Space Communications and Navigation (SCaN) Network Simulation Tool Development and Its Use Cases

AIAA Modeling and Simulation Technologies Conference
August 11, 2009

E. Jennings, R. Borgen, S. Nguyen, J. Segui, T. Stoenescu, S.-Y. Wang, S. Woo
Jet Propulsion Laboratory / California Institute of Technology

B. Barritt, C. Chevalier, W. Eddy
NASA Glenn Research Center

Presentation Outline

- Introduction
- Purpose of the Tool
- Simulator Design
- Custom Models
- Use Cases

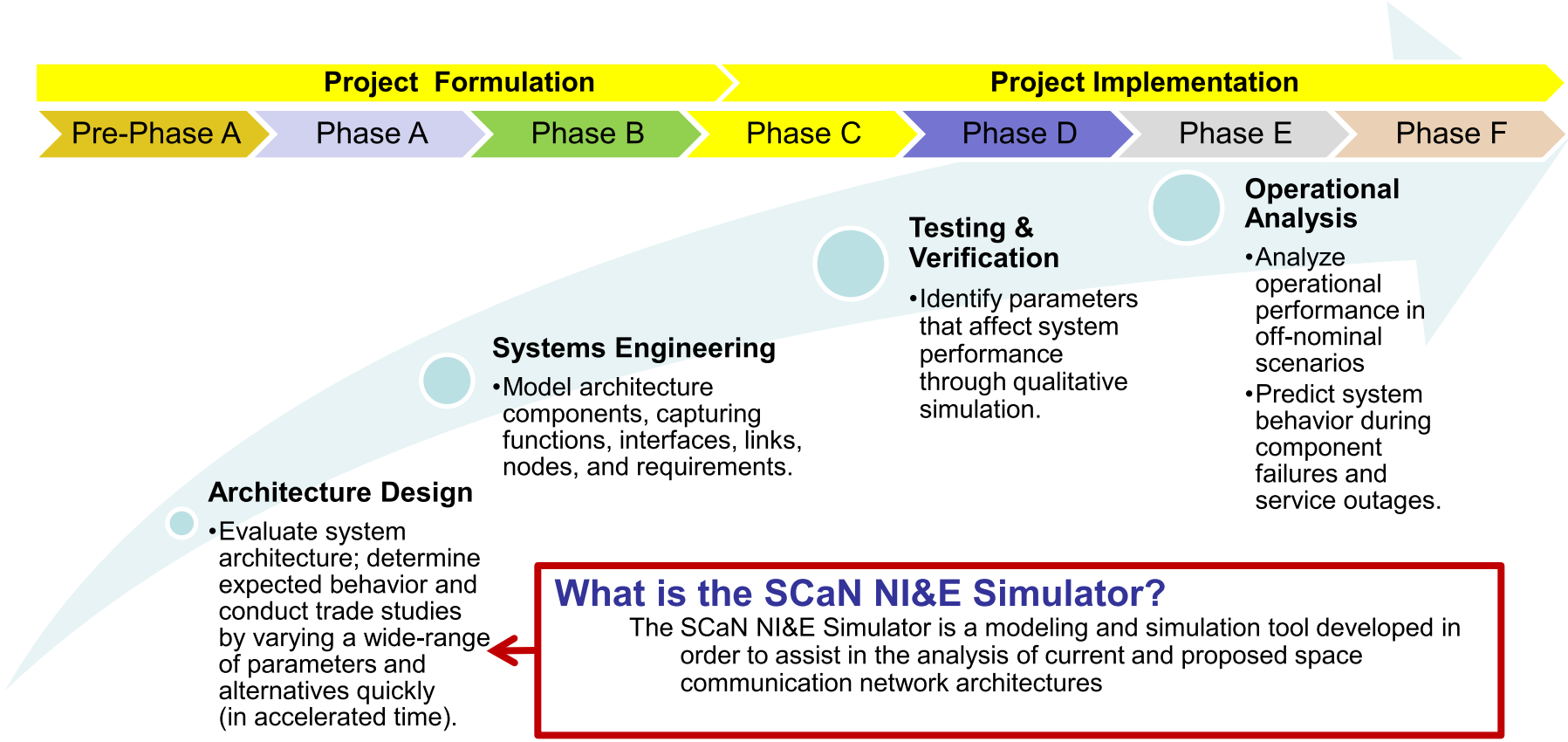
Introduction

- Space exploration missions (Moon, Mars)
- Need to model non-standard, non-COTS protocols
  - TOAST: Telecom/Orbital Analysis Tool (JPL)
  - SCaN NI&E Simulator (JPL, GRC)

Benefits of Simulation

Benefits of Network Simulation

- Gain insight into system architecture, design, and expected behavior in the early-stage of the mission lifecycle to **reduce costs**, **increase reliability**, and to aid decision-making.
- Enable **faster development** and **more robust designs**. The trade-off is model development earlier in the project life-cycle.
- Characterize the **complex** interactions and **performance** of the network architecture.

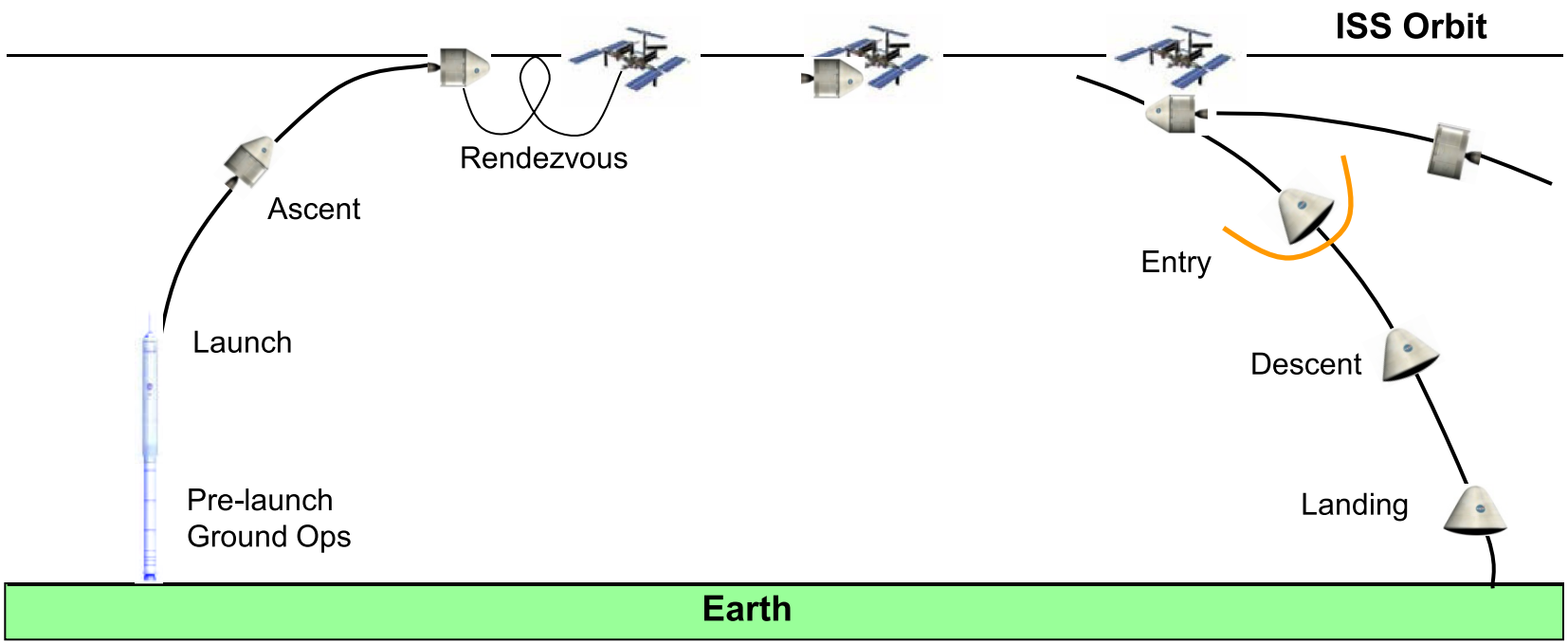


What is the SCaN NI&E Simulator?

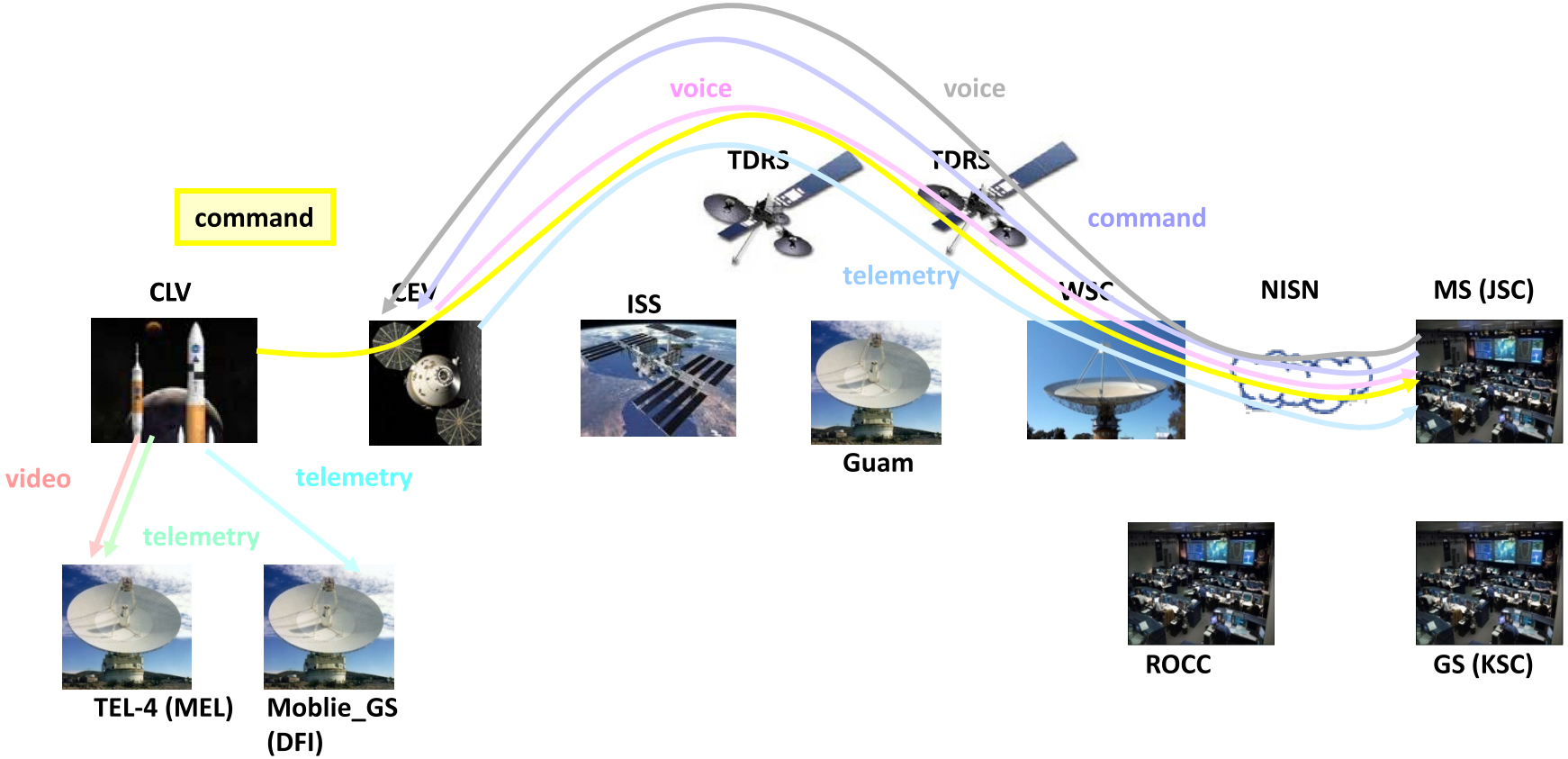
The SCaN NI&E Simulator is a modeling and simulation tool developed in order to assist in the analysis of current and proposed space communication network architectures

Orion to ISS Mission Scenario

- **Mission phases**
  - Pre-launch ground operations (not simulated)
  - Launch, ascent, orbit insertion
  - ISS rendezvous, docking
  - Entry, descent, and landing



Traffic Flows (Ascent example)



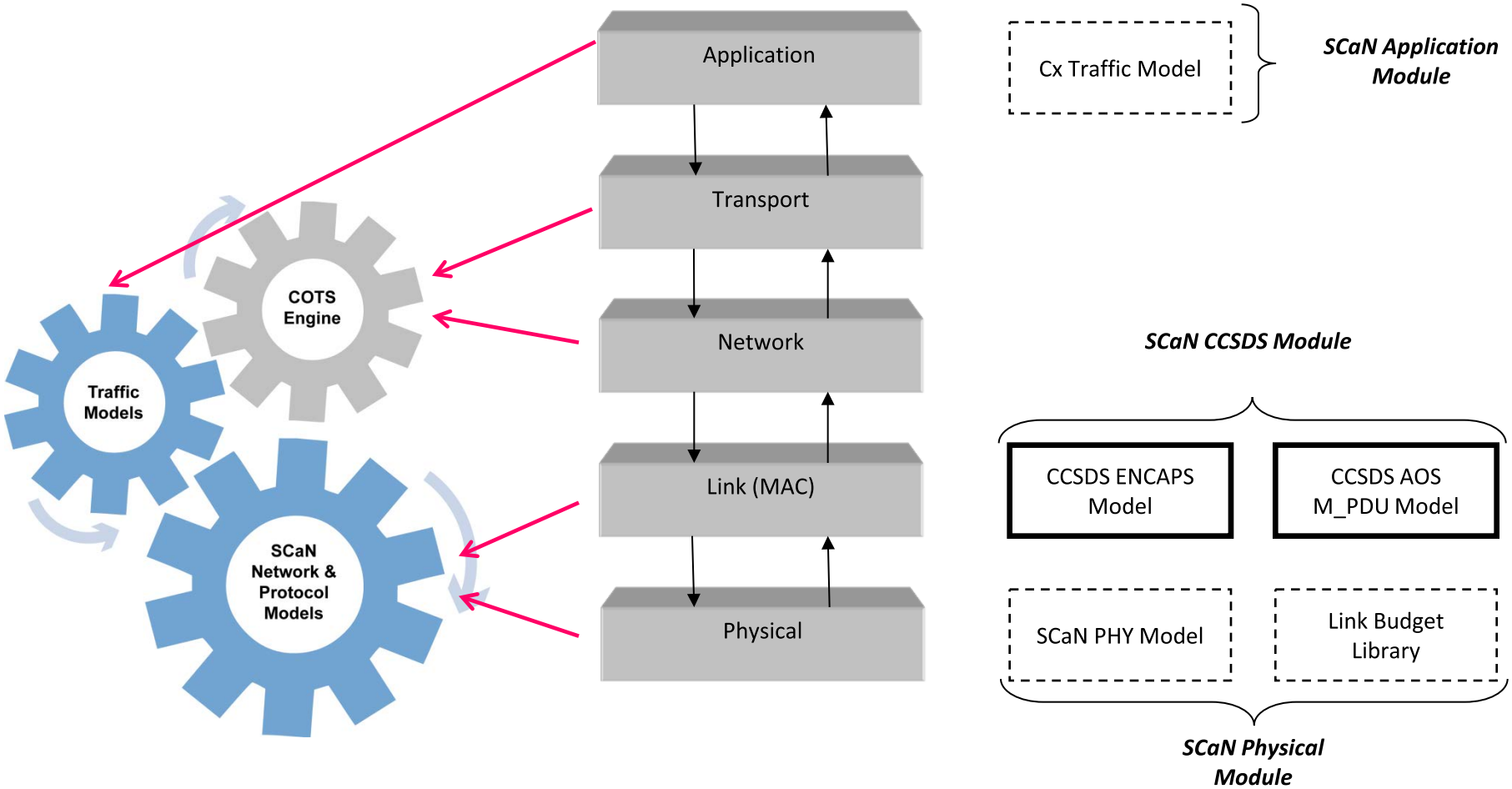
Protocol Stack Example

voice					
CEV	**WSC**		**NISN**		**MS**
Voice					Voice
RTP					RTP
UDP					UDP
IP					IP
ENCAPS					ENCAPS
AOS M-PDU	AOS M-PDU	AOS M-PDU			AOS M-PDU
LDPC/RF	LDPC/RF	TCP or UDP			TCP or UDP
		IP	IP	IP	IP
		Ethernet	Ethernet	Ethernet	Ethernet
		Wired	Wired	Wired	Wired

Simulator Requirements

- *CxP C3I Protocol Support*
  - RTP, IP, CCSDS AOS M_PDU, and the CCSDS Encapsulation Service (ENCAPS).
- *Simulation Results*
  - Latency, throughput, and jitter
- *Physical Delay Modeling*
  - Propagation delay between the Orion spacecraft and WSC through the TDRSS, with respect to the distances / trajectories.
- *Link Budget Library*
  - Computes the link budget for various mission phases / links according to the Master Link Book design specifications.
- *Link Coding Support*
  - Effects of link coding

Simulator Models Overview



Legend:

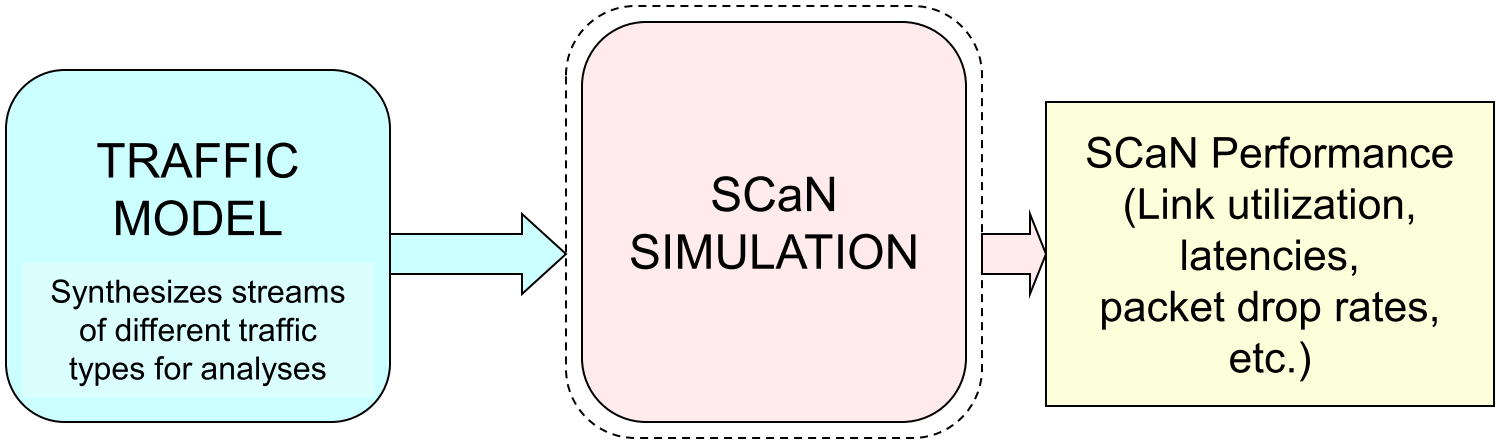
- Custom model is specific to a specific customer or mission scenario
- Custom model is not dependent on the scenario or customer

Traffic Model Objective

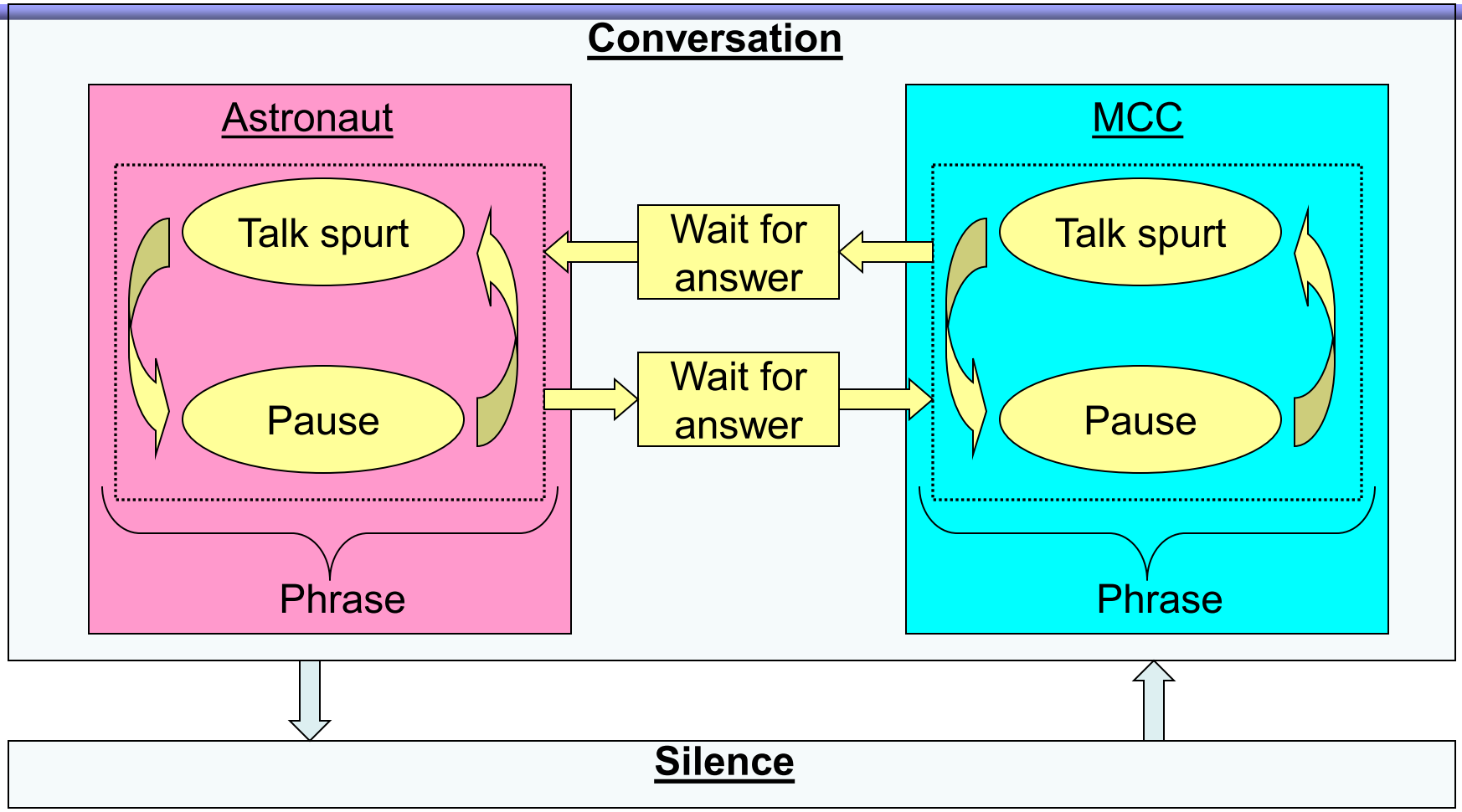
- Develop prototype traffic model characterizing traffic expected to be offered to the SCaN by Cx users
- Develop tools for traffic generation to be used in SCaN traffic simulations

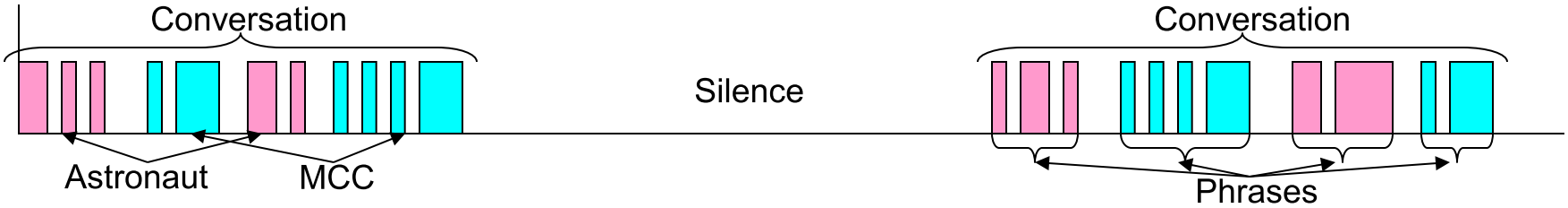
- Traffic types: voice, video, command, telemetry

"Telemetry" and "Command" include both real-time data (non-voice, non-video) streams and non-real-time data (file transfer) traffic types



Voice Traffic Model





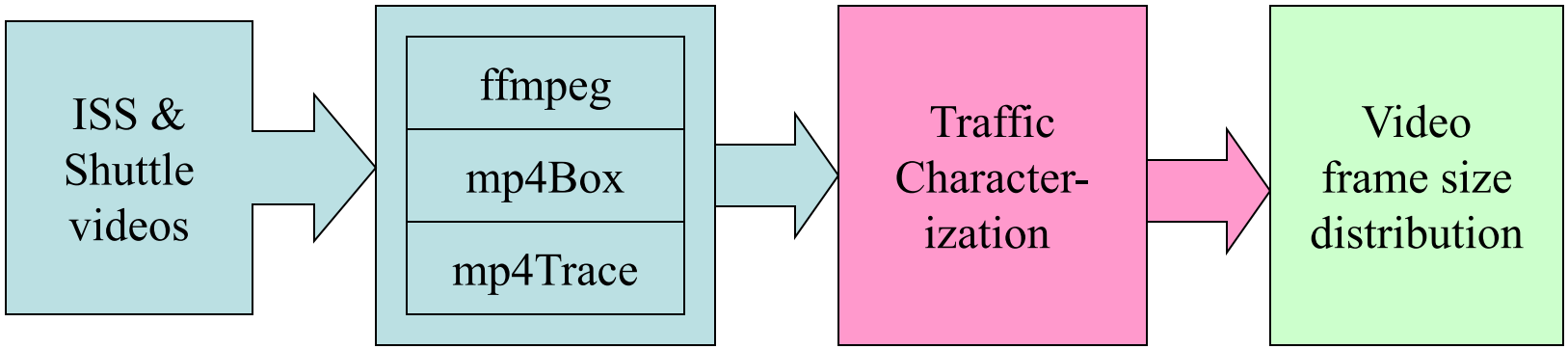
Video Traffic Analysis

Utilized video streams from ISS and Shuttle missions to determine the distribution of the packet sizes for various scenarios

- e.g. space walks, astronauts working in the Shuttle, fuel tank separation

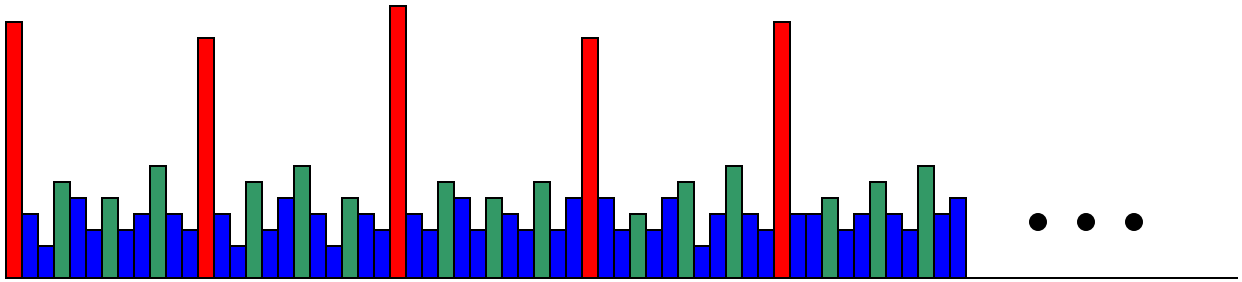
Video Traffic Analysis

- Used ffmpeg to rip video files from DVD and recode in MPEG CIF format
  - MPEG4 part 10 at highest quality (q = 1) with GOP pattern IBBPBBPBBPBB
- Used MP4Box to put mpeg4 codec frames into mp4 multiplexed stream
- Used mp4trace transmit the stream to the network to collect the traffic trace
- Analyzed the traffic trace using Matlab to determine frame size distributions

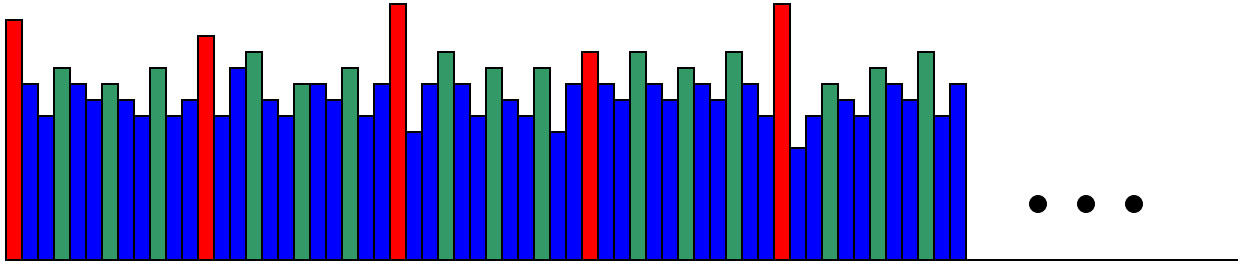


Video Traffic Analysis

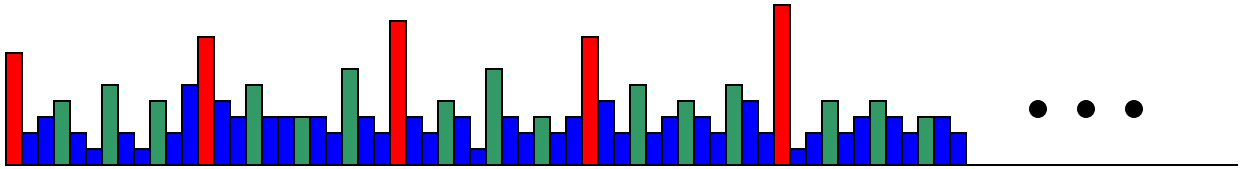
Laboratory



Earth in background



Space walk in the dark



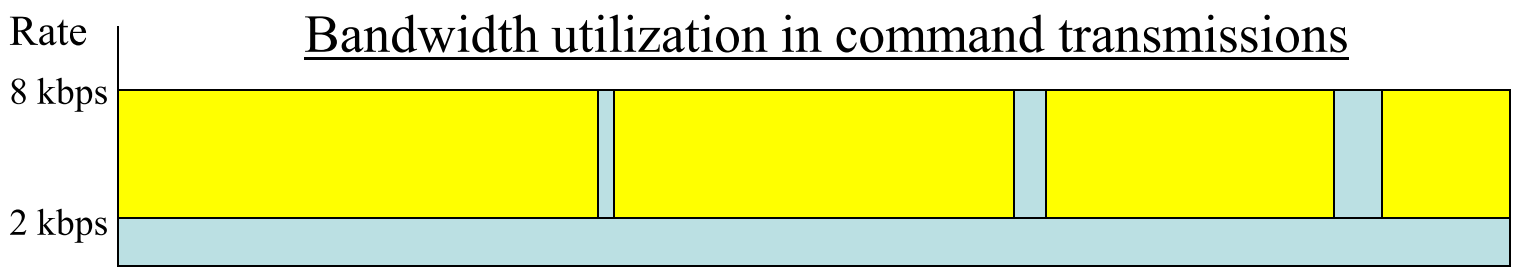
GOP = I B B P B B P B B P B B

Potential Gains in Command and Telemetry

Shuttle command

- In Shuttle missions command is allocated 8 kbps constant bit rate
- Since most commands are just function calls to preloaded subroutines, the whole 8 kbps is generally not utilized
- The full 8 kbps is only utilized for brief periods of time when a new subroutine must be loaded to the shuttle for future execution

As in the case of command similar gains may be attained in the case of telemetry transmissions



ENCAPS / AOS Model

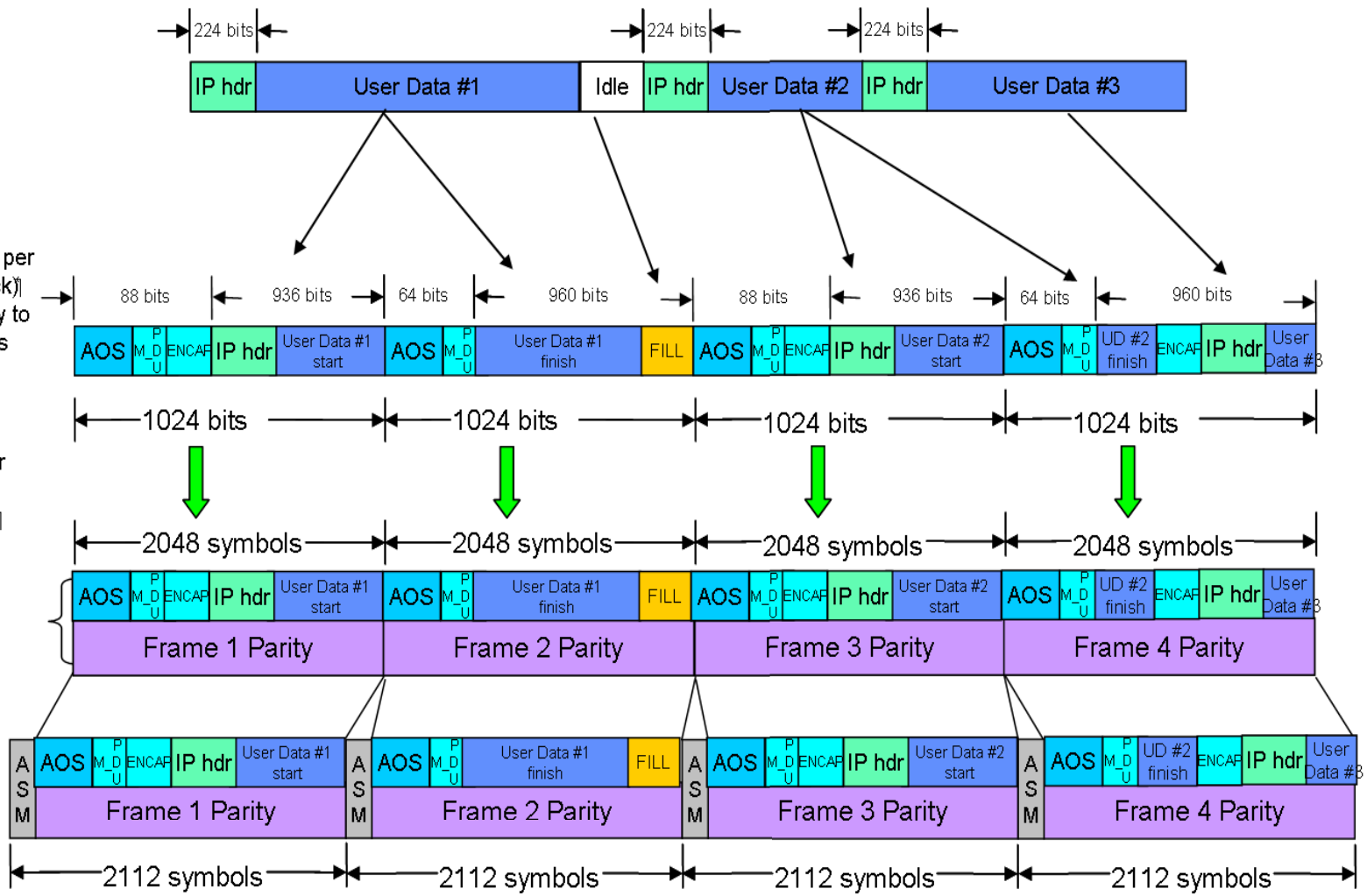
1kB LDPC codeblock and 3B encap header shown as an example
When IP header compression is used, the size of the 'IP hdr' block (IP+Transport) will be different.

1. **IP packets** are generated (20 byte IP hdr & 8 byte UDP hdr per packet)

2. **AOS framing** (6 byte AOS hdr & 2 byte M_PDU hdr per 128 byte code block)
* FILL inserted only to finish partial frames

3. **LDPC encoder** (info + parity bit 2-to-1 expansion)

4. **Attached sync marker** attached (32 bits = 64 symbols assuming QPSK modulation)



Physical Model

- Two major components
  - TDRSS Models
    - Selection & Handover
    - Bent-pipe
  - Physical Propagation
    - Integrated with Link Budget Library
- TDRS selection criteria
  - Determined by schedule derived from customer and SN
    - On the other hand, model uses periodic distance check; assumes handover is scheduled when Orion crosses midpoint.
  - TDRS Selection Criteria Model
    - Dynamic based on Orion-TDRS range and line-of-sight
    - User-specified period for continuous check
    - User-specified acquisition interval parameter
      - antenna slew, carrier acquisition, etc…

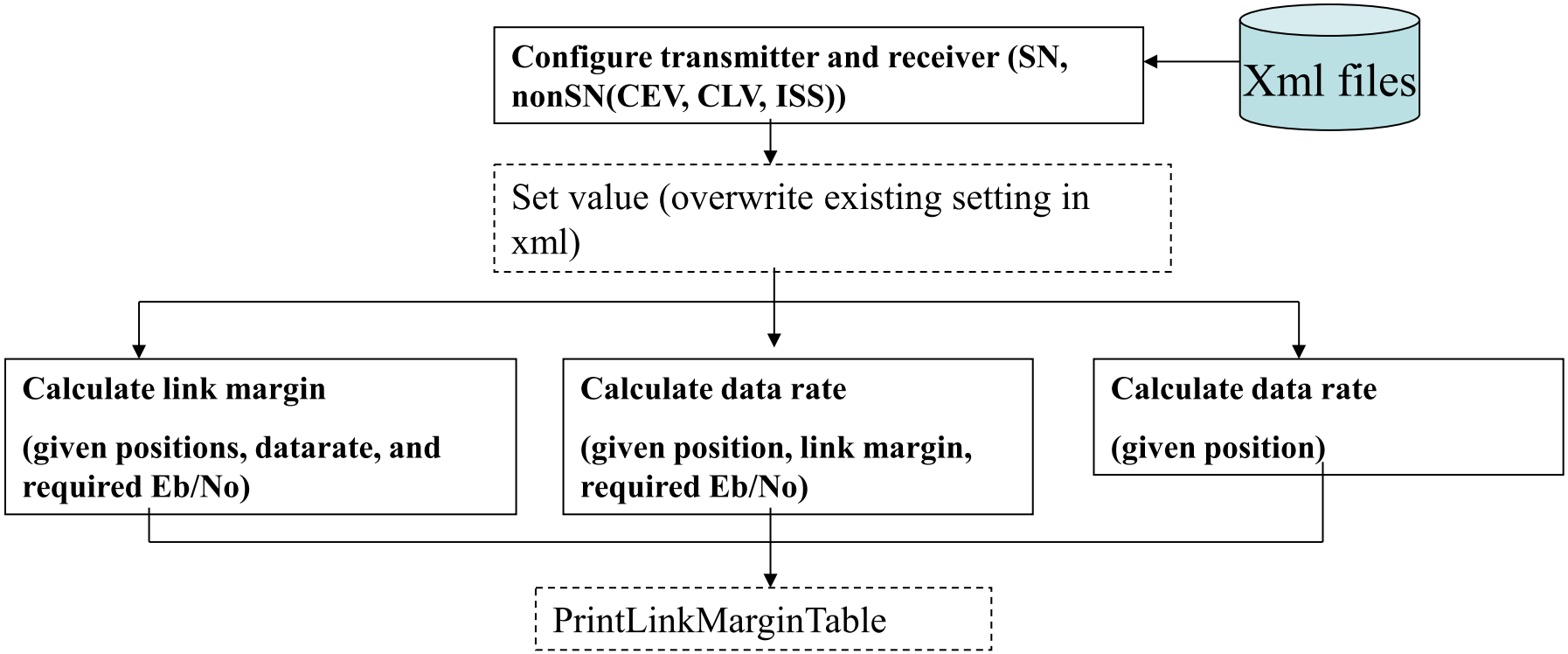
DSIL Link Budget Analysis Library

- link performance analysis for CEV-SN, CLV-SN, CEV-ISS at different phases and different bands.

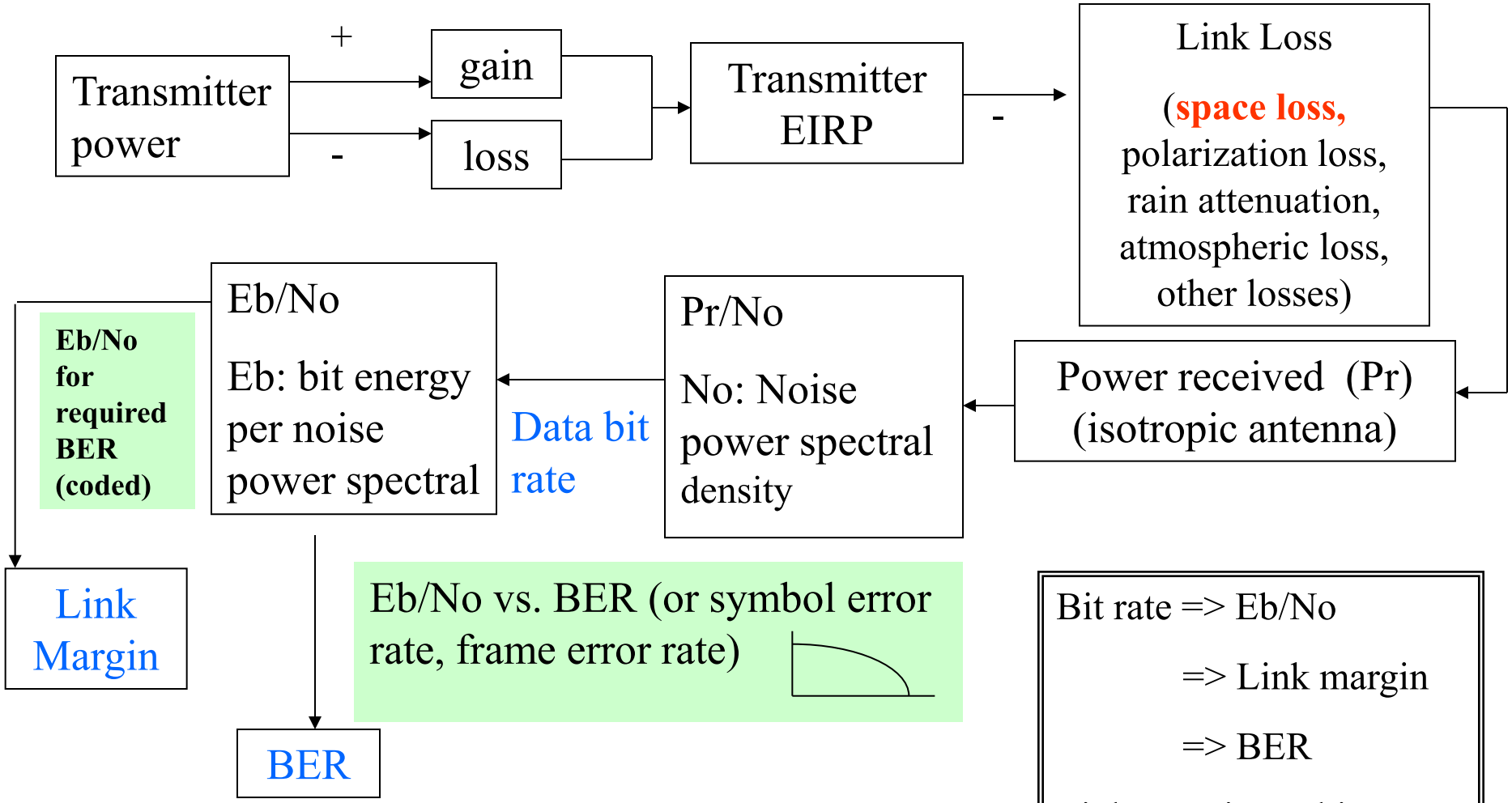
- C++, Windows and Linux

- all static communication parameter values are set in XML files

- dynamic parameter values are set externally



Link Budget Calculation



Use Case: Stand-alone simulations

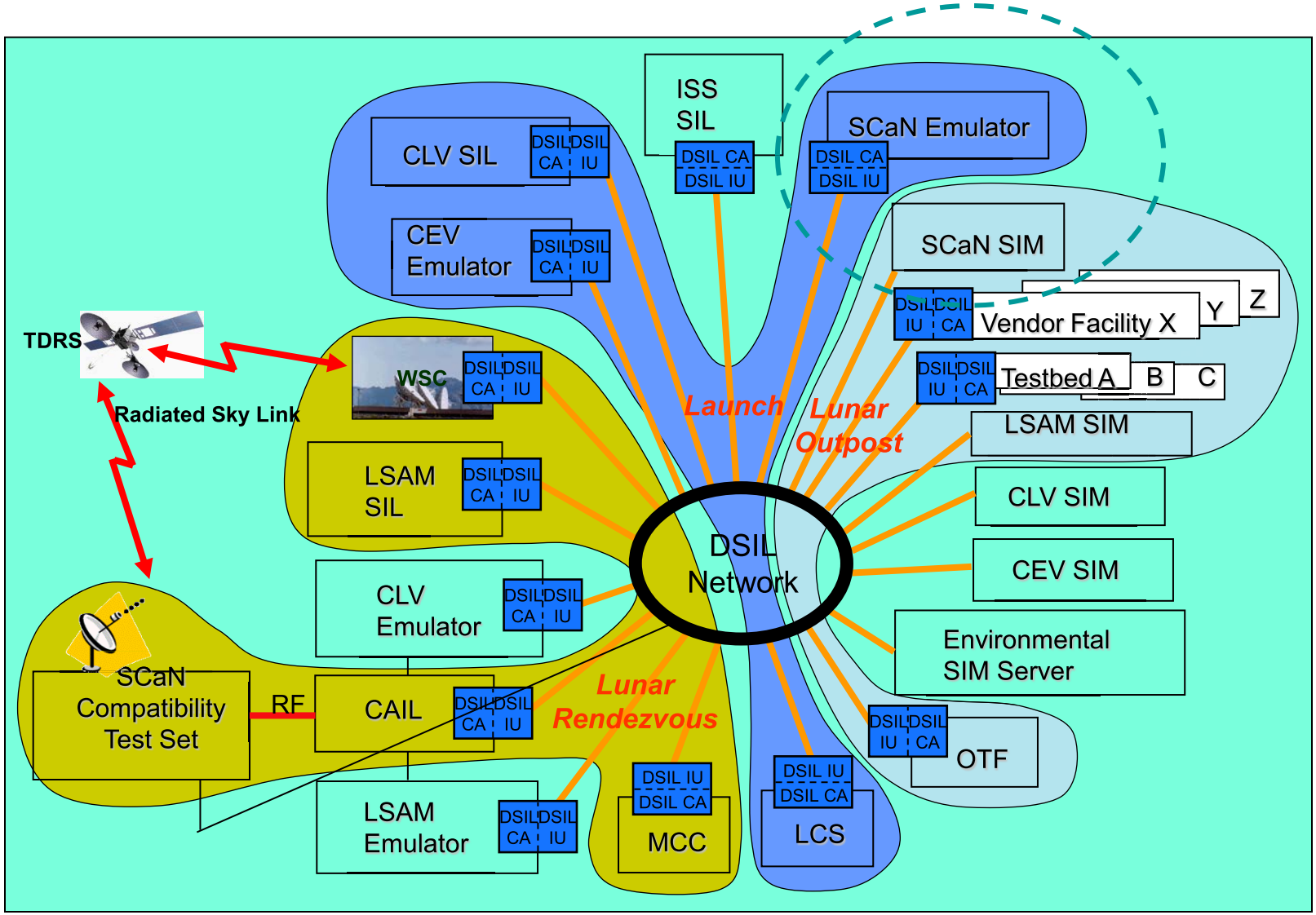
SCaN Simulations of Cx CSADD Scenarios Listing

Thu Mar 5 17:27:51 PST 2009

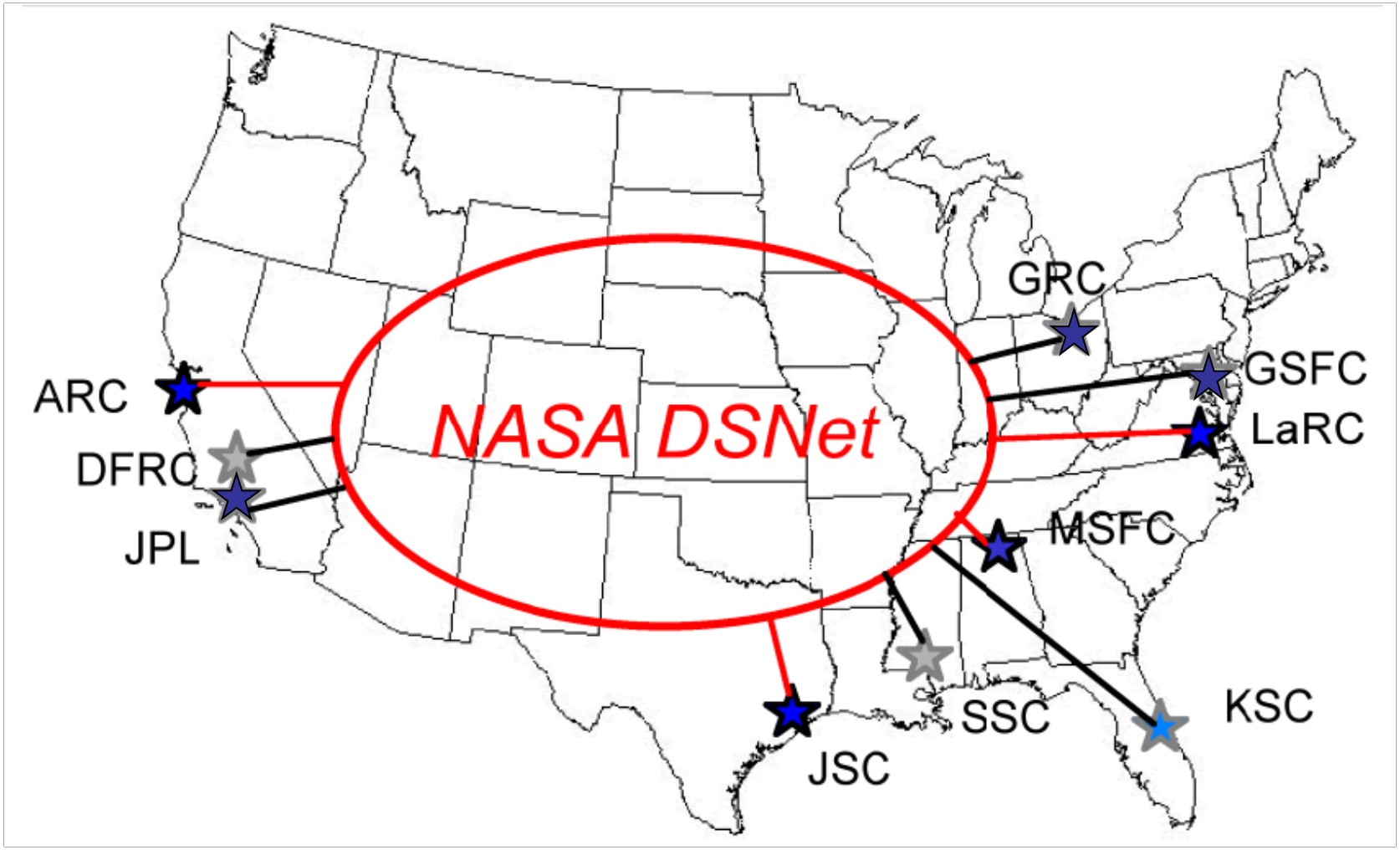
Test Name	Sim Date	CSADD Needline	Pkts Sent	Thruput (bps)	Latency (msecs)	Jitter (usecs)	Pkt Loss (per mill)
CLOSE RENDEZVOUS CEV-A-ISS - Baseline	2009-03-05	CEV-ICCA-TLM-docked-MOD	4200	16804	0	6	0
FAR RENDEZVOUS CEV-A-ISS - Baseline	2009-03-05	CEV-ICCA-TLM-docked-MOD	4200	16804	100	11102	0
NEAR RENDEZVOUS CEV-A-ISS - Baseline	2009-03-05	CEV-ICCA-TLM-docked-MOD	4200	16804	33	2839	0
Launch Ascent Post-ALAS CEV-MS - Baseline	2009-03-05	CEV-MS-TLM-ascent-MOD	4200	122269	352	1211	0
Launch Ascent Post-ALAS CEV-MS - Baseline	2009-03-05	CEV-MS-voice-ascent-ag1	4200	7201	357	1211	0
Launch Ascent Pre-ALAS CEV-MS - Baseline	2009-03-05	CEV-MS-TLM-ascent-MOD	4200	122269	352	1211	0
Launch Ascent Pre-ALAS CEV-MS - Baseline	2009-03-05	CEV-MS-voice-ascent-ag1	4200	7201	357	1211	0
Launch Countdown CLV-MS - Baseline	2009-03-05	CLV-MS-TLM-countdown-MOD	6000	122260	352	1181	0
Launch Countdown CLV-MS - Baseline	2009-03-05	CEV-MS-voice-countdown-ag1	6000	7201	357	1181	0
Launch Countdown CLV-MS - Baseline	2009-03-05	CEV-MS-voice-countdown-ag2	6000	7201	366	1181	0
DESCENT CEV-MS - Baseline	2009-03-05	CEV-MS-TLM-entry-MOD	4200	93462	335	1211	0
DESCENT CEV-MS - Baseline	2009-03-05	CEV-MS-voice-entry-ag1	4200	7201	340	1211	0
LDR LEO CEV-MS - Baseline	2009-03-05	CEV-MS-TLM-LEO-MOD	4200	93462	289	147	0
LDR LEO CEV-MS - Baseline	2009-03-05	CEV-MS-voice-LEO-ag1	4200	7201	289	147	0
LDR LEO CEV-MS - Baseline	2009-03-05	CEV-MS-voice-LEO-ag2	4200	7201	290	147	0

28 experiments from Countdown to Descent

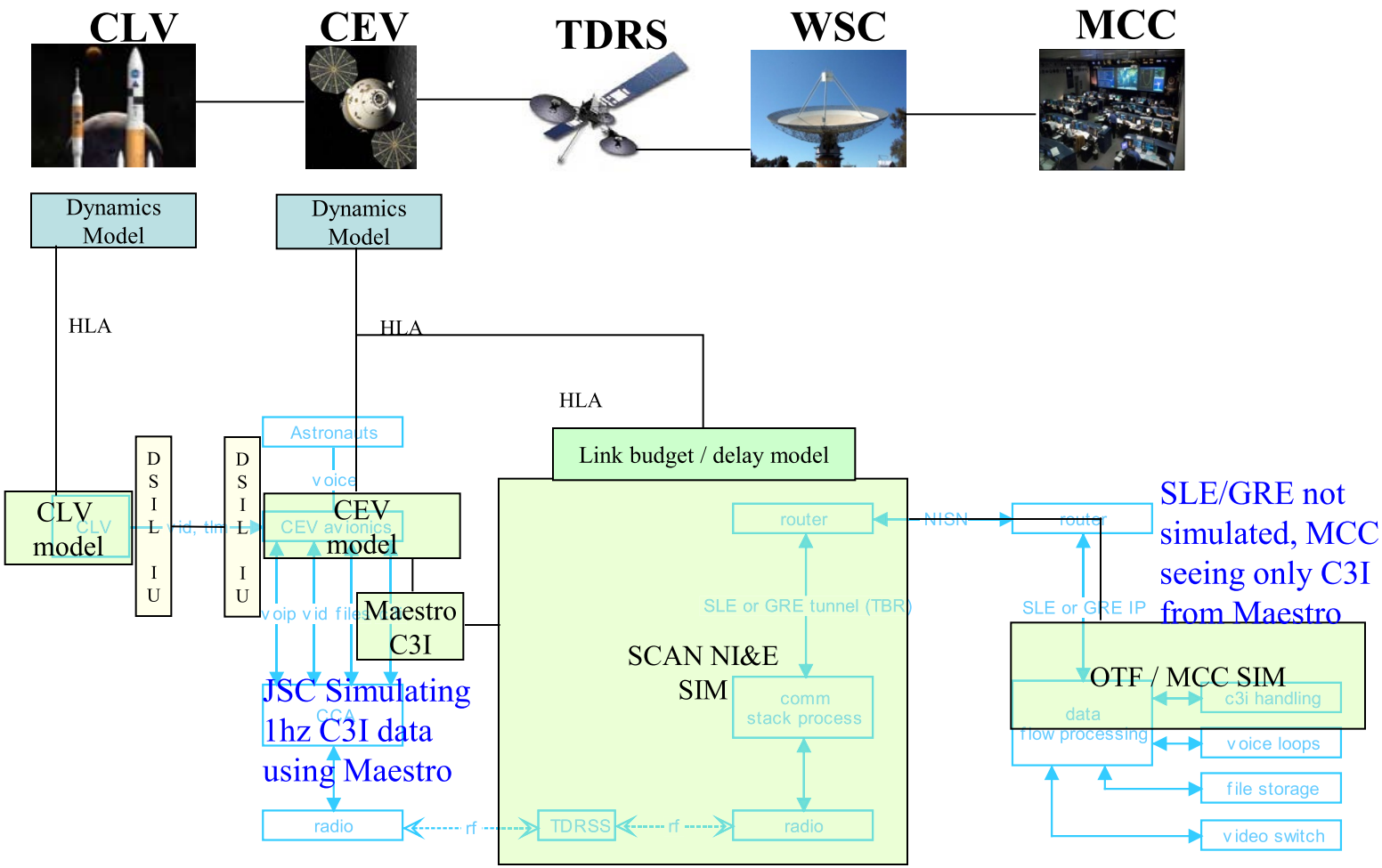
Use Case: DSIL



Network – Geographical View

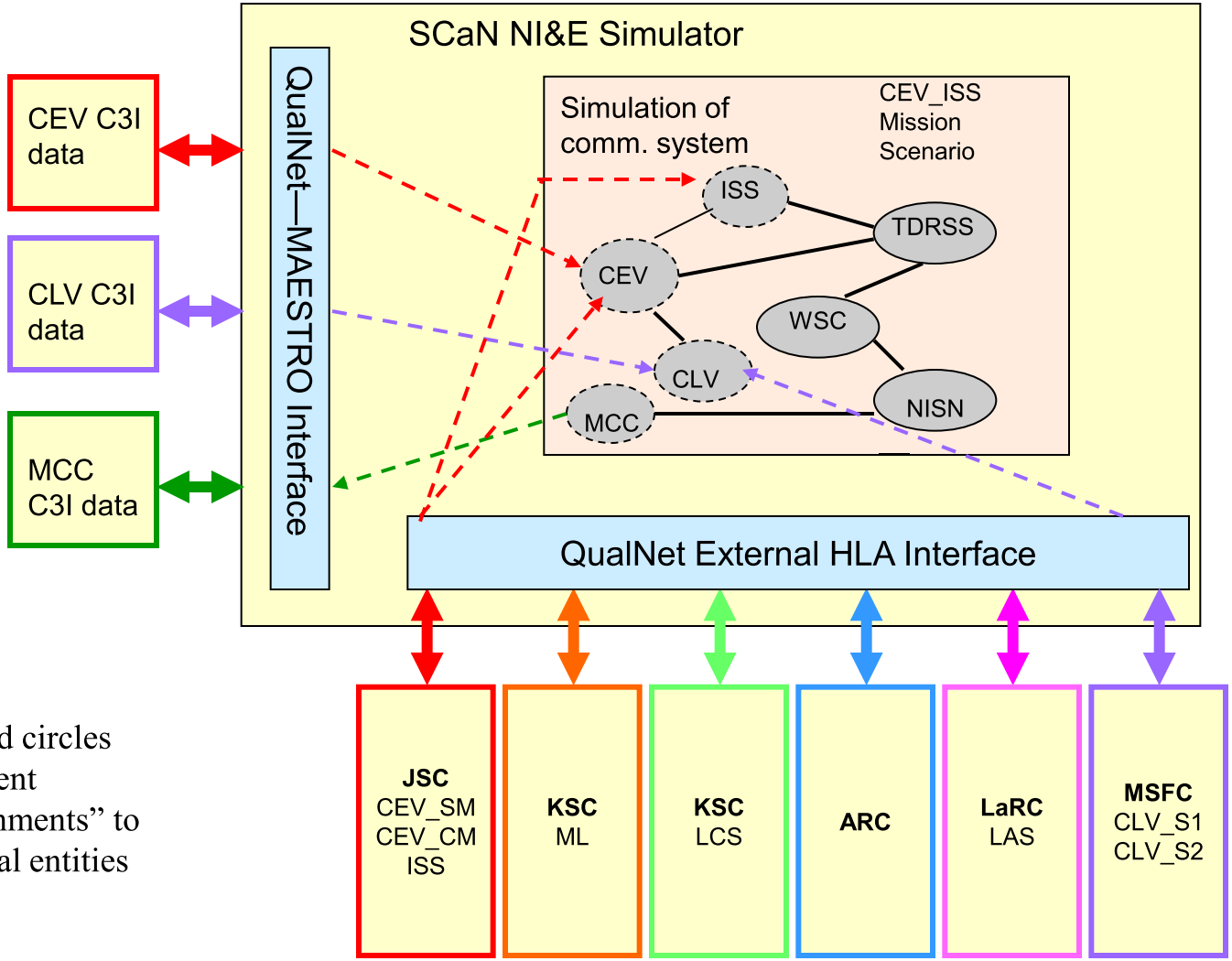


Distributed Simulation (DSIL Demo)



MSFC JSC JPL JSC

SCaN NI&E Simulator Interfaces



Dashed circles represent "attachments" to external entities

Conclusion & Future Work

- What was done:
  - Developed custom simulation models to evaluate IP-based network performance for space exploration missions
  - Used the tool for early integration tests
- Future extensions:
  - More accurate trajectory, antenna model
  - QoS, Security issues