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# Design and Implementation of Data Models & Instrument Scheduling of Satellites in a Space Based Internet Emulation System

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Masters Thesis Defense  
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# Organization

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- SBI Mission
- Introduction
- SBI Approach
- SBI Emulation System
- Satellite Data Models
- Earth Surface Database
- Instrument Scheduling
- Tests and Results
- Summary
- Future Work

# SBI Mission

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Space Based Internet (SBI) aims at applying mobile wireless technology and innovative topology and routing algorithms suitable for satellite systems to enable routing between satellites or satellites and ground stations.

# Introduction

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- Earth Observing System (EOS) satellites are capable of receiving, recording and transmitting data
- EOS satellites gather data over specific regions of the Earth
- Data is stored in high capacity, solid state recorders
- Data is transmitted from the satellite to the ground station or to the TDRSS

*TDRSS : Tracking & Data Relay Satellite System*

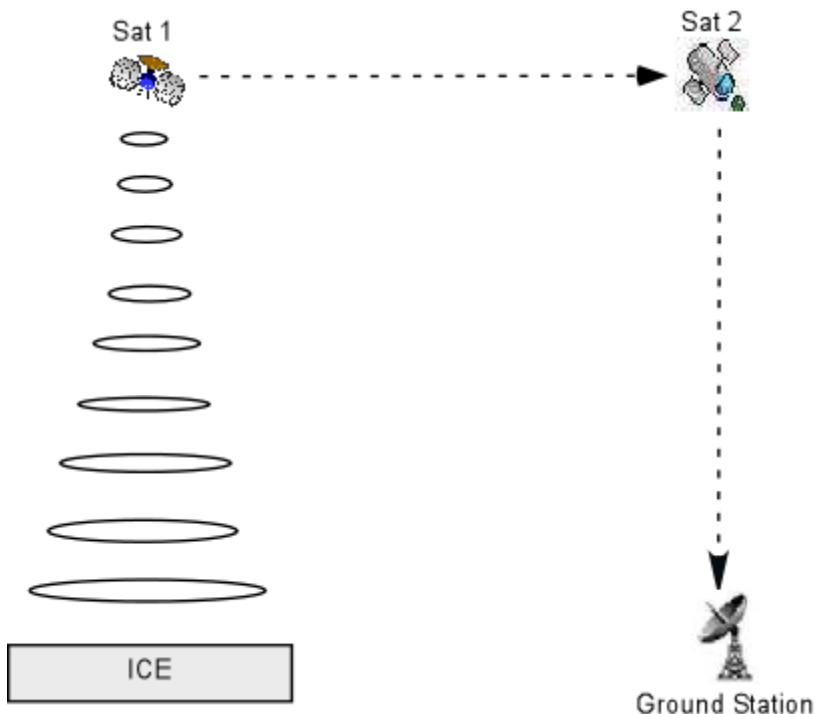
# Limitations

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- Data needs to be stored until the satellite has *Line of Sight* with the ground station or TDRSS
- Non availability of near real time data
- Satellite is only capable of communicating with ground station or TDRSS
- Satellite communication systems are specific to individual satellites

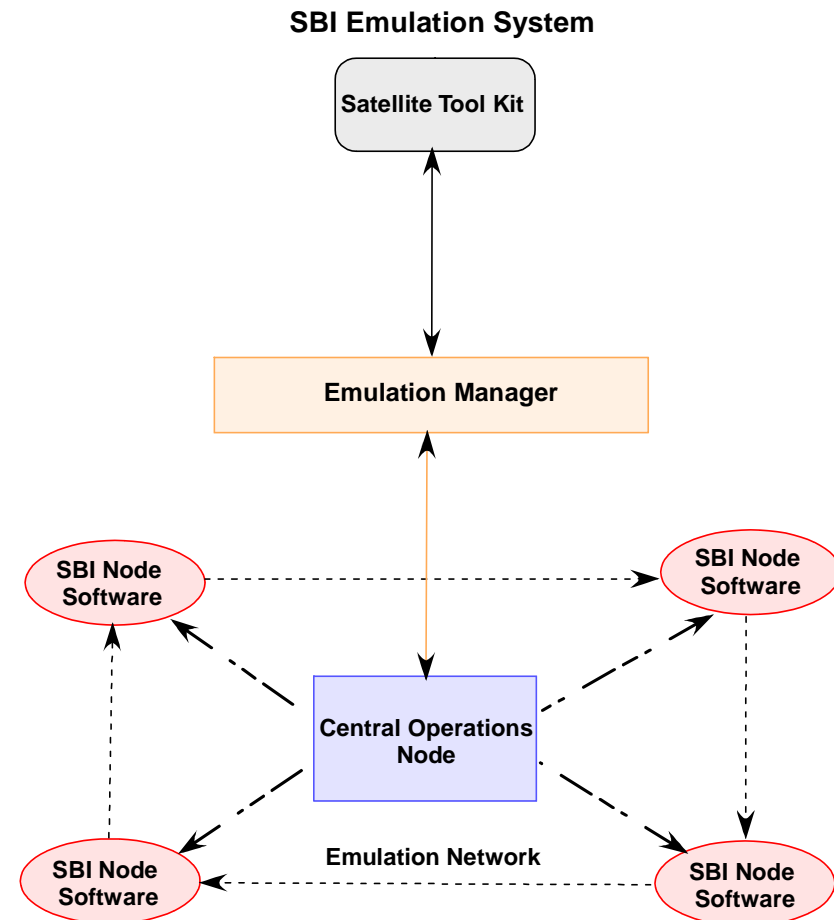
# Solution: SBI Approach

- Enable routing among satellites
- Scalability
- Special SBI satellites can be constructed and deployed when required
- Build realistic data traffic models of space-based applications for current / planned satellites
- Emulated Environment



# SBI Emulation system

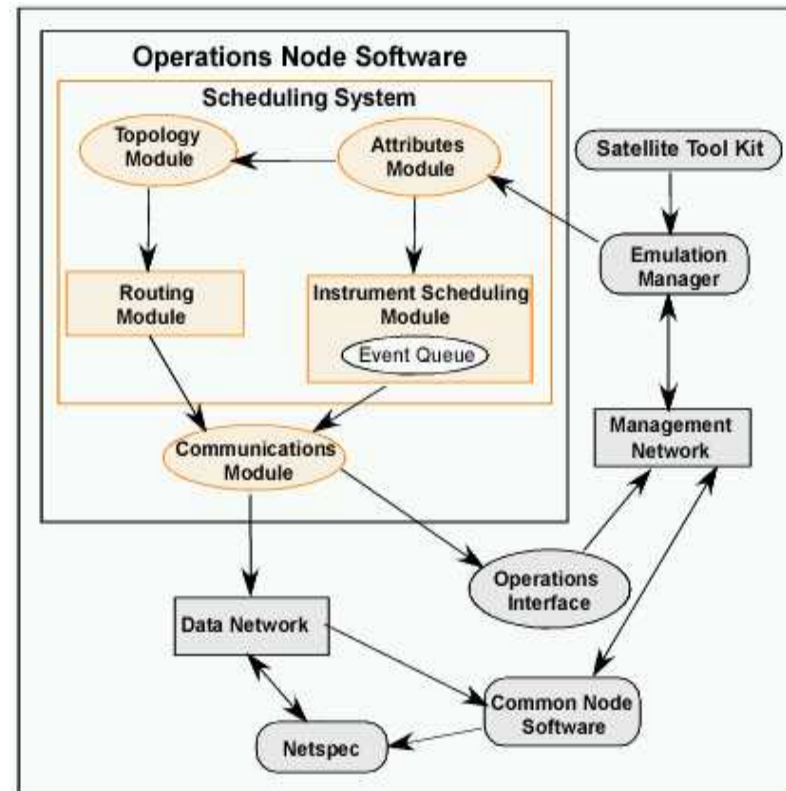
- Emulation Manager
  - Configure, Control and Monitor
- Emulation Network
  - Emulates communication links



# Operations Node Software

## Constituent Modules

- Attributes Module
- Topology Module
- Routing Module
- Instrument Scheduling Module
- Communications Module

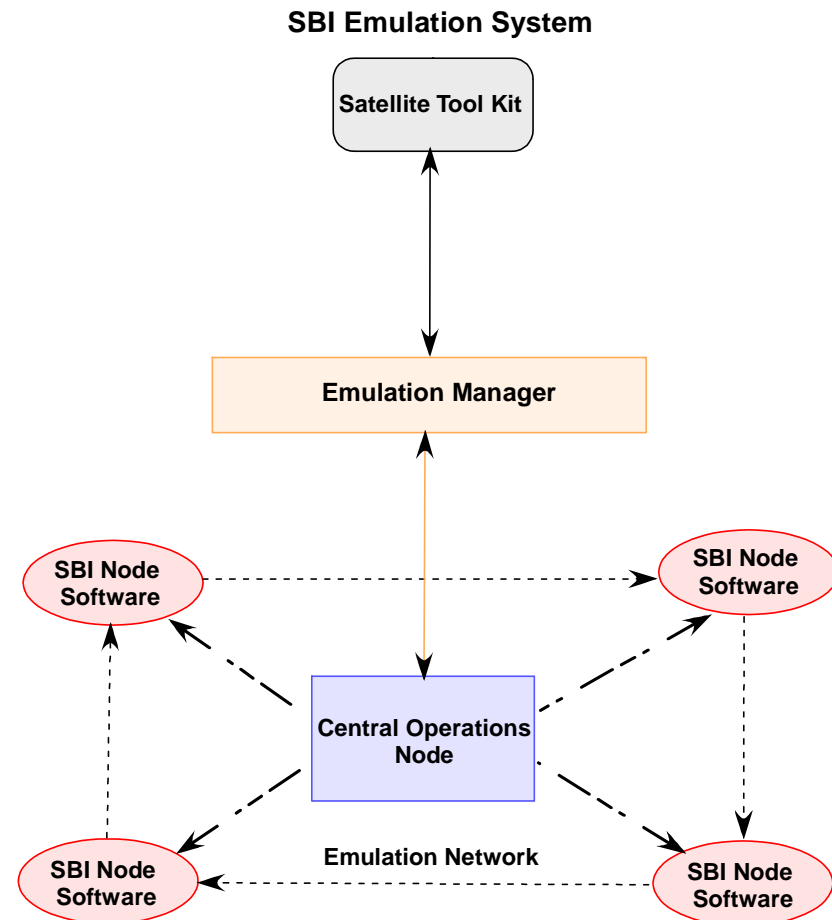


*STK : Satellite Tool Kit*



# SBI Emulation system

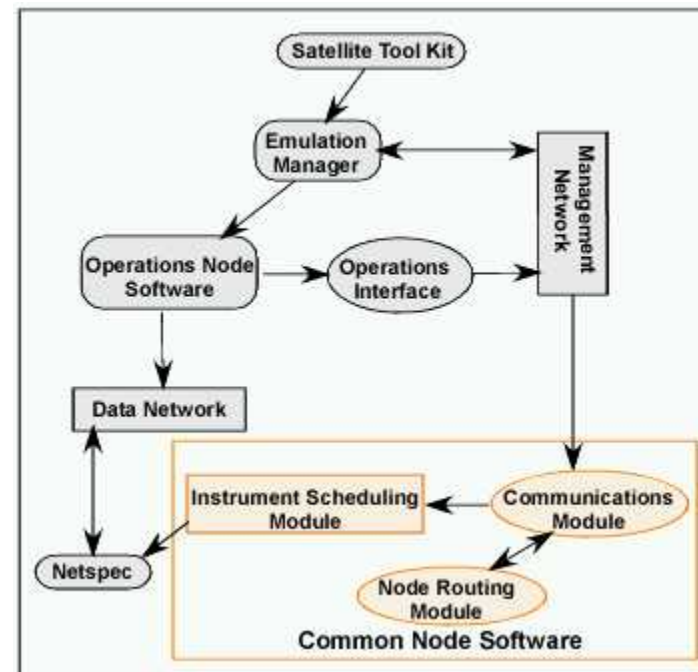
- Emulation Manager
  - Configure, Control and Monitor
- Emulation Network
  - Emulate communication links
- SBI Node
  - Represents a satellite or ground station



# Common Node Software

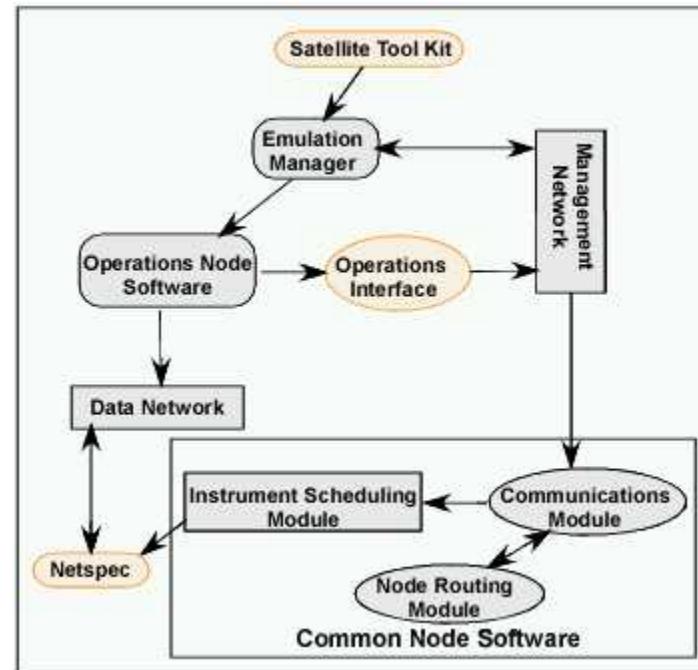
## Constituent Modules

- Communications Module
- Instrument Scheduling Module
- Node Routing Module



# Other Software

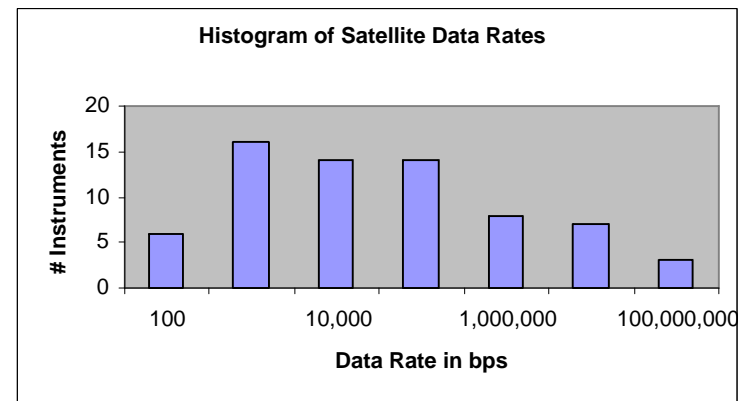
- Operations Interface
  - Performs S-Band channel functions using TCP
- Satellite Tool Kit
  - Emulates satellite environment
  - Provides animation capabilities
  - Provides data to schedule satellite instruments
- Netspec
  - Emulates satellite data



# Satellite Data Models

- Data characteristics of 24 Satellites and 68 of their instruments have been studied
- 66 instruments gather spectral image data with Constant Bit Rate
- 2 instruments gather image data (e.g. Wide Field Camera of Picaso-Cenna satellite)
- Satellite Data models are emulated using KU's Netspec system
  - MPEG and bursty are the 2 traffic types used to emulate satellite data

Data Rates		# Instruments
From	To	
100	1 Kbps	6
1 Kbps	10 Kbps	16
10 Kbps	100 Kbps	14
100 Kbps	1 Mbps	14
1 Mbps	10 Mbps	8
10 Mbps	100 Mbps	7
100 Mbps	1 Gbps	3

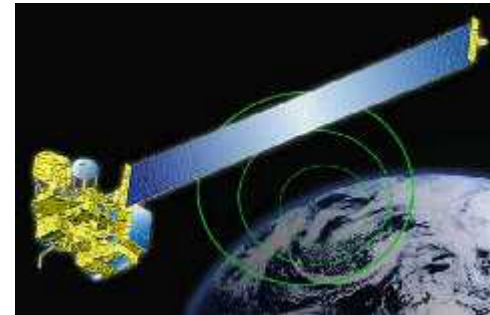


- More than 75 % of the instruments have a data rate between 100 bps - 10 Mbps

# Instrument Scheduling

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- Satellite instruments gather data on specific regions of the Earth
- Regions where satellites gather data:
  - Land
  - Ocean
  - Cryosphere / Ice
  - Atmosphere
- Data can be gathered in one or any combination of the above regions



# Instrument Scheduling Contd...

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- Satellite instruments fall into one of 3 scheduling types
  - Earth Surface measurements
  - Solar Occultation or Sunrise-Sunset measurements
  - Day / Night measurements

Measurement	# Instruments
Earth Surface Type	42
Sunrise-Sunset	6
Day / Night	20

# Earth Surface Measurements

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- Measurements & Applications
  - Land - mapping the Earth, vegetation distribution, volcanic activity ( ASTER)
  - Ocean - weather conditions, ocean surface temperature, wind patterns (SeaWiFS)
  - Cryosphere - albedo values, areal extent of snow and ice brought by winter storms and frigid temperatures (MODIS)
- Satellite / Instrument Characteristics
  - Orbit: Sun-synchronous and polar, sun-synchronous and circular, circular, elliptical
  - Orbital period: 90 - 115 minutes
  - Data rate: 1 Kbps - 300 Mbps

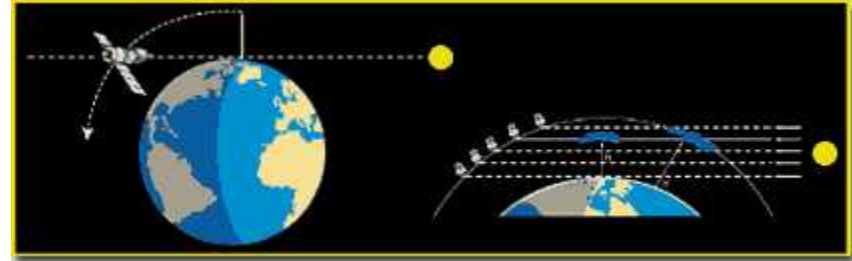
*ASTER - Advanced Spaceborne Thermal Emission & Reflection Radiometer*

*MODIS - Moderate Resolution Imaging Spectroradiometer*

# Sunrise Sunset Measurements

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- Measurements & Applications
  - Measurement of vertical profile of ozone hole related components (ILAS)
  - Identification of responses to episodic events such as volcanic eruptions (SAGE II)
- Satellite / Instrument Characteristics
  - Orbit: Circular or near - circular
  - Orbital period: 90 - 105 minutes
  - 32 to 28 measurements per 24 hour period
  - Data rate: 1 Kbps - 600 Kbps



*ILAS - Improved Limb Atmospheric Spectrometer*

*SAGE II - Stratospheric Aerosol & Gas Experiment II*



# Day / Night Measurements

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- Measurements & Applications
  - Pollution measurement in the troposphere (MOPITT)
  - Sunlight scatter by the Earth surfaces and the atmosphere (MISR)
  - Determination of aerosol properties (MISR)
- Satellite / Instrument Characteristics
  - Orbit: Sun-synchronous and polar, sun-synchronous and circular, circular
  - Orbital period: 96 - 105 minutes
  - Data rate: 1 Kbps - 25 Mbps

*MOPITT - Measurements Of Pollution In The Troposphere*

*MISR - Multi-angle Imaging Spectro - Radiometer*

# Earth Surface Database

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- Necessity
- Database built from world map JPEG image file
- 4 Surface Types
  - Ice / Cryosphere
  - Water
  - Arid Land (Brown Regions)
  - Vegetative Land (Green Regions)
- Surface resolution:  $0.5^{\circ}$  Latitude and  $0.5^{\circ}$  Longitude

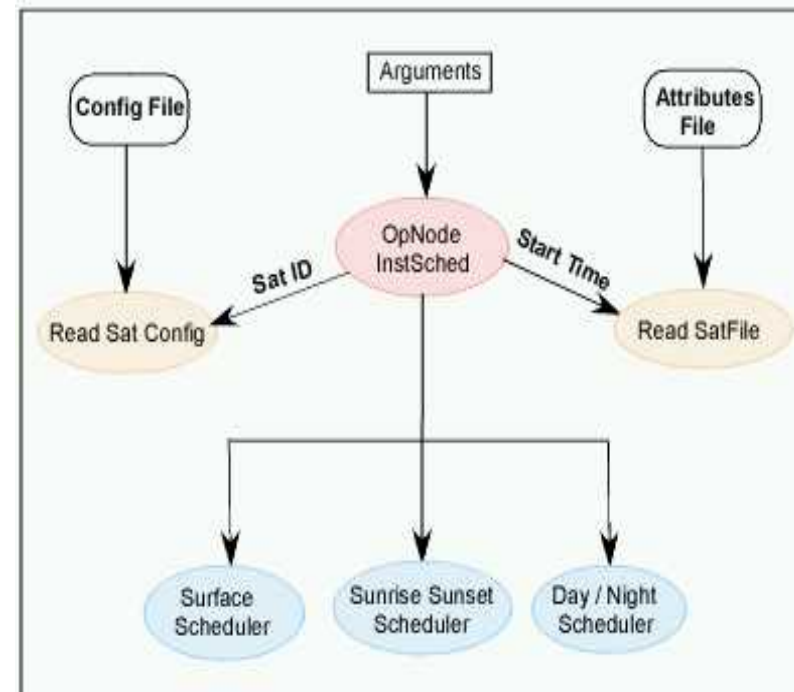
# Operations Node Instrument Scheduler

## Configuration File

- Scheduler ID
- Surface value at which the instrument goes ON
- Data characteristics (e.g. Bursty)
- Data Rate in Kbps

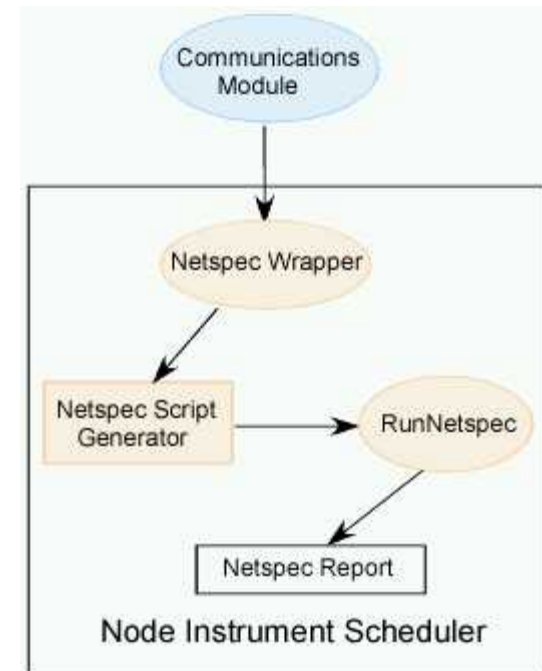
## Attributes File

- Satellite orbital path
- Satellite daylight times



# SBI Node Instrument Scheduler

- NetspecWrapper
  - Receives Netspec parameters from Communications module
  - Selects appropriate Netspec script generator
- Netspec Script Generator
  - Generate Netspec script
  - Types of data generation scripts
    - Burst
    - Queued Burst
    - MPEG
    - Video Teleconferencing
- RunNetspec
  - Executes generated Netspec script and stores it in the output file



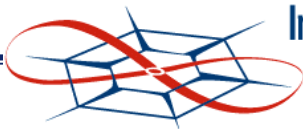
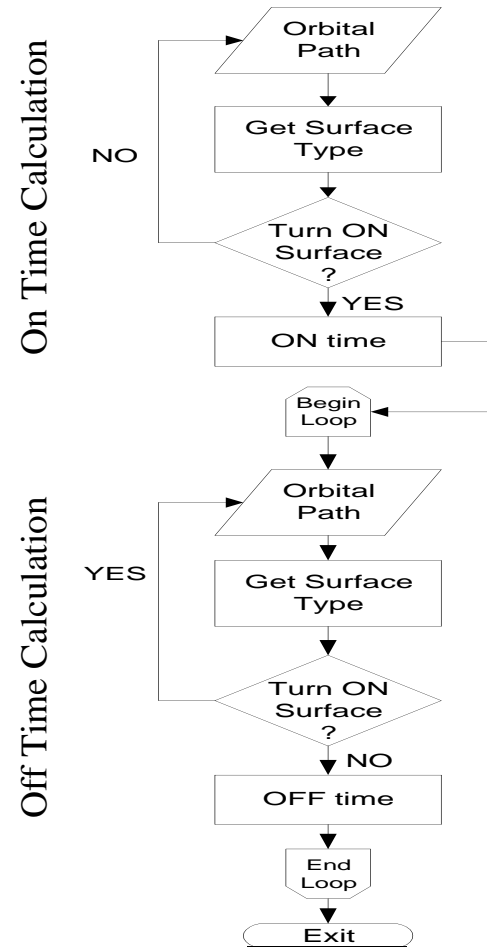
# Schedulers

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- Schedule satellite instruments for gathering data
- 3 types of satellite instrument schedulers
  - Earth surface - based
  - Day / Night
  - Sunrise Sunset
- Satellite instrument is scheduled for one pair of ON and OFF times within one orbit from current position
- Turn On Surface - Earth Surface above which the instrument turns ON

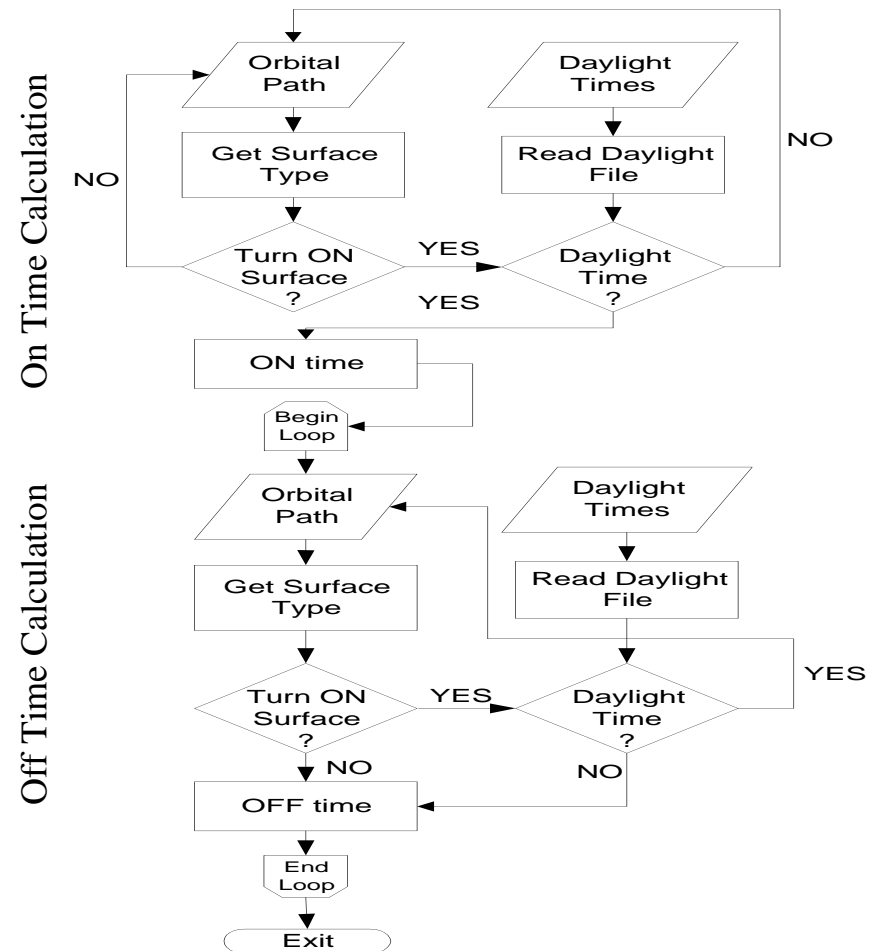
# Surface based scheduler

- Scheduling
  - Earth surface / atmosphere below the satellite's current orbital path
- On time
  - Time at which the satellite passes over Turn On Surface
- Off time
  - Time at which the satellite passes over surface other than Turn On Surface



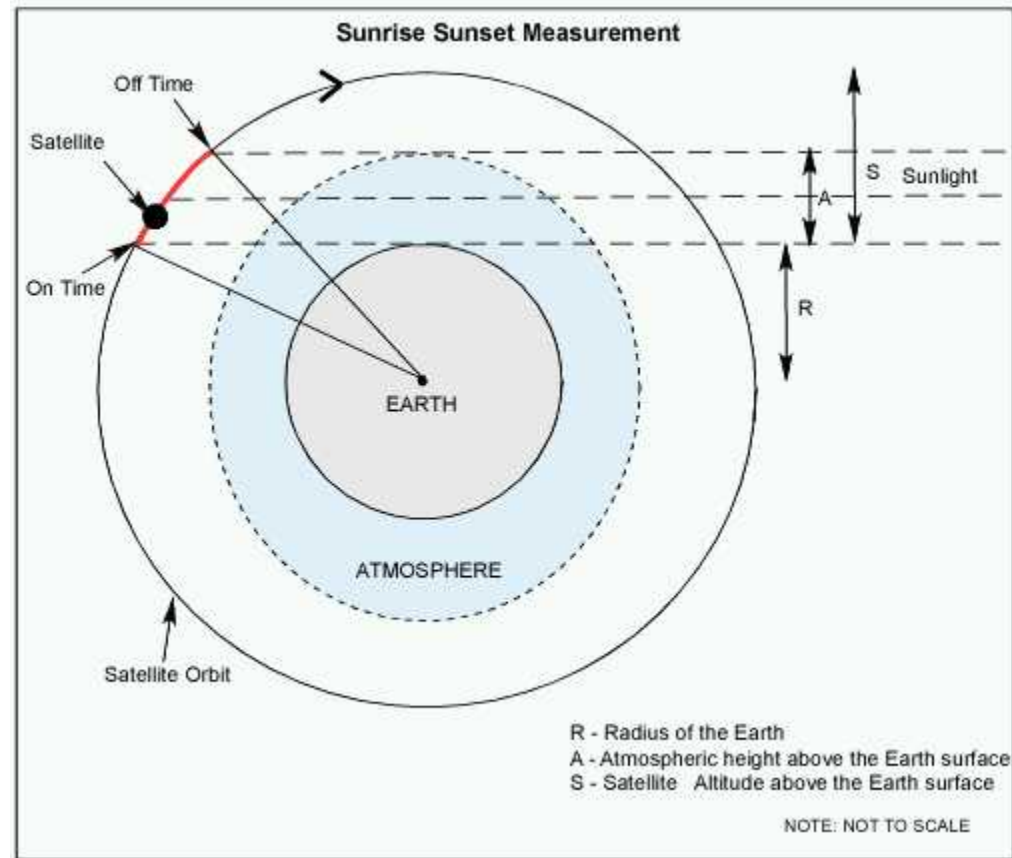
# Day / Night Scheduler

- Scheduling
  - Day / Night
  - Earth surface / atmosphere below the satellite's current orbital path
- On time
  - Time at which the satellite passes over Turn On Surface during the day
- Off time
  - Time at which the satellite passes over a surface other than Turn On Surface
  - Time at which the satellite passes over a surface where it is night



# Sunrise Sunset Scheduler

- Scheduling done based on
  - Satellite Sunrise
  - Satellite Sunset
- On time
  - Beginning of Sunrise / Sunset
- Off time
  - End of Sunrise / Sunset



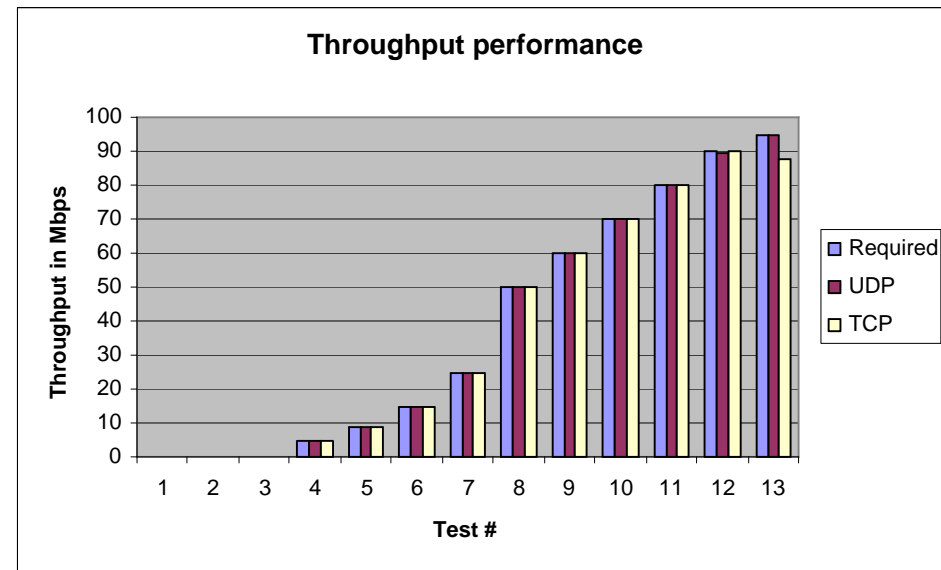


# Tests and Results

## Throughput Tests

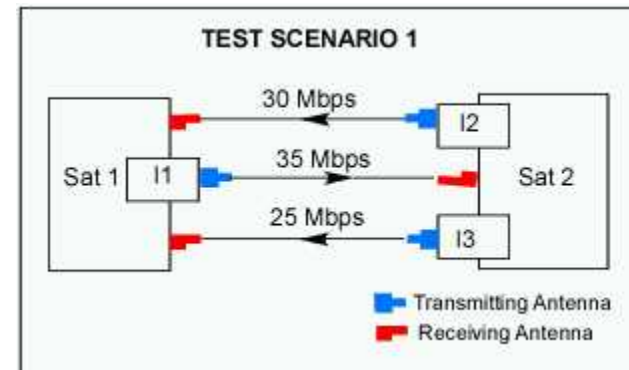
- Scheduling done for single satellite instrument
- Tests done using both TCP and UDP

Test #	Throughput in Mbps		
	Required	UDP	TCP
1	0.001	0.001	0.001
2	0.01	0.01	0.01
3	0.1	0.1	0.1
4	5	4.991	4.994
5	9	8.992	8.993
6	15	14.975	14.985
7	25	24.966	24.964
8	50	49.955	49.955
9	60	59.86	59.945
10	70	69.824	69.924
11	80	79.791	79.872
12	90	89.605	89.712
13	95	94.624	87.611



# Test Scenario 1

- Simulation Start Time: 0 seconds (from current time)
- Sat 1
  - Instrument I1 - Sunrise sunset measurement  
Data rate: 35 Mbps, Data Characteristic: Qburst
- Sat 2
  - Instrument I2 - Measurement over Vegetative land  
Data Rate: 30 Mbps, Data Characteristic: Burst
  - Instrument I3 - Measurement over Arid land only during the day  
Data Rate: 25 Mbps , Data Characteristic: Qburst



Satellite	Instrument	Scheduler	Orbital Period secs	Altitude km	Surface to turn ON	Data Type	Required Data Rate	Scheduler Onset Time secs
sat 1	I1	Sunrise Sunset	5760	566	NA	Qburst	35 Mbps	0
sat 2	I2	Earth surface	5760	566	Arid	Burst	30 Mbps	0
sat 2	I3	Day / Night	5760	566	Veg	Qburst	25 Mbps	0

# Test Scenario 1 - Results

- Instrument ON and OFF times

Satellite	Instrument	Surface turned ON	ON Time secs	OFF Time secs
Sat 1	I1	NA	0	27.06903
Sat 2	I2	Arid	1350.125	1621.748
Sat 2	I3	Veg	1621.748	1645.714

- TCP Results

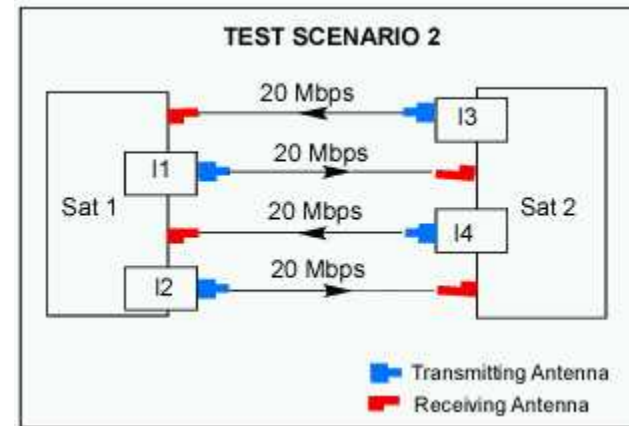
Satellite	Instrument	Duration in seconds			Throughput	
		Expected	Calculated	Actual TX	Expected	Actual TX
Sat 1	I1	27.069	27	27.031	35 Mbps	34.96 Mbps
Sat 2	I2	271.623	271	302.349	30 Mbps	26.89 Mbps
Sat 2	I3	23.9667	24	24.01	25 Mbps	24.99 Mbps

- UDP Results

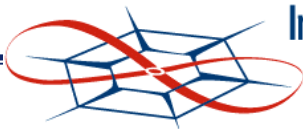
Satellite	Instrument	Duration in seconds			Throughput	
		Expected	Calculated	Actual TX	Expected	Actual TX
Sat 1	I1	27.069	27	27.002	35 Mbps	34.998 Mbps
Sat 2	I2	271.623	271	271.211	30 Mbps	29.978 Mbps
Sat 2	I3	23.9667	24	24.02	25 Mbps	24.979 Mbps

# Test Scenario 2

- Simulation Start Time: 0 seconds (from current time)
- Sat 1
  - Instrument I1 - Sunrise sunset measurement  
Data rate: 20 Mbps, Data Characteristic: Qburst
  - Instrument I2 - Measurement over Vegetation only during the day  
Data Rate: 20 Mbps, Data Characteristic: Qburst
- Sat 2
  - Instrument I3 - Measurement over Arid land  
Data Rate: 20 Mbps, Data Characteristic: Burst
  - Instrument I4 - Measurement over Arid land only during the day  
Data Rate: 20 Mbps , Data Characteristic: Qburst



Satellite	Instrument	Scheduler	Orbital Period secs	Altitude km	Surface to turn ON	Data Type	Required Data Rate	Scheduler Onset Time secs
Sat 1	I1	Sunrise Sunset	5760	566	NA	Qburst	20 Mbps	0
Sat 1	I2	Day / Night	5760	566	Veg	Qburst	20 Mbps	0
Sat 2	I3	Earth Surface	5760	566	Arid	Burst	20 Mbps	0
Sat 2	I4	Day / Night	5760	566	Veg	Qburst	20 Mbps	0



# Test Scenario2 - Results

- Instrument ON and OFF times

Satellite	Instrument	Surface turned ON	ON Time secs	OFF Time secs
Sat 1	I1	NA	0	27.06903
Sat 1	I2	Veg	1621.748	1645.714
Sat 2	I3	Arid	1350.125	1621.748
Sat 2	I4	Veg	1621.748	1645.714

- TCP Results

Satellite	Instrument	Duration in seconds			Throughput	
		Expected	Calculated	Actual TX	Expected	Actual TX
Sat 1	I1	27.069	27	27.031	20 Mbps	19.977 Mbps
Sat 1	I2	23.9667	24	24.019	20 Mbps	19.984 Mbps
Sat 2	I3	271.623	271	303.739	20 Mbps	17.846 Mbps
Sat 2	I4	23.9667	24	24.04	20 Mbps	19.967 Mbps

- UDP Results

Satellite	Instrument	Duration in seconds			Throughput	
		Expected	Calculated	Actual TX	Expected	Actual TX
Sat 1	I1	27.069	27	27.001	20 Mbps	20 Mbps
Sat 1	I2	23.9667	24	24.02	20 Mbps	19.983 Mbps
Sat 2	I3	271.623	271	271.511	20 Mbps	19.963 Mbps
Sat 2	I4	23.9667	24	24.029	20 Mbps	19.976 Mbps

# Other Traffic Types

- MPEG and Video Conferencing traffic types

#	Scheduler	Orbital Period secs	Altitude km	Surface to turn ON	Data Type	Required Data Rate	Scheduler Onset Time secs
1	Earth Surface	5760	566	Arid	MPEG	640 Kbps	0
2	Sunrise Sunset	5760	566	NA	MPEG	400 Kbps	0
3	Earth Surface	5760	566	Arid	VidTel	500 Kbps	5000
4	Day / Night	5760	566	Arid	VidTel	400 Kbps	0

- Instrument ON and OFF times

#	Surface turned ON	ON Time secs	OFF Time secs
1	Arid	1621.748	1645.714
2	NA	0	27.06903
3	Arid	5351.512	5455.368
4	Arid	1621.748	1645.714

# Other Traffic Types Contd...

- TCP Results

#	Duration in seconds			Throughput	
	Expected	Calculated	Actual TX	Expected	Actual TX
1	23.9667	24	31.401	640 Kbps	474 Kbps
2	27.0688	27	29.431	400 Kbps	351 Kbps
3	103.856	104	107.993	500 Kbps	489 Kbps
4	23.9668	24	25.87	400 Kbps	371 Kbps

- UDP Results

#	Duration in seconds			Throughput	
	Expected	Calculated	Actual TX	Expected	Actual TX
1	23.9667	24	31.404	640 Kbps	474 Kbps
2	27.0688	27	29.435	400 Kbps	351 Kbps
3	103.856	104	107.998	500 Kbps	489 Kbps
4	23.9668	24	25.867	400 Kbps	371 Kbps

# Summary

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- This work presents a design for emulating satellite instrument scheduling and data generation
  - Instruments can be scheduled based on their mode of operation
  - Different data characteristics can be emulated
  - Data transfer between satellites or satellite and ground station can be simulated



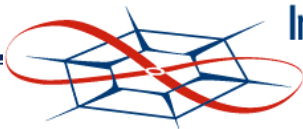
# Future Work

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- Schedule instruments by obtaining satellite configurations directly from STK
- Use a topology database of higher resolution (Current database resolution is  $0.5^\circ$ )

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Questions ?



Information and  
Telecommunication  
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University of Kansas