Dynamic Access for the Future NASA Space Communications Network

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Objectives & Significance

Current State of the Art:

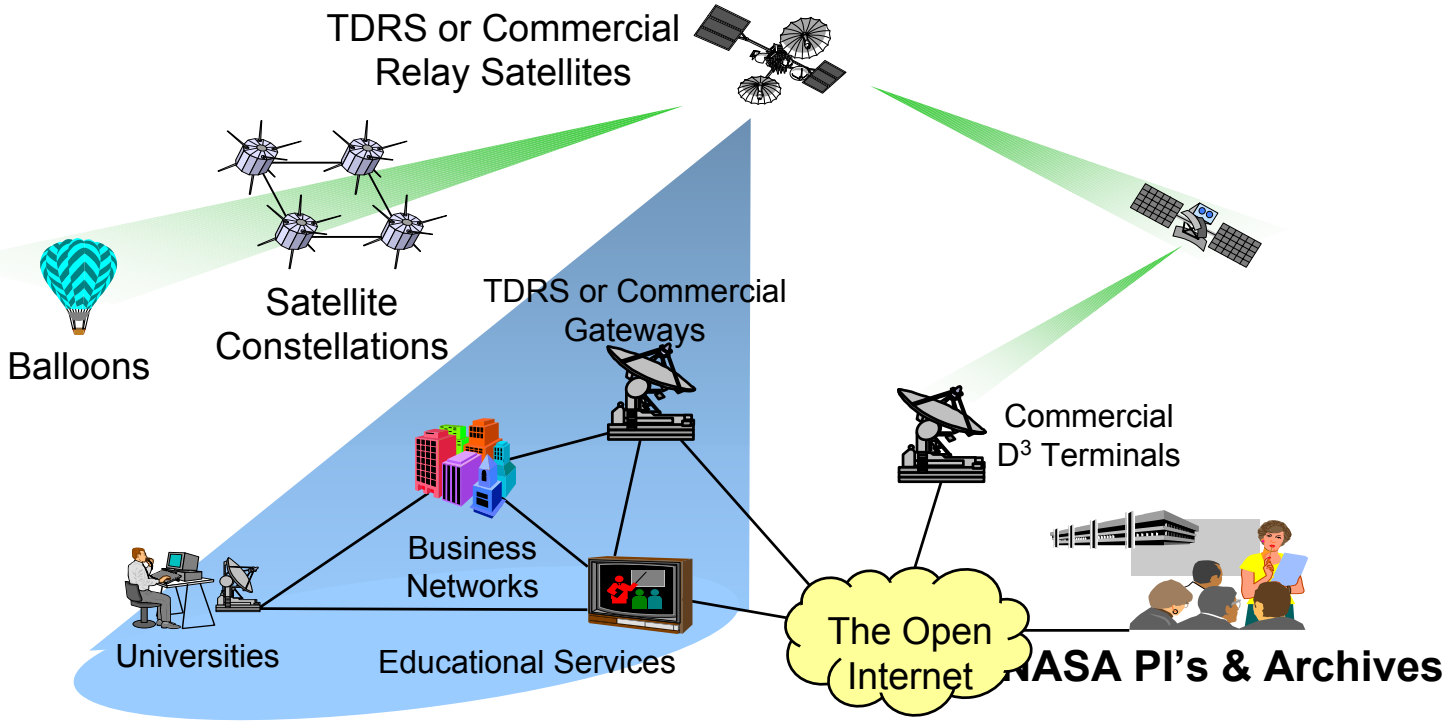
- **Missions have a limited communication capability (wrt bandwidth).**
- **Mission Operation is done using a static, pre-planned concept and mainly (including ISS Comms.) rely on TDRSS for data relay to the ground.**
- **There is a heavy reliance on custom-developed communication protocols and technology.**

Facts:

- **Number of active NASA missions is increasing and communication requirements are exploding, quickly reaching a data transfer requirement in the range of Gigabits/s.**
- **ISS deployment provides a unique platform for tele-science in space and generates a vast and diverse set of data communication requirements.**
- **Control of assets in Space will become automatic/decentralized:**
  - distributed spacecraft (constellations), addressable instruments, etc.
- **Deployment of technology and commercial Internet infrastructure on the ground (and in space) vastly outpaces NASA infrastructure.**

Future Mission Network Evolution

- **NASA network supports large numbers of single or constellation spacecraft with IP-addressable instruments**
- **Mission Operation gradually evolves to a dynamic concept and uses a NASA & commercial assets for communication support; direct-to-ground as well as GEO relay solutions are employed.**
- **Commercial technology and standard communication protocols are employed (where possible).**



How do we help in achieving this transition?

- Performed high level study of potential communication architectures that could support "anytime, anywhere", IP-compatible access to space.
- Developed (following the conclusions/recommendations of that study) an initial framework for investigating the performance advantages of an on-demand access scheme for dynamic mission operations.
- Completed modular, OPNET-based, simulation model consisting of the several mission spacecraft, realistic traffic sources, possible candidate satellite constellations and a ground network architecture.
- Currently investigating flexible and secure access solutions that can lead to more efficient access to space

Evolution from Pre-planned Mode to On-demand mode

- **Pre-planned Concept**
  - Principal Investigator (PI) sends request for communication service to Space Network Center days to weeks ahead.
  - PI receives schedule of allocated access times after completing conflict resolution.
  - PI retrieve data from storage at allocated time.
- **On-demand Concept**
  - PI accesses his instrument to set control parameters or retrieve data as desired- “Any Time, Any Where”
  - If connectivity not available, network returns “ subscriber not in service” message similar to wireless service

Current Operation: Pre-planned Mode

- **Pre-planned Operational Scenario:**
  - **Multiple Spacecraft share access to ground station.**
  - **A priori bandwidth allocations based on advance requests/scheduled passes over certain position.**
- **Advantages: Simple to plan & implement, QoS guarantee possible, low hardware cost**
- **Disadvantages:Might result in inefficient use of bandwidth, cannot accommodate "Any Time, Any Where" concept, cannot accommodate emergencies, limits number of possible users sharing channel**

Future Operation: On-demand Mode

- **On-demand Operational Scenario:**
  - Multiple Spacecraft share access to ground station.
  - A priori bandwidth allocations still based on advance requests/scheduled passes over certain position.
  - Can add an option for dynamically assigned additional bandwidth on demand
- **Advantages: QoS guarantee possible, efficient channel utilization, number of supported users can be increased, emergencies could be accommodated.**
- **Disadvantages:More complex implementation, more complex hardware and software on-board, signaling channel required.**

On-Demand Access for Dynamic Mission Operations

To enable an on-demand operation that efficiently supports multiple spacecraft we need to:

- **Understand Mission Traffic Characteristics**
- **Understand priorities and QoS guarantees that must be met**
- **Develop an on-demand mode multiple access able to support space to ground communications**
- **Implement suitable protocol support and security solution**

Profiles of NASA Mission Traffic

NASA's Vision: Re-design future communication support network and make it more adaptive to traffic flow

Our Objective: Develop a quantitative, mathematical and statistical basis for analyzing, changes to NASA communications network architectures that prescribe entirely new concepts for NASA networks.

Approach:

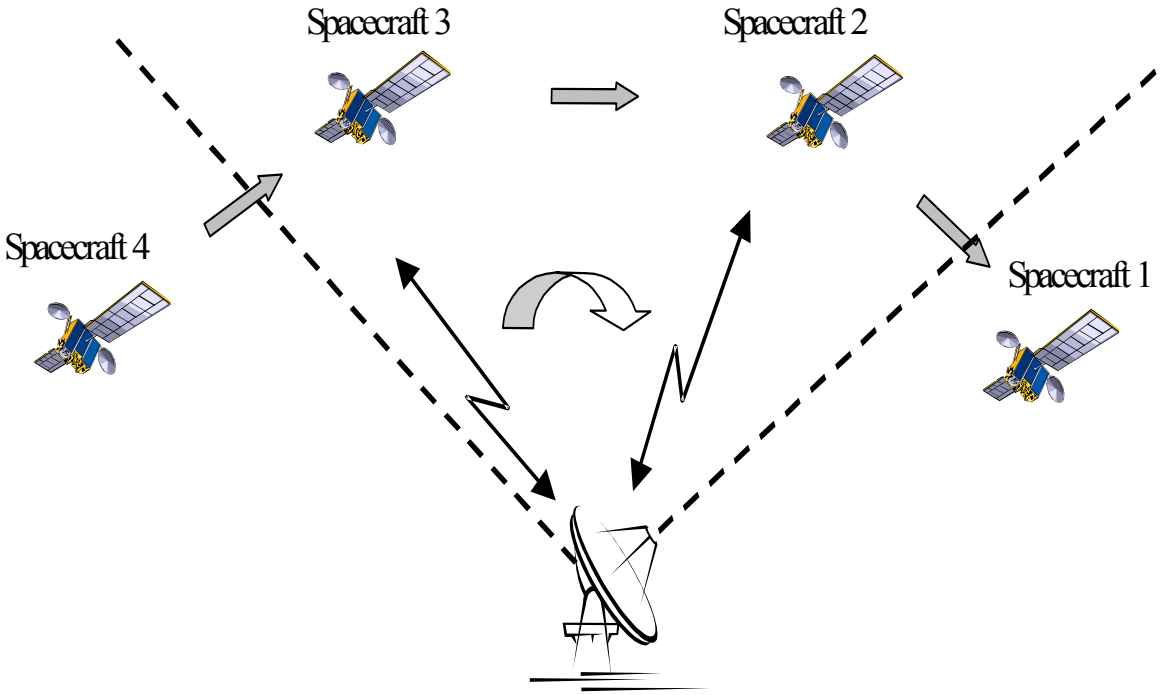
- **Establish a baseline set of statistical models of the traffic currently carried on NASA networks, driven by usage statistics collected by NASA relay sites.**
- **Develop statistical & simulation models for future NASA communications traffic.**
- **Employ models representing current and planned communications traffic to analyze NASA network.**

Dynamic MAC Requirements

As number of users (spacecraft) and associated data volumes increase, need an efficient MAC scheme that satisfies the following requirements:

- **Multiple Spacecraft share access to ground station efficiently**
- **Provides required QoS guarantees for different classes, priorities of traffic (TT&C, science data)**
- **Handles mobility of spacecraft**
- **Takes advantage of special architecture (limited number of users, predictable mobility)**

Space-to-Ground Scenario



- Spacecraft are the "Ultimate Mobile Platform"!
- They are visible by Ground Station for a limited (usually predictable) time period.
- This introduces another dimension on the Multiple Access problem

On-demand Mode for LEO NASA Spacecraft?

- **LEO mobile satellite environment presents challenges to MAC schemes:**
  - **Limited and expensive bandwidth**
  - **Non-negligible propagation delay**

Is on-demand mode MAC scheme suitable for this environment?

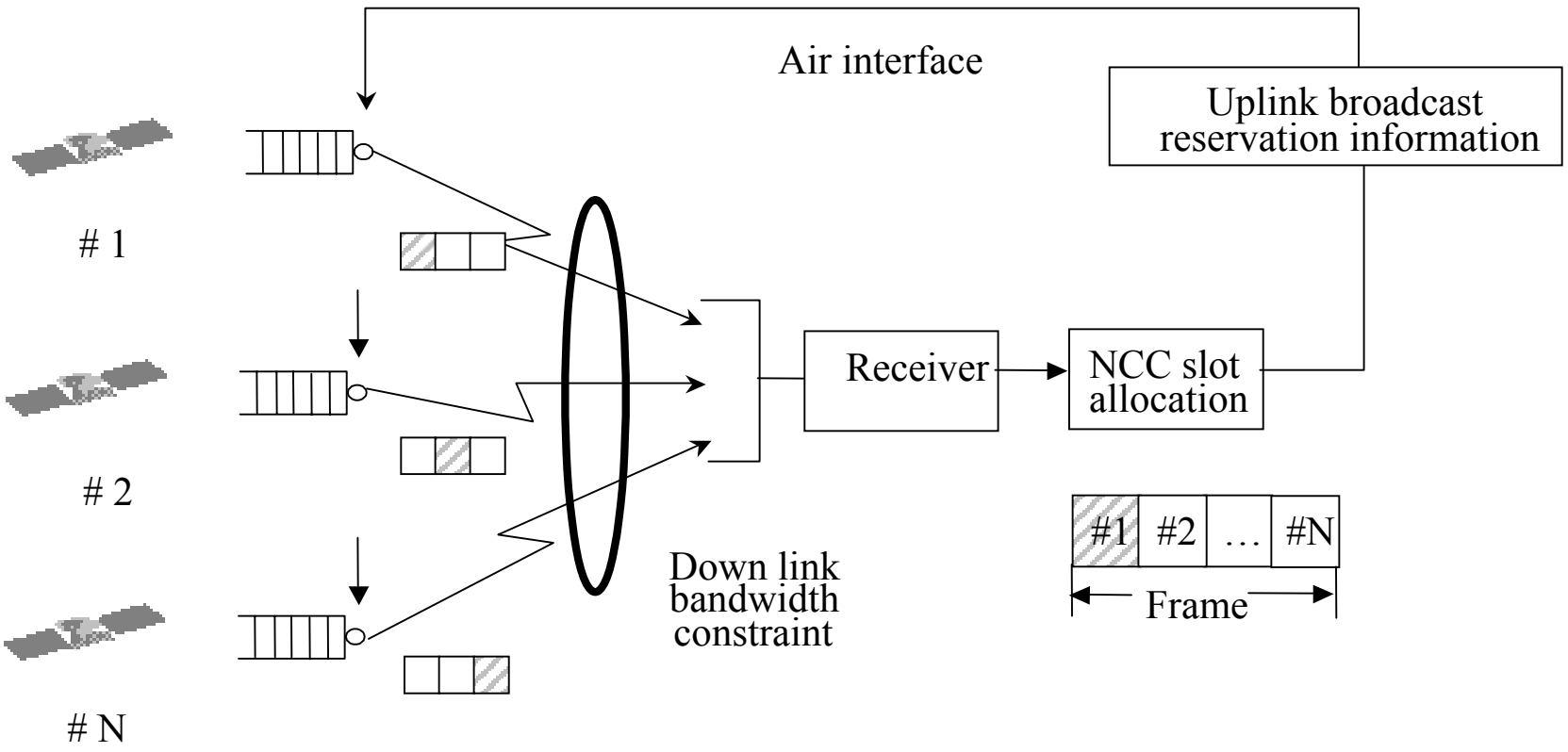
  - **Utilization/throughput: How much can on-demand mode outperform pre-planned mode?**
  - **Could on-demand mode offer better delay performance than preplanned mode?**
  - **What are the other advantages that on-demand mode has over pre-planned mode?**

Proposed RD-TDMA Scheme

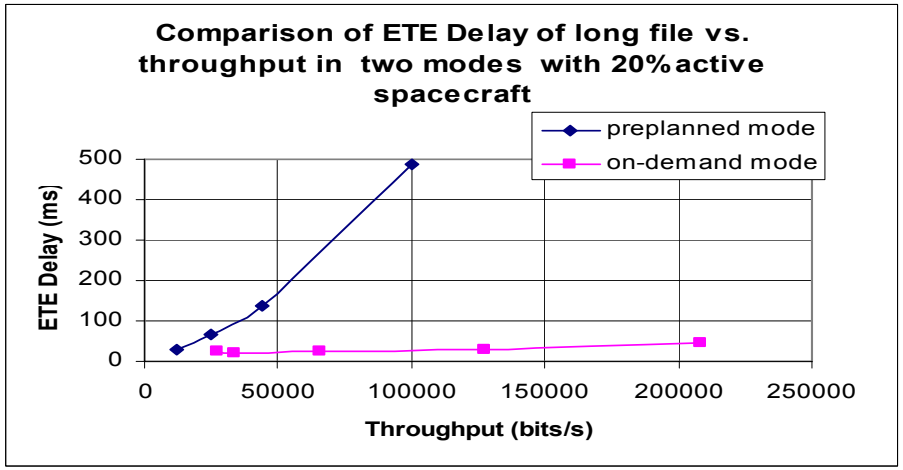
- Although a lot of demand TDMA protocols were proposed in the literature, they addressed the MAC issues for cellular network and packet-switched radio satellite network architecture.
- Proposed RD-TDMA protocol for our unique LEO network scenario with the novel on-demand mode network architecture.
  - **The RD-TDMA protocol is a reservation based demand TDMA protocol.**
  - **It uses slotted-ALOHA for reservation.**
  - **$T_f = RTD_{max}$.**
- Advantages of Proposed RD-TDMA
  - **efficient in bandwidth utilization under bursty traffic environment;**
  - **able to accommodate larger number of spacecrafts.**

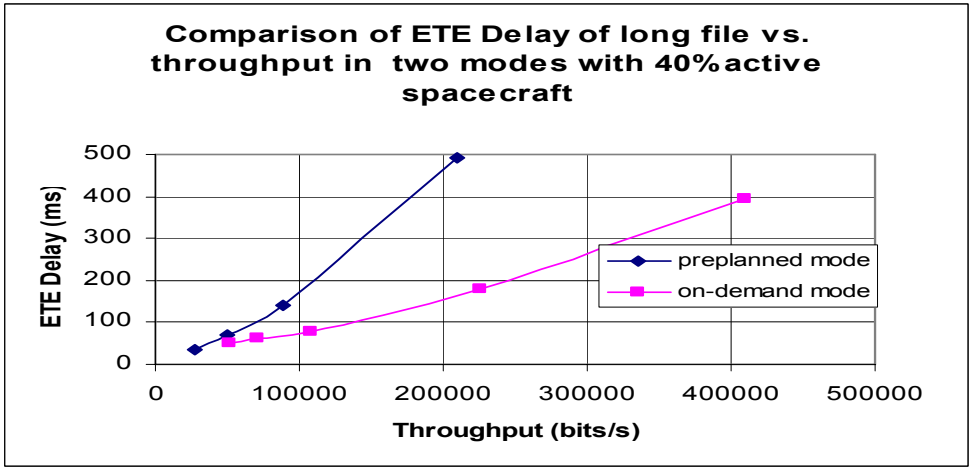
On-Demand MAC for Dynamic Mission Operations- Protocol Operation

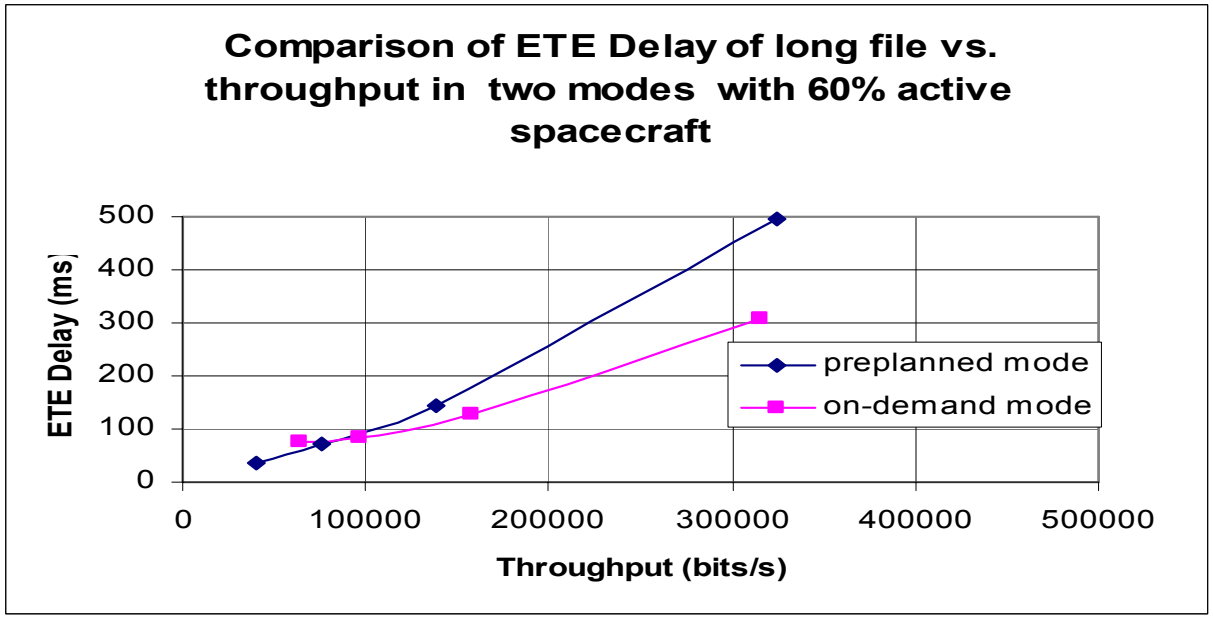
- **Protocol Operation**
  - Channel Reservation
  - Data Message Transmission



On-Demand MAC for Dynamic Mission Operations- Performance Comparison







Modeling Tool Development

- Developed a discrete event modular simulation platform based on OPNET that includes:
  - The NASA DSN Network
  - The NASA TDRS Relay Network
  - Other potential relays using commercial satellite constellations
  - Other potential Direct-to-Ground Relays
  - The International Space Station
  - Models of typical mission spacecraft (such as MMS and TERRA) and detailed orbital models using the Satellite Tool Kit (STK) for the above spacecraft.
- The model includes network elements such as traffic generation, layered protocol support, MAC layer and physical channel and antenna properties.

Conclusions

- Defined the need for understanding mission traffic characteristics, and dynamically sharing access to Ground Stations by mission spacecraft, with priorities and QoS guarantees
- Addressed multiple access for this topology and proposed a basis for developing a suitable Demand MAC Protocol
- Developed a modular simulation test-bed that includes satellite orbits/mobility, coverage, traffic and network modules.
- Performed simulation study with a set-up of EOS typical Missions
- Initial simulation results prove that for sample scenario on-demand mode has significant advantages over pre-planned mode, especially under bursty traffic load condition leading to :
  - **more efficient utilization of bandwidth,**
  - **accommodating larger network size**

Future Work

What we plan to do next:

- Formulate and optimize a dynamic multi-access protocol that offers both guaranteed and on-demand sharing of the available bandwidth
- Perform end-to-end optimization and suggest solutions that would support particular protocols or QoS requirements for specific services over the space-to-ground link that might involve:
  - i. special random access slot can be added to the TDMA frame, which is used for short file transmission without reservation.
  - ii. Adaptive collision algorithms can be developed to minimize the number of contentions.
  - iii. a priority-based solution
- Investigate traffic statistics (provided by NASA) to determine how we can adapt protocol operation to reflect realistic traffic scenarios
- Implement a discrete event simulation of this with several spacecraft in orbit generating appropriate traffic
- Address potential problems with PEP-based solutions to TCP introduced if IPSec is used, and investigate alternative security approaches.

