Space Internetworking for Small Projects

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The CCSDS Recommendations on Telemetry and Telecommand are used by many space projects around the world because they specify efficient, flexible methods for communications between ground systems and onboard instruments. They specify a method for addressing onboard instruments and subsystems, which uses the combination of the Spacecraft Identifier (SCID) and the Application Process Identifier (APID). Onboard instruments and subsystems can be identified with the combination of these identifiers uniquely if each spacecraft is operated independently of other spacecraft. In a constellation of space elements, however, the communications method of the CCSDS Recommendations does not work, and capabilities for internetworking must be introduced. This paper proposes a simple method for space internetworking, which is based on the methods used by the current space projects. The proposed method uses the technique of Packet encapsulation. Packets to be relayed by a relay element are transmitted between the ground and the relay element encapsulated in Packets for the relay element. This method does not require development of a new protocol at all. It can be implemented by just adding a component that encapsulates and decapsulates Packets to current systems, and components developed for current space projects can be reused without any modification. This method can also be used for constellations with several hops and several elements without any modification to the basic concept.

I. Introduction

THE CCSDS Recommendations on Telemetry and Telecommand[1-4] are used by many space projects around the world because they specify efficient, flexible methods for communications between ground systems and onboard instruments. There are also various generic communications and data handling components developed based on these CCSDS Recommendations. Development of spacecraft can be done with less cost and time if these generic components are used to build spacecraft.

These CCSDS Recommendations specify a method for addressing onboard instruments and subsystems, which uses the combination of the Spacecraft Identifier (SCID) and the Application Process Identifier (APID). Onboard instruments and subsystems can be identified with the combination of these identifiers uniquely if each spacecraft is operated independently of other spacecraft.

In a constellation of space elements (consisting of orbiters, landers, rovers, etc.), however, this communications method of the CCSDS Recommendations does not work if there are elements (which may be orbiters or landers) that relay data to and from other elements. A relay element receives from the ground commands to be relayed to target elements, multiplexed with commands for it. The relay element also sends to the ground telemetry generated by target elements, multiplexed with telemetry generated by it. If data to/from targets are to be multiplexed with data to/from the relay element at the Packet level, there is no way for telling what space element each Packet is associated with.

To solve this problem, capabilities for internetworking must be introduced. The method used in the Internet for internetworking on the ground (that is, the routing method based on IP) can be used to solve this problem in principle, but it is not compatible with the communications method used by current space projects. This paper proposes a simple method for space internetworking, which is based on the method used by the current space projects. The method proposed in this paper uses the technique of Packet encapsulation. Packets to be relayed by a relay element are transmitted between the ground and the relay element encapsulated in Packets for the relay element. This method does not require development of a new protocol at all. It can be implemented by just adding a component that encapsulates and decapsulates Packets to the current systems and can be used for internetworking in

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small constellations of space elements. Generic communications and data handling components developed for current space projects can be reused without any modification. Therefore, this method can be implemented with only a small cost.

This method can also be applied to complex scenarios without modifying the basic concept. It can be used for configurations with several hops and several elements, and the same procedures for relaying Packets can be used in any configuration.

Presently, some constellations of space elements (orbiter-lander-rover constellations and mother-daughter constellations) are planned or have already been deployed by some space agencies, but most of them consist of a relatively small number of space elements, and no inter-constellation communications are required (for example, there is no need for a Mercury orbiter to communicate with a Mars lander). Therefore, the method proposed in this paper is applicable to almost all the constellations planned by the space agencies.

II. Communications Methods Used by Current Space Projects

The CCSDS Recommendations on Telemetry and Telecommand[1-4] use the combination of the Spacecraft Identifier (SCID) and the Application Process Identifier (APID) for identifying onboard instruments and subsystems. The SCID[2-4] is contained in the Header of Frames exchanged between the ground system and a spacecraft and identifies the spacecraft associated with the Packets contained in the Frames. The APID[1] is contained in the Header of Packets carried in Frames and identifies the Logical Data Paths that the Packets should traverse. A Logical Data Path is a route from a source user application to one or more destination user applications and is always associated with an onboard instrument or subsystem.

This method of the CCSDS Recommendations is illustrated in Fig. 1 and Fig. 2. Fig. 1 shows an example in which a single, independent Spacecraft T is controlled by the Ground System. In this example, telecommand Frames with the SCID for Spacecraft T are sent from the Ground System to the Spacecraft T and telemetry Frames with the same SCID are sent from Spacecraft T to the Ground System. These Frames carry Packets, each of which has an APID value associated with one of the onboard instruments or subsystems onboard Spacecraft T. Fig. 2 shows how Packets are routed in Spacecraft T. As shown in this figure, Packets with the APID value for Instrument 1 are sent to and received from Instrument 1, and Packets with the APID value for Instrument 2 are sent to and received from Instrument 2.

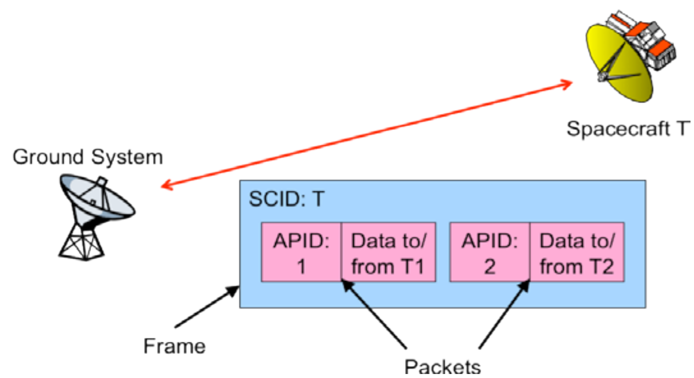

Figure 1. Example of a Frame and Packets used for a single, independent spacecraft.

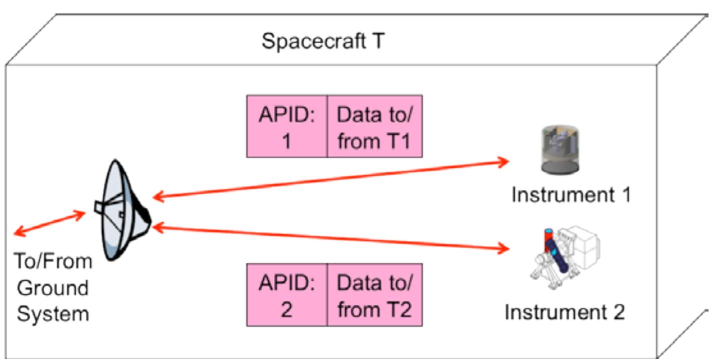

Figure 2. How Packets are routed in a spacecraft.

This addressing method is efficient and flexible and has been used by many space projects. There are also generic components that handle Packets and Frames based on this method. However, they do not work in a constellation having space elements that relay data to and from other space elements, as shown in the next section.

III. Space Internetworking Scenarios

In a constellation of space elements, some space elements may be used to relay data to and from other space elements. Two examples of such constellations with relay elements are shown in Fig. 3 and Fig. 4. In these constellations, a group of ground systems may be used to support the space elements, but the group of ground systems is represented by a single Ground System in these examples for simplicity. Fig. 3 is an example of a constellation consisting of multiple (Mars or lunar) orbiters and multiple (Mars or lunar) landers and/or rovers, in which the orbiters relay data to/from the landers and rovers. Fig. 4 is an example of a constellation consisting of a single mother spacecraft and multiple daughter spacecraft, in which the mother spacecraft relays data to/from the daughter spacecraft.

To explain the problem that the current CCSDS addressing method has in these relay scenarios, let's consider the simplest relay scenario shown in Fig. 5. In this scenario, a relay orbiter R relays data to and from a target lander T. Since the instruments and subsystems on Relay Orbiter R also needs to receive commands from the Ground System and send telemetry to the Ground System, Link GR between the Ground System and Relay Orbiter R needs to carry command Packets for both Relay Orbiter R (yellow Packets) and Target Lander T (pink Packets) and telemetry Packets from both R (yellow Packets) and T (pink Packets).

In this scenario, the addressing method of the CCSDS Recommendations work well only if Packets to/from Relay Orbiter R and Packets to/from Target Lander T are multiplexed on Link GR at the Frame level, which is illustrated in Fig. 6. In this case, on Link GR, Packets to/from R are carried in Frames with the SCID value for R, and Packets to/from T are carried in Frames with the SCID value for T. This method works well, but multiplexing at the Packet level will be preferred to multiplexing at the Frame level by many projects because the former gives more efficiency and flexibility than the latter in handling data with different handling requirements.

If data to/from R and T are to be multiplexed on Link GR at the Packet level, the only way allowable in CCSDS Recommendations for distinguishing Packets to/from T from Packets to/from R is to use two separate sets of APID values for R and T. However, this method is feasible only if all of the space elements in the constellation are developed with close coordination because each space element needs to use a set of APID values that are not used by other elements. If the spacecraft in the constellation are developed independently at different times, this method is impractical.

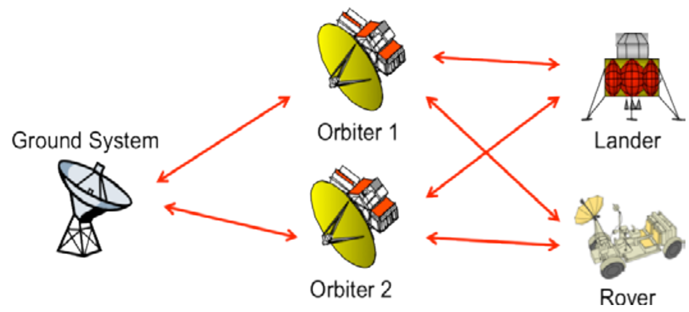

Figure 3. Mars or lunar exploration scenario.

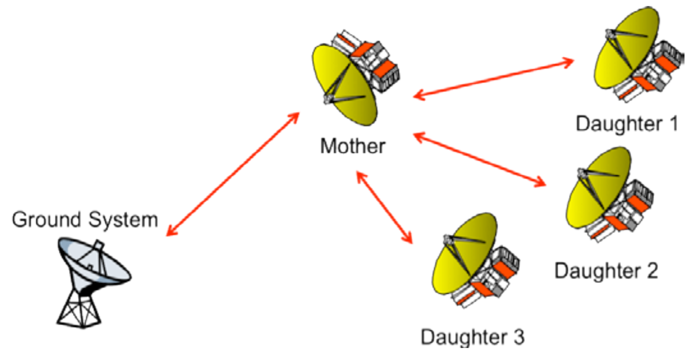

Figure 4. Mother-daughter scenario.

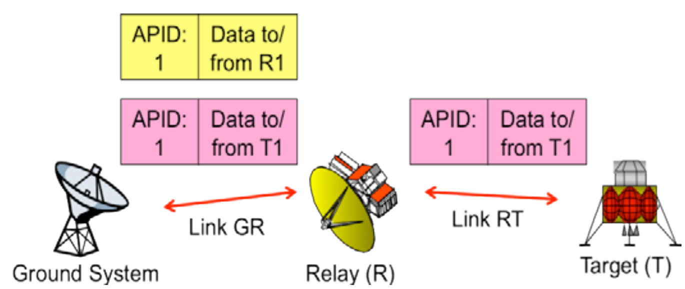

Figure 5. Simplest relay scenario.

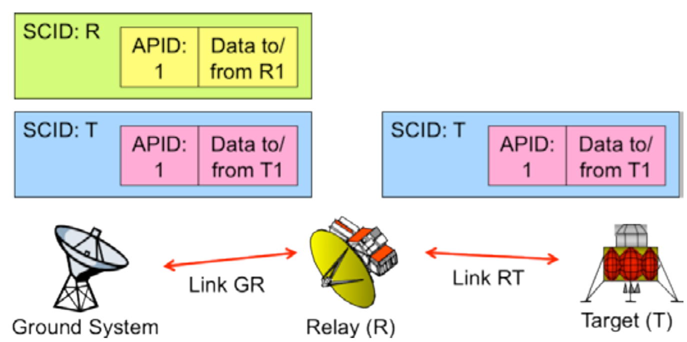

Figure 6. Multiplexing at the Frame level.

IV. Space Internetworking by Packet Encapsulation

This section explains a method for enabling space internetworking for small constellations using the well-known technique of Packet encapsulation.

A. Simplest Scenario

To explain how this method works, let's use the simplest relay scenario shown in Fig. 5 as an example. In this scenario, command Packets to both Relay Orbiter R and Target Lander T are multiplexed on Link GR between the Ground System and Relay Orbiter R. Also, telemetry Packets from both R and T are multiplexed on Link GR. The difference of the proposed method from the method shown in Fig. 6 is that Packets to/from Target Lander T are transmitted encapsulated in Packets for Relay Orbiter R on Link GR. All Packets (Packets to/from R and Packets to/from T) are carried by Frames with the SCID value for R on Link GR (see Fig. 7). Packets to/from T are sent with two Packet Headers on Link GR. The inner Packet Header is the original Packet Header for Target Lander T and the values of APID are associated with instruments and subsystems on Target Lander T. The outer Packet Header is used only on Link GR and its APID value indicates that Packets with this APID value are associated with Target Lander T. Packets to/from Relay Orbiter R are transmitted in the original format with only one Packet Header on Link GR.

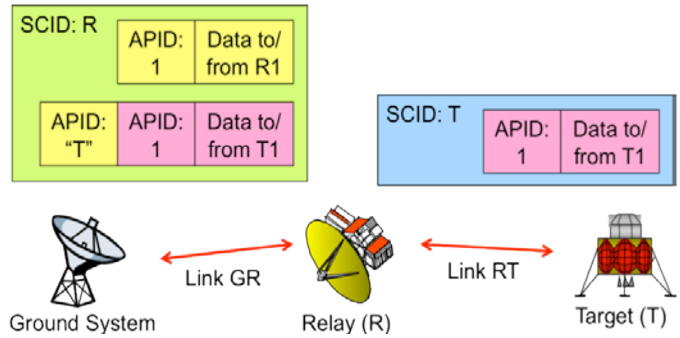

Figure 7. Multiplexing at the Packet level with Packet encapsulation.

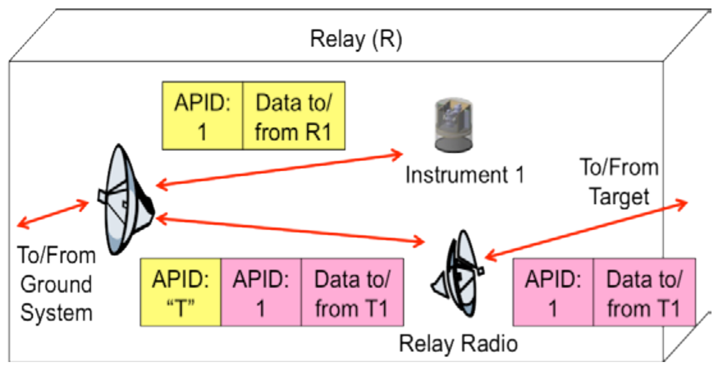

Figure 8. How Packets are routed in Relay (R).

Relay Orbiter R can determine which of the incoming command Packets are for it and which command Packets are to be relayed to Target Lander T by looking at the APID value contained in the outer Packet Header. Fig. 8 shows how Packets are routed in Relay Orbiter R. As shown in this figure, Packets with APID values for the instruments of R are sent to and received from the instruments of R as the case of Fig. 2. Packets with the APID value associated with T are sent to and received from the Relay Radio that relays data to and from Target Lander T.

When the Relay Radio of Relay Orbiter R has received from the Ground System a command Packet for Target Lander T, it removes the outer Packet Header and sends the inner Packet Header and the Data Field to Target Lander T on Link RT between R and T. When the Relay Radio has received a telemetry Packet from Target Lander T on Link RT, it attaches the outer Packet Header containing the APID value associated with T to the Packet received from T and sends it to the Ground System.

When the Ground System sends a command Packet to T through R, it attaches an outer Packet Header for routing operations performed in R. When the Ground System has received a telemetry Packet from T through R, it removes the outer Packet Header before processing its Data Field.

An optional Secondary Header can be attached to the first Packet Header for providing the relay element with additional information on how to relay Packets (see Fig. 9). The contents of the Secondary Header can be used, for example, for specifying for each command Packet which options or parameters should be used for transferring the Packet on Link RT.

Figure 9. Optional Secondary Header.

B. Extended Scenarios

This method can be applied to more complex scenarios without any change as shown below.

If there are multiple target elements using the relay service of a relay element, a set of special APID values of the outer Packet Header should be allocated to the targets elements. Each of these APID values corresponds to one of the target elements. The procedures for relaying Packets in the relay element explained in subsection A can be used without any change. In the relay element, a single Relay Radio can be shared among all the targets or a different Relay Radio can be used for each of the targets. An example having multiple targets is shown in Fig. 10.

This method can also be applied to scenarios where there are multiple hops to the final target element(s). In such scenarios, a series of Packet Headers are attached to original Packets for the target element. For example, if Packets to/from Target B should be relayed by two relay elements (Relay Orbiter R and Target A), three Packet Headers are used on the link between the Ground System and Relay Orbiter R, and two Packet Headers are used on the link between Relay Orbiter R and Target A (see Fig. 11). The procedures for relaying Packets explained in subsection A can be used without any modification in the two relay elements of this scenario. That is, the outermost Packet Header is removed from command Packets and attached to telemetry Packets at each relay element.

As shown in the above examples, this method is quite scalable and can be applied to any scenario involving multiple relays and multiple targets without modifying its operational procedures.

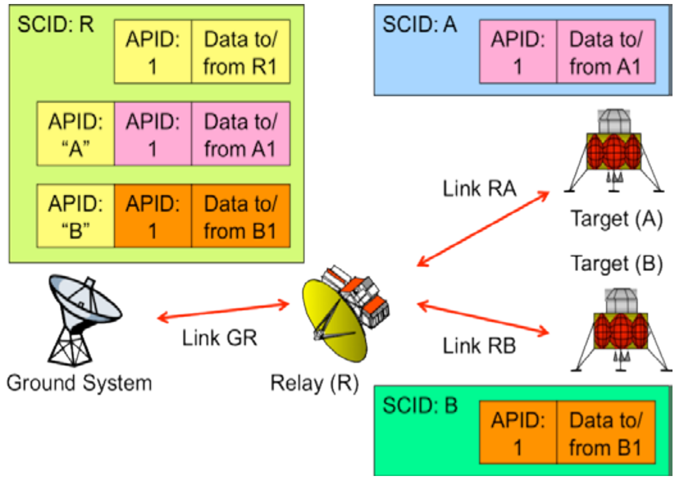

Figure 10. A scenario with multiple targets.

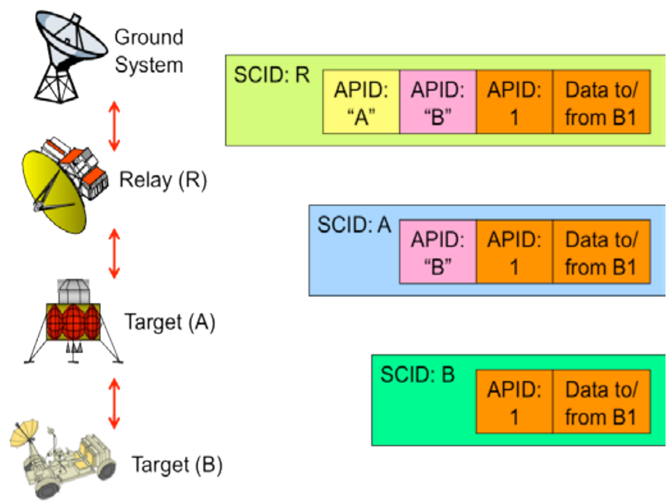

Figure 11. A scenario with multiple hops.

V. Benefits of This Method

The method for space internetworking proposed in this paper has several advantages over using special protocols for realizing space internetworking.

In the proposed method, the CCSDS TC/TM Recommendations[1-4] currently used by many space projects can be used without any change. In order to perform relay operations, the function for encapsulating and decapsulating Packets (that is, attaching and removing outmost Packet Headers) should be performed by Relay Radios, but this is the only addition required to implement this method. All generic communications and data handling components developed based on the CCSDS TC/TM Recommendations can be reused without any modification to support space internetworking.

Furthermore, this method is quite scalable. The logical operations of Relay Radios can be designed independently from any particular scenario. The physical performance of each Relay Radio must meet the physical requirements for the links used by the Relay Radio, but this is necessary regardless of the selection of protocols used by the Relay Radio. In terms of protocol operations, Relay Radios can be designed without knowing how many targets it should support or how many hops there exist. Therefore, the logical design of Relay Radios can be shared by different projects having different configurations (in terms of the number of targets and the number of hops).

For the same reasons, this method can also support interoperability among different space agencies. Since the CCSDS TC/TM Recommendations are used by most space agencies in the world and the method of this paper is simple and straightforward, no special inter-agency arrangements are necessary to achieve space internetworking involving multiple agencies.

Finally, this method can be used for almost all the constellations planned by the agencies because it can support any small constellation as discussed in section IV. This method may not work if there is a requirement that any instrument on any spacecraft should communicate with any other instrument on any other spacecraft. Meeting such a requirement may be interesting form the technical point of view, but it is not necessary at all from the operational point of view for most space missions.

VI. Conclusion

This paper has presented a method for performing space internetworking for small projects using the technique of Packet encapsulation. Space internetworking can be implemented with a very small extra cost by using this method because (1) this method only requires the addition of the function of encapsulating and decapsulating Packets to the current space communications systems and (2) components developed for current projects can be reused to support this method. It can also be used for inter-agency collaboration without any special arrangement among space agencies. Finally, this method can support almost all the constellations planned by the space agencies.

JAXA is planning some lunar and planetary missions involving a constellation of space elements. This method has been developed to support such missions. We also hope that this method will be used as the baseline for future collaboration among space agencies to build international constellations of space elements and to realize space internetworking in them.

Appendix A
Acronym List

APID	Application Process Identifier
CCSDS	Consultative Committee for Space Data Systems
IP	Internet Protocol
SCID	Spacecraft Identifier

Appendix B
Glossary

Application Process Identifier	An identifier that identifies the Logical Data Path which the Packet should traverse. A Logical Data Path is a path from a source user application to one or more destination user applications and is always associated with an onboard instrument or subsystem.
Spacecraft Identifier	An identifier that identifies the spacecraft associated with the data contained in Frames.

References

[1]Consultative Committee for Space Data Systems (CCSDS), "Space Packet Protocol," Recommendation for Space Data Systems Standards, CCSDS 133.0-B-1, Blue Book, Issue 1, Washington, D.C., Sept. 2003.

[2]Consultative Committee for Space Data Systems (CCSDS), "TM Space Data Link Protocol," Recommendation for Space Data Systems Standards, CCSDS 132.0-B-1, Blue Book, Issue 1, Washington, D.C., Sept. 2003.

[3]Consultative Committee for Space Data Systems (CCSDS), "TC Space Data Link Protocol," Recommendation for Space Data Systems Standards, CCSDS 232.0-B-2, Blue Book, Issue 2, Washington, D.C., Sept. 2010.

[4]Consultative Committee for Space Data Systems (CCSDS), "AOS Space Data Link Protocol," Recommendation for Space Data Systems Standards, CCSDS 732.0-B-2, Blue Book, Issue 1, Washington, D.C., July 2006.