Coarse-Grain Bandwidth Estimation Techniques for Large-Scale Network

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Agenda

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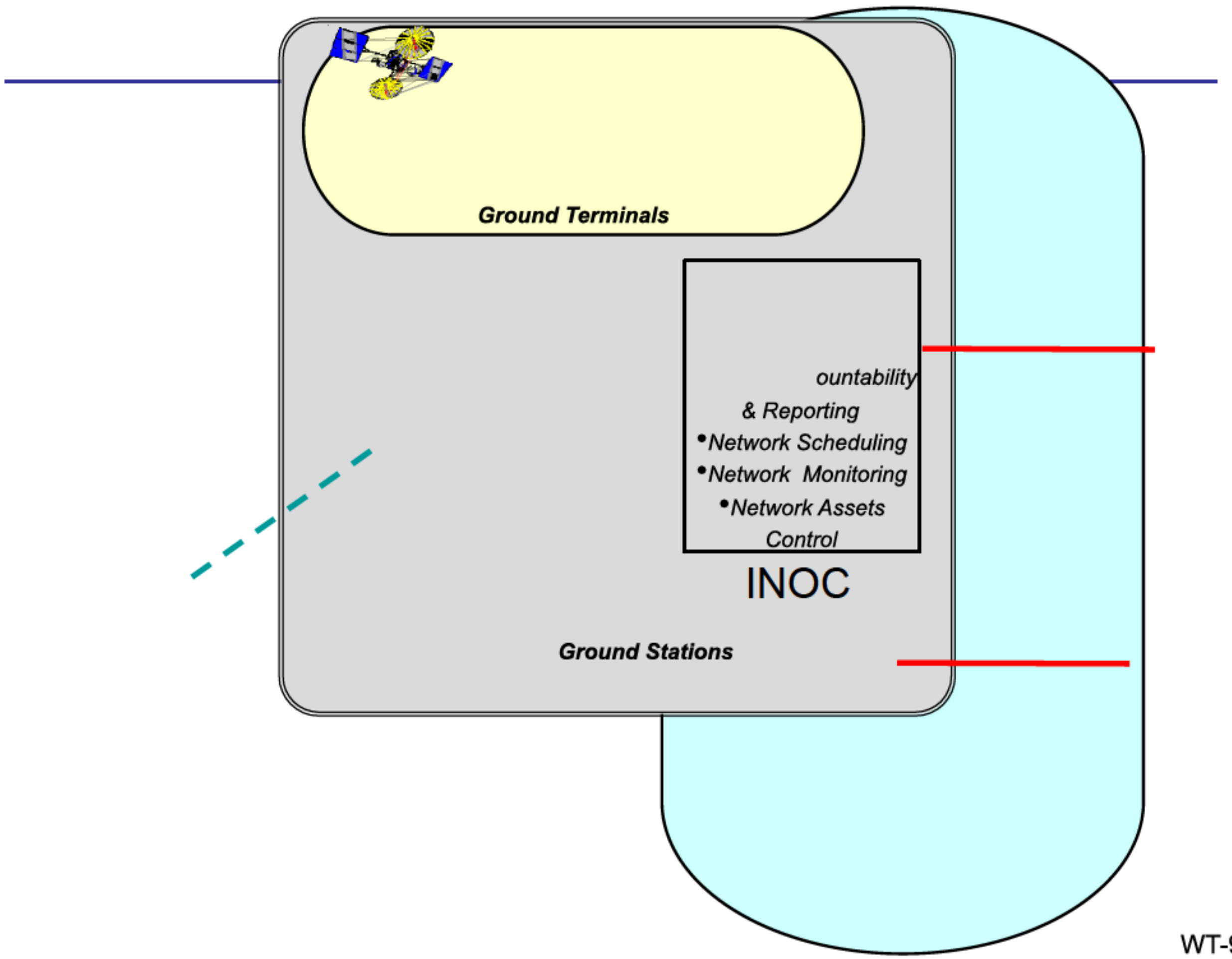
- Scope and Assumptions
- Problem Setup
- Straight-Forward Leveling Scheme
- 2-State Markov Leveling Scheme
- Bandwidth Estimation Results for the SCaN Integrated Network
- Concluding Remarks and Future Work

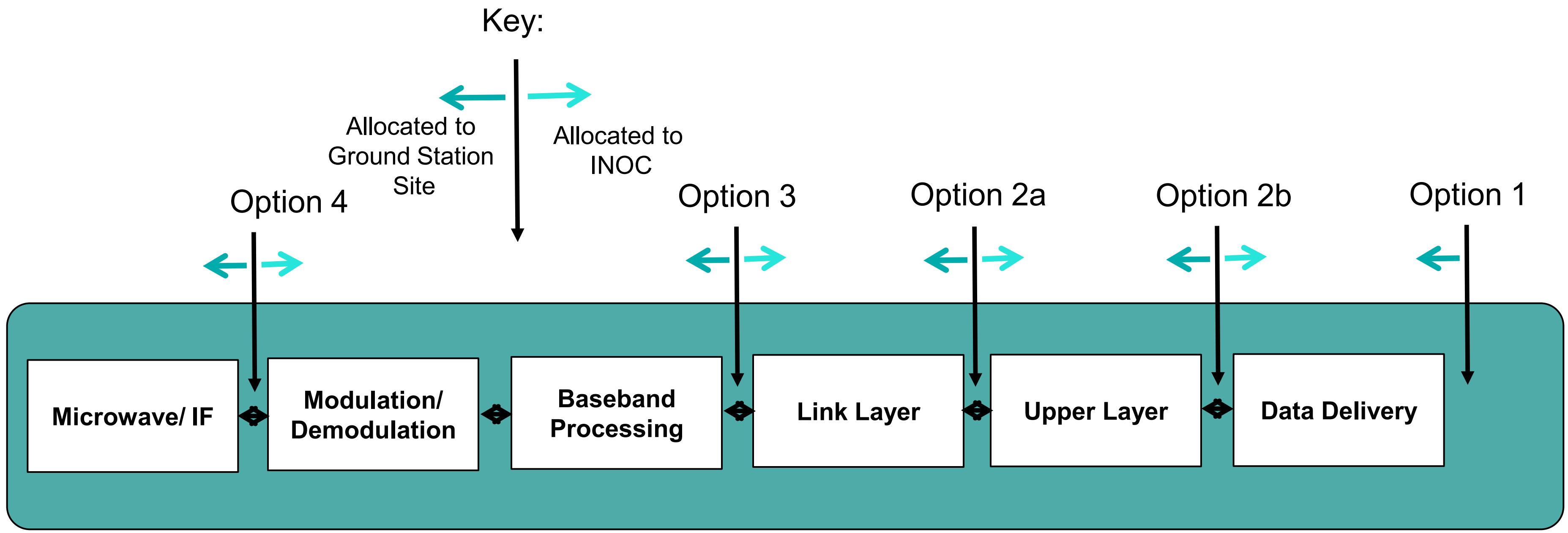
Background of NASA SCaN Integrated Network Schematics

- **NASA communication infrastructure consists of three distinct networks**
  - Space Network (SN), Near-Earth Network (NEN), Deep Space Network (DSN)
- **The three NASA networks will be re-architected into a single network that is interoperable with international/commercial agencies**



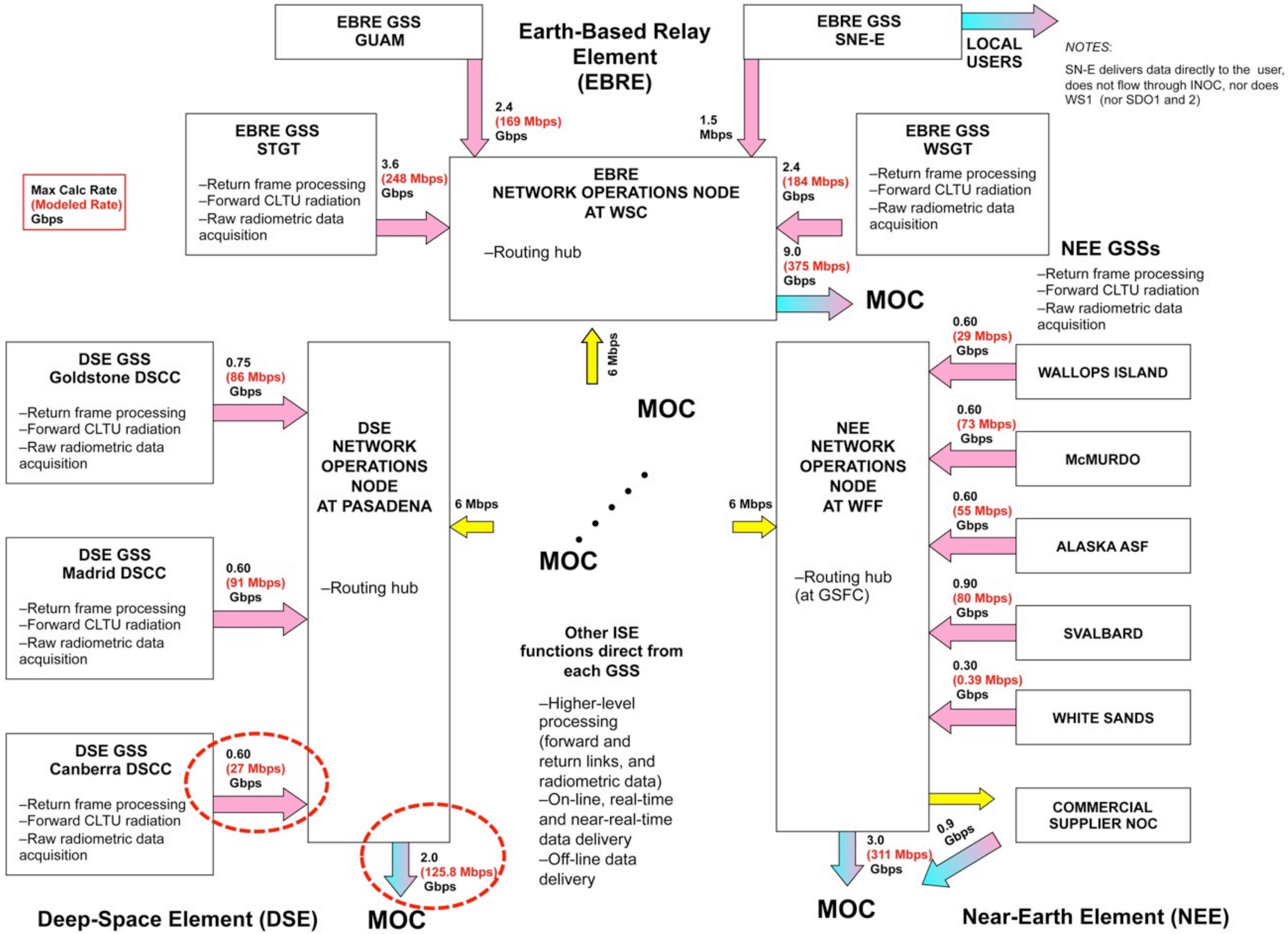
Background of NASA SCaN Integrated Network ISE Allocation of Functions

- **The Space Communication and Navigation (SCaN) Program of NASA conducted a trade-study on the Integrated Network Architecture (INA)**
  - Focus on Integrated Network Management and Integrated Service Execution
  - Four Integrated Service Execution (ISE) architecture options are identified based on the allocation of network signal processing and data delivery functions between the ground station sites and the integrated network operation center

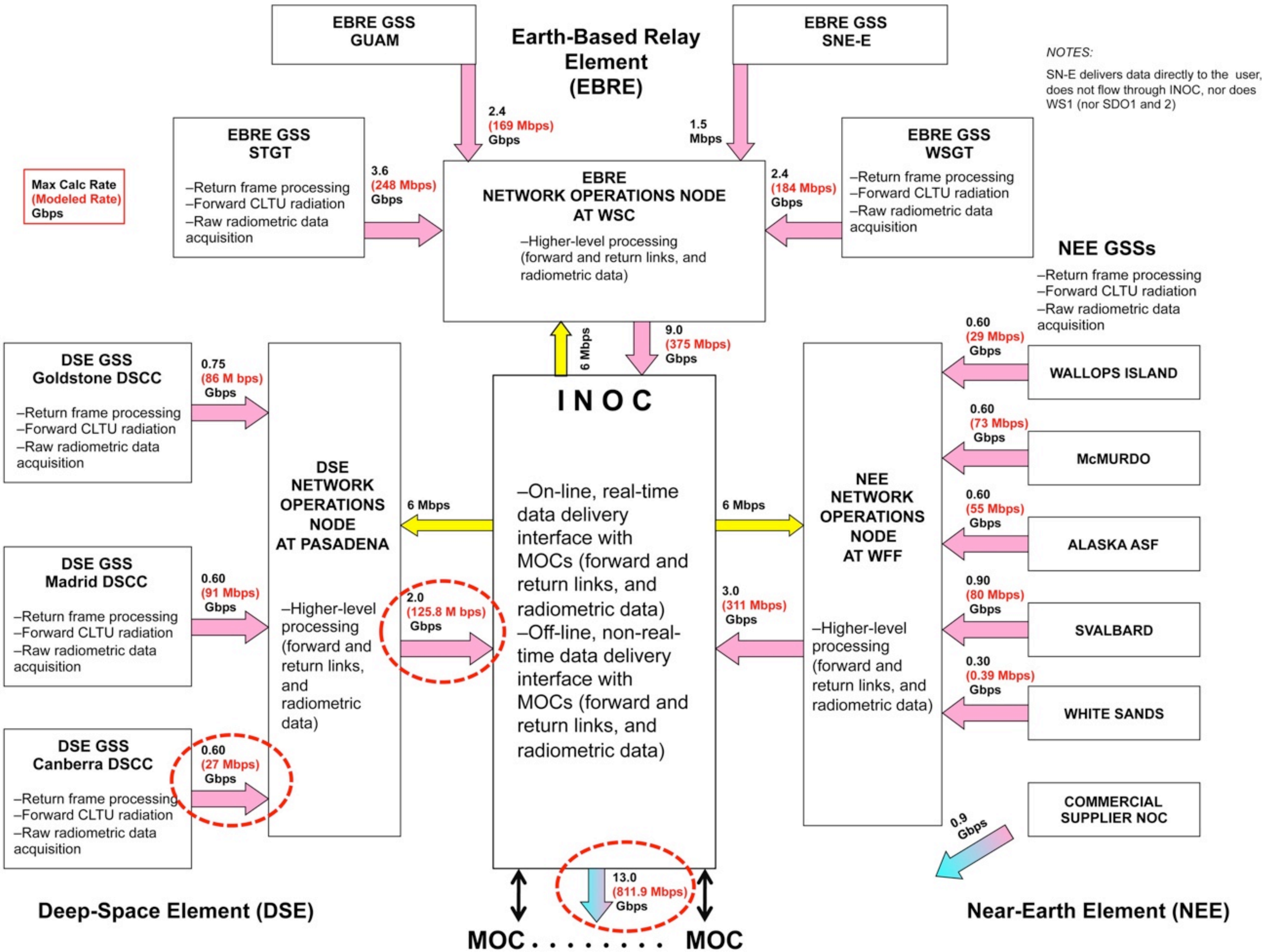


- **Key discriminator of ISE options is wide area network (WAN) bandwidth for data flow among SCaN ground assets, and from SCaN to missions**
  - Substantial recurring cost and technical risks

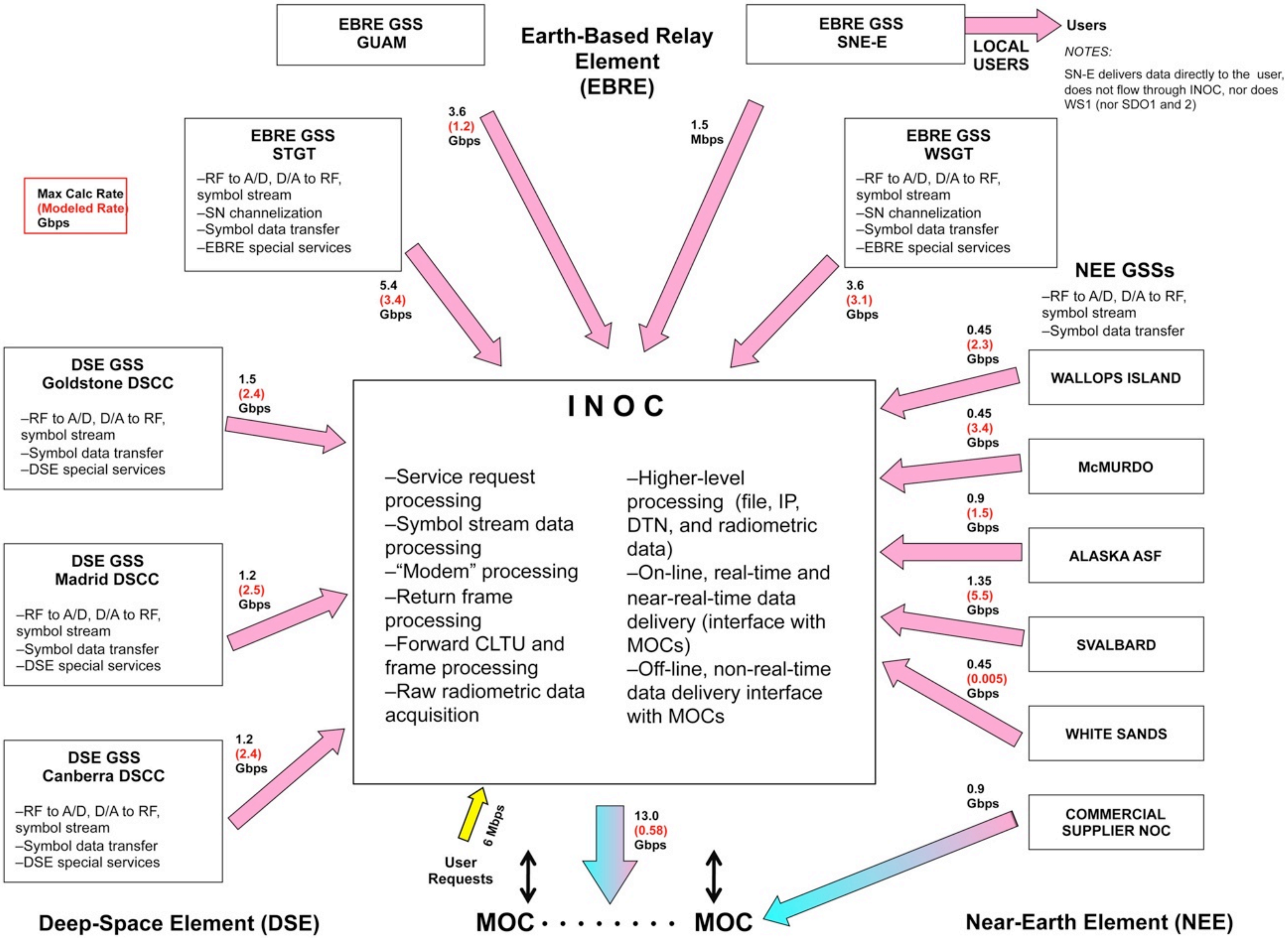
Background of NASA SCaN Integrated Network ISE Architecture Option ISE-1



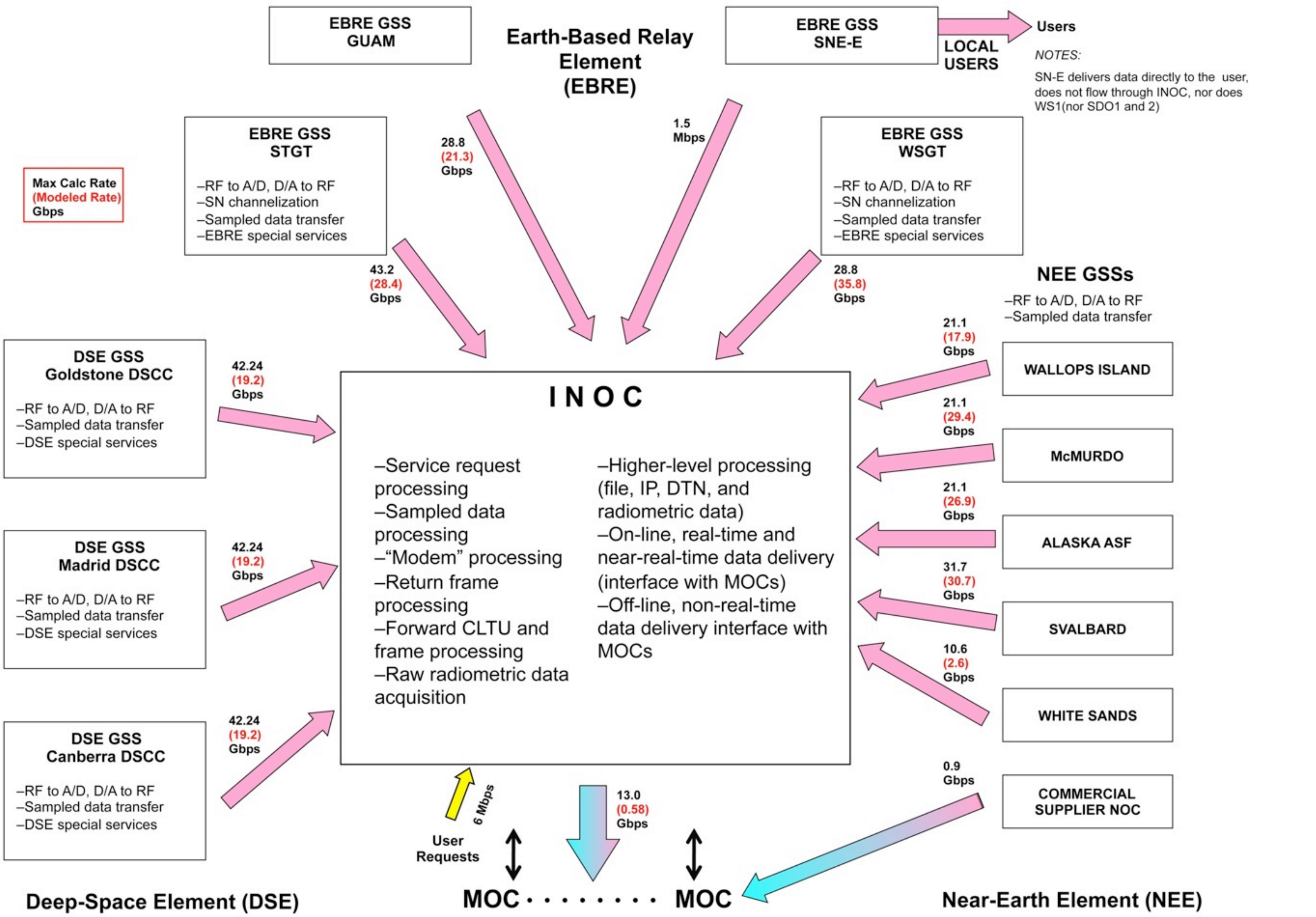
Background of NASA SCaN Integrated Network ISE Architecture Option ISE-2



Background of NASA SCaN Integrated Network ISE Architecture Option ISE-3



Background of NASA SCaN Integrated Network ISE Architecture Option ISE-4



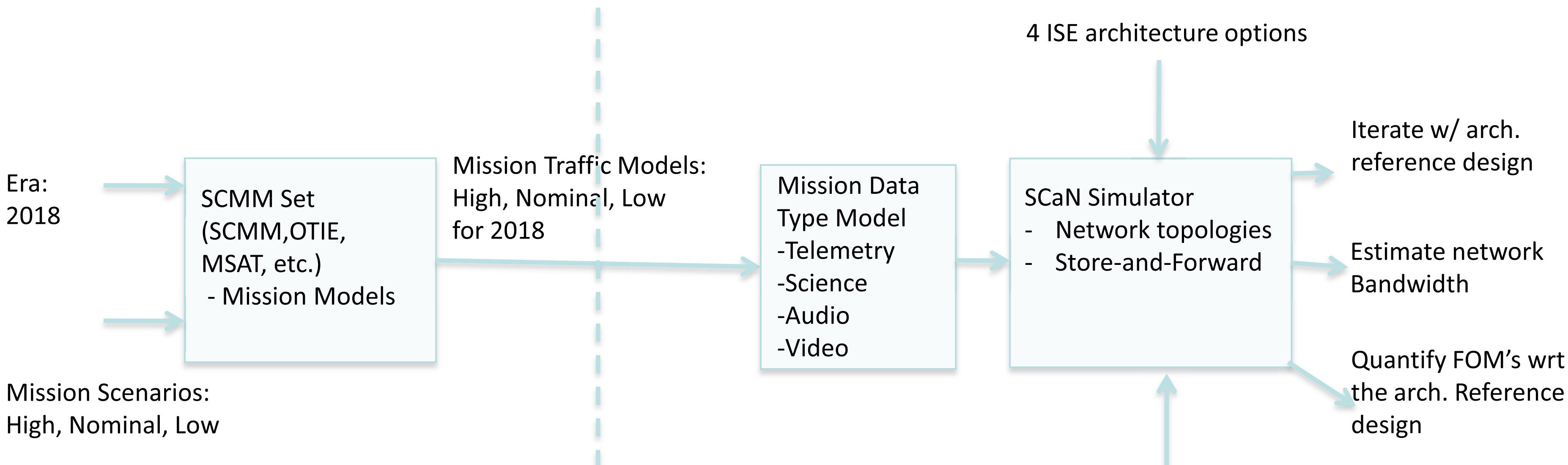
Scope and Assumptions

- **The SCaN Integrated Network has a star-like topology that does not require routing mechanism and flow control**
  - Only need to model the Store-and Forward mechanism of the ground nodes
- **Data traffic flows are driven by spacecraft downlinks, and are offered and serviced as constant bit rate flows over a pre-determined time intervals**
- **Different mission data types have different latency requirements:**
  - Audio/video data: 2 seconds
  - Engineering telemetry: 5 seconds
  - Quick-look science: 30 minutes
  - Bulk science: 1 hour or 8 hours
- **The Space Communication Mission Model (SCMM) is used to derive the mission traffic for the 31-day period in July 2018**
  - Based on NASA's Agency Mission Planning Mission Manifest (AMPM)
  - Consider "base" case, "high" case, and "low" case
- **The SCaN Integrated Network has an aggregated data rate in the order of a few Gbps, and a daily data volume of a few terabytes per day**
  - COTS network and routing analysis tools, which provide high-fidelity protocol, routing, and flow control simulation, are not well-suited for the SCaN large-scale network

Problem Setup

- **Find the integrated Network bandwidths that meet the latency requirements**
- **For ISE-3 and ISE-4, the GSS-INOC links are bit-streams with no store-and-forward rate buffering (quantized coded symbols and RF/IF samples)**
- **All other ground links are store-and-forward, and link sizes are driven by the combined effects of mission data rates, data types, and different latency requirements**

Mission Traffic Model | **End-to-End Network Traffic Model**

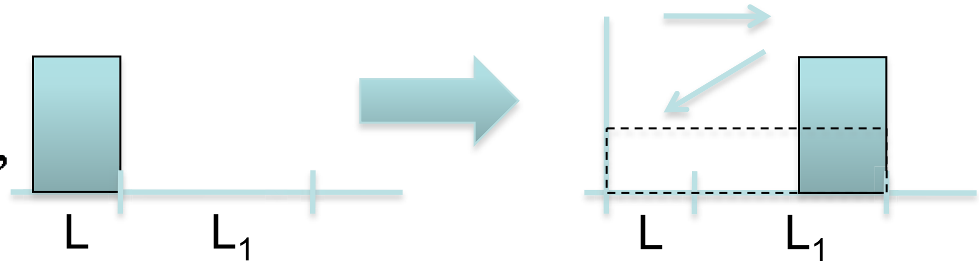


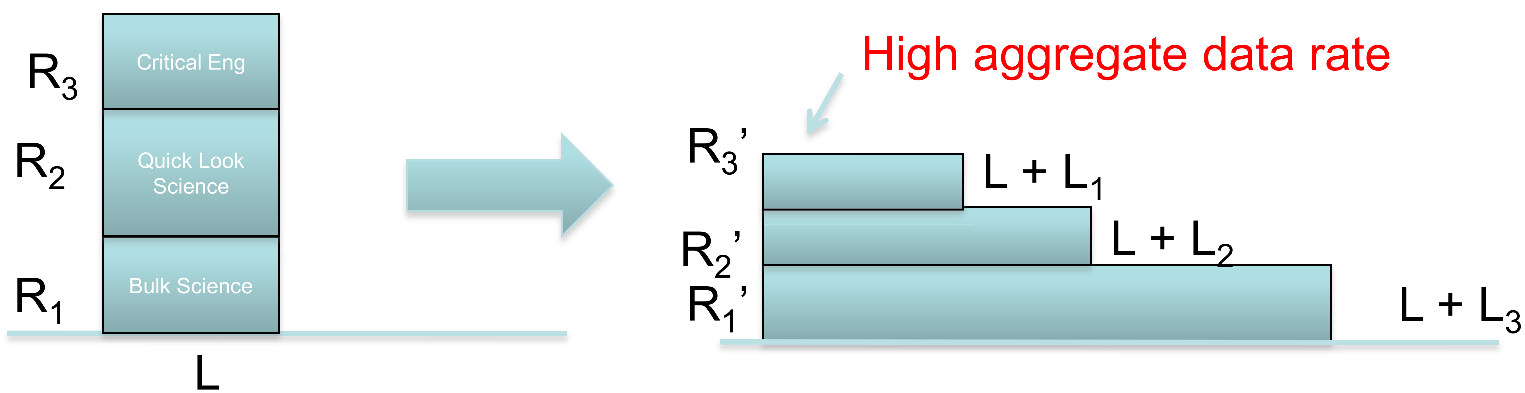
Store-and-Forward Modeling Using Leveling Schemes

Straight-Forward Leveling Scheme

- **"Straight-forward" way to spread the data of each data types along the timeline in a way to meet the latency requirement**
- **The beginning of a communication pass can be unnecessarily penalized with higher aggregate data rate**

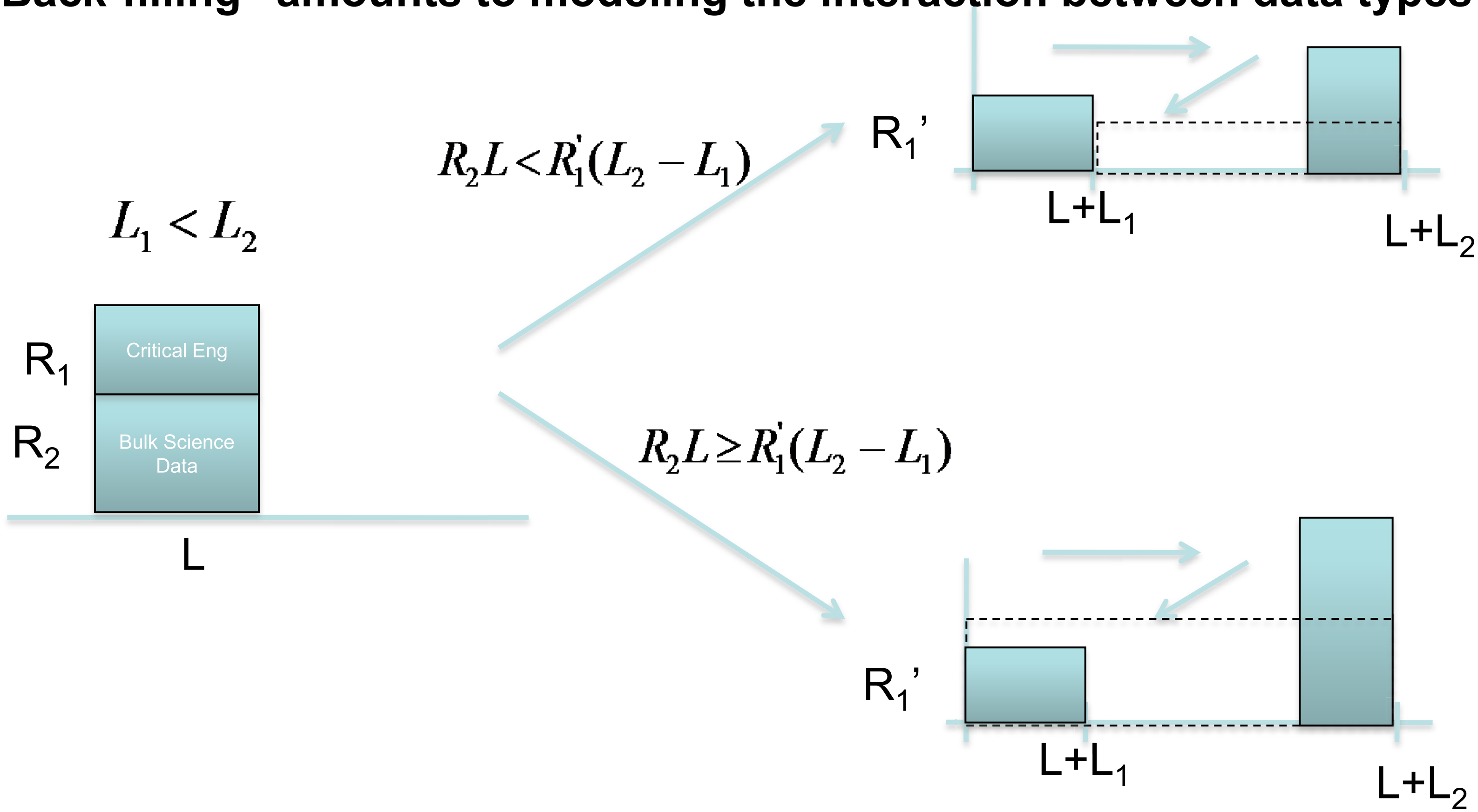
$$R_i' = R_i \frac{L}{L + L_i}, \quad 1 \leq i \leq N,$$





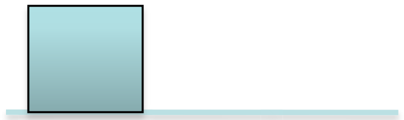
2-State Markov Modeling Scheme Observation

- **Smaller aggregated bandwidth can be achieved by back-filling the vacant timeline between $L+L_1$ and $L+L_2$ with Type 2 data (Greedy Algorithm)**
- **Example: For L=1 hour, L_1=5 second, L_2=8 hours, R_1=20 kbps, R_2=180 kbps**
  - "Straight-Forward" scheme yields 40 Kbps
  - "Back-filling" scheme yields 20.3 Kbps
- **"Back-filling" amounts to modeling the interaction between data types**

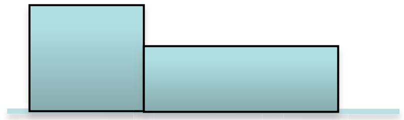


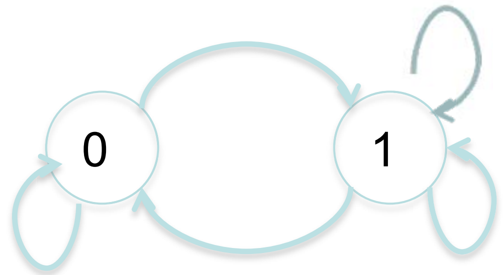
2-State Markov Modeling Scheme
State Representation

State 0



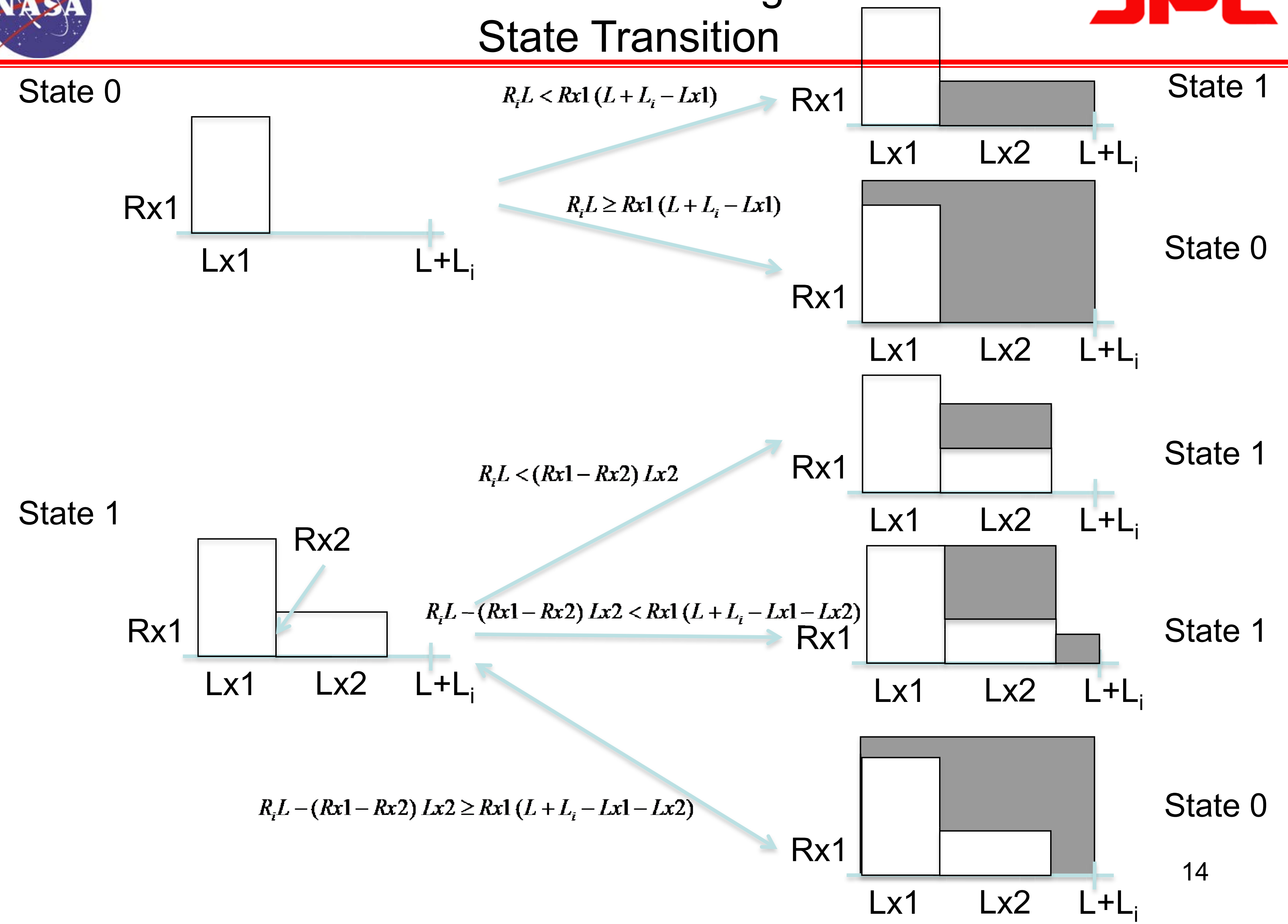
State 1





State Transition Diagram

2-State Markov Modeling Scheme
State Transition



Bandwidth Estimation Results of the Integrated Network

- **Validity of the Model: Comparing Leveling Scheme with Qualnet for DSN**

Base Case (Mbps)	Goldstone	Canberra	Madrid
Leveling Scheme	136.4	102.0	120.9
Qualnet	139.5	99.6	121.9

- **Aggregated WAN bandwidths (Gbps) for bulk science latency of 1 hour, straight-forward scheme**

Latency = 1 hr	Option 4	Option 3	Option 2a	Option 1
Base Case	182.444	15.742	3.514	2.352
High Case	207.353	43.612	8.209	6.021

- **Aggregated WAN bandwidths (Gbps) for bulk science latency of 8 hour**

Latency = 8 hr	Option 4	Option 3	Option 2a	Option 1
Base Case	182.157	15.456	2.259	1.712
High Case	206.606	42.865	5.847	4.145

Bandwidth Estimation Results for the SCaN Integrated Network

- **Aggregated WAN bandwidths (Gbps) for bulk science latency of 1 hour, 2-State Markov scheme**

Latency = 1 hr	Option 4	Option 3	Option 2a	Option 1
Base Case	182.207	15.505	2.664	1.938
High Case	206.809	43.068	7.116	4.708

- **Aggregated WAN bandwidths (Gbps) for bulk science latency of 8 hour, 2-State Markov scheme**

Latency = 8 hr	Option 4	Option 3	Option 2a	Option 1
Base Case	182.010	15.308	1.789	1.444
High Case	206.211	42.470	4.644	3.210

Concluding Remarks and Future Work

- **In this paper, we describe new leveling schemes to model the traffic flow and rate buffering mechanism of a large-scale store-and-forward network**
- **We apply these techniques to estimate the WAN bandwidths of the ground links for different ISE architecture options**
- **Future work and possible improvements**
  - Instead of sizing the bandwidth based on the “min-max” approach, a better approach to quantize the link sizes is to use the statistics from traffic simulations
  - Instead of making blanket assumptions on mission data types across all mission, one can provide data type modeling for each individual mission
  - Instead of just considering the store-and-forward latency, which accounts for the majority of the end-to-end latency, one can improve the accuracy by including other latency contributions like code-word buffering delay, frame buffering delay, and ground transmission delay
  - The authors believe that the leveling scheme can be extended for use in more complex WAN scenarios that share diverse network resources among diverse users and have a complex topology that requires rounting mechanism and flow control

- **A companion paper that provides a general overview of the SCaN Integrated Network traffic flow modeling can be found in reference [3]**