BPv7 Custody Transfer and Compressed Status Reporting

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Agenda

- Motivation / Constraints / Status
- Bundle Sequence Identification – General Concepts
- Custody Transfer
- Compressed Bundle Reporting
- CBR-based End-to-End Services

Motivation / Constraints / Status

- Efficient Reporting on Bundle Status (eg, delivery) required in space mission scenarios
- Custody Transfer Mechanism allowing 'opportunistic' custody
- Focus on immediate needs (EO missions, LunaNet) – suitable for small, tightly-managed networks or single mission scenarios
- CCSDS Orange Book (almost) ready – publication early 2026
- A lot of choices are 'left to implementation' – still the specification should provide a basic level of interoperability (with providing sufficient flexibility for different use cases)
- Prototyping in ESA BP & Evaluation (Master Thesis Yanik Jeck)

Bundle Sequence Identification – General Concepts

Bundle Identification

- Identification of sequences of bundles by **bundle sequence numbers** qualified by a **bundle sequence ID**
- Bundle Sequence Numbers are used in extension blocks
- **Unique Identification of bundles** (during bundle lifetime) by
  - Bundle Sequence ID != 0:
    Block Source Administrative Endpoint ID* (eid) + Bundle Sequence ID (unsigned int) + Bundle Sequence Number (unsigned int)
  - Bundle Sequence ID == 0:
    Block Source Administrative Endpoint ID* (eid) + Destination Endpoint ID + Bundle Sequence Number (unsigned int)

* Block Source Administrative Endpoint ID may be omitted if it is the same as the source node ID in primary block.

Bundle Identification - Remarks

- Handling of bundle sequence number counters (by IDs / destination endpoint IDs) done within administrative element
- Assignment of bundles IDs is use case specific, eg
  - service number of bundle originating service if ipn naming is used
  - depending on next hop (eg, for reception reporting)
  - destination endpoint ID (sequence ID ‘0’), eg for delivery reporting

Bundle Sequences / Bundle Sequence Collections

A **Bundle Sequence** shall be a CBOR definite-length array of 3 or 4 items:

- **The Bundle Sequence ID** - CBOR unsigned integer OR common **Destination Endpoint ID** of all bundles in the sequence – endpoint ID
- **First Sequence Number** – CBOR unsigned integer; this indicates the first Bundle Sequence Number of the bundles the bundle sequence is referring to
- **Bundle Range** – CBOR unsigned integer; length of the sequence OR CBOR definitive-length array with the lengths of included / excluded sub-sequences
- Optional: **Block Source Administrative Endpoint ID** - endpoint ID

A **Bundle Sequence Collection** shall be a CBOR definite-length array of Bundle Sequence(s).

Bundle Sequence Example

```
[
  ipn:2.0,     // Sequence ID
  0,           // First Sequence Number

  Bundle Sequence Range:
   [
     5,        // Included sequence length
     10,       // Excluded sequence length
     20,       // Included sequence length
     ...       ...
   ],

  ipn:1.0      // Block Source Administrative Endpoint ID
],
```

Bundles
destination ipn:2.0

#0,#1,#2,#3,#4,

#15,#16,#17,#18, …

…, #32, #33,#34

numbering ipn:1.0

Custody Transfer

Custody Transfer - Remarks

- ‘Custody Transfer’ != ‘Reliable Bundle Delivery’
  - reliability depends on the conditions for custody acceptance
  - custody transfer can increase the efficiency by enabling retransmission from a custodian (yes, CL-based re-transmission is more efficient)
  - can be combined with (compressed) delivery reporting and end-to-end re-transmission for ‘reliable bundle delivery’
- Should be possible to request nodes to take custody without knowing the custodian a-priori
- Yes, there are security concerns → discussion/recommendations in the Orange Book, eg only accept custody signals from trusted, authenticated nodes

Custody Transfer Extension Block (CTEB)

- Custody Transfer is requested through a **Custody Transfer Extension Block** with the following block-type-specific data
  - **Bundle Sequence Number** – CBOR unsigned integer
  - **Bundle Sequence ID** – CBOR unsigned integer
  - **Block Source Administrative Endpoint ID** - endpoint ID (“current custodian”)
- A bundle shall never contain more than one Custody Transfer Extension Block.

Compressed Custody Signal (CCS)

- A Compressed Custody Signal is an **administrative record** containing a CBOR map composed by key/value pairs as record content:
  - Keys of of the map shall be the Disposition Codes of the Custody Signal:
    - **Custody Acceptance**: a positive CBOR integer:
      - 1 – Custody Accepted (no further information)
      - Values above 1 – reserved for future use
    - **Custody refusal**: a negative CBOR integer
      - -1 – custody refused (no further information)
      - Values below -1 – reserved for future use
  - Values shall be **Bundle Sequence Collections***

*Bundle Sequences in the Bundle Sequence Collections above shall never contain a Block Source Administrative Endpoint ID (as the signal will be received by that administrative element)

Custody Procedures – Custody Decision

- Any node can **request custody** transfer by inserting a CTEB into a bundle.
- Any node receiving a CTEB which is not the destination of a received bundle shall **decide whether to take or refuse custody** of the received bundle.
- The decision whether to take custody are mission or network-specific:
  - A node may take custody of a bundle when there are ‘reasonable good chances’ that the bundle can be forwarded to a next custodian. This can be based e.g. on a combination of bundle time-to-live, knowledge about upcoming contacts, past experiences, etc.
  - By local policy (which could be set by network management)
  - Other means
- A node receiving a CTEB which is delivering the received bundle shall always take custody of the received bundle.

Custody Procedures – Custody Processing

- In case the node **takes custody**, it shall:
    - store all required information for creating a compressed custody acceptance signal
    - **delete the current CTEB**
    - before forwarding the bundle, **add a new CTEB** requesting custody transfer with its own Administrative Endpoint ID as the Block Source Administrative Endpoint ID
    - store the bundle until a custody acceptance signal is received or the bundle life-time has expired.
- In case the node **refuses custody** it shall store all required information for creating a compressed custody refusal signal.

Custody Procedures – Custody Signalling

- A Compressed Custody Signal shall be sent based on the stored information according to the MIB configuration or based on external events.
- The decision when to transmit a Compressed Custody Signal is an implementation matter:
  - Implementation may transmit Compressed Custody Signals **periodically based on a timer** if there are any CTEB requests to respond to.
  - Implementations may transmit Compressed Custody Signals **depending on size constraints** like the overall report bundle size or the number of bundles to report on. In this case, it is recommended that an additional timer is used to transmit a Compressed Custody Signal even if the size limit is not reached but no additional bundles to report on have been received for some time.
  - Implementations may transmit Compressed Custody Signals based on **external events** (e.g., the establishment of a communication link or reception of an explicit command).

Custody Procedures – Bundle Re-forwarding

- In case no Compressed Custody Signal acceptance signal is received by a custodian for a specific bundle, the bundle should be re-forwarded.
- The decision when to re-forward a bundle is an implementation decision. It may be based on:
  - **Timers**: If no custody signal for a bundle or is received for a certain amount of time, the bundle will be re-forwarded
  - **Received Custody Signals**: if in-sequence reception of bundles and custody signals can be assumed, gaps in the reporting of accepted custody signals can indicate lost bundles and lead to re-forwarding
  - **Explicit command**: based on an explicit command, all or certain bundles with pending custody acceptance may be re-forwarded
  - **Other Internal/External events** such as the initiation of a contact
  - **Reported failure** to forward the bundle via a Convergence Layer Adapter

Compressed Bundle Reporting

Compressed Reporting Extension Block (CREB)

- Compressed reporting is requested through a **Compressed Reporting Extension Block** with a definite-length CBOR array of 1 to 5 elements as block-type-specific data
  - Length 1: sequence number only
  - Length 2: sequence number with sequence ID
  - Length 3: reporting request by bundle source
  - Length 4: reporting request
  - Length 5: reporting request with report-to-eid
- A bundle may contain more than one Compressed Reporting Extension Block.

Compressed Reporting Extension Block (CREB) – Full Array Content

- **Bundle Sequence Number** – CBOR unsigned integer
- **Bundle Sequence ID** – CBOR unsigned integer (defaults to ‘0’)
- **Status Report Request Flags** – CBOR unsigned integer (for report requesting)
    - Bit 0 – reception reporting request
    - Bit 1 – forwarding reporting request
    - Bit 2 – delivery reporting request
    - Bit 3 – deletion reporting request
    - Bit 4 – custody acceptance reporting request
    - Bit 5 – custody rejection reporting request
    - Bit 6 to 63 – reserved for future use
- **Block Source Administrative Endpoint ID** - endpoint ID (defaults to administrative endpoint ID of bundle source node)
- **Report-to Endpoint ID**

Compressed Reporting Signal (CRS)

- A Compressed Reporting Signal is an administrative record containing a CBOR map composed by key/value pairs as record content:
  - Keys of the map shall be the Status Report Reason - CBOR unsigned integer providing the reporting reason.
    - 0 – reception report
    - 1 – forwarding report
    - 2 – delivery report
    - 3 – deletion report
    - 4 – custody acceptance report
    - 5 – custody rejection report
    - Values above 6 – reserved for future use
  - Values shall be **Bundle Sequence Collections**

Compressed Reporting Processing

- Reception of a CREB with a **three, four or five-element array** shall cause the receiving bundle node to store all required information for generating a Compressed Reporting Signals.
- Compressed Reporting Signals shall be generated and transmitted to a common Compressed Reporting Signal Destination based on the stored information.
  - The decision when to transmit a Compressed Reporting Signal is an implementation matter.
  - Implementations may transmit Compressed Reporting Signals **periodically** if there is any information to report.
  - Implementations may transmit Compressed Reporting Signals depending on **size constraints** such as the overall report bundle size or the number of bundles to report on.
- Compressed Reporting Signal Destination shall be:
  - the **Source Node ID in the primary block** (three-element array)
  - the **Block Source Administrative Endpoint ID** (four-element array)
  - the **Report-To-Endpoint** (five-element array)

Bundle Fragmentation

- DON'T DO FRAGMENTATION !!!
  - CTEB/CREB shall not be added to fragments
  - Bundles with CTEB/CREB shall not be fragmented (set the Do Not Fragment Flag, if you can)
- (If you really would need to fragment, use BIBE segmentation)

CBR-based End-to-End Services

E2E Services – without CRS

- The following services can be realised with CREB containing just a sequence number per destination endpoint Id (sequence Id ‘0’)
  - **E2E in-sequence Bundle Delivery**
    - Re-ordering at destination node according to sequence number
  - **Duplicate suppression**
    - Deletion of bundles with the same sequence number
  - **Gap Detection**
    - Identify gaps (or late bundles) by missing sequence numbers

E2E Services – with CRS

- The following services can be realised with the use of Compressed Reporting
  - **E2E Accounting**
    - Delivery Reporting by destination node (must support compressed reporting)
    - Deletion Reporting by deleting node (must support compressed reporting)
    - Reporting to source node or a different report-to node
  - **E2E Reliability**
    - Based on E2E Accounting
    - Resending of bundles in case deletion reports are received or expected delivery reports are not received

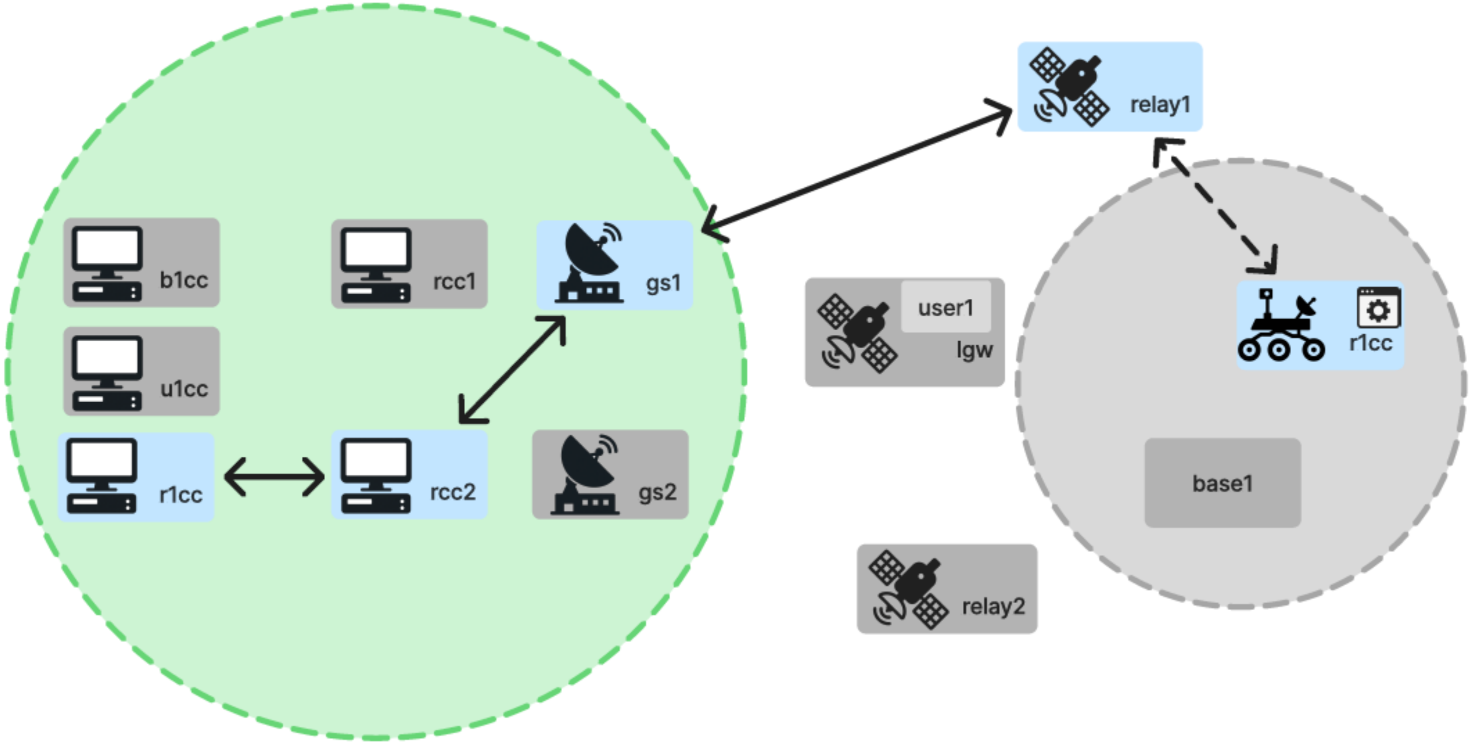
Prototyping, Testing & Validation

Prototyping & Testing

- Custody Transfer & Compressed Status Reporting based on bundle-sequencing is implemented in ESA BP
- 113 JUnit Test covering the structures
- Dockerized Simulation Environment (simple UDPCL)
  - Simple 3-node scenario covering
    - custody transfer (timer-based)
    - all reporting variants
    - included bundle loss, storage depletion, no known route, …

Validation – Lunar Comms Scenario

Figure 4.2: Lunar Communication Scenario [24] with irrelevant data flows omitted and nodes not participating in the relevant communication grayed out.

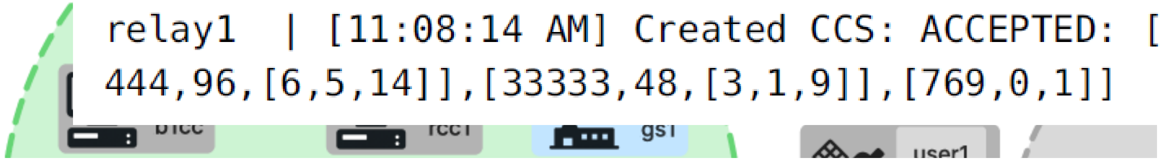


- Rover control centre (r1cc) sending commands requesting delivery reports
- Rover requesting custody for the delivery reports and additional traffic

Validation – Lunar Comms Scenario

Figure 4.2: Lunar Communication Scenario [24] with irrelevant data flows omitted and nodes not participating in the relevant communication grayed out.

```
relay1  | [11:07:38 AM] INFO: Received CREB:CREB 3: [8,678,4]
relay1  | [11:07:48 AM] INFO: Received CREB:CREB 3: [9,678,4]
relay1  | [11:07:58 AM] INFO: Received CREB:CREB 3: [10,678,4]
relay1  | [11:08:08 AM] INFO: Received CREB:CREB 3: [11,678,4]
relay1  | [11:08:14 AM] Created CCS: ACCEPTED: [[44
444,96,[6,5,14]],[33333,48,[3,1,9]],[769,0,1]]
```




```
r1cc     | [11:08:05 AM] Received CRS: DELIVERY: [[678,10,1]]
r1cc     | [11:08:16 AM] Received CRS: DELIVERY: [[678,11,1]]
r1cc     | [11:08:23 AM] Created CCS:
r1cc     | ACCEPTED: [[44444,0,[13,5,1,4,1,1,1,1,1
,8,1,74,7]],[33333,0,[5,2,1,3,2,2,1,39,4,2,3]],[769,0,2]]
r1cc     | REFUSED: [[44444,122,7]]
r1cc     | [11:08:24 AM] Created CCS:
r1cc     | ACCEPTED: [[44444,13,[5,1,4,1,1,1,1,1,8,2,4,2,
3,1,1,2,1,3,3,60,1]],
[33333,5,[2,1,3,2,2,1,2,1,2,2,3,1,2,35,1]]]
r1cc     | REFUSED: [[44444,129,1]]
```

```
rover1   | [11:07:59 AM] INFO: Received CREB:CREB 3: [10,678,4]
rover1   | [11:08:09 AM] INFO: Received CREB:CREB 3: [11,678,4]
rover1   | [11:08:04 AM] Created CRS: DELIVERY: [[678,10,1]]
rover1   | [11:08:14 AM] Created CRS: DELIVERY: [[678,11,1]]
rover1   | [11:08:24 AM] Created CRS: DELIVERY: [[678,12,1]]
```

- Rover control centre (r1cc) sending custody for the delivery reports and additional traffic

(Potential) Next Steps

(Potential) Next Steps

- Publication of ‘Custody Transfer & Compressed Status Reporting’ CCSDS Orange Book
- Possible split into 3 IETF drafts
    1. Bundle Sequence Identification
    2. BPv7 Custody Signalling (referring to 1.)
    3. Compressed Bundle Status Reporting (referring to 1.)
- (CCSDS Blue Book adopting / profiling the IETF RfCs)