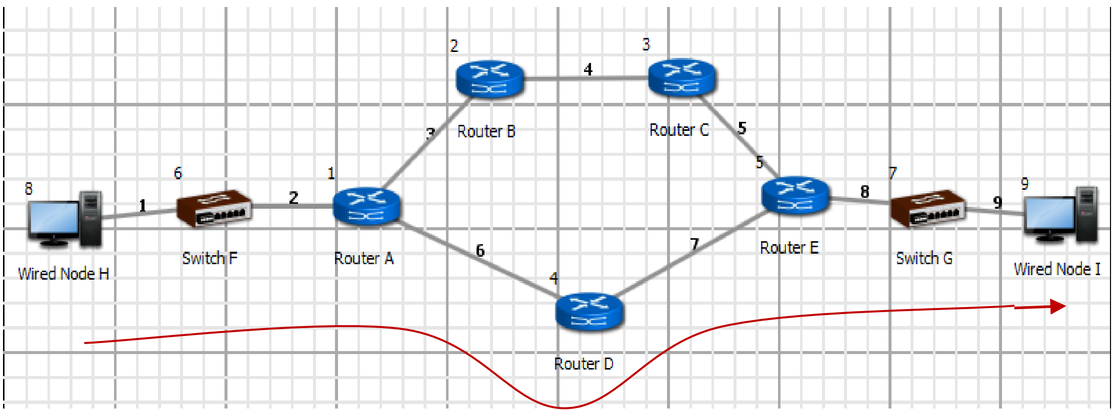
DestinationIP	Subnet mask	NextHopIP	Interface	Metric	Timer(Micro sec)
11.1.0.0	255.255.0.0	11.1.1.1	1	0	3000000.000000
11.2.0.0	255.255.0.0	11.2.1.1	2	0	3000000.000000
11.3.0.0	255.255.0.0	11.3.1.1	3	0	3000000.000000
12.2.0.0	255.255.0.0	11.2.1.2	2	1	48.200000

Final

DestinationIP	Subnet mask	NextHopIP	Interface	Metric	Timer(Micro sec)
11.1.0.0	255.255.0.0	11.1.1.1	1	0	3000000.000000
11.2.0.0	255.255.0.0	11.2.1.1	2	0	3000000.000000
11.3.0.0	255.255.0.0	11.3.1.1	3	0	3000000.000000
12.2.0.0	255.255.0.0	11.2.1.2	2	1	48.200000

Shortest Path from Wired Node H to WiredNode I in RIP (Use Packet Animation to view) :

WiredNode H→Switch F→Router1→Router4→Router5→Switch G→Wired Node I



OSPF

The main operation of the OSPF protocol occurs in the following consecutive stages and leads to the convergence of the internetworks:

1. Compiling the LSDB.
2. Calculating the Shortest Path First (SPF) Tree.
3. Creating the routing table entries.

Compiling the LSDB

The LSDB is a database of all OSPF router LSAs. The LSDB is compiled by an ongoing exchange of LSAs between neighboring routers so that each router is synchronized with its neighbor. When the Network converged, all routers have the appropriate entries in their LSDB.

Calculating the SPF Tree Using Dijkstra's Algorithm

Once the LSDB is compiled, each OSPF router performs a least cost path calculation called the Dijkstra algorithm on the information in the LSDB and creates a tree of shortest paths to each other router and network with themselves as the root. This tree is known as the SPF Tree and contains a single, least cost path to each router and in the Network. The least cost path calculation is performed by each router with itself as the root of the tree

Calculating the Routing Table Entries from the SPF Tree

The OSPF routing table entries are created from the SPF tree and a single entry for each network in the AS is produced. The metric for the routing table entry is the OSPF-calculated cost, not a hop count.

The OSPF table in NetSim

- After running Sample 2, click OSPF Metrics in Performance Metrics screen. Then click the router to view the Routing table
- We have shown the routing table for Router 1:

Performance Metrics

Router1

Link State Database

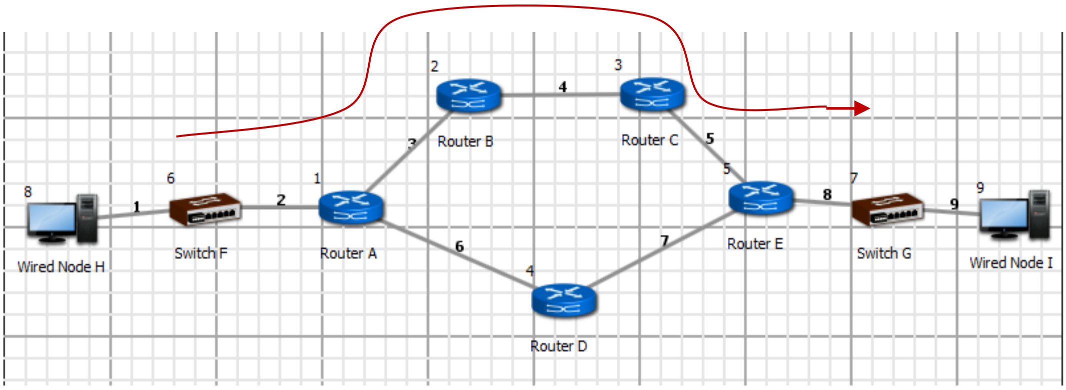
Advertising Router	LinkStateId	LS Sequence Number
11.2.1.1	11.2.1.1	0x80000031

Routing Table

Destination IP	Next Hop IP	Subnet mask	Cost	AreaID	Pathtype
11.1.0.0	11.1.1.1	255.255.0.0	1	0	intra_area
11.2.0.0	11.2.1.1	255.255.0.0	1	0	intra_area
11.3.0.0	11.3.1.1	255.255.0.0	10	0	intra_area
12.2.0.0	11.2.1.2	255.255.0.0	2	0	intra_area
13.2.0.0	11.2.1.2	255.255.0.0	3	0	intra_area
15.2.0.0	11.2.1.2	255.255.0.0	13	0	intra_area
14.3.0.0	11.2.1.2	255.255.0.0	4	0	intra_area

Shortest Path from Wired Node H to WiredNode I in OSPF (Use Packet Animation to view):

WiredNode H→Switch F→Router1→Router2→Router3→Router5→Switch G →WiredNode I



Note: The Cost is calculated by using the following formula

$$Cost = \frac{ReferenceBandwidth}{LinkSpeedUp}$$

Reference Bandwidth = 100 Mbps

For Example,

Let us take, Link Speed UP = 100 Mbps

$$Cost = \frac{100\ (ReferenceBandwidth)}{100\ (LinkSpeedUP)} = 1$$

8. Experiment on M/D/1 Queue:

-To create an M/D/1 queue: a source to generate packets, a queue to act as the buffer and server, a sink to dispose of serviced packets.

-To study how the queuing delay of such a system varies.

8.1 Theory:

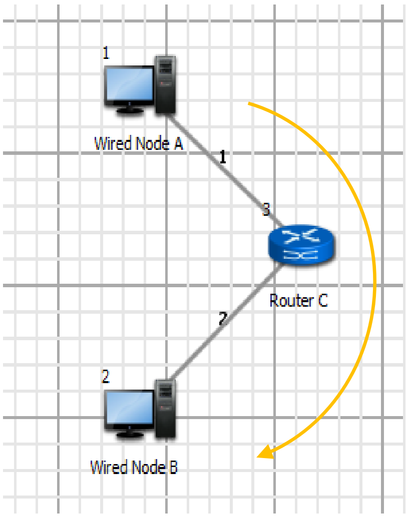
In systems where the service time is a constant, the M/D/1, single-server queue model, can be used. Following Kendall's notation, M/D/1 indicates a system where:

- **Arrivals** are a Poisson process with parameter λ
- **Service time(s)** is deterministic or constant
- There is **one server**

For an M/D/1 model, the total expected queuing time is $\boldsymbol{T = \frac{1}{2\mu} \times \frac{\rho}{1-\rho}}$

Where μ = Service Rate = 1/Service time and ρ is the utilization given as follows, $\boldsymbol{\rho = \frac{\lambda}{\mu}}$

To model an M/D/1 system in NetSim, we use the following model



Traffic flow from Node 1 to Node 2 (Node 1: Source, Node 2: Sink) Inter-arrival time: Exponential Distribution with mean 2000 µs Packet size: Constant Distribution with mean of 1250 bytes

Note:

1. Exponentially distributed inter-arrivals times give us a Poisson arrival process. Different mean values are chosen as explained in the section Sample Inputs. (Dropping the devices in different order may change the result because the random number generator will get initialized differently)

2. To get constant service times, we use constant distribution for packet sizes. Since, the service (which in our case is link transmission) times are directly proportional to packet size (greater the packet size, greater the time for transmission through a link), a constant packet size leads to a constant service time.

Procedure:

Create Scenario: "Simulation → New → Internetworks".

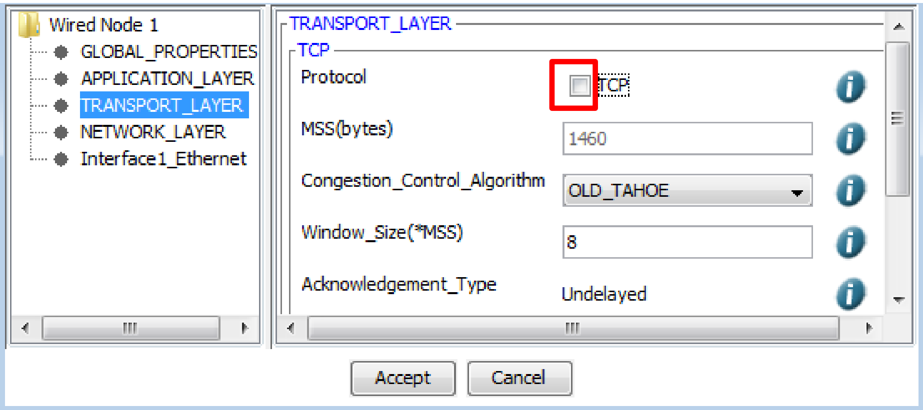
Nodes 1 and Node 2 are connected with Router 1 by Link 1 and Link 2 respectively. Set the properties for each device as given below,

Sample 1:

Application Properties: Click and drop the Application icon and set following properties:

Application Type	Custom	
Source_Id	1	
Destination_Id	2	
Packet Size	**Distribution**	Constant
	Value (bytes)	1250
Inter Arrival Time	**Distribution**	Exponential
	Packet Inter Arrival Time (µs)	2000

Disable TCP in the Transport Layer in **Node Properties** as follows:



Link Properties	Link 1	Link 2
Uplink Speed (Mbps)	10	10
Downlink Speed (Mbps)	10	10
Uplink BER	0	0
Downlink BER	0	0
Uplink Propagation Delay (ms)	0	0
Downlink Propagation Delay (ms)	0	0

Router Properties: Accept the default properties for Router.

Simulation Time: 100 Sec

Observation:

Even though the packet size at the application layer is 1250 bytes, as the packet moves down the layers, some overhead is added which results in a greater packet size. This is the actual payload that is transmitted by the physical layer. The overheads added in different layers are shown in the table:

Layer	Overhead (Bytes)
Transport Layer	8
Network Layer	20

MAC layer	26
Physical Layer	0
Total	54

Therefore, the payload size = Packet Size + Overhead

= 1250 + 54

= **1304 bytes**

Theoretical Calculation:

By formula,

$$\textbf{\textit{Queuing Time}} = \boldsymbol{T} = \frac{\mathbf{1}}{\mathbf{2}\boldsymbol{\mu}} \times \frac{\boldsymbol{\rho}}{\mathbf{1}-\boldsymbol{\rho}}$$

μ = Service Rate, i.e., the time taken to service each packet

= Link capacity (bps) / (Payload Size (Bytes) * 8)

= (10×10^6) / (1304*8)

= **958.59 packets / sec**

λ = Arrival rate, i.e., the rate at which packets arrive (Packets per second)

Inter-arrival time = 2,000 micro sec

Arrival rate **λ** = 1/ Inter Arrival time

= 1/2000 micro sec

= **500 packets / sec**

ρ = Utilization

= λ/μ

= 500/958.59

= 0.522

By formula, **Queuing Time** = $\frac{1}{2\times958.59} \times \frac{0.522}{1-0.522}$ = **569.61 micro sec**

8.2 Output:

After running the simulation, check the **"Delay"** in the Application Metrics.

Delay = 2656.855 micro sec

This Delay (also known as Mean Delay) is the sum of Queuing Delay, Total Transmission time and Routing Delay.

$$\begin{pmatrix}\textbf{Mean}\\\textbf{Delay}\end{pmatrix} = \begin{pmatrix}\textbf{Queuing}\\\textbf{Delay}\end{pmatrix} + \begin{pmatrix}\textbf{Total Transmission}\\\textbf{Time}\end{pmatrix} + \begin{pmatrix}\textbf{Routing}\\\textbf{Delay}\end{pmatrix}$$

Total Transmission Time is the sum of transmission time through Link 1 and Link 2.

Transmission time through each link is the same and is given by:

$$\text{Transmission time through each link} = \frac{Payload\ Size\ (Bytes) \times 8}{Uplink\ Speed\ (bps)}$$

$$= \frac{1304 \times 8}{10 \times 10^6}$$

= 1043.2 micro sec

Routing Delay is approximately 1 micro sec and can be found from the Event Trace. It is the difference between “Physical In” and “Physical Out” time for the Router.

Therefore, for simulation

Queuing Delay = 2656.855– (2 × 1043.2) – 1 = 569.455 micro sec

Sample 2

Keeping all the other parameters same as in previous example, if Packet Inter Arrival Time is taken as 1500 micro sec, then

λ = 666.67 packets per sec

Utilization **ρ = λ/µ = 666.67/958.59 = 0.695**

And **Queuing Time T = 1188.56 micro sec**

From NetSim,

Delay = 3279.297 micro sec

Therefore, **Queuing Time** = 3279.298 - (2×1043.2) – 1

= **1191.898 micro sec**

Note: Obtained value is slightly higher than the theoretical value because of initial delays in forming ARP table, Switch table and Routing table etc.

A Note on M/M/1 queuing in NetSim

M/M/1 queue can be generated similarly by setting the "**Packet Size Distribution**" as "**Exponential**" instead of "**Constant**". However, the results obtained from simulation deviate from the theoretical value because of the effect of packet fragmentation. Whenever a packet with size greater than Transport Layer MSS and / or MAC Layer MTU (which is 1500 bytes in NetSim) is generated, it gets fragmented in the application layer. Then the packet is sent as multiple frames, and makes it impossible to calculate the exact queuing time.

9. Plot the characteristic curve throughput versus offered traffic for a Slotted ALOHA system

9.1 Theory:

ALOHA provides a wireless data network. It is a multiple access protocol (this protocol is for allocating a multiple access channel). There are two main versions of ALOHA: pure and slot ed. They differ with respect to whether or not time is divided up into discrete slots into which all frames must fit.

Slotted ALOHA:

In slotted Aloha, time is divided up into discrete intervals, each interval corresponding to one frame. In Slotted ALOHA, a computer is required to wait for the beginning of the next slot in order to send the next packet. The probability of no other traffic being initiated during the entire vulnerable period is given by e^{-G} which leads to $S = G\, e^{-G}$ where, S (frames per frame time) is the mean of the Poisson distribution with which frames are being generated. For reasonable throughput S should lie between 0 and 1.

G is the mean of the Poisson distribution followed by the transmission attempts per frame time, old and new combined. Old frames mean those frames that have previously suffered collisions.

It is easy to note that Slotted ALOHA peaks at G=1, with a throughput of $S = {}^{1}/_{e}$ or about 0.368. It means that if the system is operating at G=1, the probability of an empty slot is 0.368

Calculations used in NetSim to obtain the plot between S and G:

Using NetSim, the attempts per packet time (G) can be calculated as follows;

$$G = \frac{\text{Number of packets Transmitted} * \text{PT}}{\text{ST} * 1000}$$

Where,	G	=	Attempts per packet time
	PT	=	Packet time (in seconds)

ST = Simulation time (in seconds)

The throughput (in Mbps) per packet time can be obtained as follows:

$$S = \frac{\text{Throughput(in Mbps)} * 1000 * PT}{PS * 8}$$

Where, S = Throughput per packet time

PT = Packet time (in milliseconds)

PS = Packet size (in bytes)

Calculations for the packet time:

$$PT = \frac{\text{Packet Size(bits)}}{\text{Band Width(Mbps)}}$$

In the following experiment, we have taken packet size=1472 (Data Size) + 28 (Overheads) = 1500 bytes

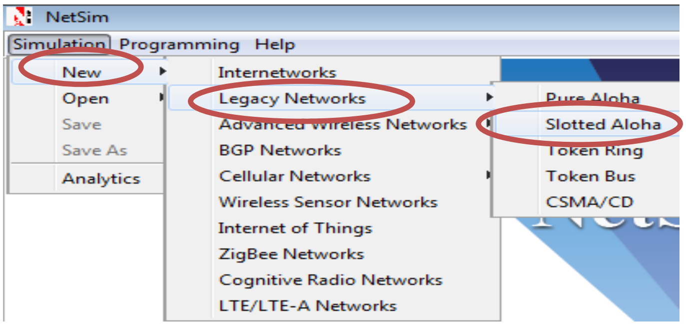
Bandwidth is 10 Mbps and hence, packet time comes as 1.2 milliseconds.

9.2 Procedure:

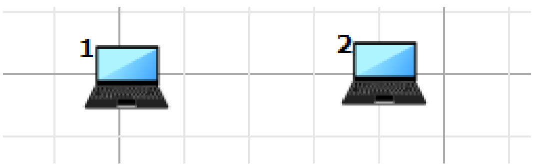
Step 1:

How to Create Scenario:

- **Create Scenario:** “Simulation → New →Legacy Networks → Slotted Aloha”.



Click and drop two nodes as shown in the screen shot.

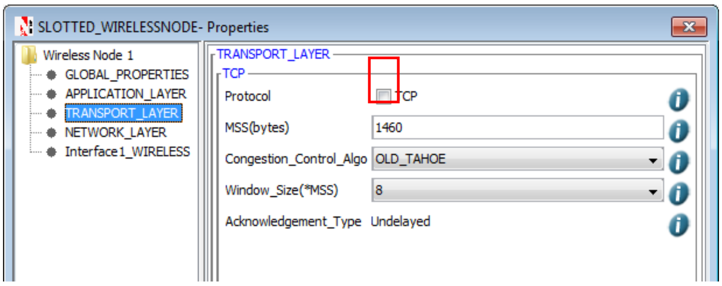


Sample Inputs:

Input for Sample 1: Node 1 generates traffic. The properties of Node 1 which transmits data to Node 2 are selected as follows:

Wireless Node Properties:

Wireless Node Properties	
Transport Layer	
TCP	disable
Interface1_Wireless	
Slot Length(mus)	1500
Data Rate(mbps)	10



Right click on the Grid environment and select the channel characteristics as **no path loss**.

Application Properties: Click and drop the Application icon and set following properties as shown in below figure:-

Application Type	Custom	
Source_Id	1	
Destination_Id	2	
Packet Size	**Distribution**	Exponential
	Value (bytes)	1472
Inter Arrival Time	**Distribution**	Exponential
	Packet Inter Arrival Time (μs)	20000

Simulation Time- 10 Seconds

(***Note:*** *The Simulation Time can be selected only after doing the following two tasks,*

- *Set the properties of Nodes*
- *Then click on Run Simulation button*).
    - Obtain the values of Throughput and Total Number of Packets Transmitted from the statistics of NetSim simulation for various numbers of traffic generators.

Input for Sample 2: Node 1 and Node 2 both generate traffic. Node 1 transmits data to Node 2 & Node 2 transmits data to Node 1.The properties of Node 1 and Node 2 are set as shown in Sample 1.

Input for Sample 3: 3 Nodes are generating traffic. Node 1 transmits data to Node 2, Node 2 transmits data to Node 3 and Node 3 transmits data to Node 1.

And so on continue the experiment by increasing the number of nodes generating traffic as 4, 5, 7, 9, 10, 15, 20 22 and 24 nodes.

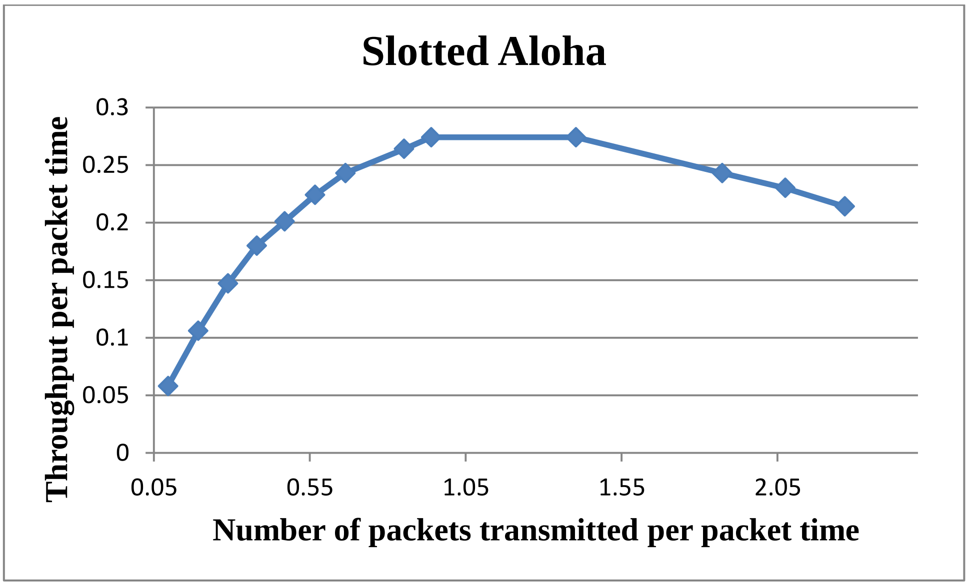
Comparison Table:

The values of Throughput and Total Number of Packets Transmitted obtained from the network statistics after running NetSim simulation are as follows. Throughput per packet time and Number of Packets Transmitted per packet time calculated from the above mentioned formulae are tabulated as below:

Number of nodes generating traffic	Throughput (in Mbps)	Total number of Packets Transmitted	Throughput per packet time	Number of Packets Transmitted per packet time
1	0.58	793	0.058	0.095
2	1.06	1602	0.106	0.192
3	1.47	2394	0.147	0.287
4	1.8	3164	0.18	0.379
5	2.01	3913	0.201	0.469

7	2.43	5531	0.243	0.663
9	2.64	7101	0.264	0.852
10	2.74	7824	0.274	0.938
15	2.74	11695	0.274	1.403
20	2.43	15606	0.243	1.872
22	2.3	17288	0.23	2.074
24	2.14	18884	0.214	2.266

Thus the following characteristic plot for the Slotted ALOHA is obtained, which matches the theoretical result.



Note: The optimum value is slightly less than the theoretical maximum of 0.368 because NetSim's simulation is per real-world and includes overheads, inter-frame gaps etc.

10. Understand the impact of bit error rate on packet error and investigate the impact of error of a simple hub based CSMA / CD network

10.1 Theory:

Bit error rate (BER): The bit error rate or bit error ratio is the number of bit errors divided by the total number of transferred bits during a studied time interval i.e.

$$\mathbf{BER} = \frac{\mathbf{Bit\ errors}}{\mathbf{Total\ number\ of\ bits}}$$

For example, a transmission might have a BER of 10^{-5}, meaning that on average, 1 out of every of 100,000 bits transmitted exhibits an error. The BER is an indication of how often a packet or other data unit has to be retransmitted because of an error.

Unlike many other forms of assessment, bit error rate, BER assesses the full end to end performance of a system including the transmitter, receiver and the medium between the two. In this way, bit error rate, BER enables the actual performance of a system in operation to be tested.

Bit error probability (p_e): The bit error probability is the expectation value of the BER. The BER can be considered as an approximate estimate of the bit error probability. This estimate is accurate for a long time interval and a high number of bit errors.

Packet Error Rate (PER):

The PER is the number of incorrectly received data packets divided by the total number of received packets. A packet is declared incorrect if at least one bit is erroneous.

The expectation of the PER is denoted as packet error probability p_p, which for a data packet length of N bits can be expressed as,

$$p_p = 1 - (1 - p_e)^N$$

It is based on the assumption that the bit errors are independent of each other.

Derivation of the packet error probability:

Suppose packet size is N bits.

p_e is the bit error probability then probability of no bit error=1-p_e

As packet size is N bits and it is the assumption that the bit errors are independent. Hence,

Probability of a packet with no errors = $(1-p_e)^N$

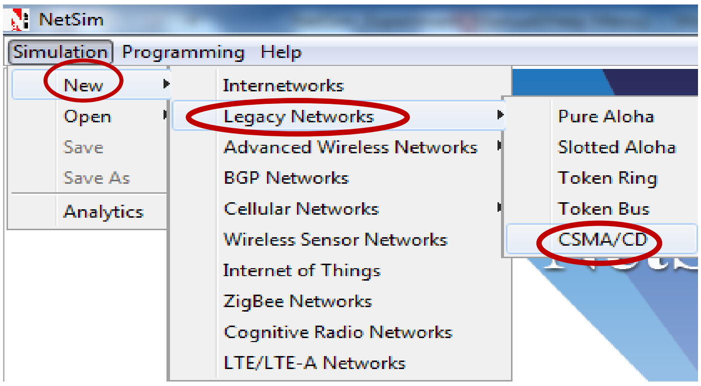
A packet is erroneous if at least there is one bit error, hence

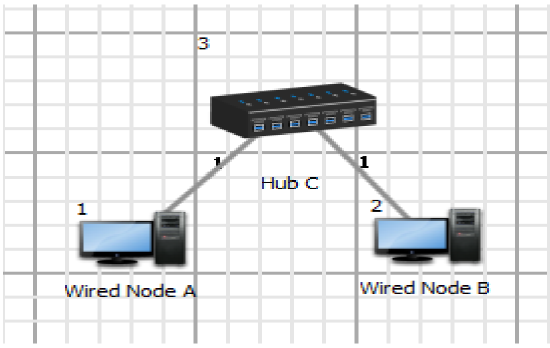
Probability of packet error=1-$(1-p_e)^N$

10.2 Procedure:

How to create a scenario and generate traffic:

- **Create Scenario:** "Simulation → New →Legacy Networks →CSMA/CD".





Example 1:

Create samples by varying the bit error rate (10^{-6}, 10^{-7}, 10^{-8}, 10^{-9}, No error) and check whether packet error output matches the PER formula.

Sample Inputs:

To perform this sample experiment, two nodes and one hub are considered.

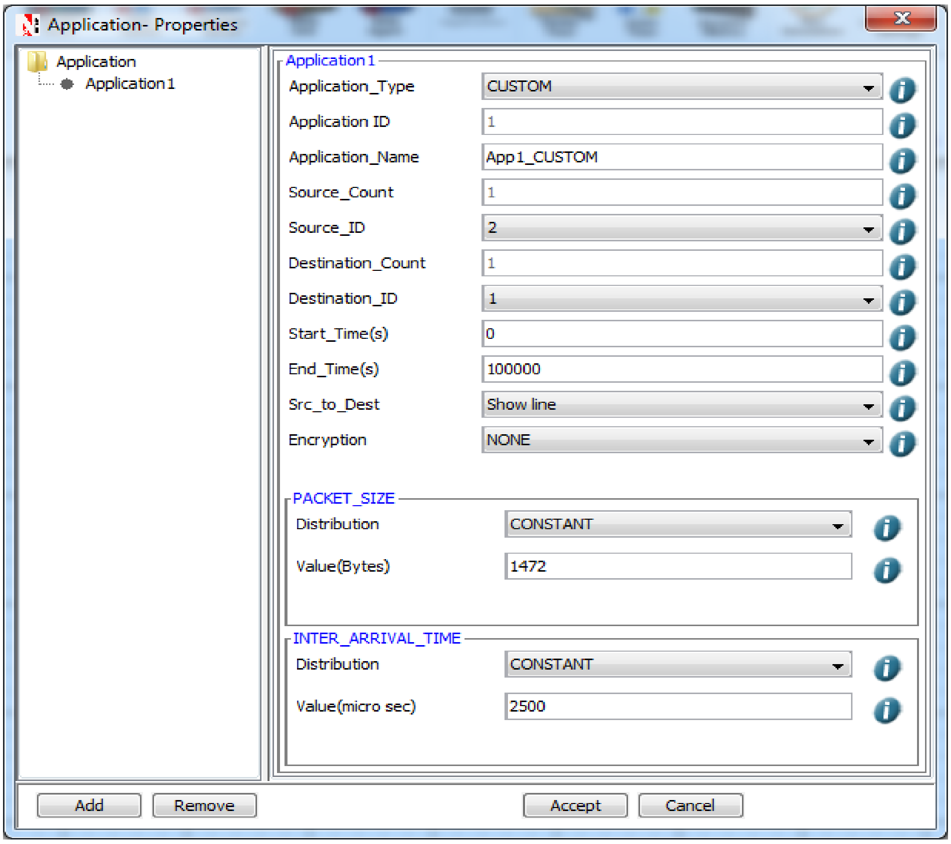
- Click and drop Hub on the environment builder.
- Click and drop Node1.
- Click and drop Node2.

The properties of Node 1 and Hub are as follows: (Node 2 has default properties)

Link Properties	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**
Data rate (Mbps)	10	10	10	10	10
Error Rate (BER)	No Error	10^{-9}	10^{-8}	10^{-7}	10^{-6}

Wireless Node Properties: Disable TCP in transport layer

Application Properties: Click and drop the Application icon and set the following properties



Simulation Time - 10 Sec

*(**Note:** The Simulation Time can be selected only after the following two tasks,*

- *Set the properties for the Nodes& The Hub*
- *Click on the Simulate button).*

Example 2:

Sample Inputs:

In this sample experiment, four nodes and one hub are considered.

- Click and drop Hub on the environment builder
- Click and drop Node1
- Click and drop Node2
- Click and drop Node3
- Click and drop Node4

Link Properties	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Data rate (Mbps)	10	10	10	10	10
Error Rate (BER)	No Error	10^{-9}	10^{-8}	10^{-7}	10^{-6}

The properties of Node 1 are same as in Example 1 and Node 2 properties are shown below: (Node 3 and Node 4 have default properties)

Application Properties: Click and drop the Application icon and set the properties as in example 1.

Simulation Time - 10 Sec

*(**Note:** The Simulation Time can be selected only after the following two tasks,*

- *Set the properties for the Nodes& The Hub*
- *Click on the Simulate button)*.

NetSim simulation output:

Example 1: One node transmission

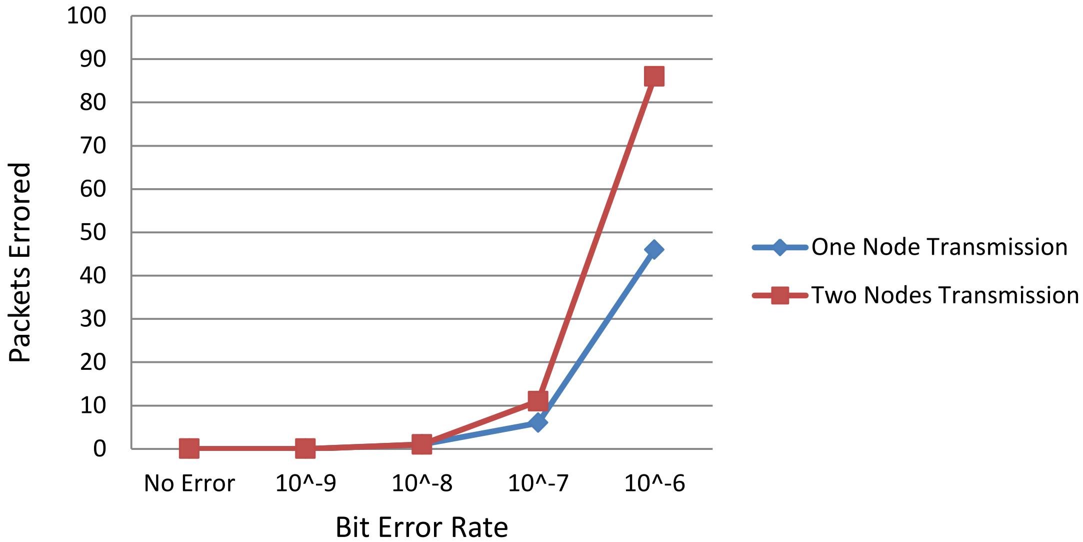
BER	Packets Errored	Packets Generated
0	0	3999
1E-09	0	3999
1E-08	1	3999
1E-07	6	3999
1E-06	46	3999

Example 2: Two nodes transmission

BER	Packets Errored	Packets Generated
0	0	7998
1E-09	0	7998
1E-08	1	7998
1E-07	11	7998
1E-06	86	7998

Packet size for the calculation of the output table=1500 bytes or 12000 bits

Comparing Packets errored with Bit error rate:



10.3 Inference:

From the Graph, we see that as the error rate is increased the number of errored packets increase. The increase is exponential since the error rate is increased in powers of 10.

11. To determine the optimum persistence of a p-persistent CSMA / CD network for a heavily loaded bus capacity.

11.1 Theory:

Carrier Sense Multiple Access Collision Detection (CSMA / CD)

This protocol includes the improvements for stations to abort their transmissions as soon as they detect a collision. Quickly terminating damaged frames saves time and bandwidth. This protocol is widely used on LANs in the MAC sub layer. If two or more stations decide to transmit simultaneously, there will be a collision. Collisions can be detected by looking at the power or pulse width of the received signal and comparing it to the transmitted signal. After a station detects a collision, it aborts its transmission, waits a random period of time and then tries again, assuming that no other station has started transmitting in the meantime.

There are mainly three theoretical versions of the CSMA /CD protocol:

1-persistent CSMA / CD: When a station has data to send, it first listens to the channel to see if anyone else is transmitting at that moment. If the channel is busy, the station waits until it becomes idle. When station detects an idle channel, it transmits a frame. If a collision occurs, the station waits a random amount of time and starts all over again. The protocol is called 1-persistent because the station transmits with a probability of 1 whenever it finds the channel idle.

Ethernet, which is used in real-life, uses 1-persistence. A consequence of 1-persistence is that, if more than one station is waiting for the channel to get idle, and when the channel gets idle, a collision is certain. Ethernet then handles the resulting collision via the usual exponential back off. If N stations are waiting to transmit, the time required for one station to win the back off is linear in N.

Non-persistent CSMA /CD: In this protocol, before sending, a station senses the channel. If no one else is sending, the station begins doing so itself. However, if the channel is already in use, the channel does not continually sense it for the purpose of seizing it immediately upon detecting the end of the previous transmission. Instead, it waits a random period of time and then repeats the algorithm. Intuitively this algorithm should lead to better channel utilization and longer delays than 1-persistent CSMA

p-persistent CSMA / CD: This protocol applies to slotted channels. When a station becomes ready to send, it senses the channel. If it is idle, it transmits with a probability of p. With a probability q=1-p it defers until the next slot. If that slot is also idle, it either transmits or defers again, with probabilities p and q respectively. This process is repeated until either the frame has been transmitted or another station has begun transmitting. In the latter case, it acts as if there had been a collision (i.e., it waits a random time and starts again). If the station initially senses the channel busy, it waits until the next slot and applies the above algorithm.

How does the performance of LAN (throughput) that uses CSMA/CD protocol gets affected as the numbers of logged in user varies:

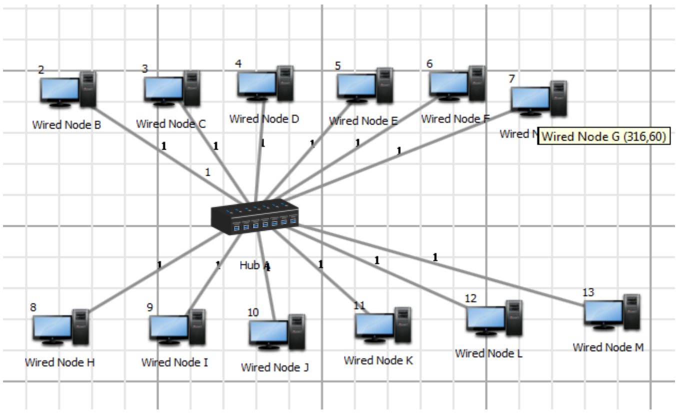
Performance studies indicate that CSMA/CD performs better at light network loads. With the increase in the number of stations sending data, it is expected that heavier traffic have to be carried on CSMA/CD LANs (IEEE 802.3). Different studies have shown that CSMA/CD performance tends to degrade rapidly as the load exceeds about 40% of the bus capacity. Above this load value, the number of packet collision raise rapidly due to the interaction among repeated transmissions and new packet arrivals. Collided packets will back off based on the truncated binary back off algorithm as defined in IEEE 802.3 standards. These retransmitted packets also collide with the newly arriving packets.

11.2 Procedure:

How to create a scenario and generate traffic:

- **Create Scenario**: “Simulation → New →Legacy Networks → CSMA/CD”.

Scenario:



Sample Input:

In this Sample experiment 12 Nodes and 1 Hubs need to be clicked and dropped onto the Environment Builder.

Input for the Sample experiments (i.e. Totally 11 Samples) are given below,

Sample Input 1:

In the first sample for each Node the following properties have to be set,

Node Properties	Values to be Selected
Persistence	1

Vary persistence from 1/2, 1/3, 1/4, 1/5… 1/10, 1/11 to generate other experiments.

Create broadcast application for all nodes and set the properties as follows:

Application Properties		
Packet Size	Distribution	Constant
	Application Data Size (bytes)	1472
Inter Arrival Time	Distribution	Exponential
	Mean Inter Arrival Time(μs)	1000

Wired Link Properties:

Link Properties	Values to be Selected
Uplink bit error rate	0
Downlink bit error rate	0

Simulation Time - 10 Sec

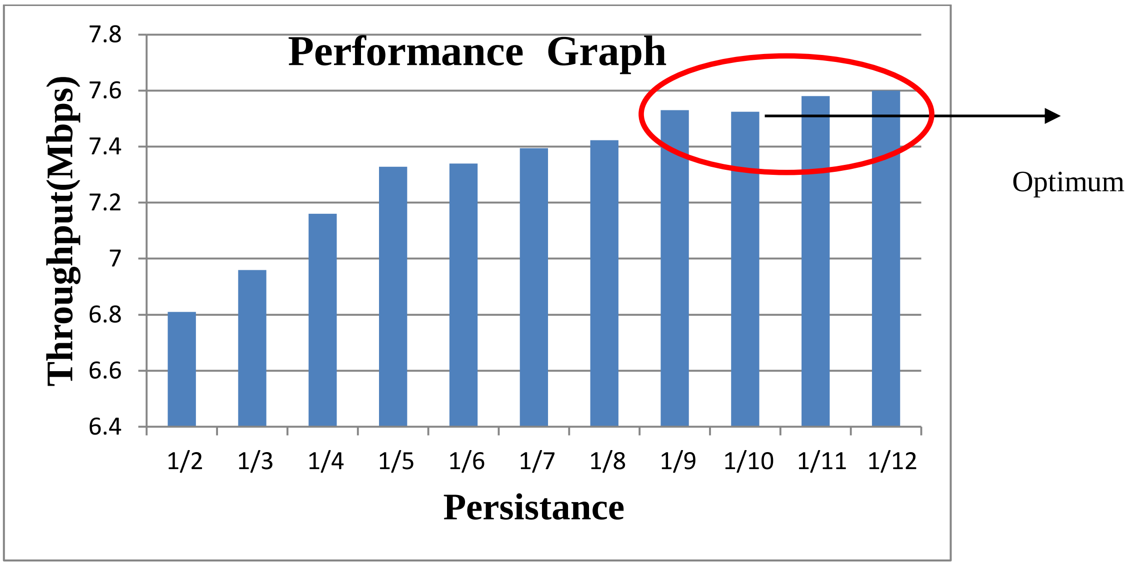
*(**Note:** The Simulation Time can be selected only after the following two tasks,*

- *Set the properties for the Nodes & The Hub*
- *Click on Run Simulation button)***.**

11.3 Output:

After simulation of each experiment, click on the network statistics and note down the user level throughput values. Open an excel sheet and plot a graph for these noted values against their respective persistence values.

Comparison Chart:



11.4 Inference:

As the number of logged in users is quite large in this experiment, the performance of a p-persistent CSMA/CD network with large p, is not optimal because of a large number of collisions. Therefore, we have minimum throughput when the persistence was 1/2. But as persistence is decreased (lower and lower probabilities), the likelihood of collisions reduce and hence throughput starts to increase. However, beyond a certain limit, in this case 1/11 the probability of transmitting packets becomes very low and hence there aren't many transmissions. Therefore, throughput starts to decline. In this experiment with 12 nodes generating traffic, we notice that the maximum throughput is at a persistence value lying between 1/9 and 1/12.

12. Analyze the performance of a MANET, (running CSMA/CA (802.11b) in MAC) with increasing node density

12.1 Theory:

Mobile Ad-Hoc Network (MANET) is a self-configuring network of mobile nodes connected by wireless links to form an arbitrary topology without the use of existing infrastructure. The nodes are free to move randomly. Thus the network's wireless topology may be unpredictable and may change rapidly.

The node density also has an impact on the routing performance. With very sparsely populated network the number of possible connection between any two nodes is very less and hence the performance is poor. It is expected that if the node density is increased the throughput of the network shall increase, but beyond a certain level if density is increased the performance degrades.

12.2 Performance metrics:

The different parameters used to analyze the performance are explained as follows:

- **Throughput:** It is the rate of successfully transmitted data packets in unit time in the network during the simulation.

- **Average Delay:** It is defined as the average time taken by the data packets to propagate from source to destination across a MANET. This includes all possible delays caused by routing discovery latency, queuing at the interface queue, and retransmission delays at the MAC, propagation and transfer times.

12.3 Procedure:

In NetSim, Select "Simulation → New → Advanced Wireless Networks →MANET".

Step 1: Create /Design the Network

Devices Required: 2 Wireless Nodes

Step 2: Configure the Network (Sample 1)

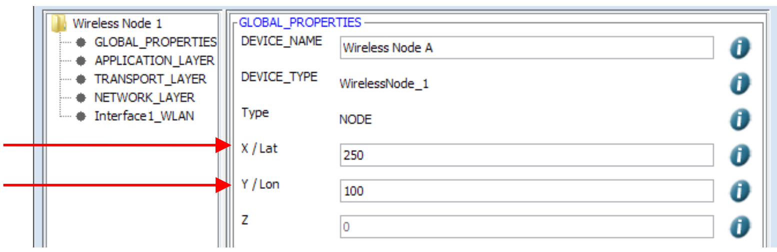
Wireless Node Properties:

- Click & drop 2 Wireless Nodes onto the Simulation Environment.
- Arrange the positions of the nodes as per the following table:

Wireless Node	X-Coordinate	Y-Coordinate
1	50	100
2	100	150

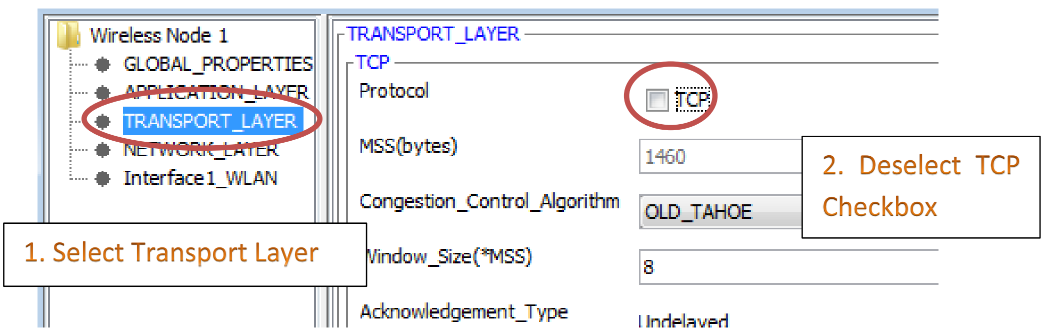
NOTE: To edit the position, change the (x, y) co-ordinates in Global Properties as shown:

To change Co-ordinates, click & edit



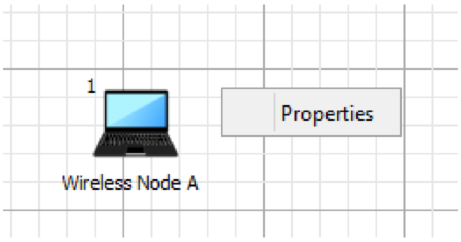
- Disable TCP in all Wireless Nodes.

Right Click on any **Wireless Node →**Properties

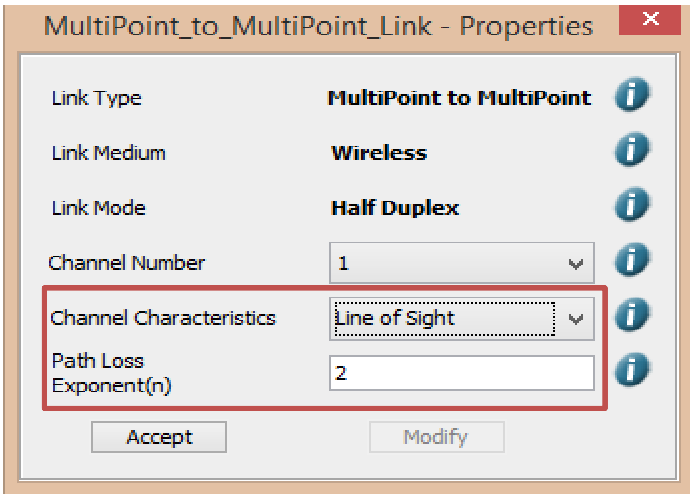


Wireless Link Properties:

Right Click anywhere on the Grid Environment→Properties



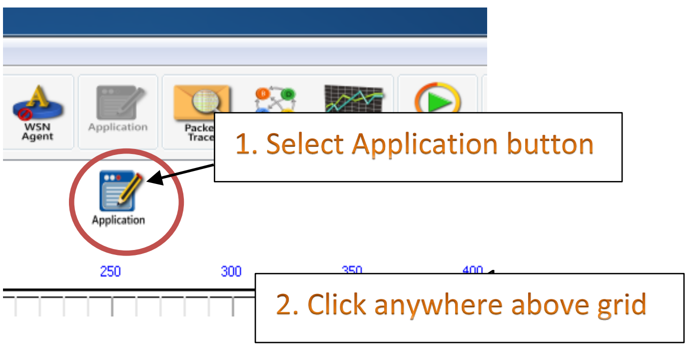
Channel Characteristics	Line of Sight
Path Loss Exponent (n)	2

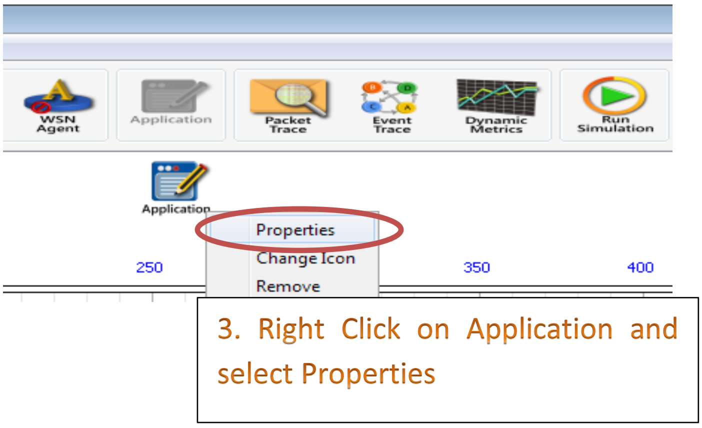


Path loss is the reduction in the power density of radio wave as it travels. The loss is proportional to (distance) to the power (n), where n is the path loss exponent. The general value of n is from 2 to 5. As the value of n is increased there will be more reduction in power and hence higher likelihood of error in the packet. In general, users would notice that as n increases the error increases, the data rate decreases and the throughput decreases.

Step 3: Model Traffic in the Network (Sample 1)

Select the Application Button and click on the gap between the Grid Environment and the ribbon. Now right click on Application and select Properties.





<u>Application Properties:</u>

Application Type	Custom
Source ID	1 (Wireless Node A)
Destination ID	2 (Wireless Node B)
Packet Size	
Distribution	Constant
Value(Bytes)	1460
Inter Arrival Time	
Distribution	Constant
Value(µs)	60000

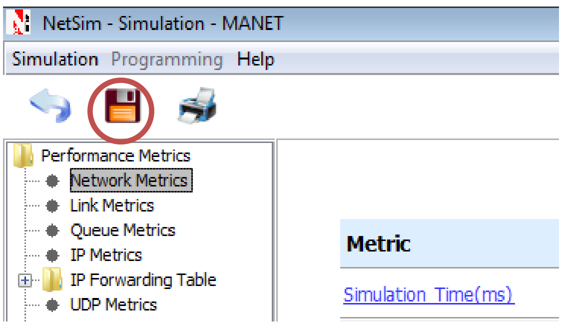
Step 4: Simulate

Simulation Time - 100 Sec

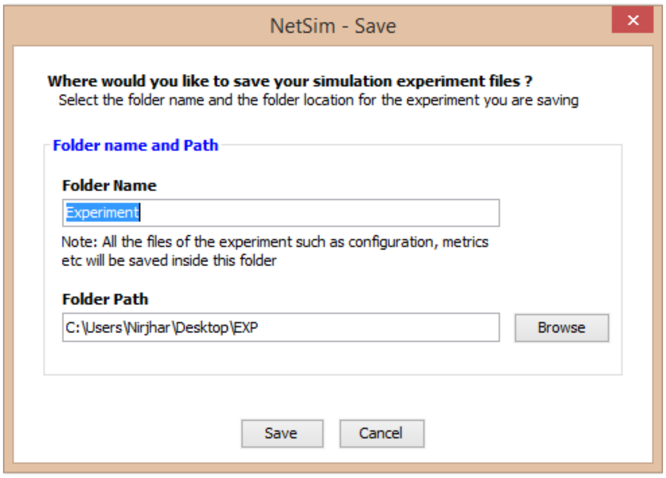
After completion of the experiment, “Save” the experiment for future analysis of results.

Steps to save an experiment:

Step 1: After simulation of the network, on the top left corner of Performance metrics screen, click on the “Save Network and Metric as” button



Step 2: Specify the **Experiment Name** and **Save Path** and click on **OK**



Step 5: Configure the Network (Sample 2)

Wireless Node Properties:

- Click & drop 2 more Wireless Nodes onto the Simulation Environment.
- Arrange the positions of the nodes as per the following table:

Wireless Node	X-Coordinate	Y-Coordinate
1	50	100
2	100	150
3	75	75
4	125	125

- Disable TCP in all Wireless Nodes.

Right Click on any **Wireless Node** →Properties

The remaining properties are same as Sample 1.

Step 6: Model Traffic in the Network (Sample 2)

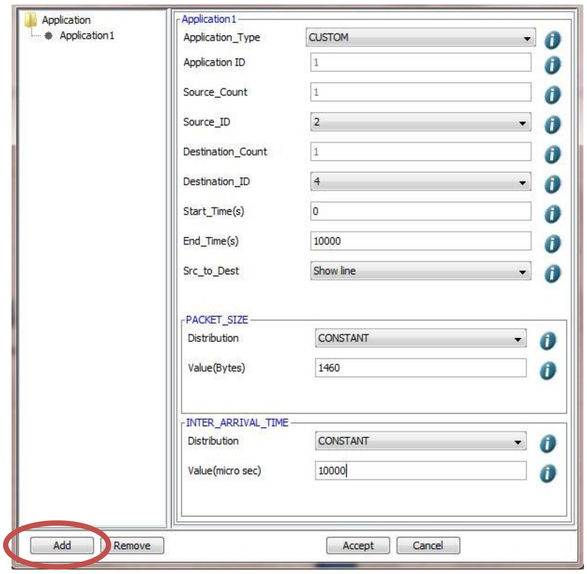
Select the Application Button and click on the gap between the Grid Environment and the ribbon. Now right click on Application and select Properties.

Application Properties:

Application Type	Custom	Custom
Source ID	1 (Wireless Node A)	3 (Wireless Node C)
Destination ID	2 (Wireless Node B)	4 (Wireless Node D)
Packet Size		
Distribution	Constant	Constant
Value(Bytes)	1460	1460
Inter Arrival Time		
Distribution	Constant	Constant
Value(µs)	60000	60000

NOTE: The procedure to create multiple applications are as follows:

Step 1: Click on the ADD button present in the bottom left corner to add a new application.



Step 7: Simulate

Simulation Time - 100 Sec

After completion of the experiment, "Save" the experiment for future analysis of results.

Step 8: Configure the Network (Sample 3)

Wireless Node Properties:

- Click & drop 2 more Wireless Nodes onto the Simulation Environment.

- Arrange the positions of the nodes as per the following table:

Wireless Node	X-Coordinate	Y-Coordinate
1	50	100
2	100	150
3	80	70
4	140	130
5	110	40
6	160	90

- Disable TCP in all Wireless Nodes.

The remaining properties are same as Sample 2.

Step 9: Model Traffic in the Network (Sample 3)

- Select the Application Button and click on the gap between the Grid Environment and the ribbon. Now right click on Application and select Properties.

Application Properties:

Application Type	Custom	Custom	Custom
Source ID	1 (Wireless Node A)	3 (Wireless Node C)	5 (Wireless Node E)
Destination ID	2 (Wireless Node B)	4 (Wireless Node D)	6 (Wireless Node F)
Packet Size			
Distribution	Constant	Constant	Constant
Value(Bytes)	1460	1460	1460
Inter Arrival Time			
Distribution	Constant	Constant	Constant
Value(μs)	60000	60000	60000

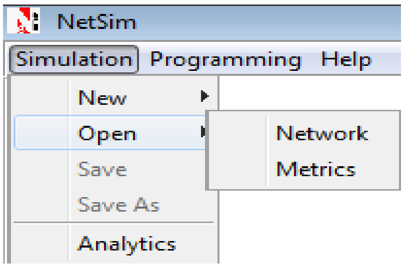
Step 10: Simulate

Simulation Time - 100 Sec

After completion of the experiment, “Save” the experiment for future analysis of results.

12.4 Output

Go to **Simulation → Open → Metrics** menu to open the results of saved experiments.



- Go to Application metrics and compute the sum of all column wise values of throughput.

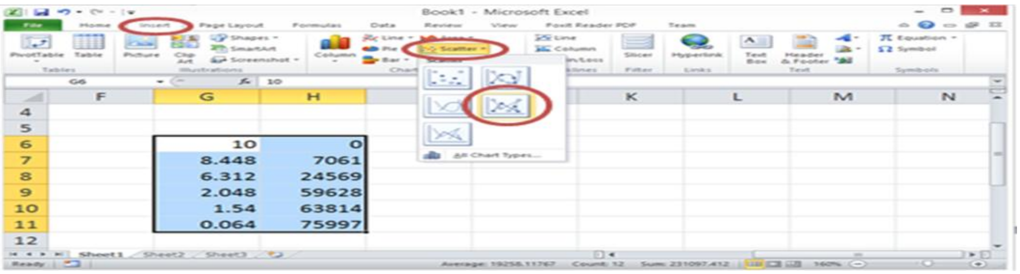
Throughput = Sum of throughputs obtained from all Applications

- Go to Application metrics and compute the Average delay by taking average of all row wise values of Delay.

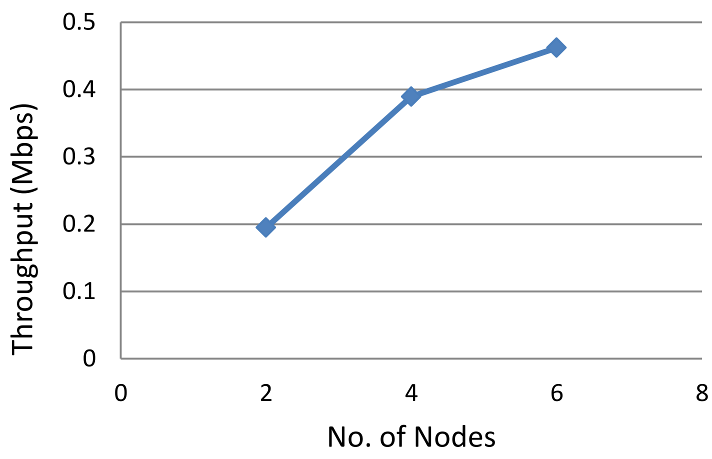
Delay = Average delay obtained from all Applications

NOTE – To create Graph in Excel 2010, follow the steps

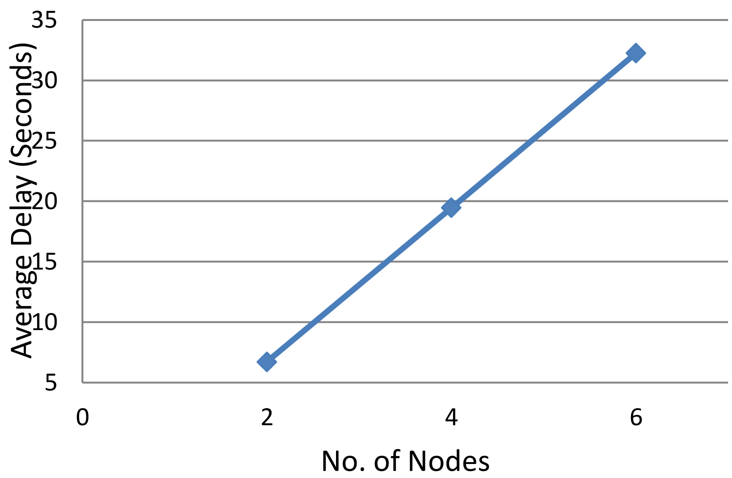
1. Copy the data in an Excel sheet.
2. Select the data. Go to **Insert → Scatter (under Charts) → Scatter with Straight lines and Markers.**



Plotting the Throughput obtained from the above 3 samples with respect to Number of Nodes and the graph which is obtained, follows the pattern as below:



Plot the Average Delay obtained from the above 3 samples with respect to Number of Nodes and the graph obtained is similar to:



12.5 Inference

As the number of nodes increases (2 → 4 → 6) the throughput of the network increases because the channel is able to handle additional network traffic. However, if the number of nodes is increased further, the throughput may decreases as the network traffic is too high, and this leads to collisions.

As the number of nodes increases, the delay also increases as it takes more time for a packet to reach its destination.

13. Analyze the performance of a MANET, (running CSMA/CA (802.11b) in MAC) with increasing node mobility

13.1 Theory:

Mobile Ad-Hoc Network (MANET) is a self-configuring network of mobile nodes connected by wireless links to form an arbitrary topology without the use of existing infrastructure. The nodes are free to move randomly. Thus the network's wireless topology may be unpredictable and may change rapidly.

Mobility and node density are the two major factors which influences the performance of any routing protocol of mobile ad hoc network. The mobility of the nodes affects the number of connected paths, which in turn affect the performance of the routing algorithm.

13.2 Performance metrics:

The different parameters used to analyze the performance are explained as follows:

- **Throughput:** It is the rate of successfully transmitted data packets in unit time in the network during the simulation.

13.3 Procedure:

In NetSim, Select “Simulation → New → Advanced Wireless Networks →MANET”.

Step 1: Create /Design the Network

Devices Required: 6 Wireless Nodes

Step 2: Configure the Network (Sample 1)

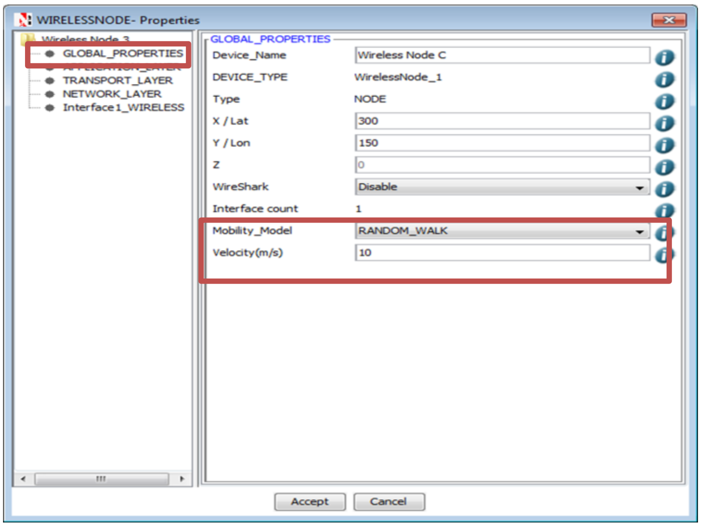
Wireless Node Properties:

- Click & drop 6 Wireless Nodes onto the Simulation Environment.
- Arrange the positions of the nodes as per the following table:

Wireless Node	X-Coordinate	Y-Coordinate
1	100	50
2	100	150
3	200	150
4	200	50
5	100	100
6	200	100

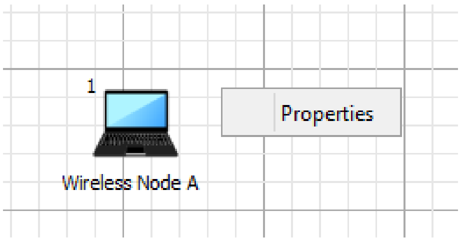
- Disable TCP in all Wireless Nodes.
- Change Mobility model to **RANDOM_WALK** and set velocity **10 m/s** for all nodes.

NOTE: To change Mobility Model, go to **Global Properties →Mobility Model**



Wireless Link Properties:

Right Click anywhere on the Grid Environment→Properties



Channel Characteristics	Line of Sight
Path Loss Exponent (n)	2

Path loss is the reduction in the power density of radio wave as it travels. The loss is proportional to (distance) to the power (n), where n is the path loss exponent. The general value of n is from 2 to 5. As the value of n is increased there will be more reduction in power and hence higher likelihood of error in the packet. In general, users would notice that as n increases the error increases, the data rate decreases and the throughput decreases.

NetSim provides various propagation models such as fading only, fading and shadowing and line of sight.

In Line of sight, sender and receiver have an unobstructed path between them. The reduction in signal power is only due to the path loss explained above.

In fading only, signal can take many different paths between sender and receiver due to reflection, scattering, diffraction and others.

In fading and shadowing, apart from fading then received signal is shadowed by obstructions such as hills and buildings.

Step 3: Model Traffic in the Network (Sample 1)

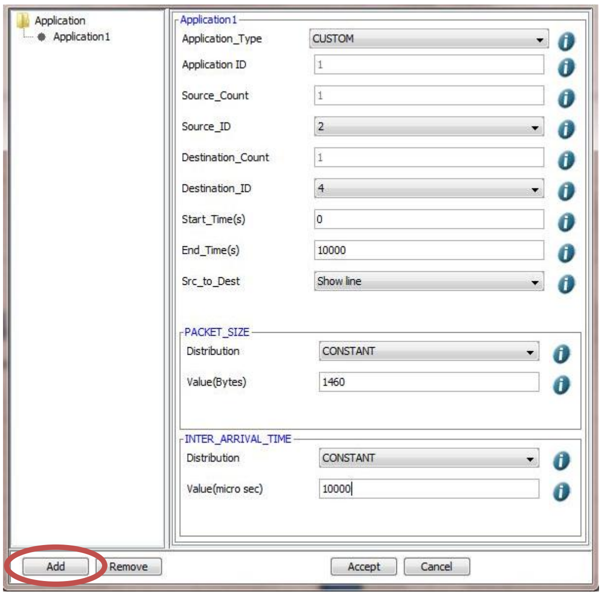
Select the Application Button and click on the gap between the Grid Environment and the ribbon. Now right click on Application and select Properties.

Application Properties:

Application Type	Custom	Custom	Custom
Source ID	1 (Wireless Node A)	2 (Wireless Node B)	5 (Wireless Node E)
Destination ID	4 (Wireless Node D)	3 (Wireless Node C)	6 (Wireless Node F)
Packet Size			
Distribution	Constant	Constant	Constant
Value(Bytes)	1460	1460	1460
Inter Arrival Time			
Distribution	Constant	Constant	Constant
Value(μs)	20000	20000	20000

NOTE: The procedure to create multiple applications are as follows:

Step 1: Click on the ADD button present in the bottom left corner to add a new application.



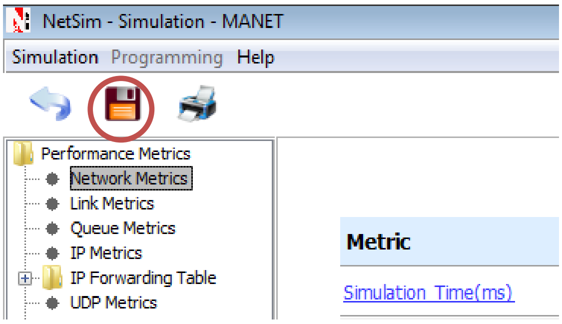
Step 4: Simulate

Simulation Time - 100 Sec

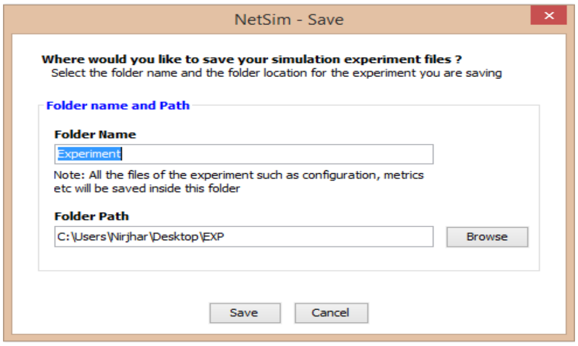
After completion of the experiment, "Save" the experiment for future analysis of results.

Steps to save an experiment:

Step 1: After simulation of the network, on the top left corner of Performance metrics screen, click on the "Save Network and Metric as" button



Step 2: Specify the **Experiment Name** and **Save Path** and click on **OK**



Step 5: Configure the Network (Sample 2)

Wireless Node Properties:

Change Mobility model to **RANDOM_WALK** and set velocity **30 m/s** for all nodes.
The remaining properties are same as Sample 1.

Step 6: Simulate

Simulation Time - 100 Sec

After completion of the experiment, “Save” the experiment for future analysis of results.

Step 7: Configure the Network (Sample 3)

Wireless Node Properties:

Change Mobility model to **RANDOM_WALK** and set velocity **50 m/s** for all nodes.
The remaining properties are same as Sample 1.

13.4 Simulate

Simulation Time - 100 Sec

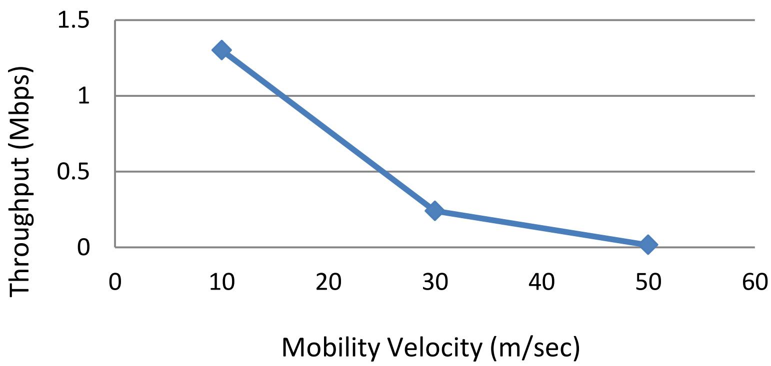
After completion of experiment, “Save” the experiment, for future analysis of results. Users can view the mobility of the nodes and flow of packets clearly using packet animation.

13.5 Analysis of Result

Go to **Simulation → Open → Metrics** menu to open the results of saved experiments.

- Go to Application metrics and compute the sum of all column wise values of throughput.

Throughput = Sum of throughputs obtained from all Applications



13.6 Inference

As the mobility of nodes increases, the throughput decreases. This is because as the velocity increases, more packets get lost in lieu of ad hoc movement of the nodes. The packet delivery ratio decreases as the sum of total packets received decreases with increased mobility.

NOTE: The results are highly dependent on position/velocity/ traffic etc given the inherent characteristics of MANET protocols. Any modifications with the above mentioned input parameters will change the final output result.

14. Study the working of BGP and formation of BGP Routing table

14.1 Theory:

In BGP, the Packets are transmitted between the Autonomous system using Path vector Routing.

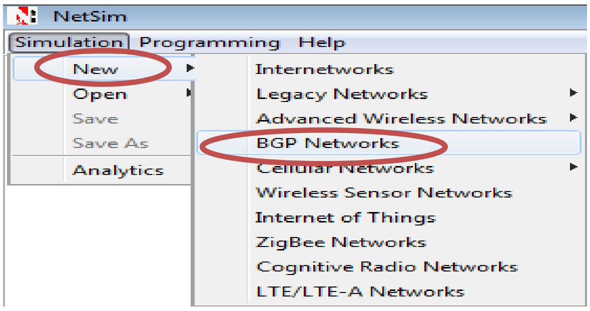
Path Vector Routing:

Path vector routing is used for inter-domain routing. It is similar to distance vector routing. In path vector routing we assume that there is one Router (there can be many) in each autonomous system which acts on behalf of the entire autonomous system. This Router is called the Border Router. The Border Router in one Autonomous System creates a routing table and advertises it to neighboring Border Router which belongs to neighboring autonomous systems. The idea is same as distance vector routing except that only Border Routers in each autonomous system can communicate with each other. The Border Routers advertises the path, not the metric, in its autonomous system or other autonomous systems.

14.2 Procedure:

Step 1:

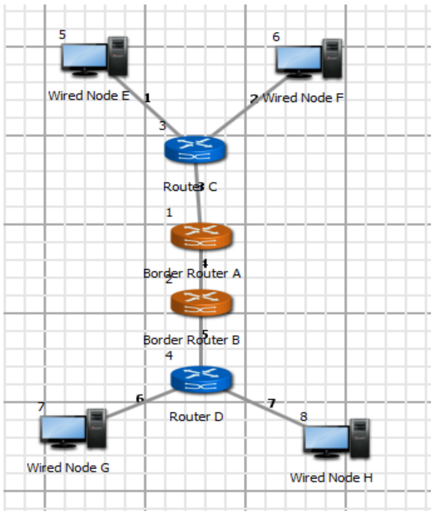
Go to Simulation → New → BGP Networks



Sample Inputs:

Follow the steps given in the different samples to arrive at the objective.

- Total no of nodes used: 4
- Total number of Internal Routers used: 2
- Total number of Border Routers used: 2



The devices are interconnected as given below,

- Wired Node E and Wired Node F are connected by Link 1 and Link 2 to Router C.
- Internal Router C and Border Router A are connected by Link 3.
- Border Router A and Border Router B are connected by Link4.
- Border Router B and Router D are connected by Link 5.
- Router D is connected by Link 6 and Link 7to Wired Node G and Wired Node H respectively.

Set the properties for each device by following the tables,

Application Properties	Application 1	Application 2
Application_Type	CUSTOM	CUSTOM
Source_Id	5	6
Destination_Id	7	8
Application Data size		
Distribution	Constant	Constant
Application Data size (bytes)	1472	1472
Inter Arrival Time		
Distribution	Constant	Constant
Mean Inter Arrival Time (µs)	20000	20000

Link Properties	Link 1	Link 2	Link 3	Link 4	Link 5	Link 6	Link 7
Bit Error Rate (BER)	0	0	0	0	0	0	0
Downlink Speed (Mbps)	8.448	8.448	10	1000	10	8.448	8.448
Uplink Speed (Mbps)	8.448	8.448	10	1000	10	8.448	8.448

Sample 1:

If selected internal gateway protocol is RIP then Router properties are as follows:

Router Properties	Border_ Router A		Border_ Router B	
	Interior Routing table	Exterior Routing table	Interior Routing table	Exterior Routing table
Protocol Type	RIP	BGP	RIP	BGP
Update Timer	30	-	30	-
Timeout Timer	180	-	180	-
Garbage Collection Timer	120	-	120	-

Router Properties	Router C	Router D
Routing Protocol	RIP	RIP
Update Timer	30	30
Timeout Timer	180	180
Garbage Collection Timer	120	120

Simulation Time - 10 Sec

(***Note:*** *The Simulation Time can be selected only after doing the following two tasks,*

- *Set the properties of Routers*
- *Then click on Run Simulation button***).**

After simulation save the experiment.

Sample 2:

If you want to select your internal gateway protocol as OSPF then here is the information you need to fill in for Router properties:

Router Properties	Border_ Router A		Border_ Router B	
	Interior Routing table	Exterior Routing table	Interior Routing table	Exterior Routing table
Protocol Type	OSPF	BGP	OSPF	BGP
LSRefreshTime	1800	-	1800	-
MaxAge	3600	-	3600	-

Router Properties	Router C	Router D
Routing Protocol	OSPF	OSPF
LSRefreshTime	1800	1800
MaxAge	3600	3600

Simulation Time - 10 Sec

(***Note:*** *The Simulation Time can be selected only after doing the following two tasks,*

- *Set the properties of Routers*
- *Then click on Run Simulation button*).

14.3 Output:

After running this scenario, in Performance Metrics screen, routing tables are obtained in BGP table and RIP metrics.

If you click over the RIP metrics, you will get the RIP routing table for internal routers. If you click over the BGP table, you will get the routing table for Border routers. We have shown the routing tables for Border Router 1 and 2.

Router1

Router1

PeerState	PeerLocalPort	PeerRemoteAddr	PeerRemotePort	PeerInUpdates	PeerOutUpdates	PeerInTotalMessages	PeerOutTotalMessages	NextHop
Internal	41	11.3.0.0	179	6	6	8	8	11.3.1.2
Internal	18467	12.2.0.0	179	6	6	8	8	12.2.1.1
Established	14604	13.2.0.0	179	6	6	8	8	12.2.1.2
Established	292	11.1.0.0	179	6	6	8	8	11.3.1.1
Established	17421	11.2.0.0	179	6	6	8	8	11.3.1.1
Established	17035	14.2.0.0	179	6	6	8	8	12.2.1.2
Established	23811	14.3.0.0	179	6	6	8	8	12.2.1.2

Router2

Router2								
PeerState	PeerLocalPort	PeerRemoteAddr	PeerRemotePort	PeerInUpdates	PeerOutUpdates	PeerInTotalMessages	PeerOutTotalMessages	NextHop
Internal	6334	12.2.0.0	179	6	6	8	8	12.2.1.2
Internal	26500	13.2.0.0	179	6	6	8	8	13.2.1.1
Established	4827	11.3.0.0	179	6	6	8	8	12.2.1.1
Established	19718	14.2.0.0	179	6	6	8	8	13.2.1.2
Established	5447	14.3.0.0	179	6	6	8	8	13.2.1.2
Established	14771	11.1.0.0	179	6	6	8	8	12.2.1.1
Established	19912	11.2.0.0	179	6	6	8	8	12.2.1.1

The Border Routers stores the node's remote address in its Routing Table as shown in the above Tables under "PeerRemoteAddr" column.

Output: (Sample 2)

After running this scenario, in Performance Metrics screen, routing tables are obtained in BGP table and OSPF metrics.

If you click over the OSPF metrics, you will get the OSPF routing table for internal routers. If you click over the BGP table, you will get the routing table for Border routers. We have shown the routing tables for Border Router 1 and 2.

Router1

Router1								
PeerState	PeerLocalPort	PeerRemoteAddr	PeerRemotePort	PeerInUpdates	PeerOutUpdates	PeerInTotalMessages	PeerOutTotalMessages	NextHop
Internal	41	11.3.0.0	179	6	6	8	8	11.3.1.2
Internal	18467	12.2.0.0	179	6	6	8	8	12.2.1.1
Established	14604	13.2.0.0	179	6	6	8	8	12.2.1.2
Established	19718	11.1.0.0	179	6	6	8	8	11.3.1.1
Established	5447	11.2.0.0	179	6	6	8	8	11.3.1.1
Established	14771	14.2.0.0	179	6	6	8	8	12.2.1.2
Established	19912	14.3.0.0	179	6	6	8	8	12.2.1.2

Router2

Router2

PeerState	PeerLocalPort	PeerRemoteAddr	PeerRemotePort	PeerInUpdates	PeerOutUpdates	PeerInTotalMessages	PeerOutTotalMessages	NextHop
Internal	6334	12.2.0.0	179	6	6	8	8	12.2.1.2
Internal	26500	13.2.0.0	179	6	6	8	8	13.2.1.1
Established	4827	11.3.0.0	179	6	6	8	8	12.2.1.1
Established	292	14.2.0.0	179	6	6	8	8	13.2.1.2
Established	17421	14.3.0.0	179	6	6	8	8	13.2.1.2
Established	17035	11.1.0.0	179	6	6	8	8	12.2.1.1
Established	23811	11.2.0.0	179	6	6	8	8	12.2.1.1

14.4 Inference:

First the internal Routing tables (RIP/OSPF table) are formed among all the Routers. The Border Routers contains the network address of the next hop and the destination nodes as represented in the routing table. Border Routers communicate with each other by passing their Routing tables resulting in the formation of external Routing tables (BGP table). Then actual packet transmission takes place from Source to Destination.

15. Study how call blocking probability varies as the load on a GSM network is continuously increased

15.1 Procedure:

In NetSim, Select "Simulation → New → Cellular Networks → GSM"

Follow the steps given in the different samples to arrive at the objective.

In this Experiment,

- One BTS (BTS A) and one MSC (MSC B) is used
- Total no of MS used: Vary from 4 to 20 in steps of 2.

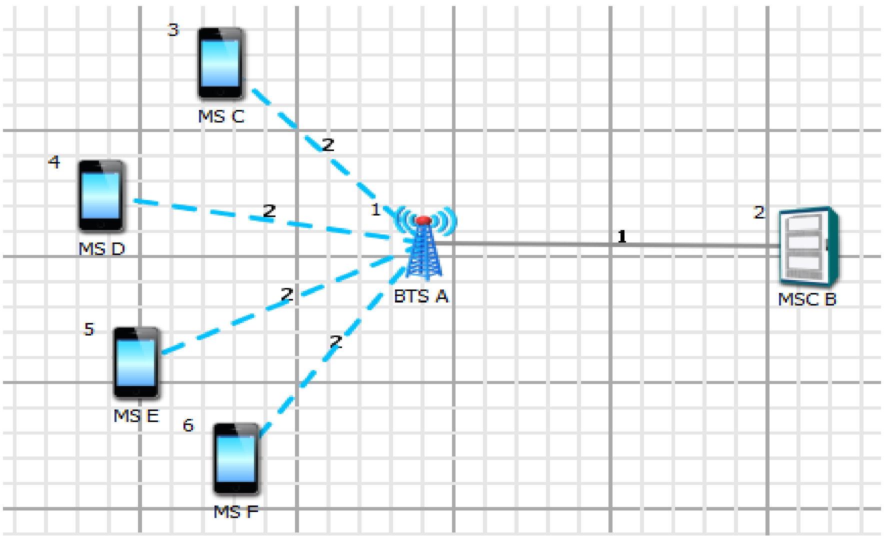
The devices are inter connected as given below,

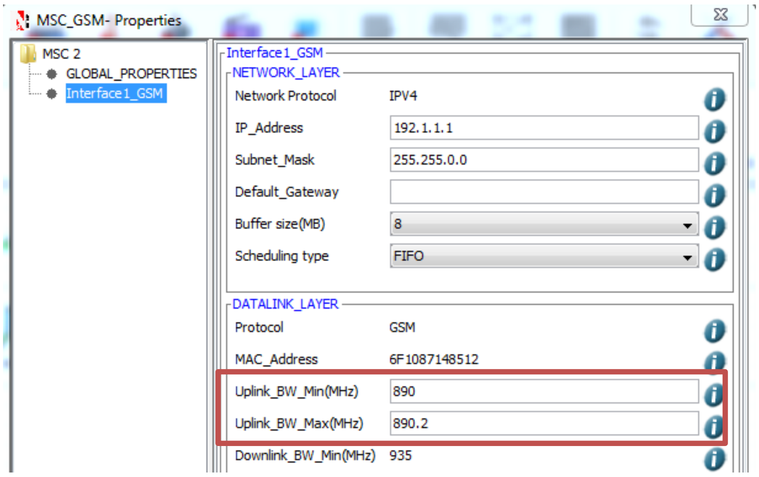
- All the MS are placed in the range of BTS A

Set the properties by following the tables for each sample,

Inputs for Sample 1

Number of MS = 4





Accept default properties for BTS.

Edit **Uplink Bandwidth Min** to **890** MHz and **Uplink Bandwidth Max** to **890.2** MHz in MSC properties.

In the Sample 1, two Applications are run. After dropping Application on the Environment menu, add application 2 from the left pane and change the following properties:

Application Properties	**Application 1**	**Application2**
Application type	Erlang_call	Erlang_call
Source_Id	3	5
Destination_Id	4	6
Call		
Duration_ Distribution	Exponential	Exponential
Duration(s)	60	60
Inter Arrival Time (sec)	10	10
IAT_ Distribution	Exponential	Exponential
Codec		
Codec	Custom	Custom
Service Type	CBR	CBR
Packet Size	33	33
Inter Arrival Time (µs)	20000	20000

Simulation Time – 100 sec

Inputs for Sample 2

Number of MS = 6

Add one more Application and set the properties as above with Source_Id as 7 and Destination_Id as 8.

Likewise, increase the number of MS by 2 upto 20 and set properties for different Samples by adding an application every time and changing Source_Id and Destination_Id.

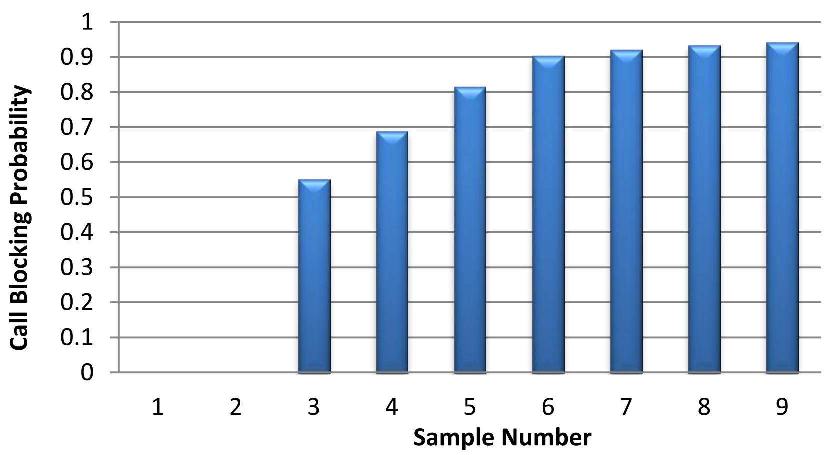
Simulation Time – 100 sec

15.2 Output

To view the output, go to the Cellular Metrics.

In MS metrics, add the call blocked and call generated column. Call blocking probability is calculated as ratio of Total call blocked to Total call generated.

Comparison Charts:



*** All the above plots highly depend upon the placement of Mobile station in the simulation environment. So, note that even if the placement is slightly different the same set of values will not be got but one would notice a similar trend.

15.3 Inference:

When the number of MS is increased from 4 to 20 the call blocking probability increases from 0 to 0.94. As we increase the number of mobile stations more calls are generated. This increases the traffic load on the system & more calls generated implies more channel requests arrive at the base station but the number of channels is fixed. So when the base station does not find any free channel the call is blocked.

An additional observation is that the call blocking is zero until 8 MS. This is because the number of channels is sufficient to handle all call that 6 MS may generate. Only after this the base station does not find free channels and blocks calls.

16. Study how the number of channels increases and the Call blocking probability decreases as the Voice activity factor of a CDMA network is decreased

16.1 Procedure:

How to Create Scenario & Generate Traffic:

In NetSim, Select "Simulation → New → Cellular Networks → CDMA"

Please navigate through the below given path to understand,

Inputs

Follow the steps given in the different samples to arrive at the objective.

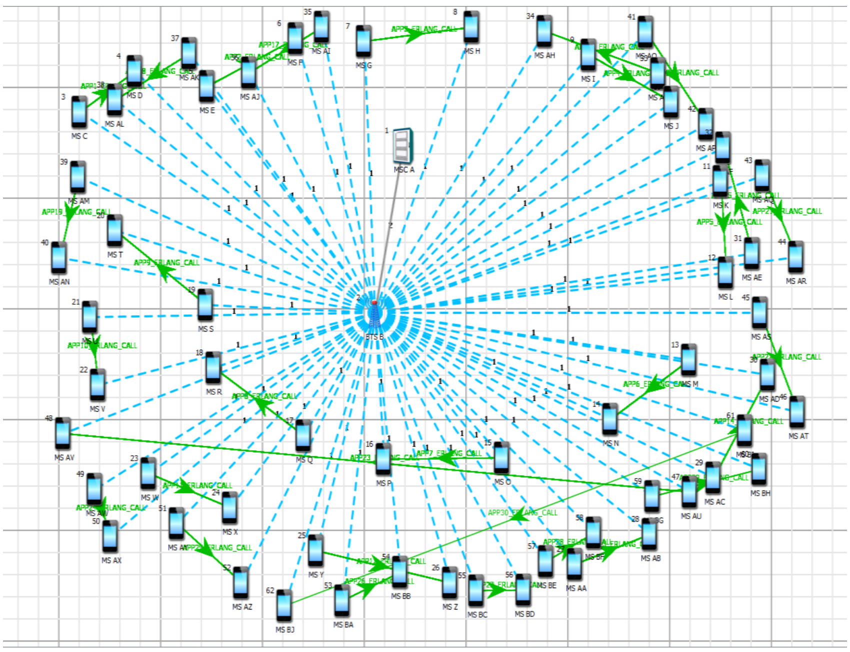
In all Samples,

- Total no of BTS used: 1
- Total no of MSC used: 1
- Total no of MS used: 60

The devices are interconnected as given below,

- All the MS are placed in the range of BTS A (default 1 Km)
- BTS A is connected via Wired Link to MSC B

Sample 1: Drop 1 BTS, 1 MSC and 60 MS and interconnect them in no specific order.



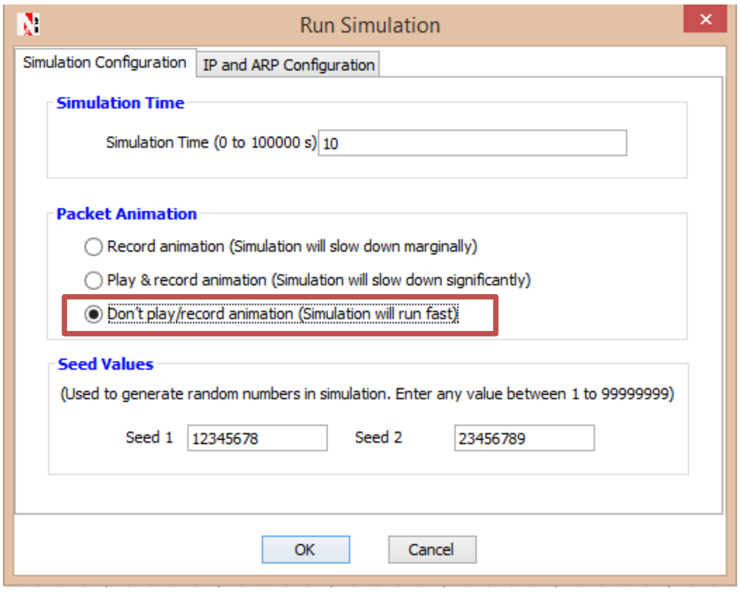
Application Properties	Application 1	Application 2	Application 3	Application 4	Application 5
Source_Id	3	5	7	9	11
Destination_Id	4	6	8	10	12
All other Properties	Default	Default	Default	Default	Default

Likewise **add 25 more applications (totaling 30)** with above properties and Source_Id13 to Destination_Id 14 for application 6… and Source_Id 61 to Destination_Id 62 for application 30.

We have considered MSC to be device ID 1, and BTS as device ID 2.

Simulation Time – 500 sec

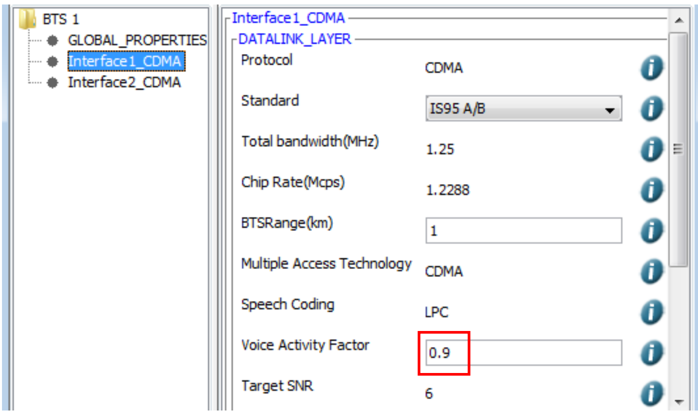
Set Packet Animation to **Don't play/record animation (Simulation will run fast)** and click OK. If record animation option is selected, the simulation may take a long time to complete.



Upon completion of the experiment "Save" the experiment

Sample 2:

Keep all properties same as Sample 1 and in the BTS properties, change the voice activity factor to 0.9 as shown:



Sample 3 and so on: Change the voice activity factor to **0.8** in **sample 3**, **0.7** in **sample 4**…. and to **0.1** in **sample 10** in BTS properties.

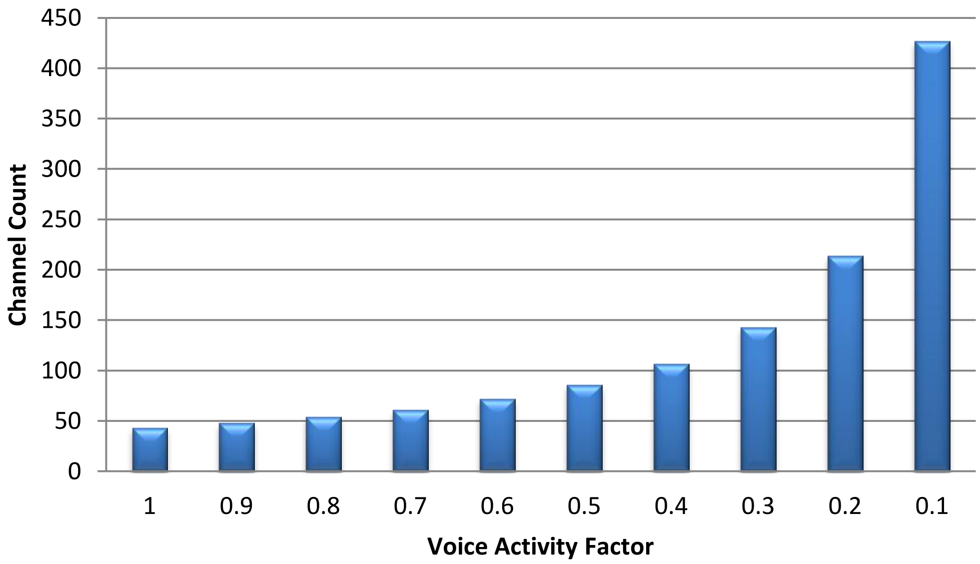
16.2 Output

To view the output, go to the Cellular Metrics.

In Channel metrics, the **channel count** is mentioned.

For every sample plot the graph.

Comparison Charts and Inference:



When the system Voice activity factor decreases from 1.0 to 0.1, the number of channels increases from 43 to 427.

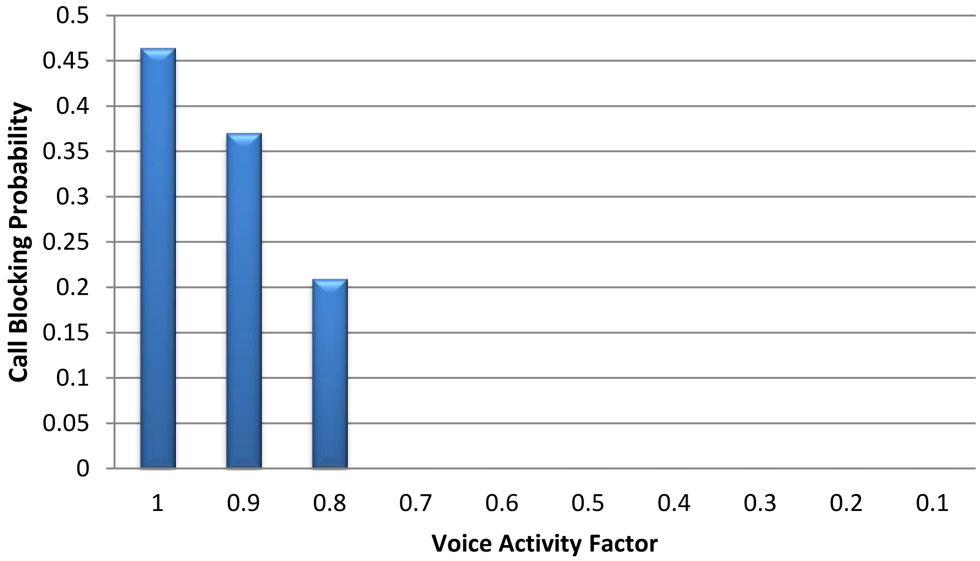
In CDMA network, the number of channels is inversely proportional to the voice activity factor.

$$\text{Number of Channels} \propto \frac{1}{\text{Voice activity factor}}$$

Chart 1 is a mirrored form of $y = \frac{1}{x}$ graph. (This is because VAF is decreasing along +ve X)

In MS metrics, the call generated and call blocked is shown for each MS. Add all the calls generated to obtain Total call generated, and add calls blocked for all MS Ids to obtain Total call blocked.

Calculate **call blocking probability** as ratio of Total call blocked to Total call generated.



When voice activity factor is decreased the number of channels available increases. Thus the system has more number of channels to handle the same number of calls (Note - Number of MS is constant and their properties are same across all experiments. So, they generate approximately same number of calls throughout). As the number of channels increases the call blocking probability decreases.

17. Study the SuperFrame Structure and analyze the effect of SuperFrame order on throughput

17.1 Introduction:

Beacon frame is one of the management frames in IEEE 802.11 based WLANs and contains all the information about the network.

A coordinator in a PAN can optionally bound its channel time using a SuperFrame structure which is bound by beacon frames and can have an active portion and an inactive portion. The coordinator enters a low-power (sleep) mode during the inactive portion.

The structure of this SuperFrame is described by the values of macBeaconOrder and macSuperframeOrder. The MAC PIB attribute macBeaconOrder, describes the interval at which the coordinator shall transmit its beacon frames. The value of macBeaconOrder, BO, and the beacon interval, BI, are related as follows:

$$\text{For } 0 \leq BO \leq 14,\ BI = \text{aBaseSuperframeDuration} * 2^{BO} \text{ symbols.}$$

If BO = 15, the coordinator shall not transmit beacon frames except when requested to do so, such as on receipt of a beacon request command. The value of macSuperframeOrder, SO shall be ignored if BO = 15.

An example of a SuperFrame structure is shown in following Figure.

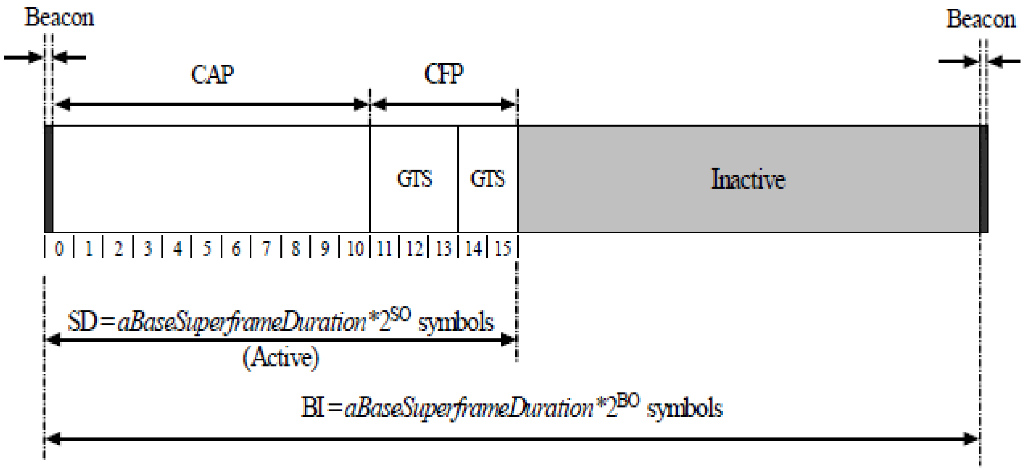


Fig: An example of the Super Frame structure

Theoretical Analysis:

From the above SuperFrame structure,

$$SuperFrame\ Duration \quad = aBaseSuperframeDuration * 2^{BO}$$

$$Active\ part\ of\ SuperFrame = aBaseSuperframeDuration * 2^{SO}$$

$$Inactive\ part\ of\ SuperFrame = aBaseSuperframeDuration * (2^{BO} - 2^{SO})$$

If SuperFrame Order (SO) is same as Beacon Order (BO) then there will be no inactive period and the entire SuperFrame can be used for packet transmissions.

If BO=10, SO=9 half of the SuperFrame is inactive and so only half of SuperFrame duration is available for packet transmission. If BO=10, SO=8 then (3/4)th of the SuperFrame is inactive and so nodes have only $(1/4)^{th}$ of the SuperFrame time for transmitting packets and so we expect throughput to approximately drop by half of the throughput obtained when SO=9.

Percentage of inactive and active periods in SuperFrame for different SuperFrame Orders is given below:

Beacon Order (BO)	**SuperFrame Order (SO)**	**Active part ofSuperFrame(%)**	**Inactive part of SuperFrame (%)**	**Throughput estimated (%)**
10	10	100	0	> 200% of T
10	9	50	50	Say T = 20.18 (Got from simulation)
10	8	25	75	50 % T
10	7	12.5	87.5	25 % T
10	6	6.25	93.75	12.5 % of T
10	5	3.125	96.875	6.25 % of T
10	4	1.5625	98.4375	3.12% of T
10	3	0.78125	99.21875	1.56 % of T

We expect throughput to vary in the active part of the SuperFrame as sensors can transmit a packet only in the active portion.

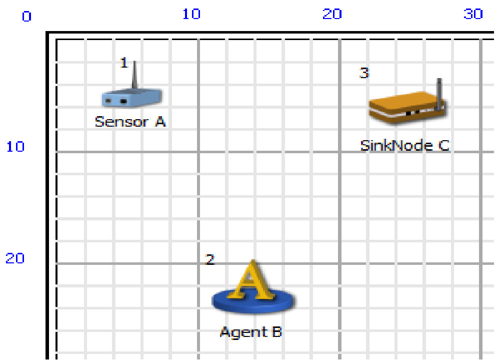
Simulation:

How to Create Scenario & Generate Traffic:

In NetSim, Go to "Simulation → New → Wireless Sensor Networks"

In grid settings, enter side length as 100 m and select sensor placement strategy as Via click & drop

Click & drop one Sensor Node, Sink Node and Agent onto the Simulation Environment:



Sensor Properties: Change the following property for Sensor.

Sensor Properties	Values
Velocity(m/s)	0
Interface1_Zigbee: Sensor	
Sensor Interval (ms)	3

Sink Node Properties: Change the following properties for PAN Coordinator.

Sink Node Properties	Values
Interface1_Zigbee: Data link Layer	
Beacon Mode	Enable
Beacon Order	10
Super frame Order	10

Simulation Time -30 Sec

(Note: *The Simulation Time can be selected only after doing the following two tasks,*

- *Set the properties of Node, PAN Coordinator & Environment.*
- *Click on Run Simulation and save the experiment)*

Sample 2 and so on: Vary the Super Frame Order for every sample (SuperFrame order = 9 for sample 2, and…, 3 for sample 8).

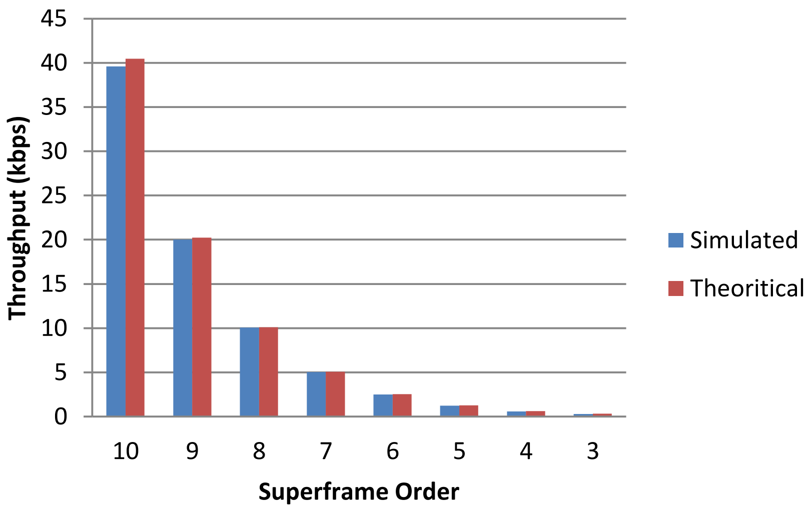
The following are the throughputs obtained from simulation for different SuperFrame Orders.

SuperFrame Order	**Throughput (Kbps)**
10	39.6
9	21.03
8	10.08
7	5.04
6	2.50
5	1.24
4	0.60
3	0.28

Note: To obtain throughput from simulation, payload transmitted values will be obtained from Network statistics and calculated using following formula:

$$Throughput(Kbps) = \frac{Total\ Payload\ transmitted\ to\ destination(Bytes) * 8}{Simulation\ Time(MilliSeconds)}$$

Comparison Chart:

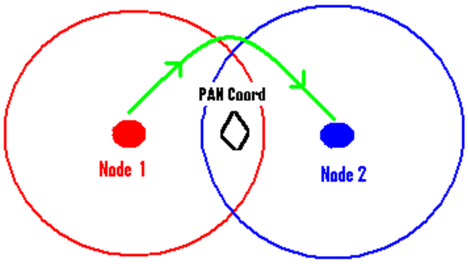


*** All the above plots highly depend upon the placement of Sensor in the simulation environment. So, note that even if the placement is slightly different the same set of values will not be got but one would notice a similar trend.

17.2 Inference:

From the comparison chart both the simulation and theoretical throughputs match except for the case with no inactive period. A sensor will be idle if the last packet in its queue is transmitted. If a packet is generated in inactive period then the packet has to wait in the queue till the next SuperFrame so sensor has packets waiting in its queue and so it cannot be idle in the next SuperFrame, but if there is no inactive period then there might be no packets waiting in the queue and so sensor can be idle resulting in lesser throughput.

18. Analyze the scenario shown, where Node 1 transmits data to Node 2, with no path loss and obtain the theoretical throughput based on IEEE 802.15.4 standard. Compare this with the simulation result.



18.1 Introduction:

IEEE Standard 802.15.4 defines the protocol and compatible interconnections for data communication devices using low-data-rate, low-power, and low-complexity short-range radio frequency (RF) transmissions in a wireless personal area network (WPAN). In Wireless sensor network IEEE 802.15.4 standard is used in MAC and PHY layers.

IEEE 802.15.4 PHYs provide the capability to perform CCA in its CSMA-CA mechanism. The PHYs require at least one of the following three CCA methods: Energy Detection over a certain threshold, detection of a signal with IEEE 802.15.4 characteristics or a combination of these methods.

18.2 Theory:

- A packet transmission begins with a random backoff (in number of slots, each slot of 20 T_s duration) which is sampled uniformly from 0 to $2^{macminBE} - 1$and followed by a CCA.
- CCA failure starts a new backoff process with the backoff exponent raised by one, i.e., to macminBE+1, provided it is lesser than the maximum backoff value given by macmaxBE.
- Maximum number of successive CCA failures for the same packet is governed by macMaxCSMABackoffs, exceeding which the packet is discarded at the MAC layer.
- A successful CCA is followed by the radio turnaround time and packet transmission.

- If the receiver successfully receives the packet i.e., without any collision or corruption due to PHY layer noise, the receiver sends an ACK after the radio turnaround time.
- A failed packet reception causes no ACK generation.
- The transmitter infers that the packet has failed after waiting for macAckWaitDuration and retransmits the packet for a maximum of aMaxFrameRetries times before discarding it at the MAC layer.

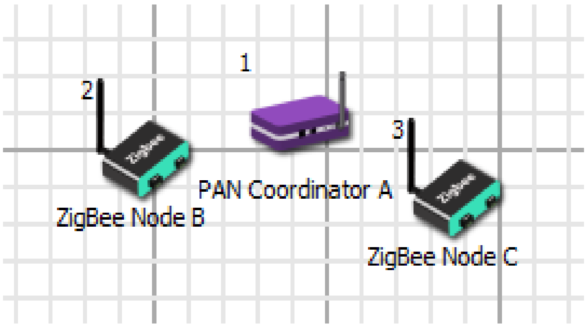
Note: In NetSim the radio turnaround time after a CCA success is not considered.

18.3 Procedure

How to Create Scenario:

In NetSim, Select "Simulation → New → Zigbee Networks"

Create the scenario as shown:



Set the properties as shown below:

Node Properties:

Node Properties	Zigbee Node B
Global Properties	
X_Coordinate	15
Y_Coordinate	20
Interface1_Zigbee : Data Link Layer	
AckRequest	Enable
MaximumFrameRetries	7

Node Properties	Zigbee Node C
Global Properties	
X_Coordinate	25
Y_Coordinate	20
Interface1_Zigbee : Data Link Layer	
AckRequest	Enable
MaximumFrameRetries	7

PAN Coordinator Properties:

Sink Node Properties	Values
Global Properties	
X_Coordinate	20
Y_Coordinate	20
Interface1_Zigbee : Data Link Layer	
Beacon Mode	Disable

Environment Properties:

Environment Properties	Values
Channel Characteristics	No Path Loss

Click and drop Application and edit the following properties:

Application Properties	
Application Type	Custom
Source_Id	2 (Zigbee Node B)
Destination_Id	3 (Zigbee Node C)
Packet_Size	
Distribution	Constant
Value(Bytes)	70

Inter_Arrival_time	
Distribution	Constant
Value(micro sec)	4000

(Note: If the size of the packet size at the Physical layer is greater than 127 bytes, the packet gets fragmented. Taking into account the various overheads added at different layers (which are mentioned below), the packet size at the application layer should be less than 80 bytes.)

Simulation Time: 100 Sec

Throughput obtained from the simulation is **100.408kbps** (0.100408 Mbps)

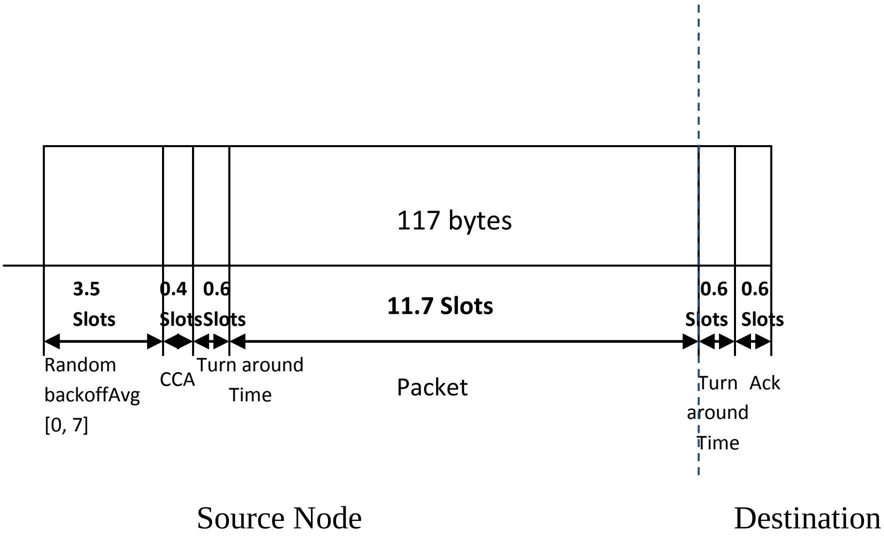
Note: This throughput is obtained when the nodes are placed at the closest possible distance from the PAN coordinator. As the distance is increased, the throughput would reduce.

Theoretical Analysis:

We have set the Application layer payload as 70 bytes in the Node1 properties and when the packet reaches the physical layer various other headers gets added like

App layer Payload	70 bytes
Transport Layer Header	8 bytes
Network Layer Header (IP + DSR)	28 bytes
MAC Header	5 bytes
PHY Header	6 bytes
Packet Size	117 bytes

In simulation, by default NetSim uses Unslotted CSMA/CA and so a packet transmission happens after random backoff, CCA and turn-around-time and is followed by turn-around-time and ACK packet and each of them occupies specific time set by the IEEE 802.15.4 standard as per the timing diagram shown below.



From IEEE standard, each slot has 20 Symbols in it and each symbol takes 16μs for transmission:

Symbol Time	T_s	16 μs
Slot Time	$20 * T_s$	0.32 ms

Random Backoff Average	$3.5 * Slots$	1.12 ms
CCA	$0.4 * Slots$	0.128 ms
Turn-around-Time	$0.6 * Slots$	0.192 ms
Packet Transmission Time	$11.7 * Slots$	3.744 ms
Turn-around-Time	$0.6 * Slots$	0.192 ms
ACK Packet Time	$0.6 * Slots$	0.192 ms
Total Time	$17.4 * Slots$	5.568ms

$$Application\ Throughput\ = \frac{70(bytes)inApplayer}{5.568\ ms} = 100.574\ kbps$$

18.4 Inference:

Throughput from simulation	100.408 kbps
Throughput from analysis	100.574 kbps

Throughput from theoretical analysis matches the results of NetSim's discrete event simulation.

(Note: The slight difference in throughput is due to fact that the average of random numbers generated for backoff need not be exactly 3.5 as the simulation is run for short time and also in Network layer DSR protocol is running, so route setup process will take some time.)

As we go on increasing the simulation time, the throughput value obtained from simulation approaches the theoretical value as can be seen from the table below:

Simulation Time (sec)	Throughput (kbps)
10	99.680
50	100.486
100	100.408
200	100.486

Note: In NetSim Academic version to run the simulation with 200 sec simulation time we can use CLI.

19. To analyze how the operational behavior of Incumbent (Primary User) affects the throughput of the CR CPE (Secondary User)

19.1 Introduction:

An important component of the Cognitive Radio concept is the ability to measure, sense, learn, and be aware of the parameters related to the radio channel characteristics, availability of spectrum and power, radio's operating environment, user requirements and applications, available networks (infrastructures) and nodes, local policies and other operating restrictions.

A spectrum hole has been defined as "a band of frequencies assigned to a primary user, but at a particular time and specific geographic location, the band is not being utilized by that user. Cognitive Radio was proposed as the means to promote the efficient use of spectrum by exploiting the existence of spectrum holes.

In cognitive radio terminology, Primary Users (Incumbent) can be defined as the users who have higher priority or legacy rights on the usage of a specific part of the spectrum. On the other hand, Secondary Users (CR CPE), which have lower priority, exploit this spectrum in such a way that they do not cause interference to primary users. Therefore, secondary users need to have cognitive radio capabilities, such as sensing the spectrum reliably to check whether it is being used by a primary user and to change the radio parameters to exploit the unused part of the spectrum.

19.2 Performance metrics:

The different parameters used to analyze the performance are explained as follows:

- **Throughput**: It is the rate of successfully transmitted data packets in unit time in the network during the simulation.

- **Spectral Efficiency**: It refers to the information rate that can be transmitted over a given bandwidth in a specific communication system. It is a measure of how efficiently a limited frequency spectrum is utilized by the physical layer protocol, and sometimes by the media access control protocol.

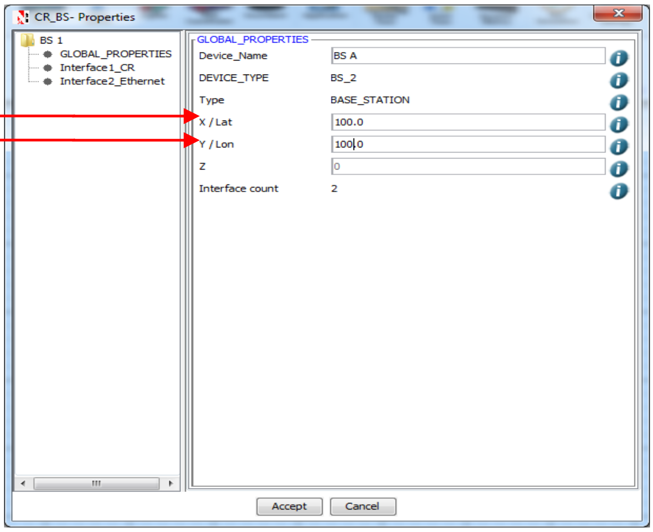
19.3 Procedure:

How to Create Scenario & Generate Traffic:

Step 1: Go to Simulation → New → Cognitive Radio

Step 2: Click & drop 1 Base Station, 1 Incumbent and 2 CR CPE onto the Simulation Environment. Connect the 2 CR-CPE and Incumbent with Base Station using Wireless Links. To edit the position, change the (x, y) co-ordinates in Global Properties as shown:

To change Co-ordinates, click & edit



Arrange the positions of the nodes as per the following table:

CR CPE	X-Coordinate	Y-Coordinate
2	100	120
3	120	100

Base Station	X-Coordinate	Y-Coordinate
1	100	100

Incumbent	X-Coordinate	Y-Coordinate
1	90	90

Note- Set Incumbent location by dropping at (90, 90) coordinates on grid environment.

Step 3:

Base Station Properties: In **Interface_CR** properties, under the **Incumbent1** section, Set

Operational_Frequency_Start (MHz) = 54

Operational_Frequency_End (MHz) = 60

Operational_Time(s) = 10

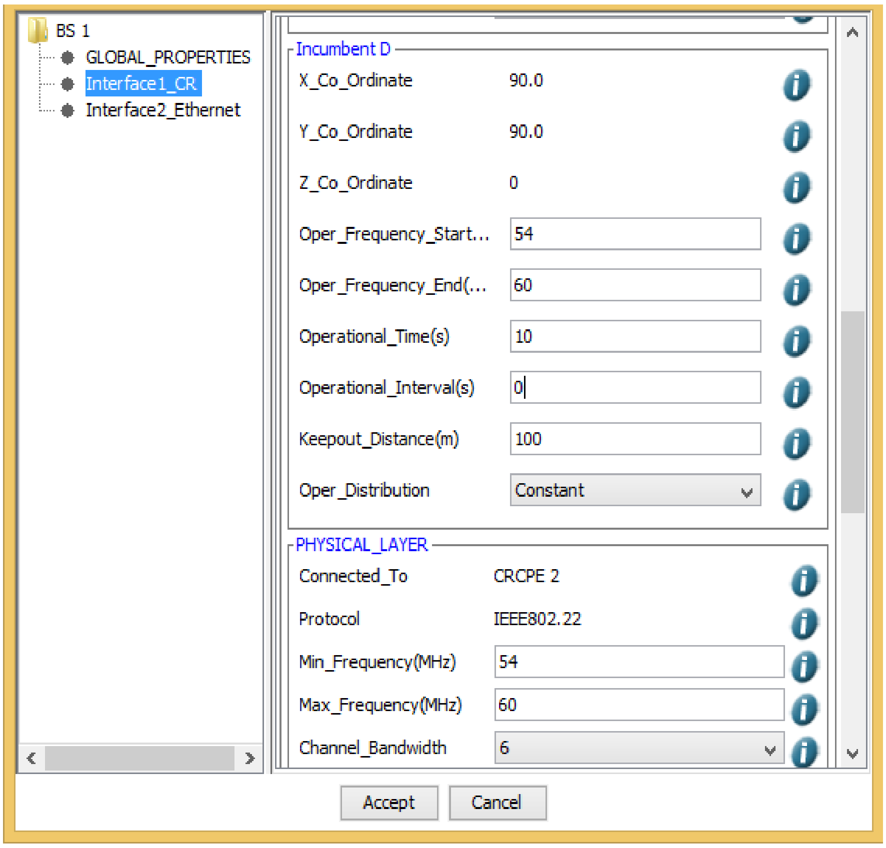
Operational_Interval(s) = 0

Keepout_Distance(m) = 100

Under the **Physical Layer** section, Set

Min_Frequency = 54

Max_Frequency = 60



Step 4:

Application Properties:

To add application, drop the Application icon. Edit the Application properties as given in table. All other properties are default.

Application Properties	Application 1
Application Type	Custom
Source ID	2
Destination ID	3

Note: *Click on the Run Simulation icon and set simulation time only after doing the following tasks:*

- *Set the properties of Nodes and*
- *Configure Applications.*

Simulation Time- 100 Seconds

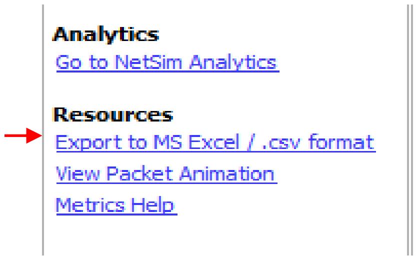
Output:

- After running the simulation, Experiment can be saved by clicking on the Save icon.
- Open Export to MS Excel/.csv (.csv is comma separated value format, which is one of the format used by MS Excel) by clicking as follows:

Click and

Export to .csv

(MS Excel)



To Calculate Performance metrics from.csv:

- Go to Application metrics in metrics file (.csv) and check the value of throughput.

  Throughput = Throughput of the application.
- Go to CR Channel metrics at the end in metrics file (.csv) and check the **Spectral Efficiency**.

Sample 2:

Perform the same steps as in Sample 1 with following changes:

Change 1: Base Station Properties: In **Interface_CR** properties, under the **Incumbent1** section, Set

Operational_Frequency_Start (MHz) = 54

Operational_Frequency_End (MHz) = 60

Operational_Time(s) = 10

Operational_Interval(s) = 5

Keepout_Distance(m) = 100

Under the **Physical Layer** section, Set

Min_Frequency = 54

Max_Frequency = 60

Sample 3:

Perform the same steps as in Sample 1 with following changes:

Change 1: Base Station Properties: In **Interface_CR** properties, under the **Incumbent1** section, set

Operational_Frequency_Start (MHz) = 54

Operational_Frequency_End (MHz) = 60

Operational_Time(s) = 10

Operational_Interval(s) = 10

Keepout_Distance(m) = 100

Under the **Physical Layer** section, Set

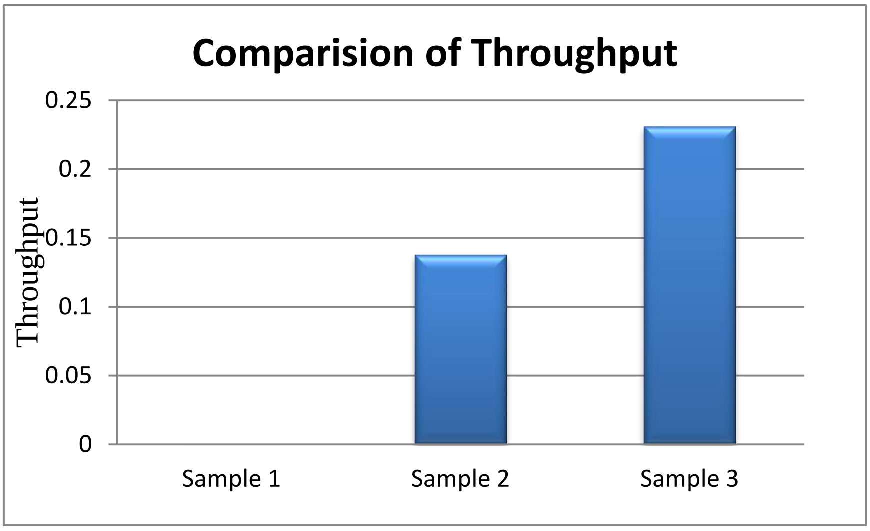
Min_Frequency = 54

Max_Frequency = 60

Comparison Table:

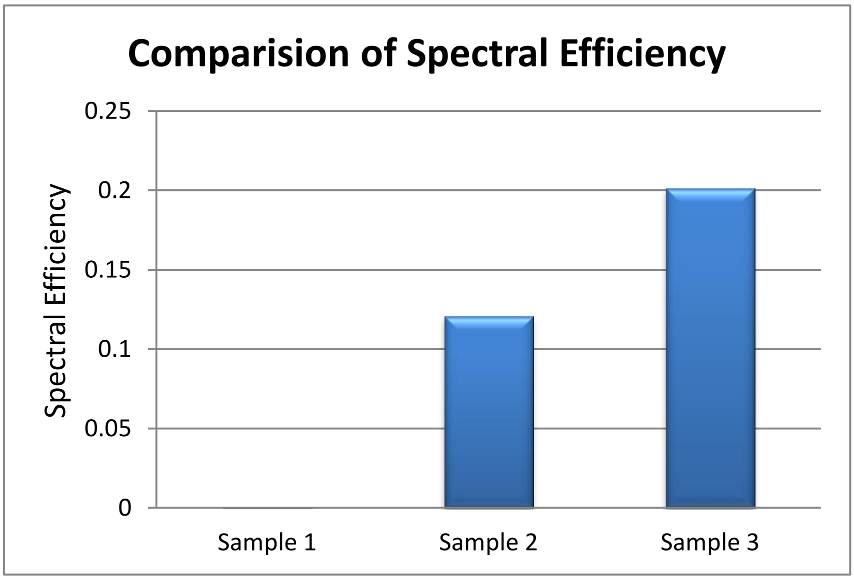
Note: Open the saved experiments (Please Refer at the end of experiment) *to obtain the various Performance metrics and note the values obtained to compare as shown in table.*

	Sample 1	Sample 2	Sample 3
Throughput(mbps)	0.000000	0.137769	0.231224



Spectral Efficiency-

Frequency(MHz)	Sample 1	Sample 2	Sample 3
Spectral efficiency	0.00001	0.12076	0.20124



19.4 Inference:

In both the samples, the Secondary User (CR-CPE) lies within the operational region of Primary User (Incumbent), hence the frequency spectrum used by operational Primary User (Incumbent) cannot be used by Secondary User (CR-CPE) for transmitting data. Both the Primary User (Incumbent) and the Secondary User(CR-CPE) has been allocated the same channel (frequency band of 54 - 60 MHz). Hence whenever Incumbent will use the allocated channel, there will be no Spectrum Hole, and so the secondary user will not be able to transmit any data during that time.

In the first sample, Operational Interval under Incumbent is set to zero i.e. the Incumbent will continuously use the channel allocated to it. Hence there is no spectrum hole and throughput of the data transmitted by secondary user and the spectral is approximately equal to zero.

In the second sample, the Primary User (Incumbent) is utilizing the frequency band of 54 - 60 MHz for 10 seconds after an interval of every 5 seconds. So the Secondary User(CR-CPE) uses this allocated the frequency band of 54 - 90 MHz in an opportunistic manner i.e. during the interval of 5 seconds when Incumbent is not utilizing the channel, a spectrum hole is created and the CR-CPE will utilize it to transmit data. Hence the Throughput and Spectral Efficiency is better compared to Sample1.

In the third sample, Operational Interval of Incumbent is set to 10. Hence the Secondary User (CR-CPE) gets a bigger spectrum hole and hence Throughput and Spectral Efficiency is better compared to other samples.

NOTE: The results are highly dependent on position/velocity/ traffic etc. Any modifications with the above mentioned input parameters will change the final output result.

20. To analyze how the allocation of frequency spectrum to the Incumbent (Primary) and CR CPE (Secondary User) affect the throughput of the CR CPE (Secondary User).

20.1 Introduction:

An important component of the cognitive radio concept is the ability to measure, sense, learn, and be aware of the parameters related to the radio channel characteristics, availability of spectrum and power, radio's operating environment, user requirements and applications, available networks (infrastructures) and nodes, local policies and other operating restrictions.

A spectrum hole has been defined as "a band of frequencies assigned to a primary user, but at a particular time and specific geographic location, the band is not being utilized by that user. Cognitive Radio was proposed as the means to promote the efficient use of spectrum by exploiting the existence of spectrum holes.

In cognitive radio terminology, Primary Users (Incumbent) can be defined as the users who have higher priority or legacy rights on the usage of a specific part of the spectrum. On the other hand, Secondary Users (CR CPE), which have lower priority, exploit this spectrum in such a way that they do not cause interference to primary users. Therefore, secondary users need to have cognitive radio capabilities, such as sensing the spectrum reliably to check whether it is being used by a primary user and to change the radio parameters to exploit the unused part of the spectrum.

Performance metrics:

The different parameters used to analyze the performance are explained as follows:

- **Throughput**: It is the rate of successfully transmitted data packets in unit time in the network during the simulation.

- **Spectral Efficiency**: It refers to the information rate that can be transmitted over a given bandwidth in a specific communication system. It is a measure of how efficiently a limited frequency spectrum is utilized by the physical layer protocol, and sometimes by the media access control protocol.

20.2 Procedure:

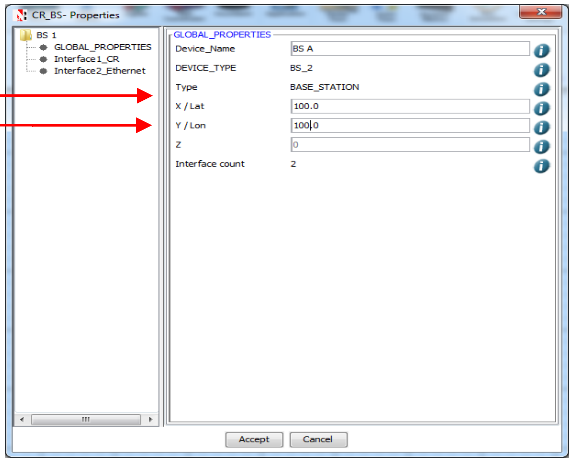
How to Create Scenario & Generate Traffic:

Sample 1:

Step 1: Go to Simulation → New →Cognitive Radio

Step 2: Click & drop 1 Base Station, 1 Incumbent and 2 CR CPE onto the Simulation Environment. To edit the position, change the (x, y) co-ordinates in Global Properties as shown:

To change
Co-ordinates,
click & edit



Arrange the positions of the nodes as per the following table:

CR CPE	X-Coordinate	Y-Coordinate
2	100	120
3	120	100

BS	X-Coordinate	Y-Coordinate
1	100	100

Incumbent	X-Coordinate	Y-Coordinate
1	90	90

Step 3:

Base Station Properties: In **Interface_CR** properties, under the **Incumbent1** section, Set

Operational_Frequency_Start (Mhz) = 54

Operational_Frequency_End (Mhz) = 60

Operational_Time(s) = 10

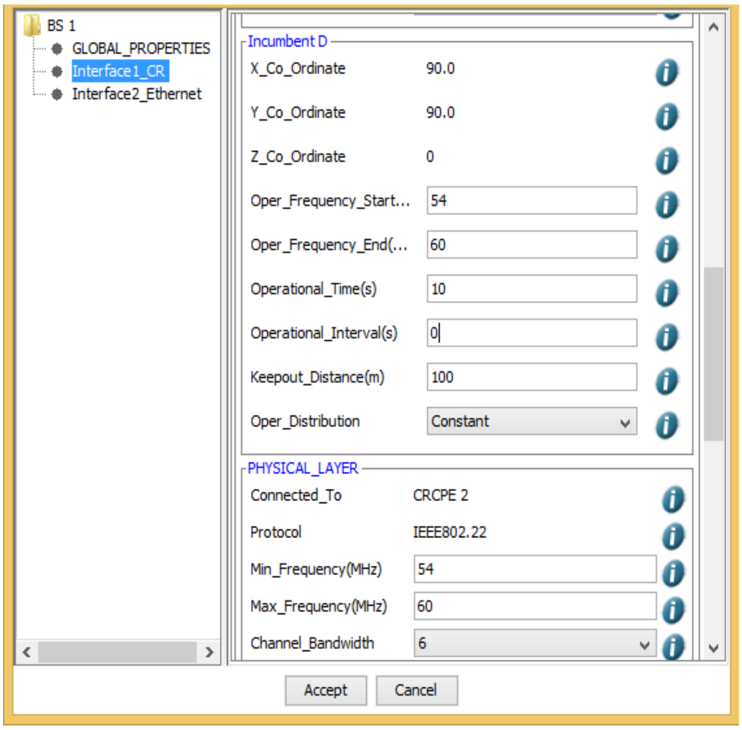
Operational_Interval(s) = 0

Keepout_Distance(m) = 100

Under the **Physical Layer** section, Set

Min_Frequency = 54

Max_Frequency = 60



Step 4:

Application Properties:

To add application, drop the Application icon. Edit the Application properties as given in table. All other properties are default.

Application Properties	Application 1
Application Type	Custom
Source ID	2
Destination ID	3

Note: *Click on the Run Simulation icon and set simulation time only after doing the following tasks:*

- *Set the properties of Nodes and*
- *Configure Applications.*

Simulation Time- 100 Seconds

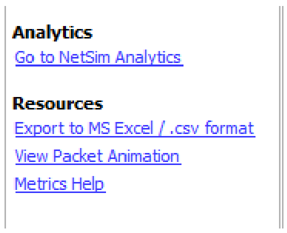
Output:

- After running the simulation, Experiment can be saved by clicking on the Save icon.
- Open Export to MS Excel/.csv (.csv is comma separated value format, which is one of the format used by MS Excel) by clicking as follows:

Click and

Export to .csv

(MS Excel)



To Calculate Performance metrics from.csv:

- Go to Application metrics in metrics file (.csv) and check the value of throughput.
  Throughput = Throughput of the application.
- Go to CR Channel metrics at the end in metrics file (.csv) and check the **Spectral Efficiency**.

Sample 2:

Perform the same steps as in Sample 1 with following changes:

Change1: Base Station Properties: In the **Physical Layer** section, Set

Min_Frequency = 54

Max_Frequency = 90

Comparison Table:

Note: Open the saved experiments (Please Refer at the end of experiment) *to obtain the various Performance metrics and note the values obtained to compare as shown in table.*

	Sample 1	**Sample 2**
Throughput(Mbps)	0.000000	0.583837

Spectral Efficiency-

Sample 1

Frequency(MHz)	Spectral efficiency
54-60	0.00001

Sample 2

Frequency(MHz)	Spectral efficiency
54-60	0.00001
60-66	0.00000
66-72	0.00000
72-78	0.22668
78-84	0.00643
84-90	0.19400

20.3 Inference:

In both the samples, the Secondary User (CR-CPE) lies within the operational region of Primary User (Incumbent), hence the frequency spectrum used by operational Primary User (Incumbent) will not be used by Secondary User (CR-CPE).Also the Operational Interval under Incumbent is set to zero ,i.e., the Incumbent will continuously use the channel allocated to it.

In the first sample, both the Primary User (Incumbent) and the Secondary User (CR-CPE) has been allocated the same channel (frequency band of 54 - 60 MHz). As Incumbent will continuously use the channel allocated to it, so there will be no Spectrum Hole, hence the secondary user will not be able to transmit any data in an opportunistic manner. Therefore the throughput of the application in the CR-CPE and the spectral efficiency is almost equal to zero.

In the second sample, the Primary User (Incumbent) has been allocated frequency band of 54 - 60 MHz and the Secondary User (CR-CPE) has been allocated the frequency band of 54 - 90 MHz. Incumbent will continuously use the channel allocated to it, but the rest channels will remain free i.e. there will be Spectrum Hole, which the CR-CPE will utilize to transmit data.

NOTE: The results are highly dependent on position/velocity/ traffic etc. Any modifications with the above mentioned input parameters will change the final output result.

21. Study how the throughput of LTE network varies as the distance between the ENB and UE (User Equipment) is increased

21.1 Theory:

LTE or Long Term Evolution, commonly known as 4G LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface.

The path loss in LTE is the decay of the signal power dissipated due to radiation on the wireless channels. Path loss may be due to many effects, such as free space loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption.

Received power (**P_r**) can be calculated as:

Case 1: When no **path loss** Received power is same as Transmitted power, i.e., $P_r = P_t$

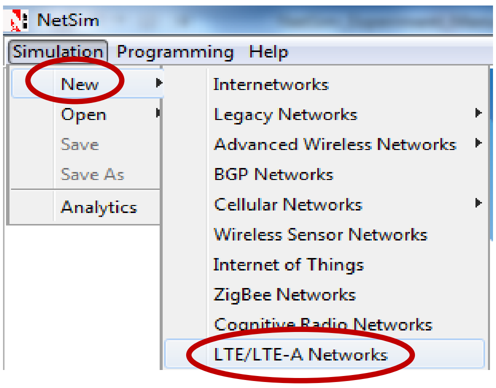
Case 2: When **Line of Sight** is there, Received power P_r is

$$P_r = P_t + G_t + G_r + 20\ \log_{10}\left(\frac{\lambda}{4\pi d}\right) + 10\, n\ \log_{10}\frac{d0}{d}$$

Where **G_t** and **G_r** are gains of transmitting and receiving antenna respectively. Here **d** is the distance between transmitter and receiver, λ is the wavelength of the transmitted signal and $d0$ is reference distance at which channel gain becomes 1. **n** is path loss exponent and **P_t** is transmitted power.

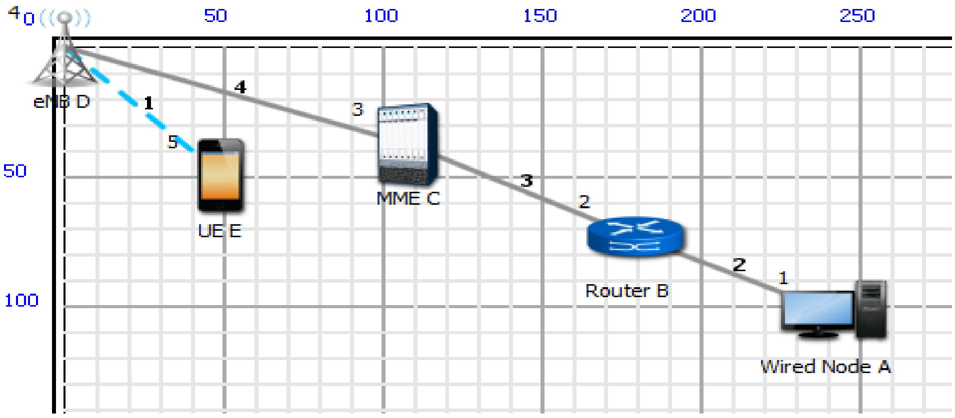
21.2 Procedure:

To create a LTE Scenario, go to "Simulation → New → LTE Networks".



Sample Inputs:

In this experiment, 1 Wired Node, 1 Router, 1 MME , 1 ENB and 1 UE is clicked and dropped onto the Simulation environment from tool bar as shown below.



Sample 1:

These properties can be set only after devices are linked to each other as shown above.

Wired Node Properties:

Node Properties	Wired Node A
Transport Layer Properties	
TCP	Disable

Router Properties: Default properties.

MME Properties: Default properties.

ENB Properties:

ENB Properties	ENB 4
Global Properties	
X_Coordinate	0
Y_Coordinate	0

UE Properties:

UE Properties	UE D
Global Properties	
X_Coordinate	50
Y_Coordinate	50
Velocity(m/s)	0

To run the simulation, drop the Application icon and change the following properties:

Application Properties	
Application Type	Custom
Source ID	1 (Wired Node A)
Destination ID	5 (UE D)
Packet Size	
Distribution	Constant
Value(Bytes)	1460
Inter Arrival Time	
Distribution	Constant
Value(µs)	165

Wired Link Properties:

Link Properties	Wired Link 2	Wired Link 3	Wired Link 4
Uplink Speed (Mbps)	100	100	100
Downlink Speed (Mbps)	100	100	100
Uplink BER	0	0	0
Downlink BER	0	0	0

Wireless Link Properties:

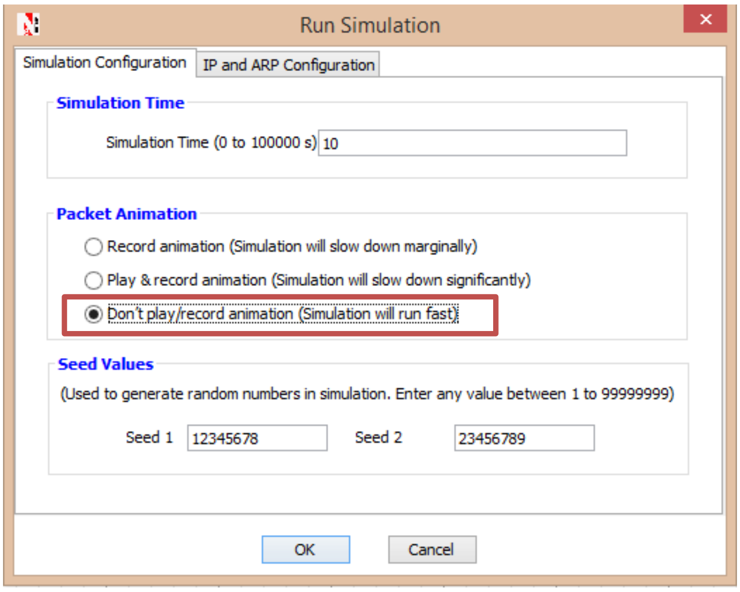
Link Properties	**Wireless Link 1**
Channel characteristics	Line of Sight
Path loss Exponent(n)	4

Simulation Time – 10 Sec

(**Note:** *The Simulation Time can be selected only after the following two tasks,*

- *Set the properties for the Wired Node, Router, MME, UE, Wired, Wireless Links and Application.*
- *Click on Run Simulation*).

Set Packet Animation to **Don't play/record animation (Simulation will run fast)** and click OK. If record animation option is selected, the simulation may take a long time to complete.



Upon completion of the experiment "Save" the experiment and note down the Application throughput which is available in Application metrics for each sample case.

Sample 2:

Change the following properties in UE and run the simulation for 10 seconds as above. All other properties are default.

UE Properties:

UE Properties	UE D
Global Properties	
X_Coordinate	100
Y_Coordinate	100
Velocity(m/s)	0

From Sample 3 to Sample 9:

Change the UE property every time (for all samples) by varying the (x, y) coordinates values as follows:

Change in UE Properties: (x, y)	
Sample 3	(150,150)
Sample 4	(200,200)
Sample 5	(250,250)
Sample 6	(300,300)
Sample 7	(350,350)
Sample 8	(400,400)
Sample 9	(450,450)

And note down the throughput values from the Application metrics in each sample case.

21.3 Output:

Step 1: Distance calculation:

Calculate the Distance between ENB (x_1, y_1) and UE(x_2, y_2) as follows: $\sqrt{(x_2-x_1)^2+(y_2-y_1)^2}$

For example for Sample 1:

ENB $(x_1, y_1) = (0, 0)$; UE$(x_2, y_2) = (50, 50)$;

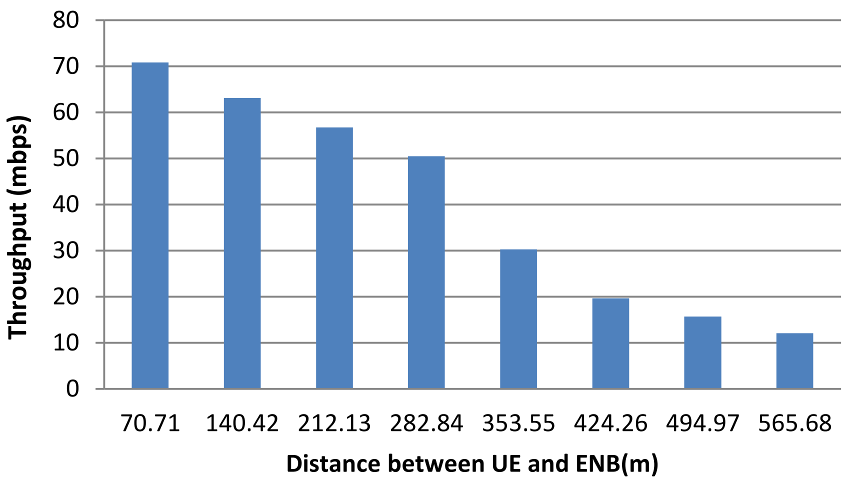
Distance = $\sqrt{(50-0)^2+(50-0)^2} = \sqrt{2} \times 50 = \mathbf{50\sqrt{2}}$ meters.

Step 2: Open the Excel file and note down the distance between UE and ENB and throughput values as shown in below table.

Sample nos.	Distance between UE and ENB (meters)	Throughput (Mbps)
1	50√2 = 70.71	70.786
2	100√2 = 140.42	63.07
3	150√2 = 212.13	56.7
4	200√2 = 282.84	50.448
5	250√2 = 353.55	30.223
6	300√2 = 424.26	19.603
7	350√2 = 494.97	15.645
8	400√2 = 565.68	12.065

Comparison Chart:

To draw these graphs by using Excel "Insert →Chart" option and then select chart type as "Line chart".



21.4 Inference

As the distance increases between ENB and UE, throughput value is getting decreased. The reason is if distance increases between the devices, the received signal power will decrease due to high path loss.

22. Study how the throughput of LTE network varies as the Channel bandwidth changes in the ENB (Evolved node B)

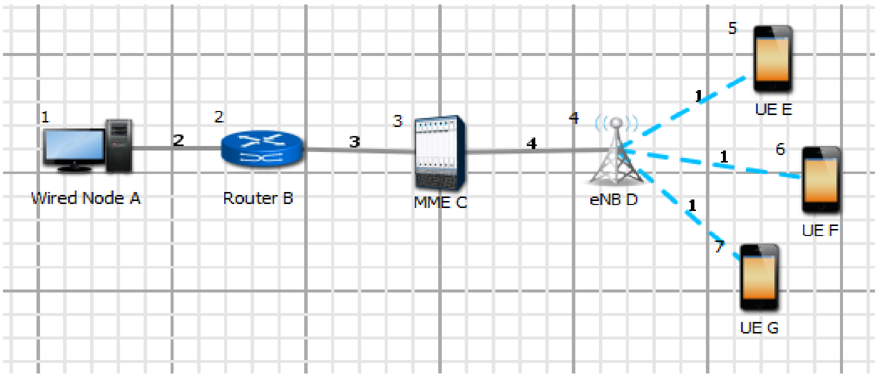
22.1 Theory:

LTE or Long Term Evolution, commonly known as 4G LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface.

LTE supports flexible carrier bandwidths, from 1.4 MHz up to 20 MHz as well as both FDD and TDD. LTE designed with a scalable carrier bandwidth from 1.4 MHz up to 20 MHz which bandwidth is used depends on the frequency band and the amount of spectrum available with a network operator.

22.2 Procedure:

- **Create Scenario:** Go to Simulation → New → LTE/LTE-A networks.



Sample Inputs:

In this experiment, 1 Wired Node ,1 Router, 1 MME , 1 ENB and 3 UE are clicked and dropped onto the Simulation environment from tool bar as shown.

Sample 1:

Note: These properties can be set only after devices are linked to each other as shown above.

Wired Node Properties:

Node Properties	Wired Node A
Transport Layer Properties	
TCP	Disable

Router Properties: Default properties.

MME Properties: Default properties.

ENB Properties:

ENB Properties	ENB D
Interface_LTE (Physical Layer)	
Carrier aggregation	**Inter_Band_Noncontingious_CA**
1st CA	
Channel Bandwidth (MHz)	**10**
2nd CA	
Channel Bandwidth (MHz)	**10**

To run the simulation, drop the Application icon and change the following properties:

Application Properties	Application 1	Application 2	Application 3
Application Type	Custom	Custom	Custom
Source ID	1 (Wired Node A)	1 (Wired Node A)	1 (Wired Node A)
Destination ID	5(UE E)	6(UE F)	7(UE G)
Packet Size			
Distribution	Constant	Constant	Constant
Value(Bytes)	1460	1460	1460

Inter Arrival Time			
Distribution	Constant	Constant	Constant
Value(μs)	146	146	146

UE Properties:

UE Properties	UE E	UE F	UE G
Global Properties			
Velocity(m/s)	0	0	0

Wired Link Properties:

Link Properties	Wired Link 2	Wired Link 3	Wired Link 4
Uplink Speed (Mbps)	1000	1000	1000
Downlink Speed (Mbps)	1000	1000	1000
Uplink BER	0	0	0
Downlink BER	0	0	0

Wireless Link Properties:

Link Properties	Wireless Link 1
Channel characteristics	No Path Loss

Simulation Time – 10 Sec

(**Note:** *The Simulation Time can be selected only after the following two tasks,*

- *Set the properties for the Wired Node, Router, MME, UE, Wired, Wireless Links and Application.*
- *Click on Run Simulation*).

Upon completion of the experiment "Save" the experiment and note down the Application throughputs of all applications which is available in Application metrics for each sample case.

Sample 2:

Change the following properties in ENB and run the simulation for 10 seconds as above. All other properties are default.

ENB Properties	ENB D
Interface_LTE (Physical Layer)	
Carrier aggregation	Inter_Band_Noncontingious_CA
1st CA	
Channel Bandwidth (MHz)	10
2nd CA	
Channel Bandwidth (MHz)	5

From Sample 3:

Change the ENB property, Channel Bandwidth to 10, 5, 3, 1.4 MHz (Refer below table)

ENB Properties	ENB D
Interface_LTE (Physical Layer)	
Carrier aggregation	Inter_Band_Noncontingious_CA
1st CA	
Channel Bandwidth (MHz)	5
2nd CA	
Channel Bandwidth (MHz)	5

And note down the throughput values from the Application metrics in each sample case.

22.3 Output

Step 1: Add the sum of all throughput values in each sample case:

Example:

Sample 1:	**Application ID**	**Throughput (mbps)**
	1	23.177
	2	23.177
	3	23.177

Sum **=** 69.531 mbps

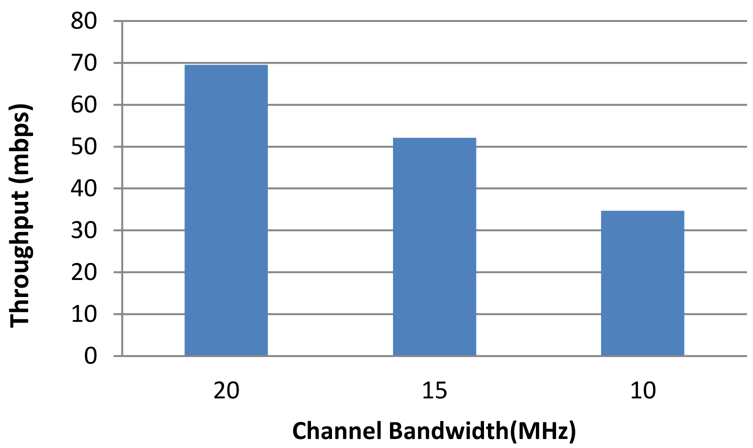
Same procedure for all other sample cases also.

Step 2: Open the Excel file and note down the sum of applications throughput values as shown in below table.

Sample nos.	Channel Bandwidth(MHz)	Throughput (Mbps)
1	20	69.533
2	15	52.117
3	10	34.703

Comparison Chart:

To draw these graphs by using Excel "Insert →Chart" option and then select chart type as "Line chart".



22.4 Inference

The LTE solution provides spectrum flexibility with scalable transmission bandwidth between 1.4 MHz and 20 MHz depending on the available spectrum for flexible radio planning. The 20 MHz bandwidth can provide up to 150 Mbps downlink user data rate and 75 Mbps uplink peak data rate with 2×2 MIMO, and 300 Mbps with 4×4 MIMO.

As the channel bandwidth decreases the number of resource blocks also decreases. If more resource blocks are available then more number of packets can be transmitted.

Channel Bandwidth (MHz)	1.4	3	5	10	15	20
Transmission Bandwidth Configuration NRB: (1 resource block = 180kHz in 1ms TTI)	6	15	25	50	75	100

23. Analysis of LTE Handover

23.1 Introduction

Handover is an important function that maintains seamless connectivity when transitioning from one base station to another.

23.2 LTE Handover Call Flow Description

1. A data call is established between the UE, S-eNB (Source-eNB) and the network elements. Data packets are transferred to/from the UE to/from the network in both directions (Downlink as well as Uplink)
2. The network sends the MEASUREMENT CONTROL REQ message to the UE to set the parameters to measure and set thresholds for those parameters. Its purpose is to instruct the UE to send a measurement report to the network as soon as it detects the thresholds.
3. The UE sends the MEASUREMENT REPORT to the S-eNB after it meets the measurement report criteria communicated previously. The S-eNB makes the decision to hand off the UE to a T-eNB (Target-eNB) using the handover algorithm; each network operator could have its own handover algorithm.
4. The S-eNB issues the RESOURCE STATUS REQUEST message to determine the load on T-eNB (this is optional). Based on the received RESOURCE STATUS RESPONSE, the S-eNB can make the decision to proceed further in continuing the handover procedure using the X2 interface.
5. The S-eNB issues a HANDOVER REQUEST message to the T-eNB passing necessary information to prepare the handover at the target side
6. The T-eNB checks for resource availability and, if available, reserves the resources and sends back the HANDOVER REQUEST ACKNOWLEDGE message including a transparent container to be sent to the UE as an RRC message to perform the handover.
7. The S-eNB generates the RRC (Radio resource control->used for signalling transfer) message to perform the handover, i.e., RRC CONNECTION RECONFIGURATION message including the mobility Control Information. The S-eNB performs the necessary integrity protection and ciphering of the message and sends it to the UE.

8. The S-eNB starts forwarding the downlink data packets to the T-eNB for all the data bearers (which are being established in the T-eNB during the HANDOVER REQ message processing).
9. In the meantime, the UE tries to access the T-eNB cell using the non-contention-based Random Access Procedure. If it succeeds in accessing the target cell, it sends the RRC CONNECTION RECONFIGURATION COMPLETE to the T-eNB.
10. The T-eNB now requests the S-eNB to release the resources. With this, the handover procedure is complete.

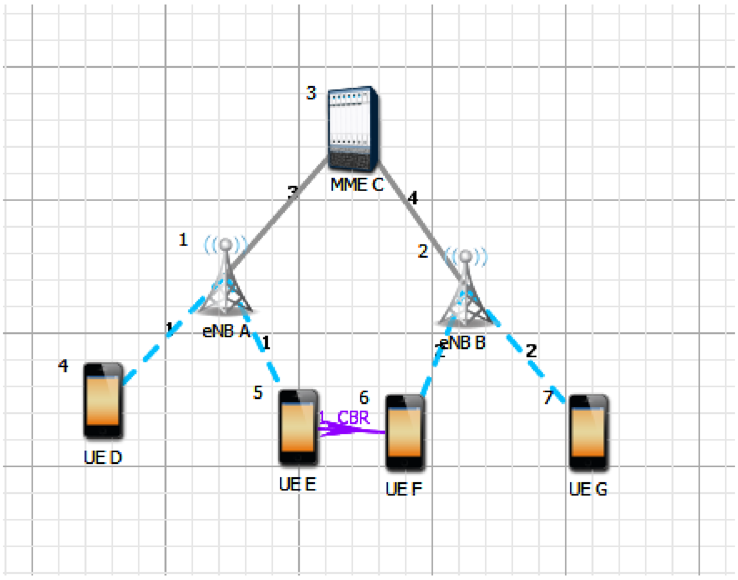
- Due to mobility UEs can move from one place to another
- As shown in the above image, User Equipment is moving from Source-eNB to the Target-eNB
- Then UE sends the MEASUREMENT REPORT to the S-eNB
- The S-eNB issues a HANDOVER REQUEST message to the T-eNB
- The T-eNB checks for resource availability and, if available, reserves the resources and sends back the HANDOVER REQUEST ACKNOWLEDGE message

23.3 Procedure

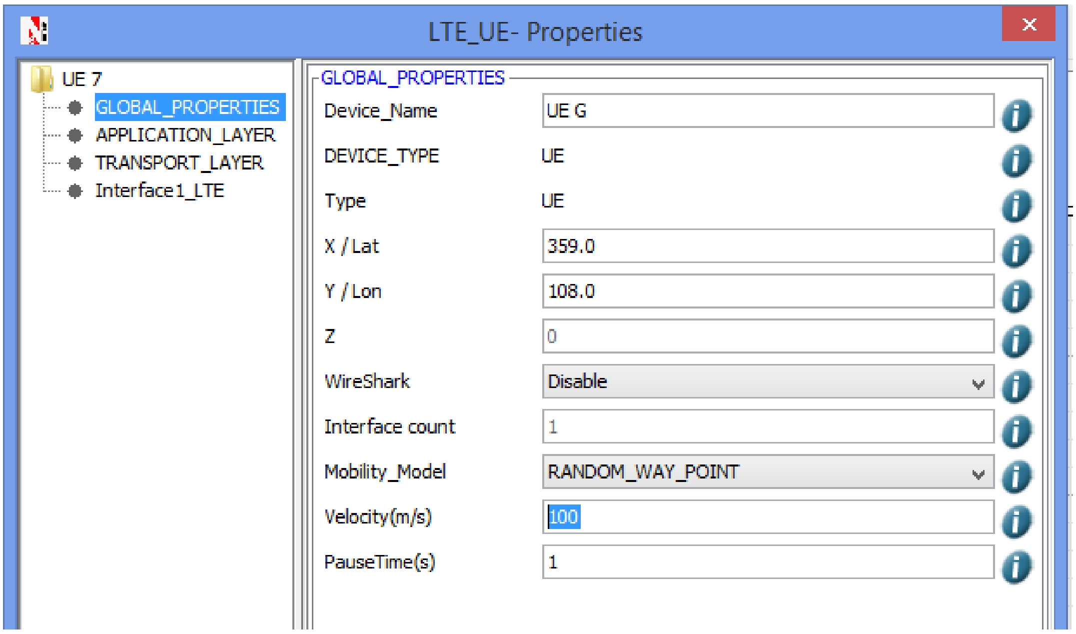
How to Create Scenario & Generate Traffic in NetSim:

Step 1: Go to Simulation -> New -> LTE/LTE-A

Step 2: Click & drop 2 eNB's, 1 MME and 4 UE's onto the Simulation Environment. Connect the 2 eNB's with MME using Wired Link.



Right click on UE and select Properties. Change the Velocity to 100m/s in Global Properties for all UE's



Accept default properties for eNB and MME

Step 3:

Application Properties:

To add application, drop the Application icon. Edit the Application properties as given in table. All other properties are default.

Application Type	CUSTOM
Source ID	5
Destination ID	6

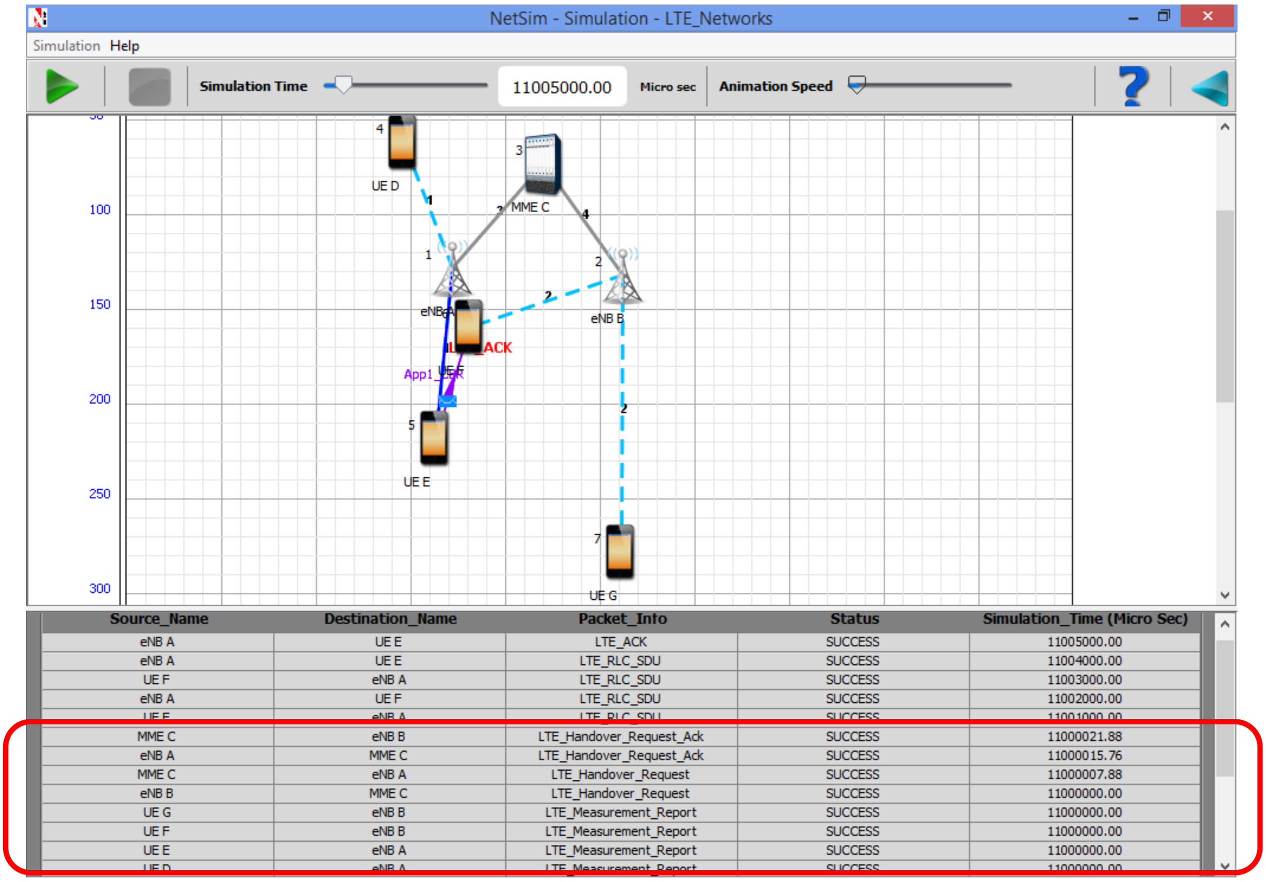
Step 4:

Click on Run Simulation icon and set simulation time = 100s.

23.4 Output

Open Packet Animation:

Due to Mobility UEs can move from one cell to another. In the below figure, users can see the handover packet flow in packet animation table.



- Users can see the Handover messages in red box present in the above image
- As shown in the above packet animation table, UE E, UE D connected to eNB A and UE F, UE G connected to eNB B
- UE F is moving from eNB B to eNB A due to mobility

- Then UEs send the LTE_Measurement_Report to eNB A, eNB B
- The eNB B sends a LTE_Handover_Request message to the eNB A
- The eNB A checks for resource availability and sends a LTE_Handover_Request_Ack message to the eNB B

23.5 Inference

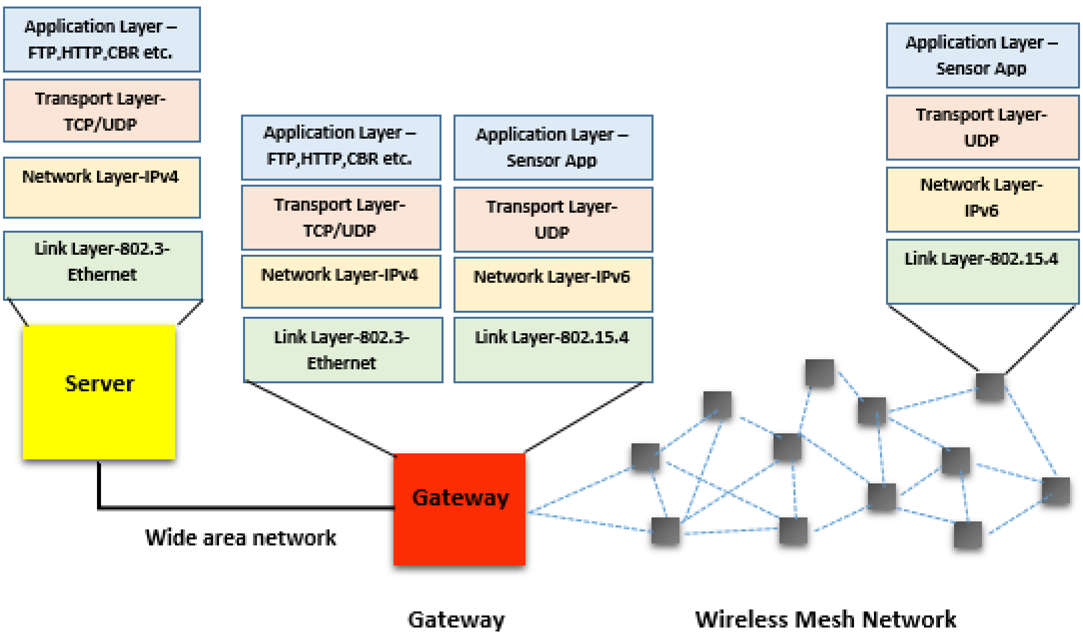
Firstly UE F is communicating with eNB B. Due to mobility UE F moves from one cell to another. So Handover occurs. Now UE F starts communicating with eNB A.

24. Introduction and working of internet of things (iot)

24.1 Introduction

Internet of Things (**IoT**) is a network of physical devices, vehicles, buildings and other items—embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data. An IoT network allows objects to be sensed and/or controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy and economic benefit.

24.1.1 Simple IOT scenario



24.1.2 Components

1. **Sensors**

Sensors are used to detect physical phenomena such as light, heat, pressure, temperature, humidity etc. Sensors are regarded as a revolutionary information gathering method to build the information and communication system which will greatly improve the reliability and efficiency of infrastructure systems. It follows IPv6 addressing system. IP addresses are the backbone to the entire IoT ecosystem. IPv6's huge increase in address space is an important factor in the development of the Internet of Things.

2. **LowPAN Gateway**

These are the Gateways to Internet for all the things/devices that we want to interact with. Gateway help to bridge the internal network of sensor nodes with the external Internet i.e., it will collect the data from sensors and transmitting it to the internet infrastructure.

A 6LowPAN Gateway will have 2 interfaces, one is Zigbee interface connected to sensors (follows 802.15.4 MAC and PHY) and the other is WAN interface connected to ROUTER.

Wired I/F TCP/IP stack	**Wireless I/F (Zigbee) Stack**
Application Layer – FTP,HTTP,CBR etc.	Application Layer – Sensor App
Transport Layer-TCP/UDP	Transport Layer-UDP
Network Layer-IPv4	Network Layer-IPv6
Link Layer-802.3-Ethernet	Link Layer-802.15.4

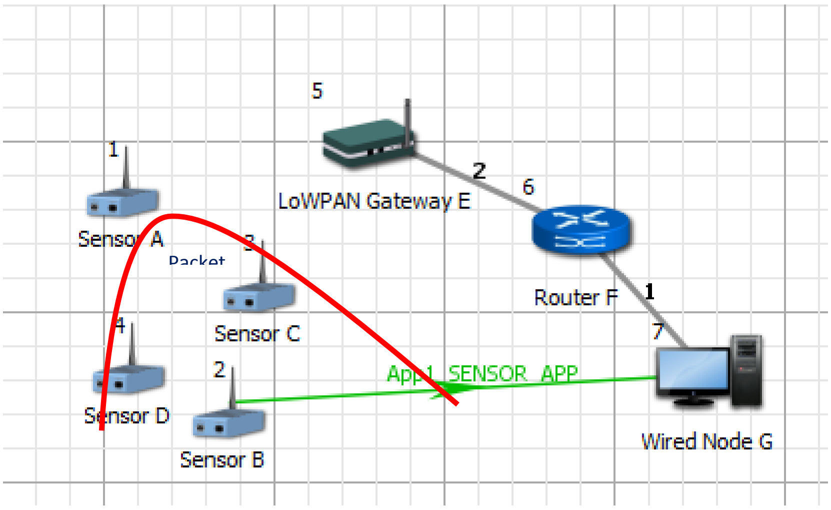
6LowPAN Gateway Stack at wired and wireless Interfaces

6LoWPAN is an acronym of IPv6 over Low Power Wireless Personal Area Network. The 6LoWPAN concept originated from the idea that "the Internet Protocol should be applied even to the smallest devices, and that low-power devices with limited processing capabilities should be able to participate in the Internet of Things.

24.2 PART A: To Model and Simulate an IOT Network Scenario in NetSim

Step 1: Go to Simulation -> New -> IOT

Step 2: Click and drop 4 sensors, 1 LowPAN Gateway, 1 router and 1 wired node. Connect Router, LowPAN Gateway and wired node using wired links

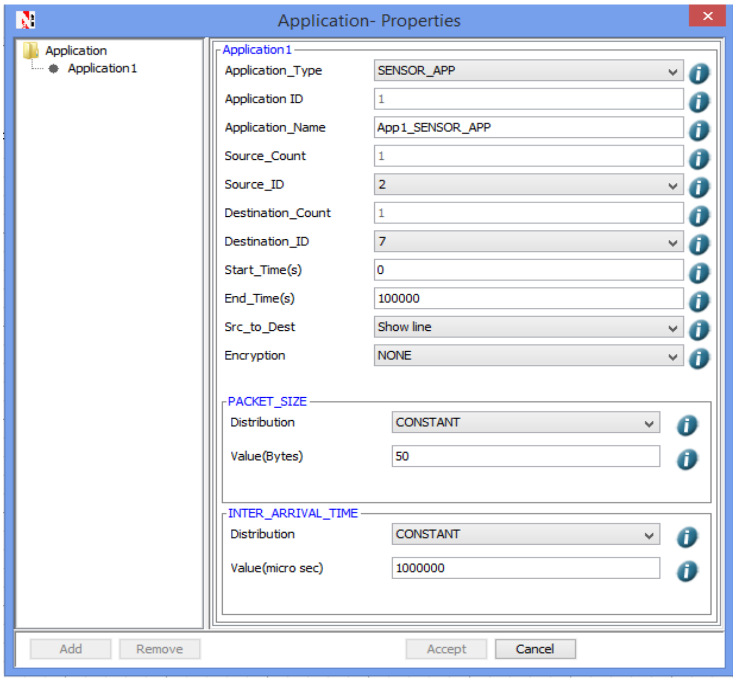


Step 3:

Application Properties:

To add application, drop the Application icon. Edit the Application properties as given in table. All other properties are default.

Application Type	Sensor_App
Source ID	2
Destination ID	7



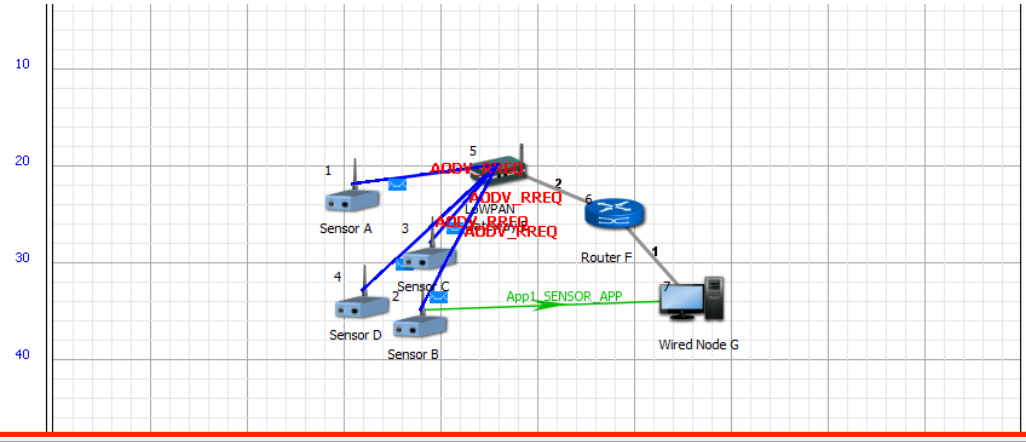
Step 4:

Click on Run Simulation icon and set simulation time = 100s

24.3 Output

At the end of simulation, NetSim provides various performance metrics such as Network Metrics, Link Metrics, Application Metrics, and Protocol Metrics etc.

In Packet Animation Table, users can see the packet flow.

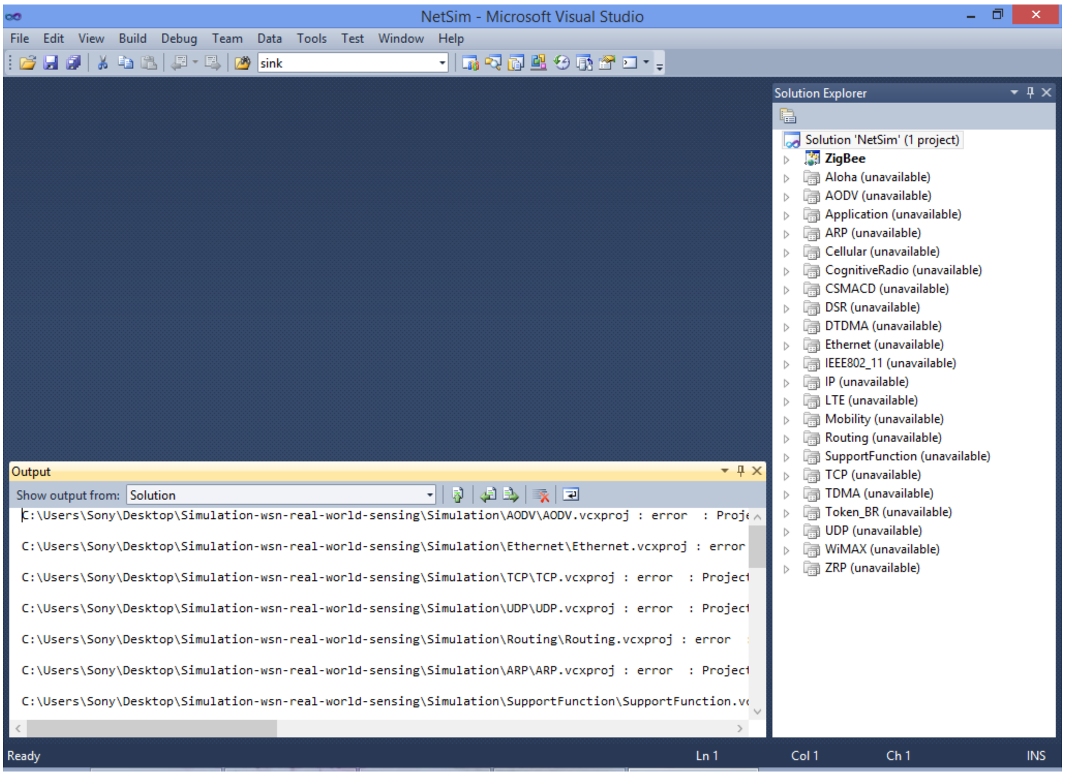


Source_Name	Destination_Name	Packet_Info	Status	Simulation_Time (Micro Sec)
LoWPAN Gateway E	Sensor A	AODV_RREQ	SUCCESS	6214753.00
LoWPAN Gateway E	Sensor D	AODV_RREQ	SUCCESS	6214753.00
LoWPAN Gateway E	Sensor C	AODV_RREQ	SUCCESS	6214753.00
LoWPAN Gateway E	Sensor B	AODV_RREQ	SUCCESS	6214753.00
LoWPAN Gateway E	Sensor B	Zigbee_ACK	SUCCESS	6010146.00
Router F	Wired Node G	APP1_SENSOR_APP-6	SUCCESS	6009966.20
LoWPAN Gateway E	Router F	APP1_SENSOR_APP-6	SUCCESS	6009954.00
Sensor B	LoWPAN Gateway E	APP1_SENSOR_APP-6	SUCCESS	6007106.00
Sensor D	Sensor A	AODV_RREP	SUCCESS	6005473.00
Sensor D	Sensor C	AODV_RREP	SUCCESS	6005473.00
Sensor D	Sensor B	AODV_RREP	SUCCESS	6005473.00
Sensor D	LoWPAN Gateway E	AODV_RREP	SUCCESS	6005473.00
Sensor A	Sensor D	AODV_RREP	SUCCESS	6003873.00
Sensor A	Sensor C	AODV_RREP	SUCCESS	6003873.00
Sensor A	Sensor B	AODV_RREP	SUCCESS	6003873.00

24.4 PART B: To print IP addresses of Source, Destination, Transmitter and Receiver devices and understand the flow from IPv6 to IPv4 network (NetSim standard version is required for this section)

1. Go to NetSim installed directory. The NetSim install directory would look something like < C:\Program Files (x86)\NetSim Standard\bin>
2. Open the simulation folder

3. Open the NetSim.sln file inside the Simulation folder, it displays a message “One or more projects in the solution were not loaded completely”
4. Click on OK and when this opens in MS Visual Studio 2010, it would look like



5. Open IP project

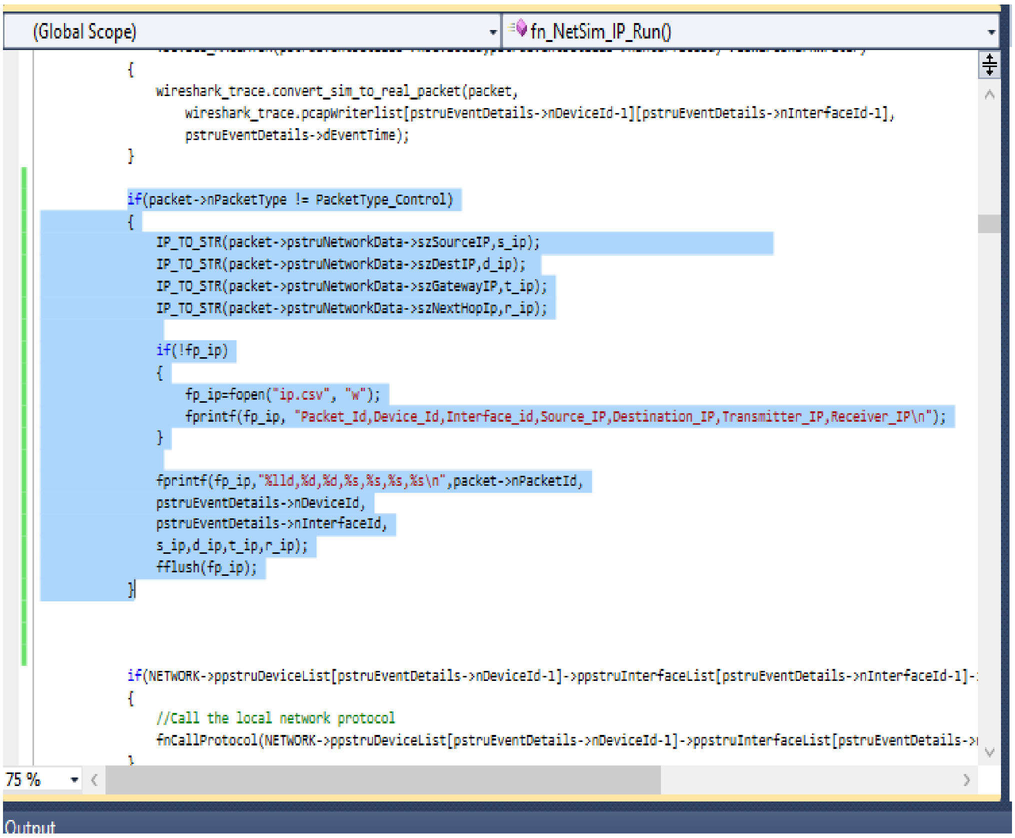
Code Modifications to print ip addresses:

6. Add the following lines of code in NETWORK_OUT_EVENT and NETWORK_IN_EVENT events in fn_NetSim_IP_Run() function present in IP.c file

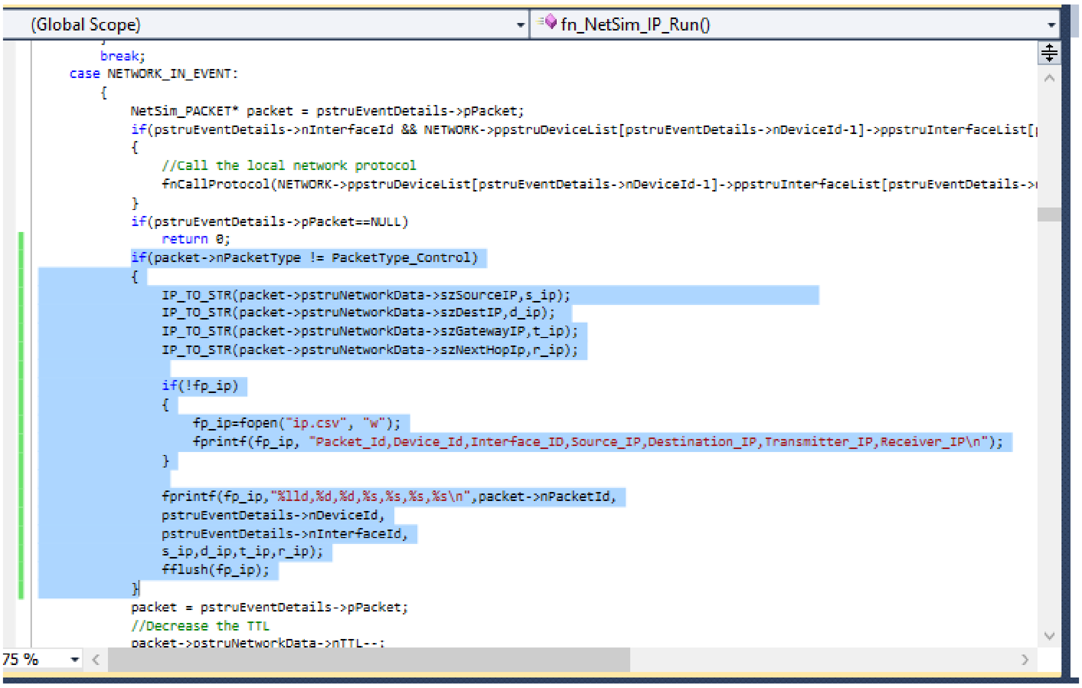
```
if(packet->nPacketType != PacketType_Control)
{
        IP_TO_STR(packet->pstruNetworkData->szSourceIP,s_ip);
        IP_TO_STR(packet->pstruNetworkData->szDestIP,d_ip);
        IP_TO_STR(packet->pstruNetworkData->szGatewayIP,t_ip);
        IP_TO_STR(packet->pstruNetworkData->szNextHopIp,r_ip);
        if(!fp_ip)
        {
                fp_ip=fopen("ip.csv", "w");
```

```
                    fprintf(fp_ip,
"Packet_Id,Device_Id,Interface_id,Source_IP,Destination_IP,Transmit
ter_IP,Receiver_IP\n");
            }
            fprintf(fp_ip,"%lld,%d,%d,%s,%s,%s,%s\n",packet-
>nPacketId,
            pstruEventDetails->nDeviceId,pstruEventDetails-
>nInterfaceId, s_ip, d_ip, t_ip, r_ip);
        fflush(fp_ip);
}
```

In NETWORK_OUT_EVENT

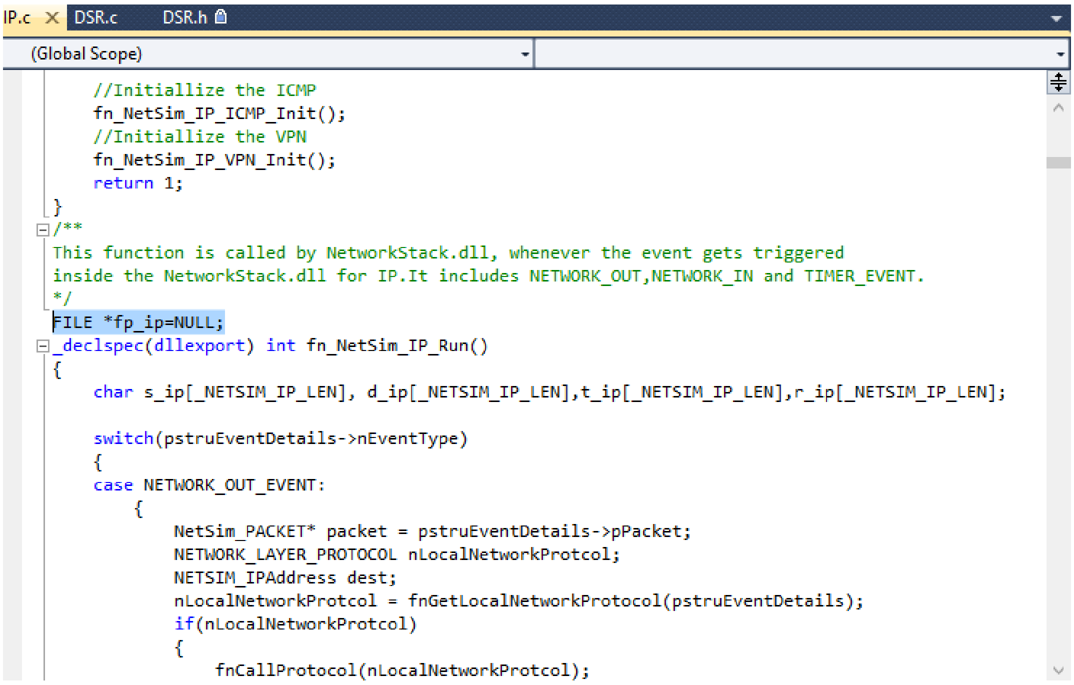


In NETWORK_IN_EVENT



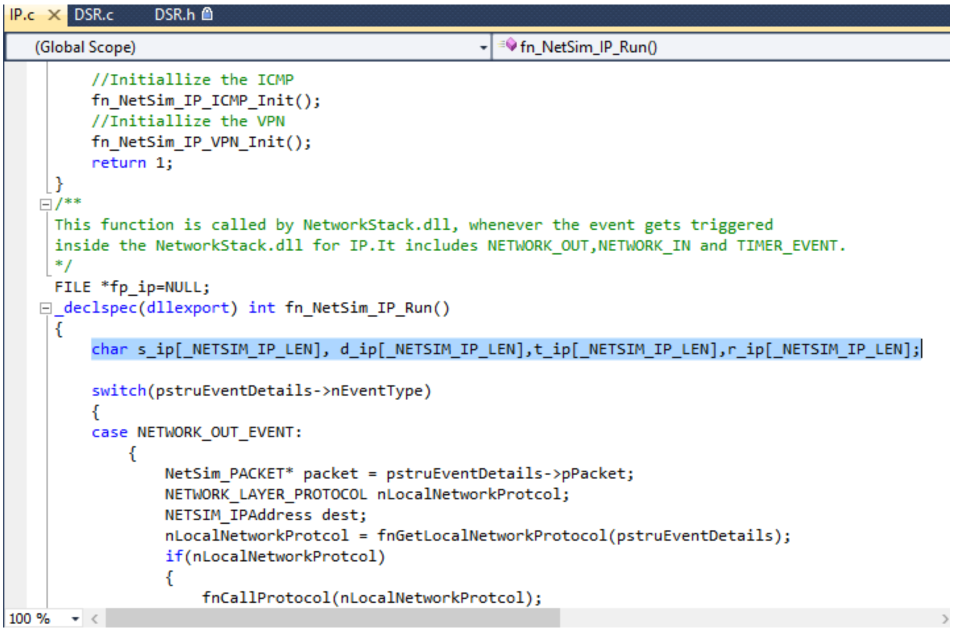
7. Add the following code in IP.c file

FILE *fp_ip=NULL;



8. Add the following code in fn_NetSim_IP_Run() function present in IP.c file

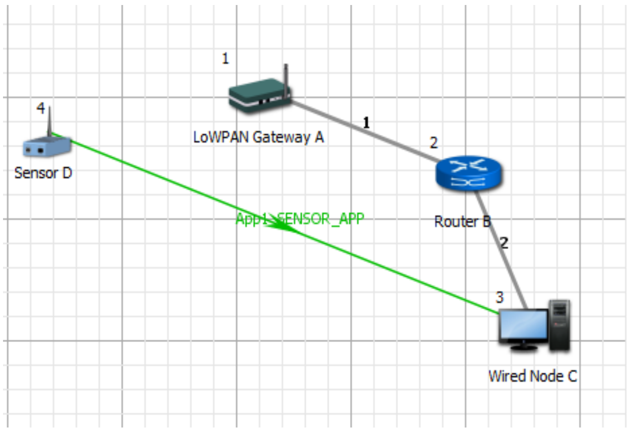
char s_ip[_NETSIM_IP_LEN],
d_ip[_NETSIM_IP_LEN],t_ip[_NETSIM_IP_LEN],r_ip[_NETSIM_IP_LEN];



```
IP.c  DSR.c  DSR.h
(Global Scope)    fn_NetSim_IP_Run()
    //Initiallize the ICMP
    fn_NetSim_IP_ICMP_Init();
    //Initiallize the VPN
    fn_NetSim_IP_VPN_Init();
    return 1;
}
/**
This function is called by NetworkStack.dll, whenever the event gets triggered
inside the NetworkStack.dll for IP.It includes NETWORK_OUT,NETWORK_IN and TIMER_EVENT.
*/
FILE *fp_ip=NULL;
_declspec(dllexport) int fn_NetSim_IP_Run()
{
    char s_ip[_NETSIM_IP_LEN], d_ip[_NETSIM_IP_LEN],t_ip[_NETSIM_IP_LEN],r_ip[_NETSIM_IP_LEN];

    switch(pstruEventDetails->nEventType)
    {
    case NETWORK_OUT_EVENT:
        {
            NetSim_PACKET* packet = pstruEventDetails->pPacket;
            NETWORK_LAYER_PROTOCOL nLocalNetworkProtcol;
            NETSIM_IPAddress dest;
            nLocalNetworkProtcol = fnGetLocalNetworkProtocol(pstruEventDetails);
            if(nLocalNetworkProtcol)
            {
                fnCallProtocol(nLocalNetworkProtcol);
100 %
```

9. Right click on IP in Solution Explorer and select rebuild.
10. Upon rebuilding, libIP.dll will get created in the path...\simulation\DLL
11. Now copy the libIP.dll from this DLL folder and paste it in NetSim bin folder present in the NetSim installed directory. The NetSim install directory would look something like < C:\Program Files (x86)\NetSim Standard\bin>
12. Note that there exists a libIP.dll in this bin folder. This is the default file being shipped with NetSim. The user is replacing this file with the newly built file.
13. Therefore, take care to rename the original libIP.dll file, so that it isn't lost. For example, you may rename it as libIP_default.dll
14. Open NetSim and create a Network Scenario in NetSim IOT Network with 1 sensor, 1 LoWPAN Gateway, 1 Router and 1 Wired Node. Create 1 Sensor application from Sensor D to Wired Node C.



15. Run the simulation.
16. Now you can see ip.csv file in the bin folder of NetSim installed directory. It looks like

Packet_Id	Device_Id	Interface_id	Source_IP	Destination_IP	Transmitter_IP
1	4	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	21AF:435D:7F02:92B1:4219:FCD2:C7A3:3A14	21AF:435D:7F02:92B1:4219:AF26:
1	1	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	21AF:435D:7F02:92B1:4219:FCD2:C7A3:3A14	21AF:435D:7F02:92B1:4219:AF26:
2	4	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	21AF:435D:7F02:92B1:4219:AF26:
2	1	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	21AF:435D:7F02:92B1:4219:AF26:
2	1	2	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	11.1.1.2
2	2	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	11.1.1.2
2	2	2	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	11.3.1.1
2	3	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	11.3.1.1
3	4	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	21AF:435D:7F02:92B1:4219:AF26:
3	1	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	21AF:435D:7F02:92B1:4219:AF26:
3	1	2	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	11.1.1.2
3	2	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	11.1.1.2
3	2	2	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	11.3.1.1
3	3	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	11.3.1.1
4	4	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	21AF:435D:7F02:92B1:4219:AF26:
4	1	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	21AF:435D:7F02:92B1:4219:AF26:
4	1	2	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	11.1.1.2
4	2	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	11.1.1.2
4	2	2	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	11.3.1.1
4	3	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	11.3.1.1
5	4	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	21AF:435D:7F02:92B1:4219:AF26:
5	1	1	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	21AF:435D:7F02:92B1:4219:AF26:
5	1	2	21AF:435D:7F02:92B1:4219:AF26:0551:EE95	11.3.1.2	11.1.1.2

17. Users can understand how the IP addresses are changing from IPv6 to IPv4 and vice versa with the help of ip.csv file.
18. Sensor and LoWPAN gateways 1^{st} interface follows IPv6 addressing.
19. LoWPAN gateways 2nd interface, Router, Wired Node follows IPv4 addressing.
20. As shown in the above image, users can identify the changing of IP addresses from source to destination.