About the presenter (me)

- Research scientist in VTT Technical Research Centre of Finland from 2004 -
- Research scientist in University of Oulu, Centre for Wireless Communications & Telecommunication laboratory from 1998 to 2004
- M.Sc. (EE) degree in 2001
- Research interests include:
  - Cross-layer design methods
  - Wireless Networks
  - Channel Access methods
  - Ad Hoc networks
  - MAC protocols
  - Quality of Service (QoS) in heterogeneous networks
  - QoS measurement methods and tools
- Working with OPNET since 1999
  - Mainly wireless system research and ad hoc networking techniques
Contents

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General Information

• A common presentation of the OPNET simulator (OPNET Modeler) is provided
• OPNET is very large and powerful software with wide variety of possibilities
  • Enables the possibility to simulate entire heterogeneous networks with various protocols
• Development work was started in 1986 by MIL3 Inc. (nowadays OPNET Technologies Inc.)
• Originally the software was developed for the needs of military, but it has grown to be a world leading commercial network simulation tool
• OPNET is quite expensive for commercial usage but there are also free licenses for educational purposes
Introduction

• OPNET is a high level event based network level simulation tool
  • Simulation operates at “packet-level”
  • Originally built for the simulation of fixed networks
    • OPNET contains a huge library of accurate models of commercially available fixed network hardware and protocols
  • Nowadays, the possibilities for wireless network simulations are also very wide
    • Accurate radio transmission pipeline stage for the modeling of the physical layer (radio interface)
    • The simulator has a lot of potentiality, but there exists typically a lack of the recent wireless systems
      • Much of the work considering new technologies must be done by oneself
  • OPNET can be used as a research tool or as a network design/analysis tool (end user)
    • The threshold for the usage is high for the developer, but low for the end user

The structure of OPNET

• OPNET consists of high level user interface, which is constructed from C and C++ source code blocks with a huge library of OPNET specific functions
  • Hierarchical structure, modeling is divided to three main domains:
    • Network domain
      • Networks + sub-networks, network topologies, geographical coordinates, mobility
    • Node domain
      • Single network nodes (e.g., routers, workstations, mobile devices…)
    • Process domain
      • Single modules and source code inside network nodes (e.g., data traffic source model)
      • With OPNET it is also possible to run external code components (External System Domain, ESD)
The Various Tools of OPNET

- Source code editing environment
- Network model editor
- Node model editor
- Process model editor
- Antenna pattern editor
- Modulation curve editor (SNR – BER behavior)
- Packet format editor
- Analysis configuration tool
- Simulation tool
- ICI editor (Interface Control Information)
- Probe model tool (organization of result collection)
- Link model editor (properties of fixed link models)
- Path model editor (for routing and modeling virtual circuits)
- Demand model editor (wide scale application modeling)
- OPNET Animation viewer

The Network Domain (1/4) – Global Network Modeling

- Network level (main window)
The Network Domain (2/4)

- Network domain specifies the overall scope of the system to be simulated
- It is a high-level description of the objects contained in the system
- Network model specifies the objects in the system as well as their physical locations, interconnections and configurations

The Network Domain (3/4)

sub-networks

- An example of a sub-network (WLAN)

Fixed links

sub-net

network nodes
The Network Domain (4/4)

Mobility

- OPNET supports wireless mobile nodes
- Also, satellite modeling is an inbuilt feature of OPNET
- Mobility can be realized in three different ways

  - Mobility trajectory
    - A node follows a predetermined trajectory during simulation (drawn or defined step by step)
  - Mobility vector
    - A node moves according to a mobility vector defined with node attributes, which can be modified during simulation
  - Manipulation of node’s coordinates
    - A processor module is created, which directly modifies node’s coordinates during simulation according to the specified model
Node Domain (2/3)

• The node model specifies the internal structure of a network node
• Typical nodes include workstations, packet switches, satellite terminals, remote sensors..
• Nodes can be fixed, mobile or satellite type
• A node can also be a special kind of node representing e.g., an entire Ethernet, FDDI, or Token Ring network and its aggregate traffic as one entity

Node Domain (3/3)

example (WLAN workstation)

Notice the structure (OSI reference model):

• Application layer
• Presentation & session layers (Application interface)
• Transport layer (TCP & UDP)
• Network layer (IP)
• Link layer (ARP, WLAN-MAC)
• Physical layer (receiver, transmitter)
Process Domain (1/5) – Modeling Single Processor Entities, Algorithms, Protocols, etc.

• Example: from node domain to process domain (TCP processor)

Process Domain (2/5)

• Process models are used to specify the behavior of a processor and queue modules, which exists in the Node Domain
  • A module is modeled as a finite state machine (FSM)
  • FSM consists of states with transitions and conditions between them
Process Domain (3/5) – The Source Code

• An example of “code level”

• States consists of OPNET flavored C or C++ code

Process domain (4/5) – Source Code Editor

• Process model editor is just a tool to ease the development of C or C++ source code of the desired model
Process Domain (5/5) - Attributes

- Example: the parameters of 802.11 WLAN MAC
- An easy way for the user to modify model attributes
- “Promote” functionality enables the attribute modification in the upper domains

Simulations (1/3) - Simulation tool

- With OPNET's simulation tool it is possible to combine several low level attributes and make series of simulation iterations
Simulations (2/3) – Running simulations

- The basic simulations with OPNET are done as a function of simulation time
  - Accurate network behavior
  - The level of event accuracy can be extended to be as detailed as needed
- Simulation results as a function of time are typically as such not suitable as scientific results, since statistical accuracy is needed
  - A certain situation can be first verified with a simple simulation run, but then several runs should be done with different random generator seed values.
- The typical scientific simulation results are graphs of average statistics drawn from several simulation iterations. As such, the OPNET’s basic analysis tool is not the best tool for drawing graphs like this, but it can be used to collecting statistics, and exporting them to a third party software.

Simulations (3/3) – A Result Example

- BC-MAC (NSCD) with BCCA clearly outperforms the traditional 802.11
  - Consider e.g., if an application desires packet losses below $10^{-3}$: BC-MAC can offer over 20 times more capacity than 802.11!
External System Domain (ESD)

- An external system is OPNET’s representation of a model whose behavior is determined by code external to OPNET.
- Such a model can be anything from a microchip to a model of user behavior pattern.
- OPNET passes data to the external system and receives data from it with no implicit knowledge of how the external code processed the data.

On the Physical Layer Modeling (radio link) (1/3)

- The physical layer is modeled with pipeline stages, which are used to calculate step by step the total effect of the physical transmission medium including all the interference caused by other users.
- Each pipeline stage is a model made with OPNET flavored C or C++.
On the Physical Layer Modeling (radio link) (2/3)

- The used pipeline stage models can be defined by transmitter and receiver attributes.
- General channel settings can be also determined with these attributes. The attributes can be also modified during the simulation by the processors.

On the Physical Layer Modeling (radio link) (3/3)

- Modulation curves can be edited with a special editor.
Radio link: Modulation curves

- Modulation curves specify the average SNR-BER behavior of the received packet segment
- SNR (or Eb/No) in OPNET is specified by received signal strength divided by received noise + total interference power
- Modulation curves can be simulated with external simulator (e.g., Matlab) and imported to model physical layer behavior accurately in needed special situations (fading channel, channel coding, interference suppression...)

Radio link: Antenna patterns (1/2)

- Specific antenna patterns can be defined
- (Example: UMTS station)
Radio link: Antenna patterns (2/2)

- Antenna pattern editor can be used to determine specific antenna patterns
- Basically each receiver and transmitter channel can be connected to antennas, which can have different patterns
- Antennas can be dynamically directed by processor modules during simulation
- Antenna Pattern tool is somewhat clumsy to use, but patterns can also be made with EMA-code (External Model Access) functionality

Packet format editor

- Packet formats define the internal structure of packets as a set of fields
- Illustrative and valuable tool in OPNET since the whole operation of the simulator is structured from packet basis
- An example of ARP-packet
Analysis Configuration tool

- A tool for plotting and analyzing the simulated results
- The tool is practical for quick analysis but is maybe not the best one for making publishable figures
- Provides also a possibility to write the selected results to a text file for latter analysis (i.e., enables the possibility to use an external analysis tool)

OPNET Products

Network R&D
- OPNET Modeler – The main tool
  + Wireless suite and Defense additions

Capacity planning and design
- IT Guru (network and system capacity planning for enterprises)
- SP Guru (network planning and engineering for service providers)

Network operations
- IT Sentinel (network audit, security, and policy-compliance for enterprises)
- SP Sentinel (network audit, security, and policy-compliance for service providers)

Application performance management
- ACE Standard and ACE Plus (analytics for networked applications)
- LoadScaler (application stress testing)
- SLA Commander (application service level monitoring)
- Panorama for QA (application pre-deployment analytics)
- Panorama for production (real-time application monitoring and analytics)
Additional Modules and Features for Modeler

- **DOCSIS** (Data Over Cable Service Interface Specification)
- **IPv6**
- **UMTS**
- **MPLS** (Multi-Protocol Label Switching)
- **PNNI** (Private Network-Network Interface)
- **Vendor Devices** (Dozens of vendor specific devices)
- **Terrain Modeling**
  - **TIREM** (propagation modeling calculation)
- **Satellite Capability** (dozens of models for satellite systems)
- **NETWARS** Communications Model Library (Military orientated models)
- **Integration with 3rd Party Products** (several modules)

Finally, for the rookies

- **OPNET online tutorial** is a good starting point for beginners
- Various tutorials guide the user through the basic functionalities of OPNET
- **Wide product documentation** is available to help the user through all the issues considering OPNET
- Especially discrete event simulation API reference manual (simulation kernel reference manual) gives valuable information about the function libraries of OPNET
Summary

- OPNET is event based (discrete time) network simulation tool
- The software is powerful but also demanding at least for the developers
  - Using only simulations is quite straightforward
- Modeling is done mainly in three levels
  - Network Domain (top level)
    - Upper levels hide the complex structure of the lower level components, which can be totally invisible to the end user
  - Node Domain
  - Process Domain
- Different layers and functionalities can practically be modeled as accurately as needed with external model access (EMA) and external system domain (ESD) functionalities
- OPNET includes various additional modules and tools for easing the usage of the software

References

- OPNET Modeler Wireless (version 10.0)
- OPNET (versions 10.0 (+ 8.1)) Online Documentation
- OPNET Technologies Ltd. WWW-page, http://www.opnet.com