# Development and Verification Plan of Space Internet Technologies for Korean Lunar Exploration

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***Abstract*— The Space Internet, also known as the Interplanetary Internet, is a proposed network intended to connect stations on Earth with others in orbit around and on the surface of other planets and moons in the Solar System. This paper reports on a space Internet development and test plans for Korean lunar exploration program. First, Korean lunar program was reviewed. Then Delay Tolerant Network (DTN) characteristics and DTN protocols used in lunar exploration are reviewed. DTN communication architectures are presented. The Korea lunar exploration program is divided into two phases. In first phase, test lunar Orbiter will be launched without Lander or Rover. So, proposed DTN test architecture is based on Lander and Rover located on earth. In second phase, Lander and Rover will be landed on the moon. The DTN architecture and protocol stacks for second phase are also proposed.**

***Keywords-Ionosphere; Delay Tolerant Network(DTN); CCSDS File Delivery Protoclo(CFDP); Bundle Protocol(BP); Licklider Transmission Protocol(LTP); Proximity-1.***

## I. INTRODUCTION

Korea plans to develop a space vehicle on its own and launch it during the first half of 2020, and send up a lunar orbiter and a lunar lander for itself before the end of the same year. In the longer term, it is planning to explore Mars, asteroids, and deep space to join the ranks of space industry powerhouses [1] [2].

The Korean lunar project is divided into two phases. The goals of the first phase, which continues until 2017, include the completion of the basic technical design of the orbiter and module in cooperation with NASA, and the development of a test orbiter. At the same time, the scientific equipment to be carried in the orbiter and earth-bound control station to be responsible for deep space communication will be built.

The second phase is for the self-production of the orbiter and module and actual launch using a Korea Space Launch Vehicle (KSLV). To this end, 15 government-funded research institutes, such as the Korea Aerospace Research Institute (KARI) have formed a council and conducted 31 research tasks.

Electronics and Telecommunications Research Institute (ETRI) plan to develop space Internet technologies for the lunar communication. During the first phase, space Internet technology developed by ETRI will be tested through test lunar orbiter. If first phase testing is successful, space Internet technologies will be applied to the mission communication in the second phase of lunar exploration.

This paper focused on overview of development and test plan of space Internet technologies for Korea lunar exploration. In this paper, Delay/Disruption Tolerant Network (DTN) is reviewed first in Section 2. The protocols used in DTN communication for Korea lunar exploration is reviewed in Section 3. Architecture for DTN communication is reviewed in Section 4. In this section, DTN architecture for first and second phase is reviewed separately. Finally, research activities and future works are summarized in Section 5.

## II. DEAY TOLERANT NETWORK

The Internet has been a great success at interconnecting communication devices across the earth. It has done this by using a homogeneous set of communication protocols, called the TCP/IP protocol suite. All devices on the hundreds of thousands of networks that make up the Internet use these protocols for routing data and insuring the reliability of message exchanges.

Connectivity on the Internet relies primarily on wired links, including the wired telephone network, although wireless technologies such as satellite and short range mobile links are also an essential part of the network. These links, as used on the Internet, are continuously connected in end-to-end, low-delay paths between sources and destinations. They have low error rates and relatively symmetric bidirectional data rates.

The interplanetary network differs from the terrestrial Internet in a number ways as following that might arise individually or collectively.

- Intermittent connectivity: Connectivity may suffer from disruptions leading to link failure and network partitioning, for a large number of reasons like mobility issues, radio issues, and battery issues.
- Delay issues: Links could have a very high propagation delay or have such a highly variable delay that traditional protocol like TCP would fail.
- Asymmetric data rates: Links can suffer from highly asymmetric data rates or can be simply just unidirectional.

- High error rates: Some links may have high error rates. They could require a high level of correction and a large number of retransmissions, leading to the creation of tight bottlenecks [3].

A DTN is a network of smaller networks. It is an overlay on top of special-purpose networks, including the Internet. DTNs support interoperability of other networks by accommodating long disruptions and delays between and within those networks, and by translating between the communication protocols of those networks. In providing these functions, DTNs accommodate the mobility and limited power of evolving wireless communication devices. DTNs were originally developed for interplanetary use, where the speed of light can seem slow and delay-tolerance is the greatest need. However, DTNs may have far more diverse applications on earth, where disruption-tolerance is the greatest need. The potential earth applications span a broad range of commercial, scientific, military, and public-service applications.

The DTN architecture implements store-and-forward message switching by overlaying a new transmission protocol, called the Bundle Protocol (BP), on top of lower-lower protocols, such as the Internet protocols. The bundle protocol ties together the lower protocol layers so that application programs can communicate across the same or different sets of lower-lower protocols under conditions that involve long network delays or disruptions.

The bundle-protocol agent stores and forwards entire bundles (or bundle fragments) between nodes. A single bundle protocol is used throughout a DTN. By contrast, the lower-lower protocols below the bundle protocol are chosen to suit the characteristics of each communication environment.

## III. PROTOCOLS USED IN DTN COMMUNICATIONS

The protocols used for DTN communication in Korea lunar exploration are summarized as following.

- CCSDS (Consultative Committee for Space Data Systems) File Delivery Protocol (CFDP): The CFDP [4] is a File Transfer Protocol (FTP)-like protocol for transferring files between two entities separated by interplanetary distances, on the space links that have asymmetric bandwidths. CFDP can be used over a wide range of underlying communication services. It can be configured for either ground station to spacecraft or spacecraft to ground station transfers, apart from other configurations of a network of platforms, such as a spacecraft constellation or a series of planetary landers. The CFDP offers typical file operation commands such as delete, move, and copy that can be used to control a distant file store.
- Bundle Protocol (BP): The Bundle Protocol [5] provides effective mechanisms for communicating in and/or through highly stressed environments such as those with intermittent connectivity, large and/or variable delays, and high bit error rates. For providing its services, BP forms a store-and-forward overlay network by sitting at the application layer2 of some number of constituent Internets. The protocol data unit is called as a bundle and it comprises a sequence of two or more blocks of protocol data, which serve various purposes.
- Licklider Transmission Protocol (LTP): The Licklider Transmission Protocol [6], also known as Long-haul Transmission Protocol [7], is principally aimed at supporting the links, characterized by extremely long message route-trip times and/or frequent interruptions in connectivity. It has emerged as one of the best candidates as a convergence layer protocol in the case of interplanetary space communication. For single hop deep-space RF links, LTP is intended to serve as a retransmission-based reliable mechanism and does ARQ of data transmissions by soliciting selective-acknowledgment reception reports. LTP's design notions are directly descended from the retransmission procedures defined for CFDP.
- Proximity-1: Proximity-1 Space Link Protocol [8] is a short haul delivery communications protocol designed to establish a two-way communications link between a lander and an orbiter, negotiate data rate and communications mode, and reliably deliver data during short orbiter-to-surface contacts. Developed by CCSDS, Proximity-1 is implemented on Mars Exploration Rovers, Mars Odyssey, Mars Reconnaissance Orbiter, and Mars Express as well as on Phoenix Mars Lander. The frequency band used by this protocol is in the 400 MHz band so as to reduce complexity of the ground craft.
- Space Link Extension (SLE): The SLE transfer services [9], developed by the CCSDS, provide a standard method to transport spacecraft forward and return data between various tracking stations, mission operation control centers and data-user facilities. This standardization of the interfaces between the various facilities permits re-use of systems for successive missions and eliminates the development costs of mission-specific implementations. Mission risk is reduced since standard SLE services facilitate the rapid substitution of ground stations in the event of a failure. Since the SLE protocols run over existing communications infrastructure and utilize TCP/IP protocols, they help integrate Space Data Systems into the global communications network.

## IV. DTN COMMUNICATION ARCHITECTURE

The DTN architecture for lunar exploration consists of following communication nodes.

- Orbiter: orbiting the moon to perform data relay for the Lander and Rover
- Lander: on a moon surface to perform science mission and data relay for the Rover

 

- Rover: move on the moon surface to perform science mission
- Ground Station (GS): on earth for communication with the orbiter and lander
- Mission Control Center (MMC): on earth for monitoring and control of the lunar Orbiter
- Lander Control Center (LCC): on earth for monitoring and control of the Lander
- Rover Control Center (RCC): on earth for monitoring and control of the Rover

The communications links between the nodes are shown in Figure 1. The Orbiter can communicate with earth through GS whereas Lander and Rover cannot communicate with earth directly. Lander and Rover can communicate with earth through Orbiter relay.

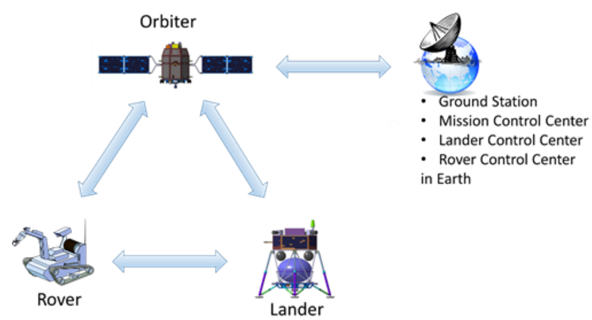


Figure 1. Communication links in lunar exporlation

### A. DTN Architecture for first phase

In the first phase of lunar exploration, test lunar orbiter called Korea Pathfinder Lunar Orbiter (KPLO) will be launched for the testing purpose. The KPLO mission is to verify Orbiter functionality and to check many parameters to be considered for the second phase of lunar exploration. In the meantime ETRI plan to test DTN technologies through KPLO in the first phase of lunar exploration. The purpose of testing is to verify DTN protocol functionality and performance and also if DTN communication architectures are acceptable for lunar mission communications. Figure 2 shows a DTN configuration in first phase of lunar exploration. Because there are no Lander and Rover on the moon in first phase, ground models of Lander and Rover will be located on earth for the communication testing. RCC is a source of DTN node and Rover is a destination of DTN node. MCC, Lander, KPLO and Cube-sat are DTN nodes which perform, store, and forward bundles between the source and destination. GS is not a DTN node because it just transfers bundles between the MCC and Orbiter. GS, MCC, RCC and Lander ground model are connected together through Internet.

Two kinds of DTN tests will be performed in first phase of lunar exploration. The first test is a DTN round trip test. In this testing, RCC controls Rover on earth through KPLO. RCC send command message or files to Rover in earth through KPLO and receive status telemetry or image files captured by Rover through KPLO also. The signal flow of round trip test is shown in Figure 3. Table 1 shows tentative protocols between the communication links.

The CFDP class 1 will be used for message or file transfer between RCC and Rover. Custody transfer based on store-and-forward mechanism and end-to-end reliability is provided by BP and LTP which are underlying CFDP. The SLE protocol will be used in the link between MCC and GS. This link can be assumed to be continuously available and there seems to be no need to apply the store-and-forward of BP in the GS. Proximity-1 can be used as a radio link between the Orbiter, Lander and Rover. Figure 7 at end of this paper shows a protocol stack for DTN round trip test in first phase.

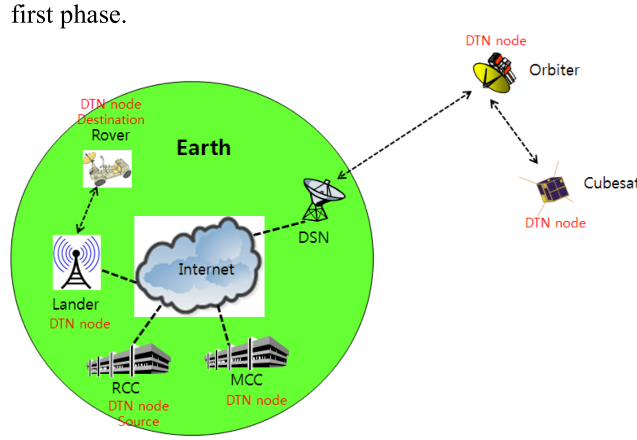


Figure 2. DTN test configuration in first phase

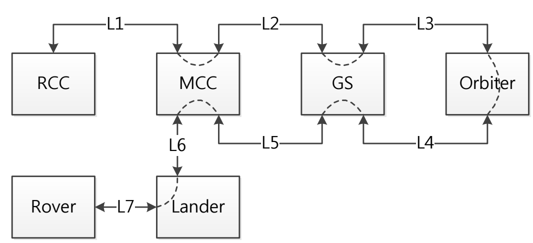


Figure 3. Signal flow of DTN round trip test in first phase

TABLE I. PROTOCOLS USED IN DTN ROUND TRIP TEST

| Links | Protocols |
|---|---|
| L1 | CFDP/BP/UDP |
| L2/L5 | CFDP/BP/LTP/SLE |
| L3/L4 | CFDP/BP/LTP/TMTC(AOS) |
| L6 | CFDP/BP/UDP |
| L7 | CFDP/BP/Proximity-1 |

Second test is a DTN communication test using Cube-sat. Cube-sat is released from the Orbiter when Orbiter is settled down in the orbit. Then, RCC on earth sends command to Cube-sat, and captured image by Cube-sat is transferred to RCC through KPLO relay. Cube-sat mission will continue

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until the link between KPLO and Cube-sat is disconnected. The signal flow of Cube-sat communication test is shown in Figure 4 and Table 2 shows tentative protocols between the communication links.

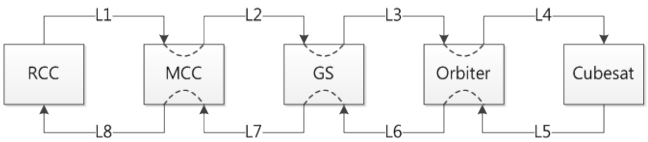


Figure 4. Signal flow of Cube-sat communication test at first phase

TABLE II. PROTOCOLS USED IN CUBE-SAT COMMUNICATION TEST

| Links | Protocols |
|---|---|
| L1/L8 | CFDP/BP/UDP |
| L2/L7 | CFDP/BP/LTP/SLE |
| L3/L6 | CFDP/BP/LTP/TMTC(AOS) |
| L4/L5 | CFDP/BP/ Proximity-1 or CFDP/BP/ 802.11 |

### B. *DTN Architecture for second phase*

In the second phase of lunar exploration, self-production of the Orbiter and Lander will be launched using a Korea Space Launch Vehicle (KSLV). The Orbiter is launched first and Lander follows. After Orbiter and Lander are settled down in its lunar orbit, Lander will be landed on the surface of moon. After safe landing, Lander deploys antenna and Rover will be released from the Lander. After safe release, Rover will perform science mission moving around landing area. Figure 5 shows a DTN communication configuration in second phase.

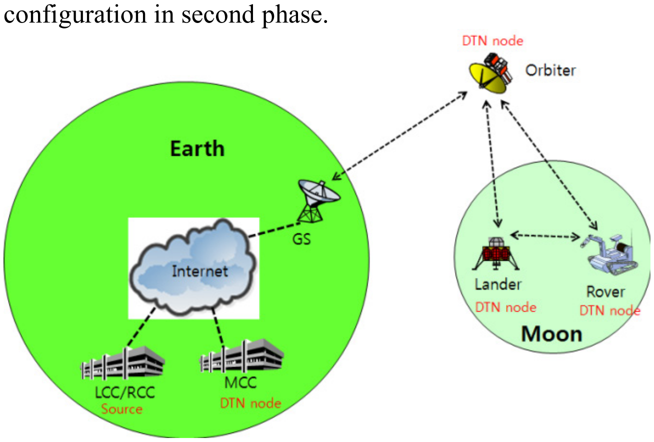


Figure 5. DTN communication configuration in second phase

As in first phase, CFDP class 1 will be used for file and message transfer between the RCC and Rover. The protocols are simular with the first phase. The signal flow of DTN communication in second phase is shown in Figure 6 and Table 3 shows tentative protocols between the communication links in second phase.

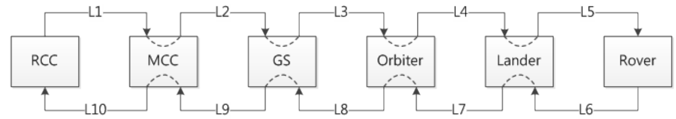


Figure 6. Signal flow of DTN communication at second phase

TABLE III. PROTOCOLS OF CUBE-SAT COMMUNICATION TEST

| Links | Protocols |
|---|---|
| L1/L10 | CFDP/BP/UDP |
| L2/L9 | CFDP/BP/LTP/SLE |
| L3/L8 | CFDP/BP/LTP/TMTC(AOS) |
| L4/L7 | CFDP/BP/ Proximity-1 |
| L5/L6 | CFDP/BP/ Proximity-1 |

Figure 8 at end of this paper shows a protocol stacks for DTN communication in second phase.

## V. CONCLUSION AND FUTURE WORK

In this paper, we presented a development and test plans of space Internet technologies for Korea lunar exploration. In the first phase of lunar exploration, two kinds of test scenarios are considered now. First scenario is DNT round trip test through KPLO. In this test, RCC controls Rover on earth through KPLO relay. RCC also monitors telemetry from the Rover on earth and also receive images captured by Rover through KPLO relay. Second scenario is DTN communication with Cube-sat. In this test, RCC controls Cube-sat through KPLO, it monitors telemetry from the Cube-sat, and also receives image captured by Cube-sat through KPLO relay. The purpose of DTN testing in first phase is to check and validate that DTN technologies are acceptable for the mission communication in second phase.

In the second phase of lunar exploration, Lander and Rover will be located on the surface of moon. In this phase DTN technologies will be applied to the communications between earth and lunar assets.

At this moment, ETRI installed DTN test-bed for the test of DTN protocols functionality and performance. Also, ETRI have a cooperation plan with NASA in the DTN and Cube-sat development. In near time, ETRI DTN test-bed will be connected to NASA test-bed for inter-operability testing. For the Cube-sat design, we are considering using smart phone as a communication payload for Cube-sat. ETRI also designs Proximity-1 space link modem for the inter spaceship communications. ETRI also participates in CCSDS meeting continuously.

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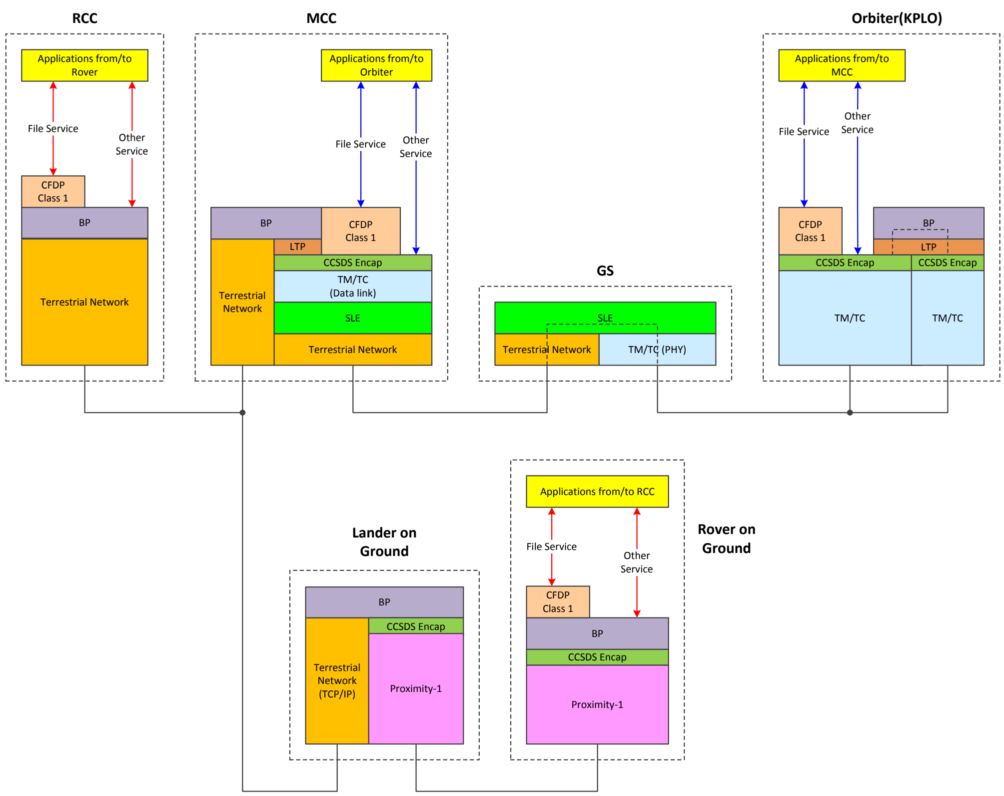


Figure 7. Protocol stacks of DTN round trip test in first phase

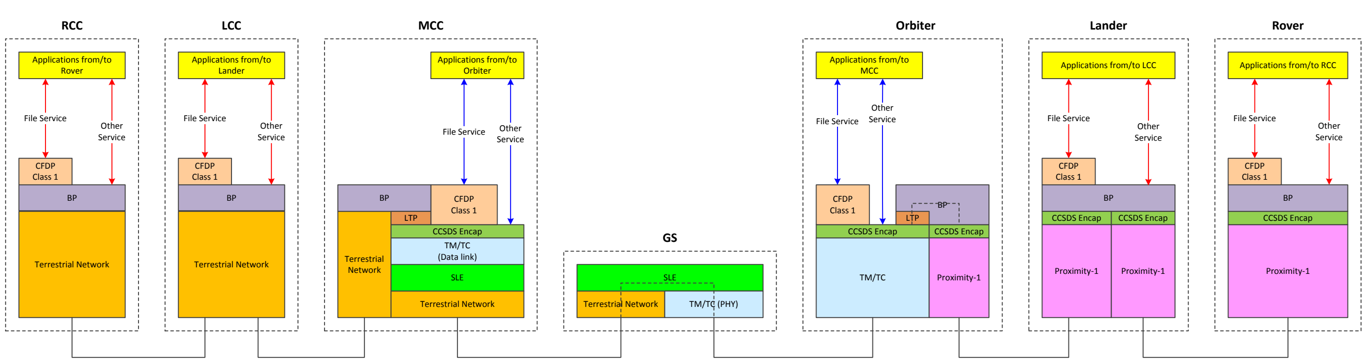


Figure 8. Protocol stacks of DTN communication in second phase