Design for a Satellite Communication Link in a Space Based Internet Emulation System

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Introduction

- Satellite communication is based on *Line of Sight* principle
- The Earth Observation Satellites (EOS) communicate with GEO relay satellites such as TDRSS to transmit their information to the Earth stations
- Each EOS satellite has a fixed time slot to transmit its data to TDRSS

Problem Definition

- EOS satellites need to have *high data rate* and *high capacity* recorders to store data onboard
- Communications systems on satellite is *satellite-specific*
- Each satellite needs to have its communication frequency, protocol and command structure
- This approach leads to incompatible and non-reusable communication components

Proposed Solution: SBI Approach

- Create a *Space Based Internet (SBI)* between the satellites and ground stations
- Each satellite would be capable of switching traffic between other satellites and ground stations
- Communication protocol would be Internet Protocol (IP)
- IP eliminates the need for any satellite-specific communications systems or any specialized ground station equipment

SBI Approach

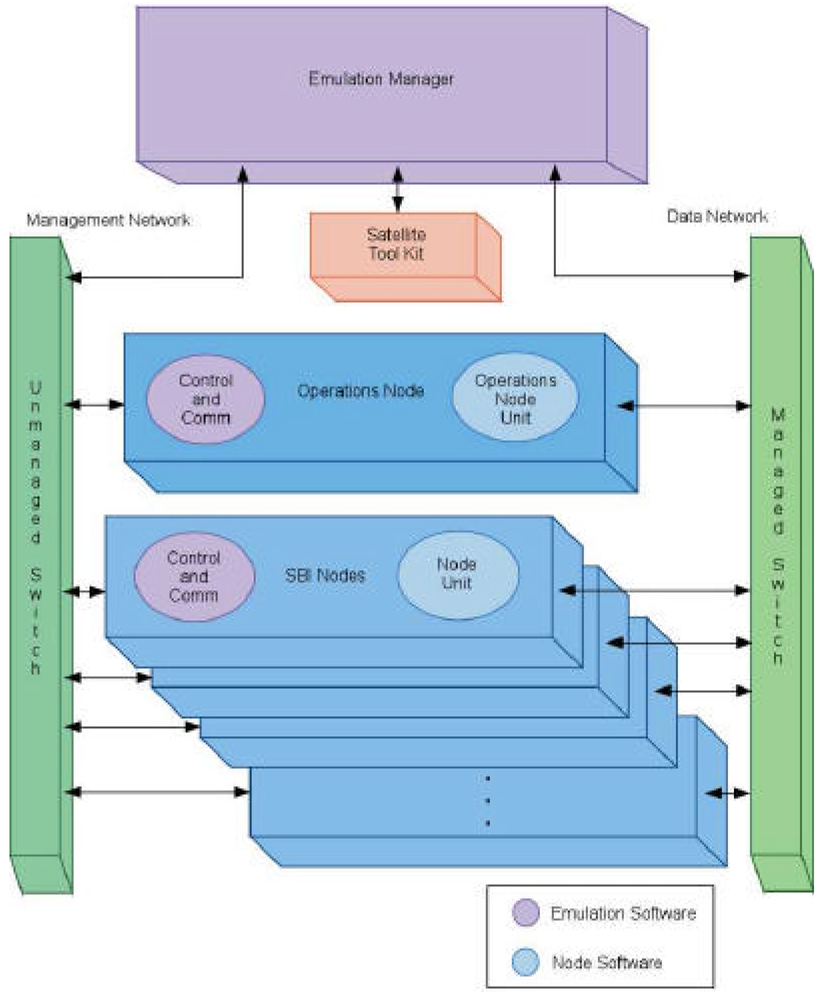
- Apply wireless Ethernet network technology to near-Earth satellite systems
- Develop innovative topology and routing algorithms suitable for satellite systems
- SBI network software contains standard modules that can be deployed to minimize the individual satellite cost
- Evaluate and test the SBI software on an emulation system that will model a satellite system

SBI Emulation Approach

- Execution of actual scenarios on the SBI system hardware with the nodes executing SBI network software
- Emulate communication channels on the satellites and ground stations
- Emulate the features of satellite transmission link on the Ethernet connections between the SBI nodes
- Model the data traffic and measure the network performance using KU NetSpec system

SBI Emulation System

- SBI Nodes
  - Emulation Nodes representing satellites and ground stations
- Emulation Manager
  - Controls and monitors the entire emulation scenario
- Emulation Network
  - Data Network - for data transfer between the nodes
  - Management Network - Control and status communication between the Emulation Manager and the nodes



SBI Node Types

- Standard capacity Data Observation and Routing satellites
- High Capacity Routing Satellites
- Ground Stations for collecting and routing data
- Operations Facility
  - Acts as a centralized ground station
  - Responsible for Data Instrument Scheduling
  - Establishes network topology and routing protocols

Emulation Manager

- Reads the configuration files and maintains logs of the network
- Creates and deletes connections between the nodes
- Responsible for interactive control of the scenario
- The Emulation Manager software on the nodes emulates the communication links between the nodes

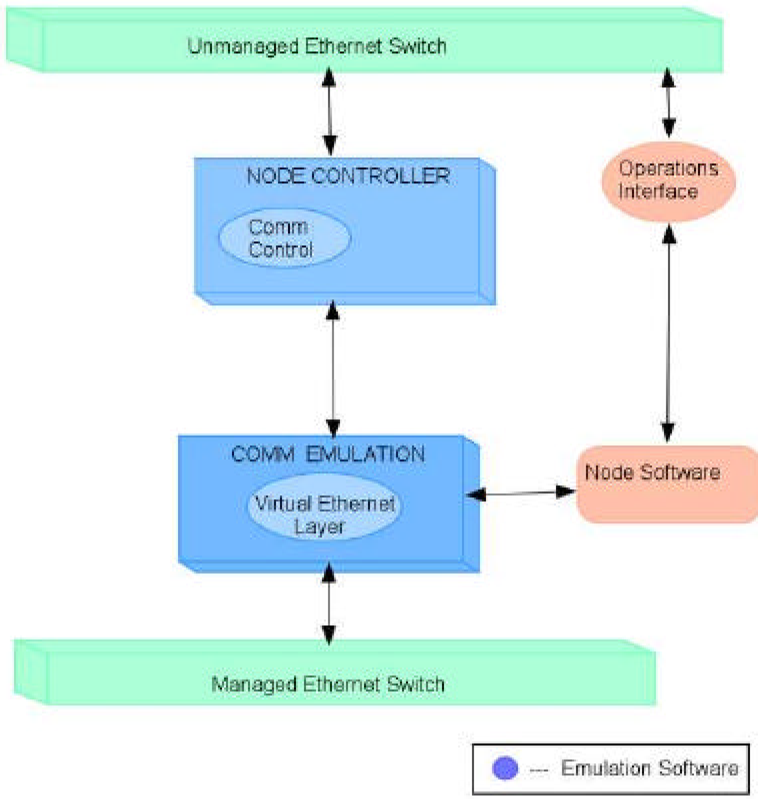
Emulation Networks

- Data Network
  - Emulates the communication channels for data transfer between the SBI nodes
  - Utilizes managed Ethernet switches for switching data traffic

- Management Network
  - Control commands from the Emulation Manager to the nodes
  - Status monitoring information from the nodes to the Emulation Manager
  - Scheduling commands and routing information from the Operations Node to the respective nodes
  - Utilizes unmanaged Ethernet switches

Node Emulation Software

- Node Controller
  - receives Control commands
  - transmits Node Status information
  - *Comm Control* controls communication emulation
- Operations Interface
  - information from Operations Node
- Comm Emulation
  - models space communication on the connections between the nodes



Communication Emulation

- Emulate multiple Virtual Ethernet (VETH) interfaces to facilitate multiple point-point connections on a single node
- A point-point connection represents a communication link
- Following features of the communication link are emulated:
  - CBR traffic by performing bandwidth limitation on the connection
  - Simulate link propagation delays occurring on actual satellite links

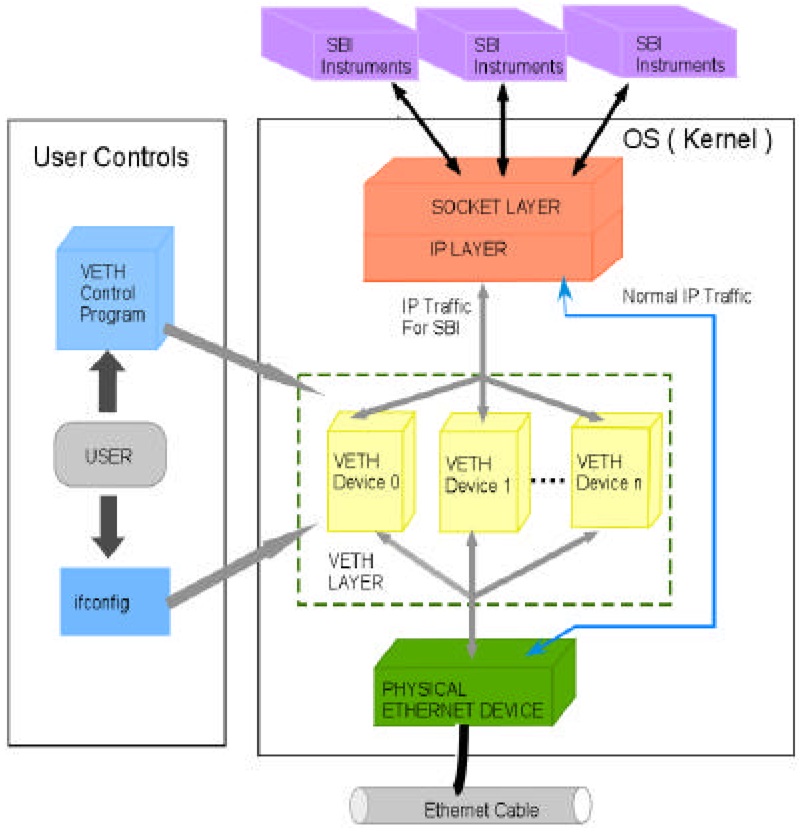
Virtual Ethernet (VETH)

Virtual Ethernet (VETH)

- Models multiple communication channels over a single physical Ethernet interface
- Each VETH device represents a communication channel on the SBI nodes
- The VETH is a layer between the IP layer and the physical Ethernet layer in the Linux Kernel
- VETH devices are controlled and configured by the *veth controller* module, a part of the emulation software

VETH : Network Layers and Controls

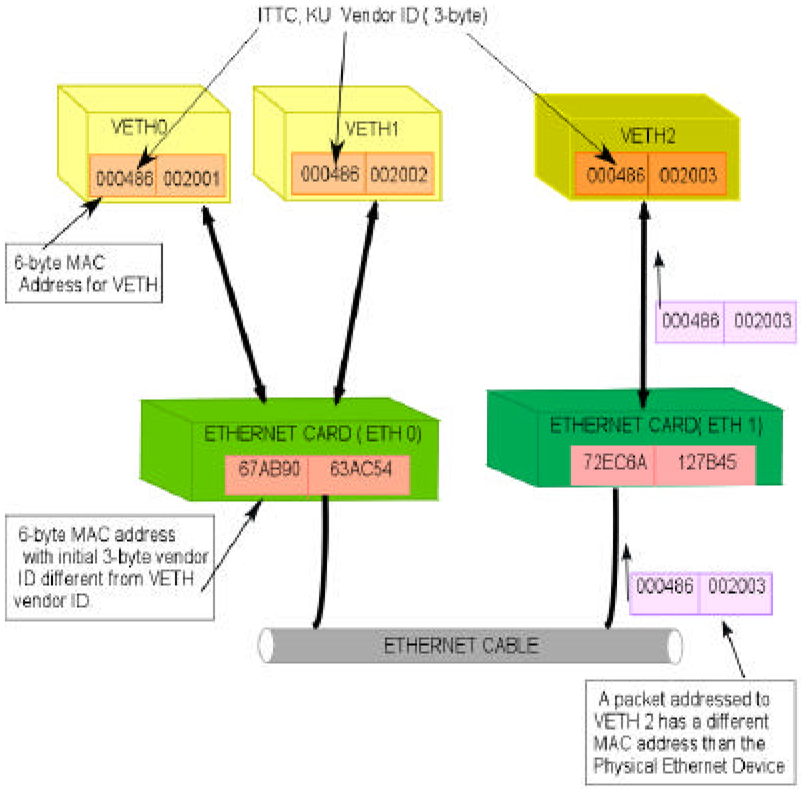
- *Veth Control* operations:
  - Create a VETH device
  - Destroy a VETH device
  - List all the devices created
- *ifconfig* command operations:
  - Setting the device IP address
  - Netmask
  - MTU (Maximum Transfer Unit)
  - Hardware Address



VETH : Specifications

- Each VETH device has :
  - IP address
  - 6-byte unique MAC address

- The first 3 bytes of VETH MAC address is the ITTC KU vendor Identifier:
  - useful for de-multiplexing packets
  - ITTC Vendor Id: 00:04:86

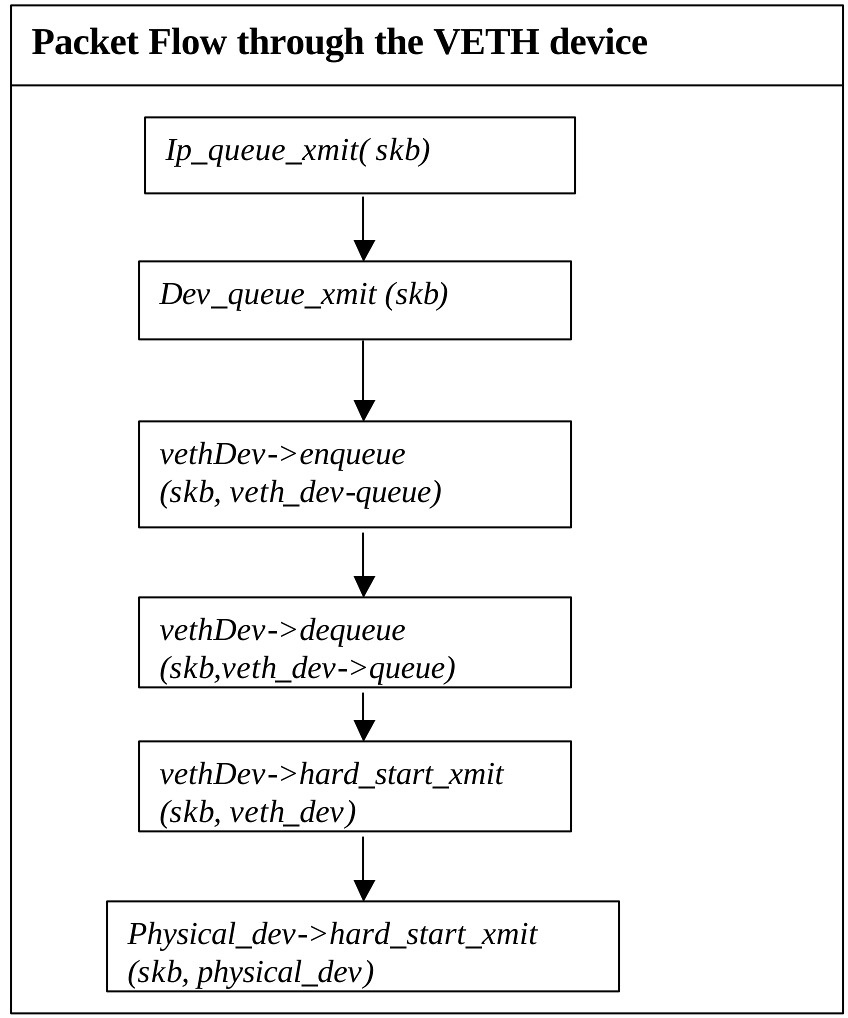


VETH : Create

- A VETH device can be created by an *ioctl ( )* system call from the *veth controller* program
- Every VETH device has an instance of *struct device*, which is a "C" structure to represent a device in Linux Kernel
- The function pointers of *struct device* such as *open*, *init*, *transmit*, etc point to appropriate functions in the VETH layer

Sending Data on VETH device

- Data Traffic from the IP layer to the VETH device
- The VETH device provides CBR control
- Delays the packets to simulate the link propagation delay
- Transmits the packets to the physical Ethernet device



Receiving Data on VETH device

- Packets are checked for the destination MAC address in the Ethernet header

- If the MAC address corresponds to a VETH device, then the packets are routed to the receive function of the VETH device

Destroying the VETH device

- A VETH device can be destroyed by an *ioctl ()* system call from the *veth controller* program

- The kernel memory occupied by the device structures has to be freed

Constant Bit Rate (CBR) control

Requirement for CBR control

- The VETH devices are capable of handling different types of satellite traffic
  - continuous - Telemetry Data
  - periodic - Observational Data such as Land-based measurements.

- Nodes representing Router satellites need to have high-capacity dedicated links

- Nodes emulating Observational satellites need to have some links dedicated to data collection and some links for routing data

Requirements

- Each communication link should have a continuous dedicated bandwidth
- The total capacity of the SBI node should be efficiently utilized to reserve bandwidth for each link
- Utilizing Token Bucket Filter (TBF) queuing disciplines to limit the rate on the link
- TBF queuing forms a part of Traffic Control mechanisms in Linux

TBF Queuing

- TBF generates tokens at a specific *rate*
- The tokens are filled into a *bucket* (buffer). The buffer limit specifies the maximum number of tokens it can store
- The number of bytes that can be de-queued from the device queue is equivalent to the number of tokens in the *bucket*
- The data rate on the link is limited to the *rate* at which the tokens are generated

Traffic Controller "tc"

- User level program to create and associate queues with the output devices

- Interacts with the kernel through *netlink sockets*

- "tc" usage for setting TBF queue:

  tc qdisc add dev <*device name*> handle <*handle #*> root tbf rate <*link rate*> burst <*bytes*> limit < *bytes*>

  – *rate* : value at which the link rate should be limited
  – *burst*: maximum number of tokens the buffer can hold at one time
  – *limit:* burst size + queue size which places the packets in case the tokens are exhausted

CBR control for SBI

- The TBF queue has to be created on the VETH device
- Parameters passed by the Emulation Manager to the nodes:
  - Virtual device on which the TBF queue has to be created
  - data rate for that virtual device
- The *Comm Control* module has the “tc” utility, sets up the TBF queue on the specified device
- The Central Operations Node monitors the bandwidth utilization for each SBI node

Link Propagation Delays

Link Propagation Delay

- Large distances between the satellites and ground stations
- Link propagation delays can be vary from 10 - 250 ms (one way) between satellites
- Large amount of data is *in-flight* on the communication link
- Propagation delay on a link can vary due to satellites being in motion

Delay Analysis

- Find out the delay variations with respect to time for some of the actual satellite links
- Using Satellite Tool Kit (STK) to obtain a report of the delay variations
- The following types of links were examined:
  - LEO-MEO, LEO-GEO , LEO- Ground Station
  - MEO-GEO, MEO- Ground Station, GEO-Ground Station

STK Report

- STK gives the following reports :
  - Duration Time (minutes) for each access for a link
  - Delay Variations with respect to time for each access duration

- Example : Access Report for a MEO-Ground Station link

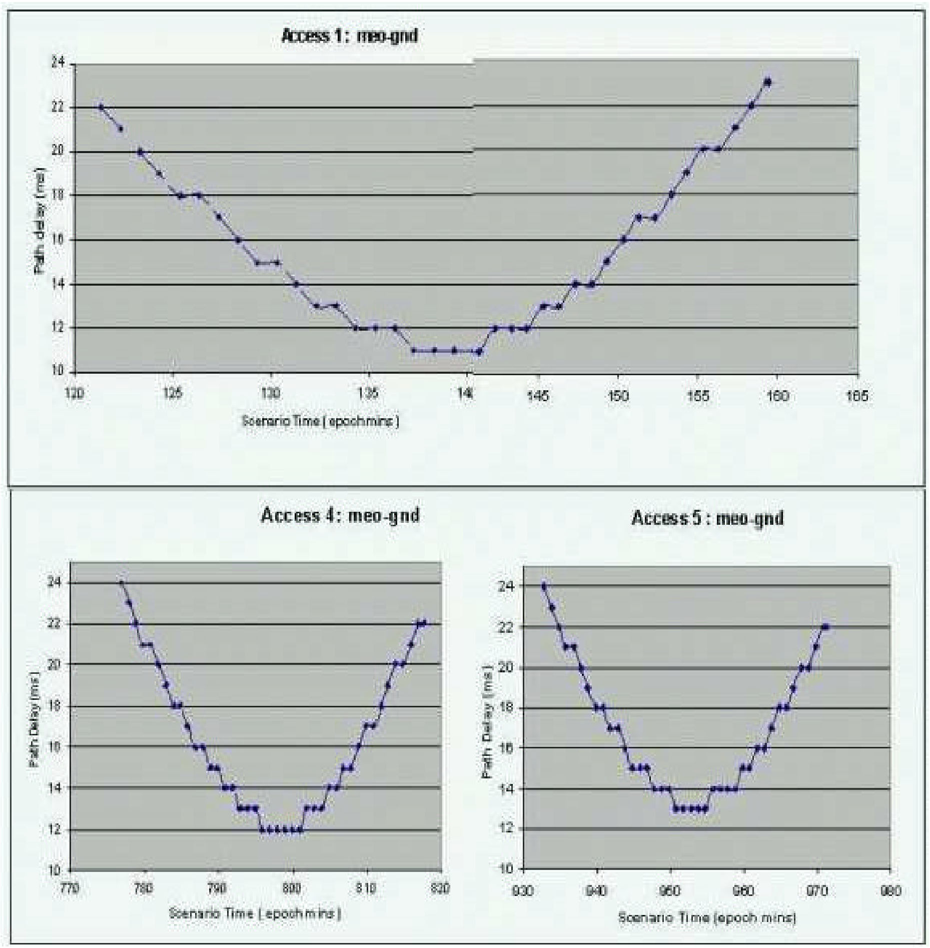
Access	Start Time (Epoch Minutes)	Stop Time (Epoch Minutes)	Duration (Minutes)
1	121.344	159.444	38.1
2	276.7916	314.3661	37.574
3	626.3372	646.9397	20.602
4	776.8671	817.618	40.751
5	932.7947	971.2767	38.482

STK Report

- A graph showing the delay variations for Access 1, 4 and 5

- Delay varies from 24ms to 12ms

- Delay variations per minute : 1ms



Delay Algorithm

- Packets are queued on the VETH device before transmission on the physical layer

- Queue size should be equal to number of bytes that can be *in-flight* at one time on the link
  - Number of packets in-flight = Propagation delay / Transmission delay
  - Number of bytes in-flight = packets * (average packet size in bytes)

- The packets queued are delayed for the required amount of time and then de-queued for transmission

Delay Algorithm

- The queue size has to change with the delay variations
- Delay variations are 1-3 ms per minute
- The queue size should change by +/- 25 packets for an average packet size of 1500 bytes and a 100 Mbps link

Simulating the delay

- Packets coming on the VETH device are time stamped and placed in the *veth queue*
- While de-queuing, the time stamp on the packet is compared with the current time
- If time difference equals the delay value, then the packet is de-queued and sent on the physical device
- Otherwise, the packet is queued at the head of the queue

Simulating the delay

- The following parameters have to be given to the SBI Nodes:
  - The name of virtual device
  - link rate and average packet size for calculating the transmission delay
  - STK report giving the delay values with respect to time

- The delay value along with the queue size is passed to the VETH device through an *ioctl ()* system call

Summary

- This work presents a design for emulating a Satellite Communication Link
  - Multiple communication channels on the satellites can be emulated by creating multiple VETH devices on a single node
  - Traffic control mechanisms such as TBF queuing can be utilized to model CBR traffic on the communication links
  - Propagation delays can be simulated on the emulation link to model actual space communication

Future Work

- Modeling Bit Error Rate on the link
  - introducing bit errors in packets to achieve the specified bit error rate

- Implementation of the proposed design

Questions ?