Delay-Tolerant Networking Working Group
Internet Draft
Intended status: Standards Track
Expires: December 2015

S. Burleigh
JPL, Calif. Inst. Of Technology
K. Fall
Carnegie Mellon University / SEI
E. Birrane
APL, Johns Hopkins University

June 21, 2015

Bundle Protocol
draft-dtnwg-bp-00.txt

Status of this Memo

Abstract

This Internet Draft presents a specification for Bundle Protocol, adapted from the experimental Bundle Protocol specification developed by the Delay-Tolerant Networking Research group of the Internet Research Task Force and documented in RFC 5050.

Table of Contents

1. Introduction

Since the publication of the Bundle Protocol Specification (Experimental RFC 5050[RFC5050]) in 2007, the Delay-Tolerant Networking Bundle Protocol has been implemented in multiple programming languages and deployed to a wide variety of computing platforms for a wide range of successful exercises. This implementation and deployment experience has demonstrated the general utility of the protocol for challenged network operations.

It has also, as expected, identified opportunities for making the protocol simpler, more capable, and easier to use. The present document, standardizing the Bundle Protocol (BP), is adapted from RFC 5050 in that context.

This document describes version 7 of BP.

Delay Tolerant Networking is a network architecture providing communications in and/or through highly stressed environments. Stressed networking environments include those with intermittent connectivity, large and/or variable delays, and high bit error rates. To provide its services, BP sits at the application layer of some number of constituent networks, forming a store-carry-forward overlay network. Key capabilities of BP include:

- Custodial forwarding
- Ability to cope with intermittent connectivity
- Ability to take advantage of scheduled, predicted, and opportunistic connectivity (in addition to continuous connectivity)
- Late binding of overlay network endpoint identifiers to underlying constituent network addresses

For descriptions of these capabilities and the rationale for the DTN architecture, see [ARCH] and [SIGC]. [TUT] contains a tutorial-level overview of DTN concepts.

BP's location within the standard protocol stack is as shown in Figure 1. BP uses underlying "native" network protocols for communications within a given constituent network.

The interface between the bundle protocol and a specific underlying protocol is termed a "convergence layer adapter".

Figure 1 shows three distinct transport and network protocols (denoted T1/N1, T2/N2, and T3/N3).

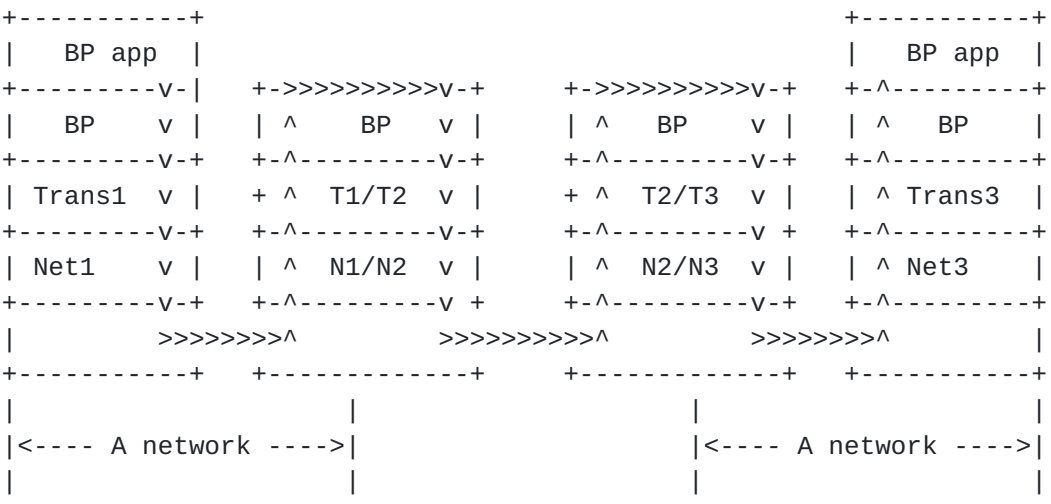


Figure 1: The Bundle Protocol Sits at the Application Layer of the Protocol Stack Model

This document describes the format of the protocol data units (called bundles) passed between entities participating in BP communications.

The entities are referred to as "bundle nodes". This document does not address:

- Operations in the convergence layer adapters that bundle nodes use to transport data through specific types of internets. (However, the document does discuss the services that must be provided by each adapter at the convergence layer.)
- The bundle route computation algorithm.
- Mechanisms for populating the routing or forwarding information bases of bundle nodes.
- The mechanisms for securing bundles en-route.

. The mechanisms for managing bundle nodes.

2. Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC-2119 [RFC2119].

In this document, these words will appear with that interpretation only when in ALL CAPS. Lower case uses of these words are not to be interpreted as carrying RFC-2119 significance.

3. Service Description

3.1. Definitions

Bundle - A bundle is a protocol data unit of BP, so named because negotiation of the parameters of a data exchange may be impractical in a delay-tolerant network: it is often better practice to "bundle" with a unit of data all metadata that might be needed in order to make the data immediately usable when delivered to applications. Each bundle comprises a sequence of two or more "blocks" of protocol data, which serve various purposes. Multiple instances of the same bundle (the same unit of DTN protocol data) might exist concurrently in different parts of a network -- possibly in different representations and/or differing in some blocks -- in the memory local to one or more bundle nodes and/or in transit between nodes. In the context of the operation of a bundle node, a bundle is an instance of some bundle in the network that is in that node's local memory.

Bundle payload - A bundle payload (or simply "payload") is the application data whose conveyance to the bundle's destination is the purpose for the transmission of a given bundle. The terms "bundle content", "bundle payload", and "payload" are used interchangeably in this document. The "nominal" payload for a bundle forwarded in response to a bundle transmission request is the application data unit whose location is provided as a parameter to that request. The nominal payload for a bundle forwarded in response to reception of that bundle is the payload of the received bundle.

Fragment - A fragment is a bundle whose payload block contains a fragmentary payload. A fragmentary payload is either the first N bytes or the last N bytes of some other payload -- either a nominal payload or a fragmentary payload -- of length M, such that 0 < N < M.

Bundle node - A bundle node (or, in the context of this document, simply a "node") is any entity that can send and/or receive bundles. In the most familiar case, a bundle node is instantiated as a single process running on a general-purpose computer, but in general the definition is meant to be broader: a bundle node might alternatively be a thread, an object in an object-oriented operating system, a special-purpose hardware device, etc. Each bundle node has three conceptual components, defined below: a "bundle protocol agent", a set of zero or more "convergence layer adapters", and an "application agent".

Bundle protocol agent - The bundle protocol agent (BPA) of a node is the node component that offers the BP services and executes the procedures of the bundle protocol. The manner in which it does so is wholly an implementation matter. For example, BPA functionality might be coded into each node individually; it might be implemented as a shared library that is used in common by any number of bundle nodes on a single computer; it might be implemented as a daemon whose services are invoked via inter-process or network communication by any number of bundle nodes on one or more computers; it might be implemented in hardware.

Convergence layer adapters - A convergence layer adapter (CLA) sends and receives bundles on behalf of the BPA, utilizing the services of some 'native' protocol stack that is supported in one of the networks within which the node is functionally located. As such, every CLA implements its own thin layer of protocol, interposed between BP and the (usually "top") protocol(s) of the underlying native protocol stack; this "CL protocol" may only serve to multiplex and de-multiplex bundles to and from the underlying native protocol, or it may offer additional CL-specific functionality. The manner in which a CLA sends and receives bundles is wholly an implementation matter, exactly as described for the BPA. The definitions of CLAs and CL protocols are beyond the scope of this specification.

Application agent - The application agent (AA) of a node is the node component that utilizes the BP services to effect communication for some purpose. The application agent in turn has two elements, an administrative element and an application-specific element. The application-specific element of an AA constructs, requests transmission of, accepts delivery of, and processes application-specific application data units; the only interface between the BPA and the application-specific element of the AA is the BP service interface. The administrative element of an AA constructs and requests transmission of administrative records (including status reports and custody signals), and it accepts delivery of and

processes any custody signals that the node receives. In addition to the BP service interface, there is a (conceptual) private control interface between the BPA and the administrative element of the AA that enables each to direct the other to take action under specific circumstances. In the case of a node that serves simply as a BP "router", the AA may have no application-specific element at all. The application-specific elements of other nodes' AAs may perform arbitrarily complex application functions, perhaps even offering multiplexed DTN communication services to a number of other applications. As with the BPA, the manner in which the AA performs its functions is wholly an implementation matter.

Administrative record - A BP administrative record is an application data unit that is exchanged between the administrative elements of nodes' application agents for some BP administrative purpose. The formats of some fundamental administrative records (and of no other application data units) are defined in this specification.

Bundle endpoint - A bundle endpoint (or simply "endpoint") is a set of zero or more bundle nodes that all identify themselves for BP purposes by some common identifier, called a "bundle endpoint ID" (or, in this document, simply "endpoint ID"; endpoint IDs are described in detail in Section 4.4.4 below). The special case of an endpoint that contains exactly one node is termed a "singleton" endpoint. Singletons are the most familiar sort of endpoint, but in general the endpoint notion is meant to be broader. For example, the nodes in a sensor network might constitute a set of bundle nodes that identify themselves by a single common endpoint ID and thus form a single bundle endpoint. For a bundle to be considered "delivered" to an endpoint, a minimum number of receiving nodes may be required to receive it successfully. This lower limit is called the minimum reception group, and is defined in the Transmission discussion below. *Note* too that a given bundle node might identify itself by multiple endpoint IDs and thus be a member of multiple bundle endpoints. The destination of every bundle is an endpoint, which may or may not be singleton. The source of every bundle is a singleton endpoint.

Transmission - A transmission is an attempt by a node's BPA to cause copies of a bundle to be delivered at all nodes in the minimum reception group of some endpoint (the bundle's destination) in response to a transmission request issued by the node's application agent. The minimum reception group of an endpoint may be any one of the following: (a) ALL of the nodes registered (see definition below) in an endpoint that is permitted to contain multiple nodes (in which case forwarding to the endpoint is functionally similar to "multicast" operations in the Internet, though possibly very

different in implementation); (b) ANY N of the nodes registered in an endpoint that is permitted to contain multiple nodes, where N is in the range from zero to the cardinality of the endpoint; or (c) THE SOLE NODE registered in a singleton endpoint (in which case forwarding to the endpoint is functionally similar to "unicast" operations in the Internet). The nature of the minimum reception group for a given endpoint can be determined from the endpoint's ID (again, see Section 4.4 below): for some endpoint ID "schemes", the nature of the minimum reception group is fixed - in a manner that is defined by the scheme - for all endpoints identified under the scheme; for other schemes, the nature of the minimum reception group is indicated by some lexical feature of the "scheme-specific part" of the endpoint ID, in a manner that is defined by the scheme. Any number of transmissions may be concurrently undertaken by the bundle protocol agent of a given node.

Forwarding - When the bundle protocol agent of a node determines that a bundle must be "forwarded" to a node (either a node that is a member of the bundle's destination endpoint or some intermediate forwarding node) in the course of completing the successful transmission of that bundle, it invokes the services of a CLA in a sustained effort to cause a copy of the bundle to be received by that node.

Registration - A registration is the state machine characterizing a given node's membership in a given endpoint. Any number of registrations may be concurrently associated with a given endpoint, and any number of registrations may be concurrently associated with a given node. Any single registration must at any time be in one of two states: Active or Passive. A registration always has an associated "delivery failure action", the action that is to be taken when a bundle that is "deliverable" (see below) subject to that registration is received at a time when the registration is in the Passive state. Delivery failure action must be one of the following:

- defer "delivery" (see below) of the bundle subject to this registration until (a) this bundle is the least recently received of all bundles currently deliverable subject to this registration and (b) either the registration is polled or else the registration is in the Active state; or
- "abandon" (see below) delivery of the bundle subject to this registration.

An additional implementation-specific delivery deferral procedure may optionally be associated with the registration. While the state of a registration is Active, reception of a bundle that is deliverable subject to this registration must cause the bundle to be

delivered automatically as soon as it is the next bundle that is due for delivery according to the BPA's bundle delivery scheduling policy, an implementation matter. While the state of a registration is Passive, reception of a bundle that is deliverable subject to this registration must cause delivery of the bundle to be abandoned or deferred as mandated by the registration's current delivery failure action; in the latter case, any additional delivery deferral procedure associated with the registration must also be performed.

Delivery - Upon reception, the processing of a bundle that has been received by a given node depends on whether or not the receiving node is registered in the bundle's destination endpoint. If it is, and if the payload of the bundle is non-fragmentary (possibly as a result of successful payload reassembly from fragmentary payloads, including the original payload of the received bundle), then the bundle is normally "delivered" to the node's application agent subject to the registration characterizing the node's membership in the destination endpoint. A bundle is considered to have been delivered at a node subject to a registration as soon as the application data unit that is the payload of the bundle, together with the value of the bundle's "Acknowledgement by application is requested" flag and any other relevant metadata (an implementation matter), has been presented to the node's application agent in a manner consistent with the state of that registration and, as applicable, the registration's delivery failure action.

Deliverability, Abandonment - A bundle is considered "deliverable" subject to a registration if and only if (a) the bundle's destination endpoint is the endpoint with which the registration is associated, (b) the bundle has not yet been delivered subject to this registration, and (c) delivery of the bundle subject to this registration has not been abandoned. To "abandon" delivery of a bundle subject to a registration is simply to declare it no longer deliverable subject to that registration; normally only registrations' registered delivery failure actions cause deliveries to be abandoned.

Deletion, Discarding - A bundle protocol agent "discards" a bundle by simply ceasing all operations on the bundle and functionally erasing all references to it; the specific procedures by which this is accomplished are an implementation matter. Bundles are discarded silently; i.e., the discarding of a bundle does not result in generation of an administrative record. "Retention constraints" are elements of the bundle state that prevent a bundle from being discarded; a bundle cannot be discarded while it has any retention constraints. A bundle protocol agent "deletes" a bundle in response to some anomalous condition by notifying the bundle's report-to node

of the deletion (provided such notification is warranted; see Section 5.13 for details) and then arbitrarily removing all of the bundle's retention constraints, enabling the bundle to be discarded.

Custody - A node "takes custody" of a bundle when it determines that it will retain a copy of the bundle for some period, forwarding and possibly re-forwarding the bundle as appropriate and destroying that retained copy only when custody of that bundle is formally "released". Custody of a bundle may only be taken if the destination of the bundle is a singleton endpoint. A "custodial node" (or "custodian") of a bundle is a node that has taken custody of the bundle and has not yet released that custody. To "accept custody" upon receiving a bundle is to take custody of the bundle, mark the bundle in such a way as to indicate to nodes that subsequently receive the bundle that it has taken custody, and notify all current custodians of the bundle that it has taken custody. Custody may only be released when either (a) notification is received that some other node has accepted custody of the same bundle; (b) notification is received that the bundle has been delivered at the (sole) node registered in the bundle's destination endpoint; (c) the current custodian chooses to fragment the bundle, releasing custody of the original bundle and taking custody of the fragments instead, or (d) the bundle is explicitly deleted for some reason, such as lifetime expiration. To "refuse custody" of a bundle is to notify all current custodians of that bundle that an opportunity to take custody of the bundle has been declined.

The custody transfer mechanism in BP is primarily intended as a means of recovering from forwarding failures. When a bundle arrives at a node from which it cannot be forwarded, BP must recover from this error. BP can "return" the bundle back toward some node for forwarding along some different path in the network, or else it can instead send a small "signal" bundle back to such a node, in the event that this node has retained a copy of the bundle ("taken custody") and is therefore able to re-forward the bundle without receiving a copy. Custody transfer sharply reduces the network traffic required for recovery from forwarding failures, at the cost of increased buffer occupancy and state management at the custodial nodes.

Note that custodial re-forwarding can also be initiated by expiration of a timer prior to reception of a custody acceptance signal. Since the absence of a custody acceptance signal might be caused by failure to receive the bundle, rather than only a disinclination to take custody, custody transfer can additionally serve as an automated retransmission mechanism. Because custody transfer's only remedy for loss of any part of a bundle is

retransmission of the entire bundle (not just the lost portion), custody transfer is a less efficient automated retransmission mechanism than the reliable transport protocols that are typically available at the convergence layer; configuring BPAs to use reliable convergence-layer protocols between nodes is generally the best means of ensuring bundle delivery at the destination node(s). But there are some use cases (typically involving unidirectional links) in which custody transfer in BP may be a more cost-effective solution for reliable transmission between two BP agents than operating retransmission protocols at the convergence layer.

Embargo - Forwarding failures are not just operational anomalies; they may also convey information about the network, i.e., a forwarding failure may indicate a sustained lapse in forwarding capability. Since forwarding a bundle to a dead end wastes time and bandwidth, the bundle protocol agent may choose to manage such a lapse by imposing a temporary "embargo" on subsequent forwarding activity that is similar to the forwarding attempt that has been seen to fail. Mechanisms for motivating, imposing, enforcing, and lifting embargoes are beyond the scope of this document.

3.2. Implementation Architectures

The above definitions are intended to enable the bundle protocol's operations to be specified in a manner that minimizes bias toward any particular implementation architecture. To illustrate the range of interoperable implementation models that might conform to this specification, four example architectures are briefly described below.

3.2.1. Bundle protocol application server

A single bundle protocol application server, constituting a single bundle node, runs as a daemon process on each computer. The daemon's functionality includes all functions of the bundle protocol agent, all convergence layer adapters, and both the administrative and application-specific elements of the application agent. The application-specific element of the application agent functions as a server, offering bundle protocol service over a local area network: it responds to remote procedure calls from application processes (on the same computer and/or remote computers) that need to communicate via the bundle protocol. The server supports its clients by creating a new (conceptual) node for each one and registering each such node in a client-specified endpoint. The conceptual nodes managed by the server function as clients' bundle protocol service access points.

3.2.2. Peer application nodes

Any number of bundle protocol application processes, each one constituting a single bundle node, run on each computer. The functionality of the bundle protocol agent, all convergence layer adapters, and the administrative element of the application agent is provided by a library to which each node process is dynamically linked at run time. The application-specific element of each node's application agent is node-specific application code.

3.2.3. Sensor network nodes

Each node of the sensor network is the self-contained implementation of a single bundle node. All functions of the bundle protocol agent, all convergence layer adapters, and the administrative element of the application agent are implemented in simplified form in hardware, while the application-specific element of each node's application agent is implemented in a programmable microcontroller. Forwarding is rudimentary: all bundles are forwarded on a hard-coded default route.

3.2.4. Dedicated bundle router

Each computer constitutes a single bundle node that functions solely as a high-performance bundle forwarder. Many standard functions of the bundle protocol agent, the convergence layer adapters, and the administrative element of the application agent are implemented in specialized hardware, but some functions are implemented in a high-speed processor to enable reprogramming as necessary. The node's application agent has no application-specific element. Substantial non-volatile storage resources are provided, and arbitrarily complex forwarding algorithms are supported.

3.3. Services Offered by Bundle Protocol Agents

The BPA of each node is expected to provide the following services to the node's application agent:

- commencing a registration (registering the node in an endpoint);
- terminating a registration;
- switching a registration between Active and Passive states;
- transmitting a bundle to an identified bundle endpoint;
- canceling a transmission;
- polling a registration that is in the passive state;
- delivering a received bundle.

4. Bundle Format

Each bundle shall be a concatenated sequence of at least two block structures. The first block in the sequence must be a primary bundle block, and no bundle may have more than one primary bundle block. Additional bundle protocol blocks of other types may follow the primary block to support extensions to the bundle protocol, such as the Bundle Security Protocol [BSP]. Exactly one of the blocks in the sequence must be a payload block. The last block in the sequence must have the "last block" flag (in its block processing control flags) set to 1; for every other block in the bundle after the primary block, this flag must be set to zero.

4.1. Self-Delimiting Numeric Values (SDNVs)

The design of the bundle protocol attempts to reconcile minimal consumption of transmission bandwidth with:

- extensibility to address requirements not yet identified, and
- scalability across a wide range of network scales and payload sizes.

A key strategic element in the design is the use of self-delimiting numeric values (SDNVs). The SDNV encoding scheme is closely adapted from the Abstract Syntax Notation One Basic Encoding Rules for sub-identifiers within an object identifier value [ASN1]. An SDNV is a numeric value encoded in N octets, the last of which has its most significant bit (MSB) set to zero; the MSB of every other octet in the SDNV must be set to 1. The value encoded in an SDNV is the unsigned binary number obtained by concatenating into a single bit string the 7 least significant bits of each octet of the SDNV. The following examples illustrate the encoding scheme for various hexadecimal values.

0xABC : 1010 1011 1100

is encoded as

{1 00 10101} {0 0111100}

= 10010101 00111100

0x1234 : 0001 0010 0011 0100

= 1 0010 0011 0100

is encoded as

```
      {1 0 100100} {0 0110100}

      = 10100100 00110100

0x4234 : 0100 0010 0011 0100

      = 100 0010 0011 0100

      is encoded as

      {1 000000 1} {1 0000100} {0 0110100}

      = 10000001 10000100 00110100

0x7F : 0111 1111

      = 111 1111

      is encoded as

      {0 1111111}

      = 01111111
```

Figure 2: SDNV Example

Note: Care must be taken to make sure that the value to be encoded is (in concept) padded with high-order zero bits to make its bitwise length a multiple of 7 before encoding. Also note that, while there is no theoretical limit on the size of an SDNV field, the overhead of the SDNV scheme is 1:7, i.e., one bit of overhead for every 7 bits of actual data to be encoded. Thus, a 7-octet value (a 56-bit quantity with no leading zeroes) would be encoded in an 8-octet SDNV; an 8-octet value (a 64-bit quantity with no leading zeroes) would be encoded in a 10-octet SDNV (one octet containing the high-order bit of the value padded with six leading zero bits, followed by nine octets containing the remaining 63 bits of the value). 148 bits of overhead would be consumed in encoding a 1024-bit RSA encryption key directly in an SDNV. In general, an N-bit quantity with no leading zeroes is encoded in an SDNV occupying ceil(N/7) octets, where ceil is the integer ceiling function.

Implementations of the bundle protocol may handle as an invalid numeric value any SDNV that encodes an integer larger than (2^64 - 1).

An SDNV can be used to represent both very large and very small integer values. However, SDNV is clearly not the best way to represent every numeric value. For example, an SDNV is a poor way to represent an integer whose value typically falls in the range 128 to 255. In general, though, we believe that SDNV representation of numeric values in bundle blocks yields the smallest block sizes without sacrificing scalability.

4.2. Bundle Processing Control Flags

The bundle processing control flags field in the primary bundle block of each bundle is an SDNV; the value encoded in this SDNV is a string of bits used to invoke selected bundle processing control features. The significance of the value in each currently defined position of this bit string is described here. Note that in the figure and descriptions, the bit label numbers denote position (from least significant ('0') to most significant) within the decoded bit string, and not within the representation of the bits on the wire. This is why the descriptions in this section and the next do not follow standard RFC conventions with bit 0 on the left; if fields are added in the future, the SDNV will grow to the left, and using this representation allows the references here to remain valid.

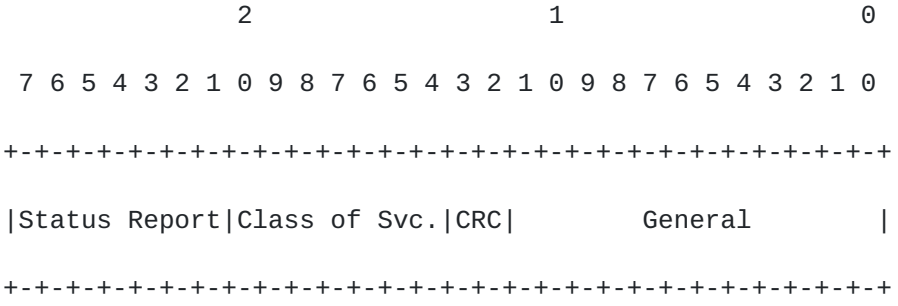


Figure 3: Bundle Processing Control Flags Bit Layout

The bits in positions 0 through 13 of the value of the bundle processing control flags SDNV are flags that characterize the bundle as follows:

0 -- Bundle is a fragment.

1 -- Payload is an administrative record.

2 -- Bundle must not be fragmented.

3 -- Custody transfer is requested.

4 -- Destination endpoint is a singleton.

5 -- Acknowledgement by application is requested.

6 -- Bundle is critical.

7 -- Best-efforts forwarding is requested.

8 -- Reliable forwarding is requested.

9-11 -- Reserved for future use.

The bits in positions 12 through 13 are used to indicate the type of CRC that is present at the end of the primary block. The options are:

0 -- No CRC.

1 -- CRC-8.

2 -- CRC-16.

3 -- CRC-32.

The bits in positions 14 through 20 are used to indicate the bundle's class of service. They constitute a seven-bit priority field indicating the bundle's priority, a value from 0 to 127, with higher values being of higher priority (greater urgency). Within this field, bit 20 is the most significant bit.

The bits in positions 21 through 27 are status report request flags. These flags are used to request status reports as follows:

21 -- Request reporting of bundle reception.

22 -- Request reporting of custody acceptance.

23 -- Request reporting of bundle forwarding.

24 -- Request reporting of bundle delivery.

25 -- Request reporting of bundle deletion.

26 -- Reserved for future use.

27 -- Reserved for future use.

If the bundle processing control flags indicate that the bundle's application data unit is an administrative record, then the custody transfer requested flag must be zero and all status report request flags must be zero. If the custody transfer requested flag is 1, then the source node requests that every receiving node accept custody of the bundle. If the bundle's source endpoint is the null endpoint (see below), then the bundle is not uniquely identifiable and all bundle protocol features that rely on bundle identity must therefore be disabled: the bundle's custody transfer requested flag must be zero, the "Bundle must not be fragmented" flag must be 1, and all status report request flags must be zero.

4.3. Block Processing Control Flags

The block processing control flags field in every block other than the primary bundle block is an SDNV; the value encoded in this SDNV is a string of bits used to invoke selected block processing control features. The significance of the values in all currently defined positions of this bit string, in order from least significant position in the decoded bit string (labeled '0') to most significant (labeled '6'), is described here.

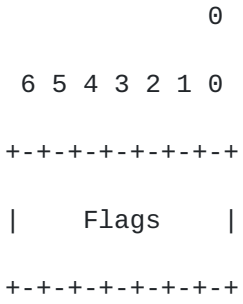


Figure 4: Block Processing Control Flags Bit Layout

0 - Block must be replicated in every fragment.

1 - Transmit status report if block can't be processed.

2 - Delete bundle if block can't be processed.

3 - Last block.

4 - Discard block if it can't be processed.

5 - Block was forwarded without being processed.

6 - Reserved for future use.

For each bundle whose primary block's bundle processing control flags (see above) indicate that the bundle's application data unit is an administrative record, the "Transmit status report if block can't be processed" flag in the block processing flags field of every other block in the bundle must be zero.

The 'Block must be replicated in every fragment' bit in the block processing flags must be set to zero on all blocks that follow the payload block.

4.4. Identifiers

4.4.1. Endpoint ID

The destinations of bundles are bundle endpoints, identified by text strings termed "endpoint IDs" (see Section 3.1). Each endpoint ID (EID) conveyed in any bundle block takes the form of a Uniform Resource Identifier (URI; [URI]). As such, each endpoint ID can be characterized as having this general structure:

< scheme name > : < scheme-specific part, or "SSP" >

The scheme identified by the < scheme name > in an endpoint ID is a set of syntactic and semantic rules that fully explain how to parse and interpret the SSP. The set of allowable schemes is effectively unlimited. Any scheme conforming to [URIREG] may be used in a bundle protocol endpoint ID.

As used for the purposes of the bundle protocol, the length of an SSP must not exceed 1023 bytes.

Note that, although endpoint IDs are URIs, implementations of the BP service interface may support expression of endpoint IDs in some internationalized manner (e.g., Internationalized Resource Identifiers (IRIs); see [RFC3987]).

The endpoint ID "dtn:none" identifies the "null endpoint", the endpoint that by definition never has any members.

Whenever an endpoint ID appears in a bundle block, it is encoded not in its native URI representation but rather in an encoded representation that reduces consumption of transmission bandwidth. The encoded representation of an endpoint ID is as follows:

. An SDNV identifying the scheme of the EID (as discussed below), followed by
. the encoded representation of the EID's scheme-specific part.

The encoded representation of the null endpoint ID is scheme identifier zero, followed by zero octets of scheme-specific part.

Every URI scheme used for forming any other EID is classified as either "numeric", meaning that all information conveyed in the scheme-specific part is to be encoded as a sequence of one or more unsigned integers in SDNV representation, or else "non-numeric" (otherwise). The scheme identifier numbers used in the encoded representations of EIDs are assigned as follows:

- Scheme identifier zero is reserved for the null endpoint ID.
- Scheme identifier numbers in the range 1-63 are used exclusively for numeric EID schemes.
- All other scheme identifier numbers are used exclusively for non-numeric EID schemes.

Note that scheme of the EID is numeric if and only if the scheme identifier is non-zero and the two high-order bits of the first octet of the scheme identifier are both zero.

For each numeric EID scheme, the encoded representation of the EID's scheme-specific part shall be a sequence of from 1 to 100 SDNVs as mandated by the definition of the scheme.

For each non-numeric EID scheme, the encoded representation of the EID's scheme-specific part shall comprise:

- a single SDNV indicating the length of the remainder of the encoded representation of the scheme-specific part of the EID, followed by
- the remainder of the encoded representation of the scheme-specific part of the EID, formed according to the definition of the scheme. If the scheme's definition does not include a specification for encoded representation, then the EID's native scheme-specific part appears here without alteration.

It is important to note that not all BP implementations are required to implement the definitions of all EID schemes. The BP implementations used to instantiate nodes in a given network must be chosen with care in order for every node to be able to exchange bundles with every other node.

4.4.2. Node ID

For many purposes of the Bundle Protocol it is important to identify the node that is operative in some context.

As discussed in 3.1 above, nodes are distinct from endpoints; specifically, an endpoint is a set of zero or more nodes. But rather than define a separate namespace for node identifiers, we instead use endpoint identifiers to identify nodes, subject to the following restrictions:

. Every node must be a member of at least one singleton endpoint.
. The EID of any singleton endpoint of which a node is a member may be used to identify that node. A "node ID" is an EID that is used in this way.
. A node's membership in a given singleton endpoint must be sustained at least until the nominal operation of the Bundle Protocol no longer depends on the identification of that node by that endpoint's ID.

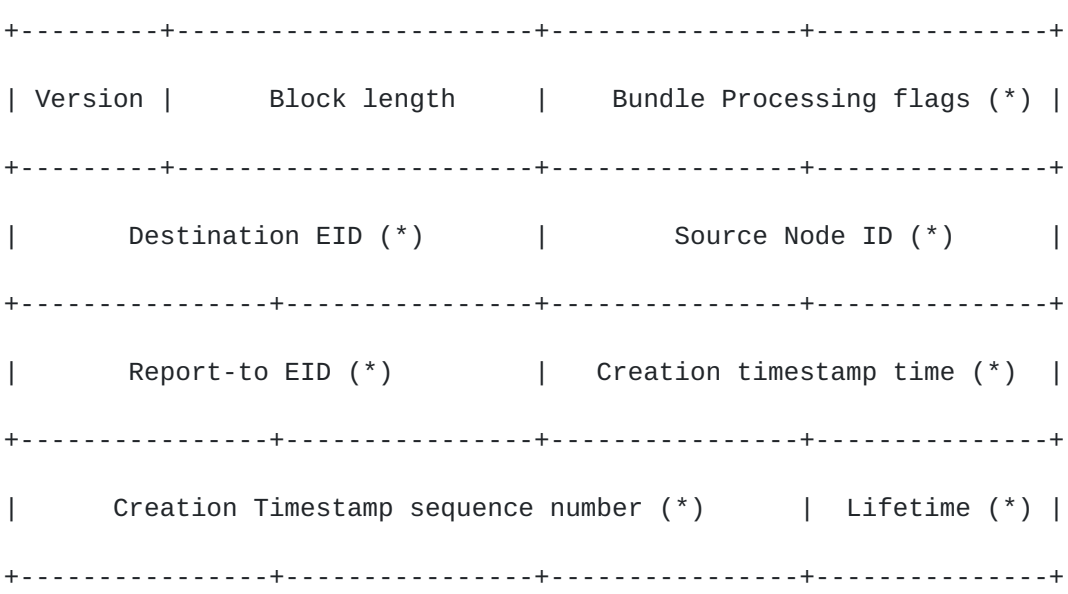
4.5. Formats of Bundle Blocks

This section describes the formats of the primary block and payload block. Rules for processing these blocks appear in Section 5 of this document.

Note that supplementary DTN protocol specifications (including, but not restricted to, the Bundle Security Protocol [BSP]) may require that BP implementations conforming to those protocols construct and process additional blocks.

The format of these two basic BP blocks is shown in Figure 5 below.

Primary Bundle Block



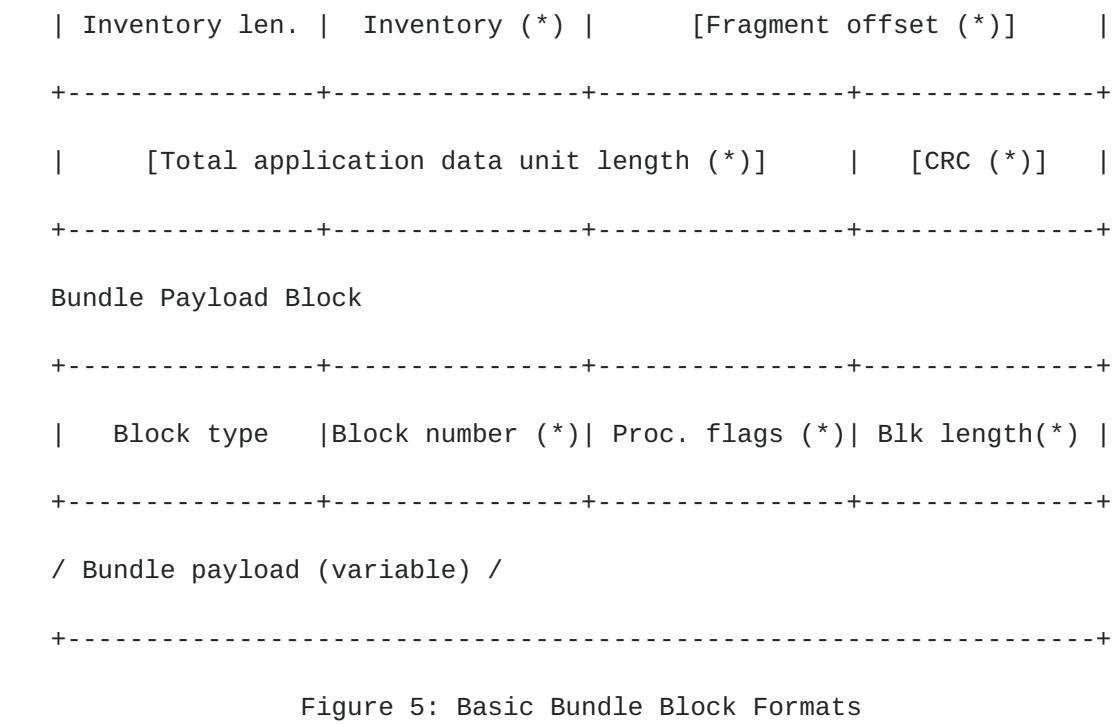


Figure 5: Basic Bundle Block Formats

(*) Notes:

The bundle processing control flags field in the Primary Bundle Block is an SDNV and is therefore of variable length. A two-octet SDNV is shown here for convenience in representation.

The destination EID, source node ID, and report-to EID in the Primary Bundle Block are EIDs in encoded representation and are therefore of variable length. Two-octet fields are shown here for convenience in representation.

The creation timestamp time in the Primary Bundle Block is an SDNV and is therefore of variable length. A two-octet SDNV is shown here for convenience in representation.

The creation timestamp sequence number field in the Primary Bundle Block is an SDNV and is therefore of variable length. A three-octet SDNV is shown here for convenience in representation.

The lifetime field in the Primary Bundle Block is an SDNV and is therefore of variable length. A one-octet SDNV is shown here for convenience in representation.

The inventory field in the Primary Bundle Block is an array of block types (one octet each) whose length is given by the value of the

Inventory Length field and is therefore variable. A one-octet inventory array is shown here for convenience in representation.

The fragment offset field of the Primary Bundle Block is present only if the Fragment flag in the block's processing flags field is set to 1. It is an SDNV and is therefore of variable length; a two-octet SDNV is shown here for convenience in representation.

The total application data unit length field of the Primary Bundle Block is present only if the Fragment flag in the block's processing flags field is set to 1. It is an SDNV and is therefore of variable length; a three-octet SDNV is shown here for convenience in representation.

The CRC field of the Primary Bundle Block is present only if the CRC type field in the block's processing flags field is non-zero. Its actual length depends on the CRC type; a one-octet CRC is shown here for convenience in representation.

The block processing control flags ("Proc. flags") field of the Payload Block is an SDNV and is therefore of variable length. A one-octet SDNV is shown here for convenience in representation.

The block length ("Blk length") field of the Payload Block is an SDNV and is therefore of variable length. A one-octet SDNV is shown here for convenience in representation.

4.5.1. Primary Bundle Block

The primary bundle block contains the basic information needed to forward bundles to their destinations. The fields of the primary bundle block are:

Version: A 4-bit field indicating the version of the bundle protocol that constructed this block. The present document describes version 0x07 of the bundle protocol.

Block Length: a 12-bit field that contains the aggregate length (in bytes) of all remaining fields of the primary block. Note that, although many fields of the primary bundle block are variable-length SDNVs, the lengths of all of these SDNVs are in practice limited; the lengths of the scheme-specific parts of non-numeric EIDs are likewise limited. These limitations make it reasonable to limit the total length of the primary block to 4095 octets.

Bundle Processing Control Flags: The Bundle Processing Control Flags field is an SDNV that contains the bundle processing control flags discussed in Section 4.2 above.

Destination EID: The Destination EID field contains the encoded representation of the endpoint ID of the bundle's destination, i.e., the endpoint containing the node(s) at which the bundle is to be delivered.

Source node ID: The Source node ID field contains the encoded representation of an endpoint ID that identifies the node from which the bundle was initially transmitted, except that it may contain the null endpoint ID in the event that the bundle's source chooses to remain anonymous.

Report-to EID: The Report-to EID field contains the encoded representation of the ID of the endpoint to which status reports pertaining to the forwarding and delivery of this bundle are to be transmitted.

Creation Timestamp: The creation timestamp is a pair of SDNVs that, together with the source node ID and (if the bundle is a fragment) the fragment offset and payload length, serve to identify the bundle. The first SDNV of the timestamp is the bundle's creation time, while the second is the bundle's creation timestamp sequence number. Bundle creation time is the time -- expressed in seconds since the start of the year 2000, on the Coordinated Universal Time (UTC) scale [UTC] -- at which the transmission request was received that resulted in the creation of the bundle. Sequence count is the latest value (as of the time at which that transmission request was received) of a monotonically increasing positive integer counter managed by the source node's bundle protocol agent that may be reset to zero whenever the current time advances by one second. For nodes that lack accurate clocks (that is, nodes that are not at all moments able to determine the current UTC time to within 30 seconds), bundle creation time MUST be set to zero and the counter used as the source of the bundle sequence count MUST NEVER be reset to zero. In either case, a source Bundle Protocol Agent must never create two distinct bundles with the same source node ID and bundle creation timestamp. The combination of source node ID and bundle creation timestamp serves to identify a single transmission request, enabling it to be acknowledged by the receiving application (provided the source node ID is not the null endpoint ID).

Lifetime: The lifetime field is an SDNV that indicates the time at which the bundle's payload will no longer be useful, encoded as a number of seconds past the creation time. When bundle's age exceeds

its lifetime, bundle nodes need no longer retain or forward the bundle; the bundle SHOULD be deleted from the network.

Inventory: The Primary block may contain an accounting of all blocks that were in the bundle at the time it was transmitted from the source node. This accounting comprises an inventory list length (an SDNV) followed by an inventory list (an array of N octets, where N is the value of the inventory list length). This feature is optional: if the inventory is to be omitted, the inventory length must be set to zero. Otherwise the values of the octets in the inventory list must be the block types of all of the non-primary blocks in the bundle as originally transmitted, exactly one list element per block. Since a bundle may contain multiple instances of a given block type, multiple elements of the inventory list may have the same value. The order of block types appearing in the inventory list is undefined.

Fragment Offset: If the Bundle Processing Control Flags of this Primary block indicate that the bundle is a fragment, then the Fragment Offset field is an SDNV indicating the offset from the start of the original application data unit at which the bytes comprising the payload of this bundle were located. If not, then the Fragment Offset field is omitted from the block.

Total Application Data Unit Length: If the Bundle Processing Control Flags of this Primary block indicate that the bundle is a fragment, then the Total Application Data Unit Length field is an SDNV indicating the total length of the original application data unit of which this bundle's payload is a part. If not, then the Total Application Data Unit Length field is omitted from the block.

CRC: If and only if the CRC type in the Bundle Processing Control Flags of this Primary block is non-zero, a CRC is appended to the primary block. The length of the CRC is 8 bits, 16 bits, or 32 bits as indicated by the CRC type. The CRC is computed over the concatenation of all bytes of the primary block including the CRC field itself, which for this purpose is temporarily populated with the value zero.

4.5.2. Canonical Bundle Block Format

Every bundle block of every type other than the primary bundle block comprises the following fields, in this order:

. Block type code, expressed as an 8-bit unsigned binary integer. Bundle block type code 1 indicates that the block is a bundle payload block. Block type codes 2 through 10 are defined as

noted later in this specification. Block type codes 192 through 255 are not defined in this specification and are available for private and/or experimental use. All other values of the block type code are reserved for future use.

. Block number, an unsigned integer expressed as an SDNV. The block number uniquely identifies the block within the bundle, enabling blocks (notably bundle security protocol blocks) to explicitly reference other blocks in the same bundle. Block numbers need not be in continuous sequence, and blocks need not appear in block number sequence in the bundle. The block number of the payload block is always zero.

. Block processing control flags, an unsigned integer expressed as an SDNV. The individual bits of this integer are used to invoke selected block processing control features.

. Block data length, an unsigned integer expressed as an SDNV. The Block data length field contains the aggregate length of all remaining fields of the block, i.e., the block-type-specific data fields.

. Block-type-specific data fields, whose format and order are type-specific and whose aggregate length in octets is the value of the block data length field. All multi-byte block-type-specific data fields are represented in network byte order.

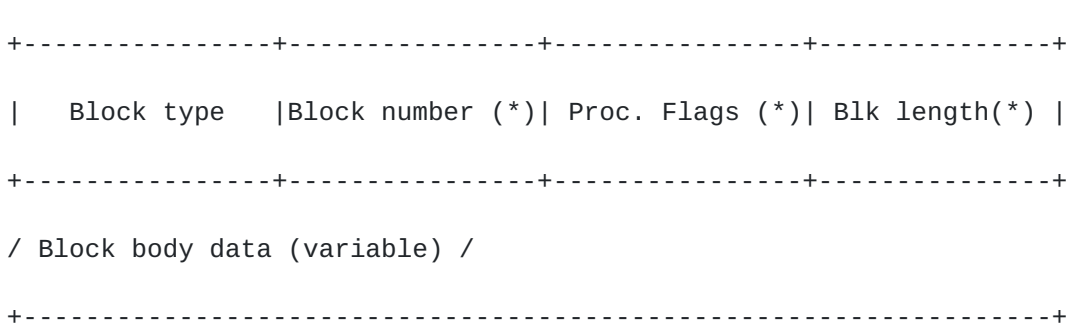


Figure 6: Block Layout

4.5.3. Bundle Payload Block

The fields of the bundle payload block are:

Block Type: The Block Type field is a 1-byte field that indicates the type of the block. For the bundle payload block, this field contains the value 1.

Block Number: The Block Number field is an SDNV that contains the unique identifying number of the block. The block number of the bundle payload block is always zero.

Block Processing Control Flags: The Block Processing Control Flags field is an SDNV that contains the block processing control flags discussed in Section 4.3 above.

Block Data Length: The Block Data Length field is an SDNV that contains the aggregate length of all remaining fields of the Payload block - which is to say, the length of the bundle's payload.

Block-type-specific Data: The Block-type-specific Data field of the Payload Block contains the "payload", i.e., the application data carried by this bundle.

That is, bundle payload blocks conform to the canonical format described in the previous section.

4.6. Extension Blocks

"Extension blocks" are all blocks other than the primary and payload blocks. Because not all extension blocks are defined in the Bundle Protocol specification (the present document), not all nodes conforming to this specification will necessarily instantiate Bundle Protocol implementations that include procedures for processing (that is, recognizing, parsing, acting on, and/or producing) all extension blocks. It is therefore possible for a node to receive a bundle that includes extension blocks that the node cannot process.

Whenever a bundle is forwarded that contains one or more extension blocks that could not be processed, the "Block was forwarded without being processed" flag must be set to 1 within the block processing flags of each such block. For each block flagged in this way, the flag may optionally be cleared (i.e., set to zero) by another node that subsequently receives the bundle and is able to process that block; the specifications defining the various extension blocks are expected to define the circumstances under which this flag may be cleared, if any.

The extension blocks of the Bundle Security Protocol (block types 2, 3, and 4) are defined separately in the Bundle Security Protocol specification (work in progress).

The following extension blocks are defined in the current document.

4.6.1. Current Custodian

The Current Custodian block, block type 5, identifies a node that is known to have accepted custody of the bundle. The block-type-specific data of this block is the encoded representation of the

node ID of a custodian. The bundle MAY contain one or more occurrences of this type of block.

4.6.2. Flow Label

The Flow Label block, block type 6, indicates the flow label that is intended to govern transmission of the bundle by convergence-layer adapters. The syntax and semantics of BP flow labels are beyond the scope of this document.

4.6.3. Previous Node ID

The Previous Node ID block, block type 7, identifies the node that forwarded this bundle to the local node; its block-type-specific data is the encoded representation of the node ID of that node. If the local node is the source of the bundle, then the bundle MUST NOT contain any Previous Node ID block. Otherwise the bundle MUST contain one (1) occurrence of this type of block. If present, the Previous Node ID block MUST be the FIRST block following the primary block, as the processing of other extension blocks may depend on its value.

4.6.4. Bundle Age

The Bundle Age block, block type 9, contains the number of seconds that have elapsed between the time the bundle was created and time at which it was most recently forwarded. It is intended for use by nodes lacking access to an accurate clock, to aid in determining the time at which a bundle's lifetime expires. The block-type-specific data of this block is an SDNV containing the age of the bundle (the sum of all known intervals of the bundle's residence at forwarding nodes, up to the time at which the bundle was most recently forwarded) in seconds. If the bundle's creation time is zero, then the bundle MUST contain exactly one (1) occurrence of this type of block; otherwise, the bundle MAY contain at most one (1) occurrence of this type of block.

4.6.5. Hop Count

The Hop Count block, block type 10, contains two SDNVs, hop limit and hop count, in that order. It is mainly intended as a safety mechanism, a means of identifying bundles for removal from the network that can never be delivered due to a persistent forwarding error: a bundle may be deleted when its hop count exceeds its hop limit. Procedures for determining the appropriate hop limit for a block are beyond the scope of this specification. A bundle MAY contain at most one (1) occurrence of this type of block.

5. Bundle Processing

The bundle processing procedures mandated in this section and in Section 6 govern the operation of the Bundle Protocol Agent and the Application Agent administrative element of each bundle node. They are neither exhaustive nor exclusive. That is, supplementary DTN protocol specifications (including, but not restricted to, the Bundle Security Protocol [BSP]) may require that additional measures be taken at specified junctures in these procedures. Such additional measures shall not override or supersede the mandated bundle protocol procedures, except that they may in some cases make these procedures moot by requiring, for example, that implementations conforming to the supplementary protocol terminate the processing of a given incoming or outgoing bundle due to a fault condition recognized by that protocol.

5.1. Generation of Administrative Records

All transmission of bundles is in response to bundle transmission requests presented by nodes' application agents. When required to "generate" an administrative record (such as a bundle status report or a custody signal), the bundle protocol agent itself is responsible for causing a new bundle to be transmitted, conveying that record. In concept, the bundle protocol agent discharges this responsibility by directing the administrative element of the node's application agent to construct the record and request its transmission as detailed in Section 6 below. In practice, the manner in which administrative record generation is accomplished is an implementation matter, provided the constraints noted in Section 6 are observed.

Under some circumstances, the requesting of status reports could result in an unacceptable increase in the bundle traffic in the network. For this reason, the generation of status reports is mandatory only in one case, the deletion of a bundle for which custody transfer is requested. In all other cases, the decision on whether or not to generate a requested status report is left to the discretion of the bundle protocol agent. Mechanisms that could assist in making such decisions, such as pre-placed agreements authorizing the generation of status reports under specified circumstances, are beyond the scope of this specification.

Notes on administrative record terminology:

. A "bundle reception status report" is a bundle status report with the "reporting node received bundle" flag set to 1.

- A "custody acceptance status report" is a bundle status report with the "reporting node accepted custody of bundle" flag set to 1.
- A "bundle forwarding status report" is a bundle status report with the "reporting node forwarded the bundle" flag set to 1.
- A "bundle delivery status report" is a bundle status report with the "reporting node delivered the bundle" flag set to 1.
- A "bundle deletion status report" is a bundle status report with the "reporting node deleted the bundle" flag set to 1.
- A "Succeeded" custody signal is a custody signal with the "custody transfer succeeded" flag set to 1.
- A "Failed" custody signal is a custody signal with the "custody transfer succeeded" flag set to zero.
- A "current custodian" of a bundle is a node identified in a Current Custodian extension block of that bundle.

5.2. Bundle Transmission

The steps in processing a bundle transmission request are:

Step 1: If custody transfer is requested for this bundle transmission then the destination must be a singleton endpoint. If, moreover, custody acceptance by the source node is required but the conditions under which custody of the bundle may be accepted are not satisfied, then the request cannot be honored and all remaining steps of this procedure must be skipped.

Step 2: Transmission of the bundle is initiated. An outbound bundle must be created per the parameters of the bundle transmission request, with the retention constraint "Dispatch pending". The source node ID of the bundle must be either the EID of a singleton endpoint whose only member is the node of which the BPA is a component or else the null endpoint ID, indicating that the source of the bundle is anonymous.

Step 3: Processing proceeds from Step 1 of Section 5.4.

5.3. Bundle Dispatching

The steps in dispatching a bundle are:

Step 1: If the bundle's destination endpoint is an endpoint of which the node is a member, the bundle delivery procedure defined in Section 5.7 must be followed.

Step 2: Processing proceeds from Step 1 of Section 5.4.

5.4. Bundle Forwarding

The steps in forwarding a bundle are:

Step 1: The retention constraint "Forward pending" must be added to the bundle, and the bundle's "Dispatch pending" retention constraint must be removed.

Step 2: The bundle protocol agent must determine whether or not forwarding is contraindicated for any of the reasons listed in Figure 12. In particular:

. The bundle protocol agent must determine which node(s) to forward the bundle to. The bundle protocol agent may choose either to forward the bundle directly to its destination node(s) (if possible) or to forward the bundle to some other node(s) for further forwarding. The manner in which this decision is made may depend on the scheme name in the destination endpoint ID and/or other state but in any case is beyond the scope of this document. If the BPA elects to forward the bundle to some other node(s) for further forwarding:
  - If the "Bundle is critical" flag (in the bundle processing flags) is set to 1, then ALL nodes that have some plausible prospect of forwarding the bundle to its destination node(s) SHOULD be selected for this purpose.
  - If the agent finds it impossible to select any node(s) to forward the bundle to, then forwarding is contraindicated.
. Provided the bundle protocol agent succeeded in selecting the node(s) to forward the bundle to, the bundle protocol agent must select the convergence layer adapter(s) whose services will enable the node to send the bundle to those nodes. If both the "Best-efforts forwarding requested" and the "Reliable forwarding is requested" bundle processing flags are set to 1, then all selected CLAs MUST be for bundle streaming CL protocols such as the proposed Bundle Streaming Service Protocol. Otherwise, if only the "Reliable forwarding is requested" bundle processing flag is set to 1, then all selected CLAs MUST be for reliable protocols such as TCP/IP. Otherwise, if only the "Best-efforts forwarding requested" bundle processing flag is set to 1, then all selected CLAs MUST be for best-efforts protocols such as UDP/IP. Otherwise, any available CLAs may be selected. The manner in which specific appropriate convergence layer adapters are selected is beyond the scope of this document. If the agent finds it impossible to select appropriate convergence layer adapters to use in forwarding this bundle, then forwarding is contraindicated.

Step 3: If forwarding of the bundle is determined to be contraindicated for any of the reasons listed in Figure 12, then the Forwarding Contraindicated procedure defined in Section 5.4.1 must be followed; the remaining steps of Section 5 are skipped at this time.

Step 4: If the bundle's custody transfer requested flag (in the bundle processing flags field) is set to 1, then the custody transfer procedure defined in Section 5.10.2 must be followed.

Step 5: For each node selected for forwarding, the bundle protocol agent must invoke the services of the selected convergence layer adapter(s) in order to effect the sending of the bundle to that node. Determining the time at which the bundle is to be sent by each convergence layer adapter is an implementation matter. Note that:

- The order in which convergence layer adapters send bundles SHOULD normally conform to the priority indicated in each bundle's bundle processing control flags field: all bundles of priority 255 sent from any single source should be sent before all bundles of priority 254 sent from the same source and so on.
- But if the bundle contains a flow label extension block then that flow label value may identify overriding procedures for determining the order in which convergence layer adapters must send bundles, e.g., considering bundle source when determining the order in which bundles are sent. The definition of such procedures is beyond the scope of this specification.
- If the bundle has a bundle age block, then at the last possible moment before the CLA initiates conveyance of the bundle node via the CL protocol the bundle age value MUST be increased by the difference between the current time and the time at which the bundle was received (or, if the local node is the source of the bundle, created).

Step 6: When all selected convergence layer adapters have informed the bundle protocol agent that they have concluded their data sending procedures with regard to this bundle:

- If the "request reporting of bundle forwarding" flag in the bundle's status report request field is set to 1, then a bundle forwarding status report should be generated, destined for the bundle's report-to endpoint ID. If the bundle has the retention constraint "custody accepted" and all of the nodes to which the bundle was forwarded are known to be unable to send bundles back to this node, then the reason code on this bundle forwarding status report must be "forwarded over unidirectional

link"; otherwise, the reason code must be "no additional information".

. The bundle's "Forward pending" retention constraint must be removed.

5.4.1. Forwarding Contraindicated

The steps in responding to contraindication of forwarding for some reason are:

Step 1: The bundle protocol agent must determine whether or not to declare failure in forwarding the bundle for this reason. Note: this decision is likely to be influenced by the reason for which forwarding is contraindicated.

Step 2: If forwarding failure is declared, then the Forwarding Failed procedure defined in Section 5.4.2 MUST be followed.

Otherwise, (a) if the bundle's custody transfer requested flag (in the bundle processing flags field) is set to 1, then the custody transfer procedure defined in Section 5.10 MUST be followed; (b) when -- at some future time - the forwarding of this bundle ceases to be contraindicated, processing proceeds from Step 5 of Section 5.4.

5.4.2. Forwarding Failed

The steps in responding to a declaration of forwarding failure for some reason are:

Step 1: If the bundle's custody transfer requested flag (in the bundle processing flags field) is set to 1, custody transfer failure must be handled. The bundle protocol agent MUST handle the custody transfer failure by generating a "Failed" custody signal for the bundle, destined for the bundle's current custodian(s); the custody signal must contain a reason code corresponding to the reason for which forwarding was determined to be contraindicated. (Note that discarding the bundle will not delete it from the network, since each current custodian still has a copy.)

If the bundle's custody transfer requested flag (in the bundle processing flags field) is set to 0, then the bundle protocol agent MAY forward the bundle back to the node that sent it, as identified by the Previous Node ID block.

Step 2: If the bundle's destination endpoint is an endpoint of which the node is a member, then the bundle's "Forward pending" retention

constraint must be removed. Otherwise, the bundle must be deleted: the bundle deletion procedure defined in Section 5.13 must be followed, citing the reason for which forwarding was determined to be contraindicated.

5.5. Bundle Expiration

A bundle expires when the bundle's age exceeds its lifetime as specified in the primary bundle block. Bundle age MAY be determined by subtracting the bundle's creation timestamp time from the current time if (a) that timestamp time is not zero and (b) the local node's clock is known to be accurate (as discussed in section 4.5.1 above); otherwise bundle age MUST be obtained from the Bundle Age extension block. Bundle expiration MAY occur at any point in the processing of a bundle. When a bundle expires, the bundle protocol agent MUST delete the bundle for the reason "lifetime expired": the bundle deletion procedure defined in Section 5.13 MUST be followed.

5.6. Bundle Reception

The steps in processing a bundle received from another node are:

Step 1: The retention constraint "Dispatch pending" must be added to the bundle.

Step 2: If the "request reporting of bundle reception" flag in the bundle's status report request field is set to 1, then a bundle reception status report with reason code "No additional information" should be generated, destined for the bundle's report-to endpoint ID.

Step 3: For each block in the bundle that is an extension block that the bundle protocol agent cannot process:

- If the block processing flags in that block indicate that a status report is requested in this event, then a bundle reception status report with reason code "Block unintelligible" should be generated, destined for the bundle's report-to endpoint ID.
- If the block processing flags in that block indicate that the bundle must be deleted in this event, then the bundle protocol agent must delete the bundle for the reason "Block unintelligible"; the bundle deletion procedure defined in Section 5.13 must be followed and all remaining steps of the bundle reception procedure must be skipped.
- If the block processing flags in that block do NOT indicate that the bundle must be deleted in this event but do indicate

that the block must be discarded, then the bundle protocol agent must remove this block from the bundle.

. If the block processing flags in that block indicate NEITHER that the bundle must be deleted NOR that the block must be discarded, then the bundle protocol agent must set to 1 the "Block was forwarded without being processed" flag in the block processing flags of the block.

Step 4: If the bundle's custody transfer requested flag (in the bundle processing flags field) is set to 1 and the bundle has the same source node ID, creation timestamp, and (if the bundle is a fragment) fragment offset and payload length as another bundle that (a) has not been discarded and (b) currently has the retention constraint "Custody accepted", custody transfer redundancy must be handled. Otherwise, processing proceeds from Step 5. The bundle protocol agent must handle custody transfer redundancy by generating a "Failed" custody signal for this bundle with reason code "Redundant reception", destined for this bundle's current custodian, and removing this bundle's "Dispatch pending" retention constraint.

Step 5: Processing proceeds from Step 1 of Section 5.3.

5.7. Local Bundle Delivery

The steps in processing a bundle that is destined for an endpoint of which this node is a member are:

Step 1: If the received bundle is a fragment, the application data unit reassembly procedure described in Section 5.9 must be followed. If this procedure results in reassembly of the entire original application data unit, processing of this bundle (whose fragmentary payload has been replaced by the reassembled application data unit) proceeds from Step 2; otherwise, the retention constraint "Reassembly pending" must be added to the bundle and all remaining steps of this procedure must be skipped.

Step 2: Delivery depends on the state of the registration whose endpoint ID matches that of the destination of the bundle:

. If the registration is in the Active state, then the bundle must be delivered subject to this registration (see Section 3.1 above) as soon as all previously received bundles that are deliverable subject to this registration have been delivered.

. If the registration is in the Passive state, then the registration's delivery failure action must be taken (see Section 3.1 above).

Step 3: As soon as the bundle has been delivered:

- If the "request reporting of bundle delivery" flag in the bundle's status report request field is set to 1, then a bundle delivery status report should be generated, destined for the bundle's report-to endpoint ID. Note that this status report only states that the payload has been delivered to the application agent, not that the application agent has processed that payload.
- If the bundle's custody transfer requested flag (in the bundle processing flags field) is set to 1, custodial delivery must be reported. The bundle protocol agent must report custodial delivery by generating a "Succeeded" custody signal for the bundle, destined for the bundle's current custodian(s).

5.8. Bundle Fragmentation

It may at times be advantageous for bundle protocol agents to reduce the sizes of bundles in order to forward them. This might be the case, for example, if a node to which a bundle is to be forwarded is accessible only via intermittent contacts and no upcoming contact is long enough to enable the forwarding of the entire bundle.

The size of a bundle can be reduced by "fragmenting" the bundle. To fragment a bundle whose payload is of size M is to replace it with two "fragments" -- new bundles with the same source node ID and creation timestamp as the original bundle -- whose payloads are the first N and the last (M - N) bytes of the original bundle's payload, where 0 < N < M. Note that fragments may themselves be fragmented, so fragmentation may in effect replace the original bundle with more than two fragments. (However, there is only one 'level' of fragmentation, as in IP fragmentation.)

Any bundle that has any Current Custodian extension block citing any node other than the local node MUST NOT be fragmented. This restriction aside, any bundle whose primary block's bundle processing flags do NOT indicate that it must not be fragmented may be fragmented at any time, for any purpose, at the discretion of the bundle protocol agent.

Fragmentation shall be constrained as follows:

- The concatenation of the payloads of all fragments produced by fragmentation must always be identical to the payload of the bundle that was fragmented. Note that the payloads of fragments resulting from different fragmentation episodes, in different

parts of the network, may be overlapping subsets of the original bundle's payload.

. The bundle processing flags in the primary block of each fragment must differ from those of the bundle that is being fragmented, in that they must indicate that the bundle is a fragment, and both fragment offset and total application data unit length must be provided at the end of each fragment's primary bundle block. Additionally, the CRC of the bundle that is being fragmented, if any, must be replaced in each fragment by a new CRC computed for the primary block of that fragment.
. The primary blocks of the fragments will differ from that of the fragmented bundle as noted above.
. The payload blocks of fragments will differ from that of the fragmented bundle as noted above.
. If the bundle being fragmented is not a fragment or is the fragment with offset zero, then all extension blocks of the bundle being fragmented MUST be replicated in the fragment whose offset is zero.
. Each extension block whose "Block must be replicated in every fragment" flag, in the block processing flags, is set to 1 MUST be replicated in every fragment.
. Beyond these rules, replication of extension blocks in the fragments is an implementation matter.
. If the local node had taken custody of the fragmented bundle, then the BPA MUST release custody of the fragmented bundle before fragmentation occurs and MUST take custody of every fragment.

5.9. Application Data Unit Reassembly

If the concatenation -- as informed by fragment offsets and payload lengths -- of the payloads of all previously received fragments with the same source node ID and creation timestamp as this fragment, together with the payload of this fragment, forms a byte array whose length is equal to the total application data unit length in the fragment's primary block, then:

. This byte array -- the reassembled application data unit -- must replace the payload of this fragment.
. For each fragmentary bundle whose payload is a subset of the reassembled application data unit, for which custody transfer is requested but the BPA has not yet taken custody, the BPA must take custody of that bundle.
. The BPA must then release custody of all fragments whose payload is a subset of the reassembled application data unit, for which it has taken custody.

. The "Reassembly pending" retention constraint must be removed from every other fragment whose payload is a subset of the reassembled application data unit.

Note: reassembly of application data units from fragments occurs at the nodes that are members of destination endpoints as necessary; an application data unit may also be reassembled at some other node on the path to the destination.

5.10. Custody Transfer

The decision as to whether or not to accept custody of a bundle is an implementation matter that may involve both resource and policy considerations.

If the bundle protocol agent elects to accept custody of the bundle, then it must follow the custody acceptance procedure defined in Section 5.10.1.

5.10.1. Custody Acceptance

Procedures for acceptance of custody of a bundle are defined as follows.

The retention constraint "Custody accepted" must be added to the bundle.

If the "request reporting of custody acceptance" flag in the bundle's status report request field is set to 1, a custody acceptance status report should be generated, destined for the report-to endpoint ID of the bundle. However, if a bundle reception status report was generated for this bundle (Step 1 of Section 5.6), then this report SHOULD be generated by simply turning on the "Reporting node accepted custody of bundle" flag in that earlier report's status flags byte.

The bundle protocol agent must generate a "Succeeded" custody signal for the bundle, destined for the bundle's current custodian(s).

The bundle protocol agent must assert the new current custodian for the bundle. It does so by inserting a new Current Custodian extension block whose value is the node ID of the local node or by changing the value of an existing Current Custodian extension block to the local node ID.

The bundle protocol agent may set a custody transfer countdown timer for this bundle; upon expiration of this timer prior to expiration

of the bundle itself and prior to custody transfer success for this bundle, the custody transfer failure procedure detailed in Section 5.12 may be followed. The manner in which the countdown interval for such a timer is determined is an implementation matter.

The bundle should be retained in persistent storage if possible.

5.10.2. Custody Release

When custody of a bundle is released, the "Custody accepted" retention constraint must be removed from the bundle and any custody transfer timer that has been established for this bundle should be destroyed.

5.11. Custody Transfer Success

Upon receipt of a "Succeeded" custody signal at a node that is a custodial node of the bundle identified in the custody signal, custody of the bundle must be released as described in Section 5.10.2.

5.12. Custody Transfer Failure

Custody transfer is determined to have failed at a custodial node for that bundle when either (a) that node's custody transfer timer for that bundle (if any) expires or (b) a "Failed" custody signal for that bundle is received at that node.

Upon determination of custody transfer failure, the action taken by the bundle protocol agent is implementation-specific and may depend on the nature of the failure. For example, if custody transfer failure was inferred from expiration of a custody transfer timer or was asserted by a "Failed" custody signal with the "Depleted storage" reason code, the bundle protocol agent might choose to re-forward the bundle, possibly on a different route (Section 5.4). Receipt of a "Failed" custody signal with the "Redundant reception" reason code, on the other hand, might cause the bundle protocol agent to release custody of the bundle and to revise its algorithm for computing countdown intervals for custody transfer timers.

5.13. Bundle Deletion

The steps in deleting a bundle are:

Step 1: If the retention constraint "Custody accepted" currently prevents this bundle from being discarded, then:

. Custody of the node is released as described in Section 5.10.2.
. A bundle deletion status report citing the reason for deletion must be generated, destined for the bundle's report-to endpoint ID.

Otherwise, if the "request reporting of bundle deletion" flag in the bundle's status report request field is set to 1, then a bundle deletion status report citing the reason for deletion should be generated, destined for the bundle's report-to endpoint ID.

Step 2: All of the bundle's retention constraints must be removed.

5.14. Discarding a Bundle

As soon as a bundle has no remaining retention constraints it may be discarded.

5.15. Canceling a Transmission

When requested to cancel a specified transmission, where the bundle created upon initiation of the indicated transmission has not yet been discarded, the bundle protocol agent must delete that bundle for the reason "transmission cancelled". For this purpose, the procedure defined in Section 5.13 must be followed.

6. Administrative Record Processing

6.1. Administrative Records

Administrative records are standard application data units that are used in providing some of the features of the Bundle Protocol. Two types of administrative records have been defined to date: bundle status reports and custody signals. Note that additional types of administrative records may be defined by supplementary DTN protocol specification documents.

Every administrative record consists of a five-bit record type code followed by three bits of administrative record flags, followed by record content in type-specific format. Record type codes are defined as follows:

Value	Meaning

00001	Bundle status report.
00010	Custody signal.
(other)	Reserved for future use.

Figure 8: Administrative Record Type Codes

Value	Meaning
0001	Record is for a fragment; fragment offset and length fields are present.
(other)	Reserved for future use.

Figure 9: Administrative Record Flags

The contents of the two types of administrative records defined in the present document are described below.

6.1.1. Bundle Status Reports

The transmission of 'bundle status reports' under specified conditions is an option that can be invoked when transmission of a bundle is requested. These reports are intended to provide information about how bundles are progressing through the system, including notices of receipt, custody transfer, forwarding, final delivery, and deletion. They are transmitted to the Report-to endpoints of bundles.

Status Flags	Reason code	Fragment offset (*) (if present)	Fragment length (*) (if present)
Source node ID of bundle X (*)			
Copy of bundle X's Creation Timestamp time (*)			
Copy of bundle X's Creation Timestamp sequence number (*)			

Figure 10: Bundle Status Report Format

(*) Notes:

The Fragment Offset field, if present, is an SDNV and is therefore variable length. A three-octet SDNV is shown here for convenience in representation.

The Fragment Length field, if present, is an SDNV and is therefore variable length. A three-octet SDNV is shown here for convenience in representation.

The Source Node ID and Creation Timestamp fields replicate the Source Node ID and Creation Timestamp fields in the primary block of the subject bundle. As such they are of variable length. Four-octet values are shown here for convenience in representation.

The fields in a bundle status report are:

Status Flags: A 1-byte field containing the following flags:

Value	Meaning

00000001	Reporting node received bundle.
00000010	Reporting node accepted custody of bundle.
00000100	Reporting node forwarded the bundle.
00001000	Reporting node delivered the bundle.
00010000	Reporting node deleted the bundle.
00100000	Unused.
01000000	Unused.
10000000	Unused.

Figure 11: Status Flags for Bundle Status Reports

Reason Code: A 1-byte field explaining the value of the flags in the status flags byte. The list of status report reason codes provided here is neither exhaustive nor exclusive; supplementary DTN protocol specifications (including, but not restricted to, the Bundle Security Protocol [BSP]) may define additional reason codes. Status report reason codes are defined as follows:

Value	Meaning

0x00	No additional information.
0x01	Lifetime expired.
0x02	Forwarded over unidirectional link.
0x03	Transmission canceled.
0x04	Depleted storage.
0x05	Destination endpoint ID unintelligible.
0x06	No known route to destination from here.
0x07	No timely contact with next node on route.
0x08	Block unintelligible.
(other)	Reserved for future use.

Figure 12: Status Report Reason Codes

Fragment Offset: If the bundle fragment bit is set in the status flags, then the offset (within the original application data unit) of the payload of the bundle that caused the status report to be generated is included here.

Fragment length: If the bundle fragment bit is set in the status flags, then the length of the payload of the subject bundle is included here.

Source Node ID of Subject Bundle: The source node ID of the bundle that caused the status report to be generated.

Creation Timestamp of Subject Bundle: A copy of the creation timestamp of the bundle that caused the status report to be generated.

6.1.2. Custody Signals

Custody signals are administrative records that effect custody transfer operations. They are transmitted to the nodes that are the current custodians of bundles.

Custody signals have the following format.

Custody signal regarding bundle 'X':

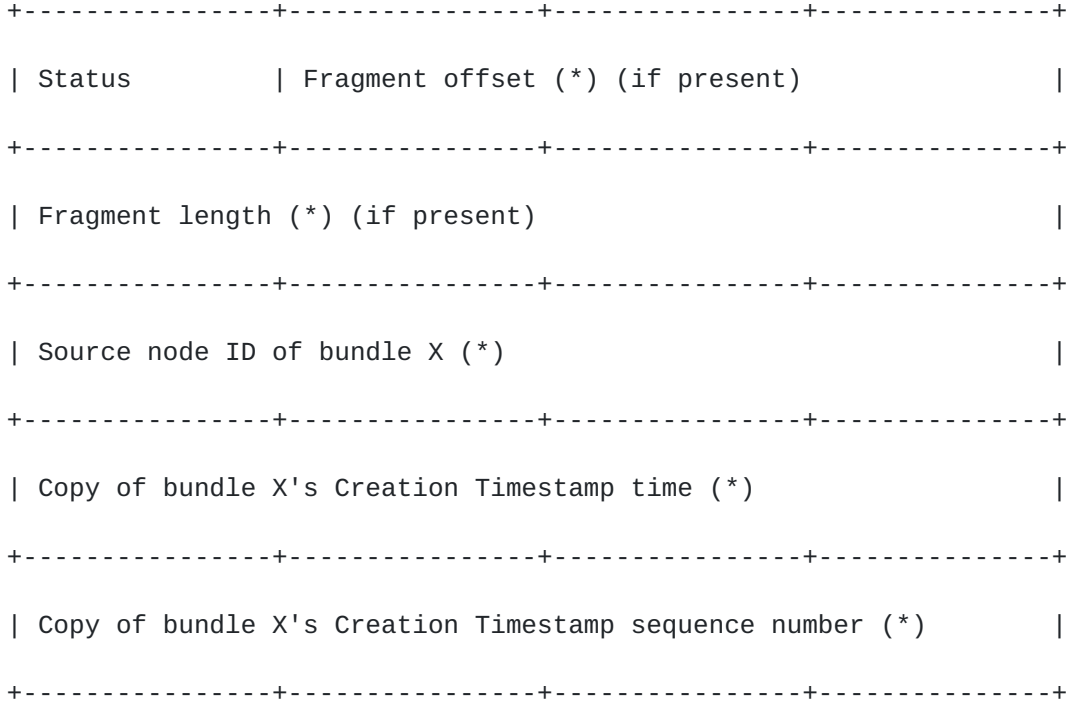


Figure 13: Custody Signal Format

(*) Notes:

The Fragment Offset field, if present, is an SDNV and is therefore variable length. A three-octet SDNV is shown here for convenience in representation.

The Fragment Length field, if present, is an SDNV and is therefore variable length. A four-octet SDNV is shown here for convenience in representation.

The Source Node ID and Creation Timestamp fields replicate the Source Node ID and Creation Timestamp fields in the primary block of the subject bundle. As such they are of variable length. Four-octet values are shown here for convenience in representation.

The fields in a custody signal are:

Status: A 1-byte field containing a 1-bit "custody transfer succeeded" flag followed by a 7-bit reason code explaining the value of that flag. Custody signal reason codes are defined as follows:

Value	Meaning
0x00	No additional information.
0x01	Reserved for future use.
0x02	Reserved for future use.
0x03	Redundant (reception by a node that is a custodial node for this bundle).
0x04	Depleted storage.

0x05	Destination endpoint ID unintelligible.
0x06	No known route destination from here.
0x07	No timely contact with next node on route.
0x08	Block unintelligible.
(other)	Reserved for future use.

Figure 14: Custody Signal Reason Codes

Fragment offset: If the bundle fragment bit is set in the status flags, then the offset (within the original application data unit) of the payload of the bundle that caused the custody signal to be generated is included here.

Fragment length: If the bundle fragment bit is set in the status flags, then the length of the payload of the subject bundle is included here.

Source Node ID of Subject Bundle: The source node ID of the bundle that caused the custody signal to be generated.

Creation Timestamp of Subject Bundle: A copy of the creation timestamp of the bundle to which the signal applies.

6.2. Generation of Administrative Records

Whenever the application agent's administrative element is directed by the bundle protocol agent to generate an administrative record with reference to some bundle, the following procedure must be followed:

Step 1: The administrative record must be constructed. If the referenced bundle is a fragment, the administrative record must have the Fragment flag set and must contain the fragment offset and

fragment length fields. The value of the fragment offset field must be the value of the referenced bundle's fragment offset, and the value of the fragment length field must be the length of the referenced bundle's payload.

Step 2: A request for transmission of a bundle whose payload is this administrative record must be presented to the bundle protocol agent.

6.3. Reception of Custody Signals

For each received custody signal that has the "custody transfer succeeded" flag set to 1, the administrative element of the application agent must direct the bundle protocol agent to follow the custody transfer success procedure in Section 5.11.

For each received custody signal that has the "custody transfer succeeded" flag set to 0, the administrative element of the application agent must direct the bundle protocol agent to follow the custody transfer failure procedure in Section 5.12.

7. Services Required of the Convergence Layer

7.1. The Convergence Layer

The successful operation of the end-to-end bundle protocol depends on the operation of underlying protocols at what is termed the "convergence layer"; these protocols accomplish communication between nodes. A wide variety of protocols may serve this purpose, so long as each convergence layer protocol adapter provides a defined minimal set of services to the bundle protocol agent. This convergence layer service specification enumerates those services.

7.2. Summary of Convergence Layer Services

Each convergence layer protocol adapter is expected to provide the following services to the bundle protocol agent:

- sending a bundle to a bundle node that is reachable via the convergence layer protocol;
- delivering to the bundle protocol agent a bundle that was sent by a bundle node via the convergence layer protocol.

The convergence layer service interface specified here is neither exhaustive nor exclusive. That is, supplementary DTN protocol specifications (including, but not restricted to, the Bundle Security Protocol [BSP]) may expect convergence layer adapters that

serve BP implementations conforming to those protocols to provide additional services such as retransmitting data that were lost in transit, discarding bundle-conveying data units that the convergence layer protocol determines are corrupt or inauthentic, or reporting on the integrity and/or authenticity of delivered bundles.

8. Security Considerations

The bundle protocol has taken security into concern from the outset of its design. It was always assumed that security services would be needed in the use of the bundle protocol. As a result, the bundle protocol security architecture and the available security services are specified in an accompanying document, the Bundle Security Protocol specification [BSP]; an informative overview of this architecture is provided in [SECO].

The bundle protocol has been designed with the notion that it will be run over networks with scarce resources. For example, the networks might have limited bandwidth, limited connectivity, constrained storage in relay nodes, etc. Therefore, the bundle protocol must ensure that only those entities authorized to send bundles over such constrained environments are actually allowed to do so. All unauthorized entities should be prevented from consuming valuable resources as soon as practicable.

Likewise, because of the potentially high latencies and delays involved in the networks that make use of the bundle protocol, data sources should be concerned with the integrity of the data received at the intended destination(s) and may also be concerned with ensuring confidentiality of the data as it traverses the network. Without integrity, the bundle payload data might be corrupted while in transit without the destination able to detect it. Similarly, the data source can be concerned with ensuring that the data can only be used by those authorized, hence the need for confidentiality.

Internal to the bundle-aware overlay network, the bundle nodes should be concerned with the authenticity of other bundle nodes as well as the preservation of bundle payload data integrity as it is forwarded between bundle nodes.

As a result, bundle security is concerned with the authenticity, integrity, and confidentiality of bundles conveyed among bundle nodes. This is accomplished via the use of two independent security-specific bundle blocks, which may be used together to provide multiple bundle security services or independently of one another, depending on perceived security threats, mandated security requirements, and security policies that must be enforced.

To provide end-to-end bundle authenticity and integrity, the Block Integrity Block (BIB) is used. The BIB allows any security-enabled entity along the delivery path to ensure the integrity of the bundle's payload or any other block other than a Block Confidentiality Block.

To provide payload confidentiality, the use of the Block Confidentiality Block (BCB) is available. The bundle payload, or any other block aside from the primary block and the Bundle Security Protocol blocks, may be encrypted to provide end-to-end payload confidentiality/privacy.

Additionally, convergence-layer protocols that ensure authenticity of communication between adjacent nodes in BP network topology SHOULD be used where available, to minimize the ability of unauthenticated nodes to introduce inauthentic traffic into the network.

Bundle security must not be invalidated by forwarding nodes even though they themselves might not use the Bundle Security Protocol.

In particular, while blocks may be added to bundles transiting intermediate nodes, removal of blocks with the 'Discard block if it can't be processed' flag unset in the block processing control flags may cause security to fail.

Inclusion of the Bundle Security Protocol in any Bundle Protocol implementation is RECOMMENDED. Use of the Bundle Security Protocol in Bundle Protocol operations is OPTIONAL.

9. IANA Considerations

The "dtn" and "ipn" URI schemes have been provisionally registered by IANA. See http://www.iana.org/assignments/uri-schemes.html for the latest details.

Registries of scheme type numbers, extension block type numbers, and administrative record type numbers will be required.

10. References

10.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

[URI] Berners-Lee, T., Fielding, R., and L. Masinter, "Uniform Resource Identifier (URI): Generic Syntax", RFC 3986, STD 66, January 2005.

[URIREG] Thaler, D., Hansen, T., and T. Hardie, "Guidelines and Registration Procedures for URI Schemes", RFC 7595, BCP 35, June 2015.

10.2. Informative References

[ARCH] V. Cerf et. al., "Delay-Tolerant Network Architecture", RFC 4838, April 2007.

[ASN1] "Abstract Syntax Notation One (ASN.1), "ASN.1 Encoding Rules: Specification of Basic Encoding Rules (BER), Canonical Encoding Rules (CER) and Distinguished Encoding Rules (DER)," ITU-T Rec. X.690 (2002) | ISO/IEC 8825- 1:2002", 2003.

[BSP] Symington, S., "Bundle Security Protocol Specification", Work Progress, October 2007.

[RFC3987] Duerst, M. and M. Suignard, "Internationalized Resource Identifiers (IRIs)", RFC 3987, January 2005.

[RFC5050] Scott, M. and S. Burleigh, "Bundle Protocol Specification", RFC 5050, November 2007.

[SECO] Farrell, S., Symington, S., Weiss, H., and P. Lovell, "Delay-Tolerant Networking Security Overview", Work Progress, July 2007.

[SIGC] Fall, K., "A Delay-Tolerant Network Architecture for Challenged Internets", SIGCOMM 2003.

[TUT] Warthman, F., "Delay-Tolerant Networks (DTNs): A Tutorial", <http://www.dtnrg.org>.

[UTC] Arias, E. and B. Guinot, "Coordinated universal time UTC: historical background and perspectives" in "Journees systemes de reference spatio-temporels", 2004.

11. Acknowledgments

This work is freely adapted from [RFC5050], which was an effort of the Delay Tolerant Networking Research Group. The following DTNRG participants contributed significant technical material and/or inputs to that document: Dr. Vinton Cerf of Google, Scott Burleigh, Adrian Hooke, and Leigh Torgerson of the Jet Propulsion Laboratory,

Michael Demmer of the University of California at Berkeley, Robert Durst, Keith Scott, and Susan Symington of The MITRE Corporation, Kevin Fall of Intel Research, Stephen Farrell of Trinity College Dublin, Peter Lovell of SPARTA, Inc., Manikantan Ramadas of Ohio University, and Howard Weiss of SPARTA, Inc.

This document was prepared using 2-Word-v2.0.template.dot.

12. Significant Changes From RFC 5050

Points on which this draft significantly differs from RFC 5050 include the following:

- Clarify the difference between transmission and forwarding.
- Amplify discussion of custody transfer. Move current custodian to an extension block, of which there can be multiple occurrences (possible support for the MITRE idea of multiple concurrent custodians, from several years ago); define that block in this specification.
- Introduce the concept of "node ID" as functionally distinct from endpoint ID, while having the same syntax.
- Introduce a new method of encoding endpoint IDs (including node IDs) in a transmitted bundle, replacing both the "dictionary" and the CBHE compression mechanism.
- Add ECOS features to primary block.
- Restrict the scope of bundle prioritization to all bundles from the same source.
- Restructure primary block, making it immutable. Add optional CRC and inventory.
- Add optional CRCs to non-primary blocks.
- Add block ID number to canonical block format (to support streamlined BSP).
- Add bundle age extension block, defined in this specification.
- Add previous node ID extension block, defined in this specification.
- Add flow label block, *not* defined in this specification.
- Add hop count extension block, defined in this specification.
- Clean up a disconnect between fragmentation and custody transfer that Ed pointed out.
- Remove "DTN time" values from admin records.

13. Open Issues

13.1. Definitions section structure

Would it be better to restrict the Definitions section to definitions only, and move description, conceptual operation,

potential implementation, justification, and commentary to one or more additional sections? Or would fractionating this information across multiple sections would make it harder to grasp?

13.2. Payload nomenclature

It has been proposed that (a) there is no need to define "nominal payload" and (b) "partial" payload would be better than "fragmentary" payload. (The term "nominal payload" is used in the definition of fragmentation.)

13.3. Application Agent

Does the discussion of Application Agent functionality need to be in the BP spec? If so, should there be a diagram explaining how the various components of the BPA interact?

13.4. Bundle Endpoint definition

Is the source of a bundle always a node, or do we want to define a way in which a set of nodes (an endpoint) can collectively transmit a bundle? Does the latter trace back to a use case we need to support?

Is a bundle custodian always a node, or do we want to define a way in which a set of nodes (an endpoint) can collectively take custody of a bundle? Does the latter trace back to a use case we need to support?.

13.5. Alignment with ICN

Is it necessary to modify the bundle transmission procedure to enable BP to be used for information-centric networking, i.e., delivering data to a node who requests that data after it has already been transmitted? Specifically, would a DTN ICN cache point "transmit" data to a client (i.e., source a new bundle) or would it merely "forward" a previously transmitted bundle of which it has retained a copy?

13.6. Implementation Architectures

Should the BP spec be divided into two documents? One to talk about conops and context and one that focuses specifically on the protocol?

13.7. Security protocol name

Will the name of the DTN security protocol be Bundle Security Protocol or Streamlined Bundle Security Protocol?

13.8. Bundle format

Should the rules for defining block structure be presented at the start of section 4 or in the discussion of the payload block and the "last block" flag? Should we require that the payload block always be the last block of the bundle, so that the "last block" flag is no longer needed? (This would make reactive fragmentation easier.)

13.9. SDNVs

Should the SDNV discussion in 4.1 be deleted?

13.10. Bundle Processing Control Flags

Should the bit numbering convention described in section 4.2 be moved to another location in the document?

13.11. Extended class of service features

Should these features (critical bundle, best-efforts forwarding requested, reliable forwarding requested) be omitted from the primary block? If they are omitted, should these application-selected CoS markings be supported in some other way? If the "critical" CoS feature is retained, should it have a different name?

Note: a node selection (route computation) procedure might consider the availability of CLAs that match the bundle's CoS when selecting a node to forward to, and that is entirely the business of the route computation procedure. (Not all route computation procedures will do so.)

13.12. Primary block CRC type

What are the best CRC options to support here? CRC-16-ARINC, CRC-16-CCITT, CRC-16-CDMA2000, CRC-16-DECT, etc.? Are there more than 4?

13.13. Inventory

Is a list of the block types of all blocks in the bundle as forwarded by the source node a good implementation of the requested "inventory" feature? If not, what would be better?

13.14. Block numbers

Should the payload always have block number zero?

13.15. Clearing flag

Should an node that is able to process a given extension block be permitted to clear block's "Block was forwarded without being processed" flag?

13.16. Overriding BP spec

Is a supplementary DTN protocol specification allowed to override or supersede the BP specification (other than making some BP procedures moot by requiring that the processing of a bundle be terminated under fault conditions recognized by that protocol)?

13.17. Time of forwarding

Should the BPA control the time at which a bundle is to be forwarded to another node, or should that determination be left to the selected convergence-layer protocol adapter(s)?

13.18. Block multiplicity

Would it be good to restrict BP extensions to one extension block per extension per bundle? That is, should we require that all information needed to implement a given BP extension for a given bundle be contained in a single extension block?

This would entail encapsulating any necessary multiplicity for a given extension (for example, multiple Metadata records) within a single block.

Among the advantages: no need for block numbers (block type would always be sufficient to identify the block), therefore no need for a block number generation mechanism; shorter and simpler inventory; simpler extension implementation (all information is in one block, no need to search through extension blocks for additional relevant information).

Among the disadvantages: very different from RFC 5050; would in some cases require that security blocks operate on data structures that are internal to extension blocks rather than always operate on entire extension blocks.

Appendix A. For More Information

Please refer comments to dtn@ietf.org. The Delay Tolerant Networking Research Group (DTNRG) Web site is located at http://www.dtnrg.org.

Authors' Addresses

Scott Burleigh
Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Dr.
Pasadena, CA 91109-8099
US
Phone: +1 818 393 3353
EMail: Scott.Burleigh@jpl.nasa.gov

Kevin Fall
Carnegie Mellon University / Software Engineering Institute
4500 Fifth Avenue
Pittsburgh, PA 15213
US
Phone: +1 412 268 3304
Email: kfall@cmu.edu

Edward J. Birrane
Johns Hopkins University Applied Physics Laboratory
11100 Johns Hopkins Rd
Laurel, MD 20723
US
Phone: +1 443 778 7423
Email: Edward.Birrane@jhuapl.edu