NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

OPNET/STK INTEGRATED ENVIRONMENT FOR MODELING AN UAV NETWORK

by

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September 2003

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REPORT DOCUMENTATION PAGE				*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.				
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** September 2003	**3. REPORT TYPE AND DATES COVERED** Master's Thesis		
4. TITLE AND SUBTITLE: OPNET/STK Integrated Environment for Modeling an UAV Network				**5. FUNDING NUMBERS**
6. AUTHOR(S) Yang Shun Yu				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000				**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A				**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited				**12b. DISTRIBUTION CODE**
13. ABSTRACT *(maximum 200 words)* In this thesis, an OPNET/STK integrated model is used as an example to demonstrate the development of an UAV communication network. First, the concept of using an UAV as a mobile node in a network is addressed. Second, both OPNET and STK modeling tools are described in a separate chapter to describe each individual modeling characteristic. Third, an OPNET/STK integrated model is illustrated to show the characteristics of a combined environment and to analyze the interoperability and performance of this combined model. Finally, some recommendations and conclusions are stated for further study.				
14. SUBJECT TERMS OPNET, STK, C4I, HALE, UAV, Global Hawk, Wireless Communications, Network Centric Warfare, Network Centric Operation, Military Satellite Communication, Computer Models				**15. NUMBER OF PAGES** 63
				16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified		**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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OPNET/STK INTEGRATED ENVIRONMENT FOR MODELING AN UAV NETWORK

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING

from the

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ABSTRACT

In this thesis, an OPNET/STK integrated model is used as an example to demonstrate the development of an UAV communication network. First, the concept of using an UAV as a mobile node in a network is addressed. Second, both OPNET and STK modeling tools are described in a separate chapter to describe each individual modeling characteristic. Third, an OPNET/STK integrated model is illustrated to show the characteristics of a combined environment and to analyze the interoperability of these two tools. Finally, some recommendations and conclusions are stated for further study.

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ACKNOWLEDGMENTS

First, I want to express my deepest gratitude to my wife and my son for their understanding and continued support during the course of my studies and thesis work at the Naval Postgraduate School.

Secondly, I want to thank my thesis advisor, Professor Alex Bordetsky, for his superb advice and mentorship.

Finally, I would like to give special thanks to my thesis second reader, Professor Rex Buddenberg for the support he has provided.

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I. INTRODUCTION

A. BACKGROUND

Communications are the cornerstone of today's military forces. Without effective communications, the forces are limited to the capabilities within the scope and are sometimes isolated from the major player. In order to receive and transmit the message between units, the units need to be connected. However, this is not always possible because of the terrain or when the forces are beyond the communication range.

In the U.S. Naval Institute Proceedings, Vice Admiral A. K. Cebrowski outlines how military operations increasingly will capitalize on the advances and advantages of information technology. He specifies, “The shift from platform to network is what enables the more flexible and more dynamic network centric operation. Therefore, the construction of high quality networks is top priority.” [CAK98]

As the military continues into the new century, it must take full advantage of network centric warfare in order to gain situation awareness. A major player in acquiring the speed of command is a well-coordinated Command, Control, Communication, Computer, and Intelligence (C4I) infrastructure.

B. PURPOSE OF RESEARCH

The C4I infrastructure forms the foundation of unity and speed of command that is vital to conducting military operations. Before implementing the infrastructure, a modeling process needs to be taken into account in order to monitor both the budget and model's performance as well as the feasibility accordingly.

The purpose of this thesis is to demonstrate the integrated environment of the Optimum Network Performance (OPNET)/Satellite Tool Kit (STK) that can be used for modeling the Unmanned Aerial Vehicle mobile communication network. Model integration can promote the model's performance while the use of an UAV as a mobile node in a network can extend the communication range so that the forces can stay connected. Once the forces are connected, the network centric operations can then be implemented.

C. SCOPE AND METHODOLOGY

System integration is an important issue in many aspects. Model integrations play a key role in making the model's performance as close as possible to a real world scenario. For modern network simulations, both dynamic platform and terrestrial networks must be modeled. These two areas start from different environments so there must be some integration not only from a system point of view but also from a modeling standpoint. Although dynamic platform and terrestrial network models can work in collaboration, automated interface mechanisms between the two models should be devised to provide intimate real-time integration. [KYJ01]

In this thesis, an OPNET/STK integrated model is used as an example to demonstrate the development of an UAV communication network. First, the concept of using an UAV as a mobile node in a network will be addressed. Second, both OPNET and STK modeling tools will be described in a separate chapter to describe each individual modeling characteristic. Third, an OPNET/STK integrated model will be illustrated to show the characteristics of a combined environment and to analyze the interoperability and performance of this combined model. Finally, some recommendations and conclusions will be stated for further study.

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II. UNMANNED AERIAL VEHICLE NETWORK CONCEPT

A. INTRODUCTION

The current revolution in military affairs is based on information. Systems and concepts of warfare based on obtaining and distributing information have been created to meet this need. However, these systems need a flexible platform equipped with communication mechanisms to connect and relay information to each other efficiently. Current operational communications system rely on satellite-based equipment that is inflexible, finite, expensive, and overloaded. The use of an UAV as a central node in a network can address all four of these aspects. Furthermore, it can play a vital role in network centric operations.

B. CONCEPT OF OPERATION

1. Communication Network

Networking technologies have connected almost the entire world together. The concept of a Global Information Grid (GIG) communication network would power information limitlessly. [CHP02] The use of an UAV as a mobile node is an implement of networking. Moreover, this thesis explores the use of an UAV as a network node. Therefore, establishing the basic design parameters for a communication network renders it necessary to define some preliminary considerations before describing the model.

a. Types of Network

A Local Area Network (LAN), Metropolitan Area Network (MAM), and Wide Area Network (WAN) are all examples of communication networks. WAN covers a large geographical area. Typically, a WAN consists of a number of interconnected switching nodes. A transmission from any one device is routed through these internal nodes to the specified destination device.

A LAN is a communication network that interconnects a variety of devices and provides a means for information exchange among those devices. The scope of the LAN is small, typically a single building, or a cluster of buildings.

b. Switch Technique

For the transmission of data beyond a local area, communication is typically achieved by transmitting data from source to destination through a network of intermediate switching nodes. The switching nodes are not concerned with the content of the data. Rather, their purpose is to provide a switching facility that will move that data from node to node until they reach their destination. The end devices that wish to communicate may be referred to as stations. The stations may be computers, terminals, telephones, or other communicating devices.

c. Packet Switching

Data is transmitted in blocks called packets. A typical upper bound on packet length is 1,000 octets (bytes). If a source has a longer message to send, the message is broken up into a series of packets. Each packet consists of a portion of the data, or all of the data for a short message, that a station wants to transmit, plus a packet header that contains control information. The control information, at a minimum, includes the information that the network requires in order to be able to route the packet through the network and deliver it to the intended destination. At each node en route, the packet is received, stored briefly, and passed on to the next node. [SWC02]

2. Satellite Platform

Current operational communications systems rely on satellite-based equipment that is inflexible, finite, expensive, and overloaded. A geo-synchronous satellite operates at approximately 23,000 miles above the earth's equator providing constant 24 hours access. [TOM01] This is the altitude that a satellite must maintain to provide continuous coverage of a specific geographic area, approximately 1/3 of the earth.

Satellites are expensive to build and launch. The cost is not just measured in dollars. If anything goes wrong during the launch or while in orbit, repairs are impossible. The shuttle only travels to approximately 350 miles above earth. Therefore, it does not have the range to retrieve a geosynchronous satellite. If a problem should occur, there is no current way to repair it in orbit. The satellite becomes a liability if units are dependent on it for connectivity.

Current trends in technology also limit the usefulness of legacy systems. The usefulness of a satellite lasts only a few years before new technology overtakes the embedded circuitry. Since upgrading systems is impossible, a satellite quickly becomes obsolete. The advantage of an UAV is that it can be constantly repaired and upgraded with new technology.

3. UAV as a Mobile Node

The communications environment has a growing need for increased bandwidth, more satellite services, and enriched transmission capability at cheaper costs. An up and coming idea to help with this situation is the use of airborne communications nodes (ACN). These platforms will orbit at a high altitude for the purpose of relaying wireless services. Not only will these platforms be able to supplement the growing demand cheaper, it will also provide better security because of its higher altitude.

The concept of placing communications on these platforms in the stratosphere is ever-increasing. The stratospheric region of interest extends from about 39,500 feet to just below 100,000 feet. In a military environment, this altitude provides added security for UAV flight operations from enemy observation and retaliation. As the development of UAV becomes more sophisticated, using UAV as a mobile node for a communication network for today's military operations is understandable not only because it is beneficial but also essential.

Several platforms for UAV networking could be considered, yet the most popular militarily is Global Hawk. The Air Force has begun to study using Global Hawk as an ACN and has investigated some payload, flight, and frequency parameters. Table 1 lists the Global Hawk's characteristics. [USAF98]

Contractor:	Northrop Grumman Integrated Systems
Power plant:	Alison model AE3007H turbofan
Length:	44 feet (13.5 meters)
Height:	15 feet (4.6 meters)
Weight:	92000 pounds (3,680 Kilos) empty 25600 pounds (9,846 Kilos) gross
Wingspan:	116 feet (35.4 meters)
Speed:	Cruise 343 knots
Range:	Ferry 13,500 nm Mission 3000 nm with 30 hours on station
Loiter Altitude:	65,000 feet (19,810 meters)
Fuel Capacity:	14,500 pounds (5,800 Kilos)
Payload:	2,000 pounds (907.2 Kilos)
System Cost:	$15 Million per airframe
Ingress/Egress:	300 nm
Climb/Descent:	200 nm
Runway clearance:	5000 feet
Sensor Coverage:	40,000 nm square
Communications:	VHF/UHF voice UHF (SATCOM and LOS) X-Band (LOS) Ku-Band (SATCOM)

Table 1. Global Hawk Characteristics.

For the UAV to function as a mobile node in a network, several factors need to be considered, including but not limited to, loiter time, altitude, and payload. Access is one of the most important requirements for a local area network to operate effectively. This requirement dictates that an UAV must be available 24 hours a day with minimal disruption in service, similar to a Geosynchronous satellite. The use of Global Hawk can certainly fulfill this requirement.

This thesis uses Global Hawk as an example in demonstrating the UAV network concept. However, it is not necessary to use any prototype of an UAV. Furthermore, it would be costly if UAVs were used to test and evaluate (T&E) the performance of a network without doing simulation and modeling in advance, which is why OPNET and STK modeling tools are so critical and useful.

A generic network topology is shown in Figure 1.

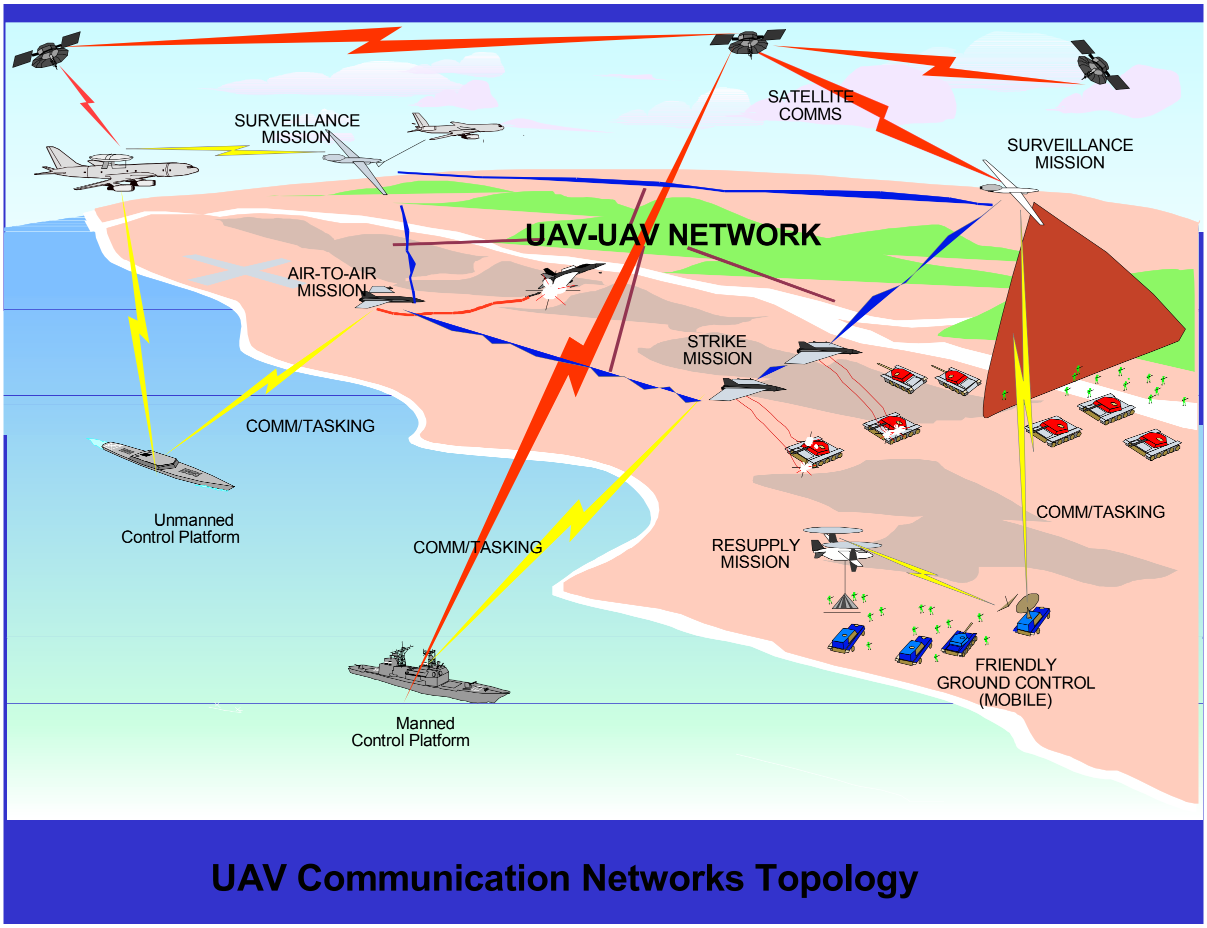

Figure 1. UAV Communication Network Topology.

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III. OPNET IN NETWORK MODELING

A. INTRODUCTION TO OPNET MODELING

1. Capabilities

The OPNET simulation software has the ability to build hierarchical network models and manage complex network topologies with unlimited sub-network nesting. It can model wireless, point-to-point, and multipoint links. This part of the software makes it a good tool for modeling networks.

OPNET can incorporate physical layer characteristics, environmental effects, as well as account for delay, availability, and throughput characteristics of links. OPNET has the ability to use geographical and mobility modeling by controlling each node's position dynamically or in predefined trajectories. Maps and other background graphics can be added to facilitate graphical representations for easier assimilation of data.

Results from OPNET are easily interpreted with comprehensive tools to display, plot and analyze time series, histograms, probability functions, parametric curves, and confidence intervals, which can be exported to a spreadsheet.

2. Various Models

The main advantage of this software is the vast library of models that are readily available and accepted within the industry.

a. Data Link Layer

- Asynchronous Transfer Mode (ATM)
- Ethernet
- Fiber Distributed Data Interface (FDDI)

- Frame Relay
- LAN Emulation (LANE)
- Link Access Procedure, Balanced (LAPB)
- Sliding Window Protocol (SWP)
- Spanning Tree Bridge (STB)
- Spatial Reuse Protocol (SRP)
- Token Ring
- X.25

b. Routing Protocols

- Border Gateway Protocol (BGP)
- Interior Gateway Routing Protocol (IGRP)
- Open Shortest Path First (OSPF)
- Routing Information Protocol (RIP)

c. Transmission Protocol

- Transmission Control Protocol (TCP)
- Transport Adaptation Layer

d. Network Layer Protocol

- Internet Protocol (IP)
- Resource Reservation Protocol (RSVP)
- IPX

e. Miscellaneous Models

- Applications Model
- ISDN/xDSL
- Job Service Discipline (JSD)
- Raw Packet Generator (RPG)
- Static Distributed Routing (SDR)
- Vendor Models
- Wireless LAN (802.11)
- Specialized Models

- Circuit-Switched
- DOCSIS
- IP Multicasting
- Multi-Protocol Label Switching (MPLS)
- Private Network-Network Interface (PNNI) [OPN01]

3. Radio Module

The Radio Module provides the added capability of modeling radio links and mobile communications nodes. Mobile nodes include ground, airborne and satellite systems. Mobile node models incorporate three-dimensional position attributes that can change dynamically as a simulation progresses. Node motion can either be scripted as a position history or determined on an adaptive basis by position control processes. Node movement can be automatically displayed during or after a simulation with OPNET's animation features. Network diagrams and animations can include standard or custom map backdrops.

B. OPNET IN MODELING UAV NETWORK

Brian Chau's LEO Satellite Network Model was chosen and downloaded from www.opnet.com to demonstrate the concept of an UAV network. [OPN00] The practical reason is that UAV provides many of the advantages that a LEO satellite possesses. Figure 2 depicts the Network Topology.

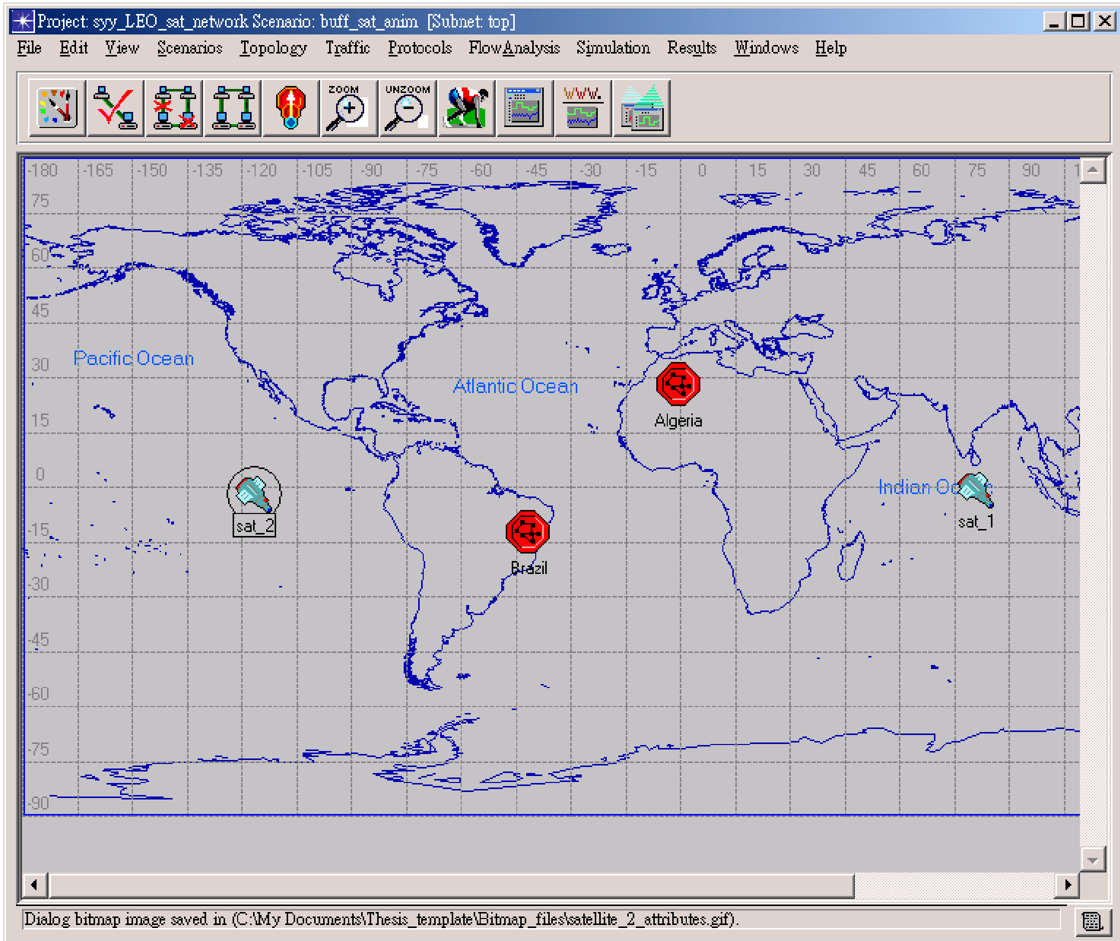

Figure 2. Network Topology.

From the README file, the author, Brian Chau, describes the model as follows:

> This project contains a simple radio network. It contains two sub-networks, one in Brazil and the other in Algeria. Mobile users from each sub-network generate traffic that is destined for broadcast in the other sub-network. This project studies the effect of using two low earth orbit (LEO) satellites with and without on-board data buffers.
>
> There are many different scenarios that measure the throughput and end-to-end delay through the network; each with different traffic loads. There are also scenarios that have animations

associated. The animations contain custom animation code. There are also two scenarios that produce scalar data, one for the buffered and one for the un-buffered satellite.

The mobile users sent data packets to the local base station using a CSMA protocol. This data is then queued at the base station until it can be uploaded to the satellite. In the un-buffered satellite case, the base station must wait to hear the control signal from the other base station before sending a packet. This ensures that the satellite has line-of-sight (LOS) to both base stations.

In the buffered satellite case, the base station waits until it hears its own control signal returned from the satellite. This ensures that the satellite has line-of-sight to the base station. For every control signal that is returned, a data packed can be sent to the satellite. It will be queued on the satellite until line of sight is established with the destination base station. [OPN00]

One could think of the model as two types of LANs, one in Brazil and the other in Algeria. The two units could not communicate with each other due to the nature of terrain and communication range. By using the UAV as a node, flights above these two LANs would connect the LANs at a rather low cost, preventing frequency interference, while the valuable satellites' resources could be spared for other paramount users.

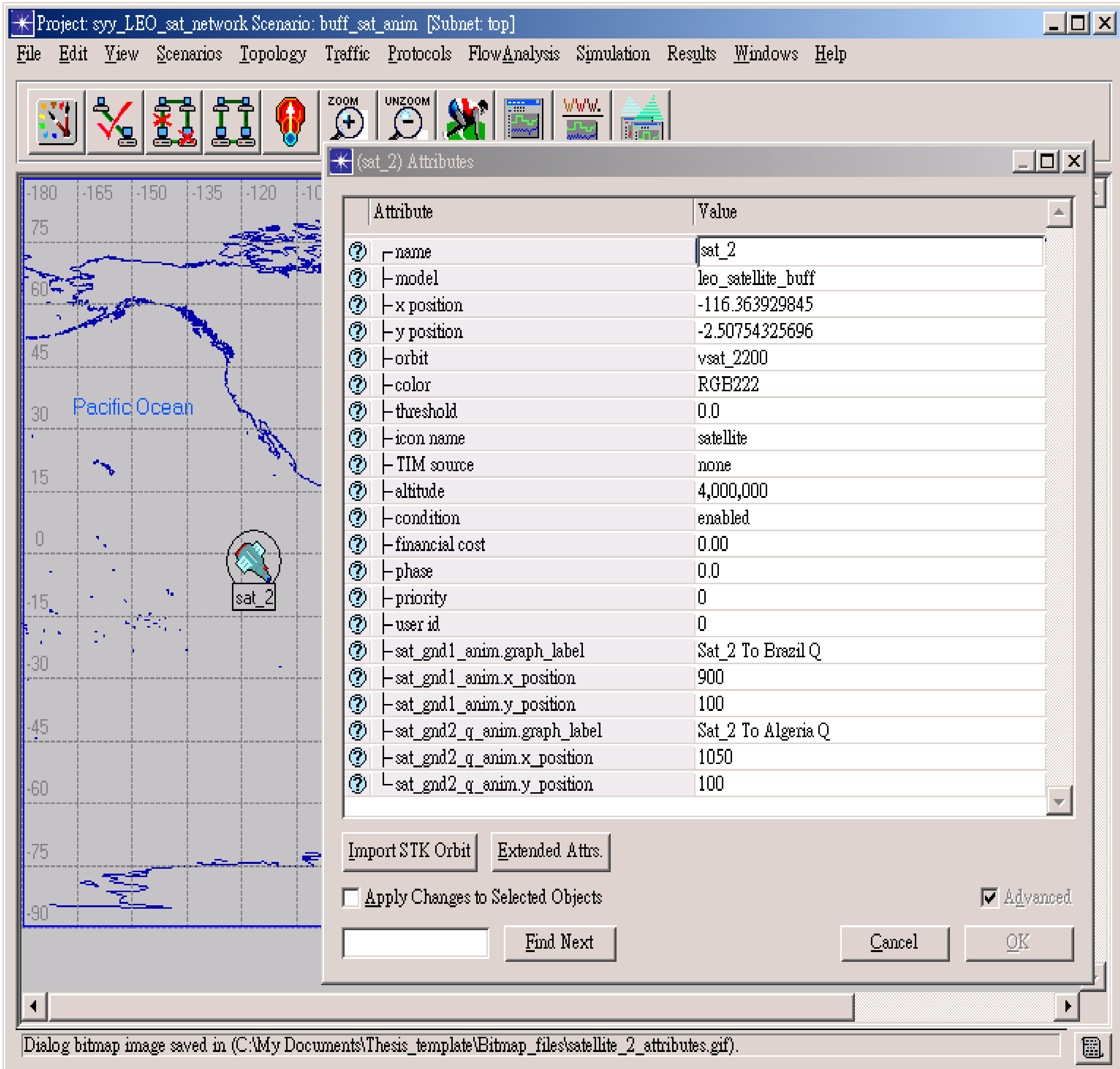

Figure 3. Satellite 2 Attributes.

Figure 3 shows the attributes for Satellite 2 and the Brazilian subnet. The attributes for the two satellites are identical and the two-subnet nodes, Brazil and Algeria, are also identical.

As shown in Figure 3, the attributes editor depicts a vsat_2200 orbit model that has 4,000,000 meters as altitude, which is insufficient and unrealistic for the UAV model. OPNET has a built-in pathway to import the Satellite

Tool Kit (STK) by Analytical Graphics, Inc. if the models provided are not sufficient. While OPNET is able to model orbit data as a standalone product, the interface enables the STK's user to import orbit data from that software into the OPNET Modeler/Radio, thereby eliminating a possible duplication of effort. [OPN03]

The Satellite Tool Kit is the widely accepted satellite simulation software. In the next chapter, the interface will be introduced and the orbital parameter will be created and imported into the OPNET.

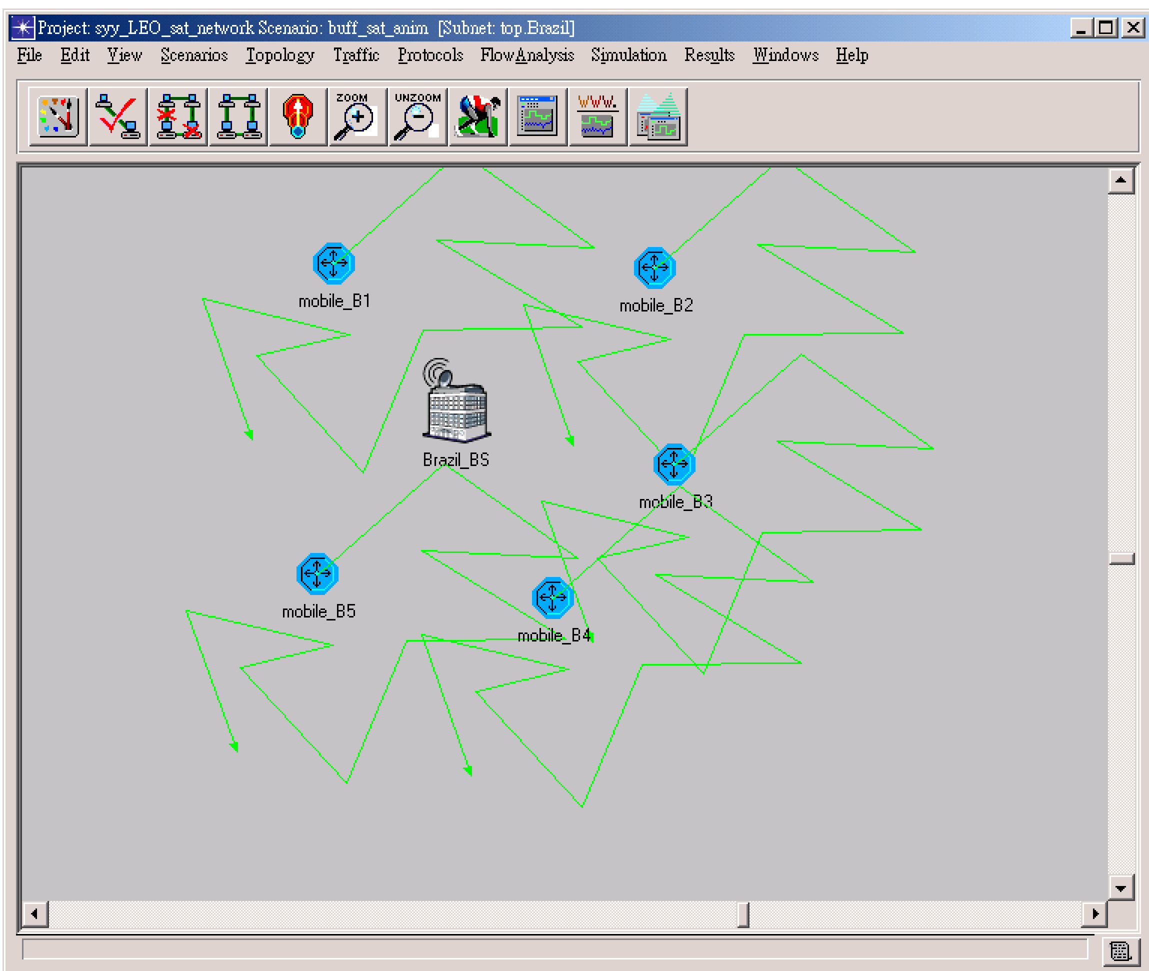

Figure 4. Brazil Subnet Node Architecture.

Figure 4 shows the Brazil subnet node architecture. Since OPNET uses a hierarchical set of graphical editors, a user can progressively develop more detailed attributes for the nodes by clicking on each one of the nodes. One can view the Brazil subnet by double clicking. The zigzag lines in Figure 4 are the trajectory paths that were defined by a series of 11 Cartesian coordinates. By right clicking on the mouse, one can edit this attribute in the same manner. The mobile node attributes and base station attributes are shown in Figure 5. For the base station, the minimum receiving frequency is 350 MHz, minimum transmitting frequency is 300 MHz, and the altitude is set at 300. The node is a leo-sat base-station model in OPNET. A user can modify this by clicking on the description and then editing. Mobile node attributes within the subnets are set at 50 for altitude and a ground speed of 2 meters per second. The node is a leo-sat-mobile model, which can be modified in the same manner as the base station node.

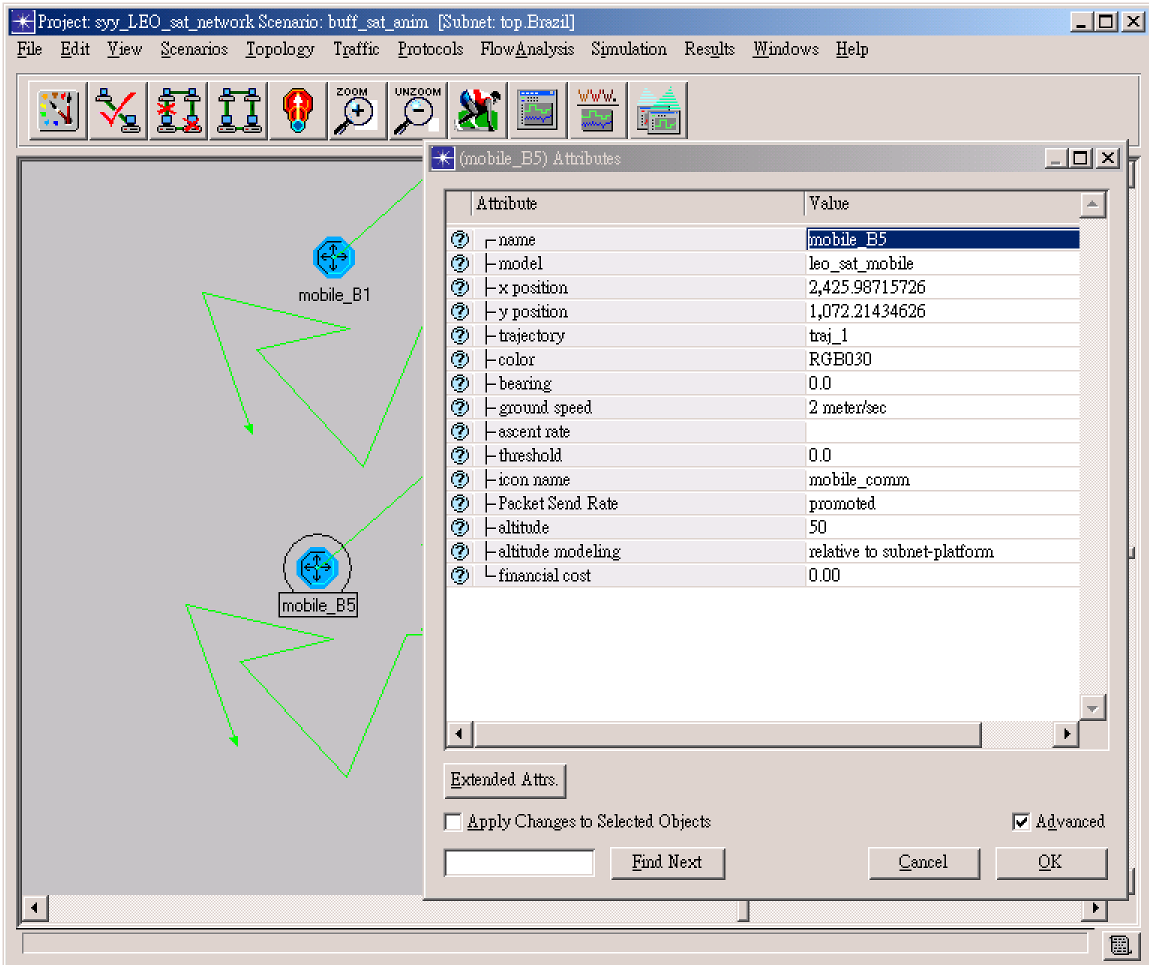

Figure 5. Mobile Node Attributes.

The mobile nodes are all identical and the architecture can be seen through the node editor in Figure 6 below. Data flow and the physical resources are depicted in the editor. Network devices and the system can be edited by right clicking the mouse. The antenna model is isotropic, which has a uniform gain in all directions. The pointing reference theta is 180 degrees. The other option is directional in that the user must define the pattern.

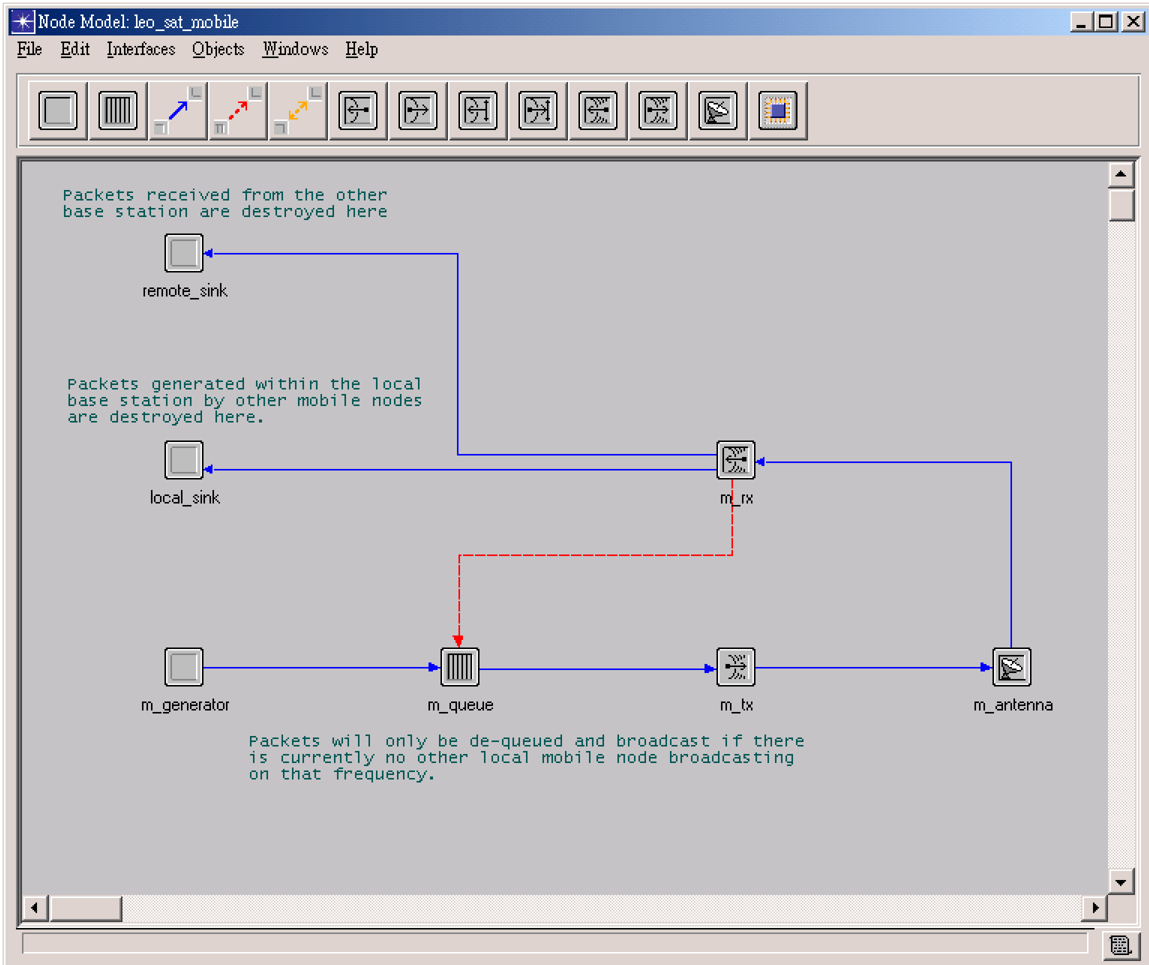

Figure 6. Mobile Node Architecture.

By double clicking m_queue, m_generator, local_sink, and remote_sink, the Process Editor can be opened so as to graphically specify the level of detail for these processes in response to events. The Process Editor in OPNET uses a finite state machine (FSM) approach to enable the user to specify the details. Default settings are provided with the model. However, the attributes can be modified. Packet generators use an exponential distribution instead of a constant, and this could be modified via the Editor.

Transmitter modules transmit packets to the antenna at 1024 bits/second, using 100 percent of its channel bandwidth. For each arriving candidate packet, the receiver module consults several properties to determine if the packet's average BER (bit error rate) is less than some specified threshold. If the BER is low enough, the packet is sent to the sink and destroyed. [OPN01]

The processor module calculates the latitude, longitude, and altitude coordinates that the antenna requires for a specific target. The pointing processor makes this calculation by using a kernel procedure that converts a node’s position in a subnet, described by the x position and y position attributes, into the global coordinates the antenna requires. [OPNO1]

C. NETWORK PERFORMANCE

In Figure 7 below, on the left hand side, a user can select the statistics to view for further analysis and the results of the analysis are shown on the right. The quantity and detail of reports are scalable in OPNET. In this example, nearly all of the options are selected for the thru-8-pph scenario. The statistics gathered are delay, queue size, throughput, and load. Global statistics as well as individual subnet statistics are computed.

A user can change the collection mode for different statistics. These modes specify the way in which statistics are captured (all values, bucket, sample, glitch removal), as well as their collection mode. [OPN0l] Additionally, the sample frequency can be manually set for each collection mode selected.

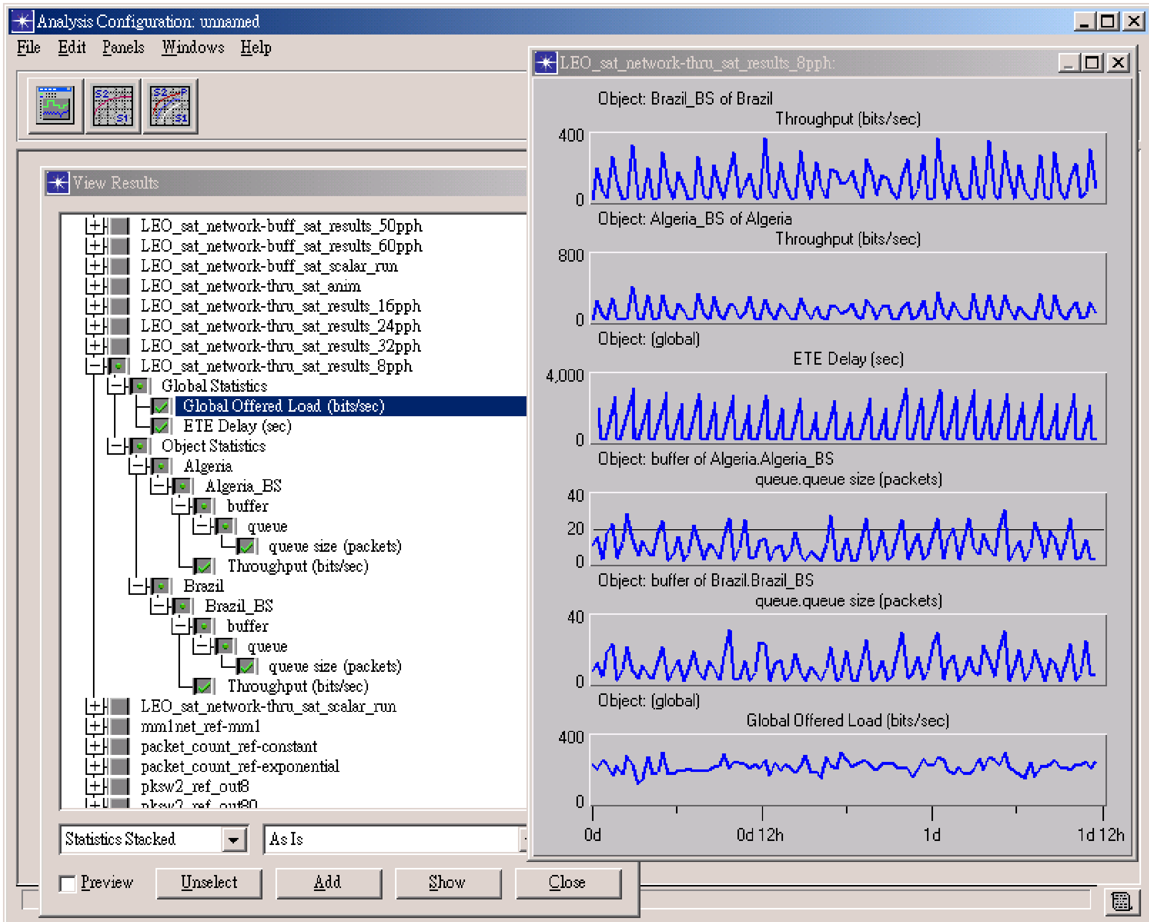

Figure 7. Statistics.

Figure 8 demonstrates the animation viewer whereby events for a particular scenario are visually displayed. The buffers for each satellite flash on the screen in the upper left hand corner bar charts once the animation begins to run. The relative size of the queue is shown in red. Blue and green lines flash for varying lengths of time to indicate the transmission of packets. The satellites change their position periodically and only one satellite at a time is actually shown communicating with the ground base stations. Toolbar options at the top of the window allow the user to control the animated simulation.

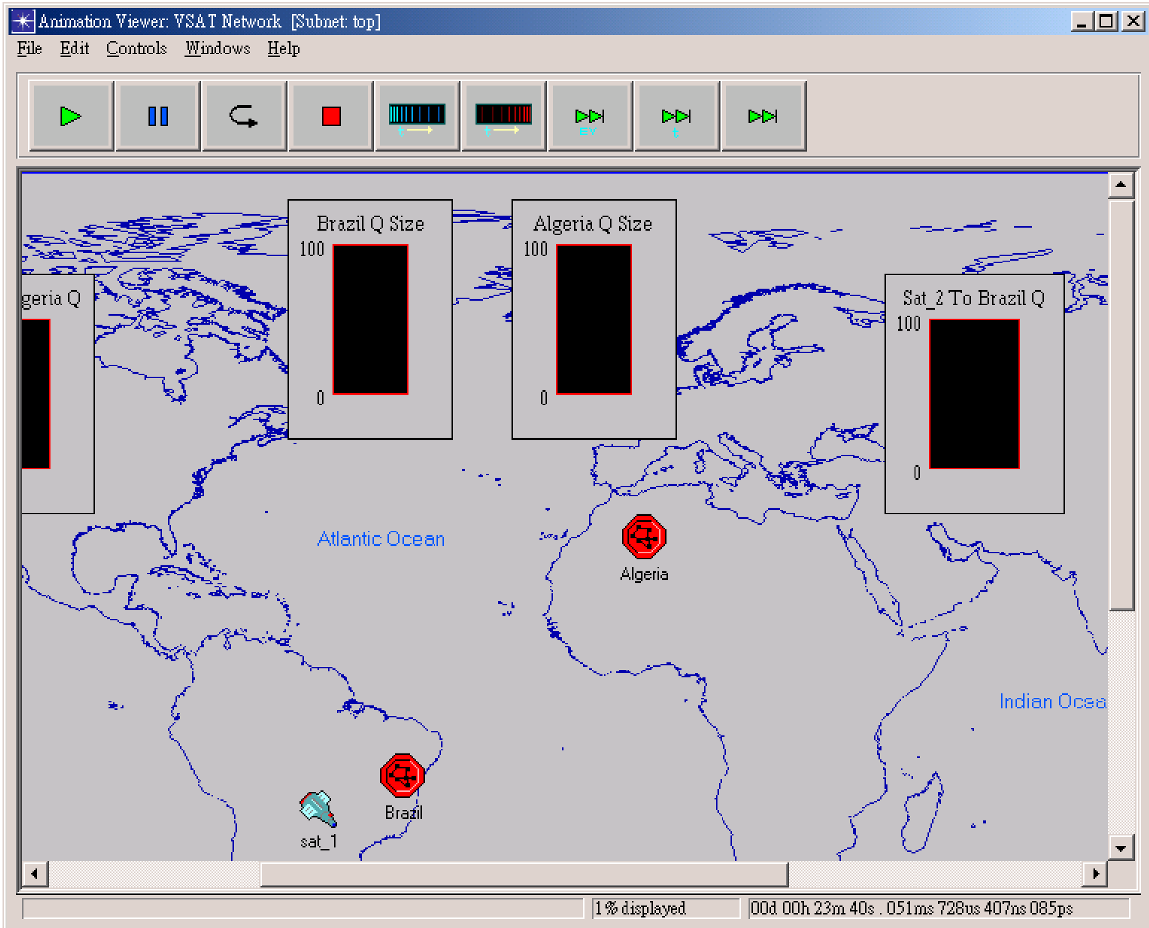

Figure 8. Demonstration of Animation.

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IV. STK IN AIRBORNE PLATFORM MODELING

A. INTRODUCTION TO STK MODELING

STK is the commercial-off-the-shelf (COTS) analysis and visualization tool that supports aerospace, defense, and intelligence initiatives. The STK makes it easy to analyze complex land, sea, air, and space scenarios and determine optimal solutions with the ability to present results in graphical and text formats for easy interpretation and analysis.

STK provides the analytical engine to calculate data and display multiple 2-D maps to visualize various time-dependent information for satellites and other space-related objects such as launch vehicles, missiles, and aircraft.

1. Key Features

a. Analytical Capability

STK includes complex algorithms that take care of number-crunching exercises in a matter of seconds. With STK, the user can quickly and accurately calculate a satellite's position and attitude in time, evaluate complex in-view relationships among space, air, land and sea objects as well as compute satellite and ground-based sensor coverage areas.

b. Orbit/Trajectory Generation

STK provides multiple analytical and numerical propagators (Two-body, J2, J4, SGP4, imported ephemeris data) to compute satellite position data in a wide variety of coordinate types and systems.

c. Visibility Analysis

Inter-visibility access times between any STK objects can be calculated and displayed on the 2-D map during animation. These times can be reported and graphed as visibility timelines. The STK can calculate access between all types of vehicles, facilities, targets, and sensors to all objects, including planets and stars, within the scenario. In addition to simple line-of-sight, these visibilities can be constrained by geometric constraints such as sensor field-of-view, ground- or space-based minimum elevation angle, azimuth angle, and range.

d. Sensor Analysis

Sensor fields-of-view can be added to ground- and space-based STK objects to provide an additional level of fidelity to the visibility calculations. These time-varying sensor coverage areas are displayed on the 2-D map and can be pointed either via a user-specified azimuth and elevation angle or targeted at another ground or space-based object.

e. Attitude Analysis

Standard attitude profiles generated within STK, external attitude quaternion files, provide a means to analyze attitude motion and its effect on various STK calculated parameters.

f. Visualization of Results

STK allows users to view all time-dependent information in a variety of 2-D map displays. Multiple maps with different styles can be displayed at once. Time can be animated forward, reverse and in real-time to display scenario dynamics: space and ground-based object positions, sensor coverage areas, visibility status, lighting conditions and star and planet positions. Output can also be recorded as streamed map images.

g. Comprehensive Data Reporting

STK features a number of standard report and graph styles that summarize key information. With access to hundreds of data elements, the user can also create custom reports or graphs for individual objects or a group of objects. All reports can be exported in industry-standard formats for export into popular spreadsheet tools. [STK03]

2. Analysis Modules

a. STK/ASTROGATOR

This supports interactive, orbit maneuver planning for Earth-orbiting and interplanetary missions. STK/ASTROGATOR includes finite and impulsive burn modeling, targeted maneuver sequences, fuel usage calculations, and multiple constrained stopping conditions. All STK/ASTROGATOR calculations are supported by a variety of sophisticated drag models and numerical integrators.

b. STK/ATTITUDE

This provides the capability to assess numerous attitude profiles within a single trajectory. User-defined vectors and axes can be used to define new attitude profiles. Attitude view adds the capability to see results in 3-D of any propagated attitude projected into any desired reference frame. Environmental forces and open or closed-loop control can be accounted for using the attitude simulation capability.

c. STK/CHAIN

This extends STK pair-wise access capabilities with multi-hop link analysis and constellation analysis for complex networks. In addition to visibility periods, STK/CHAIN also provides information regarding the nature of the link, such as the angle between consecutive objects and the number of potential visibilities for each object.

d. STK/COMMUNICATIONS(STK/COMM)

These provide dynamic link performances and RF interference analysis for communication networks. It includes gain contours, RF environment modeling, multiple antenna types, laser communication link modeling, and the full spectrum of link analysis parameters.

e. STK/CONJUCTION ANALYSIS TOOLS (STK/CAT)

These tools conduct proximity analysis to determine potential collisions, laser firing opportunities, and launch windows.

f. STK/COVERAGE

This performs detailed coverage analysis of user-defined geographic regions over time. The STK/COVERAGE allows users to evaluate a variety of figures of merit (FOM) to optimize systems design and mission planning.

g. STK/MISSILE MODELING TOOLS

These offer a high fidelity missile propagator that simulates all events of unclassified/classified missile flights, including boost, staging, post-boost maneuver, deployment, and re-entry as well as interceptor capabilities.

h. STK/PRECISION ORBIT DETERMINATION SYSTEM (STK/PODS)

This system provides precise orbit determination that uses space and ground based observation data to accurately predict spacecraft orbits and related parameters.

i. STK/ORBIT DETERMINATION(STK/OD)

This processes spacecraft tracking data to determine orbits and related parameters such as tracking system biases. In addition, STK/OD calculates a realistic assessment of the orbit and bias estimate errors, which can be used to verify accuracy requirements of proposed systems and planned mission schedules.

j. STK/RADAR

This analyzes both mono-static and bi-static radar systems and supports operations in Synthetic Aperture Radar (SAR) and Search/Track modes.

k. STK/SCHEDULER

This provides a powerful scheduling and planning application. Users define tasks and resource requirements, request schedule solutions, and analyze results via a Graphical User Interface (GUI) or Application Program Interface (API).

l. STK/SPACE ENVIRONMENT

This predicts the ionizing dose rate and total radiation dosage, South Atlantic Anomaly(SAA) entry/exit times, vehicle equilibrium temperature and exposure impacts from debris along an orbit or trajectory. [STK03]

B. STK IN MODELING AIRBORNE NODES

As addressed in the previous chapter, the attributes editor depicts a vsat_2200 orbit model that has 4,000,000 meters as altitude, which is insufficient and unrealistic for the UAV model. For a deployed UAV, the orbit shall be arbitrary and unlimited to fit the mission’s need.

In line with the OPNET model, two rectangle orbits are created for the two UAVs in STK. One flight is above the Brazil LAN and the other flight is above the Algeria LAN.

Due to the geographical range, the two LANs could not communicate with each other. Using the UAV that served as a relay node, it will connect the two LANs while valuable satellite resources can be freed for other fundamental users. The STK modeling environment is depicted in Figure 9.

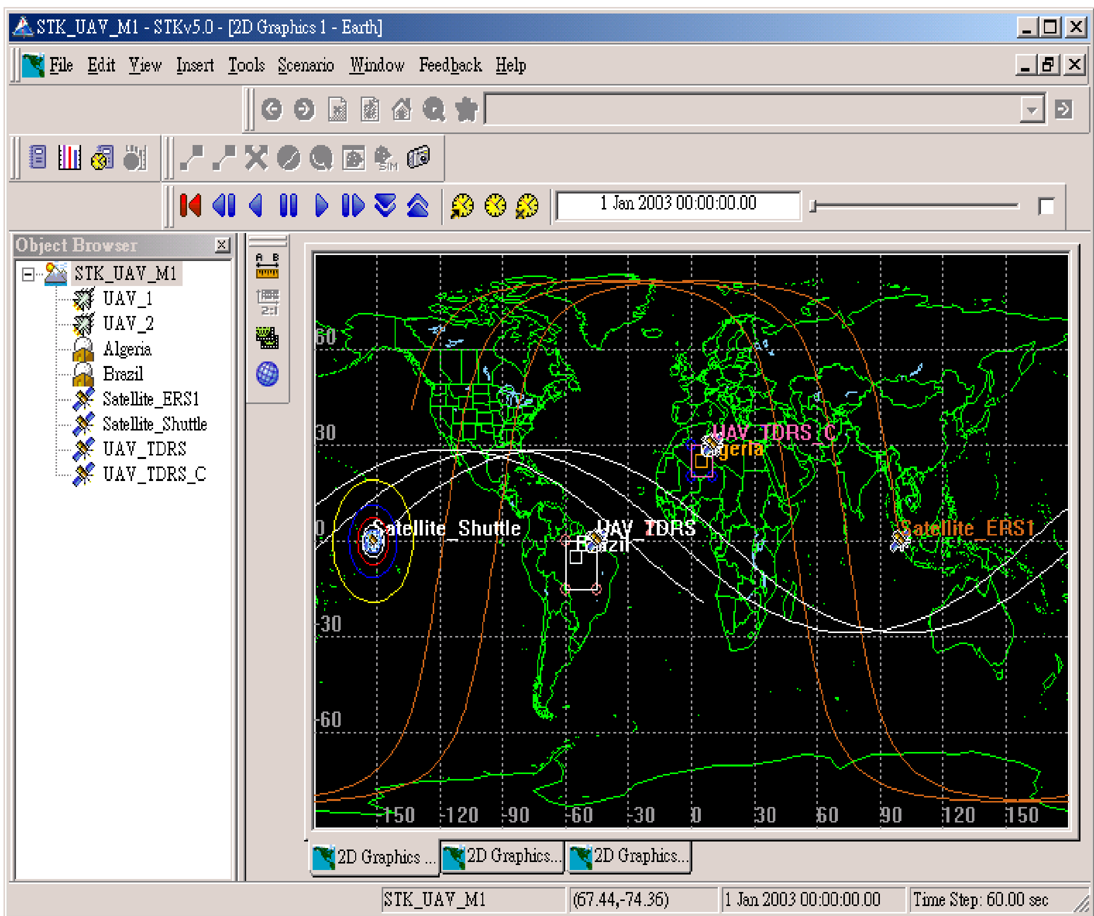

Figure 9. STK Orbit Design Environment.

The users could set up the flight path parameters in STK, such as longitude, latitude, altitude, flight speed, acceleration, and turn radius for the UAV to operate. In this example, the altitude is set as 19,000 meters and the flight speed is set as 343 knots so as to reflect the Global Hawk characteristics. The UAV orbital parameters are created and depicted in Figure 10.

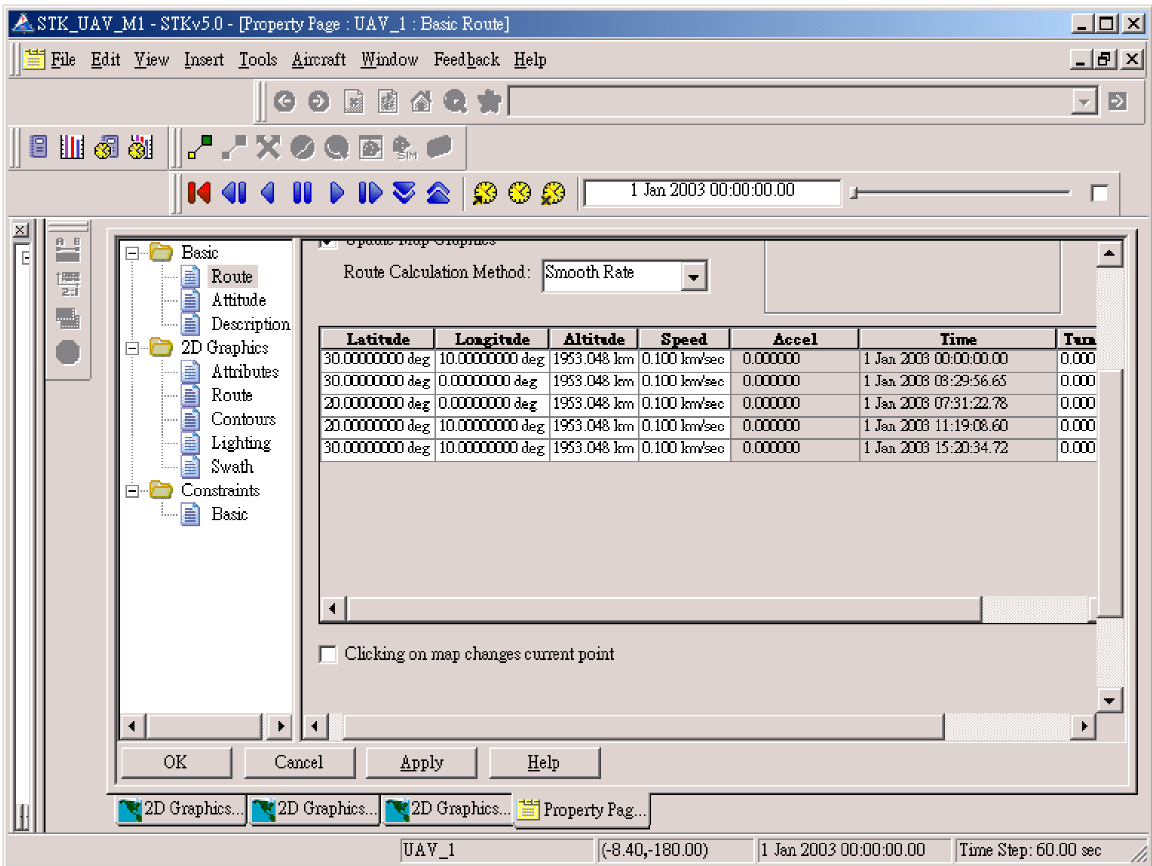

Figure 10. UAV Orbital Parameters.

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V. OPNET/STK INTEGRATED MODEL

A. INTRODUCTION TO OPNET/STK MODEL INTEGRATION

The main purpose of M&S is to get the most equivalence out of the proposed model in order to gain the benefits from the model. However, one model tool may be strengthened in certain domains while the other model tool may be good in other areas that might cause a certain level of the model's insufficiency. In other words, models could not reflect the equivalence because of the lack of an integrated mechanism for a specific need.

The success of modeling the mobile network relies mostly on how well the mobile nodes are modeled. Models need to be able to reflect reality. Otherwise, the model would be useless. The tool OPNET has been used mainly for network-performance modeling and simulation. However, it fails to represent dynamic nodes in the mobile network. In contrast, STK is strong in mobile platform modeling and analysis but lacks a network-performance analyzed mechanism. Therefore, combining these two tools should illustrate the behavior of the dynamic node in the mobile network with sufficient network-performance support.

For modern network simulations, both dynamic platform and terrestrial networks must be modeled. System modelers will first augment existing network simulation models with dynamic behaviors. These two areas start from different environments so there must be some integration not only from a system point of view but also from a modeling standpoint. Although dynamic platform and terrestrial network models can work in collaboration. Automated interface mechanisms between the two models should be devised to provide intimate real-time integration. [KYJ01]

B. MODELS INTEGRATION

In the previous chapter, the attributes editor depicts a vsat_2200 orbit model that has 4,000,000 meters as altitude, which is insufficient and unrealistic for the UAV model. For a deployed UAV, the orbit shall be arbitrary and unlimited to fit the mission's need.

An interface for the OPNET Modeler/Radio allows users to import orbit data for use in the performance analysis of communications satellites. The OPNET's interface into STK is designed to provide users with more flexibility as they tailor the modeling and simulation environments to study the performance of proposed and existing satellite-communication networks. While OPNET is able to model orbit data as a standalone product, the interface enables STK's users to import orbit data from that software into the OPNET Modeler/Radio, thereby eliminating a possible duplication of effort. [OPN03]

Prior to importing data from STK into OPNET, the STK orbit files need to be created. The OPNET converts the orbit file into an .orb file and store the file in the op_models directory. Only .v or .sa format orbits files created in STK 3.0 or higher can be converted. [OPN03] Figures 11 and 12 depict the integrating process.

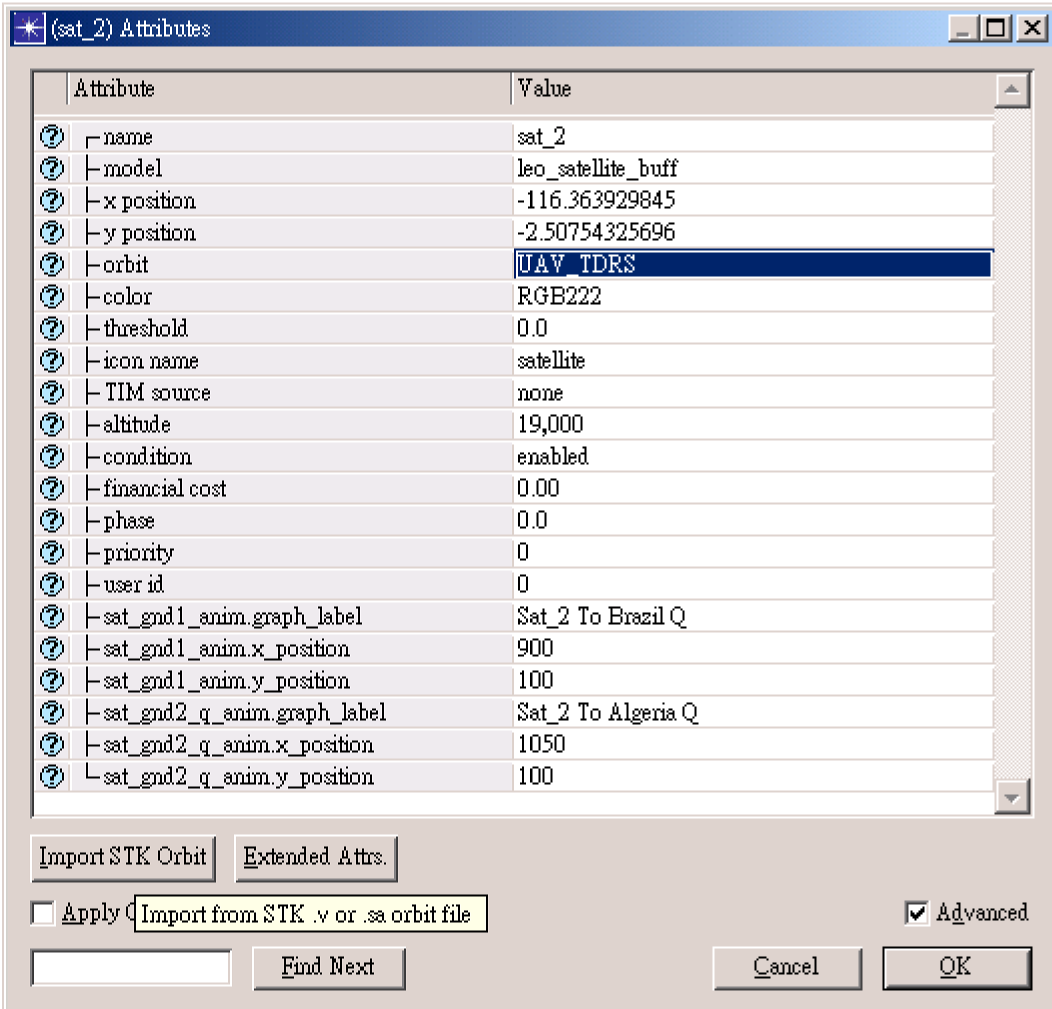

Figure 11. STK/OPNET Integration.

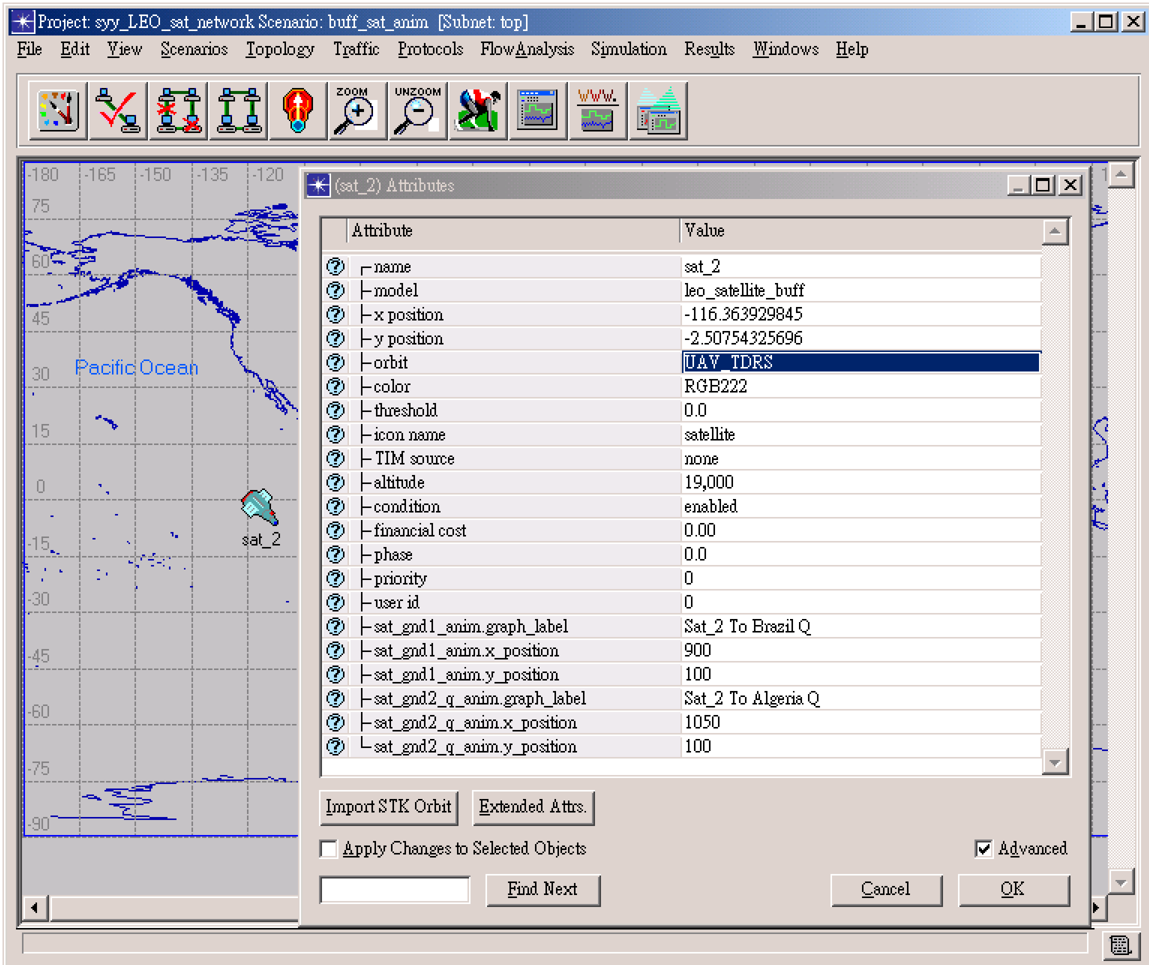

Figure 12. STK/OPNET Integration.

C. MODEL ANALYSIS

For network simulation, the Measure of Performance (MOP) such as latency, delay, queue size, and throughput should be consistent with the overall combined network of dynamic platform and terrestrial systems. [KYJ03] The OPNET/STK integrated environment is used to model the UAV in a communication network. From the modeling and simulation perspective, the best effort is to integrate different modeling tools so as to exam the interoperability of the proposed model. In other words, those MOPs for the integrated modes shall not be significantly different before and after the integration. Figure 13 shows the statistics of this integrated model. Figure 14 demonstrates there is no significant difference before and after integration.

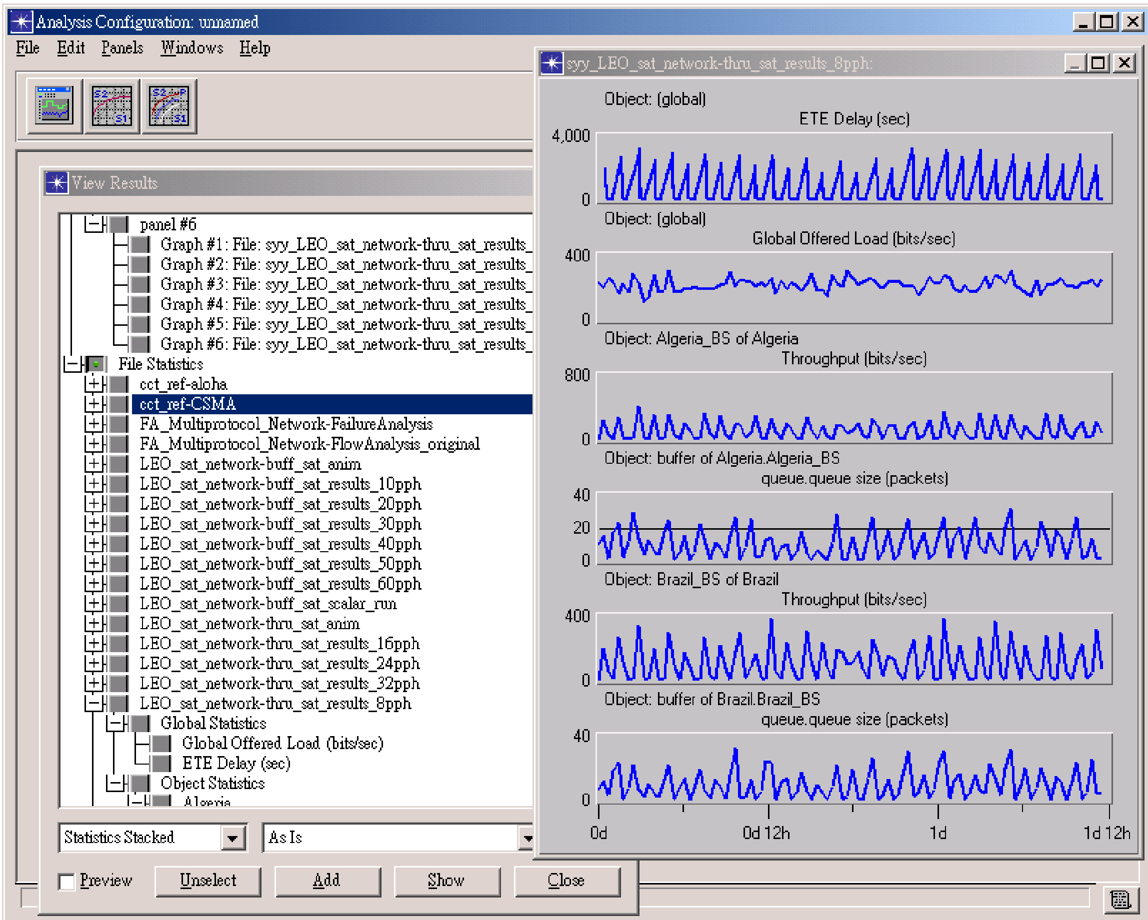

Figure 13. STK/OPNET MODEL Statistics.

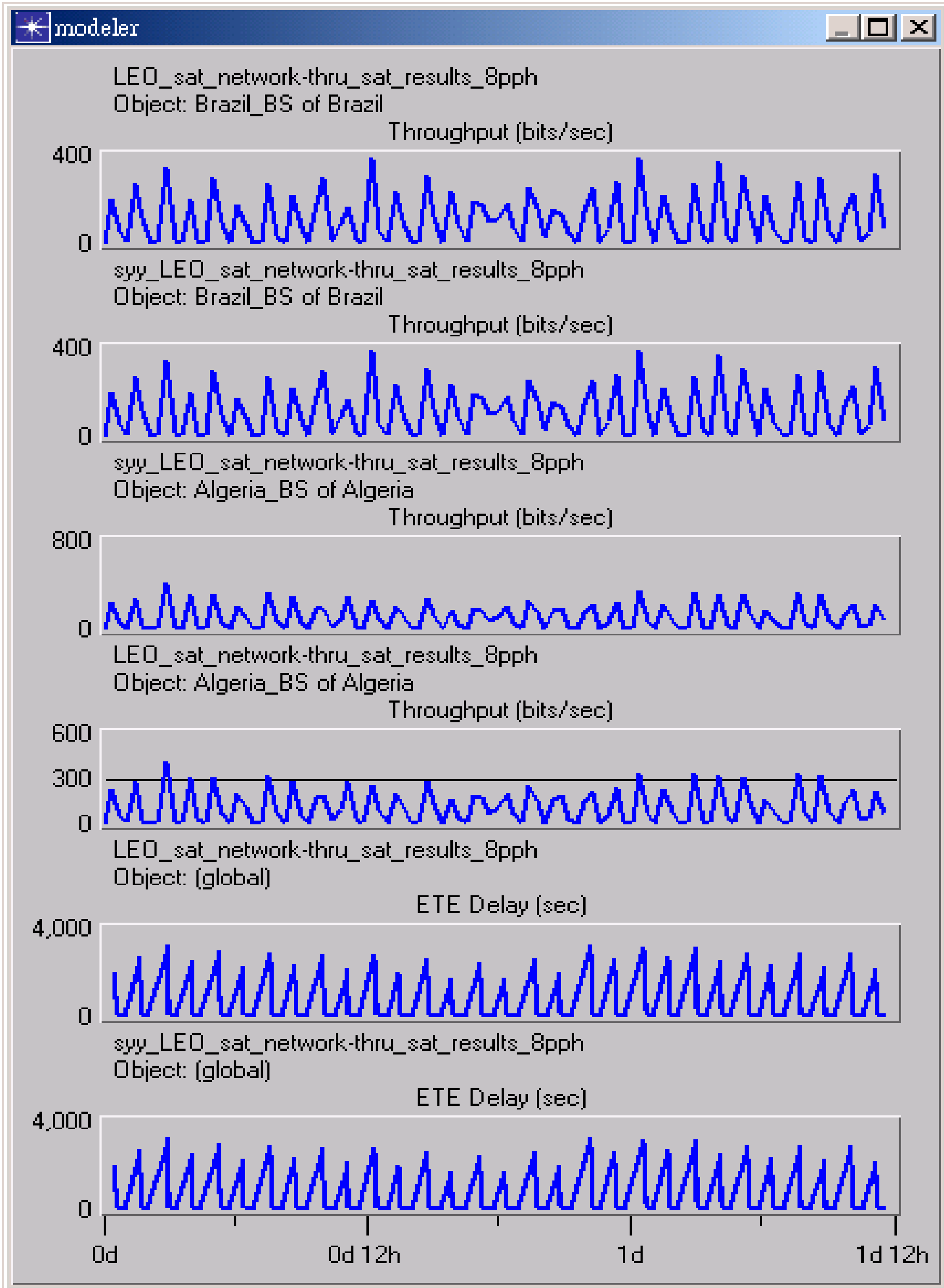

Figure 14. Comparison of Before and After Integration.

VI. CONCLUSION AND RECOMMENDATIONS

A. SUMMARY

The concept of using UAV as a mobile node in a communication network and the OPNET/STK integrated environment were addressed. Furthermore, both OPNET and STK modeling tools were introduced in separate chapters to demonstrate each individual modeling characteristics. Finally, the OPNET/STK integrated model was illustrated to show the characteristics of a combined environment and to analyze the interoperability and performance of this combined model.

B. CONCLUSIONS

The author arrived at several conclusions during the course of this research. The following are considered the most pertinent. The research conducted provided support for the UAV concept as a viable option and should be further studied. The following are the most viable conclusions drawn from this research:

- The use of an UAV as a mobile node will free up valuable satellite time allowing currently constrained systems to operate more efficiently. The UAV is not a replacement for satellite communications but a complement to its capabilities.
- The success of modeling the mobile network relies heavily on modeling the mobility of the node within the network and STK can support the modeling of these mobile nodes.
- The combination of OPNET/STK provides sufficient capability to study the mobile platform within the terrestrial network.
- The interoperability between OPNET and STK works pretty well, however, the importing process is

limited and awkward. For the UAV data files created in STK to be eligible to be imported to OPNET, the format has to be either .v or .sa, furthermore, it takes several conversions to make the UAV data files to be the .sa format, this does not reflect the reality properly when the subject is simply the UAV.

The following difficulties were discovered with this model:

- Although the orbital parameter can be modeled and shown in STK, however, those movements could not be seen in OPNET.
- Although OPNET is a powerful and effective modeling and simulation tool, incorporating various attributes from a link budget such as altitude, transmitter power, and bandwidth can require significant time in order to gain the familiarity necessary to run the system.
- Due to the complexity of the model, it is difficult to test the feasibility of the network communication plan, and how attenuation factors, i.e. rain, dust, and noise would affect the performance of the model.
- The OPNET can model many data link layer protocols, i.e., ATM, FDDI, Frame Relay, nevertheless, none of these protocols reflect the characteristics of a multi-nodes radio based network. The illustration used masks this shortcoming by limiting the radio-nodes to two, i.e., a point-to-point radio link, however, when numerous exist as suggested in Figure 1, the need for a Medium Access Protocol (MAC) becomes apparent. Since general purpose MAC protocol for radio-WANs do not exist, therefore neither OPNET nor STK model them.

C. RECOMMENDATIONS

The research conducted in this thesis suggests that the use of an UAV as a mobile node in a communication network is a feasible option. Further research using the modeling and simulation tools OPNET and STK for this concept is justified. Significant savings in money and efforts can be attained from these insightful and flexible tools.

Link budgets that analyze current operational parameters are necessary before conducting any further research using OPNET/STK. Also, link analysis that reflects future communication requirements should be made. A best effort case scenario from link analysis is needed before any modifications to the contributed model are completed. Otherwise, the model may be dramatically inaccurate and useless.

OPNET provides a jammer node that introduces noise into the network. This should be introduced in later research in order to provide a more accurate depiction of a real world scenario.

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