Space Mobile Network (SMN) User Demonstration Satellite (SUDS) for a practical on-orbit demonstration of User Initiated Services (UIS)

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This paper will discuss the various aspects of implementation of the Space Mobile Network (SMN) architecture framework within the context of operations of various nodes equipped with the User Initiated Services (UIS) protocol. These aspects include development of a Client-Server architecture in which space based Clients can create links with ground based Servers to negotiate passes with ground stations or contacts with the Tracking and Data Relay Satellite fleet. A key feature of this concept is that Users may require a mix of low data rate continuous contacts with one or more of the TDRS fleet and sporadic contacts with ground stations as passes become available. SUDS will have the availability of TDRS contacts, the U.S. Naval Academy's ground station, NASA Near Earth Network ground sites and others. This mode of operations must be integrated within the traditional mode of scheduling contacts and passes. Thus, SUDS fits into a heterogeneous network operations concept of operations.

I.   Introduction

A collaboration between NASA Goddard Space Flight Center and the U.S. Naval Academy (USNA) will be leveraged in providing a practical demonstration of unscheduled, on-demand space-to-ground network access. It will be demonstrated using the planned SUDS CubeSat. Because the access is initiated by the space based user, the protocol behind the service is called User Initiated Services (UIS). The collaboration combines student-led development of CubeSats by the USNA undergraduate engineers with a communications payload provided by NASA Goddard Space Flight Center (GSFC). The USNA has a program of training undergraduate engineers through continuous development of CubeSats and CubeSat missions

In this paper, the various aspects of implementing the Space Mobile Network architecture framework within the context of operations of various nodes equipped with the UIS protocol will be discussed [1][2]. These aspects include development of a Client-Server architecture in which space based Clients can create links with ground based Servers to negotiate SMN passes with ground stations or contacts with the Tracking and Data Relay Satellite (TDRS) fleet [3]. A key feature of this concept is that Users may require a mix of low data rate continuous contacts with one or more or the TDRS fleet and sporadic contacts with ground stations as passes become available. SUDS will have the availability of TDRS contacts, the USNA ground station, NASA Near Earth Network ground sites and others. This mode of operations must be integrated within the traditional mode of scheduling contacts and passes. Thus, SUDS fits into a heterogeneous network operations concept of operations.

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Lastly, the paper will describe a roadmap for UIS. The initial implementation will be UIS 1.0 but the plan is to evolve enhancements for future versions that can be implemented in future missions of any size. The plan is to make the UIS protocol hardware agnostic as an application for any mission.

II.   Background – What Science Users Want

Science users of space communications services want more flexibility in being able to bring the services on-line to their spacecraft only when needed. Typically, these services are negotiated and scheduled in advance anywhere from weeks to months prior to the actual contact. Figure 1 was developed based upon needs expressed by the science community for their desirements with space communications services.
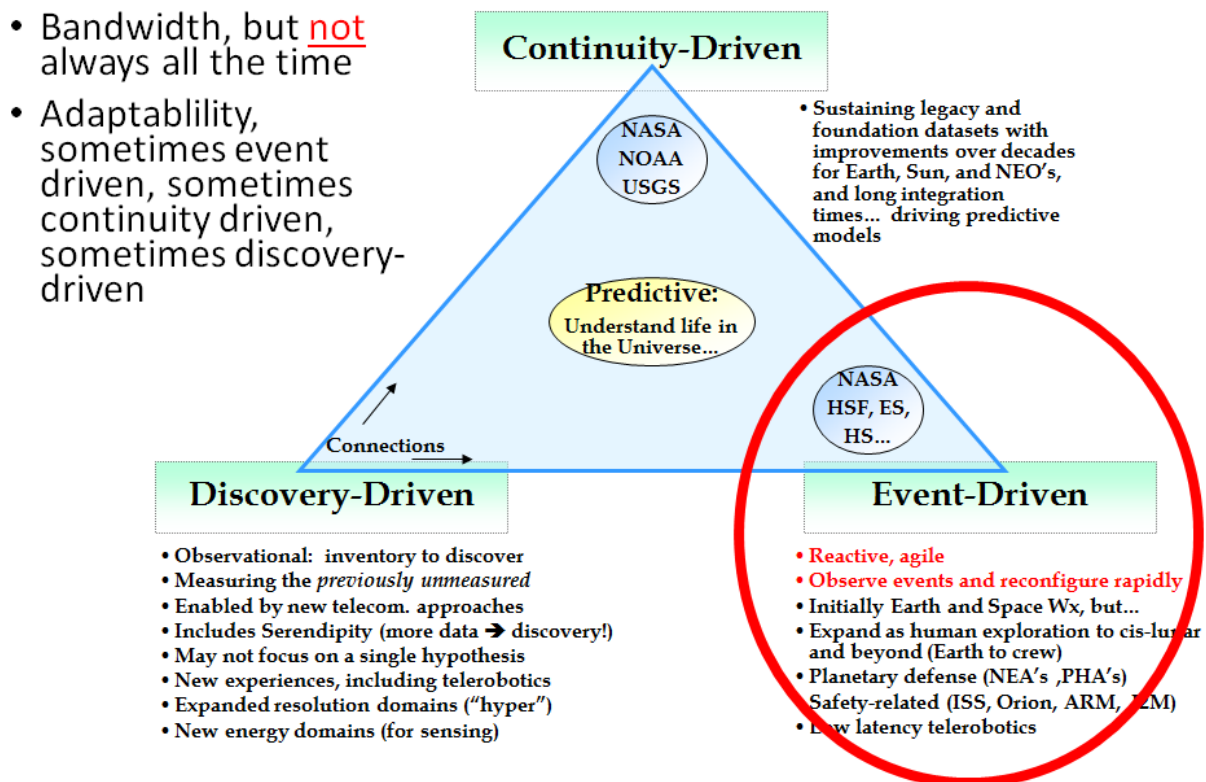

Figure 1.   What Science Wants for the 2020's. Adapted from 2015 charts from Dr. Jim Garvin, GSFC Chief Scientist. The circled item is where SMN and UIS have potential benefits.

The key points are the desirement for reactive, agile services to observe events and reconfigure rapidly as required. From a space communications standpoint, these are difficult requirements to meet due to the following reasons.

- There are a large number of users competing for limited space communications resources
- Costs of the space communications infrastructure must be amortized over long time intervals (at least decades). Projects typically cannot bear the full cost of providing new space communications services
- Space communications projects are typically planned to provide the greatest benefit to the widest set of users, not the corner cases requiring specialized services

Two concepts are being developed to address the science community desirements in the most cost effective manner possible. One is the Space Mobile Network and the other is User Initiated Services. Both concepts are being brought together for demonstration in the SUDS mission.

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III.   Space Mobile Network (SMN) and User Initiated Services (UIS) Description

A.   User Initiated Services Description

User Initiated Services is a new network service acquisition method that enables responsiveness to unplanned events using both batch and flow processes. Consider the differences between pre-planned and on-demand network access as shown in Table 1.

Table 1. Network Access Methods: Pre-Planned vs. On-Demand

Pre-Planned Network Access	On-Demand Network Access
Batch processing: Request ➔ Disposition ➔ Execute	Flow processing: Event-triggered service execution, requires highly available link
Ensures prioritization/policy optimization	Commonly used in terrestrial wireless networks for control and user data flows
Mission Operations and Network Provider personnel negotiate contacts in a rolling wave batch process	Arrival rate > service rate leads to blocking/queueing; congestion management
Low responsiveness to unplanned events	High responsiveness to unplanned events

UIS development has been aimed at establishing a protocol interface over which user missions, either the ground-based control center or the mission platform in space, can request and be provisioned communications services in response to unplanned events and on-the-fly needs of the spacecraft mission. This concept of operations also is greatly benefitted by the ability to request those services agnostic to the specific service means of implementation. A comparison to modern terrestrial cellular network communications is helpful here. When a cellular customer determines a need to place a phone call or fetch some information from an internet server, the initial request is simply a request for some data from a source or for some open communication channel. It is agnostic to the specifics of the network's physical assets and communications protocols (frequency, antenna tower, routing protocol etc.) that will be used. Likewise, the UIS-enabled missions will benefit from the ability to, in very simplistic ways, request their data service needs over the UIS protocol and be dispositional services that satisfy those needs.

B.   Space Mobile Network Architecture Description

SMN is an architectural framework inspired by current terrestrial on-demand communications services and the associated applications users have come to expect from cellular networks which adapts these concepts and technologies for space communications users. UIS is one of the key concepts/technologies that will enable NASA's vision for a SMN. There will always be a requirement for pre-scheduling of some services. In a traditional mobile cell phone service, when a service is not available at the relay, the call is rejected by the communicating relay asset. When a SMN/UIS-equipped spacecraft requires services, such as a high data rate link, it transmits a request to the network over the low rate link. The network determines the next available opportunity to support the mission and responds to the request with the time and information required for the mission to access the service. When the service time arrives, the mission receives the requested service. Figure 3 shows a depiction of the notional dynamic end-to-end datapath.

Figure 2. UIS provide users the capability to have continuously available forward and return user links via a space relay such as TDRS.

The requested service could be provided by a space relay or ground station from any compatible and participating provider (NASA, commercial, international, etc.). Thus, the system architecture would still support pre-scheduled services as today, as well as a larger percentage of users on the
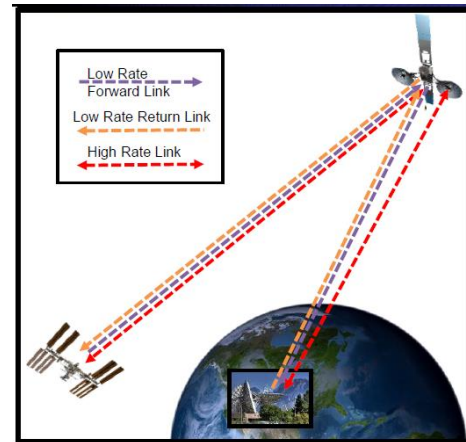
continuously available and UIS scheduled services. This should allow ground networks with UIS Servers to be more responsive and efficient service providers. The implementation of UIS requires a protocol for a user to negotiate a service request, either over a space link or terrestrially. The architecture of the Space Network Project that operates the TDRS fleet is very flexible and can be expanded to accommodate numerous simultaneous users. GSFC is developing a series of SMN/UIS flight demonstrations to validate the performance and operational concepts of the UIS protocol within the SMN architectural framework, beginning with SUDS.. Figure 4 depicts a basic demonstration that is under development.

   UIS will operate as a client-server application with the client flying aboard the spacecraft and with a server on the ground. Essential to the implementation of UIS is high-availability channels of communication. The User (client) needs a means of contacting the Provider (server) to request services. The current baseline of the demonstration is to use an existing contact with GS-1 to schedule a contact with GS-2. The demonstrations will be performed using a variety of GSFC communications assets at GSFC Greenbelt, MD, Near Earth Network facilities in Wallops, VA and Space Network facilities at the White Sands Complex in Las Cruces, NM. The demonstration success criteria is shown in Table 2.
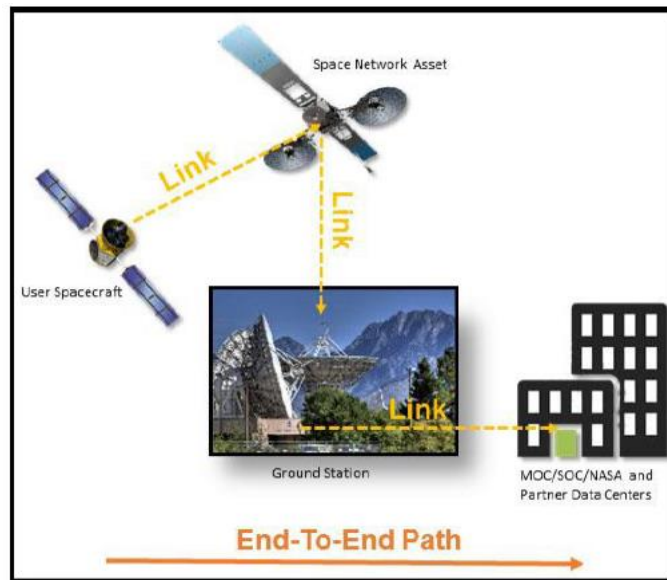

Figure 3. Dynamic End-to-End Datapath. Most science users want the ability to create an end-to-end link for their data at their convenience without concern for scheduling specific assets in specific locations.

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UIS Baseline Demonstration Steps:

1. User Client sends "Service Request" through preplanned return link (with GS-1).
2. Provider Server receives and responds with "Ack".
3. Provider Server distributes the schedule to User and User MOC.
4. User Client receives the "Schedule" and sends a "Schedule Accept" response.
5. Provider Server disseminates schedule to network assets (GS-2).
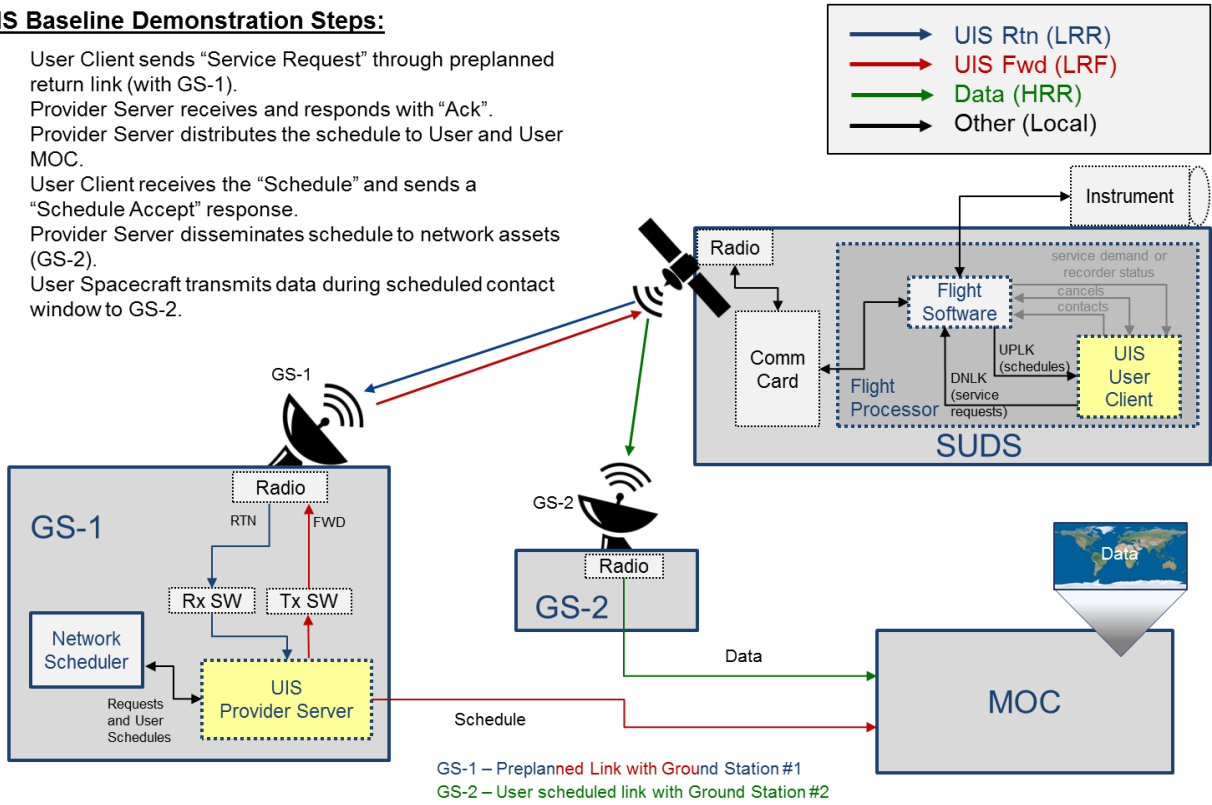6. User Spacecraft transmits data during scheduled contact window to GS-2.

Figure 4. SUDS-UIS Demonstration Concept of Operations.

Table 2. Demonstration Success Criteria.

Basic Service Demonstration	
A.	Client sends service request
B.	Client receives acknowledgement
C.	Client receives schedule
D.	Client sends schedule acceptance
E.	User carries out communications contacts in the schedule
i.	Transmit in the right direction at the right time.
Advanced Service Demonstration	
A.	Service Event Generation
i.	Example: Get Service Demand from Flight Data Recorder
ii.	Example: Telemetry out of limit.
B.	Implement multiple passes from a single schedule
C.	Registration to the UIS-SMN
D.	Cancellation of a Service Request/Schedule
E.	Rescheduling of a Service
F.	Third-Party Requested Service
G.	Perform automated scheduling with an operational network scheduler

C. NASA-United States Naval Academy partnership

The United States Naval Academy and NASA/Goddard Space Flight Center entered into a no-exchange of funds Space Act Agreement to permit GSFC to supply payloads of mutual interest for flight opportunities. This agreement

is beneficial for both parties because it provides GSFC opportunities to fly additional payloads aboard U.S. Naval Academy CubeSats at the same time providing the US Naval Academy access to payloads that would otherwise be unavailable to them. Additionally, GSFC will support the Academy satellite operation whenever it is practical and feasible to do so. Such support can come from either the GSFC-run Near Earth Network and/or the GSFC-run Space Network. The intended outcome of the partnership is for SUDS to be the first of a line of payloads provided by GSFC to the mutual benefit of both institutions.

IV.   United States Naval Academy Small Satellite Program

A.   Program Description

The United States Naval Academy Small Satellite Program (NASSP) was founded in 1999 to provide education and training opportunities to Midshipmen (students) in satellite design, integration, testing and operations. Starting with a micro-satellite launch in 2001, NASSP has developed and launched 13 space payloads as of 2017, with about half of them being CubeSats. Three more CubeSats are manifested for launch in 2018, and two more satellites are under development. Most midshipman student satellite projects to date at USNA have been designed mainly for the Amateur Satellite Service for their education and self-training at the undergraduate level in the radio/satellite art. Over the years these satellites have carried a common thread to maintain a worldwide digital VHF experimental satellite relay channel for student experimenters around the world. With an addition of higher-capability communication equipment to the ground station, the next generation NASSP CubeSats will also include radios in S-band for missions requiring a higher data-rate.

The Naval Academy's Aerospace Engineering Department laboratory facilities, in support of this mission, include structures labs, propulsion labs, computer labs, Satellite Ground Station, and Satellite Environment Test Lab. Some of the key equipment include a vibration table, a thermal-vacuum chamber, communication antennas and radios, and a clean room. The environmental test equipment is fully capable of accommodating a 3U CubeSat enabling complete self-sufficiency for qualification tests, which provides a more complete education and training opportunities to the students. The ground station antennas include Yagi-antennas, a 3 m dish antenna, and mobile ground station trailer, providing transmission and receive capability in HF, VHF, UHF, 900 MHz, and S-band. NASSP ground station is also a node in the Mobile CubeSat Command and Control (MC3) ground station network.

In addition to the Amateur Satellite Service, NASSP CubeSats have also performed on-orbit demonstration of the new satellite technology. The past NASSP CubeSat missions include gravity-gradient boom experiment, internet server in space experiment, robotic arm actuation demonstration, and micro-pulse-plasma electric propulsion unit experiment (developed by the George Washington University). The current and near-future student project missions will concentrate on two main areas of improving communication network and demonstrating on-orbit assembly. One of these satellites is a 3U CubeSat that will incorporate multiple payloads, including the SUDS payload. NASSP CubeSat launches are provided by both NASA CubeSat Launch Initiative (CSLI) and Department of Defense Space Experiment Review Board opportunities.

The CubeSat under development by USNA for this mission is called USNA-17 NSat. NSat is a 3U CubeSat with approximate dimensions of 10 cm x 10 cm x 30 cm with total mass of 4 kg. The bus will consist of NASSP Standard Bus configuration, including COTS components for its structure, on-board computer (OBC), and electrical power system (EPS). The bus will employ distributed command and data handling architecture where the main microcontroller OBC will communicate with each subsystem managed by individual Arduino processors. The OBC function will be limited to house-keeping activities such as health monitoring, telemetry collection, beaconing, and executing ground commands. Each subsystem's functions will be controlled by an Arduino processor, and only higher-level commands and data will be communicated between the OBC and subsystem Arduinos. This means the SUDS payload will also be controlled by an Arduino processor that will handle all low-level functionality.

NSat's main mission is on-orbit test and demonstration of new communication architectures. In addition to the standard NASSP CubeSat radio module for satellite command and control, NSat will have two radio payloads. The first payload is the SUDS payload that will communicate with TDRS network. A second payload is a pair government radios that will test and characterize UHF/S-band communication capability.

The satellite development facilities at USNA include a ground station room, computer lab, electronics work benches, and test equipment room. Overall space is approximately 3,000 ft2. The space is fully equipped to handle

satellite development and the academy has been developing, launching, and operating small satellites for the past decade. The ground station includes antennas and radio equipment that can handle the full spectrum of the amateur band, including the UHF, VHF, and S-band. In addition to its other antennas, the lab has a 12 m dish antenna, though it is not currently utilized.

B. SUDS Payload Mission aboard NSat

NSat is expected to be completed in 2019 with a potential launch in 2020. Desired orbit is a 400 km to 500 km altitude LEO in order to ensure that the ground command and control communication link can be closed reliably. NSat will not have active attitude control, and will transmit using low-gain, omni-directional antenna setup, limiting altitude of the potential orbits. Once in space, the satellite will perform a series of experiments that will validate the performance of the payloads.

Normal Operation:
The day-to-day satellite operation will rely on NASSP standard satellite radio that utilizes VHF uplink and VHF/UHF downlink. This communication link will be used for commanding the satellite, downloading telemetry data, and mission payload status. Depending on the amount of data generated by the two payloads, the performance data can also be downlinked utilizing this UHF transmitter at 9600 baud. This radio will beacon both in VHF and UHF frequencies. UHF beacon will contain key telemetry info, as well as the status of payloads. VHF beacon will be a part of the Amateur Radio Service mission, and will be used by amateur ground operators. This operation is expected to last until the hardware fails on orbit, normally 3-4 years.

Government Radio Characterization Experiment:
Two identical radios that are setup differently will communicate with the ground station at USNA in near-simultaneous fashion in order to characterize the differences in signal performance. This communication link is designed to uplink in UHF and downlink in S-band. The main experiments will occur when the satellite is in view of the USNA ground station, and the radios are not expected to be operating outside the contact window. This mission will be completed within 12 months from the time of launch.

C. SUDS Payload Operation

Because NSat payloads consist only of communication experiments, the payloads can start operation soon after deployment. Post-deployment, on-orbit check out is expected to take only a few days. As soon as the battery and solar panel health is verified, the SUDS payload can immediately begin operation. The other payload of NSat will only be operating during contacts with the ground station, which enables SUDS payload to be able to perform its mission throughout the orbit. The experiment is divided into three phases.

Phase 1) NASA Operation

At the beginning of the operation, NASA will take full control of the SUDS payload via USNA ground station. Pre-determined sets of transmit and receive commands will be executed, testing and validating the performance of SUDS. Expected duration of this phase is 3 months.

Phase 2) NSat Command and Control

At the conclusion of the primary communication link characterization activities by NASA, NSat will switch over its command and control functionalities to be performed via SUDS payload. This phase will characterize the performance of using the SUDS payload as the main satellite command and control radio.

Phase 3) NSat Data Download

Once a reliable operation of NSat using SUDS is accomplished, stored "science data" consisting of telemetry, payload health, and picture data will be downloaded using the SUDS payload. In this phase, the performance of the SUDS payload as a data service negotiator (i.e. user service initiator) will be tested and characterized.

V.   Roadmap for SUDS and UIS

Table 3 depicts a notional roadmap for UIS and future SUDS payloads.

Table 3. Notional Roadmap for UIS. The circled item is where the first flight application of SUDS aboard NSat will occur. Acronyms: DAS – Demand Access Service: a lightweight, easy to schedule TDRS return (downlink) service. NGBS – Next Generation Broadcast Service: a broadcast service using TDRS that provides integrated communications and navigation services. IOC – Initial Operating Capability. EI&T - Engineering Integration & Test activities.

	FY17	FY18	FY19	FY20	FY21	FY22
Operational Demo. & Infusion	First UIS On-Orbit Experiment w/ISS STB	Second UIS On-Orbit Experiment w/ISS STB	Space Mobile Network User Demo. Satellite (SUDS) #1	SUDS #2 with Scheduler I/F Enhancement	UIS Early Adopter Infusion	UIS Early Adopter Infusion
Resource Management	SCaN Test Bed specific UIS software, UIS Server Dev.	UIS Server Integration with cFS User Node	Next Gen Scheduler Funding for UIS Server	Next Gen Scheduler Funding for UIS Server	UIS Server Integration w/ Next Gen Scheduler	UIS Server Extensions for Federated Schedulers
Space Link On-Demand Service	Emulated TDRS DAS and NGBS On-Demand Market Survey	Utilization of TDRS DAS and NGBS vs. Comm. Trade	On-Demand Service/UIS Requirements Definition	UIS Early Adopter/IOC	Commercial On-Demand Service Providers(?)	Commercial On-Demand Service Providers(?)
User Mission	SCaN Test Bed specific UIS software	cFS UIS flight software EI&T, with UIS Server	Mission-Specific Behavior Extensions	Mission-Specific Behavior Extensions	Mission-Specific Behavior Extensions	Mission-Specific Behavior Extensions
Model-Based Architecture	Architecture Definition/User Engagement Ongoing	Timing Analysis, Computational Experiments	Operational HW/SW in the Loop Simulations	End-to-End Experiments w/Next Gen Scheduler	Enhanced Functionality & Refinements	Enhanced Functionality & Refinements

There are a variety of possibilities that are under consideration.

1. SUDS is reflown as demonstrations on successive missions as a payload with CubeSats having greater power generation and larger EIRP (effective isotropic radiated power). This will permit SUDS to close the space link with relay satellites such as TDRS at data rates high enough to support sciences operations (minimum 100's of kbps)
2. UIS client is provided as an application package to any mission desiring to use it. The UIS server application would be provided to ground stations and/or ground networks to process UIS messages and data.
3. UIS and DTN (Delay/Disruption Tolerant Network) protocols are packaged together in an application for use by future customers.

All of these possibilities assume that successive versions of UIS will be developed for future missions.

VI.   Summary

This paper presented a view of a future application of a protocol called User Initiated Services (UIS) within the Space Mobile Network (SMN) architecture framework. SMN and UIS together will provide spacecraft communications that is more responsive to the needs of the operator of on-orbit assets by adding flexibility to the use of space and ground communications assets. The plan is to continually grow and evolve UIS so that the majority of space communications users can avail themselves of these capabilities and shift away from rigid scheduling paradigms that currently exists today.

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Acknowledgments

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