Network Simulation Tools – OPNET Modeler

Wi-Fi Network Implementation

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Workshop Plan

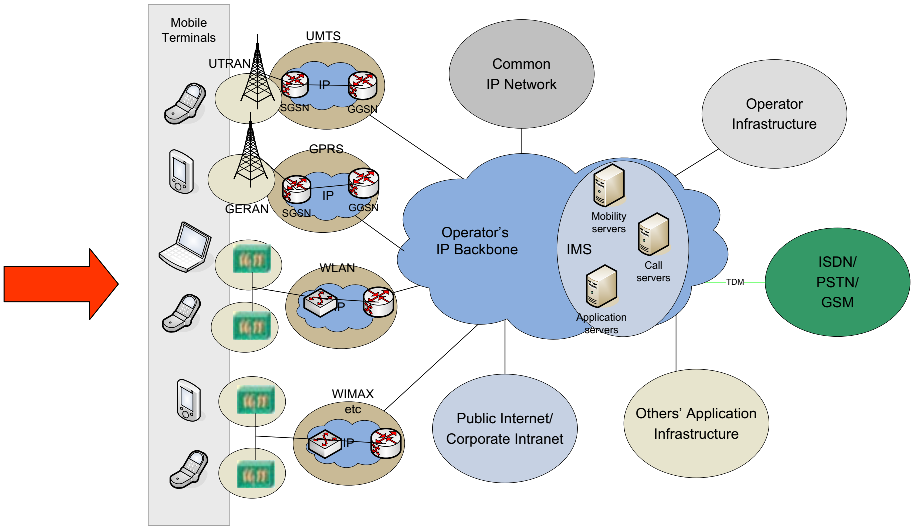
1. Wireless Local Area Network Standard IEEE802.11 – Background: Protocols and Operation
2. IEEE802.11 Support in OPNET Modeler
3. IEEE802.11 - Example Network - 1
4. IEEE802.11 - Example Network – 2 (advanced)

Wireless Local Area Network Standard IEEE802.11 - Background

Direction of 3G and WLAN Technologies

- 3G/WLAN Transmission Speeds:
  - 3G is now offering speeds in 100s of kb/s for outdoor
  - 3.5G will offer speeds in Mb/s
  - 802.11b/g offer 54 Mb/s
  - 802.11n will offer speeds in ~ 100s Mb/s
- 3GPP release 6 offers a framework for integrating 3G and WLAN networks

3G/WLAN Integrated Network

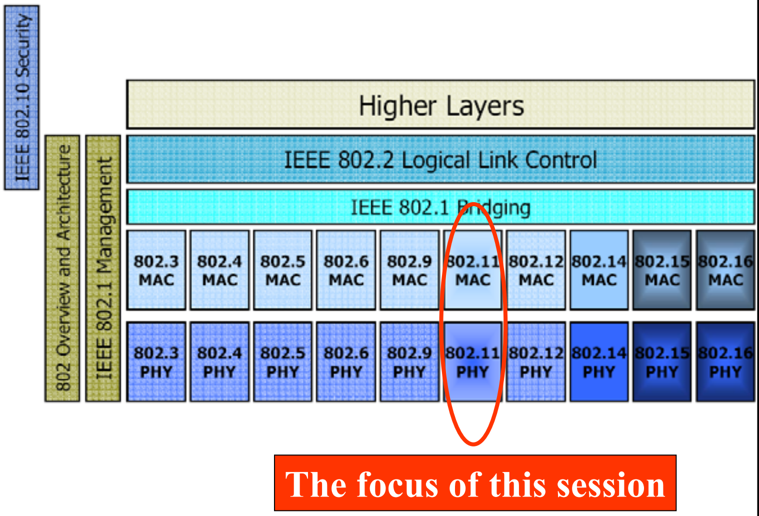


Business Cases

- In some countries 85% of population own a cell phone
- In the US, home networking business is in the billions of dollars
- Annual Wi-Fi hardware sales ~ 3 billion US dollar

Overview of IEEE802 Protocols

- 802.1 and 802.2 are common
- 802.10 - security
- 802.3 (CSMA/CD), 802.4 (Token Bus), 802.5 (Token Ring) – all wired LANs
- 802.6 DQDB – MLAN
- 802.7 - broadband
- 802.8 - FDDI
- 802.9 ISO-Ethernet – voice & data over Ethernet
- **802.11 (WLAN)**,15, &16
- 802.12 – 100BaseVG; priority
- 802.14 cable network
- 802.16 - WMAN



Overview of IEEE802.11

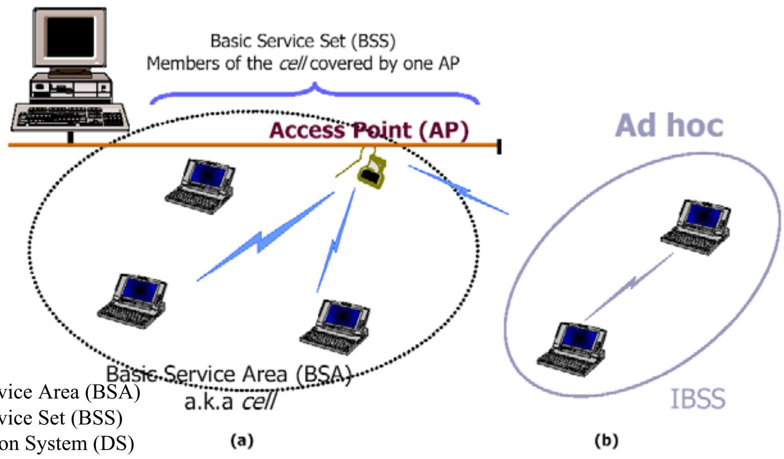
- History:
  - 1997: completion of first IEEE802.11 standards (1 and 2 Mb/s) – PHY: DSSS, FHSS, and DFIR
  - Afterwards: IEEE802.11b – 11 Mb/s using CCK and IEEE802.11a – 54 Mb/s using OFDM
  - IEEE802.11g – 54 Mb/s using OFDM and backward compatible with IEEE802.11b
- Same MAC layer for all three
  - CSMA/CA-based for contention data
  - Support RTS/CTS mechanism to solve hidden terminal problem
  - Point coordination function (PCF) – optional; for real-time traffic
- Topology
  - Centralized – through AP
  - Ad-hoc – supporting peer-to-peer communication between terminals

IEEE802.11 and its Derivatives

Protocol	Release date	Frequency Range (GHz)	Data rates (Mb/s)	Range
Legacy	1997	2.4 -2.5	2	?
802.11a	1999	5.15-5.35/5.47-5.725/5.725-5.875	54	~ 30 m
802.11b	1999	2.4 -2.5	11	~ 50 m
802.11g	2003	2.4 -2.5	54	~ 30 m
802.11n	2007 (expected)	2.4 or 5	540	~ 50 m

Reference Architecture

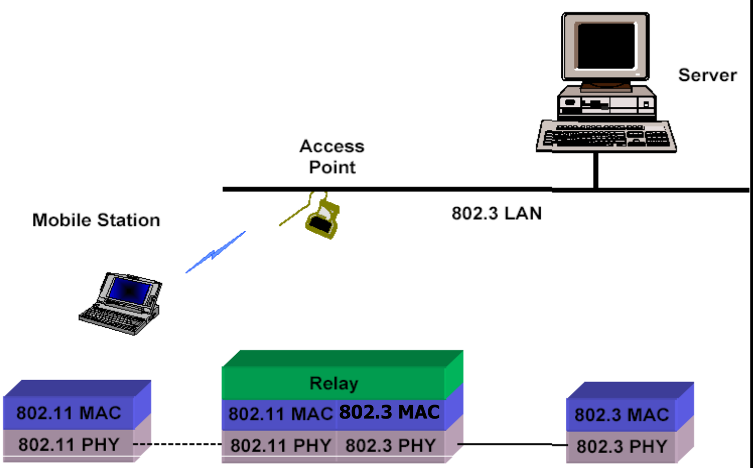
(a) Infrastructure Network (b) Ad-Hoc Network



Basic Service Area (BSA)
Basic Service Set (BSS)
Distribution System (DS)
Extended Service Set (ESS)

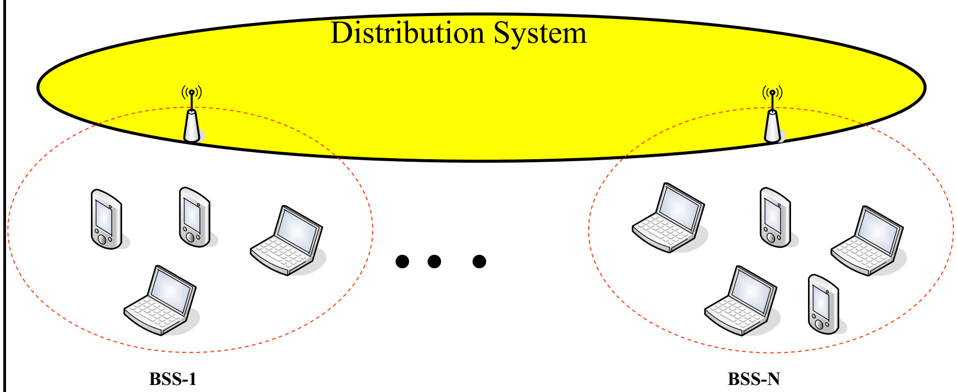
Reference Architecture - Typical Deployment

(c) Extended Service Set (ESS)



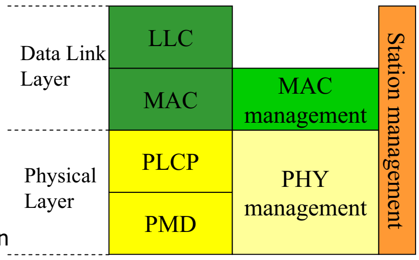
Reference Architecture - Typical Deployment (2)

(d) Distribution System – not part of 802.11 specification



Protocol Architecture

- MAC sublayer responsibilities:
  - Access mechanism
  - Fragmentation and reassembly of packets
- MAC management sublayer responsibilities:
  - Roaming within ESS
  - Power management
  - Registration: Association, disassociation, and re-association
- PLCP responsibilities:
  - Carrier sensing
  - Forming packets for different PHYs
- PMD responsibilities:
  - Modulation, Coding
- PHY layer management: channel tuning to different options within PHY
- Station management sublayer:
  - Coordination and interaction between MAC and PHY



PMD: Physical Medium dependent
PLCP: Physical layer convergence protocol

IEEE802.11 (Legacy) PHY Layer

- Radio frequency: ISM – 2.4 GHz
- Three options:
  - Infra-red (IR)
  - Frequency hopping spread spectrum (FHSS), or
  - Direct sequence spread spectrum (DSSS)
- Data rate: 1-2 Mb/s
- Modulation:
  - BPSK – for 1 Mb/s
  - QPSK – for 2 Mb/s

IEEE802.11b PHY Layer

- Radio frequency: ISM – 2.4 GHz
- Direct sequence spread spectrum (DSSS)
- Three 22-MHz non-overlapping channels
- Channels
  - North America: 11 channels
  - Europe: 13 channels
  - Japan: 14 channels
- Data rate: up to 11 Mb/s
- Modulation:
  - Complementary code keying (CCK) – a form of spread spectrum – for 5.5 and 11 Mb/s
  - DQPSK – for 2 Mb/s
  - BPSK – for 1 Mb/s

IEEE802.11a PHY Layer

- Radio frequency: U-NII – 5 GHz
- Modulation: Orthogonal Frequency Division Multiplexing (OFDM) – using 64-QAM
  - Convolutional coding: 1/2, 2/3, and 3/4
- Offers up to 20 MHz non-overlapping channels
  - Each channel is 52 subcarriers (48 data, 4 pilot)
- Data rate: up to 54 Mb/s
  - 6,9 Mb/s → BPSK
  - 12, 18 Mb/s → QPSK
  - 24, 36 Mb/s → 16-QAM
  - 48, 54 Mb/s → 64 QAM

IEEE802.11g PHY Layer

- Radio frequency: ISM – 2.4 GHz
- Modulation: Orthogonal Frequency Division Multiplexing (OFDM)
- Data rate: up to 54 Mb/s
- Backward compatible with 802.11b

IEEE802.11 family and Carrier Sensing

- PHY Sensing - Clear Channel Assessment (CCA) signal
  - Generate by the PLCP
  - Sensing: Detected data sensing vs Carrier Sensing
    - Any detected bits?, or – slow but reliable
    - RSS of carrier against threshold – fast but many false alarms
- Virtual carrier sensing:
    - Network Allocation Vector (NAV) signal supported by the RTS/CTS and PCF mechanisms at MAC – indicates the medium is occupied for a given (length field) time duration
    - Used for RTS/CTS and PCF based schemes only

IEEE802.11 MAC

- MAC Layer:
  - MAC sublayer
  - MAC layer management sublayer
- Major responsibilities of MAC sublayer:
  - Define access scheme
  - Define packet formats
- Major responsibilities of management sublayer:
  - Support ESS
  - Power management
  - Security

MAC Sublayer

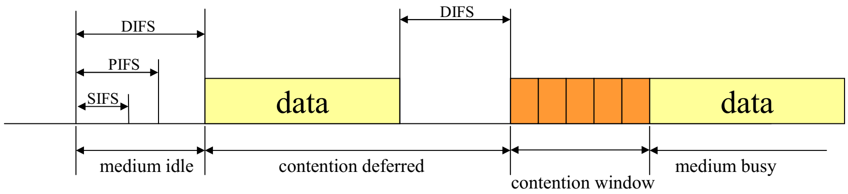
- Supported access schemes
  - CSMA/CA – contention data
  - RTS/CTS – contention-free

  These two modes are referred to as DCF

  - PCF – contention-free - for time-bounded traffic
- Inter-frame spacing (IFS) – can be used to prioritize users
  - Short – SIFS - highest priority terminal
  - Point – PIFS – used in conjunction with PCF function
  - Distributed – DIFS – lowest priority terminal – used with DCF
- Refer to CSMA/CA slides

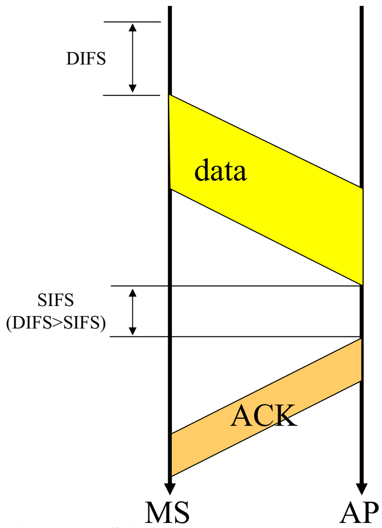
Primary Operation of CSMA/CA

- Primary operation of CSMA/CA as shown in figure
- After the completion of a transmission all terminals having data to transmit must wait S/DIFS – depending on their priority before they start their back-off timers
- Binary exponential back-off scheme is used to minimize probability of collision



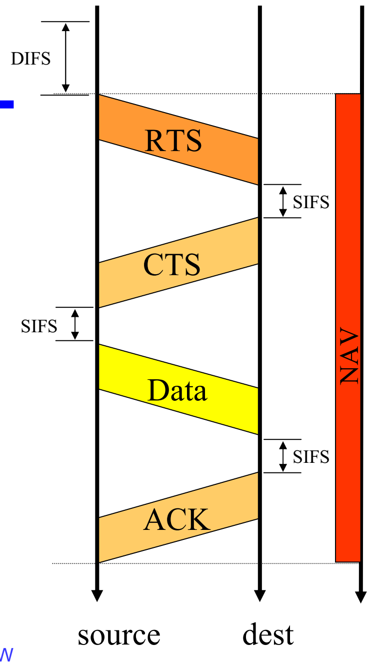
Operation of CSMA/CA with ACK for MAC Recovery

- Note that IEEE802.3 does not support ACK on the MAC level – connectionless
- AP waits for SIFS before ACK
  - Since SIFS is shorter than DIFS, all stations hear the ACK before they attempt transmission



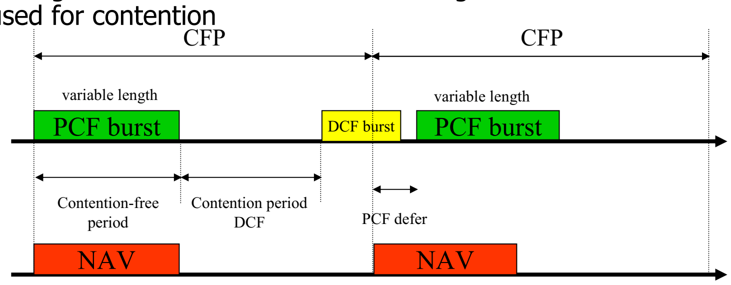
RTS/CTS Operation

- When source is ready – RTS (20 bytes) is sent
- Destination responds with CTS (16 bytes) after SIFS
- Source terminal received CTS and after SIFS sends data
- Destination terminal sends ACK after SIFS
- Other terminal listening to RTS/CTS will turn their NAV signal on – used for virtual carrier sensing
- NAV signal turned off when after the transmission and reception of the ACK frame



PCF for Contention-Free Access

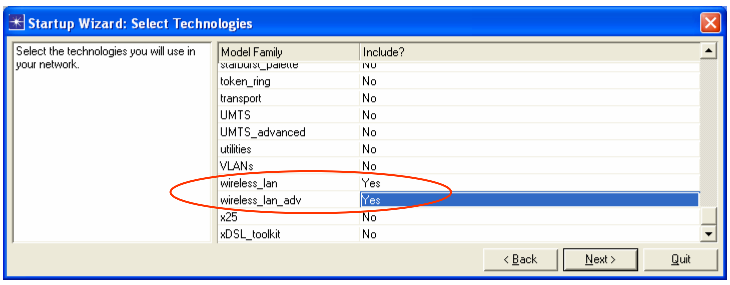
- Optional MAC service – Not implemented by all manufacturers
- Available only for infrastructure networks – not Ad-hoc
- AP – point coordinator organizes periodical contention-free periods (CFP) for delay-sensitive services
- PCF operation
- During PCF operation (part of CFP) NAV signal is on –
- During the remainder of the CFP NAV signal is off and that can be used for contention



IEEE802.11 Support in OPNET Modeler

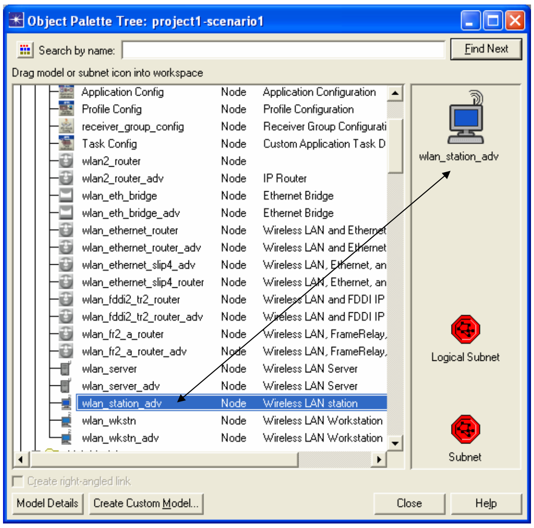
Modeler Support for Wireless

- When you build a project in Modeler, the user is prompted to select the relevant technologies
- WLAN technology support
  - To include all standard (built in) WLAN related nodes
  - Sample of these nodes are explained in the next few slides



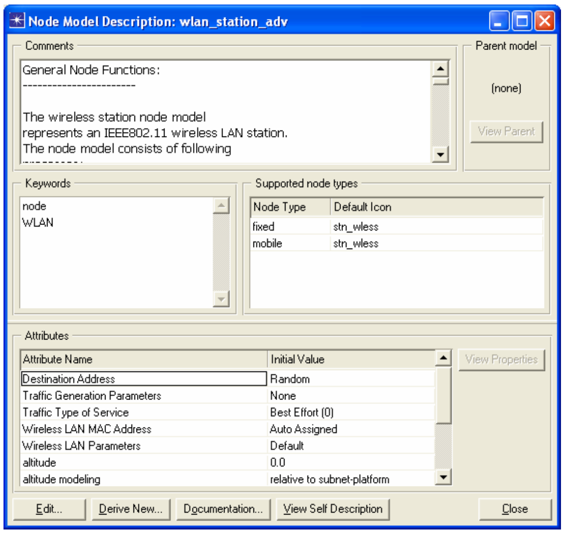
Modeler Support for Wireless – Object Palette Tree

- Snapshot of the defined nodes for WLAN technology
- Selected nodes are copied into the project space to form the desired network
- The lab will include more details on building and simulating a WLAN network



Modeler Support for Wireless – Model Details

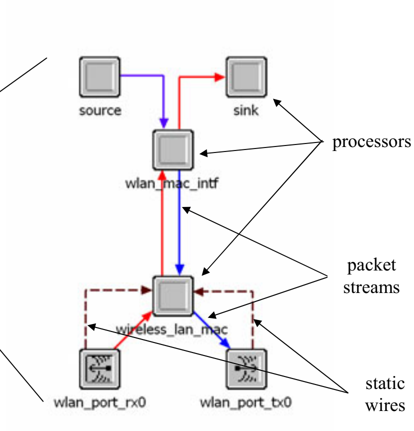
- Model Details provide more information regarding the node and its function



Modeler Nodes: WLAN Station

- WLAN Station
- Note: this model does not include upper layers!

Node



Node model

This model is used when the focus is on the performance for the MAC layer and/or the physical layer

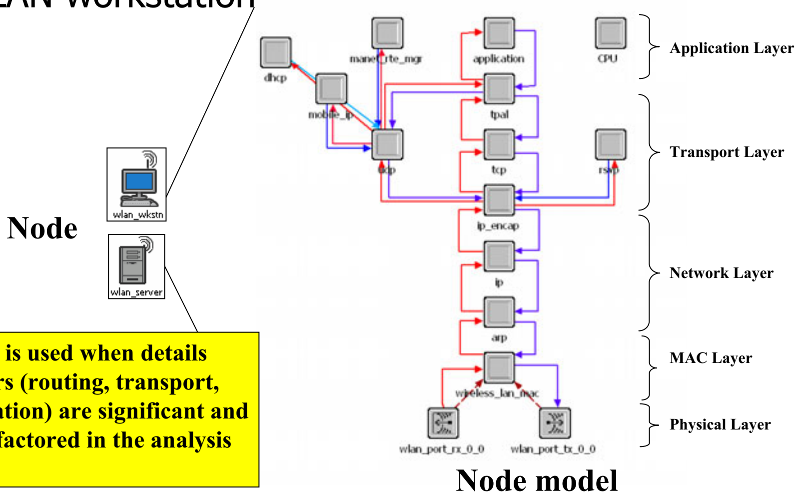
Our basic building block for lab exercises

Modeler Nodes: WLAN Station – cont'd

- A node model consists of the following processor nodes (or queues) and links (static wires or packet streams
- The node model for WLAN station consists of the following processor nodes:
  - source: a processor that generates packets
  - sink: a processor that destroys packets
  - wlan_mac_intf: a processor that interfaces the traffic to the MAC layer
  - wireless_lan_mac: a processor that executes the MAC protocol
  - wlan_port_rx0: receiver port
  - wlan_port_tx0: transmit port
- More details on this node later

Modeler Nodes: WLAN Workstation/Server

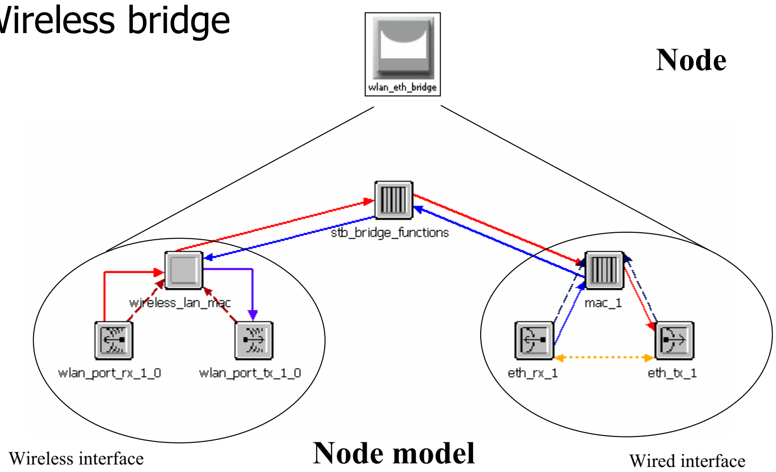
- WLAN workstation



This model is used when details upper layers (routing, transport, and application) are significant and need to be factored in the analysis

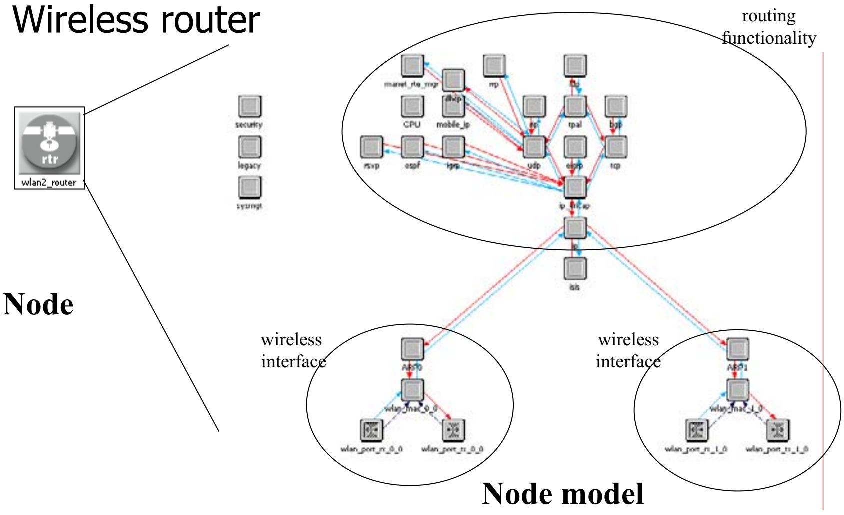
Modeler Nodes: Bridge/Switch

- Wireless bridge



Modeler Nodes: Wireless Router

- Wireless router

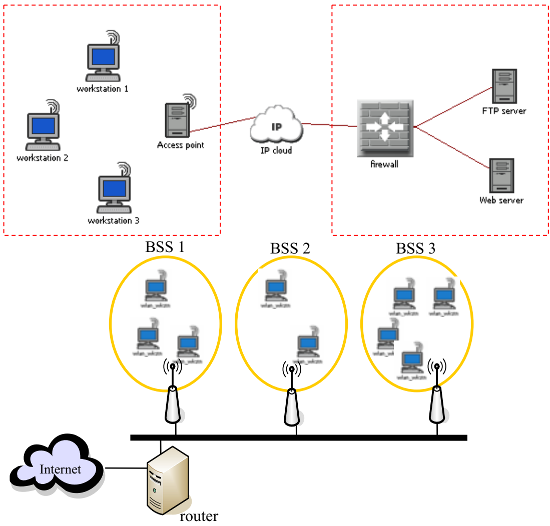


Node Attributes and Parameters

- For every node, you can right-click and a list of options appear
- These options control the node and specify its behavior
  - User can also select which (of the built in) statistics to collect during simulation – more on this later

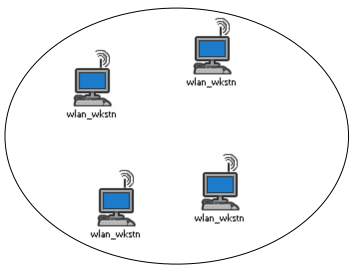
Examples of Supported Wireless Networks

- Extended service set (ESS)

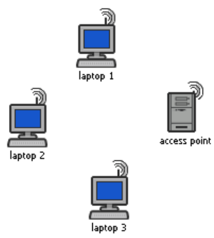


Examples of Supported Wireless Networks - 2

- Ad-Hoc network

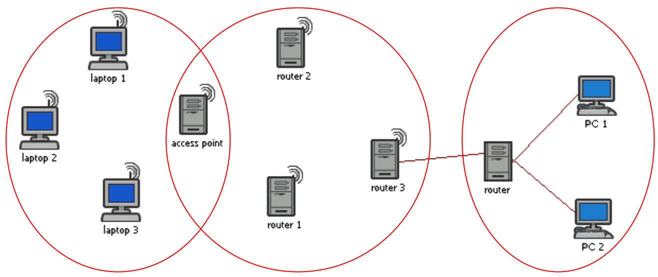


- Infrastructure BSS



Examples of Supported Wireless Networks - 3

- Wireless backbone

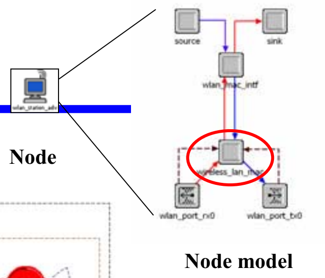


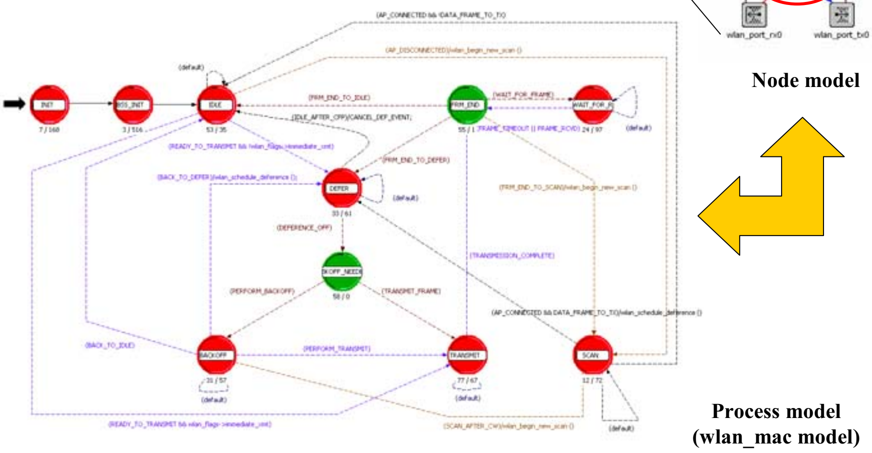
More Details on WLAN Station Node

- This node will be used in the lab
- Contains:
  - Simple (bursty) traffic source – source
  - Traffic sink - sink
  - Interface layer between MAC and traffic - wlan_mac_intf
  - IEEE802.11 MAC implementation – wireless_lan_mac
  - Rx/Tx wireless ports: wlan_port_rx0 and wlan_port_tx0
- We are going to highlight some of these processes

Process Model – wireless_lan_mac

- Wireless station example



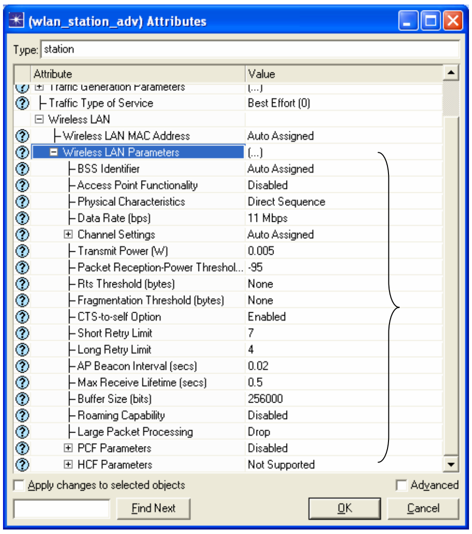


Process Model – wireless_lan_mac – cont'd

- The process model consists of states and transitions
  - Code is executed in states
  - Transitions correspond to events/conditions
- This process model is a faithful and detailed translation of the IEEE802.11 MAC protocol
- The difficulty in modeling lies in designing the correct process model that reflects your protocol/procedure
- The number of lines of code that make the wireless_lan_mac process is 10183 lines!!
  - Not all processes are that involved – see the sink process model on the coming slides
- If you develop your own process model, it should compile correctly before it can be integrated with other process models
  - Requires the OPNET include files (definitions of OPNET variables and routines)

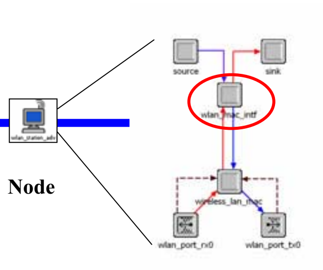
Process Model – wireless_lan_mac – cont'd

- Parameters for the wireless_lan_mac need to be specified by the user
- Right-click on wlan_station_adv and select "Edit Attributes" from the list of options



Process Model – wlan_mac_intf

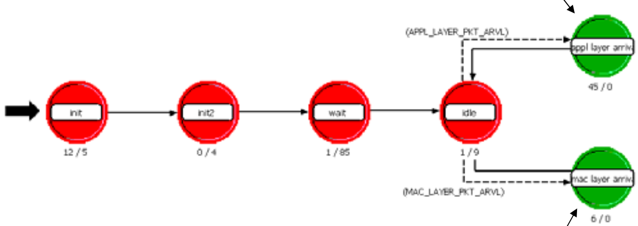
- WLAN station example



Node

Node model

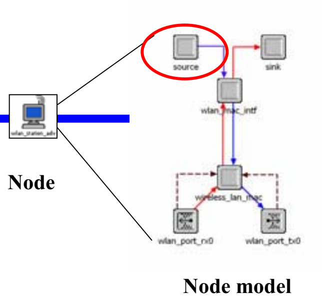
If a frame is generated by the application layer (source process), it is sent to the MAC layer (wireless_lan_mac process)

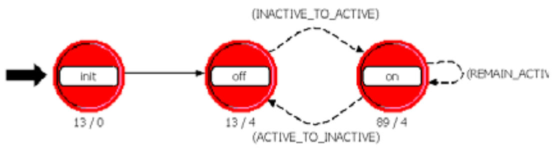


If a frame is received from MAC layer (wireless_lan_mac process), it is sent to the application layer (sink process)

Process Model – source

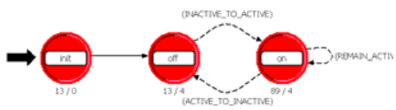
- One of the most used process models
- Simple on/off model
- User defines:
  - Parameters for the on/off time – distribution, mean, etc.
  - Parameters for the traffic generation during the on period - packet length and distribution

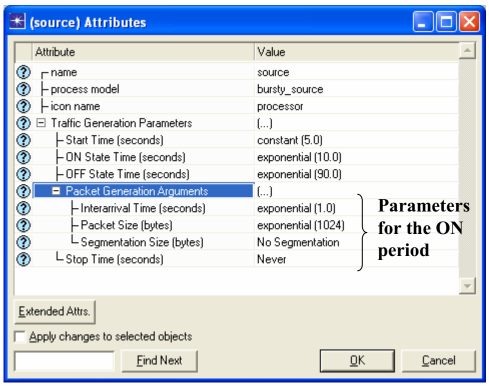




Process Model – source - 2

- Let us try to shed more light on the operation of the traffic source model
- OFF period
  - Can be of any distribution
  - There is not traffic generation (i.e. zero b/s)
- ON period
  - Interarrival time of packets can follow any distribution
  - Packet length can follow any distribution
- For example: ON State time set to exponential (10) – means the ON period is exponentially distributed with mean equal to 10 seconds.





Process Model – source - 3

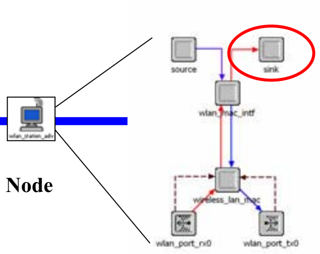
- Average bit rate of the source is given by

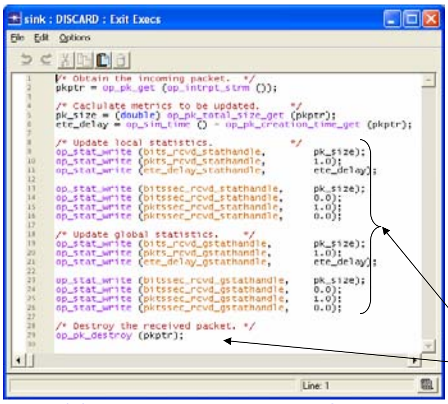
$$\text{Avg Rate} = \frac{\text{Avg ON Period}}{(\text{Avg ON Period} + \text{Avg OFF Period})} \times \frac{\text{Avg Packet Size}}{\text{Avg Interarrival Time}}$$

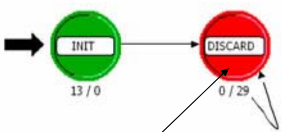
- This Avg rate computation will help us estimate loading for the Wi-Fi example exercises
- This source is bursty – in contrast to constant bit rate sources

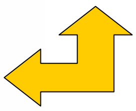
Process Model – sink

- One of the most used process models
- No need for user parameters
- The process model corresponds to 365 lines of code









The code contained in the exit part of the "DISCARD" state:

-Writes statistics regarding received frame – uses op_stat_write() system call

-Destroys frame (releases memory)

General Modeling & Simulation Tips - Summary

- Modeler is a very powerful tool
  - Numerous built in technologies and node models
  - Allows custom design of technologies and protocols
- The required skills for relatively high
  - The user have access to the process models and the low level code
- Simulation time versus real-time

General Modeling & Simulation Tips – Summary (2)

- User must choose carefully the level of abstraction for the network of interest
  - In real-life every node has at least on CPU dedicated for its function; Within Modeler all system/node events will be executing on your workstation
  - Simulation optimization and speed up techniques do exist – but they effect is limits – also add to the required skills
  - Example: do not import the network topology of your Enterprise and attempt to build in all nodes and then simulate
    - Software limitations
    - It will never run in economical terms

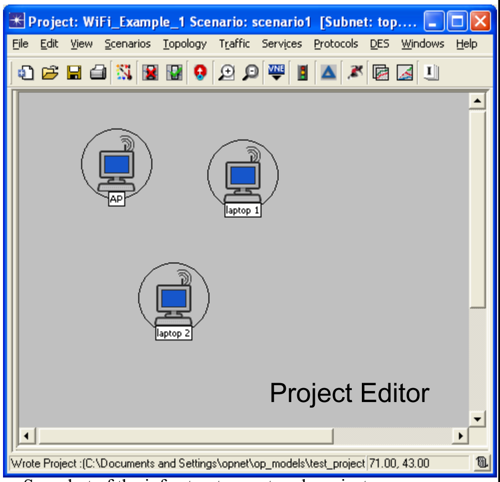
IEEE802.11 - Example Network - 1

Objective of LAB 1

- Familiarization with "wlan_station" node and embedded process models
- Basic procedures to design and simulate a simple infrastructure WLAN network
- Collecting and viewing simple performance figures such as throughput and delay versus load
- Introduce the concept of vector results

Design of Infrastructure Network

- It is desired to design an infrastructure network
  - Multiple wireless LAN work stations with one access point
  - All peripheral nodes transmit traffic to the access point
  - The AP does not send traffic
- Sample network: one access point surrounded by two wireless stations (laptops)
  - The number of peripheral station can be extended (to say 5 or 50) at the expense of more computational power requirement
- This network employs contention-based (DCF and RTS/CTS) access



Snapshot of the infrastructure network project

Design of Infrastructure Network – Project Creation Steps

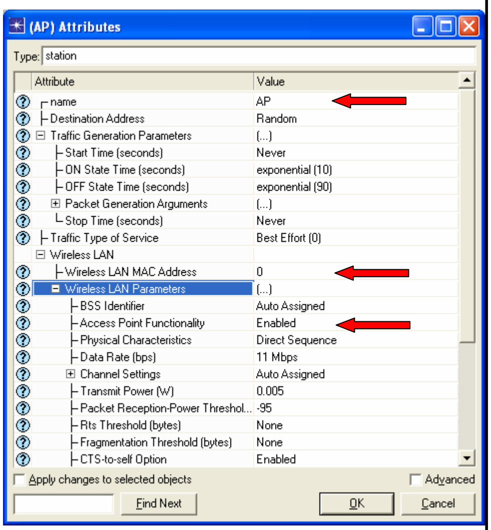
1. From the project editor window, open a new project
2. From the "Startup Wizard Initial Topology" window, select "Create empty scenario"
   - For advanced OPNET components one can import network topological/configuration info from a real-network
3. From the Startup Wizard Choose Network Scale window select "Logical Scale"
   - We can select maps or other environments
4. From the "Startup Wizard Select Technologies" window select "wireless_lan" and "wireless_lan_adv"
5. End the startup wizard by pressing "Finish"
6. OPNET opens an "Object Palette Tree" window where all built in nodes and links for the technologies of interest are listed

Design of Infrastructure Network – Project Creation Steps - 2

7. From the "Object Palette Tree" select the "wlan_station_adv" node and place two copies in the project editor window
   - Note OPNET gives sequential names for two nodes: node 0 and node 1
   - To end the placing of node – right click the mouse
8. In the following two slides we will customize node 0 to behave as an access point while node 1 will be customized to behave as a regular laptop transmitting traffic to the access point

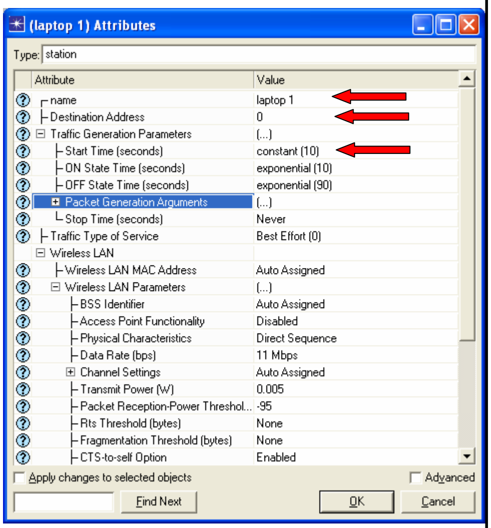
Customizing Node Behavior – Access Point

- Select one node and prepare it to function as an access point
  - Select the node, right click and choose "Edit Attributes"
  - Set the node name to "AP"
  - Set the "Wireless LAN MAC Address" property to "0"
  - Enable the "Access Point Functionality" property.
- The final attributes should look like the figure on the side
- **Note:**
  - This node will not be generating traffic, therefore the "Start Time" for the "Traffic Generation Parameters" should be set to "Never"
  - The "Destination Address" attribute need not be set
  - Make sure the "PCF Parameters" and "HCF Parameters" are both disabled – we are only characterizing the contention access mechanism
- Click "OK" to finalize the setting



Customizing Node Behavior – Wireless Laptop

- Select node 1 and prepare it to function as wireless laptop
  - Select the node, right click and choose "Edit Attributes"
  - Set the node name to "Laptop 1"
  - Set the "Destination Address" property to "0" – i.e. this node will be sending traffic to the access point
  - Set the "Start Time" for the "Traffic Generation Parameters" to "constant(10)" – this means the node will start generating traffic 10 seconds into the start of the simulation
- The final attributes should look like the figure on the side
- **Note:**
  - While the destination address should be set to 0, its own address can be left to be "Auto Assigned"
  - The "Access Point Functionality", the "PCF Parameters", and the "HCF Parameters" all should be disabled.
- Click "OK" to finalize the setting



Creating Multiple Peripheral Wireless Stations

- We would like to make copies of Laptop 1
- This can be achieved either using the Edit/Copy/Paste menu of the Project Editor or through Ctrl-C/Ctrl-V operation!
- Again note, OPNET renames the multiple copies sequentially – i.e. Laptop 2, Laptop 3, etc.

Network Design Complete

- The steps outlines in the previous slides complete the network design!
- We are in a position to simulate the network and obtain performance figures
- For supported network models, simulating and characterizing performance is mainly building the network using OPNET nodes and links, and setting the correct (or desired) objects' attributes!
- For unsupported network models, the user is required to design the corresponding nodes and links using OPNET's primitives (processors, queues, streams, etc.)
  - Refer to the process model slides in the previous section

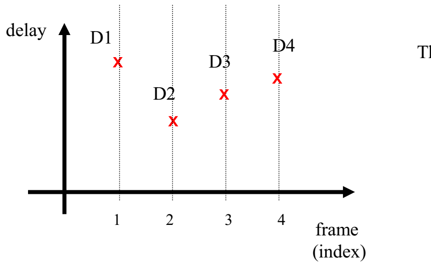
Simulation Results (Overview)

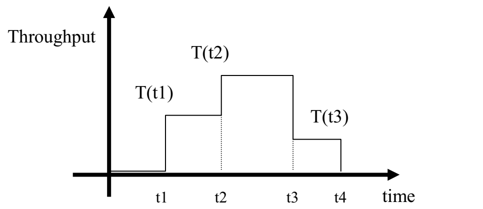
- For any event or time-based simulation, the collected results for ONE simulation run can be in either of two forms:
  1. Samples of the performance figure: frame delays
     - Eg. D1, D2, …, DN – where Di is the delay for the ith frame
  2. Performance figure associated with time: throughput of a link, queue size, etc.
     - Eg. T(t1), T(t2), …, T(tN) – where T(ti) is the throughput at time instant ti
- Collecting the information above (i.e. all Di or all T(ti)) – corresponds to obtaining a full *trace* for the performance figure of interest

These traces are referred to as "VECTOR RESULTS/FILES" in OPNET terminology

Simulation Results (Overview) - 2

- Traces or Vector results





Example: frames in one simulation run have the following delay (samples) are D1, D2, …, DN
➔ Avg Delay = Σ Di / N

Example: throughput figure for one simulation run the shape depicted by the above function
➔ Avg Throughput = Area under curve / t4

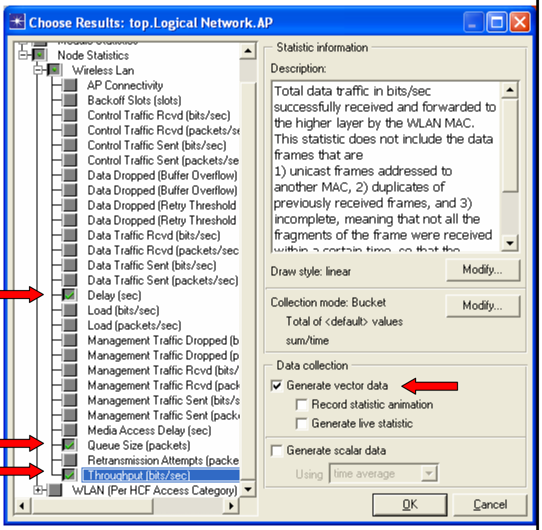
Using OPNET terminology Avg frame delay or Avg Throughput figures are referred to by "SCALAR RESULTS"

Selecting Performance Figures

- Before simulation is run, user must specify what results to collect
- We are interested in the performance figures at the access point (AP)
- For the built in statistics, the simulation code (e.g. at the process model level) should contain variable definitions and appropriate procedures to properly perform statistic collection
- If you design your own node models or processes, you must included these statistics definitions and procedures yourself – Subject for advanced topics on Modeler

Selecting Performance Figures

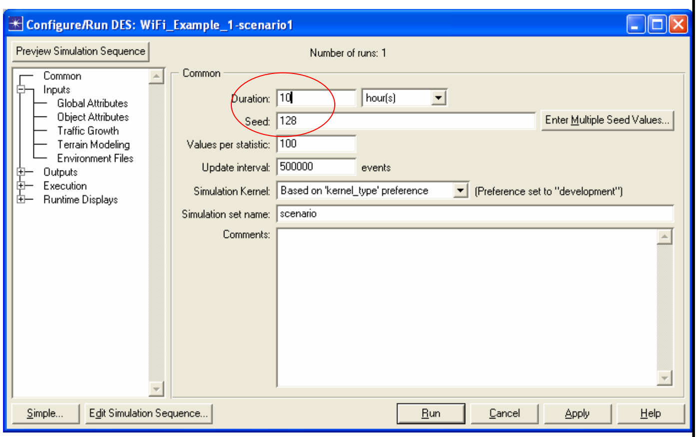
- Right click on the access point (AP) node and select "Choose Individual DES Statistics"
- A window similar to the one shown on the side is displayed – It lists all statistics already defined by OPNET
- Select "Delay", "Throughput", and "Queue Size" as required performance figures
- Note that we are collecting full traces and thus "Generate vector data" should be selected
- Press "OK" to save your selections



Simulation Setup

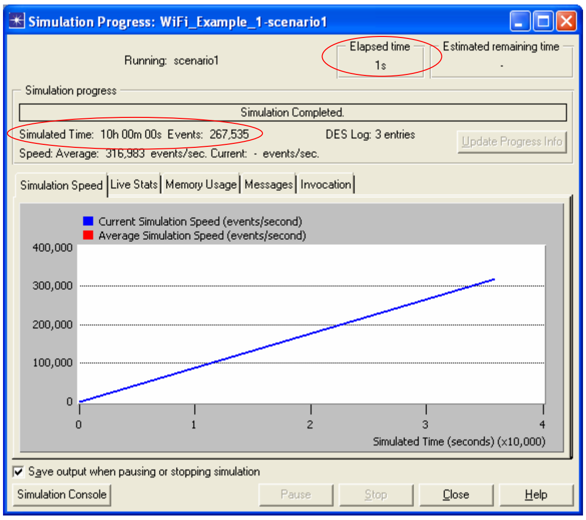
- On the Project window drop down menu click on DES and select "Configure/Run Discrete Event Simulation"
- A window appears similar to the one shown below

- Important Fields:
  - Duration
  - Seed
- Other fields may be discussed later
- Set "Duration" field to 10 hours – This prolongs the simulation time and allows the system to reach steady state



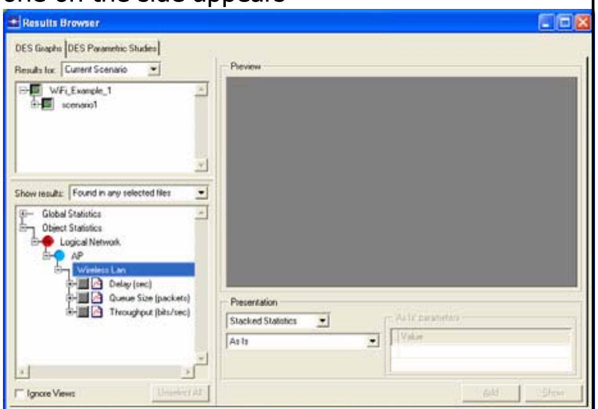
Simulation Execution

- To apply your changes press "Apply" and to execute the simulation press "Run"
- OPNET compiles (if needed) the entire simulation code, and launches the simulation
  - Progress of simulation can be observed on the window
  - Simulation speed in terms of events/second are displayed
- Typically the simulation is allowed to complete – however you can pause the simulation at any time and then resume it!



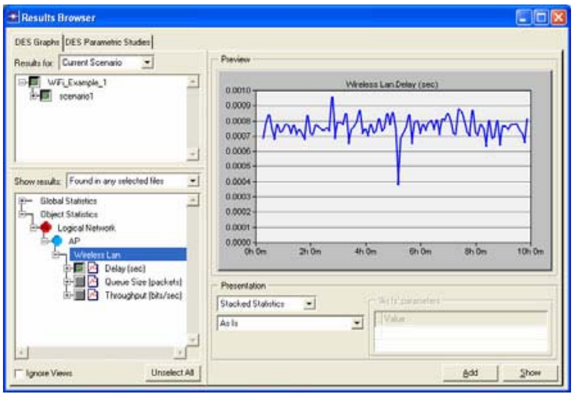
Viewing Results

- We are in a position to view simulation output as specified by the statistics selected earlier
- On the AP node, right click and choose "View Results"
- A window similar to the one on the side appears
- Note that the selected statistics for the AP node appear – namely Delay, Queue Size, and Throughput



Viewing Results - 2

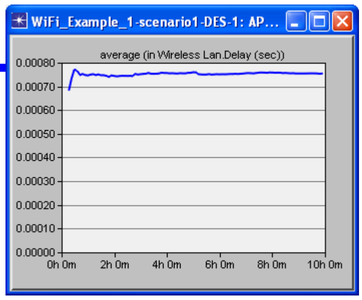
- Click on "Delay" to see the trace for frames delay
  - Once the graph is finalized, you can obtain a separate graph click on the "Show" button
- Observe that Delay is variable
- Delay is plotted versus time – unlike the example given in the Simulation Results (Overview) slides!
  - Why/How?

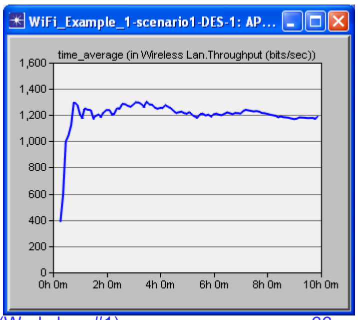


Viewing Results - 3

- To observe the average frame delay for all simulation run, choose "average" in the presentation box
  - Note the avg delay is equal to 7.5 micro second
- Similarly display the avg throughput of the network – use the time average to correctly reflect the average throughput
  - Note the avg throughput is 1196 b/s
- Verify that Queues Size is always ZERO

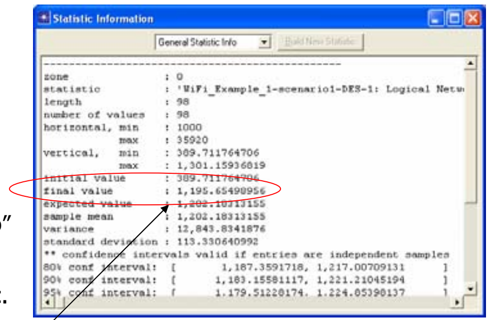
- Important: If you run a simulation scenario where these averages do not reach steady state (seem to stabilize), you need to extend your simulation time!





Viewing Results - 4

- You can also observe a summary of the performance figure of interest
- On the throughput graph, right-click on the window and select "Show Statistic Data" – this will display summary of the statistics collected (average, min, max, standard deviation, confidence intervals, etc.) and also show the actual recoded samples!
  - To view the samples, change the option from "General Statistic Info" to "Statistic Data"
- In addition, you can manipulate graph properties, export data, etc.



Value quoted for network throughput

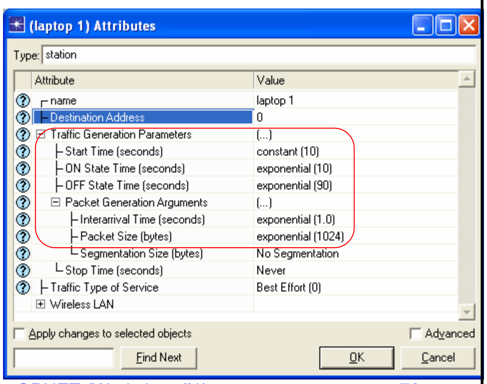
IEEE802.11 - Example Network - 2

Objective of LAB 2

- Extension of LAB 1
- Utilize same network design to for multiple runs and more meaningful output figures
- Introduce object attribute promotion and simulation scenarios
- Familiarization with Probe file design
- Collecting and viewing simple output figures using scalar files
  - The use of "Parametric Studies"

Introduction to Parametric Studies

- In LAB 1 we learned how to collect performance results for the simple WLAN infrastructure network
- For the default traffic source setting we obtained
  - Avg Delay = 7.5 micro seconds
  - Avg Throughput = 1196 b/s
- The default traffic source attributes are as shown
  - Can be obtained from the attributes of the laptop1 node or the source processor model
- The given numbers correspond to an avg rate of 10/(10+90)*1024/1 = **102.4 kB/s**



Introduction to Parametric Studies - 2

- We would like to obtain these performance figures for different intensities of the traffic source
- To change the intensity of the traffic source, we can (Refer to the traffic source process model):
  - Increase the ratio of the ON period to the cycle time
  - In crease packet size
  - Reduce the packet interarrival time
- In this LAB we will change the mean packet size to generate different traffic intensities
- To obtain the previous results, the packet size attribute was set to "exponential (1024)"
  - i.e. generated packet sizes are random (exponentially distributed) with mean equal to 1024 Bytes

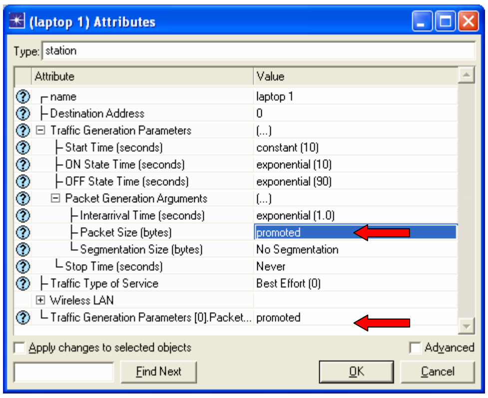
Introduction to Parametric Studies - 3

- Exercise:
  - Change the packet size attribute to correspond to the values shown the following table, execute the simulation and verify the results shown in the table
  - One configuration/run per load point! Tedious
- In this LAB, we will show how to design a series of simulations (referred to as simulation scenario) and make OPNET collect the required performance figure for every scenario

Mean Packet Size (Load)	Avg Throughput (b/s)	Avg Frame Delay (μsec)
256	480	4
512	830	5
1024	1200	7
2048	1100	9
4096	850	10

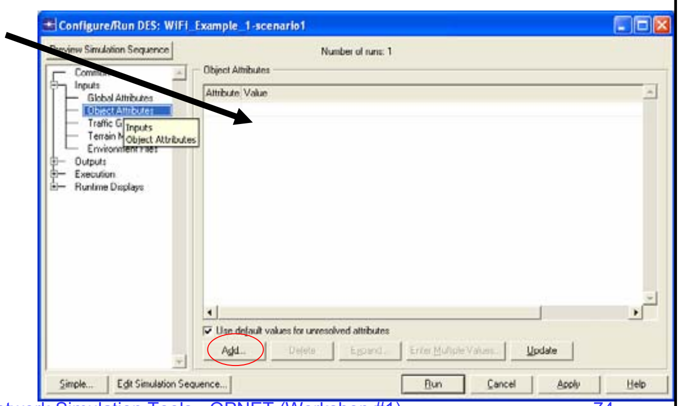
Attribute Promotion

- Attribute promotion is one method for allowing simulation parameters to take different values at the simulation execution stage
- On the project editor, click on the laptop 1 node and right-click on the value for the attribute “Packet Size (bytes)” and choose promote.
- Repeat the procedure for the node laptop 2
- The new attributes for laptop node look like the figure on the side
- Note – “Traffic Generation Parameters [0].Packet …” appears as on o the promoted attributes

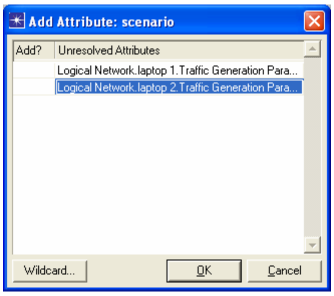


Setting Multiple Values for the Promoted Attribute

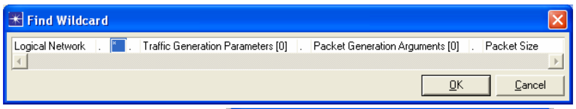
- We would like to set multiple values for the parameter of interest – Packet Size
- Open the Configure/Run DES window and select input/Object Attributed
- A window similar to one shown appears
- Promoted object attributes area
- Click on “Add”

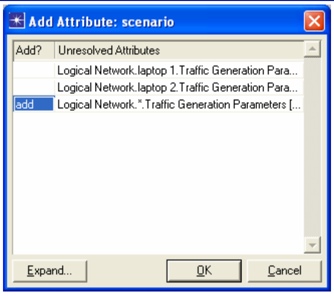


Setting Multiple Values for the Promoted Attribute - 2



- Click on "Add" – a list of unresolved attributes appear
- Select on the attribute for one of the laptop nodes and click on wildcard

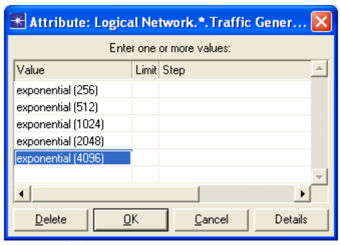




- Since we want the parameter to correspond to the two nodes, we insert a "wildcard" in the node name
- Click on the "Add?" column to assert dd
- The final "Add Attributes" window looks similar to the one shown on the right
- Click "OK" to save your choices

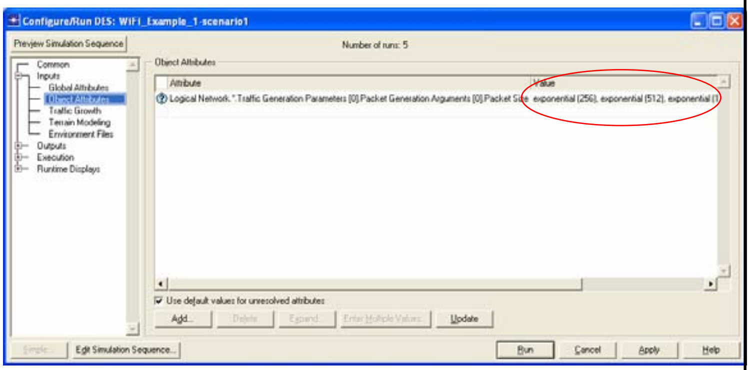
Setting Multiple Values for the Promoted Attribute - 3

- Now the "Configure/Run DES" window should display the promoted attribute in the respective area
- Highlight the promoted attribute and click "Enter Multiple Values"
- In the attributes window enter the values shown in the window on the side
  - Note, you may have to enter the default value "exponential (1024)" and then choose to edit it
- Click "OK" and save the values
- Value-Limit-Step – for vectors of numbers



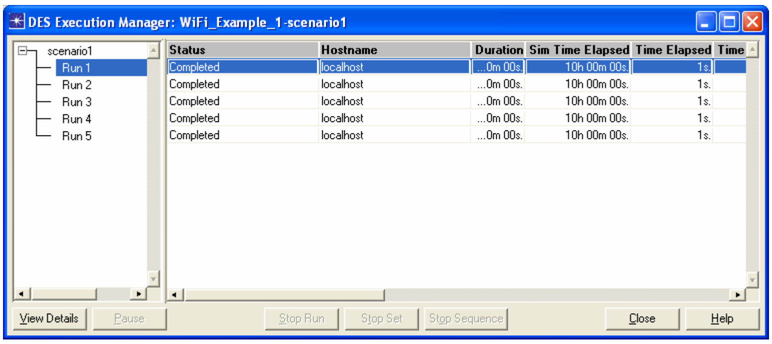
Simulation Setup

- Having set the multiple values, the final "Configure/Run DES" window looks like the one shown
  - Note – the list of entered values should be listed as shown



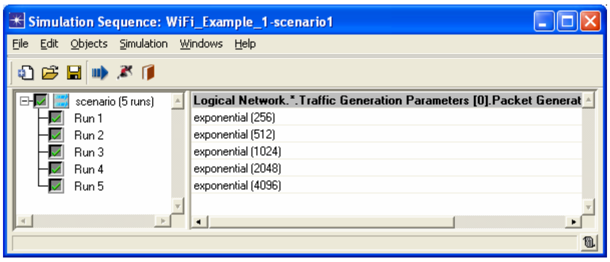
Simulation Execution

- Click on "Apply" and then "Run" on the "Configure/Run DES" window or alternatively from the "Simulation Sequence" window
  - This launches the execution of 5 simulations
- The execution manager reports details of each of these executions as shown in Figure



Simulation Setup - 2

- One can also create, edit, run these simulation scenarios by clicking on the "Edit Simulation Scenario" button on the "Configure/Run DES" window
- This interface is as shown below

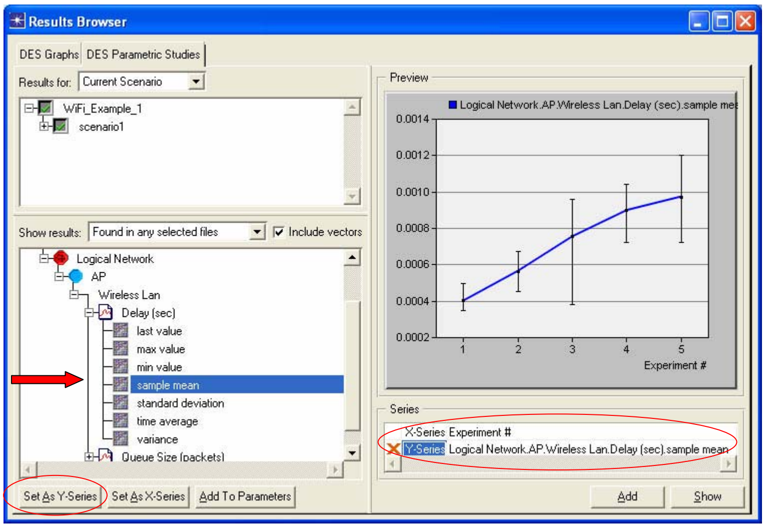


Viewing Results

- Use the same procedure described in LAB ONE to view results
- Click on the "Parametric Studies" tab
- You can use either scalar statistics (display results without confidence intervals) or object statistics

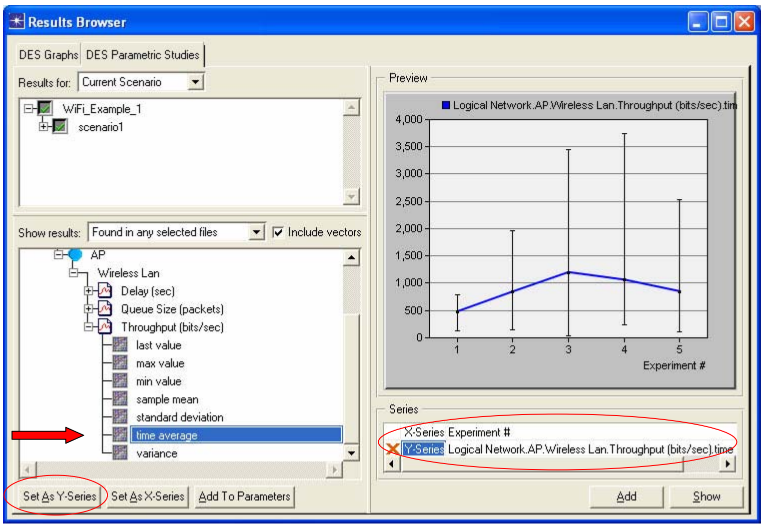
Viewing Results - 2

Avg Delay (with confidence intervals) versus experiment number



Viewing Results - 3

Avg Throughput (with confidence intervals) versus experiment number



Viewing Results - 4

- Verify that results obtained using simulation sequence match those shown in the table earlier in LAB 2

References

- The material in these slides is adapted from:
  - Dr. Ashraf Mahmoud – Course notes on Wireless and Mobile Computing (COE 543)
  - Principles of Wireless Networking – A Unified Approach, K. Pahlavan and P. Krishnamurthy – Prentice Hall, 2002.
  - www.opnet.com and the links therein
  - Opnet conferences material (2004, 2005, and 2006)
  - Opnet tutorials and documentation