<u>Next Generation Space Link Protocol (NGSLP) Concept Paper</u>

SLS-SLP WG

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1) Purpose and Timeliness

The purpose of this Concept Paper is to describe a new unified CCSDS Data Link layer protocol, the Next Generation Space Link Protocol (NGSLP). This unified protocol is intended to define the required formats, services, and primitives for CCSDS space links in all of the operating regimes, i.e., Direct to Earth (DTE), Direct from Earth (DFE), and Proximity Environments (Space to Space). The NGSLP also adds new features for higher performance (higher data rates and throughput) and enhanced security that are targeted for agencies' emerging missions, both human and robotic. This new space data link layer protocol is largely based upon the proven features of the existing CCSDS link protocols and it adds options to allow it to be tailored to meet future mission link layer requirements. In addition, the NGSLP operations concept utilizes emerging channel coding options currently under study by the CCSDS Coding & Synchronization Working Group (C&S) and describes their fundamental relationship to the NGSLP common transfer frame format. These options include removing the constraint to align the transfer frame with the codeblock, allowing frame sizes to be explicitly tailored to mission requirements, allowing codeblock sizes to be selected and optimized for changing link characteristics without affecting upper layer protocols, and enabling future mission operational link layer modes.

This concept paper documents the importance of developing a new convergent space data link protocol, i.e., the "Next Generation Space Link Protocol (NGSLP)" in support of forming a new project, i.e. the NGSLP project within the CCSDS Space Link Protocols Working Group (SLP WG). This project is timely for several reasons: 1) a long lead time will be required to develop and mature this standard due to both flight and ground segment development; 2) there are new emerging link layer requirements (much higher speeds, different encoding) within the newly formed optical communications Working Group (WG); 3) this new unified protocol can address current shortcomings in the existing CCSDS space data link layer protocols and provide a framework for the inclusion of new features as related CCSDS protocols mature e.g., Space Data Link Security (SDLS).

2) Key Technical Features and Benefits

The four existing protocols each have limitations and changes should be made to handle even higher data rates, increasing space vehicle populations, and to remove the key constraint of forced alignment between the transfer frame and the codeblock as defined in the Coding and Synchronization sublayer. CCSDS has already removed this constraint for the Proximity environments. Once this constraint is removed for Direct-from-Earth (DFE) and Direct-to-Earth (DTE) links, it is no longer necessary to maintain distinct link layer formats for forward (typically command) and return (typically telemetry) links.

2-1) One CCSDS Link protocol for all Space Data Links

Currently each different space link use (DFE, DTE, and Proximity Environments) has its own unique protocols, largely due to the historical evolution of the protocols and the incremental nature of emerging mission needs. For example, when it was apparent that a new type of space vehicle was to be developed (e.g., the ISS), CCSDS developed a new protocol (AOS) to handle higher data rates and provide more Virtual Channels. When relay orbiters were being planned for Mars exploration a new, adaptive data rate, protocol (Proximity-1) was developed to address the needs of the in situ environment. For Proximity-1, differences between the forward and return links were mandated in part by typical asymmetrical data rates, and also by the simple on-board processors in the landed entities at the time. However some missions, particularly those for human space flight, require higher bi-directional data rates and optical communications will drive these rates even higher. Powerful on-board processors, Field Programmable Gate Arrays (FPGAs), and large memories enable much more capable protocols than were possible decades ago.

While there will be significant costs in developing and deploying this new unified link protocol we anticipate future agency savings in terms of end-to-end link testing as well as reduced implementation and operations costs due to the consolidation of four space data link protocol formats into one. As older system installations get updated, due to aging, technology refresh, and updated to meet new higher rate mission requirements, this new protocol may be slotted into the update plans. For example all spacecraft receivers could utilize and implement the same decoders and security services with processes to delimit and deliver frames to the link layer requiring but a single development and test cycle.

2-2) Increased Variable length Frame Size, Frame Sequence Counter for higher rate links

There are numerous missions in the planning phase that require significantly higher rates, including Earth Science missions planning to use Ka, Ku band, more advanced coding schemes and optical downlinks. It is anticipated that Observatory Class missions in this decade will exceed 10 Mbps by the NASA James Webb Space Telescope (JWST) and 100 Mbps by the NASA Transiting Exoplanet Survey Satellite (TESS). Part of the problem with today's ground systems is that they are incapable of processing the data received at rates that are above 1 Gbps. Thus operational equipment needs to be developed to handle those very high rates, and these developments need to start soon enough to ensure mission success. NASA's Constellation Program identified performance problems with the ground services utilizing their selected frame size even when uplink rates were lower than 10 Mbps. In addition, in a recent telecon held with NASA JSC engineers concerning this very issue, JSC voiced a strong concern that the current CCSDS downlink transfer frame size is too small to effectively meet their future mission needs.

NGSLP proposes a maximum frame size of 65536 bytes (i.e. 64 x 1024), due to the 16 bit field assigned to the frame length. This enhanced frame length capability would provide for frame sizes 32 times larger than the current set of standards. A larger maximum CCSDS frame size would reduce frame rate for very high (bit) rate missions and the increased size of the VC sequence counter would provide the needed accountability. . The variability in frame size would reduce packet segmentation and reconstruction because frame boundaries could stretch to encompass complete packets or user data units (i.e., supporting in particular IP data grams or Delay Tolerant Networking Bundles).

2-3) Insertion of Messages and Potential Applications of an Insert Zone

A variable length frame accommodates the insertion of either a data driven Master or Virtual Channel Insert Zone. These insert zones could carry real time data or messages carried within the Insert Zone, signaled in the transfer frame header. The aperiodic insertion of real time data on demand is not possible using a fixed frame approach.

Moreover, NGSLP could reduce the latency associated with the transfer of voice data by allowing the insertion of idle bits instead of idle frames across synchronous data links when ground transport has unexpected transient delays that break the timing required for synchronous data availability. Defining and providing the rational for all the applications of these new operational modes will be within the scope of the NGSLP project.

DLR has identified a use case and therefore a potential requirement for the use of the Insert Zone on both the uplink and downlink. The DLR/GSOC is preparing for operation of robotic low-earth orbit missions, with remote robotic fixtures operated remotely by the ground control center in a real-time manner. For sending commands to the robotic payload and receiving the associated feedback, a protocol is needed that can handle timely realtime conditions. As details emerge, further investigations for the potential use of NGSLP for this mission class will be made.

2-4) Data Accountability Considerations

Agency data accountability at Data Link Layer level services depend also but not only (e.g., ERT) upon a suitable frame sequence counter, one whose frame sequence count does not return to zero over short periods of time. CCSDS agencies currently utilize this type of counter as the primary means of uniquely identifying and ordering telemetry frames. At a 10 Gbps downlink rate and using the current maximum transfer frame size of 2048 bytes, the extended frame sequence counter rolls over in ~ 7 minutes. We have heard from several NASA mission operations personal that this amount of time is unacceptable for data accountability. In the proposed NGSLP protocol this counter can be extended to larger sizes, and it could take years to overflow the counter. . For emergency conditions this sequence counter could just be another piece of overhead; Its size could be set to zero, eliminating its presence.

Thus it is imperative to increase the frame size and frame sequence counter to reduce the impact on future link communications service implementations both on the ground and on-board.

2-5) Increased Spacecraft ID (SCID) Name Space

The number of available Spacecraft IDs available to future missions is limited and current missions consume 75% of the available Version 1 SCIDs and 63% of the Version 2 SCIDs, according to the CCSDS Secretariat. Currently there are two sets of SCIDs, one for the TC and TM recommendations (Version 1) up to 1024 SCIDs, and one for AOS that supports 256 SCIDs. As a result, if a spacecraft uses the TC-SDLP on the forward link and the AOS-SDLP on the return link, it must be assigned two SCIDs, one for the TC-SDLP (V=1) and the other for the AOS-SDLP (V=2). Another factor that leads to the rapid consumption of SCIDs is multiple assignments per spacecraft. Currently most missions require multiple SCID assignments in order to differentiate the data based upon mission phase (i.e., System Test vs. Mission Operations). Another driver for an increased number of SCIDs is increased agency activities in developing cubesat/microsats and the future expectation of internetworking in space.

A larger SCID field, along with the addition of an associated field signaling how the SCID will be used, provides a single unified SCID for all mission phases and on all links.

2-6) Accommodation of Space Data Link Security (SDLS) Protocol and New Implementations to Incorporate Security

The addition of the CCSDS SDLS Recommendation to the existing space data link layer protocols will cause changes in both ground and spacecraft implementations in the near future. SDLS is another important driver for the timeliness of this activity. The redesign of the uplink processing required for SDLS could also accommodate the changes in the NGSLP link formats and thereby extend the life of the new equipment and the compatibility with future mission needs. This will only be possible if the new NGSLP protocol is matured in a timely way.

a) Multiple addressable sub channels within a single Virtual Channel (replaces TC MAPs, Proximity-1 Ports)

- A proposed key capability in NGSLP is the creation of VC sub-channels within a given VC. VC sub-channels replace the MAP and Port ID approaches used in TC and Prox-1 with a common method that provides the sub addressing of frame data associated with a single Virtual Channel (VC). Thus for Space Station operations all the sub channels created within a single operational facility that support diverse elements can be secured with a single SA on the VC carrying those sub channels.
- This technique is perfectly suited to the COP-1 and especially useful when trying to provide security for multiple Virtual Channels utilizing a single Security Association (SA). The use of VC sub-channels allows the COP-1 to be executed on a single VC instead of requiring that these services be provided across multiple VCs each one with its own COP-1. (Note: One needs to be mindful of the fact that when the COP-1 is applied to data units transmitted on separate VCs, then each COP-1 operates independently over each VC. However COP-1 applied to the same VC containing several VC subchannels defined would be mutually dependent.) This technique also enables a single SA to use the existing VC sequence counter to provide the required uniqueness to block command replay for many years using a single key, which simplifies key management security design. Since this technique also allows the VC sequence counter to be used for anti-reply it eliminates the need to include a separate counter in the security header reducing overhead.

b) Enables SDLS protocol to work in Proximity-1 Environments

- Currently Prox-1 cannot support SDLS because there is no VCID in the protocol and SDLS is based upon VCs. The NASA Mars Program is concerned that SDLS security services does not pertain to Prox-1. Since the NGSLP provides VCs, SDLS protocol would be applicable for proximate environments wherever they are deployed.

2-7) Allows for Data-Driven Master Channel or Virtual Channel Services

The proposed NGSLP signals the presence/absence of different Master Channel/Virtual Channel fields so that computers can make run-time decisions on how to process the data as it arrives. When the frame length is allowed to vary, this data driven approach provides the ability to insert low latency messages into the link to provide rapid indication of actions that are taking place onboard a vehicle or actions that need urgent attention by the receiving entity. Thus the insert zones (one for the Master Channel and one for a Virtual Channel) can be used as needed to provide synchronous, periodic or transient insertion of data as required by the mission. All Master Channel services can be supported because the frame header contains all the necessary information to process the Master Channel services: route and deliver Master Channel and Virtual Channel frames, ingest and deliver the contents of the Insert Zone and Operational Control data, and perform frame validity checks as required.

3) Requirements of Prospective Missions

We cannot reference any single specific missions that are requesting a next generation space link protocol. However our collective experience in CCSDS has been that effective CCSDS standards are the ones that have correctly anticipated and emerged ahead of mission needs. We believe this is the case with NGSLP. We anticipate that the optical communications WG will have emerging link layer protocol needs due to much higher rates, the use of new coding schemes, and the likely introduction of adaptive data rates. We believe these needs will be better met by a well engineered and well thought through project in CCSDS as opposed to expecting the mission operations community to system engineer the problem of operating in the optical communications environment, if the existing link layer format and services are not modified.

New human exploration missions are also bringing requirements for higher data rates and the future requirements for human exploration beyond the near Earth environment. Space internetworking and the advent of low cost cubesats and microsats, some of which will require local cross links, can also drive the need to support much larger numbers of simultaneous spacecraft. The timely availability of a single unified protocol that can meet both long haul and in situ communications needs should prove to be attractive to such missions, especially if proven, high performance, low cost implementations can be provided.

4) Relationships to C&S Sublayer Requirements and Recommendations

Standards that are related to this work in C&S are: a) TM Sync and Channel Coding Blue Book, b) TC Sync and Channel Coding Blue Book, c) Proximity-1 Coding and Synchronization Sub-layer Blue Book, d) Emerging Short LDPC codes Orange Book, e) Emerging pink sheets to TM Sync and Channel Coding Blue Book that allow the transfer frame size to be independent of the codeblock size.

NGSLP offers a variable length transfer frame on all links. Therefore NGSLP requires a service from the Coding & Synchronization sublayer to accept variable length frames at the sending end and delivers (validated) variable length frames at the receiving end. Such a service should utilize one of two possible slicing configurations: Option 1: data is sliced without regard to codeword boundaries; Option 2: data is sliced on codeword boundaries. The key interface between C&S WG and this proposed NGSLP Project is the removal of the constraint present in some CCSDS authorized codes that the codeblock size determines the transfer frame size. Removing this key constraint opens up the possibility of defining new link layer operational modes e.g., links that would allow a mission to choose between the transfer of fixed or variable length frames, along with the insertion of idle data over an optimally encoded CCSDS link.

Additional flexibility is available to a mission, even when they decide to maintain the relationship between the frame and the codeblock. Namely, variable length frames can utilize an integer number of code words to form the desired codeblock. In so doing, one code word size can be utilized for an entire mission with little degradation of coding gain performance while allowing the frames to be sized to meet the need and demands of the link. (Typically one or more integral number of codewords makes up a codeblock.) This technique is similar to the one used in the current Telecommand Recommendation but with higher performance codes and a more efficient CLTU terminating method.

5) Relationships to Space Data Link Security Protocol (SDLS)

Standards related to this work in SDLS is: a) the emerging SDLS protocol.

NASA/JSC has identified a link layer security requirement that is only met by SDLS when multiple Virtual Channels use the same Security Association. Since NASA/JSC plans on assigning multiple data streams to one SA on the same virtual channel, NGSLP's design accommodates this requirement by assigning a VC sub channel to each data stream defined for that VC all under the same SA and delivery routing. This technique allows the frame sequence counter to be the field used for anti-replay eliminating the need for a separate counter and more complex accounting.

6) Relationships to Cross Support Service (CSS) Area and MOIMS Service Management (SM)

Standard related to this work in CSS are: SLE RAF Blue Book, SLE RCF Blue Book, SLE CLTU Service Blue Book, SLE Enhanced Forward CLTU Service Orange Book, the proposed Forward Frame Service, and the Service Management (SM) Blue Books.

In dialog with the CSS area, we have learned that the SLE services can handle frame sizes up to the proposed 65 KB. The return services are already able handle both TM and AOS frames. These would need to be extended to handle the NGSLP frames. The proposed Forward Frame service, to be defined on the CSTS Framework, will require the ability to handle existing TC and AOS frames as well as the proposed NGSLP frames. Since NGSLP has features related to all of the current CCSDS formats this update to the services should not be a major impact.

The new Service Management (SM) definitions that are in development should not be significantly affected by the NGSLP proposed changes because most of these features are similar to the existing protocols.

7) Under the Purview of System Engineering (SANA)

SANA registries for several link layer fields would need to be changed and some new fields (e.g., VC sub-channel) would need to be added. In general we feel that by making these fields larger we are reducing the overall impact on SANA by avoiding small incremental changes that would have to be executed across all 4 link layer protocols as technology and mission needs advance. In addition, current use of the Spacecraft IDs (SCID) requires a spacecraft to be assigned multiple IDs. These IDs are used by the project to separate data based upon operational phases. The inclusion of the SCID Use Field eliminates multiple ID requests and allows the ground handling services to use a single SCID in support of all mission data.

8) Installed Equipment Base

It must be acknowledged that a new generation of equipment and software may be required to provide these services to missions to service the anticipated very high data rates. Many of these changes will be driven by the higher data rates from optical communications and high rate missions. As a result, if the changes to the NGSLP can be combined with these other equipment updates the aggregated costs will be lower than if they were done separately.

9) Identified Deficiencies, Flaws, and Limitations in Existing Standards

9-1) Need for different CCSDS link layer protocols in each link environment
Currently each of the 4 CCSDS link layer protocols (TM, TC, AOS, and Proximity-1) has unique formats and services which prohibit their reuse across all space link applications of CCSDS member space agencies. For example, the current Mars missions are required to implement TC, either TM or AOS, and Proximity-1. The proposed NGSLP would require only a single link protocol for all of these applications.

9-2) The use of this single link protocol and the separation of frame and codeblock could if desired enable development of a frame layer relaying methodology for orbiters that provide trunk line services for supporting enterprises consisting of multiple data acquisition missions.

9-3) Currently there is limited spacecraft name space in the current SCID field. See 2-3.

9-4) The current transfer frame length is inefficient and the frame sequence counter is unacceptable for transfer frame accountability at higher data rates. See 2-2.

9-5) Frame sizes and codeblock sizes are often coupled depending on the code chosen.
This can force the use of short blocks for data that is essentially isochronous, but these are less efficient for other data types. Breaking this limitation will allow coding and link layer frame sizes to be separately optimized and changed as driven by mission needs.

9-6) NGSLP VC sub-channels enable a MOCC to assign the same SA across multiple data streams defined on a single VC.

10) Anticipated Agency Adoption of any Proposed Standards and their Dependencies

NASA, UK Space Agency, and DLR have formally acknowledged their support for the proposed project. Both

NASA (GSFC, MSFC and JPL) and UK Space Agency will work on the development of a white book, with NASA being the book captain. DLR has officially stated that they will support the development of a software prototype of NGSLP providing 3 to 6 MM of resources starting in 2015.

11) Novel Operational Scenarios related to any Proposed Standards

11-1) Supports Frame Relaying for LEO to GEO to Earth links.

NGSLP enables spacecraft to utilize the same transfer frame format across multiple links. This is more efficient since only one frame format would be required across these operational links.

11-2) Supports Frame Relaying for Proximity Mars to/from Earth links and between Mars bound assets.

Currently, and envisioned through 2020 on the telemetry link, landed assets format their telemetry in Direct-to-Earth (DTE) transfer frames that are then reliably tunneled via Proximity-1 protocol to an orbiter. These DTE frames are stored in the orbiter's data system as orbiter packets and then downlinked to Earth in Orbiter transfer frames. NGSLP enables both transfer frames generated by a landed asset and orbiter self-generated frames to be prioritized and downlinked over the same physical channel without any intermediate processing (packetizing the lander's frame for inclusion in Orbiters frame) of the landed assets telemetry. Note that frame relaying and consistent handling of frames could also apply to the command (forward) link. Moreover, the inclusion of a source address in addition to the destination address in a frame utilizing the Insert Zone can enable frames for one lander to be sent to an orbiter and then relayed to another Lander.

11-3) The Human Exploration program has very ambitious goals that include clusters of vehicles, very high data rates, link security and relay services.

The ISS already has situations in which a single uplink is used to serve multiple on-board entities that are essentially autonomous. It has the same situation on the downlink. The combination of the NGSLP and the CSTS Forward Frame service would permit each of these user communities to create and manage their own secured virtual channel between their mission operations ground system and their on-board environment. The NGSLP is designed to facilitate this sort of deployment. The NGSLP needs to be documented and matured in time for this program to utilize it.

11-4) Utilization of the CLTU service for all DFE communications can be accommodated when the frame length is independent of the codeblock length.

The ground stations can accommodate the needs of both low rate and high rate missions by continuously encoding the data stream provided by the current SLE-CLTU service using the selected code. In this mode the frame and the codeblock are independent of one another and the continuous stream of codeblocks are separated by the Codeblock Synchronization Marker (CSM). In this case, the C&S sublayer provides a virtual error free uplink upon which the CCSDS link layer frames reside. This method provides the decoding process with fixed length codeblocks thus simplifying the decoding process and ensures that the transfer frame delimiting process will be performed in a virtual error free environment. When synchronous frame delivery is not required then the current SLE-CLTU service can be used to create the data stream that will be encoded and uplinked. Idle data can be inserted when ground delivery transients disrupt continuous frame delivery to the stations thereby incurring minimum added latency on those occasions.