Delay-Tolerant Networking Working Group S. Burleigh
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E. Birrane
APL, Johns Hopkins University
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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.

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1. Introduction

Since the publication of the Bundle Protocol Specification (Experimental RFC 5050) in 2007, the Delay-Tolerant Networking (DTN) Bundle Protocol has been implemented in multiple programming languages and deployed to a wide variety of computing platforms. This implementation and deployment experience has 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 may be viewed as sitting at the application layer of some number of constituent networks, forming a store-carry-forward overlay network. Key capabilities of BP include:

- Ability to use physical motility for the movement of data
- Ability to move the responsibility for error control from one node to another
- Ability to cope with intermittent connectivity, including cases where the sender and receiver are not concurrently present in the network
- Ability to take advantage of scheduled, predicted, and opportunistic connectivity, whether bidirectional or unidirectional, 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].

BP's location within the standard protocol stack is as shown in Figure 1. BP uses underlying "native" transport and/or 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).

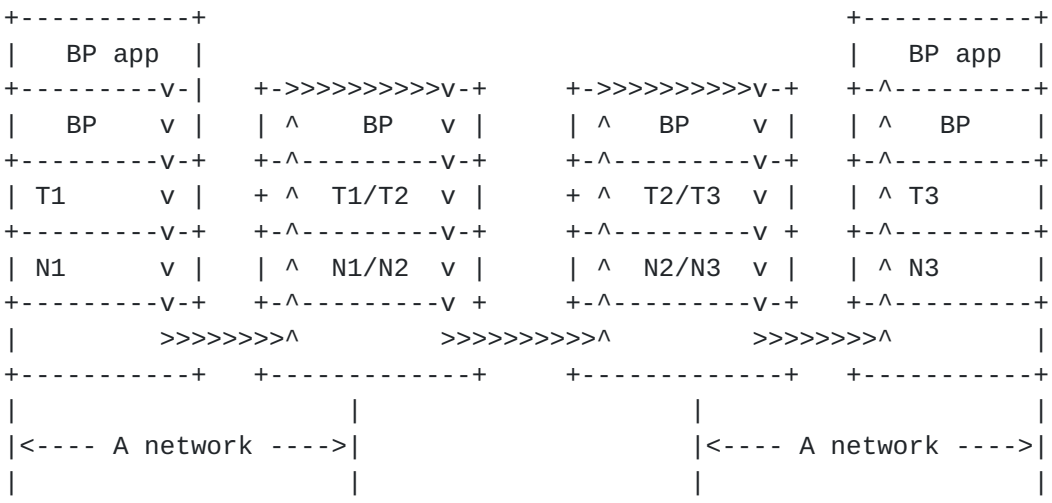


Figure 1: The Bundle Protocol in the Protocol Stack Model

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.

Note that implementations of the specification presented in this document will not be interoperable with implementations of RFC 5050.

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.

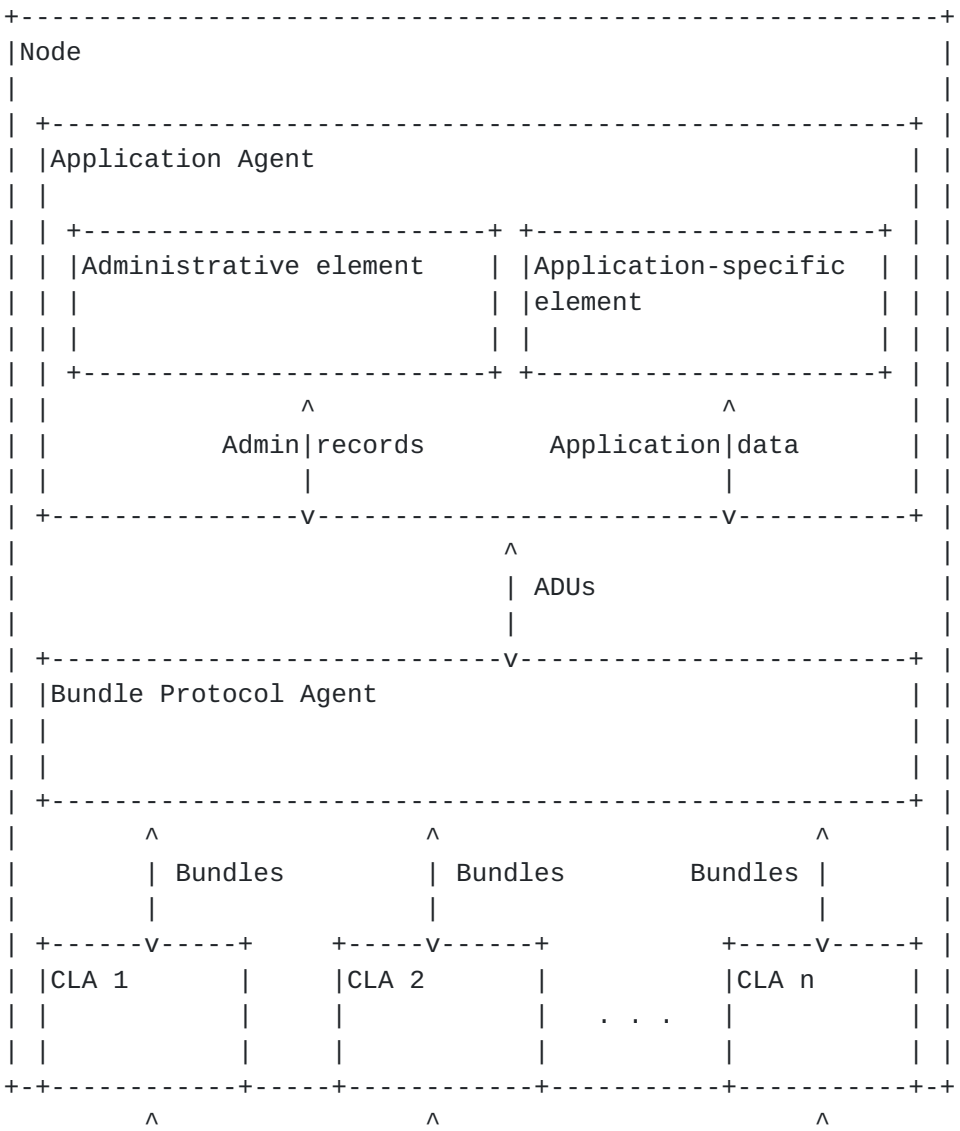
Block - A bundle protocol block is one of the protocol data structures that together constitute a well-formed bundle.

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; it is the content of the bundle's payload block. The terms "bundle content", "bundle payload", and "payload" are used interchangeably in this document.

Partial payload - A partial payload is a payload that comprises either the first N bytes or the last N bytes of some other payload of length M, such that 0 < N < M. Note that every partial payload is a payload and therefore can be further subdivided into partial payloads.

Fragment - A fragment is a bundle whose payload block contains a partial payload.

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. Each bundle node has three conceptual components, defined below, as shown in Figure 2: a "bundle protocol agent", a set of zero or more "convergence layer adapters", and an "application agent".



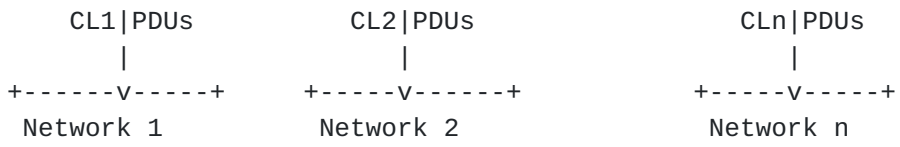


Figure 2: Components of a BP Node

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.

Convergence layer adapter - A convergence layer adapter (CLA) is a node component that 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.

Application agent - The application agent (AA) of a node is the node component that utilizes the BP services to effect communication for some user purpose. The application agent in turn has two elements, an administrative element and an application-specific element.

Application-specific element - The application-specific element of an AA is the node component that constructs, requests transmission of, accepts delivery of, and processes units of user application data.

Administrative element - The administrative element of an AA is the node component that constructs and requests transmission of administrative records (defined below), including status reports, and accepts delivery of and processes any administrative records that the node receives.

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 only administrative record defined in this specification is the status report, discussed later.

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 4.4.1 below).

Singleton endpoint - A singleton endpoint is an endpoint that always contains exactly one member.

Registration - A registration is the state machine characterizing a given node's membership in a given endpoint. Any single registration has an associated delivery failure action as defined below and must at any time be in one of two states: Active or Passive.

Delivery - 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 any relevant metadata (an implementation matter), has been presented to the node's application agent in a manner consistent with the state of that registration.

Deliverability - 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) the bundle has not yet been "abandoned" (as defined below) subject to this registration.

Abandonment - To abandon a bundle subject to some registration is to assert that the bundle is not deliverable subject to that registration.

Delivery failure action - The delivery failure action of a registration is the action that is to be taken when a bundle that is "deliverable" subject to that registration is received at a time when the registration is in the Passive state.

Destination - The destination of a bundle is the endpoint comprising the node(s) at which the bundle is to be delivered (as defined below).

Transmission - A transmission is an attempt by a node's BPA to cause copies of a bundle to be delivered to one or more of the nodes that are members of some endpoint (the bundle's destination) in response to a transmission request issued by the node's application agent.

Forwarding - To forward a bundle to a node is to invoke the services of one or more CLAs in a sustained effort to cause a copy of the bundle to be received by that node.

Discarding - To discard a bundle is to cease all operations on the bundle and functionally erase all references to it. The specific procedures by which this is accomplished are an implementation matter.

Retention constraint - A retention constraint is an element of the state of a bundle that prevents the bundle from being discarded. That is, a bundle cannot be discarded while it has any retention constraints.

Deletion - To delete a bundle is to remove unconditionally all of the bundle's retention constraints, enabling the bundle to be discarded.

3.2. Discussion of BP concepts

Multiple instances of the same bundle (the same unit of DTN protocol data) might exist concurrently in different parts of a network -- possibly 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 (copy), in that node's local memory, of some bundle that is in the network.

The 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 payload for a bundle forwarded in response to reception of a bundle is the payload of the received bundle.

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.

The manner in which the functions of the BPA are performed 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.

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, as well as the definitions of CLAs and CL protocols, are beyond the scope of this specification.

Note that the administrative element of a node's application agent may itself, in some cases, function as a convergence-layer adapter. That is, outgoing bundles may be "tunneled" through encapsulating bundles:

. An outgoing bundle constitutes a byte array. This byte array may, like any other, be presented to the bundle protocol agent as an application data unit that is to be transmitted to some endpoint.
. The original bundle thus forms the payload of an encapsulating bundle that is forwarded using some other convergence-layer protocol(s).
. When the encapsulating bundle is received, its payload is delivered to the peer application agent administrative element, which then instructs the bundle protocol agent to dispatch that original bundle in the usual way.

The purposes for which this technique may be useful (such as cross-domain security) are beyond the scope of this specification.

The only interface between the BPA and the application-specific element of the AA is the BP service interface. But between the BPA and the administrative element of the AA there is a (conceptual) private control interface in addition to the BP service interface. This private control interface enables the BPA and the administrative element of the AA to direct each 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.

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.

The destination of every bundle is an endpoint, which may or may not be singleton. The source of every bundle is a node, identified by the endpoint ID for some singleton endpoint that contains that node.

Note, though, that the source node ID asserted in a given bundle may be the null endpoint ID (as described later) rather than the endpoint ID of the actual source node; bundles for which the asserted source node ID is the null endpoint ID are termed "anonymous" bundles.

Any number of transmissions may be concurrently undertaken by the bundle protocol agent of a given node.

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

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 newly 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.

The bundle protocol does not natively ensure delivery of a bundle to its destination. Data loss along the path to the destination node can be minimized by utilizing reliable convergence-layer protocols between neighbors on all segments of the end-to-end path, but for end-to-end bundle delivery assurance it will be necessary to develop extensions to the bundle protocol and/or application-layer mechanisms.

The bundle protocol is designed for extensibility. Bundle protocol extensions, documented elsewhere, may extend this specification by:

- defining additional blocks;
- defining additional administrative records;
- defining additional bundle processing flags;
- defining additional block processing flags;
- defining additional types of bundle status reports;
- defining additional bundle status report reason codes;
- defining additional mandates and constraints on processing that conformant bundle protocol agents must perform at

specified points in the inbound and outbound bundle processing cycles.

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

The format of bundles SHALL conform to the Concise Binary Object Representation (CBOR [RFC7049]).

Each bundle SHALL be a concatenated sequence of at least two blocks, represented as a CBOR indefinite-length array. The first block in the sequence (the first item of the array) MUST be a primary bundle block in CBOR representation as described below; the bundle MUST have exactly one primary bundle block. The primary block MUST be followed by one or more canonical bundle blocks (additional array items) in CBOR representation as described below. The last such block MUST be a payload block; the bundle MUST have exactly one payload block. The last item of the array, immediately following the payload block, SHALL be a CBOR "break" stop code.

(Note that, while CBOR permits considerable flexibility in the encoding of bundles, this flexibility must not be interpreted as inviting increased complexity in protocol data unit structure.)

An implementation of the Bundle Protocol MAY discard any sequence of bytes that does not conform to the Bundle Protocol specification.

An implementation of the Bundle Protocol MAY accept a sequence of bytes that does not conform to the Bundle Protocol specification (e.g., one that represents data elements in fixed-length arrays rather than indefinite-length arrays) and transform it into conformant BP structure before processing it. Procedures for accomplishing such a transformation are beyond the scope of this specification.

4.1. BP Fundamental Data Structures

4.1.1. CRC Type

CRC type is an unsigned integer type code for which the following values (and no others) are valid:

- 0 indicates "no CRC is present."
- 1 indicates "a standard X-25 CRC-16 is present."
- 2 indicates "a standard CRC32C (Castagnoli) CRC-32 is present."

CRC type SHALL be represented as a CBOR unsigned integer.

For examples of CRC32C CRCs, see Appendix A.4 of [RFC7143].

4.1.2. CRC

CRC SHALL be omitted from a block if and only if the block's CRC type code is zero.

When not omitted, the CRC SHALL be represented as sequence of two bytes (if CRC type is 1) or as a sequence of four bytes (if CRC type is 2); in each case the sequence of bytes SHALL constitute an unsigned integer value (of 16 or 32 bits, respectively) in network byte order.

4.1.3. Bundle Processing Control Flags

Bundle processing control flags assert properties of the bundle as a whole rather than of any particular block of the bundle. They are conveyed in the primary block of the bundle.

The following properties are asserted by the bundle processing control flags:

- The bundle is a fragment. (Boolean)
- The bundle's payload is an administrative record. (Boolean)
- The bundle must not be fragmented. (Boolean)
- Acknowledgment by the user application is requested. (Boolean)
- Status time is requested in all status reports. (Boolean)
- The bundle contains a "manifest" extension block. (Boolean)

. Flags requesting types of status reports (all Boolean):

    o Request reporting of bundle reception.

    o Request reporting of bundle forwarding.

    o Request reporting of bundle delivery.

    o Request reporting of bundle deletion.

If the bundle processing control flags indicate that the bundle's application data unit is an administrative record, then all status report request flag values must be zero.

If the bundle's source node is omitted (i.e., the source node ID is the ID of the null endpoint, which has no members as discussed below; this option enables anonymous bundle transmission), then the bundle is not uniquely identifiable and all bundle protocol features that rely on bundle identity must therefore be disabled: the "Bundle must not be fragmented" flag value must be 1 and all status report request flag values must be zero.

The bundle processing control flags SHALL be represented as a CBOR unsigned integer item containing a bit field of 16 bits indicating the control flag values as follows:

. Bit 0 (the high-order bit, 0x8000): reserved.
. Bit 1 (0x4000): reserved.
. Bit 2 (0x2000): reserved.
. Bit 3(0x1000): bundle deletion status reports are requested.
. Bit 4(0x0800): bundle delivery status reports are requested.
. Bit 5(0x0400): bundle forwarding status reports are requested.
. Bit 6(0x0200): reserved.
. Bit 7(0x0100): bundle reception status reports are requested.
. Bit 8(0x0080): bundle contains a Manifest block.
. Bit 9(0x0040): status time is requested in all status reports.
. Bit 10(0x0020): user application acknowledgement is requested.
. Bit 11(0x0010): reserved.
. Bit 12(0x0008): reserved.
. Bit 13(0x0004): bundle must not be fragmented.
. Bit 14(0x0002): payload is an administrative record.
. Bit 15 (the low-order bit, 0x0001: bundle is a fragment.

4.1.4. Block Processing Control Flags

The block processing control flags assert properties of canonical bundle blocks. They are conveyed in the header of the block to which they pertain.

The following properties are asserted by the block processing control flags:

- This block must be replicated in every fragment. (Boolean)
- Transmission of a status report is requested if this block can't be processed. (Boolean)
- Block must be removed from the bundle if it can't be processed. (Boolean)
- Bundle must be deleted if this block can't be processed. (Boolean)

For each bundle whose bundle processing control flags indicate that the bundle's application data unit is an administrative record, or whose source node ID is the null endpoint ID as defined below, the value of the "Transmit status report if block can't be processed" flag in every canonical block of the bundle must be zero.

The block processing control flags SHALL be represented as a CBOR unsigned integer item containing a bit field of 8 bits indicating the control flag values as follows:

- Bit 0 (the high-order bit, 0x80): reserved.
- Bit 1 (0x40): reserved.
- Bit 2(0x20): reserved.
- Bit 3(0x10): reserved.
- Bit 4(0x08): bundle must be deleted if block can't be processed.
- Bit 5(0x04): transmission of a status report is requested if block can't be processed.
- Bit 6(0x02): block must be removed from bundle if it can't be processed.
- Bit 7(the low-order bit, 0x01): block must be replicated in every fragment.

4.1.5. Identifiers

4.1.5.1. Endpoint ID

The destinations of bundles are bundle endpoints, identified by text strings termed "endpoint IDs" (see Section 3.1). Each endpoint ID (EID) is 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.

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.

Each BP endpoint ID (EID) SHALL be represented as a CBOR array comprising a 2-tuple.

The first item of the array SHALL be the code number identifying the endpoint's URI scheme [URI], as defined in the registry of URI scheme code numbers for Bundle Protocol maintained by IANA as described in Section 10. [URIREG]. Each URI scheme code number SHALL be represented as a CBOR unsigned integer.

The second item of the array SHALL be the applicable CBOR representation of the scheme-specific part (SSP) of the EID, defined as follows:

. If the EID's URI scheme is "dtn" then the SSP SHALL be represented as a CBOR text string unless the EID's SSP is "none", in which case the SSP SHALL be represented as a CBOR unsigned integer with the value zero.
. If the EID's URI scheme is "ipn" then the SSP SHALL be represented as a CBOR array comprising a 2-tuple. The first item of this array SHALL be the EID's node number represented as a CBOR unsigned integer. The second item of this array

SHALL be the EID's service number represented as a CBOR unsigned integer.

. Definitions of the CBOR representations of the SSPs of EIDs encoded in other URI schemes are included in the specifications defining those schemes.

4.1.5.2. 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 using that endpoint's ID.

4.1.6. DTN Time

A DTN time is an unsigned integer indicating an interval of Unix epoch time that has elapsed since the start of the year 2000 on the Coordinated Universal Time (UTC) scale [UTC], which is Unix epoch timestamp 946684800. (Note that the DTN time that equates to the current time as reported by the POSIX time() function can be derived by subtracting 946684800 from that reported time value.) Each DTN time SHALL be represented as a CBOR unsigned integer item.

4.1.7. Creation Timestamp

Each creation timestamp SHALL be represented as a CBOR array item comprising a 2-tuple.

The first item of the array SHALL be a DTN time.

The second item of the array SHALL be the creation timestamp's sequence number, represented as a CBOR unsigned integer.

4.1.8. Block-type-specific Data

Block-type-specific data in each block (other than the primary block) SHALL be the applicable CBOR representation of the content of the block. Details of this representation are included in the specification defining the block type.

4.2. Bundle Representation

This section describes the primary block in detail and non-primary blocks in general. 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 [BPSEC]) may require that BP implementations conforming to those protocols construct and process additional blocks.

4.2.1. Bundle

Each bundle SHALL be represented as a CBOR indefinite-length array. The first item of this array SHALL be the CBOR representation of a Primary Block. Every other item of the array except the last SHALL be the CBOR representation of a Canonical Block. The last item of the array SHALL be a CBOR "break" stop code.

Associated with each block of a bundle is a block number. The block number uniquely identifies the block within the bundle, enabling blocks (notably bundle security protocol blocks) to reference other blocks in the same bundle without ambiguity. The block number of the primary block is implicitly zero; the block numbers of all other blocks are explicitly stated in block headers as noted below. Block numbering is unrelated to the order in which blocks are sequenced in the bundle. The block number of the payload block is always 1.

4.2.2. Primary Bundle Block

The primary bundle block contains the basic information needed to forward bundles to their destinations.

Each primary block SHALL be represented as a CBOR array; the number of elements in the array SHALL be 8 (if the bundle is not a fragment and CRC type is zero) or 9 (if the bundle is not a fragment and CRC type is non-zero) or 10 (if the bundle is a fragment and CRC type is zero) or 11 (if the bundle is a fragment and CRC-type is non-zero).

The fields of the primary bundle block SHALL be as follows, listed in the order in which they MUST appear:

Version: An unsigned integer value indicating the version of the bundle protocol that constructed this block. The present document describes version 7 of the bundle protocol. Version number SHALL be represented as a CBOR unsigned integer item.

Bundle Processing Control Flags: The Bundle Processing Control Flags are discussed in Section 4.1.3. above.

CRC Type: CRC Type codes are discussed in Section 4.1.1. above.

Destination EID: The Destination EID field identifies the bundle endpoint that is the bundle's destination, i.e., the endpoint that contains the node(s) at which the bundle is to be delivered.

Source node ID: The Source node ID field identifies the bundle node at which the bundle was initially transmitted, except that Source node ID may be the null endpoint ID in the event that the bundle's source chooses to remain anonymous.

Report-to EID: The Report-to EID field identifies the bundle 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 unsigned integers 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 of these integers is the bundle's creation time, while the second is the bundle's creation timestamp sequence number. Bundle creation time shall be the DTN time at which the transmission request was received that resulted in the creation of the bundle. Sequence count shall be 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, it is recommended that bundle creation time be set to zero and that the counter used as the source of the bundle sequence count never be reset to zero. Note that, in general, the creation of two distinct bundles with the same source node ID and bundle creation timestamp may result in unexpected network behavior and/or suboptimal performance. 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 unsigned integer that indicates the time at which the bundle's payload will no longer be useful, encoded as a number of microseconds past the creation time. (For high-rate deployments with very brief disruptions, fine-grained expression of bundle lifetime may be useful.) When a bundle's age exceeds its lifetime, bundle nodes need no longer retain or forward the bundle; the bundle SHOULD be deleted from the network. Bundle lifetime SHALL be represented as a CBOR unsigned integer item.

Fragment offset: If and only if the Bundle Processing Control Flags of this Primary block indicate that the bundle is a fragment, fragment offset SHALL be present in the primary block. Fragment offset SHALL be represented as a CBOR unsigned integer indicating the offset from the start of the original application data unit at which the bytes comprising the payload of this bundle were located.

Total Application Data Unit Length: If and only if the Bundle Processing Control Flags of this Primary block indicate that the bundle is a fragment, total application data unit length SHALL be present in the primary block. Total application data unit length SHALL be represented as a CBOR unsigned integer indicating the total length of the original application data unit of which this bundle's payload is a part.

CRC: If and only if the value of the CRC type field of this Primary block is non-zero, a CRC SHALL be present in the primary block. The length and nature of the CRC SHALL be as indicated by the CRC type. The CRC SHALL be computed over the concatenation of all bytes (including CBOR "break" characters) of the primary block including the CRC field itself, which for this purpose SHALL be temporarily populated with the value zero.

4.2.3. Canonical Bundle Block Format

Every block other than the primary block (all such blocks are termed "canonical" blocks) SHALL be represented as a CBOR array; the number of elements in the array SHALL be 5 (if CRC type is zero) or 6 (otherwise).

The fields of every canonical block SHALL be as follows, listed in the order in which they MUST appear:

. Block type code, an unsigned integer. Bundle block type code 1 indicates that the block is a bundle payload block. Block type codes 2 through 9 are explicitly reserved as noted later in this specification. Block type codes 192 through 255 are not

reserved and are available for private and/or experimental use. All other block type code values are reserved for future use.

- Block number, an unsigned integer as discussed above.
- Block processing control flags as discussed in Section 4.1.4 above.
- CRC type as discussed in Section 4.1.1 above.
- Block-type-specific data represented as a single definite-length CBOR byte string, i.e., a CBOR byte string that is not of indefinite length. For each type of block, the block-type-specific data byte string is the serialization, in a block-type-specific manner, of the data conveyed by that type of block; definitions of blocks are required to define the manner in which block-type-specific data are serialized within the block-type-specific data field. For the Payload Block in particular (block type 1), the block-type-specific data field, termed the "payload", SHALL be an application data unit, or some contiguous extent thereof, represented as a definite-length CBOR byte string.
- If and only if the value of the CRC type field of this block is non-zero, a CRC. If present, the length and nature of the CRC SHALL be as indicated by the CRC type and the CRC SHALL be computed over the concatenation of all bytes of the block (including CBOR "break" characters) including the CRC field itself, which for this purpose SHALL be temporarily populated with the value zero.

4.3. 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. The values of the block processing control flags indicate the action to be taken by the bundle protocol agent when this is the case.

The following extension blocks are defined in other DTN protocol specification documents as noted:

- Block Integrity Block (block type 2) and Block Confidentiality Block (block type 3) are defined in the Bundle Security Protocol specification (work in progress).
- Manifest Block (block type 4) is defined in the Manifest Extension Block specification (work in progress). The manifest

block identifies the blocks that were present in the bundle at the time it was created. The bundle MUST contain one (1) occurrence of this type of block if the value of the "manifest" flag in the bundle processing control flags is 1; otherwise the bundle MUST NOT contain any Manifest block.

. The Flow Label Block (block type 6) is defined in the Flow Label Extension Block specification (work in progress). The flow label block is intended to govern transmission of the bundle by convergence-layer adapters.

The following extension blocks are defined in the current document.

4.3.1. Previous Node

The Previous Node block, block type 7, identifies the node that forwarded this bundle to the local node (i.e., to the node at which the bundle currently resides); its block-type-specific data is the node ID of that forwarder node which SHALL take the form of a node ID represented as described in Section 4.1.5.2. above. If the local node is the source of the bundle, then the bundle MUST NOT contain any previous node block. Otherwise the bundle SHOULD contain one (1) occurrence of this type of block.

4.3.2. Bundle Age

The Bundle Age block, block type 8, contains the number of microseconds 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 unsigned integer containing the age of the bundle in microseconds, which SHALL be represented as a CBOR unsigned integer item. (The age of the bundle is 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, plus the summation of signal propagation time over all episodes of transmission between forwarding nodes. Determination of these values is an implementation matter.) 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. A bundle MUST NOT contain multiple occurrences of the bundle age block, as this could result in processing anomalies.

4.3.3. Hop Count

The Hop Count block, block type 9, contains two unsigned integers, hop limit and hop count. A "hop" is here defined as an occasion on which a bundle was forwarded from one node to another node. The hop limit value SHOULD NOT be changed at any time after creation of the Hop Count block; the hop count value SHOULD initially be zero and SHOULD be increased by 1 on each hop.

The hop count block 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. When a bundle's hop count exceeds its hop limit, the bundle SHOULD be deleted for the reason "hop limit exceeded", following the bundle deletion procedure defined in Section 5.10. . Procedures for determining the appropriate hop limit for a block are beyond the scope of this specification. The block-type-specific data in a hop count block SHALL be represented as a CBOR array comprising a 2-tuple. The first item of this array SHALL be the bundle's hop limit, represented as a CBOR unsigned integer. The second item of this array SHALL be the bundle's hop count, represented as a CBOR unsigned integer. 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. Supplementary DTN protocol specifications (including, but not restricted to, the Bundle Security Protocol [BPSEC]) may augment, override, or supersede the mandates of this document.

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), 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 MUST be disabled by default and enabled only when the risk of excessive network traffic is deemed acceptable.

When the generation of status reports is enabled, 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 "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.

5.2. Bundle Transmission

The steps in processing a bundle transmission request are:

Step 1: 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 null endpoint ID, indicating that the source of the bundle is anonymous, or else the EID of a singleton endpoint whose only member is the node of which the BPA is a component.

Step 2: 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 and for the purposes of all subsequent processing of this bundle at this node the node's membership in the bundle's destination endpoint SHALL be disavowed.

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 4. In particular:

- 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 on 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 but 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. 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 any appropriate convergence layer adapter(s) 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 4, 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: 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 protocol agent invokes convergence layer adapter services is a BPA implementation matter. Determining the time at which each convergence layer adapter subsequently responds to this service invocation by sending

the bundle is a convergence-layer adapter implementation matter. Note that:

- If the bundle contains a flow label extension block (to be defined in a future document) then that flow label value MAY identify 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, as defined in 4.3.2. above, 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 5: 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, and status reporting is enabled, then a bundle forwarding status report SHOULD be generated, destined for the bundle's report-to endpoint ID. The reason code on this bundle forwarding status report MUST be "no additional information".
- If any applicable bundle protocol extensions mandate generation of status reports upon conclusion of convergence-layer data sending procedures, all such status reports SHOULD be generated with extension-mandated reason codes.
- The bundle's "Forward pending" retention constraint MUST be removed.

5.4.1. Forwarding Contraindicated

The steps in responding to contraindication of forwarding are:

Step 1: The bundle protocol agent MUST determine whether or not to declare failure in forwarding the bundle. 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, when -- at some future time - the forwarding of this bundle ceases to be contraindicated, processing proceeds from Step 4 of Section 5.4.

5.4.2. Forwarding Failed

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

Step 1: The bundle protocol agent MAY forward the bundle back to the node that sent it, as identified by the Previous Node block, if present. This forwarding, if performed, SHALL be accomplished by performing Step 4 and Step 5 of section 5.4 where the sole node selected for forwarding SHALL be the node that sent the bundle.

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 5.10 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; 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 5.10 MUST be followed.

5.6. Bundle Reception

The steps in processing a bundle that has been 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, and status reporting is enabled, 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, and status reporting is enabled, 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 5.10 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 that the block must be discarded, then processing continues with the next extension block that the bundle protocol agent cannot process, if any; otherwise, processing proceeds from step 4.

Step 4: 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:

. An additional implementation-specific delivery deferral procedure MAY optionally be associated with the registration.
. If the registration is in the Active state, then the bundle MUST 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.

. If the registration is in the Passive state, or if delivery of the bundle fails for some implementation-specific reason, then the registration's delivery failure action MUST be taken. Delivery failure action MUST be one of the following:

- o defer delivery 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, and also perform any additional delivery deferral procedure associated with the registration; or

- o abandon delivery of the bundle subject to this registration (as defined in 3.1.).

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 and bundle status reporting is enabled, 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.

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 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. NOTE, however, that some combinations of bundle fragmentation, replication, and routing might result in unexpected traffic patterns.

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 fragmented bundle (that is, the bundle that is being fragmented). Note that the payloads of fragments resulting from different fragmentation episodes, in different parts of the network, may be overlapping subsets of the fragmented bundle's payload.
- The primary block of each fragment MUST differ from that of the fragmented bundle, in that the bundle processing flags of the fragment MUST indicate that the bundle is a fragment and both fragment offset and total application data unit length must be provided. Additionally, the CRC of the primary block of the fragmented bundle, if any, MUST be replaced in each fragment by a new CRC computed for the primary block of that fragment.
- The payload blocks of fragments will differ from that of the fragmented bundle as noted above.
- If the fragmented bundle is not a fragment or is the fragment with offset zero, then all extension blocks of the fragmented bundle MUST be replicated in the fragment whose offset is zero.
- Each of the fragmented bundle's extension blocks whose "Block must be replicated in every fragment" flag is set to 1 MUST be replicated in every fragment.
- Beyond these rules, replication of extension blocks in the fragments is an implementation matter.

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.
- 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. Bundle Deletion

The steps in deleting a bundle are:

Step 1: If the "request reporting of bundle deletion" flag in the bundle's status report request field is set to 1, and if status reporting is enabled, 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.

5.11. Discarding a Bundle

As soon as a bundle has no remaining retention constraints it MAY be discarded, thereby releasing any persistent storage that may have been allocated to it.

5.12. 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 5.10 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. One type of administrative record has been defined to date: bundle status reports. Note that additional types of administrative records may be defined by supplementary DTN protocol specification documents.

Every administrative record consists of:

- Record type code (an unsigned integer for which valid values are as defined below).
- Record content in type-specific format.

Valid administrative record type codes are defined as follows:

Value	Meaning
1	Bundle status report.
(other)	Reserved for future use.

Figure 3: Administrative Record Type Codes

Each BP administrative record SHALL be represented as a CBOR array comprising a 2-tuple.

The first item of the array SHALL be a record type code, which SHALL be represented as a CBOR unsigned integer.

The second element of this array SHALL be the applicable CBOR representation of the content of the record. Details of the CBOR representation of administrative record type 1 are provided below. Details of the CBOR representation of other types of administrative record type are included in the specifications defining those records.

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, forwarding, final delivery, and deletion. They are transmitted to the Report-to endpoints of bundles.

Each bundle status report SHALL be represented as a CBOR array. The number of elements in the array SHALL be either 6 (if the subject bundle is a fragment) or 4 (otherwise).

The first item of the bundle status report array SHALL be bundle status information represented as a CBOR array of at least 4

elements. The first four items of the bundle status information array shall provide information on the following four status assertions, in this order:

- Reporting node received bundle.
- Reporting node forwarded the bundle.
- Reporting node delivered the bundle.
- Reporting node deleted the bundle.

Each item of the bundle status information array SHALL be a bundle status item represented as a CBOR array; the number of elements in each such array SHALL be either 2 (if the value of the first item of this bundle status item is 1 AND the "Report status time" flag was set to 1 in the bundle processing flags of the bundle whose status is being reported) or 1 (otherwise). The first item of the bundle status item array SHALL be a status indicator, a Boolean value indicating whether or not the corresponding bundle status is asserted, represented as a CBOR Boolean value. The second item of the bundle status item array, if present, SHALL indicate the time (as reported by the local system clock, an implementation matter) at which the indicated status was asserted for this bundle, represented as a DTN time as described in Section 4.1.6. above.

The second item of the bundle status report array SHALL be the bundle status report reason code explaining the value of the status indicator, represented as a CBOR unsigned integer. Valid status report reason codes are defined in Figure 4 below but 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 [BPSEC]) may define additional reason codes.

Value	Meaning
0	No additional information.
1	Lifetime expired.
2	Forwarded over unidirectional link.

3	Transmission canceled.
4	Depleted storage.
5	Destination endpoint ID unintelligible.
6	No known route to destination from here.
7	No timely contact with next node on route.
8	Block unintelligible.
9	Hop limit exceeded.
(other)	Reserved for future use.

Figure 4: Status Report Reason Codes

The third item of the bundle status report array SHALL be the source node ID identifying the source of the bundle whose status is being reported, represented as described in Section 4.1.5.2. above.

The fourth item of the bundle status report array SHALL be the creation timestamp of the bundle whose status is being reported, represented as described in Section 4.1.7. above.

The fifth item of the bundle status report array SHALL be present if and only if the bundle whose status is being reported contained a

fragment offset. If present, it SHALL be the subject bundle's fragment offset represented as a CBOR unsigned integer item.

The sixth item of the bundle status report array SHALL be present if and only if the bundle whose status is being reported contained a fragment offset. If present, it SHALL be the length of the subject bundle's payload represented as a CBOR unsigned integer item.

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 administrative record references a bundle and the referenced bundle is a fragment, the administrative record MUST contain the fragment offset and fragment length.

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

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 [BPSEC]) may expect convergence layer adapters that serve BP implementations conforming to those protocols to provide additional services such as reporting on the transmission and/or reception progress of individual bundles (at completion and/or incrementally), 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. Implementation Status

[NOTE to the RFC Editor: please remove this section before publication, as well as the reference to RFC 7942.]

This section records the status of known implementations of the protocol defined by this specification at the time of posting of this Internet-Draft, and is based on a proposal described in RFC 7942. The description of implementations in this section is intended to assist the IETF in its decision processes in progressing drafts to RFCs. Please note that the listing of any individual implementation here does not imply endorsement by the IETF. Furthermore, no effort has been spent to verify the information presented here that was supplied by IETF contributors. This is not intended as, and must not be construed to be, a catalog of available implementations or their features. Readers are advised to note that other implementations may exist.

According to RFC 7942, "this will allow reviewers and working groups to assign due consideration to documents that have the benefit of running code, which may serve as evidence of valuable experimentation and feedback that have made the implemented protocols more mature. It is up to the individual working groups to use this information as they see fit".

At the time of this writing, there are three known implementations of the current document.

The first known implementation is microPCN (https://upcn.eu/). According to the developers:

> The Micro Planetary Communication Network (uPCN) is a free software project intended to offer an implementation of Delay-tolerant Networking protocols for POSIX operating systems (well,

and for Linux) plus for the ARM Cortex STM32F4 microcontroller series. More precisely it currently provides an implementation of

- the Bundle Protocol (BP, RFC 5050),
- the Bundle Protocol version 7 specification draft (version 6),
- the DTN IP Neighbor Discovery (IPND) protocol, and
- a routing approach optimized for message-ferry micro LEO satellites.

uPCN is written in C and is built upon the real-time operating system FreeRTOS. The source code of uPCN is released under the "BSD 3-Clause License".

The project depends on an execution environment offering link layer protocols such as AX.25. The source code uses the USB subsystem to interact with the environment.

The second known implementation is PyDTN, developed by X-works, s.r.o (https://x-works.sk/). The final third of the implementation was developed during the IETF 101 Hackathon. According to the developers, PyDTN implements bundle coding/decoding and neighbor discovery. PyDTN is written in Python and has been shown to be interoperable with uPCN.

The third known implementation is "Terra" (https://github.com/RightMesh/Terra/), a Java implementation developed in the context of terrestrial DTN. It includes an implementation of a "minimal TCP" convergence layer adapter.

9. Security Considerations

The bundle protocol security architecture and the available security services are specified in an accompanying document, the Bundle Security Protocol specification [BPSEC].

The bpsec extensions to Bundle Protocol enable each block of a bundle (other than a bpsec extension block) to be individually authenticated by a signature block (Block Integrity Block, or BIB) and also enable each block of a bundle other than the primary block (and the bpsec extension blocks themselves) to be individually encrypted by a BCB.

Because the security mechanisms are extension blocks that are themselves inserted into the bundle, the integrity and confidentiality of bundle blocks are protected while the bundle is at rest, awaiting transmission at the next forwarding opportunity, as well as in transit.

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.

Note that, while the primary block must remain in the clear for routing purposes, the Bundle Protocol can be protected against traffic analysis to some extent by using bundle-in-bundle encapsulation to tunnel bundles to a safe forward distribution point: the encapsulated bundle forms the payload of an encapsulating bundle, and that payload block may be encrypted by a BCB.

Note that the generation of bundle status reports is disabled by default because malicious initiation of bundle status reporting could result in the transmission of extremely large numbers of bundle, effecting a denial of service attack.

The bpsec extensions accommodate an open-ended range of ciphersuites; different ciphersuites may be utilized to protect different blocks. One possible variation is to sign and/or encrypt blocks in symmetric keys securely formed by Diffie-Hellman procedures (such as EKDH) using the public and private keys of the sending and receiving nodes. For this purpose, the key distribution problem reduces to the problem of trustworthy delay-tolerant distribution of public keys, a current research topic.

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 set 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, subject to the following guidelines:

. Every block (that is not a bpsec extension block) of every bundle SHOULD be authenticated by a BIB citing the ID of the node that inserted that block. (Note that a single BIB may authenticate multiple "target" blocks.) BIB authentication MAY be omitted on (and only on) any initial end-to-end path segments on which it would impose unacceptable overhead, provided that satisfactory authentication is ensured at the

convergence layer and that BIB authentication is asserted on the first path segment on which the resulting overhead is acceptable and on all subsequent path segments.

. If any segment of the end-to-end path of a bundle will traverse the Internet or any other potentially insecure communication environment, then the payload block SHOULD be encrypted by a BCB on this path segment and all subsequent segments of the end-to-end path.

10. IANA Considerations

This document defines the following additional Bundle Protocol block types, for which values are to be assigned from the Bundle Administrative Record Types namespace [RFC6255]:

Value	Name	Meaning	Reference
7	Previous node	Identifies sender	This document
8	Bundle age	Bundle age in seconds	This document
9	Hop count	#prior transmission attempts	This document

This document also defines a new URI scheme type field - an unsigned integer of undefined length - for which IANA is to create and maintain a new registry named "URI scheme type values". Initial values for the Bundle Protocol URI scheme type registry are given below; future assignments are to be made through Expert Review. Each assignment consists of a URI scheme type name and its associated value.

Value	URI Scheme Type Name	Reference
0	Reserved	
1	dtn	RFC5050, Section 4.4
2	ipn	RFC6260, Section 4
3-254	Unassigned	
255	Reserved	

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11. References

11.1. Normative References

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12. Acknowledgments

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13. 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.
- Migrate custody transfer to the bundle-in-bundle encapsulation specification [BIBE].
- Introduce the concept of "node ID" as functionally distinct from endpoint ID, while having the same syntax.
- Restructure primary block, making it immutable. Add optional CRC.
- 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 extension block, defined in this specification.
- Add flow label extension block, *not* defined in this specification.
- Add manifest extension block, *not* defined in this specification.
- Add hop count extension block, defined in this specification.
- Migrate Quality of Service markings to a new QoS extension block, *not* defined in this specification.

Appendix A. For More Information

Please refer comments to dtn@ietf.org. DTN Working Group documents are located at https://datatracker.ietf.org/wg/dtn/documents. The original Delay Tolerant Networking Research Group (DTNRG) Web site is located at https://irtf.org/concluded/dtnrg.

Appendix B. CDDL expression

For informational purposes, Carsten Bormann and Brian Sipos have kindly provided an expression of the Bundle Protocol specification in the Concise Data Definition Language (CDDL). That CDDL expression is presented below. Note that wherever the CDDL expression is in disagreement with the textual representation of the BP specification presented in the earlier sections of this document, the textual representation rules.

```
start = bundle / #6.55799(bundle)


; Times before 2000 are invalid

dtn-time = uint


; CRC enumerated type

crc-type = &(

  crc-none: 0,

  crc-16bit: 1,

  crc-32bit: 2

)

; Either 16-bit or 32-bit

crc-value = (bstr .size 2) / (bstr .size 4)


creation-timestamp = [

  dtn-time, ; absolute time of creation

  sequence: uint ; sequence within the time

]
```

```
   eid = $eid .within eid-structure
   eid-structure = [
     uri-code: uint,
     SSP: any
   ]
   $eid /= [
     uri-code: 1,
     SSP: (tstr / 0)
   ]
   $eid /= [
     uri-code: 2,
     SSP: [
       nodenum: uint,
       servicenum: uint
     ]
   ]

   ; The root bundle array
   bundle = [primary-block, *extension-block, payload-block]

   primary-block = [
     version: 7,
     bundle-control-flags,
     crc-type,
```

```
    destination: eid,
    source-node: eid,
    report-to: eid,
    creation-timestamp,
    lifetime: uint,
    ? (
      fragment-offset: uint,
      total-application-data-length: uint
    ),
    ? crc-value,
  ]
  bundle-control-flags = uint .bits bundleflagbits
  bundleflagbits = &(
    reserved: 15,
    reserved: 14,
    reserved: 13,
    bundle-deletion-status-reports-are-requested: 12,
    bundle-delivery-status-reports-are-requested: 11,
    bundle-forwarding-status-reports-are-requested: 10,
    reserved: 9,
    bundle-reception-status-reports-are-requested: 8,
    bundle-contains-a-Manifest-block: 7,
    status-time-is-requested-in-all-status-reports: 6,
    user-application-acknowledgement-is-requested: 5,
```

```
    reserved: 4,
    reserved: 3,
    bundle-must-not-be-fragmented: 2,
    payload-is-an-administrative-record: 1,
    bundle-is-a-fragment: 0
  )

  ; Abstract shared structure of all non-primary blocks
  canonical-block-structure = [
    block-type-code: uint,
    block-number: uint,
    block-control-flags,
    crc-type,
    ; Each block type defines the content within the bytestring
    block-type-specific-data,
    ? crc-value
  ]
  block-control-flags = uint .bits blockflagbits
  blockflagbits = &(
    reserved: 7,
    reserved: 6,
    reserved: 5,
    reserved: 4,
    bundle-must-be-deleted-if-block-cannot-be-processed: 3,
```

```
    status-report-must-be-transmitted-if-block-cannot-be-processed: 2,
    block-must-be-removed-from-bundle-if-it-cannot-be-processed: 1,
    block-must-be-replicated-in-every-fragment: 0
  )
  block-type-specific-data = bstr / #6.24(bstr)
  ; Actual CBOR data embedded in a bytestring, with optional tag to
  indicate so
  embedded-cbor<Item> = (bstr .cbor Item) / #6.24(bstr .cbor Item)

  ; Extension block type, which does not specialize other than the
  code/number
  extension-block = $extension-block-structure .within canonical-
  block-structure
  ; Generic shared structure of all non-primary blocks
  extension-block-use<CodeValue, BlockData> = [
    block-type-code: CodeValue,
    block-number: (uint .ne 0),
    block-control-flags,
    crc-type,
    BlockData,
    ? crc-value
  ]

  ; Payload block type
  payload-block = payload-block-structure .within canonical-block-
  structure
```

```
   payload-block-structure = [
     block-type-code: 1,
     block-number: 0,
     block-control-flags,
     crc-type,
     $payload-block-data,
     ? crc-value
   ]

   ; Arbitrary payload data, including non-CBOR bytestring
   $payload-block-data /= block-type-specific-data



   ; Administrative record as a payload data specialization
   $payload-block-data /= embedded-cbor<admin-record>
   admin-record = $admin-record .within admin-record-structure
   admin-record-structure = [
     record-type-code: uint,
     record-content: any
   ]
   ; Only one defined record type
   $admin-record /= [1, status-record-content]
   status-record-content = [
     bundle-status-information,
```

```
    status-report-reason-code: uint,
    source-node-eid: eid,
    subject-creation-timestamp: creation-timestamp,
    ? (
      subject-payload-offset: uint,
      subject-payload-length: uint
    )
  ]
  bundle-status-information = [
    reporting-node-received-bundle: status-info-content,
    reporting-node-forwarded-bundle: status-info-content,
    reporting-node-delivered-bundle: status-info-content,
    reporting-node-deleted-bundle: status-info-content
  ]
  status-info-content = [
    status-indicator: bool,
    ? timestamp: dtn-time
  ]



  ; Previous Node extension block
  $extension-block-structure /=
    extension-block-use<7, embedded-cbor<ext-data-previous-node>>
  ext-data-previous-node = eid
```

```
   ; Bundle Age extension block
   $extension-block-structure /=
     extension-block-use<8, embedded-cbor<ext-data-bundle-age>>
   ext-data-bundle-age = uint

   ; Hop Count extension block
   $extension-block-structure /=
     extension-block-use<9, embedded-cbor<ext-data-hop-count>>
   ext-data-hop-count = [
     hop-limit: uint,
     hop-count: uint
   ]
```

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.C.Burleigh@jpl.nasa.gov

Kevin Fall
Nefeli Networks, Inc.
2150 Shattuck Ave.
Berkeley, CA 94704
US
Email: kfall@kfall.com

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