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Bundle Protocol Specification

Status of this Memo

Abstract

This document describes the end-to-end protocol, header formats, and abstract service description for the exchange of messages (bundles) in Delay Tolerant Networking (DTN).

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 [1].

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1. Introduction

This document describes version 4 of the Delay Tolerant Networking (DTN) "bundle" protocol (BP). Delay Tolerant Networking is an end-to-end 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 internets, forming a store-and-forward overlay network. Key capabilities of BP include:

- Custody-based retransmission
- 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 constituent internet addresses

For descriptions of these capabilities and the rationale for the DTN architecture, see [2] and [8]. [3] contains a tutorial-level overview of DTN concepts.

BP's location within the standard protocol stack is as shown in Figure 1. BP uses the 'native' internet protocols for communications within a given internet. Note that 'internet' in the preceding is used in a general sense and does not necessarily refer to TCP/IP. The interface between the common bundle protocol and a specific internetwork protocol suite is termed a "convergence layer adapter". Figure 1 shows three distinct transport and network protocols (denoted T1/N1, T2,N2, and T3/N3).

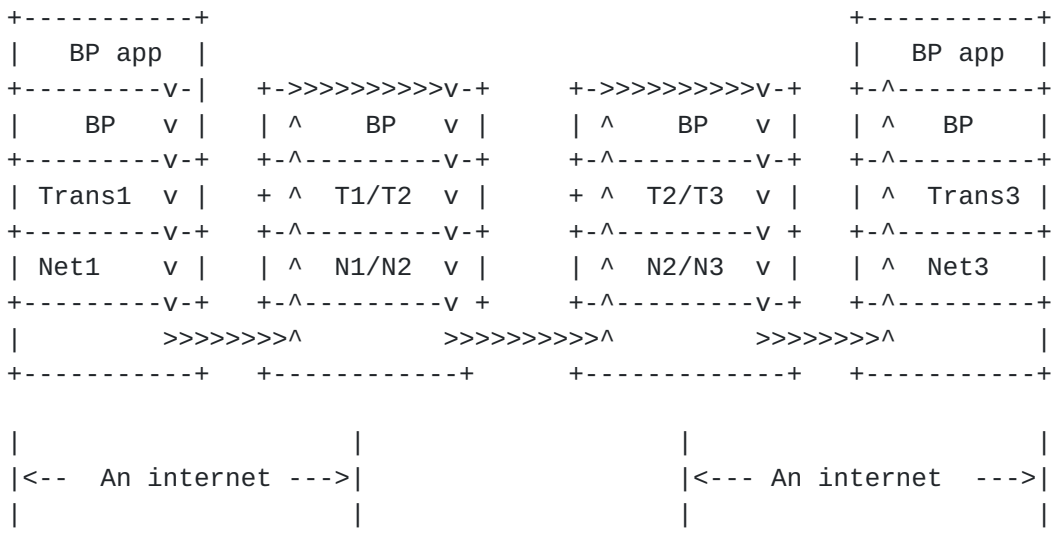


Figure 1: The bundle protocol sits at the application layer of the Internet model.

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 internet. (However, the document does discuss the services that must be provided by each adapter at the convergence layer.)
- The bundle routing algorithm.
- Mechanisms for populating the routing or forwarding information bases of bundle nodes.

2. Service Description

2.1 Definitions

Bundle A bundle is a protocol data unit of the DTN bundle protocol. 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 - 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 header 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' internet protocol that is supported in one of the internets within which the node is functionally located. The manner in which a CLA sends and receives bundles is wholly an implementation matter, exactly as described for the BPA.

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 (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 "router" in the overlay network, 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; in particular, the administrative element of an AA might be built into the library or daemon or hardware that implements the BPA, and the application-specific element of an AA might be implemented either in software or in hardware.

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 single text string, called a "bundle endpoint ID"

(or, in this document, simply "endpoint ID"; endpoint IDs are described in detail in 3.5 below). The special case of an endpoint that never contains more than one node is termed a "singleton" endpoint; every bundle node must be a member of at least one 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. **Note** too that a given bundle node might identify itself by multiple endpoint IDs and thus be a member of multiple bundle endpoints.

Forwarding - When the bundle protocol agent of a node determines that a bundle must be "forwarded" to an endpoint, it causes the bundle to be sent to all of the nodes that the bundle protocol agent currently believes are in the "minimum reception group" of that endpoint. The minimum reception group of an endpoint may be any one of the following: (a) ALL of the nodes registered 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 (in which case forwarding to the endpoint is functionally similar to "anycast" operations in the Internet); (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 3.5 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.

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, 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:

- o 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 Active state;

- o "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 least recently received bundle that is currently deliverable subject to the registration. 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 sent to 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 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 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 endpoint of the deletion (provided such notification is warranted; see 4.13 for details) and then arbitrarily removing all of the bundle's retention constraints, enabling the bundle to be discarded.

Transmission A transmission is a sustained effort by a node's bundle protocol agent to cause a bundle to be sent to all nodes in the minimum reception group of some endpoint (which may be the bundle's destination or may be some intermediate forwarding endpoint) in response to a transmission request issued by the node's application agent. Any number of transmissions may be concurrently undertaken by the bundle protocol agent of a given node.

Custody To "accept custody" upon forwarding a bundle is to commit to retaining a copy of the bundle - possibly re-forwarding the bundle when the necessity to do so is determined - until custody of that bundle is "released". Custody of a bundle whose destination is a singleton endpoint is 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, or (c) the bundle is explicitly deleted for some reason, such as lifetime expiration; the condition(s) under which custody of a bundle whose destination is not a singleton endpoint may be released are not defined in this specification. To "refuse custody" of a bundle is to decide not to accept custody of the bundle. A "custodial node" of a bundle is a node that has accepted custody of the bundle and has not yet released that custody. A "custodian" of a bundle is a singleton endpoint whose sole member is one of the bundle's custodial nodes.

2.2 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.

a) 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.

b) Peer application nodes

Any number of bundle protocol application processes, each one constituting a single bundle node, run in ad-hoc fashion 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.

c) 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 ASICs, 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.

d) 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 ASICs, 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.

2.3 Services offered by bundle protocol agents

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

a) commencing a registration (registering a node in an endpoint);
b) terminating a registration;
c) switching a registration between Active and Passive state;
d) transmitting a bundle to an identified bundle endpoint;
e) canceling a transmission;

f) polling a registration that is in passive state;
g) delivering a received bundle;

h) acknowledging receipt of a bundle's contents.

3. Bundle Format

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

3.1 Canonical Bundle Header Format

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

- Header type code, expressed as an 8-bit unsigned binary integer. Bundle header type code 1 indicates that the header is a bundle payload header. All other values of the header type code are reserved for future use.
- Header processing control flags, a set of eight 1-bit flag values.
- Header data length, an unsigned integer expressed as an SDNV (explained below). The Header data length field contains the aggregate length of all remaining fields of the header, i.e., the header-type-specific data fields.
- Header-type-specific data fields, whose format and order are type-specific and whose aggregate length in octets is the value of the header data length field. All multi-byte header-type-specific data fields are represented in network byte order.

3.2 Bundle Processing Flags

The following Boolean processing control flags are present only in the bundle processing control flags byte of the primary bundle header of each bundle:

00000001 - Bundle is a fragment.
00000010 - Application data unit is an administrative record.
00000100 - Bundle must not be fragmented.
00001000 - Custody transfer is requested.
00010000 - Destination endpoint is a singleton.
00100000 - Reserved for future use.
01000000 - Reserved for future use.
10000000 - 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. If the custody transfer requested flag is 1 then the sending node requests that the receiving node accept custody of the bundle.

3.3 Header Processing Flags

The following Boolean processing control flags are present in the header processing control flags byte of every bundle header other than the primary bundle header of each bundle:

00000001 - Header must be replicated in every fragment.
00000010 - Transmit status report if header can't be processed.
00000100 - Discard bundle if header can't be processed.
00001000 - Last header.
00010000 - Reserved for future use.
00100000 - Reserved for future use.
01000000 - Reserved for future use.
10000000 - Reserved for future use.

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

3.4 Self-Delimiting Numeric Values (SDNV)

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

- o extensibility to address requirements not yet identified, and
- o 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 [ASN1] scheme for encoding Object Identifier Arcs. 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
         {100 1010 1} {0 011 1100}
```

= 10010101 00111100

```
0x1234 : 0001 0010 0011 0100
       =    1 0010 0011 0100
         is encoded as
         {10 1 0010 0} {0 011 0100}
         = 10100100 00110100

0x4234 : 0100 0010 0011 0100
       =  100 0010 0011 0100
         is encoded as
         {1000000 1} {1 00 0010 0} {0 011 0100}
         = 10000001 10000100 00110100

0x7F   : 0111 1111
       =  111 1111
         is encoded as
         {0 111 1111}
         = 01111111
```

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 1/8-th of the bitwise length of the value to be encoded. In order to encode an 64-bit numeric value, an SDNV field of 9 octets is required. 128 bits of overhead would be consumed in encoding a 1024-bit RSA encryption key directly in an SDNV.

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 headers yields the smallest bundle header sizes without sacrificing scalability.

3.5 Endpoint IDs

The destinations of bundles are bundle endpoints, identified by text strings termed "endpoint IDs" (see section 2.1). Each endpoint ID conveyed in any bundle header takes the form of a Uniform Resource Identifier (URI; [RFC3986]). As such, each endpoint ID can be characterized as having this general structure:

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

As used for the purposes of the bundle protocol, neither the length of a scheme name nor the length of an SSP may exceed 1023 bytes.

Bundle headers cite a number of endpoint IDs for various purposes of

the bundle protocol. Many, though not necessarily all, of the endpoint IDs referred to in the headers of a given bundle are

conveyed in the "dictionary" byte array in the bundle's primary header. This array is simply the concatenation of any number of null-terminated scheme names and SSPs.

"Endpoint ID references" are used to cite endpoint IDs that are contained in the dictionary; all endpoint ID citations in the primary bundle header are endpoint ID references, and other bundle headers may contain endpoint ID references as well. Each endpoint ID reference is an ordered pair of 16-bit unsigned integers:

- The offset, within the dictionary, of the first character of the referenced endpoint ID's scheme name.
- The offset, within the dictionary, of the first character of the referenced endpoint ID's SSP.

This encoding enables a degree of header compression: when the source and report-to of a bundle are the same endpoint, for example, the text of that endpoint's ID may be cited twice yet appear only once in the dictionary.

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 [RFC2717] may be used in a bundle protocol endpoint ID. In addition, a single additional scheme is defined by the present document:

- The "dtn" scheme, which is used at minimum in the representation of the null endpoint ID "dtn:none". The forwarding of a bundle to the null endpoint is never contraindicated, and the minimum reception group for the null endpoint is the empty set.

Note that, although the endpoint IDs conveyed in bundle headers are expressed as URIs, implementations of the BP service interface may support expression of endpoint IDs in some internationalized manner (e.g., IRIs; see RFC 3987).

3.6 Formats of Bundle Headers

This section describes the formats of the primary header and payload header. Rules for processing these headers appear in section 4 of this document.

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

The format of the two basic BP headers is shown in Figure 2 below.

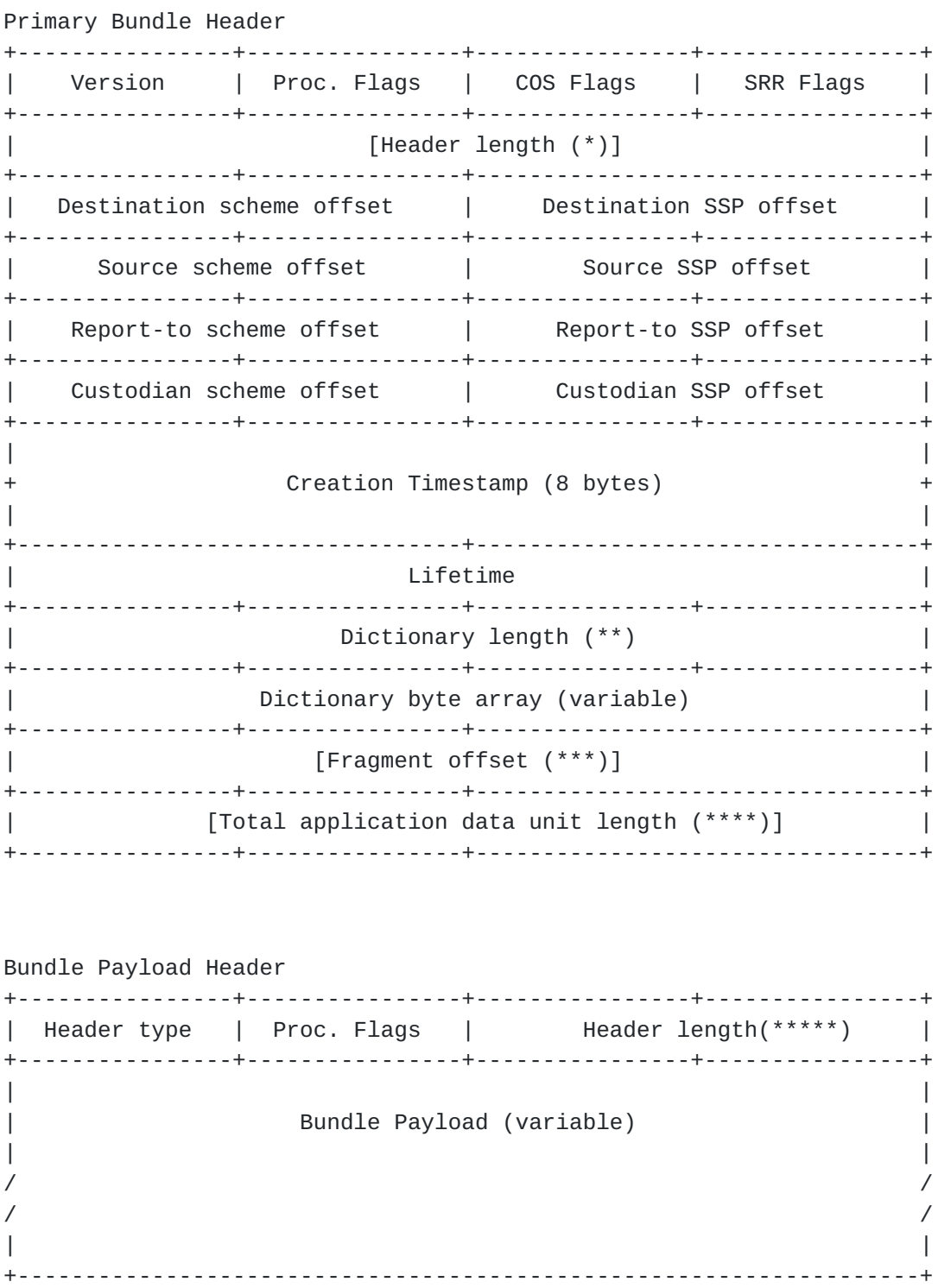


Figure 2: Bundle header formats.

Notes:

(*) The header length field of the Primary Bundle Header is an SDNV and is therefore variable-length. A four-octet SDNV is shown here

for convenience in representation.

(**) The dictionary length field of the Primary Bundle Header is an

SDNV and is therefore variable-length. A four-octet SDNV is shown here for convenience in representation.

(***) The fragment offset field of the Primary Bundle Header is present only if the Fragment flag in the header's processing flags byte is set to 1. It is an SDNV and is therefore variable-length; a four-octet SDNV is shown here for convenience in representation.

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

(*****) The header length field of the Payload Header is an SDNV and is therefore variable-length. A two-octet SDNV is shown here for convenience in representation.

3.6.1 Primary Bundle Header

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

Version. A 1-byte field indicating the version of the bundle protocol that constructed this header. The present document describes version 0x04 of the bundle protocol.

Bundle Processing Control Flags. The Bundle Processing Control Flags field is a 1-byte field that contains the bundle processing control flags discussed in section 3.2 above.

Class of Service Flags. The COS Flags byte consists of two (2) bits of priority followed by six (6) bits that are reserved for future use. The two-bit priority field indicates the bundle's priority, with higher values being of higher priority: 00 = bulk, 01 = normal, 10 = expedited, 11 is reserved for future use.

Status Report Request Flags. The status report request flags indicate the source node's requests for bundle status report generation. If the bundle processing control flags indicate that the bundle's application data unit is an administrative record, then all status report request flags must be zero. The interpretation of the status report request flags is as follows.

Table 1: Status Report Request Flag Meanings

Value	Meaning
0x00	No status reports requested.
0x01	Request reporting of bundle reception.
0x02	Request reporting of custody acceptance.
0x04	Request reporting of bundle forwarding.
0x08	Request reporting of bundle delivery.
0x10	Request reporting of bundle deletion.
0x20	Request acknowledgement by application.
0x40	Unused.
0x80	Unused.

Header Length. The Header Length field is an SDNV that contains the aggregate length of all remaining fields of the header.

Destination Scheme Offset. The Destination Scheme Offset field contains the offset within the dictionary byte array of the scheme name 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.

Destination SSP Offset. The Destination SSP Offset field contains the offset within the dictionary byte array of the scheme-specific part of the endpoint ID of the bundle's destination.

Source Scheme Offset. The Source Scheme Offset field contains the offset within the dictionary byte array of the scheme name of the endpoint ID of the bundle's nominal source, i.e., the endpoint nominally containing the node from which the bundle was initially transmitted.

Source SSP Offset. The Source SSP Offset field contains the offset within the dictionary byte array of the scheme-specific part of the endpoint ID of the bundle's nominal source.

Report-to Scheme Offset. The Report-to Scheme Offset field contains

the offset within the dictionary byte array of the scheme name of the ID of the endpoint to which status reports pertaining to the forwarding and delivery of this bundle are to be

transmitted.

Report-to SSP Offset. The Report-to SSP Offset field contains the offset within the dictionary byte array of the scheme-specific part of the ID of the endpoint to which status reports pertaining to the forwarding and delivery of this bundle are to be transmitted.

Custodian Scheme Offset. The "current custodian endpoint ID" of a primary bundle header identifies an endpoint whose membership includes the node that most recently accepted custody of the bundle upon forwarding this bundle. The Custodian Scheme Offset field contains the offset within the dictionary byte array of the scheme name of the current custodian endpoint ID.

Custodian SSP Offset. The Destination SSP Offset field contains the offset within the dictionary byte array of the scheme-specific part of the current custodian endpoint ID.

Creation Timestamp. The creation timestamp is an 8-byte field that, together with the source endpoint ID and (if applicable) the fragment offset, serves to identify the bundle. The high-order four bytes of the timestamp are the bundle's creation time while its low-order four bytes are 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 [7] - 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. A source Bundle Protocol Agent must never create two distinct bundles with the same source endpoint ID and bundle creation timestamp. The combination of source endpoint ID and bundle creation timestamp therefore serves to identify a single transmission request, enabling it to be acknowledged by the receiving application.

Lifetime. The four-byte lifetime field 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 the current time is greater than the creation time plus the lifetime, bundle nodes need no longer retain or forward the bundle; the bundle may be deleted from the network.

Dictionary Length. The Dictionary Length field is an SDNV that

contains the length of the dictionary byte array.

Dictionary. The Dictionary field is an array of bytes formed by

concatenating the null-terminated scheme names and SSPs of all endpoint IDs referenced by any fields in this Primary Header together with, potentially, other endpoint IDs referenced by fields in other TBD DTN protocol headers. Its length is given by the value of the Dictionary Length field.

Fragment Offset. If the Bundle Processing Control Flags of this Primary header 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 header.

Total Application Data Unit Length. If the Bundle Processing Control Flags of this Primary header 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 header.

3.6.2 Bundle Payload Header

The fields of the bundle payload header are:

Header Type. The Header Type field is a 1-byte field that indicates the type of the header. For the bundle payload header this field contains the value 1.

Header Processing Control Flags. The Header Processing Control Flags field is a 1-byte field that contains the header processing control flags discussed in section 3.3 above.

Header Length. The Header Length field is an SDNV that contains the aggregate length of all remaining fields of the header which is to say, the length of the bundle's payload.

Payload. The application data carried by this bundle.

4. Bundle Processing

The bundle processing procedures mandated in this section and in section 5 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) 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.

4.1 Generation of administrative records

All initial transmission of bundles is in response to bundle transmission requests presented by nodes' application agents. When required to "generate" an administrative record (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 5 below; in practice, the manner in which administrative record generation is accomplished is an implementation matter, provided the constraints noted in section 5 are observed.

Notes on administrative record terminology:

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

b. A "custody acceptance status report" is a bundle status report with the "reporting node accepted custody of bundle" flag set to 1.

c. A "bundle forwarding status report" is a bundle status report with the "reporting node forwarded the bundle" flag set to 1.

d. A "bundle delivery status report" is a bundle status report with the "reporting node delivered the bundle" flag set to 1.

e. A "bundle deletion status report" is a bundle status report with the "reporting node deleted the bundle" flag set to 1.

f. An "acknowledgement status report" is a bundle status report with the "acknowledged by application" flag set to 1.

g. A "Succeeded" custody signal is a custody signal with the "custody transfer succeeded" flag set to 1.

h. A "Failed" custody signal is a custody signal with the "custody transfer succeeded" flag set to zero.

i. The "current custodian" of a bundle is the endpoint identified by the current custodian endpoint ID in the bundle's primary header.

4.2 Bundle transmission

The steps in processing a bundle transmission request are:

Step 1: If custody transfer is requested for this bundle transmission and, moreover, custody acceptance by the source node is required, then either the bundle protocol agent must commit to accepting custody of the bundle in which case processing proceeds from Step 2 - or else 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 current custodian endpoint ID set to the null endpoint ID "dtn:none" and with the retention constraint "Dispatch pending". The source endpoint ID of the bundle must be either the ID of an endpoint of which the node is a member or else the null endpoint ID "dtn:none".

Step 3: Processing proceeds from Step 1 of section 4.3.

4.3 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 4.7 must be followed.

Step 2: Processing proceeds from Step 1 of section 4.4.

4.4 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 Table 5. In particular:

- The bundle protocol agent must determine which endpoint(s) to forward the bundle to. The bundle protocol agent may choose either to forward the bundle directly to its destination endpoint (if possible) or else to forward the bundle to some other endpoint(s) for further forwarding. The manner in which this decision is made may depend on the scheme name in the destination endpoint ID but in any case is beyond the scope of this document. If the agent finds it impossible to select any

endpoint(s) to forward the bundle to, then forwarding is contraindicated.

- Provided the bundle protocol agent succeeded in selecting the endpoint(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 the nodes of the minimum reception group of each selected endpoint. The manner in which the appropriate convergence layer adapters are selected may depend on the scheme name in the destination endpoint ID but in any case is beyond the scope of this document. If the agent finds it impossible to select 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 Table 5, then the Forwarding Contraindicated procedure defined in 4.4.1 must be followed; the remaining steps of section 4 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 4.10 must be followed.

Step 5: For each endpoint 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 the nodes constituting the minimum reception group of that endpoint. Determining the time at which the bundle is to be sent by each convergence layer adapter is an implementation matter.

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 class of service field is set to 1, then a bundle forwarding status report must 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 in the minimum reception group of the endpoint selected for forwarding 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.

4.4.1 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 4.4.2 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 4.10 must be followed; (b) when - at some future time - the forwarding of this bundle ceases to be contraindicated, processing proceeds from Step 5 of 4.4.

4.4.2 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. Procedures for handling failure of custody transfer for a bundle whose destination is not a singleton endpoint are not defined in this specification. For a bundle whose destination is a singleton endpoint, 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; 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 the current custodian still has a copy.)

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 4.13 must be followed, citing the reason for which forwarding was determined to be contraindicated.

4.5 Bundle expiration

A bundle expires when the current time is greater than the bundle's creation time plus its lifetime as specified in the primary bundle header. 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 4.13 must be followed.

4.6 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 class of service field is set to 1, then a bundle reception status report with reason code "No additional information" must be generated, destined for the bundle's report-to endpoint ID.

Step 3: If any header in the bundle cannot be processed:

- If the header processing flags in the header indicate that a status report must be generated in this event, then a bundle reception status report with reason code "Header unintelligible" must be generated, destined for the bundle's report-to endpoint ID.

- If the header processing flags in that header indicate that the bundle must be discarded in this event, then the bundle protocol agent must delete the bundle for the reason "Header unintelligible": the bundle deletion procedure defined in 4.13 must be followed. Otherwise, processing proceeds from Step 4.

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 endpoint ID, creation timestamp, and fragment offset 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. Procedures for handling redundancy in custody transfer for a bundle whose destination is not a singleton endpoint are not defined in this specification. For a bundle whose destination is a singleton endpoint, 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 4.3.

4.7 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 4.9 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 are 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 2.1 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 2.1 above).

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

- If the "request reporting of bundle delivery" flag in the bundle's class of service field is set to 1, then a bundle delivery status report must 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. Procedures for reporting custodial delivery for a bundle whose destination is not a singleton endpoint are not defined in this specification. For a bundle whose destination is a singleton endpoint, the bundle protocol agent must report custodial delivery by generating a "Succeeded" custody signal for the bundle, destined for the bundle's current custodian.

4.8 Bundle Fragmentation

It may at times be necessary for bundle protocol agents to reduce the sizes of bundles in order to forward them. This might be the case, for example, if the endpoint 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 endpoint 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 whose primary header'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 a 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 header of each fragment must be modified to 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 header.

- All fragments must contain the same headers as the original bundle, except that (a) the primary headers of the fragments will differ from that of the fragmented bundle as noted above, (b) the payload headers of fragments will differ from that of the fragmented bundle, and (c) any header whose header processing flags do NOT indicate that the header must be replicated in every fragment should be replicated only in the fragment whose fragment offset is zero.

4.9 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 endpoint 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 header, then:

- This byte array the reassembled application data unit must replace the payload of this fragment.

- 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 destination endpoints as necessary; an application data unit may also be reassembled at some other endpoint on the route to the destination.

4.10 Custody transfer

The conditions under which a node may accept custody of a bundle whose destination is not a singleton endpoint are not defined in this specification.

The decision as to whether or not to accept custody of a bundle whose destination is a singleton endpoint is an implementation matter which may involve both resource and policy considerations; however, if the bundle protocol agent has committed to accepting custody of the bundle (as described in Step 1 of 4.2) then custody must be accepted.

If the bundle protocol agent elects to accept custody of the bundle, then it must follow the custody acceptance procedure defined in 4.10.1.

4.10.1 Custody acceptance

Procedures for acceptance of custody of a bundle whose destination is not a singleton endpoint are not defined in this specification.

Procedures for acceptance of custody of a bundle whose destination is a singleton endpoint are defined as follows.

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

If the "request custody acceptance reporting" flag in the bundle's class of service field is set to 1, a custody acceptance status report must 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 4.6) 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.

The bundle protocol agent must assert the new current custodian for the bundle. It does so by changing the current custodian endpoint ID in the bundle's primary header to the endpoint ID of one of the singleton endpoints in which the node is registered. This may entail appending that endpoint ID's null-terminated scheme name and SSP to

the dictionary byte array in the bundle's primary header, and in some case it may also enable the (optional) removal of the current custodian endpoint ID's scheme name and/or SSP from the dictionary.

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 4.12 must 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.

4.10.2 Custody release

Procedures for release of custody of a bundle whose destination is not a singleton endpoint are not defined in this specification.

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

4.11 Custody transfer success

Procedures for determining custody transfer success for a bundle whose destination is not a singleton endpoint are not defined in this specification.

Upon receipt of a "Succeeded" custody signal at a node that is a custodial node of the bundle identified in the custody signal, where the destination of the bundle is a singleton endpoint, custody of the bundle must be released as described in 4.10.2.

4.12 Custody transfer failure

Procedures for determining custody transfer failure for a bundle whose destination is not a singleton endpoint are not defined in this specification. Custody transfer for a bundle whose destination is a singleton endpoint 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 4.4). 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.

4.13 Bundle deletion

The steps in deleting a bundle are:

Step 1: If the retention constraint "Custody accepted" currently prevents this bundle from being discarded, and the destination of the bundle is a singleton endpoint, then:

- Custody of the node is released as described in 4.10.2.
- 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 class of service field is set to 1, then a bundle deletion status report citing the reason for deletion must be generated, destined for the bundle's report-to endpoint ID.

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

4.14 Discarding a bundle

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

4.15 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 canceled". For this purpose, the procedure defined in 4.13 must be followed.

4.16 Polling

When requested to poll a specified registration that is in Passive state, the bundle protocol agent must immediately deliver the least recently received bundle that is deliverable subject to the indicated registration, if any.

4.17 Acknowledging an application data unit

When requested to acknowledge to an indicated report-to endpoint the bundle transmission request identified by an indicated source endpoint ID and bundle creation timestamp, the bundle protocol agent must generate an acknowledgement status report for that transmission

request, destined for that report-to-endpoint.

5. Administrative record processing

5.1 Administrative records

Two types of administrative records have been defined to date: bundle status reports and custody signals.

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

Table 2: Administrative Record Type Codes

Value	Meaning
0x01	Bundle status report.
0x02	Custody signal.
(other)	Reserved for future use.

Administrative record flags are defined as follows:

Table 3: Administrative Record Flags

Value	Meaning
0x01	Record is for a fragment; fragment offset and length fields are present.
(other)	Reserved for future use.

All time values in administrative records are UTC times expressed in "DTN time" representation. A DTN time consists of a 32-bit number in network byte order indicating the number of seconds since the start of the year 2000, followed by a 32-bit number in network byte order indicating the number of nanoseconds since the start of the indicated second.

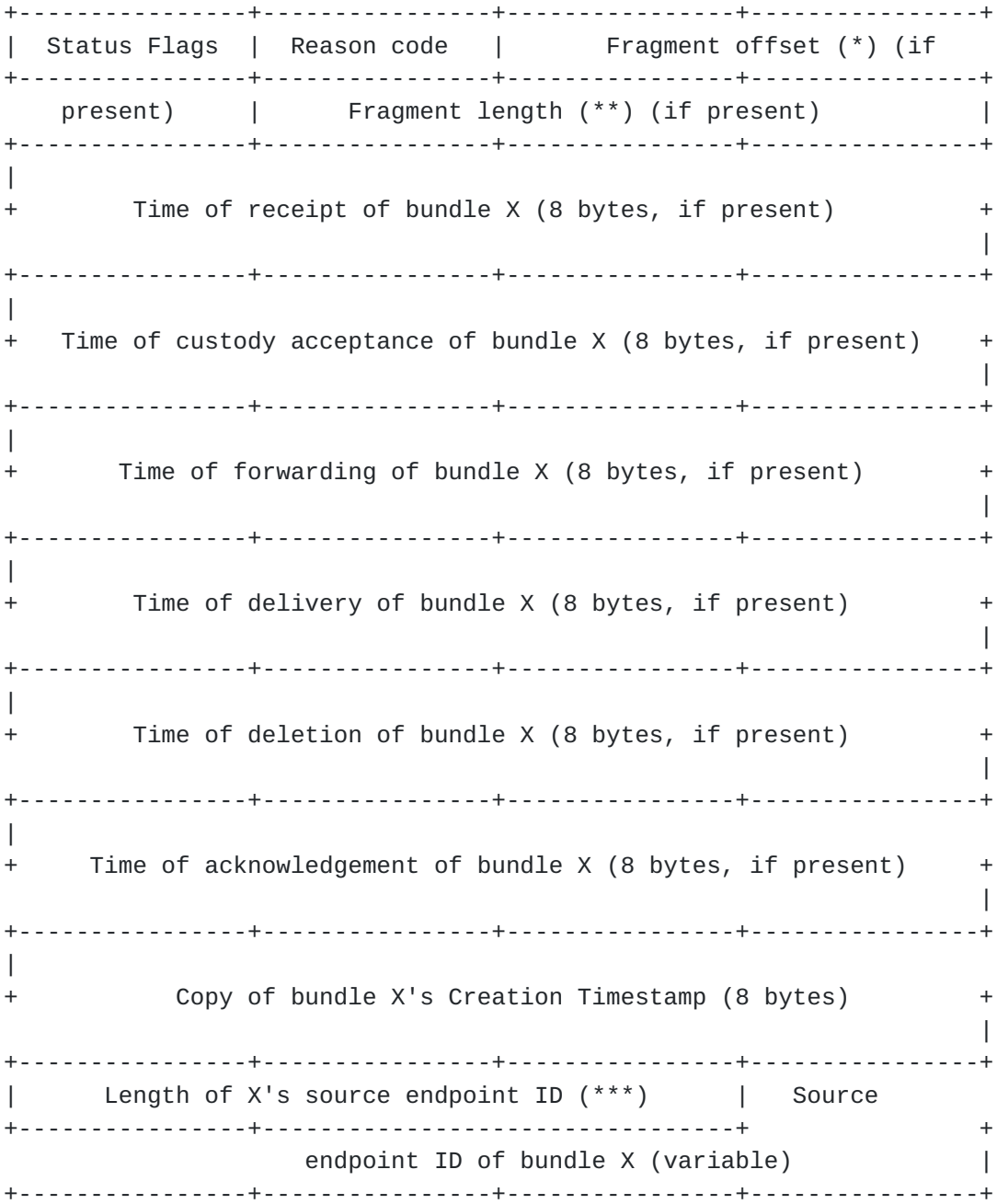
The contents of the various types of administrative records are described below.

5.1.1 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.

Format of Bundle Status Report for bundle 'X':



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 endpoint ID length field is an SDNV and is therefore variable-length. A three-octet SDNV is shown here for convenience in representation.

The fields in a bundle status report are:

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

Table 4: Status Flags for Bundle Status Reports

Value	Meaning
0x01	Reporting node received bundle.
0x02	Reporting node accepted custody of bundle.
0x04	Reporting node forwarded the bundle.
0x08	Reporting node delivered the bundle.
0x10	Reporting node deleted the bundle.
0x20	Acknowledged by application.
0x40	Unused.
0x80	Unused.

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) may define additional reason codes. Status report reason codes are defined as follows:

Table 5: Status Report Reason Codes

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	Header unintelligible.
(other)	Reserved for future use.

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.

Time of Receipt (if present). If the bundle-received bit is set in the status flags, then a DTN time indicating the time at which the bundle was received at the reporting node is included here.

Time of Custody Acceptance (if present). If the custody-accepted bit is set in the status flags, then a DTN time indicating the time at which custody was accepted at the reporting node is included here.

Time of Forward (if present). If the bundle-forwarded bit is set in the status flags, then a DTN time indicating the time at which

the bundle was first forwarded at the reporting node is included here.

Time of Delivery (if present). If the bundle-delivered bit is set in the status flags, then a DTN time indicating the time at which the bundle was delivered at the reporting node is included here.

Time of Deletion (if present). If the bundle-deleted bit is set in the status flags, then a DTN time indicating the time at which the bundle was deleted at the reporting node is included here.

Time of Acknowledgement (if present). If the bundle-acknowledged-by-application bit is set in the status flags, then a DTN time indicating the time at which the bundle was acknowledged by the application at the reporting node is included here.

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

Length of Source Endpoint ID. The length in bytes of the source endpoint ID of the bundle that caused the status report to be generated.

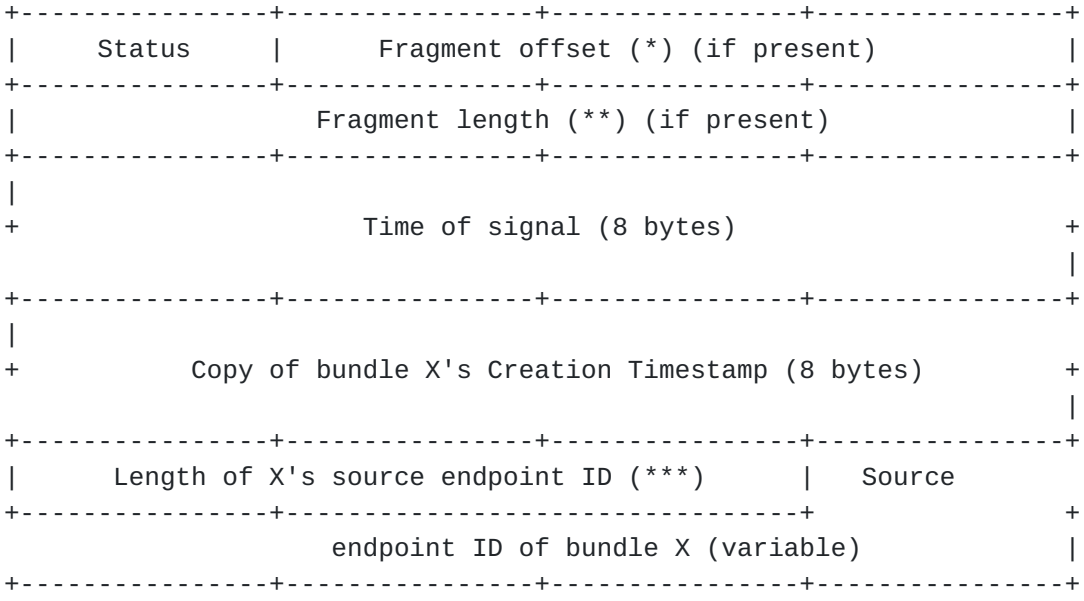
Source Endpoint ID text. The text of the source endpoint ID of the bundle that caused the status report to be generated.

5.1.2 Custody Signals

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

Custody signals have the following format.

Custody Signal regarding bundle 'X':



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 endpoint ID length field is an SDNV and is therefore variable-length. A three-octet SDNV is 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:

Table 6: Custody Signal Reason Codes

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

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.

Time of Signal. A DTN time indicating the time at which the signal was generated.

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

Length of Source Endpoint ID. The length in bytes of the source endpoint ID of the bundle to which the signal applied.

Source Endpoint ID text. The text of the source endpoint ID of the bundle to which the signal applies.

5.2 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.

5.3 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 4.11.

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 4.12.

6. Services Required of the Convergence Layer

6.1 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.

6.2 Summary of Convergence Layer Services

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

a) sending a bundle to all bundle nodes in the minimum reception group of the endpoint identified by a specified endpoint ID that are reachable via the convergence layer protocol;

b) delivering to the bundle protocol agent a bundle that was sent

by a remote 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) may expect convergence layer adapters which serve BP implementations conforming to those protocols to provide additional services.

7. 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 [5]; an informative overview of this architecture is provided in [6].

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.

Likewise, because of the potentially long 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 three, independent security specific bundle headers 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.

The Bundle Authentication Header (BAH) ensures the authenticity and integrity of bundles on a hop-by-hop basis between bundle nodes. The BAH allows each bundle node to verify a bundle s authenticity before processing or forwarding the bundle. In this way, entities that are not authorized to send bundles will have unauthorized transmissions blocked by security-aware bundle nodes.

Additionally, to provide "security-source" to "security-destination" bundle authenticity and integrity, the Payload Security Header (PSH) is used. A "security-source" may not actually be the origination point of the bundle but instead may be the first point along the path that is security-aware and is able to apply security services. For example, an enclave of networked systems may generate bundles but only their gateway may be required and/or able to apply security services. The PSH allows any security-enabled entity along the delivery path, in addition to the "security-destination" (the recipient counterpart to the "security-source"), to ensure the bundle s authenticity.

Finally, to provide payload confidentiality, the use of the Confidentiality Header (CH) is available. The bundle payload may be encrypted to provide "security-source" to "security-destination" payload confidentiality/privacy. The CH indicates the cryptographic algorithm and key IDs that were used to encrypt the payload.

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.

8. IANA Considerations

The new Uniform Resource Identifier scheme "dtn", defined by the Bundle Protocol, will need to be documented.

9. Normative References

[RFC3978] Bradner, S., "IETF Rights in Contributions", BCP 78, RFC 3978, March 2005.

[RFC3979] Bradner, S., "Intellectual Property Rights in IETF Technology", BCP 79, RFC 3979, March 2005.

[RFC3986] T. Berners-Lee, R. Fielding, L. Masinter, "Uniform Resource Identifier (URI): Generic Syntax", STD 66, RFC 3986, Jan 2005.

[RFC2717] Petke, R. and I. King, "Registration Procedures for URL Scheme Names", BCP 35, RFC 2717, November 1999.

10. Informative References

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

[2] V. Cerf, et. al., "Delay-Tolerant Network Architecture," work in progress, draft-irtf-dtnrg-arch-03.txt, July 2005

[3] F. Warthman, "Delay-Tolerant Networks (DTNs): A Tutorial", Warthman Associates, available from http://www.dtnrg.org

[4] Mills, D., "Network Time Protocol (Version 3) Specification, Implementation and Analysis", RFC 1305, March 1992

[5] S. Symington, et. al., "Bundle Security Protocol Specification," draft-irtf-dtnrg-bundle-security-00.txt, June 2005

[6] S. Farrell, S. Symington, and H. Weiss, "Delay-Tolerant Networking Security Overview," draft-irtf-dtnrg-sec-overview-00.txt, September 2005

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

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

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Intellectual Property Statement

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