AN EVALUATION OF TERRESTRIAL WIRELESS NETWORK MODELING APPROACHES FOR THE SPACE MOBILE NETWORK

Todd A. Newton¹, Christopher J. Roberts², Gregory G. Fletcher¹, Daniel S. Rossiter¹

¹Southwest Research Institute®
San Antonio, Texas
todd.newton@swri.org, christopher.j.roberts@nasa.gov,
gregory.fletcher@swri.org, dan.rossiter@swri.org

²NASA Goddard Space Flight Center
Greenbelt, Maryland
gregory.fletcher@swri.org, dan.rossiter@swri.org

ABSTRACT

The Space Mobile Network (SMN) is NASA’s next generation architecture concept for communications services between ground and space-based assets. The SMN calls for a paradigm shift in space communications. The transition will move from an approach based on static, preplanned communications over point-to-point channels to a dynamic, event-driven, and software defined network-based approach that facilitates service-oriented communications. In doing so, the SMN is able to leverage some concepts and technologies present in today’s terrestrial wireless networks, while others must be extended or adapted to the space communications domain. This paper provides background on key SMN architectural concepts and an evaluation of the suitability of terrestrial wireless network modeling tools to be used and applied for proving out SMN concepts.

KEYWORDS

Space Mobile Network, IP, Network Simulation

INTRODUCTION

The Space Mobile Network (SMN) is NASA’s next generation architecture concept for space communications services. The SMN calls for a paradigm shift in space communications. The transition will move from an approach based on static, preplanned communications over point-to-point channels to a dynamic, event-driven, and software defined network-based approach that facilitates service-oriented communications. The goal of the SMN is to provide mission users of space communications services with an experience analogous to a terrestrial mobile wireless user. A terrestrial mobile wireless user can access services and communicate with other users without a need for detailed knowledge about the underlying network infrastructure, protocols,
and processes that enable those communications. SMN seeks to allow its users to connect to the SMN architecture in the same way, eliminating human-supported prescheduling and providing reliable access for data to reach the end user. SMN features, including optical communications, delay tolerant networking (DTN) services, user initiated services (UIS), and position, navigation and timing (PNT) services, would enable SMN to provide this type of user experience.

The SMN would connect users via a continuous, low-rate data link for low-latency resource control and management, and it would allow user platforms to automatically request additional services as needed. Figure 1 illustrates how a low gain omnidirectional antenna can enable this capability.

![Figure 1 - Notional Concepts of the Space Mobile Network](image)

The SMN would provide a simpler, faster, and automated system for space-based communications and would enable providers to support higher data rates and greater volumes of data. This would enable new or improved mission concepts and use cases, including variable
data rates and collaborative platform operations. For instance, multiple operationally independent and spatially diverse user mission platforms monitoring the sun could each downlink data using lower rates to perform day-to-day functions and monitor for significant events. When a user platform detects an unexpected science event or an event that will generate an unknown quantity of data, the SMN dynamically orchestrates the necessary resources: the user platform automatically sends a service request or notification (for higher data rate links from space or ground assets, to alert other subscribed user mission platforms), using the low-rate link and associated control protocol. The SMN processes and determines the parameters of the request, determines how and when the communications need can be met, and provides a response. SMN PNT services enable precise autonomous orbit determination, allowing for satellite formation flying and improving spatial-temporal science data correlation across platforms.

NASA’s long-term vision for the SMN is to see their spacecraft communicate and interoperate with commercial spacecraft. A rendering of this vision can be seen in Figure 2 which highlights this interoperability of the spacecraft, various data link speeds, a user-driven approach to network services, and a sense of always being connected at all times.

![Figure 2 - Long-Term Vision of the Space Mobile Network](image)
The vast majority of network research is targeting terrestrial networks. There are several existing commercial and open source software tools available for network simulation, performance monitoring, and troubleshooting. Though these tools are almost explicitly utilized for terrestrial applications, the networking concepts that they deal with are directly applicable to the SMN concepts. Current research in network scheduling policies and the associated performance metrics apply in both realms. As such, the SMN community stands to gain valuable insight of SMN performance through the lessons learned from terrestrial network scheduling algorithms and the extension of current network simulation tools for the SMN environment. Prominent network simulation environments such as OPNET or ns-3 can be extended to provide simulations of the SMN. This paper provides some background on key SMN architectural concepts and an evaluation of the suitability of terrestrial wireless network modeling tools to be used and applied for proving out SMN concepts.

**ATTRIBUTES OF THE SPACE MOBILE NETWORK**

**Delay Tolerant Networking Services**

One of the major distinguishing characteristics of SMN users from terrestrial wireless network users is the intermittent availability of high data rate space links due to spatial geometry and a corresponding tolerance for delays in data receipt for most high-volume space mission users. In general, missions have two types of data latency requirements: either the user needs the data to reach its final destination quickly, possibly requiring near real-time delivery, or the user needs to offload the data from the instruments’ recorder (the store and forward method) due to data storage constraints, only requiring a link from the spacecraft to the communications asset. Delay Tolerant Network (DTN) protocols can support store-and-forward operations while opening up the availability of high-rate links when near real-time delivery is necessary. DTN also bundles data in smaller increments, increasing the efficiency of the network by allowing for greater availability of assets to service different mission data priorities. These features would allow SMN to create a standardized and scalable network.

Independent from DTN, SMN would require hardware that enables flight systems to move and process data at higher speeds; however, near-term DTN protocol-specific implementations could include hardware acceleration of the Bundle Protocol (BP), Licklider Transmission Protocol (LTP), or Bundle Protocol Security (BPSec). In the future, as the operational network grows, DTN will require advancements in DTN routing and network management, and implementation of DTN functionality will be realized within ground stations, space relay nodes, and user ground systems.

**Optical Communications Services**

Direct-to-Earth (DTE) communications links from low Earth orbit (LEO) spacecraft can be hundreds of times shorter than links from LEO to geostationary relays, making it possible for DTE links to deliver immensely greater volumes of data. Currently, service providers cannot
take full advantage of this significantly shorter link length due to the lack of available spectra necessary to transmit the data. Optical links would enable providers to offer such high data rates without being constrained by spectra availability. Past demonstrations have shown initial capabilities of optical communications; for instance, in the Lunar Laser Communications Demonstration, DTE optical downlinks performed at rates higher than 600 Mbps from the moon. Demonstrations and tests involving optical links continue. For instance, the Laser Communications Relay Demonstration (LCRD), which will launch in 2019, will spend two years conducting experiments to test optical links from a geosynchronous terminal, measuring the effects of various settings and conditions such as weather on the links. With such new technologies being developed and tested, even greater data rate capability is expected. Furthermore, due to reduced size, weight, and power requirements for optical communications systems, missions could use multiple access systems with continuously available, low-rate optical links at lower costs and with less operational complexity. Producing a reduced user burden than RF links allow, optical multiple access systems would be easier for missions to assume and utilize.

**User Initiated Services**

Today, spacecraft communication network users rely on flight operations teams to determine many aspects of the network scheduling process, which can result in long lead times when scheduling a connection. SMN would maintain support of today’s pre-planned scheduled services while engaging user initiated services (UIS) to support an increasing number of spacecraft communication networks users, allowing for a more responsive and efficient network. UIS would enable platform-triggered requests and disposition of services through continuously available low rate links, allowing any user to autonomously request services at any time. The SMN would, in turn, automatically de-conflict such requests based on state, priority, and constraint information about the network’s nodes and user capabilities. The SMN would respond by providing the service as requested, by finding different yet compatible parameters to satisfy the request, or by declining to provide the service as requested. Along with developing a protocol for spacecraft communication network users to negotiate a service request, UIS would also rely on a scheduling system that could field requests dynamically; the system would compare requests against available resources, schedules, and priorities, and it would dispatch the scheduled service control details to the user systems and provider elements. In addition, this concept may be federated through peering agreements, enabling a combination of various, possibly dynamically entering and exiting, providers and scheduling systems to provide the services. UIS would reduce operations costs and complexity for mission designers with this fundamentally unique operations concept.

**Position, Navigation, and Timing Services**

In the vein of automated services, SMN would transition beyond the use of ground-based processes to calculate spacecraft orbits, instead moving to adopt onboard navigation (aboard user spacecraft) and establish a global beacon service to create positioning and navigation autonomy. Onboard navigation would use GPS to allow the spacecraft to determine its own position and location, thus enabling the spacecraft, for instance, to orient itself and point accurately to offload data or assist the UIS system in coordinating communications services. However, some
spacecraft cannot support GPS SWaP or their orbits are outside the reach of GPS. The Next Generation Broadcast Service (NGBS) beacons would broadcast from at least three geosynchronous nodes, such as relay satellites, providing user spacecraft with the location of the node, thus allowing the user spacecraft to determine its own position and course. In this way, the beacons would serve as a global means to enhance user auto-navigation capabilities.

**NETWORK MODELING FOR TERRESTRIAL WIRELESS NETWORKS**

Network simulation has often been the first step in designing and validating robust terrestrial networks and protocols. A network simulation environment reduces deployment risk and can save money in the long run by discovering limitations and problems and addressing them prior to full scale deployment rather than having to re-deploy physical network infrastructure. A simulation environment also allows complex networks with hundreds or thousands of nodes to be simulated, which is likely beyond the scope of financial viability. Simulations can be utilized alongside real components of hardware such that hardware testing can be performed against the simulated nodes and networks for verifying proper behavior of the real hardware. When considering deployments in space, the deployment costs alone are great; being able to validate design and proper protocol implementations prior to deployment are critical.

OPNET and ns-3 are the industry leading network simulation tools in the commercial and open source realms, respectively. Both offer a large set of network and component models, including fully-simulated networks and simulation-in-the-loop where simulation is combined with some physical hardware to create a hybrid network between physical and simulated components. Models for various layers of the Open Systems Interconnection (OSI) model are available, allowing different hardware technologies such as copper interfaces or WiFi interfaces to be modeled with their particular network characteristics at the physical layer and different models to be built on top of those physical layer models. Both simulation tools support wireless network simulation including WiFi and Long-Term Evolution (LTE) networks, allowing various simulation scenarios to be constructed and measured for performance based on the associated models being simulated.

Before we can discuss how a simulation would be devised for a given scenario, some of the relevant network simulation key terms are defined:

- **Node**: A node in a simulation represents the component being simulated. The component contains one or more network interfaces for connecting to the network as well as any applications that may run on the simulated node, such as a specific type of traffic generator or receiver. It can be represented as a single computer in the network that is interconnected with other nodes to form a network.

- **Net Device**: An abstraction representing a network interface card (NIC) plus the associated driver software. This would be attached to a node to support connection to the network via a specific interface.

- **Channel**: A channel provides the interconnection between nodes. A given node may have multiple incoming/outgoing channels corresponding to the various net devices.
attached such as ones supporting Ethernet, WiFi, or Bluetooth. Each channel may have its own set of performance characteristics, such as speeds, loss, etc.

- **Application:** In the simulation context, an application is a piece of code that generates or consumes network traffic on the node it is installed on. An application running on one node in the simulation may be the data generator for an application running on another node in the simulation.

When approaching a simulation of a network, the process can either be relatively simple or quite complex depending on what is being simulated. A simple network with a few nodes all using well-known net devices, channels, and applications can be pieced together in a matter of minutes by an experienced individual. This is because well-known net devices, channels, and applications have software modules for simulation readily available, meaning that the only software to be written is to instantiate and populate the simulated nodes with the corresponding Net Device(s) and Application(s). If, however, custom components are required, then the required effort is increased. Modifications to existing modules or creation of new modules must occur to simulate these new concepts. This is the case with simulation of the Space Mobile Network, where there are custom net devices, channel characteristics, and applications that must be simulated to accurately represent the proposed network. Though some effort is required here, it is encouraging to see that the networking tools available today for modeling and simulating terrestrial networks is extensible to being able to model the SMN.

**MODELING OF NETWORK SCHEDULING POLICY OPTIMIZATION**

As part of an internal research project, Southwest Research Institute is evaluating methods for optimizing user-perceived network performance through use of a constraints-dependent and requirements-aware packet scheduler. The proposed scheduler would make use of network performance parameters collected in near-real time along with domain knowledge of what data is being scheduled in order to dynamically select an appropriate scheduling policy for the current network condition. As the network condition changes, so too will the policy selected by the algorithm and implemented by the scheduler. In this way, the algorithm will continually update the scheduling policy to keep up with dynamic network changes through time and space. This multi-policy scheduler is most applicable for highly-nomadic clients connected to wireless networks in both the terrestrial and space networking domains, where the network topology is all but certain to change relative to the connected client. In these situations, a single generalized scheduling policy cannot provide an appropriate network performance for all scenarios, but instead must adapt by selecting the policy that performs the best across all scenarios. The research is aimed at identifying the conditions in which certain policies perform better than others as well as identifying those logical transition points when a policy change would be beneficial to the network. Figure 3 provides a high-level view of the network scheduling policy selector concept.
To measure the efficacy of this scheduler and the various policy selections in various network topologies, a network testbed is being used. This testbed is composed of both physical and simulated components. This hybridized simulation approach will provide significant flexibility in testing a wide array of network environments from both earth and space. Testing will focus on accurately representing the target environments (Space Mobile Network and terrestrial mobile networks) and determining which scheduling policies provide the most significant performance improvements compared to standard scheduling techniques.

MODELING THE SPACE MOBILE NETWORK

There are several commonalities between modeling the SMN and terrestrial mobile device networks. In both cases, the goal is to allow the user to have no knowledge of the specific assets used or path traversed for the data to reach its destination (see Figure 4). This is the case for terrestrial networks; however, traditional communication to and from spacecraft or space borne assets requires very specific knowledge of other space borne components (i.e. TDRSS) and/or ground stations. The SMN is intended to enable user initiated services similar to the terrestrial mobile user experience. The user determines a need for communication at a time determined by the needs of the user asset and initiates a data transfer; the network is then responsible for delivering the data. Terrestrial network models generally accommodate a user moving between fixed communication assets. The SMN model will need to track ephemeris not only for the user asset, but also for network assets, which will be in a variety of orbits and available ground stations in relation to their positions.

Figure 4 depicts a simplified comparison of how the user experience for terrestrial networks and the SMN don’t require the user to have detailed knowledge of all the assets in the network.
DTN models currently exist and are relatively simple, requiring pre-planning of the spacecraft overpass of a particular ground station. The duration of the communication event depends on orbital altitude, inclination, transmission frequency, and data volume. The SMN model takes into account users’ needs to offload their data at whatever rate their communications link allows while optimizing flexibility on the provider side to implement, allocate, and schedule all the nodes and links along the rest of the end-to-end path. In the near-earth environment, some scenarios can be supported using IP for the network layer services.

The SMN model incorporates DTNs with the rest of the network. Efficient and effective scheduling policies must determine the priority of data packets. For example, on terrestrial networks, voice data (Voice over Internet Protocol, or VoIP) is often prioritized over other types of data, such as one-way streaming video, because end-to-end latency and jitter adversely affect communication, while streaming video can be buffered.

The SMN model will have the capability to incorporate different scheduling policies, network protocols, and network assets and to determine the effect these parameters have on overall network performance. The model will measure quality using metrics like: jitter, network latency, end-to-end delay (caused by assets within the network, like distance, protocols and congestion), throughput, packet loss, and goodput. The model will use these metrics to determine which applications would be adversely affected.

Modeling the SMN in this way provides data to optimize the network given its expected use. Scenarios can be run to test multiple nodes, paths, and users, as well as to determine the effect of the dynamic addition or loss of assets within the network. Worst-case scenarios can be run to determine the network performance during heavy instantaneous network demand.

As has been stated, the SMN represents a drastic shift from previous network models, focusing more on scalability and flexibility and less on complete predictability. With this shift comes
many benefits, but it also introduces some risks, such as data delivery failure during route changes within the SMN. Network modeling provides a cost-effective method for both quantifying these risks and for developing verifiable strategies to mitigate these risks before significant cost is spent deploying this next generation of space communication infrastructure.

**CONCLUSION**

The SMN represents a shift in spacecraft communications from the static, preplanned communications approach to a dynamic, network-based approach that is event-driven and service-oriented, similar to terrestrial wireless networks today. SwRI’s current research in network scheduling optimization, particularly over wireless networks, is one of these similarities that has applicability and relevance to the SMN. Network performance is being measured in near-real time, and the network scheduling policies are being adapted when necessary in order to meet the critical demands of the wireless network. The same concepts exist for the SMN, where the availability of some links change and/or the network is congested for a period of time but the SMN still needs to deliver certain data flows within a specific latency window. Because of the similarities with terrestrial wireless networks, the SMN is able to leverage similar concepts and common network test tools for evaluating SMN concepts. Most of the networking tools available today are extensible to cover the SMN-specific protocols and characteristics.

**REFERENCES**


