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| Project | **IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>** |
| Title | **802.16 MAC Layer Modeling: A Common Simulation Framework** |
| Date Submitted | **2000-02-29** |
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| Re: | 802.16.1 MAC Task Group Call for Contributions on MAC Layer Modeling 2000-02-29 |
| Abstract | This document proposes a Common Simulation Framework (CSF) for evaluating 802.16 MAC proposals. A common framework is desirable to fairly compare the performance of different MAC implementations, as well as, to evaluate compromises between competing proposals. Such a framework must include consistent performance metrics and common traffic sources. Well-defined interfaces between modular traffic sources and the MAC are proposed to support independent MAC model development. This open approach allows for rapid integration of MAC models with CSF traffic sources and provides flexibility for incorporating new traffic modules. This concept has been previously supported for the 802.14 Working Group. |
| Purpose | The authors recommend standardizing a CSF for the 802.16 Working Group based upon previous efforts by the 802.14 Working Group. It is also recommended that the CSF be implemented with OPNET Technologies' OPNET Modeler, based upon commonality of approach with the 802.14 Working Group, the availability of an already existing CSF that could be modified for the 802.16 Working Group, and the availability of standard traffic sources, statistics probes, and models for other common communications standards. |
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# 802.16 MAC Layer Modeling: A Common Simulation Framework

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## Introduction

This document proposes a Common Simulation Framework (CSF) for evaluating 802.16 MAC proposals. A common framework is desirable to fairly compare the performance of different MAC implementations. Such a framework must include consistent performance metrics and common traffic sources. Well-defined interfaces between modular traffic sources and the MAC are proposed to support independent MAC model development. This open approach allows for rapid integration of MAC models with CSF traffic sources and provides flexibility for incorporating new traffic modules.

## Defining a Common Simulation Framework (CSF)

To satisfy the requirements of the members of IEEE 802.16, a simulation environment is needed which is:

- Flexible
- Scalable
- Fair
- Reasonable in run time, and
- Minimizes development time.

Collected statistics must be common to ensure fairness. In addition, the interfaces to the simulation environment must minimize complexity for the MAC model designer, while at the same time providing sufficient generality to easily incorporate new traffic source applications. The logical structure of the proposed framework and interfaces to the system under test are illustrated below in Figure 1.

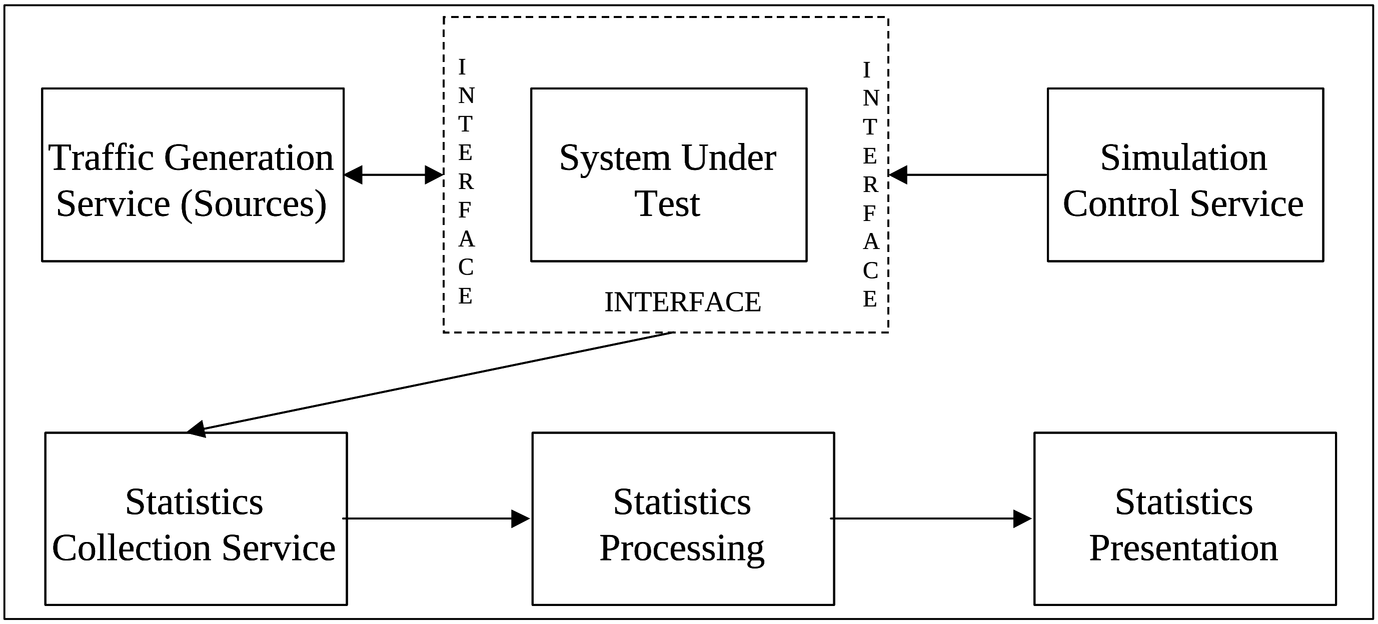


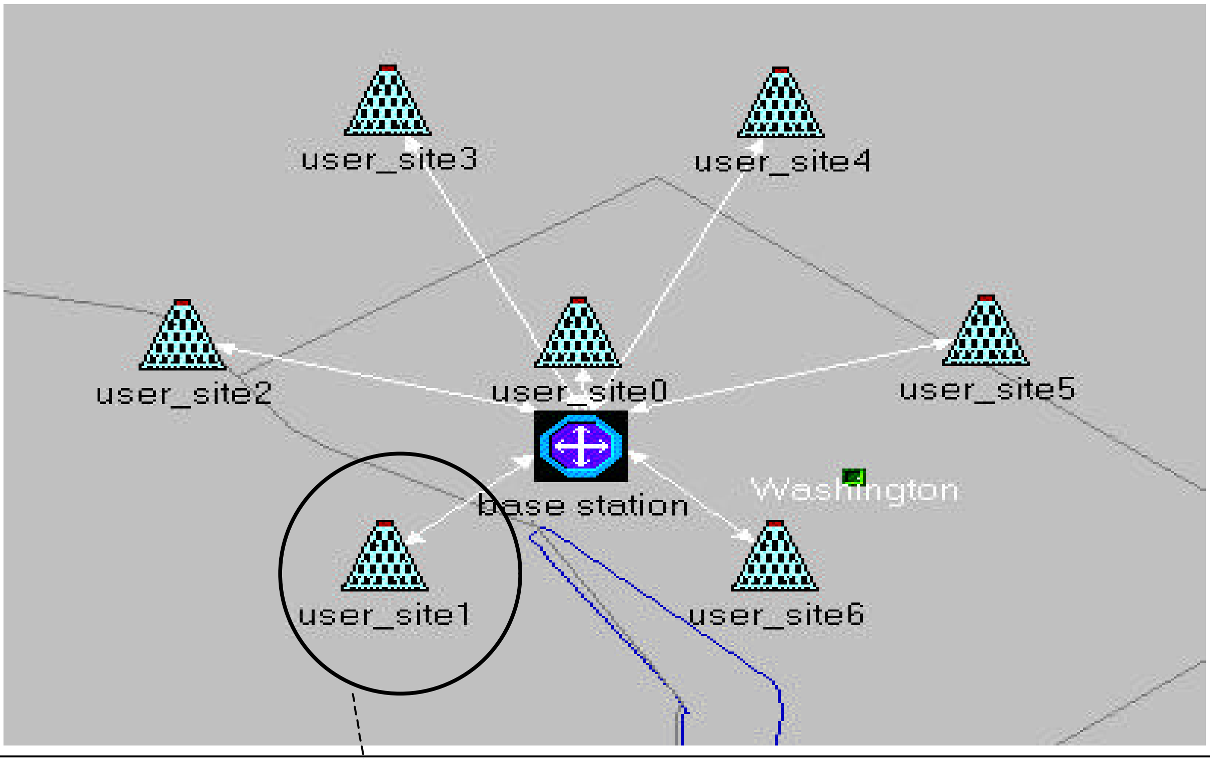
Figure 1: Common Simulation Framework

The system under test interfaces with the CSF in order to access three services:

- Traffic Generation – Generates messages from parameterized modular sources, each representing a different application.
- Statistics Collection – Collects standard performance statistics.
- Simulation Control – Provides control over test scenarios, including topology and simulation start/stop times.

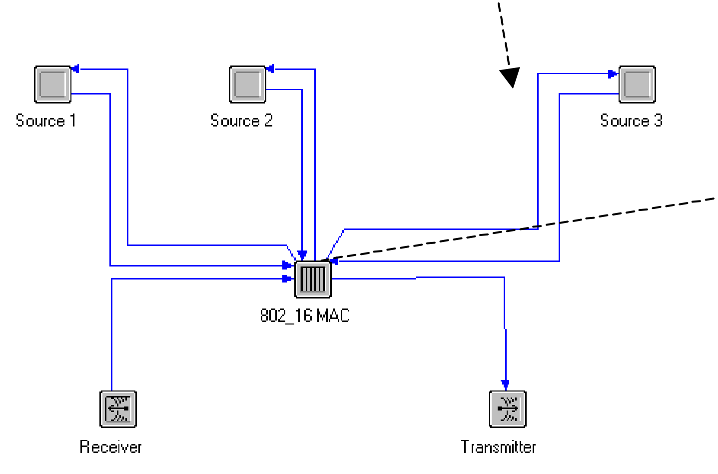
The concept and general architecture of a CSF exists independently of any specific implementation. Georgia Tech successfully implemented this approach for the 802.14 Working Group. Georgia Tech investigated simulation options ranging from custom C code development to commercial simulation tools, and decided to implement an 802.14 framework using OPNET Modeler. This framework was used in development of the DOCSIS standard. OPNET Modeler provides a modeling hierarchy that separates network topology, data flow, and control flow. The proposed framework implemented in OPNET Modelers hierarchical environment is illustrated in Figure 2.

**Network Topology**



Topologies are created by creating nodes (e.g., user sites, base station), as in the 7 user, 1 base station example above.

Example User Node



Example MAC Control Flow

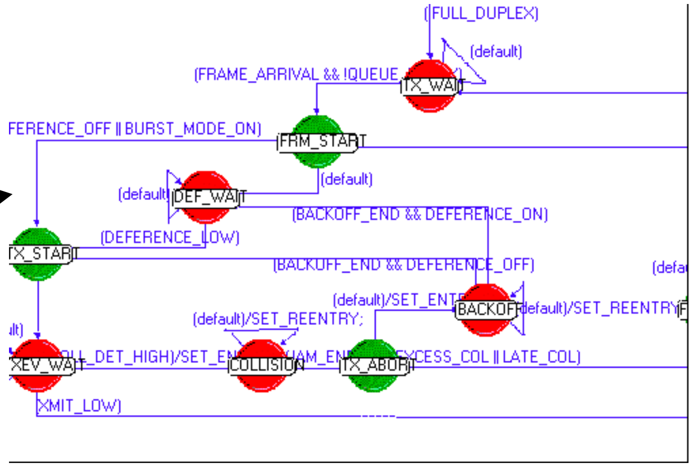


Figure 2: OPNET Modeler Implementation of a CSF

The primary purpose of the CSF is to conduct comparisons of MAC proposals using a common set of parameters determined by the 802.16 committee, although the CSF provides flexibility in determining simulation parameters. Users of the CSF define simulations at the Network Topology level and control the following:

- Number of user stations and position relative to the base station
- Parameters for traffic sources (type, session and message rates and time/size)
- Duration of simulation, random seeds, and statistics collection start and stop times.

To facilitate independent development of MAC models, there must be a published standard interface supporting the communication between the system under test and the three CSF services. Such an interface would allow a MAC developer to provide a MAC model to a third party without also having to provide access to the internals of the model. The CSF should support encryption of process models that are not part of the open standard to hide proprietary details without restricting behavioral properties in a system simulation. Interface specifications are the subject of the following sections.

## *Interface to Traffic Generation Service*

Common 802.16 traffic source models are necessary to fairly compare the performance of different MAC implementations. Ideally, the traffic sources should be designed to a published specification so that new sources can be easily added to all simulation experiments. Parameterized sources are necessary so that simulation studies can be conducted without modifying the underlying traffic source implementation.

The interface specification must define a standard data exchange format between the MAC and the traffic sources. This format must provide sufficient generality to accommodate a wide range of traffic sources. In the most general case, the interface must also support signaling between the traffic source and the MAC. An example of signaling is an STM telephony traffic source which requests a circuit and requires a response from the MAC before proceeding with a call.

A proposed data flow architecture for models of 802.16 stations is presented in figure 3. The data flow architecture is embodied in a class definition called a "node model," which can be instantiated an arbitrary number of times as "node objects" to specify the topology of the network. A node model consists of a set of packet processing elements called "modules," which are connected together. Even though station node objects are identical in structure, they are independent entities and can have different parameter values and state.

The traffic sources illustrated in this example consist of eight different applications. The modular approach provides significant flexibility by allowing currently unspecified traffic sources to be added in the future. Additional sources are added by simply creating a new module object and connecting it to the MAC.

The interface to the traffic generation service therefore consists of a mechanism supporting two-way information from the MAC protocol under test. This information consists of the following for each message:

| **Proposed Data Exchange Format with Traffic Generation Service** |
|---|
| Size – The size (in bits) of the message forwarded by the traffic source to the MAC (i.e., the data payload) |
| Message characteristics – Contains all the information about the nature of the message. In the simplest case may just be a type (e.g., data or voice) and a priority. |

| |
|---|
| Source address – Uniquely identifies the station originating the message. |
| Birth time – The time at which the last bit is created (seconds). |

## *Interface to Statistics Collection Service*

As with the traffic model discussed above, it is important to develop a view of performance metrics that is general enough to encompass all likely implementations of a MAC protocol, and is consistent with the traffic model. Just as the message is the basis of the traffic model, it is also the primary focus of performance metrics. The message is the smallest unit for which statistics will be gathered. If the statistics collection service is passed the length, type, time of birth, and time of delivery of each message that flows in the system, then any desired metric can be computed to characterize the performance of the traffic handling capability of the MAC under test.

This approach does not mean that the CSF supports generation of metrics related to all possible aspects of the performance of a specific system. For example, if a protocol uses mini-slots for reservations, it might be of interest to study the probability that a mini-slot might suffer a collision. That would be important knowledge for tuning the protocol. However, such questions are outside the domain of a general purpose framework for evaluating the comparative performance of alternative protocols.

The interface to the statistics collection service therefore consists of a mechanism supporting one way information flowing from the MAC protocol under test. This information consists of the following for each message:

| **Proposed Data Exchange Format with Statistics Collection Service** |
|---|
| Size – The size (in bits) of the message forwarded by the traffic source to the MAC (i.e., the data payload). |
| Message characteristics – Contains all the information about the nature of the message. In the simplest case may just be a type (e.g., data or voice and a priority. |
| Birth time – The time at which the last bit is created (seconds). |
| Delivery time – The time at which the last bit is received (seconds). |

Of course, each of these variables must be precisely defined to make valid comparisons between systems. The interface must be general enough so that, as the metrics evolve and change, it is not necessary to re-specify the interface.

## *Interface to Simulation Control Service*

The simulation control service provides testers with the ability to exercise a proposed MAC in diverse configurations as provided for by the following interface parameters:

| **Proposed Simulation Control Service Interface Specification** |
|---|
| Run time – Length of the simulation run (seconds). |
| Stat start time – Start time of statistics collection (seconds). |

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| Stat stop time – Stop time of statistics collection (seconds). |
| Random seeds – Simulation random seeds for statistical confidence |

# OPNET Modeler as the Basis for a CSF

## About OPNET Modeler

OPNET Modeler is a commercially available communications system simulator developed, maintained and supported by OPNET Technologies, Inc. OPNET Modeler was developed to test and assist in the design of communications protocols and to simulate network performance. It provides a hierarchical graphical interface for the definition of communications systems and protocols that progresses from a network view to a node view to a process view. A network is constructed by graphically connecting communications nodes via communications links. Nodes are constructed by defining connected process models. Individual process models typically represent different layers of the protocol stack, but are flexible enough to be user-definable. Process models are constructed by specifying state diagrams with conditional or automatic transitions. The behavior in each state is, in turn, defined by C code that is customizable by the user. Figure 3 shows examples of the OPNET Modeler graphical user interface for each of these three views.

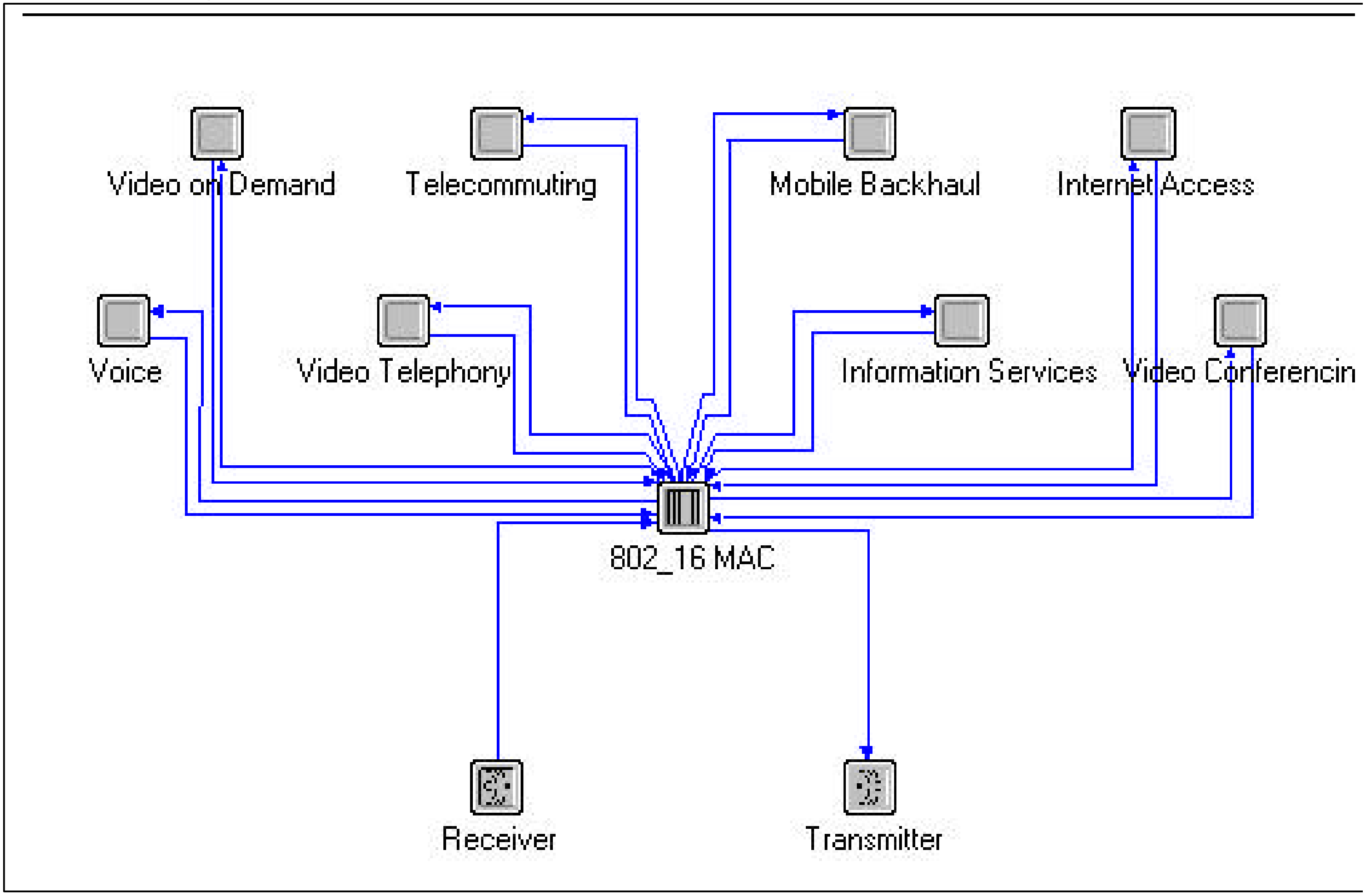

Figure 3: OPNET Modeler Graphical User Interface

OPNET Modeler is a discrete event simulator that runs on Windows based machines. The underlying code that defines the models is in C with specialized function calls available for facilitating communications simulation functionality. This includes calls to establish and manage queues, processing delays, event handling, random number generation based upon a variety of distributions, packet construction and encapsulation, and statistic collection

OPNET Modeler comes with an extensive standard model library. It includes common application traffic models, standard protocol models that have been used and validated by industry and academia, standard random variable distributions, and statistics probes. Collected statistics can be graphically displayed and overlaid with one another. A variety of representations of the statistics can be shown including discrete data, average values, standard deviations, etc.

In addition, OPNET Modeler with the Radio Module provides the ability to model propagation effects on higher layers of the protocol stack. This includes the ability to model propagation and transmission delays, line of sight calculations, and link budget construction including the ability to customize interference, rain fade, and diffraction models. The Radio Module comes with a standard RF “pipeline” that performs the basic modeling. The pipeline can be modified by the user to create specific propagation models for the problem to be studied.

OPNET Modeler is available to academic institutions at no cost to facilitate academic research in the areas of protocol development and testing, and evaluation of new network technologies. The software and the models are extensively documented with precise interface definitions. The documentation is available on-line or in published form. The software is professionally maintained with strict configuration management that ensures effective and consistent operation.

Specific features of OPNET that are applicable to the 802.16 MAC layer modeling effort include the following:

## Common Traffic Models

OPNET Modeler provides a variety of standard traffic models. This set of traffic models includes:

- Database
- E-mail
- FTP
- HTTP
- Multi-tier applications
- Remote login
- Video Conferencing
- Voice

In addition, there is a feature to provide customizable application traffic that is defined by the user. Potential traffic applications that could be developed include video on demand, video telephony, telecommuting, video gaming, and wireless backhaul.

These traffic source models can be layered on top of standard communications protocol modules. For example, the HTTP source model can be layered on top of the TCP/IP protocol model for a full closed-loop simulation of web usage. Also, since BWA is focused on business access, multiple traffic source types can be multiplexed onto a single MAC Node for traffic aggregation.

## Standard Communications Protocol Models

OPNET Modeler provides access to a vast array of standard protocol and device models that have been used and tested by industry and academia. These models are fully documented including well-defined behavior and interfaces. The set of available models includes:

- Ethernet models (all forms including switched Ethernet)
- Token Ring
- ATM (including LANE)
- FDDI
- Frame Relay
- SONET
- Bridging protocols (Ethernet, Frame Relay, Token Ring)
- TCP/IP (including QoS and VoIP)
- IPX
- PPP
- T1, T3
- DSL
- X.25
- Circuit switched models
- Routing protocols (RIP, OSPF, IGRP, EIGRP, BGP)
- 802.11
- DOCSIS

Also included are a wide variety of vendor specific devices including devices from 3Com, Ascend, Bay Networks, Cabletron, Cisco, Fore, Hewlett Packard, and Newbridge. This combination of readily available models provides the ability to test 802.16 performance internetworked with a range of different devices and protocols without the need to develop new models or integrate software packages.

## Application of Standard Traffic and Protocol Models to Simulate 802.16 Bearer Services

As stated above, OPNET provides a variety of standard traffic and protocol models. These models can be combined in a variety of ways to produce a CSF that simulates the 802.16 bearer services stated in the functional requirements document. Specifically:

- Audio and Video traffic sources are available to support digital audio and video multicast. OPNET is capable of supporting multicasting.
- Digital telephony can be supported through voice traffic models and circuit switched models.
- Existing ATM models are available.
- Robust IP models are available including a VoIP model.
- A variety of LAN bridge models are available.
- PPP and Frame Relay models are available.

## Radio Features

The OPNET Modeler Radio package also provides the ability to model radio wave propagation effects between transmitting and receiving antennas. This is accomplished through the RF pipeline. The pipeline determines equipment compatibility, line of sight availability, propagation and transmission delays, received power calculations, received noise calculations, and interfering power levels. The pipeline code is readily available to the user and can be modified to include specialized propagation models including rain fade, diffraction, and interference models. The effects of received S/N+I can be propagated to higher protocol layers to determine their performance under different environmental conditions.

### Using the Radio Pipeline to Simulate 802.16 PHY Effects on the MAC Layer

The radio pipeline in OPNET can be used to simulate several effects in the PHY layer. Transmission and propagation delay contributions to total delay and delay variation can be assessed, as well as, their impact on bandwidth assignment and node contention. Errors due to noise and interference can also be introduced in the radio pipeline. The pipeline can then be used to correct errors through simulation of an FEC algorithm. Remaining errors can be passed to the MAC layer for resolution by the MAC protocol. A variety of custom statistics can be developed to measure errored seconds and blocks. Attenuation from atmospheric conditions, LOS blockage and power levels can all be simulated in the pipeline. These effects can then be used to determine system capacity under a variety of conditions. In addition, the OPNET Terrain Modeling Module (TMM) can be used to model diffraction effects from terrain or buildings.

### Common Statistics

OPNET Modeler also provides a variety of common statistics for measuring network performance. These statistics can be generated for global values or for individual nodes and links in the network. Statistics can be viewed in a variety of graphical formats including discrete data values, PDF, CDF, histogram, average value, etc. Typical statistics that can be gathered include:

- Utilization
- Throughput
- Processing Time
- Queue Size
- Dropped Packets
- Received Packets
- BER
- End to End Delay
- Packet Inter-arrival Timing

Custom statistics can also be developed by the user to measure any variable associated with the simulation. This could include the measurement of:

- Errored seconds and blocks
- Cell capacity
- SLA compliance
- Link availability

## *Historical Use of OPNET Modeler as a CSF*

The 802 Committee has previously used OPNET Modeler as a CSF. Its first use was with the 802.14 Working Group. This effort was a joint project between Georgia Institute of Technology and OPNET Technologies, Inc. The 802.14 CSF is available for the 802.16 Working Group to modify for testing MAC layer proposals.

802.14 led to the establishment of the DOCSIS standard. The definitive DOCSIS model was developed with OPNET Modeler and is available for use by the 802.16 Working Group for modification, for at least one of the MAC layer proposals.

The availability of an existing CSF and a DOCSIS model for OPNET Modeler will provide significantly reduced time and effort to complete simulation studies of the 802.16 MAC layer proposals. Combined with the extensive standard model set, detailed documentation, and readily available support, OPNET Modeler provides the most effective simulation environment for this effort.

## Conclusions and Recommendations

This submission focuses on the philosophy of defining a common environment for performing protocol comparisons. This is the only way that true apples-to-apples comparisons between MAC protocols can be made. The 802.16 committee can define a CSF by defining specific offered loads, traffic scenarios and performance metrics. In this way, they are implemented once and then shared. Performance tests of MAC layer proposals can then be conducted independently. The results from these independently run tests will be directly comparable since the CSF ensures common traffic sources, protocols over which the traffic runs, environmental effects, and statistics collection methods. This approach was successful in 802.14 and can work in 802.16 as well. The authors conclude that developing a CSF is essential, independent of the tools used for implementation.

OPNET Modeler provides a tested environment in which to produce a CSF. It also has the functionality necessary to efficiently simulate 802.16 MAC layer proposals. There are a significant number of pre-modeled traffic sources, protocols, devices, and statistical probes available to facilitate construction of the CSF. With an OPNET Modeler based CSF, there would be no need to integrate disparate simulation software or code new models saving time and money in development effort. Where customized code is necessary, OPNET Modeler understands C/C++, which are widely understood. There is no need to learn a highly specialized scripting language. In addition, a CSF has already been built for the 802.14 standard that could serve as a baseline for the 802.16 efforts. The use of OPNET Modeler as the implementation software of the CSF will result in significant timesavings in the development of a design test environment for 802.16 MAC layer proposals due to this fact.

It is therefore recommended that the 802.16 Working Group develop a CSF for testing MAC layer proposals. This would exist in the form of specific models, interfaces, modeling scenarios and documentation. It is also recommended that OPNET Modeler be used to implement the CSF, and to act as a common environment for evaluating 802.16 MAC layer proposals.