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Delay-Tolerant Networking TCP Convergence Layer Protocol Version 4

Abstract

This document describes a TCP-based convergence layer (TCPCL) for Delay-Tolerant Networking (DTN). This version of the TCPCL protocol resolves implementation issues in the earlier TCPCL Version 3 of RFC7242 and updates to the Bundle Protocol (BP) contents, encodings, and convergence layer requirements in BP Version 7. Specifically, the TCPCLv4 uses CBOR-encoded BPv7 bundles as its service data unit being transported and provides a reliable transport of such bundles. This version of TCPCL also includes security and extensibility mechanisms.

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1. Introduction

This document describes the TCP-based convergence-layer protocol for Delay-Tolerant Networking. Delay-Tolerant Networking is an end-to-end architecture providing communications in and/or through highly stressed environments, including those with intermittent connectivity, long and/or variable delays, and high bit error rates. More detailed descriptions of the rationale and capabilities of these networks can be found in "Delay-Tolerant Network Architecture" [[RFC4838](#)].

An important goal of the DTN architecture is to accommodate a wide range of networking technologies and environments. The protocol used for DTN communications is the Bundle Protocol Version 7 (BPv7) [[I-D.ietf-dtn-bpbis](#)], an application-layer protocol that is used to construct a store-and-forward overlay network. BPv7 requires the services of a "convergence-layer adapter" (CLA) to send and receive bundles using the service of some "native" link, network, or Internet protocol. This document describes one such convergence-layer adapter that uses the well-known Transmission Control Protocol (TCP). This convergence layer is referred to as TCP Convergence Layer Version 4 (TCPCLv4). For the remainder of this document, the abbreviation "BP" without the version suffix refers to BPv7. For the remainder of this document, the abbreviation "TCPCL" without the version suffix refers to TCPCLv4.

The locations of the TCPCL and the BP in the Internet model protocol stack (described in [[RFC1122](#)]) are shown in Figure 1. In particular, when BP is using TCP as its bearer with TCPCL as its convergence layer, both BP and TCPCL reside at the application layer of the Internet model.

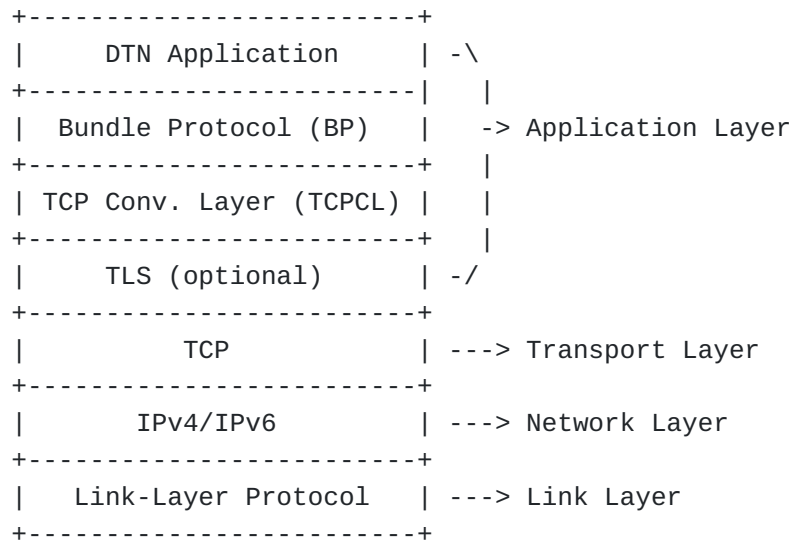


Figure 1: The Locations of the Bundle Protocol and the TCP Convergence-Layer Protocol above the Internet Protocol Stack

1.1. Scope

This document describes the format of the protocol data units passed between entities participating in TCPCL communications. This document does not address:

*The format of protocol data units of the Bundle Protocol, as those are defined elsewhere in [[I-D.ietf-dtn-bpbis](#)]. This

includes the concept of bundle fragmentation or bundle encapsulation. The TCPCL transfers bundles as opaque data blocks.

- *Mechanisms for locating or identifying other bundle entities (peers) within a network or across an internet. The mapping of Node ID to potential convergence layer (CL) protocol and network address is left to implementation and configuration of the BP Agent and its various potential routing strategies. The mapping of DNS name and/or address to a choice of end-entity certificate to authenticate a node to its peers.
- *Logic for routing bundles along a path toward a bundle's endpoint. This CL protocol is involved only in transporting bundles between adjacent entities in a routing sequence.
- *Policies or mechanisms for issuing Public Key Infrastructure Using X.509 (PKIX) certificates; provisioning, deploying, or accessing certificates and private keys; deploying or accessing certificate revocation lists (CRLs); or configuring security parameters on an individual entity or across a network.
- *Uses of TLS which are not based on PKIX certificate authentication (see [Section 8.12.2](#)) or in which authentication of both entities is not possible (see [Section 8.12.1](#)).

Any TCPCL implementation requires a BP agent to perform those above listed functions in order to perform end-to-end bundle delivery.

2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [[RFC2119](#)] [[RFC8174](#)] when, and only when, they appear in all capitals, as shown here.

2.1. Definitions Specific to the TCPCL Protocol

This section contains definitions specific to the TCPCL protocol.

Network Byte Order: Most significant byte first, a.k.a., big endian. All of the integer encodings in this protocol SHALL be transmitted in network byte order.

TCPCL Entity: This is the notional TCPCL application that initiates TCPCL sessions. This design, implementation, configuration, and specific behavior of such an entity is outside of the scope of this document. However, the concept of an entity has utility within the scope of this document as the container and initiator

of TCPCL sessions. The relationship between a TCPCL entity and TCPCL sessions is defined as follows:

*A TCPCL Entity MAY actively initiate any number of TCPCL Sessions and should do so whenever the entity is the initial transmitter of information to another entity in the network.

*A TCPCL Entity MAY support zero or more passive listening elements that listen for connection requests from other TCPCL Entities operating on other entities in the network.

*A TCPCL Entity MAY passively initiate any number of TCPCL Sessions from requests received by its passive listening element(s) if the entity uses such elements.

These relationships are illustrated in [Figure 2](#). For most TCPCL behavior within a session, the two entities are symmetric and there is no protocol distinction between them. Some specific behavior, particularly during session establishment, distinguishes between the active entity and the passive entity. For the remainder of this document, the term "entity" without the prefix "TCPCL" refers to a TCPCL entity.

TCP Connection: The term Connection in this specification exclusively refers to a TCP connection and any and all behaviors, sessions, and other states associated with that TCP connection.

TCPCL Session: A TCPCL session (as opposed to a TCP connection) is a TCPCL communication relationship between two TCPCL entities. A TCPCL session operates within a single underlying TCP connection and the lifetime of a TCPCL session is bound to the lifetime of that TCP connection. A TCPCL session is terminated when the TCP connection ends, due either to one or both entities actively closing the TCP connection or due to network errors causing a failure of the TCP connection. Within a single TCPCL session there are two possible transfer streams; one in each direction, with one stream from each entity being the outbound stream and the other being the inbound stream (see [Figure 3](#)). From the perspective of a TCPCL session, the two transfer streams do not logically interact with each other. The streams do operate over the same TCP connection and between the same BP agents, so there are logical relationships at those layers (message and bundle interleaving respectively). For the remainder of this document, the term "session" without the prefix "TCPCL" refers to a TCPCL session.

Session parameters: These are a set of values used to affect the operation of the TCPCL for a given session. The manner in which

these parameters are conveyed to the bundle entity and thereby to the TCPCL is implementation dependent. However, the mechanism by which two entities exchange and negotiate the values to be used for a given session is described in [Section 4.3](#).

Transfer Stream: A Transfer stream is a uni-directional user-data path within a TCPCL Session. Transfers sent over a transfer stream are serialized, meaning that one transfer must complete its transmission prior to another transfer being started over the same transfer stream. At the stream layer there is no logical relationship between transfers in that stream; it's only within the BP agent that transfers are fully decoded as bundles. Each uni-directional stream has a single sender entity and a single receiver entity.

Transfer: This refers to the procedures and mechanisms for conveyance of an individual bundle from one node to another. Each transfer within TCPCL is identified by a Transfer ID number which is guaranteed to be unique only to a single direction within a single Session.

Transfer Segment: A subset of a transfer of user data being communicated over a transfer stream.

Idle Session: A TCPCL session is idle while there is no transmission in-progress in either direction. While idle, the only messages being transmitted or received are KEEPALIVE messages.

Live Session: A TCPCL session is live while there is a transmission in-progress in either direction.

Reason Codes: The TCPCL uses numeric codes to encode specific reasons for individual failure/error message types.

The relationship between connections, sessions, and streams is shown in [Figure 3](#).



Figure 2: The relationships between TCPCL entities

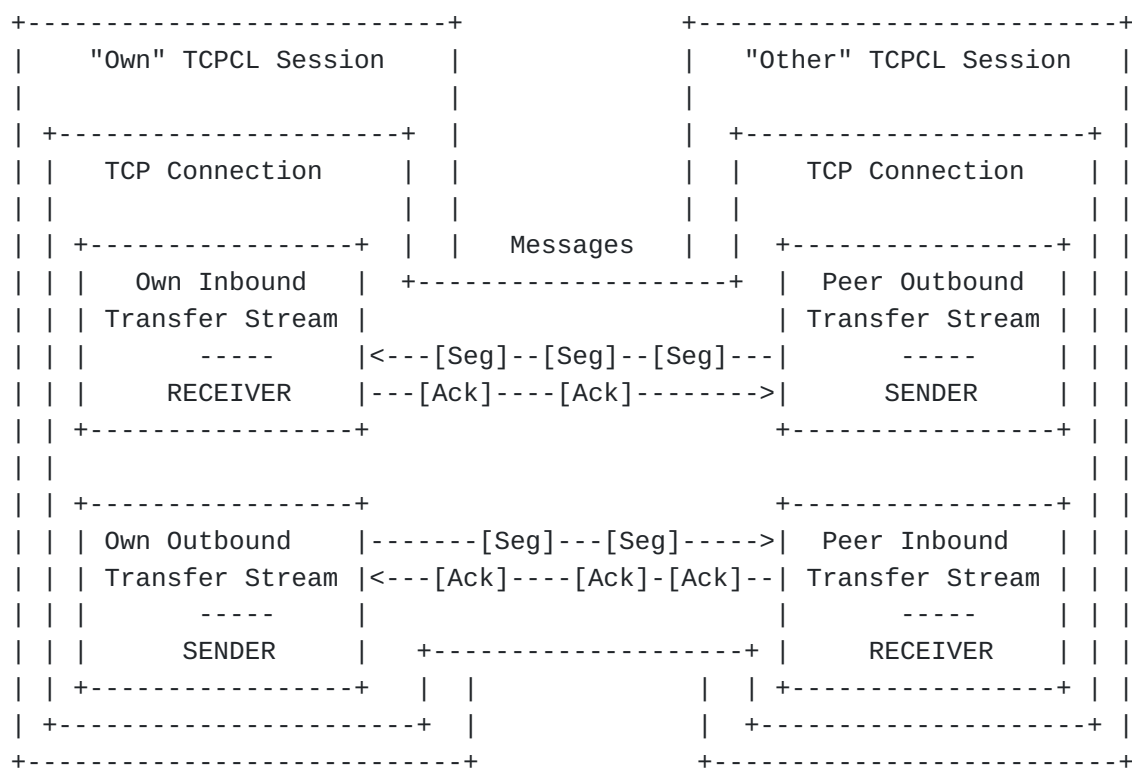


Figure 3: The relationship within a TCPCL Session of its two streams

3. General Protocol Description

The service of this protocol is the transmission of DTN bundles via the Transmission Control Protocol (TCP). This document specifies the encapsulation of bundles, procedures for TCP setup and teardown, and a set of messages and entity requirements. The general operation of the protocol is as follows.

3.1. Convergence Layer Services

This version of the TCPCL provides the following services to support the overlaying Bundle Protocol agent. In all cases, this is not an API definition but a logical description of how the CL can interact with the BP agent. Each of these interactions can be associated with any number of additional metadata items as necessary to support the operation of the CL or BP agent.

Attempt Session: The TCPCL allows a BP agent to preemptively attempt to establish a TCPCL session with a peer entity. Each session attempt can send a different set of session negotiation parameters as directed by the BP agent.

Terminate Session: The TCPCL allows a BP agent to preemptively terminate an established TCPCL session with a peer entity. The terminate request is on a per-session basis.

Session State Changed:

The TCPCL entity indicates to the BP agent when the session state changes. The top-level session states indicated are:

Connecting: A TCP connection is being established. This state only applies to the active entity.

Contact Negotiating: A TCP connection has been made (as either active or passive entity) and contact negotiation has begun.

Session Negotiating: Contact negotiation has been completed (including possible TLS use) and session negotiation has begun.

Established: The session has been fully established and is ready for its first transfer. When the session is established, the peer Node ID (along with indication of whether or not it was authenticated) and the negotiated session parameters (see [Section 4.7](#)) are also communicated to the BP agent.

Ending: The entity sent SESS_TERM message and is in the ending state.

Terminated: The session has finished normal termination sequencing.

Failed: The session ended without normal termination sequencing.

Session Idle Changed: The TCPCL entity indicates to the BP agent when the live/idle sub-state of the session changes. This occurs only when the top-level session state is "Established". The session transitions from Idle to Live at the start of a transfer in either transfer stream; the session transitions from Live to Idle at the end of a transfer when the other transfer stream does not have an ongoing transfer. Because TCPCL transmits serially over a TCP connection it suffers from "head of queue blocking," so a transfer in either direction can block an immediate start of a new transfer in the session.

Begin Transmission: The principal purpose of the TCPCL is to allow a BP agent to transmit bundle data over an established TCPCL session. Transmission request is on a per-session basis and the CL does not necessarily perform any per-session or inter-session queueing. Any queueing of transmissions is the obligation of the BP agent.

Transmission Success: The TCPCL entity indicates to the BP agent when a bundle has been fully transferred to a peer entity.

Transmission Intermediate Progress:

The TCPCL entity indicates to the BP agent on intermediate progress of transfer to a peer entity. This intermediate progress is at the granularity of each transferred segment.

Transmission Failure: The TCPCL entity indicates to the BP agent on certain reasons for bundle transmission failure, notably when the peer entity rejects the bundle or when a TCPCL session ends before transfer success. The TCPCL itself does not have a notion of transfer timeout.

Reception Initialized: The TCPCL entity indicates to the receiving BP agent just before any transmission data is sent. This corresponds to reception of the XFER_SEGMENT message with the START flag of 1.

Interrupt Reception: The TCPCL entity allows a BP agent to interrupt an individual transfer before it has fully completed (successfully or not). Interruption can occur any time after the reception is initialized.

Reception Success: The TCPCL entity indicates to the BP agent when a bundle has been fully transferred from a peer entity.

Reception Intermediate Progress: The TCPCL entity indicates to the BP agent on intermediate progress of transfer from the peer entity. This intermediate progress is at the granularity of each transferred segment. Intermediate reception indication allows a BP agent the chance to inspect bundle header contents before the entire bundle is available, and thus supports the "Reception Interruption" capability.

Reception Failure: The TCPCL entity indicates to the BP agent on certain reasons for reception failure, notably when the local entity rejects an attempted transfer for some local policy reason or when a TCPCL session ends before transfer success. The TCPCL itself does not have a notion of transfer timeout.

3.2. TCPCL Session Overview

First, one entity establishes a TCPCL session to the other by initiating a TCP connection in accordance with [\[RFC0793\]](#). After setup of the TCP connection is complete, an initial Contact Header is exchanged in both directions to establish a shared TCPCL version and negotiate the use of TLS security (as described in [Section 4](#)). Once contact negotiation is complete, TCPCL messaging is available and the session negotiation is used to set parameters of the TCPCL session. One of these parameters is a Node ID that each TCPCL Entity is acting as. This is used to assist in routing and forwarding

messages by the BP Agent and is part of the authentication capability provided by TLS.

Once negotiated, the parameters of a TCPCL session cannot change and if there is a desire by either peer to transfer data under different parameters then a new session must be established. This makes CL logic simpler but relies on the assumption that establishing a TCP connection is lightweight enough that TCP connection overhead is negligible compared to TCPCL data sizes.

Once the TCPCL session is established and configured in this way, bundles can be transferred in either direction. Each transfer is performed by segmenting the transfer data into one or more XFER_SEGMENT messages. Multiple bundles can be transmitted consecutively in a single direction on a single TCPCL connection. Segments from different bundles are never interleaved. Bundle interleaving can be accomplished by fragmentation at the BP layer or by establishing multiple TCPCL sessions between the same peers. There is no fundamental limit on the number of TCPCL sessions which a single entity can establish beyond the limit imposed by the number of available (ephemeral) TCP ports of the active entity.

A feature of this protocol is for the receiving entity to send acknowledgment (XFER_ACK) messages as bundle data segments arrive. The rationale behind these acknowledgments is to enable the transmitting entity to determine how much of the bundle has been received, so that in case the session is interrupted, it can perform reactive fragmentation to avoid re-sending the already transmitted part of the bundle. In addition, there is no explicit flow control on the TCPCL layer.

A TCPCL receiver can interrupt the transmission of a bundle at any point in time by replying with a XFER_REFUSE message, which causes the sender to stop transmission of the associated bundle (if it hasn't already finished transmission). Note: This enables a cross-layer optimization in that it allows a receiver that detects that it already has received a certain bundle to interrupt transmission as early as possible and thus save transmission capacity for other bundles.

For sessions that are idle, a KEEPALIVE message is sent at a negotiated interval. This is used to convey entity live-ness information during otherwise message-less time intervals.

A SESS_TERM message is used to initiate the ending of a TCPCL session (see [Section 6.1](#)). During termination sequencing, in-progress transfers can be completed but no new transfers can be initiated. A SESS_TERM message can also be used to refuse a session setup by a peer (see [Section 4.3](#)). Regardless of the reason, session

termination is initiated by one of the entities and responded-to by the other as illustrated by [Figure 13](#) and [Figure 14](#). Even when there are no transfers queued or in-progress, the session termination procedure allows each entity to distinguish between a clean end to a session and the TCP connection being closed because of some underlying network issue.

Once a session is established, TCPCL is a symmetric protocol between the peers. Both sides can start sending data segments in a session, and one side's bundle transfer does not have to complete before the other side can start sending data segments on its own. Hence, the protocol allows for a bi-directional mode of communication. Note that in the case of concurrent bidirectional transmission, acknowledgment segments MAY be interleaved with data segments.

3.3. TCPCL States and Transitions

The states of a normal TCPCL session (i.e., without session failures) are indicated in [Figure 4](#).

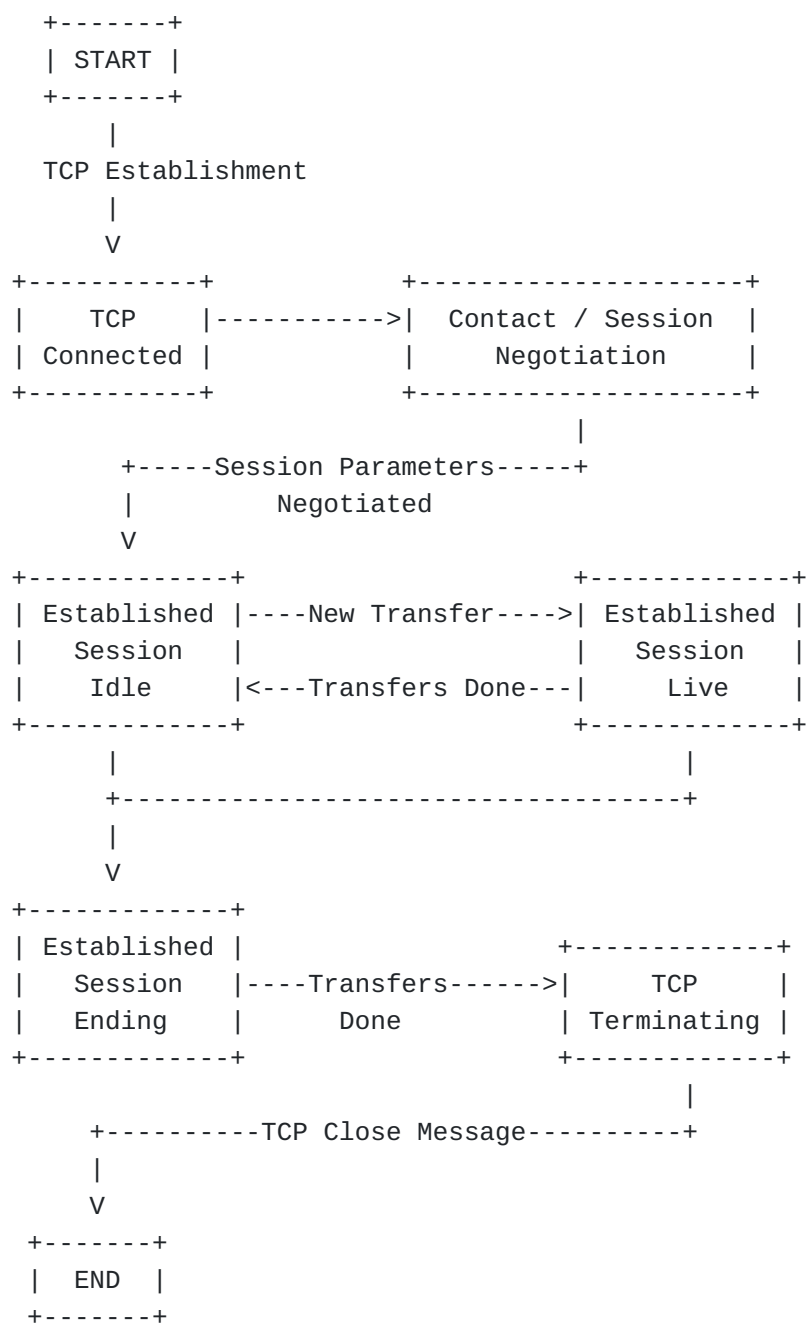


Figure 4: Top-level states of a TCPCL session

Notes on Established Session states:

Session "Live" means transmitting or receiving over a transfer stream.

Session "Idle" means no transmission/reception over a transfer stream.

Session "Ending" means no new transfers will be allowed.

Contact negotiation involves exchanging a Contact Header (CH) in both directions and deriving a negotiated state from the two headers. The contact negotiation sequencing is performed either as the active or passive entity, and is illustrated in [Figure 5](#) and [Figure 6](#) respectively which both share the data validation and negotiation of the Processing of Contact Header "[PCH]" activity of [Figure 7](#) and the "[TCPCLOSE]" activity which indicates TCP connection close. Successful negotiation results in one of the Session Initiation "[SI]" activities being performed. To avoid data loss, a Session Termination "[ST]" exchange allows cleanly finishing transfers before a session is ended.

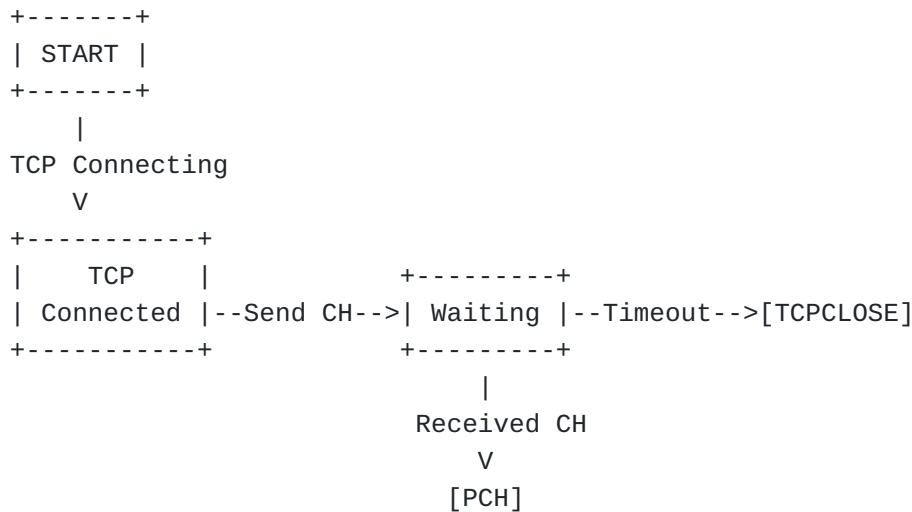


Figure 5: Contact Initiation as Active Entity

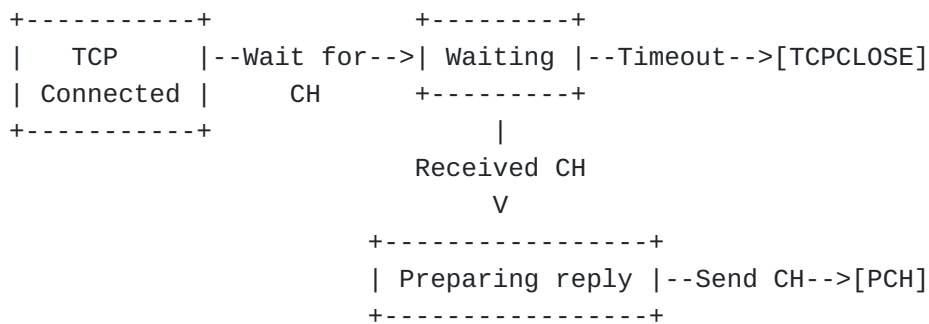


Figure 6: Contact Initiation as Passive Entity

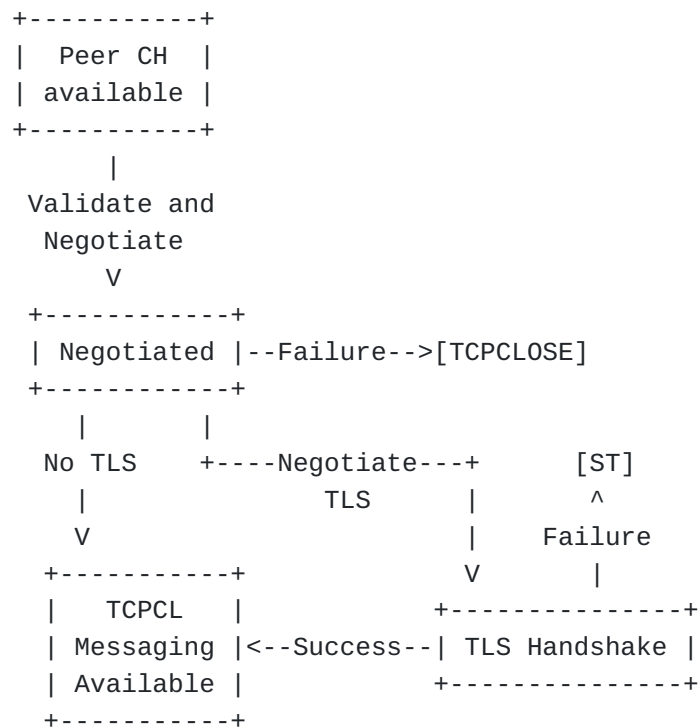


Figure 7: Processing of Contact Header [PCH]

Session negotiation involves exchanging a session initialization (SESS_INIT) message in both directions and deriving a negotiated state from the two messages. The session negotiation sequencing is performed either as the active or passive entity, and is illustrated in [Figure 8](#) and [Figure 9](#) respectively which both share the data validation and negotiation of [Figure 10](#). The validation here includes certificate validation and authentication when TLS is used for the session.

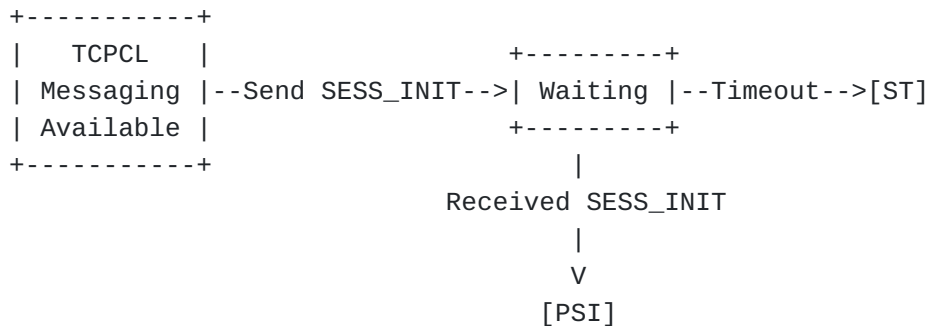


Figure 8: Session Initiation [SI] as Active Entity

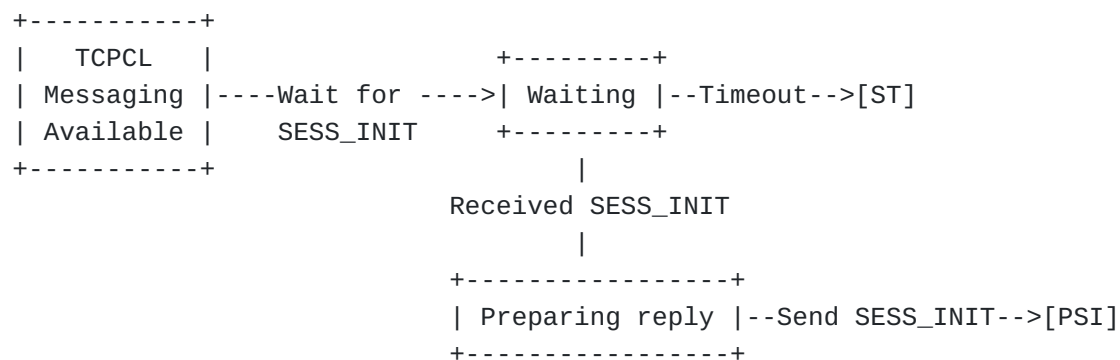


Figure 9: Session Initiation [SI] as Passive Entity

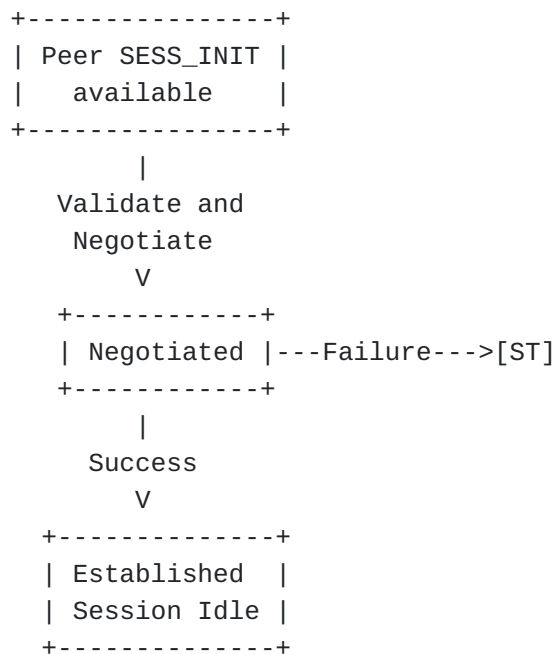


Figure 10: Processing of Session Initiation [PSI]

Transfers can occur after a session is established and it's not in the Ending state. Each transfer occurs within a single logical transfer stream between a sender and a receiver, as illustrated in [Figure 11](#) and [Figure 12](#) respectively.

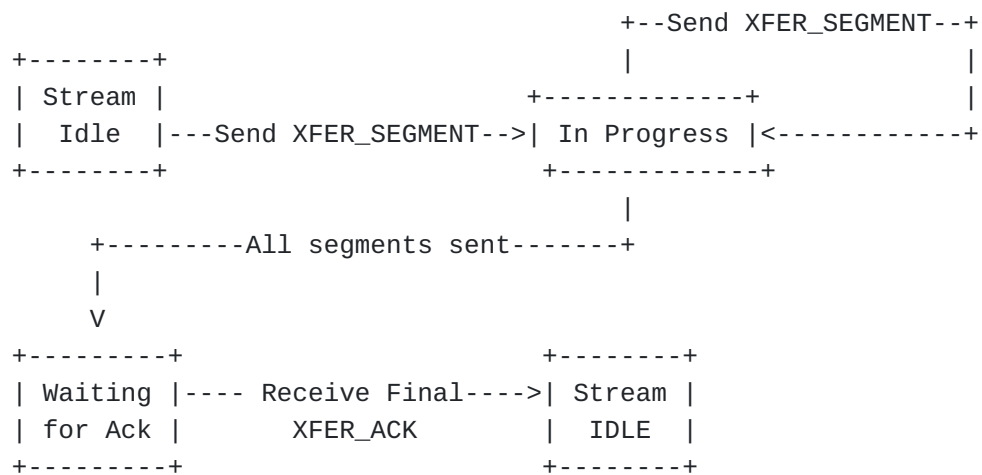


Figure 11: Transfer sender states

Notes on transfer sending:

Pipelining of transfers can occur when the sending entity begins a new transfer while in the "Waiting for Ack" state.

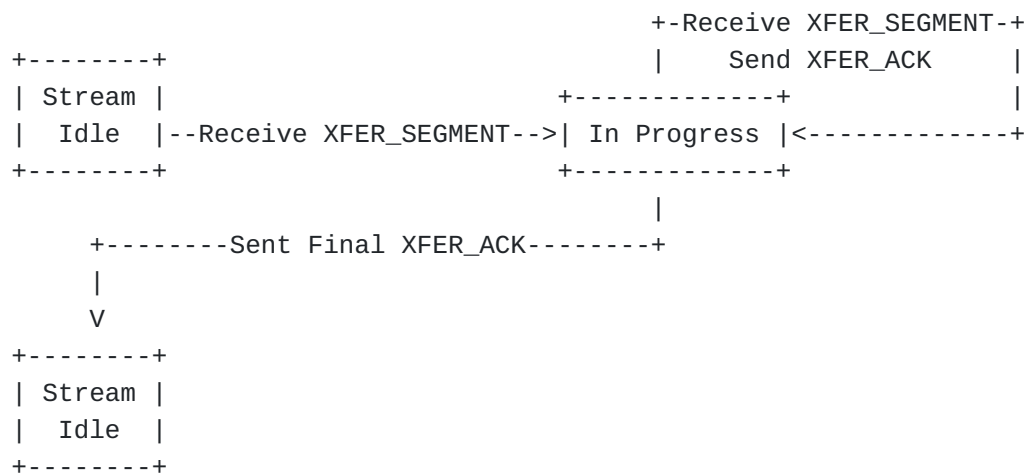


Figure 12: Transfer receiver states

Session termination involves one entity initiating the termination of the session and the other entity acknowledging the termination. For either entity, it is the sending of the SESS_TERM message which transitions the session to the Ending substate. While a session is in the Ending state only in-progress transfers can be completed and no new transfers can be started.

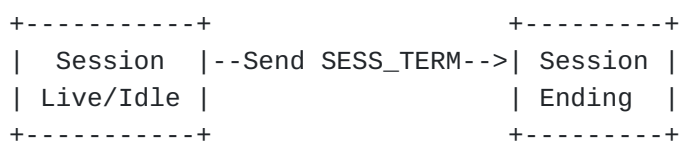


Figure 13: Session Termination [ST] from the Initiator

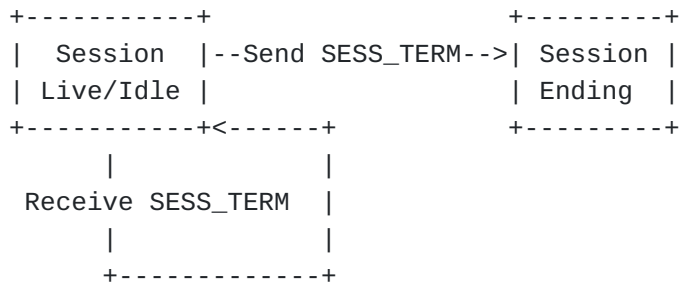


Figure 14: Session Termination [ST] from the Responder

3.4. PKIX Environments and CA Policy

This specification gives requirements about how to use PKIX certificates issued by a Certificate Authority (CA), but does not define any mechanisms for how those certificates come to be. The requirements about TCPCL certificate use are broad to support two quite different PKIX environments:

DTN-Aware CAs: In the ideal case, the CA(s) issuing certificates for TCPCL entities are aware of the end use of the certificate, have a mechanism for verifying ownership of a Node ID, and are issuing certificates directly for that Node ID. In this environment, the ability to authenticate a peer entity Node ID directly avoids the need to authenticate a network name or address and then implicitly trust Node ID of the peer. The TCPCL authenticates the Node ID whenever possible and this is preferred over lower-level PKIX identities.

DTN-Ignorant CAs: It is expected that Internet-scale "public" CAs will continue to focus on DNS names as the preferred PKIX identifier. There are large infrastructures already in-place for managing network-level authentication and protocols to manage identity verification in those environments [[RFC8555](#)]. The TCPCL allows for this type of environment by authenticating a lower-level identifier for a peer and requiring the entity to trust that the Node ID given by the peer (during session initialization) is valid. This situation is not ideal, as it allows vulnerabilities described in [Section 8.9](#), but still provides some amount of mutual authentication to take place for a TCPCL session.

Even within a single TCPCL session, each entity may operate within different PKI environments and with different identifier limitations. The requirements related to identifiers in a PKIX certificate are in [Section 4.4.1](#).

It is important for interoperability that a TCPCL entity have its own security policy tailored to accommodate the peers with which it is expected to operate. Some security policy recommendations are given in [Section 4.4.5](#) but these are meant as a starting point for tailoring. A strict TLS security policy is appropriate for a private network with a single shared CA. Operation on the Internet (such as inter-site BP gateways) could trade more lax TCPCL security with the use of encrypted bundle encapsulation [[I-D.ietf-dtn-bibect](#)] to ensure strong bundle security.

By using the Server Name Indication (SNI) DNS name (see [Section 4.4.3](#)) a single passive entity can act as a convergence layer for multiple BP agents with distinct Node IDs. When this "virtual host" behavior is used, the DNS name is used as the indication of which BP Node the active entity is attempting to communicate with. A virtual host CL entity can be authenticated by a certificate containing all of the DNS names and/or Node IDs being hosted or by several certificates each authenticating a single DNS name and/or Node ID, using the SNI value from the peer to select which certificate to use. The logic for mapping an SNI DNS name to an end-entity certificate is an implementation matter, and can involve correlating DNS name with Node ID or other certificate attributes.

3.5. Session Keeping Policies

This specification gives requirements about how to initiate, sustain, and terminate a TCPCL session but does not impose any requirements on how sessions need to be managed by a BP agent. It is a network administration matter to determine an appropriate session keeping policy, but guidance given here can be used to steer policy toward performance goals.

Persistent Session: This policy preemptively establishes a single session to known entities in the network and keeps the session active using KEEPALIVES. Benefits of this policy include reducing the total amount of TCP data needing to be exchanged for a set of transfers (assuming KEEPALIVE size is significantly smaller than transfer size), and allowing the session state to indicate peer connectivity. Drawbacks include wasted network resources when a session is mostly idle or when the network connectivity is inconsistent (which requires re-establishing failed sessions), and potential queueing issues when multiple transfers are requested simultaneously. This policy assumes that there is agreement between pairs of entities as to which of the peers will initiate sessions; if there is no such agreement, there is potential for duplicate sessions to be established between peers.

Ephemeral Sessions: This policy only establishes a session when an outgoing transfer is needed to be sent. Benefits of this policy

include not wasting network resources on sessions which are idle for long periods of time, and avoids queueing issues of a persistent session. Drawbacks include the TCP and TLS overhead of establish a new session for each transfer. This policy assumes that each entity can function in a passive role to listen for session requests from any peer which needs to send a transfer; when that is not the case the Polling behavior below needs to happen. This policy can be augmented to keep the session established as long as any transfers are queued.

Active-Only Polling Sessions: When naming and/or addressing of one entity is variable (i.e. dynamically assigned IP address or domain name) or when firewall or routing rules prevent incoming TCP connections, that entity can only function in the active role. In these cases, sessions also need to be established when an incoming transfer is expected from a peer or based on a periodic schedule. This polling behavior causes inefficiencies compared to as-needed ephemeral sessions.

Many other policies can be established in a TCPCL network between the two extremes of single persistent sessions and only ephemeral sessions. Different policies can be applied to each peer entity and to each bundle as it needs to be transferred (e.g for quality of service). Additionally, future session extension types can apply further nuance to session policies and policy negotiation.

3.6. Transfer Segmentation Policies

Each TCPCL session allows a negotiated transfer segmentation policy to be applied in each transfer direction. A receiving entity can set the Segment MRU in its SESS_INIT message to determine the largest acceptable segment size, and a transmitting entity can segment a transfer into any sizes smaller than the receiver's Segment MRU. It is a network administration matter to determine an appropriate segmentation policy for entities operating TCPCL, but guidance given here can be used to steer policy toward performance goals. It is also advised to consider the Segment MRU in relation to chunking/packetization performed by TLS, TCP, and any intermediate network-layer nodes.

Minimum Overhead: For a simple network expected to exchange relatively small bundles, the Segment MRU can be set to be identical to the Transfer MRU which indicates that all transfers can be sent with a single data segment (i.e., no actual segmentation). If the network is closed and all transmitters are known to follow a single-segment transfer policy, then receivers can avoid the necessity of segment reassembly. Because this CL operates over a TCP stream, which suffers from a form of head-of-queue blocking between messages, while one entity is transmitting

a single XFER_SEGMENT message it is not able to transmit any XFER_ACK or XFER_REFUSE for any associated received transfers.

Predictable Message Sizing: In situations where the maximum message size is desired to be well-controlled, the Segment MRU can be set to the largest acceptable size (the message size less XFER_SEGMENT header size) and transmitters can always segment a transfer into maximum-size chunks no larger than the Segment MRU. This guarantees that any single XFER_SEGMENT will not monopolize the TCP stream for too long, which would prevent outgoing XFER_ACK and XFER_REFUSE associated with received transfers.

Dynamic Segmentation: Even after negotiation of a Segment MRU for each receiving entity, the actual transfer segmentation only needs to guarantee that any individual segment is no larger than that MRU. In a situation where TCP throughput is dynamic, the transfer segmentation size can also be dynamic in order to control message transmission duration.

Many other policies can be established in a TCPCL network between the two extremes of minimum overhead (large MRU, single-segment) and predictable message sizing (small MRU, highly segmented). Different policies can be applied to each transfer stream to and from any particular entity. Additionally, future session extension and transfer extension types can apply further nuance to transfer policies and policy negotiation.

3.7. Example Message Exchange

The following figure depicts the protocol exchange for a simple session, showing the session establishment and the transmission of a single bundle split into three data segments (of lengths "L1", "L2", and "L3") from Entity A to Entity B.

Note that the sending entity can transmit multiple XFER_SEGMENT messages without waiting for the corresponding XFER_ACK responses. This enables pipelining of messages on a transfer stream. Although this example only demonstrates a single bundle transmission, it is also possible to pipeline multiple XFER_SEGMENT messages for different bundles without necessarily waiting for XFER_ACK messages to be returned for each one. However, interleaving data segments from different bundles is not allowed.

No errors or rejections are shown in this example.

Entity A =====		Entity B =====
+-----+ Open TCP Connection ->		+-----+ <- Accept Connection +-----+
+-----+ Contact Header ->		+-----+ <- Contact Header +-----+
+-----+ SESS_INIT ->		+-----+ <- SESS_INIT +-----+
+-----+ XFER_SEGMENT (start) -> Transfer ID [I1] Length [L1] Bundle Data 0..(L1-1) +-----+		
+-----+ XFER_SEGMENT -> Transfer ID [I1] Length [L2] Bundle Data L1..(L1+L2-1) +-----+	<-	+-----+ XFER_ACK (start) Transfer ID [I1] Length [L1] +-----+
+-----+ XFER_SEGMENT (end) -> Transfer ID [I1] Length [L3] Bundle Data (L1+L2)..(L1+L2+L3-1) +-----+	<-	+-----+ XFER_ACK Transfer ID [I1] Length [L1+L2] +-----+
		+-----+ <- XFER_ACK (end) Transfer ID [I1] Length [L1+L2+L3] +-----+
+-----+ SESS_TERM ->		+-----+ <- SESS_TERM +-----+
+-----+ TCP Close ->	<-	+-----+ TCP Close +-----+

Figure 15: An example of the flow of protocol messages on a single TCP Session between two entities

4. Session Establishment

For bundle transmissions to occur using the TCPCL, a TCPCL session MUST first be established between communicating entities. It is up to the implementation to decide how and when session setup is triggered. For example, some sessions can be opened proactively and maintained for as long as is possible given the network conditions, while other sessions are be opened only when there is a bundle that is queued for transmission and the routing algorithm selects a certain next-hop node.

4.1. TCP Connection

To establish a TCPCL session, an entity MUST first establish a TCP connection with the intended peer entity, typically by using the services provided by the operating system. Destination port number 4556 has been assigned by IANA as the Registered Port number for the TCP convergence layer. Other destination port numbers MAY be used per local configuration. Determining a peer's destination port number (if different from the registered TCPCL port number) is up to the implementation. Any source port number MAY be used for TCPCL sessions. Typically an operating system assigned number in the TCP Ephemeral range (49152-65535) is used.

If the entity is unable to establish a TCP connection for any reason, then it is an implementation matter to determine how to handle the connection failure. An entity MAY decide to re-attempt to establish the connection. If it does so, it MUST NOT overwhelm its target with repeated connection attempts. Therefore, the entity MUST NOT retry the connection setup earlier than some delay time from the last attempt, and it SHOULD use a (binary) exponential back-off mechanism to increase this delay in case of repeated failures. The upper limit on a re-attempt back-off is implementation defined but SHOULD be no longer than one minute (60 seconds) before signaling to the BP agent that a connection cannot be made.

Once a TCP connection is established, the active entity SHALL immediately transmit its Contact Header. Once a TCP connection is established, the passive entity SHALL wait for the peer's Contact Header. If the passive entity does not receive a Contact Header after some implementation-defined time duration after TCP connection is established, the entity SHALL close the TCP connection. Entities SHOULD choose a Contact Header reception timeout interval no longer than one minute (60 seconds). Upon reception of a Contact Header, the passive entity SHALL transmit its Contact Header. The ordering of the Contact Header exchange allows the passive entity to avoid

allocating resources to a potential TCPCL session until after a valid Contact Header has been received from the active entity. This ordering also allows the passive peer to adapt to alternate TCPCL protocol versions.

The format of the Contact Header is described in [Section 4.2](#). Because the TCPCL protocol version in use is part of the initial Contact Header, entities using TCPCL version 4 can coexist on a network with entities using earlier TCPCL versions (with some negotiation needed for interoperation as described in [Section 4.3](#)).

Within this specification when an entity is said to "close" a TCP connection the entity SHALL use the TCP FIN mechanism and not the RST mechanism. Either mechanism, however, when received will cause a TCP connection to become closed.

4.2. Contact Header

This section describes the format of the Contact Header and the meaning of its fields.

If the entity is configured to enable exchanging messages according to TLS 1.3 [[RFC8446](#)] or any successors which are compatible with that TLS ClientHello, the the CAN_TLS flag within its Contact Header SHALL be set to 1. The RECOMMENDED policy is to enable TLS for all sessions, even if security policy does not allow or require authentication. This follows the opportunistic security model of [[RFC7435](#)], though an active attacker could interfere with the exchange in such cases (see [Section 8.4](#)).

Upon receipt of the Contact Header, both entities perform the validation and negotiation procedures defined in [Section 4.3](#). After receiving the Contact Header from the other entity, either entity MAY refuse the session by sending a SESS_TERM message with an appropriate reason code.

The format for the Contact Header is as follows:

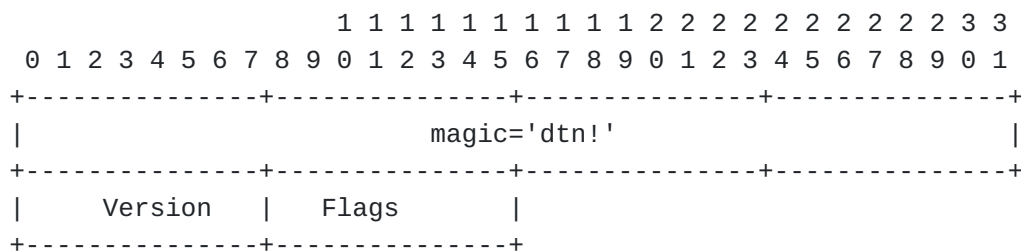


Figure 16: Contact Header Format

See [Section 4.3](#) for details on the use of each of these Contact Header fields.

The fields of the Contact Header are:

magic: A four-octet field that always contains the octet sequence 0x64 0x74 0x6E 0x21, i.e., the text string "dtn!" in US-ASCII (and UTF-8).

Version: A one-octet field value containing the value 4 (current version of the TCPCL).

Flags: A one-octet field of single-bit flags, interpreted according to the descriptions in [Table 1](#). All reserved header flag bits SHALL be set to 0 by the sender. All reserved header flag bits SHALL be ignored by the receiver.

Name	Code	Description
CAN_TLS	0x01	If bit is set, indicates that the sending peer has enabled TLS security.
Reserved	others	

Table 1: Contact Header Flags

4.3. Contact Validation and Negotiation

Upon reception of the Contact Header, each entity follows the following procedures to ensure the validity of the TCPCL session and to negotiate values for the session parameters.

If the magic string is not present or is not valid, the connection MUST be terminated. The intent of the magic string is to provide some protection against an inadvertent TCP connection by a different protocol than the one described in this document. To prevent a flood of repeated connections from a misconfigured application, a passive entity MAY deny new TCP connections from a specific peer address for a period of time after one or more connections fail to provide a decodable Contact Header.

The first negotiation is on the TCPCL protocol version to use. The active entity always sends its Contact Header first and waits for a response from the passive entity. During contact initiation, the active TCPCL entity SHALL send the highest TCPCL protocol version on a first session attempt for a TCPCL peer. If the active entity receives a Contact Header with a lower protocol version than the one sent earlier on the TCP connection, the TCP connection SHALL be closed. If the active entity receives a SESS_TERM message with reason of "Version Mismatch", that entity MAY attempt further TCPCL sessions with the peer using earlier protocol version numbers in

decreasing order. Managing multi-TCPCL-session state such as this is an implementation matter.

If the passive entity receives a Contact Header containing a version that is not a version of the TCPCL that the entity implements, then the entity SHALL send its Contact Header and immediately terminate the session with a reason code of "Version mismatch". If the passive entity receives a Contact Header with a version that is lower than the latest version of the protocol that the entity implements, the entity MAY either terminate the session (with a reason code of "Version mismatch") or adapt its operation to conform to the older version of the protocol. The decision of version fall-back is an implementation matter.

The negotiated contact parameters defined by this specification are described in the following paragraphs.

TCPCL Version: Both Contact Headers of a successful contact negotiation have identical TCPCL Version numbers as described above. Only upon response of a Contact Header from the passive entity is the TCPCL protocol version established and session negotiation begun.

Enable TLS: Negotiation of the Enable TLS parameter is performed by taking the logical AND of the two Contact Headers' CAN_TLS flags. A local security policy is then applied to determine if the negotiated value of Enable TLS is acceptable. It can be a reasonable security policy to require or disallow the use of TLS depending upon the desired network flows. The RECOMMENDED policy is to require TLS for all sessions, even if security policy does not allow or require authentication. Because this state is negotiated over an unsecured medium, there is a risk of a TLS Stripping as described in [Section 8.4](#).

If the Enable TLS state is unacceptable, the entity SHALL terminate the session with a reason code of "Contact Failure". Note that this contact failure reason is different than a failure of TLS handshake or TLS authentication after an agreed-upon and acceptable Enable TLS state. If the negotiated Enable TLS value is true and acceptable then TLS negotiation feature (described in [Section 4.4](#)) begins immediately following the Contact Header exchange.

4.4. Session Security

This version of the TCPCL supports establishing a Transport Layer Security (TLS) session within an existing TCP connection. When TLS is used within the TCPCL it affects the entire session. Once TLS is

established, there is no mechanism available to downgrade the TCPCL session to non-TLS operation.

Once established, the lifetime of a TLS connection SHALL be bound to the lifetime of the underlying TCP connection. Immediately prior to actively ending a TLS connection after TCPCL session termination, the peer which sent the original (non-reply) SESS_TERM message SHOULD follow the Closure Alert procedure of [\[RFC8446\]](#) to cleanly terminate the TLS connection. Because each TCPCL message is either fixed-length or self-indicates its length, the lack of a TLS Closure Alert will not cause data truncation or corruption.

Subsequent TCPCL session attempts to the same passive entity MAY attempt to use the TLS session resumption feature. There is no guarantee that the passive entity will accept the request to resume a TLS session, and the active entity cannot assume any resumption outcome.

4.4.1. Entity Identification

The TCPCL uses TLS for certificate exchange in both directions to identify each entity and to allow each entity to authenticate its peer. Each certificate can potentially identify multiple entities and there is no problem using such a certificate as long as the identifiers are sufficient to meet authentication policy (as described in later sections) for the entity which presents it.

Because the PKIX environment of each TCPCL entity are likely not controlled by the certificate end users (see [Section 3.4](#)), the TCPCL defines a prioritized list of what a certificate can identify about a TCPCL entity:

Node ID: The ideal certificate identity is the Node ID of the entity using the NODE-ID definition below. When the Node ID is identified, there is no need for any lower-level identification to be present (though it can still be present, and if so it is also validated).

DNS Name: If CA policy forbids a certificate to contain an arbitrary NODE-ID but allows a DNS-ID to be identified then one or more stable DNS names can be identified in the certificate. The use of wildcard DNS-ID is discouraged due to the complex rules for matching and dependence on implementation support for wildcard matching (see [Section 6.4.3](#) of [\[RFC6125\]](#)).

Network Address: If no stable DNS name is available but a stable network address is available and CA policy allows a certificate to contain a IPADDR-ID (as defined below) then one or more network addresses can be identified in the certificate.

This specification defines a NODE-ID of a certificate as being the subjectAltName entry of type otherName with a name form of BundleEID (see [Section 4.4.2.1](#)) and a value limited to a Node ID. An entity SHALL ignore any otherName with a name form of BundleEID and a value which is some URI other than a Node ID. The NODE-ID is similar to the URI-ID of [\[RFC6125\]](#) but restricted to a Node ID rather than a URI with a qualified-name authority part. Unless specified otherwise by the definition of the URI scheme being authenticated, URI matching of a NODE-ID SHALL use the URI comparison logic of [\[RFC3986\]](#) and scheme-based normalization of those schemes specified in [\[I-D.ietf-dtn-bpbis\]](#). A URI scheme can refine this "exact match" logic with rules about how Node IDs within that scheme are to be compared with the certificate-authenticated NODE-ID.

This specification reuses the DNS-ID definition of [Section 1.8](#) of [\[RFC6125\]](#), which is the subjectAltName entry of type dNSName whose value is encoded according to [\[RFC5280\]](#).

This specification defines a IPADDR-ID of a certificate as being the subjectAltName entry of type iPAddress whose value is encoded according to [\[RFC5280\]](#).

4.4.2. Certificate Profile for TCPCL

All end-entity certificates used by a TCPCL entity SHALL conform to [\[RFC5280\]](#), or any updates or successors to that profile. When an end-entity certificate is supplied, the full certification chain SHOULD be included unless security policy indicates that is unnecessary. An entity SHOULD omit the root CA certificate (the last item of the chain) when sending a certification chain, as the recipient already has the root CA to anchor its validation.

The TCPCL requires Version 3 certificates due to the extensions used by this profile. TCPCL entities SHALL reject as invalid Version 1 and Version 2 end-entity certificates.

TCPCL entities SHALL accept certificates that contain an empty Subject field or contain a Subject without a Common Name. Identity information in end-entity certificates is contained entirely in the subjectAltName extension as defined in [Section 4.4.1](#) and below.

All end-entity and CA certificates used for TCPCL SHOULD contain both a Subject Key Identifier and an Authority Key Identifier extension in accordance with [\[RFC5280\]](#). TCPCL entities SHOULD NOT rely on either a Subject Key Identifier and an Authority Key Identifier being present in any received certificate. Including key identifiers simplifies the work of an entity needing to assemble a certification chain.

Unless prohibited by CA policy, a TCPCL end-entity certificate SHALL contain a NODE-ID which authenticates the Node ID of the peer. When assigned one or more stable DNS names, a TCPCL end-entity certificate SHOULD contain DNS-ID which authenticates those (fully qualified) names. When assigned one or more stable network addresses, a TCPCL end-entity certificate MAY contain IPADDR-ID which authenticates those addresses.

When allowed by CA policy, a BPSec end-entity certificate SHOULD contain a PKIX Extended Key Usage extension in accordance with [Section 4.2.1.12](#) of [\[RFC5280\]](#). When the PKIX Extended Key Usage extension is present, it SHOULD contain a key purpose id-kp-bundleSecurity (see [Section 4.4.2.1](#)). Although not specifically required by TCPCL, some networks or TLS implementations assume the use of id-kp-clientAuth and id-kp-serverAuth are needed for, respectively, the client-side and server-side of TLS authentication. For interoperability, a TCPCL end-entity certificate MAY contain an Extended Key Usage with both id-kp-clientAuth and id-kp-serverAuth values.

When allowed by CA policy, a TCPCL end-entity certificate SHOULD contain a PKIX Key Usage extension in accordance with [Section 4.2.1.3](#) of [\[RFC5280\]](#). The PKIX Key Usage bit which is consistent with TCPCL security using TLS 1.3 is digitalSignature. The specific algorithms used during the TLS handshake will determine which of those key uses are exercised. Earlier versions of TLS can mandate use of the bits keyEncipherment or keyAgreement.

When allowed by CA policy, a TCPCL end-entity certificate SHOULD contain an Online Certificate Status Protocol (OCSP) URI within an Authority Information Access extension in accordance with [Section 4.2.2.1](#) of [\[RFC5280\]](#).

4.4.2.1. PKIX OID Allocations

This document defines a PKIX Other Name Form identifier of id-on-bundleEID in [Appendix B](#) which can be used as the type-id in a subjectAltName entry of type otherName. The BundleEID value associated with otherName type-id id-on-bundleEID SHALL be a URI, encoded as an IA5String, with a scheme which is present in the IANA "Bundle Protocol URI Scheme Type" registry [\[IANA-BUNDLE\]](#). Although this otherName form allows any Endpoint ID to be present, the NODE-ID defined in [Section 4.4.1](#) limits its use to contain only a Node ID.

This document defines a PKIX Extended Key Usage key purpose id-kp-bundleSecurity in [Appendix B](#) which can be used to restrict a certificate's use. The id-kp-bundleSecurity purpose can be combined with other purposes in the same certificate.

4.4.3. TLS Handshake

The use of TLS is negotiated using the Contact Header as described in [Section 4.3](#). After negotiating an Enable TLS parameter of true, and before any other TCPCL messages are sent within the session, the session entities SHALL begin a TLS handshake in accordance with [\[RFC8446\]](#). By convention, this protocol uses the entity which initiated the underlying TCP connection (the active peer) as the "client" role of the TLS handshake request.

The TLS handshake, if it occurs, is considered to be part of the contact negotiation before the TCPCL session itself is established. Specifics about sensitive data exposure are discussed in [Section 8](#).

The parameters within each TLS negotiation are implementation dependent but any TCPCL entity SHALL follow all recommended practices of BCP 195 [\[RFC7525\]](#), or any updates or successors that become part of BCP 195. Within each TLS handshake, the following requirements apply (using the rough order in which they occur):

Client Hello: When a resolved DNS name was used to establish the TCP connection, the TLS ClientHello SHOULD include a "server_name" extension in accordance with [\[RFC6066\]](#). When present, the "server_name" extension SHALL contain a "HostName" value taken from the DNS name (of the passive entity) which was resolved. Note: The "HostName" in the "server_name" extension is the network name for the passive entity, not the Node ID of that entity.

Server Certificate: The passive entity SHALL supply a certificate within the TLS handshake to allow authentication of its side of the session. The supplied end-entity certificate SHALL conform to the profile of [Section 4.4.2](#). The passive entity MAY use the SNI DNS name to choose an appropriate server-side certificate which authenticates that DNS name.

Certificate Request: During TLS handshake, the passive entity SHALL request a client-side certificate.

Client Certificate: The active entity SHALL supply a certificate chain within the TLS handshake to allow authentication of its side of the session. The supplied end-entity certificate SHALL conform to the profile of [Section 4.4.2](#).

If a TLS handshake cannot negotiate a TLS connection, both entities of the TCPCL session SHALL close the TCP connection. At this point the TCPCL session has not yet been established so there is no TCPCL session to terminate.

After a TLS connection is successfully established, the active entity SHALL send a SESS_INIT message to begin session negotiation. This session negotiation and all subsequent messaging are secured.

4.4.4. TLS Authentication

Using PKIX certificates exchanged during the TLS handshake, each of the entities can authenticate a peer Node ID directly or authenticate the peer DNS name or network address. The logic for handling certificates and certificate data is separated into the following phases:

1. Validating the certification path from the end-entity certificate up to a trusted root CA.
2. Validating the Extended Key Usage (EKU) and other properties of the end-entity certificate.
3. Authenticating identities from a valid end-entity certificate.
4. Applying security policy to the result of each identity type authentication.

The result of validating a peer identity (see [Section 4.4.1](#)) against one or more type of certificate claim is one of the following:

Absent: Indicating that no such claims are present in the certificate and the identity cannot be authenticated.

Success: Indicating that one or more such claims are present and at least one matches the peer identity value.

Failure: Indicating that one or more such claims are present and none match the peer identity.

4.4.4.1. Certificate Path and Purpose Validation

For any peer end-entity certificate received during TLS handshake, the entity SHALL perform the certification path validation of [\[RFC5280\]](#) up to one of the entity's trusted CA certificates. If enabled by local policy, the entity SHALL perform an OCSP check of each certificate providing OCSP authority information in accordance with [\[RFC6960\]](#). If certificate validation fails or if security policy disallows a certificate for any reason, the entity SHALL fail the TLS handshake with a "bad_certificate" alert. Leaving out part of the certification chain can cause the entity to fail to validate a certificate if the left-out certificates are unknown to the entity (see [Section 8.6](#)).

For the end-entity peer certificate received during TLS handshake, the entity SHALL apply security policy to the Key Usage extension (if present) and Extended Key Usage extension (if present) in accordance with [Section 4.2.1.12](#) of [RFC5280] and the profile in [Section 4.4.2](#).

4.4.4.2. Network-Level Authentication

Either during or immediately after the TLS handshake, if required by security policy each entity SHALL validate the following certificate identifiers together in accordance with [Section 6](#) of [RFC6125]:

- *If the active entity resolved a DNS name (of the passive entity) in order to initiate the TCP connection that DNS name SHALL be used as a DNS-ID reference identifier.

- *The IP address of the other side of the TCP connection SHALL be used as an IPADDR-ID reference identifier.

If the network-level identifiers authentication result is Failure or if the result is Absent and security policy requires an authenticated network-level identifier, the entity SHALL terminate the session (with a reason code of "Contact Failure").

4.4.4.3. Node ID Authentication

Immediately before Session Parameter Negotiation, if required by security policy each entity SHALL validate the certificate NODE-ID in accordance with [Section 6](#) of [RFC6125] using the Node ID of the peer's SESS_INIT message as the NODE-ID reference identifier. If the NODE-ID validation result is Failure or if the result is Absent and security policy requires an authenticated Node ID, the entity SHALL terminate the session (with a reason code of "Contact Failure").

4.4.5. Policy Recommendations

A RECOMMENDED security policy is to enable the use of OCSP checking during TLS handshake. A RECOMMENDED security policy is that if an Extended Key Usage is present that it needs to contain id-kp-bundleSecurity (of [Section 4.4.2.1](#)) to be usable with TCPCL security. A RECOMMENDED security policy is to require a validated Node ID (of [Section 4.4.4.3](#)) and to ignore any network-level identifier (of [Section 4.4.4.2](#)).

This policy relies on and informs the certificate requirements in [Section 4.4.3](#). This policy assumes that a DTN-aware CA (see [Section 3.4](#)) will only issue a certificate for a Node ID when it has verified that the private key holder actually controls the DTN node; this is needed to avoid the threat identified in [Section 8.9](#). This policy requires that a certificate contain a NODE-ID and allows the

certificate to also contain network-level identifiers. A tailored policy on a more controlled network could relax the requirement on Node ID validation and allow just network-level identifiers to authenticate a peer.

4.4.6. Example TLS Initiation

A summary of a typical TLS use is shown in the sequence in [Figure 17](#) below. In this example the active peer terminates the session but termination can be initiated from either peer.

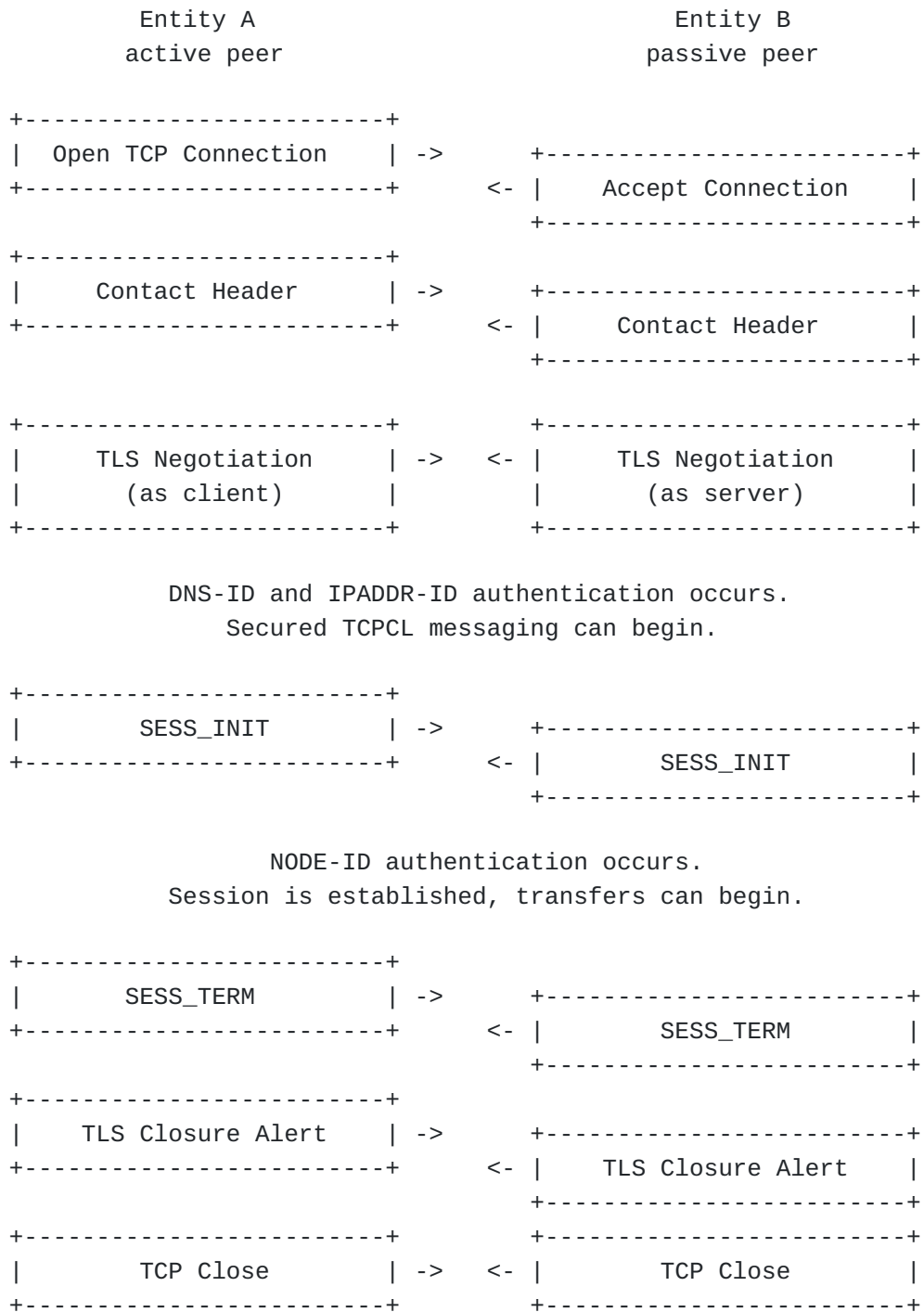


Figure 17: A simple visual example of TCPCL TLS Establishment between two entities

4.5. Message Header

After the initial exchange of a Contact Header and (if TLS is negotiated to be used) the TLS handshake, all messages transmitted over the session are identified by a one-octet header with the following structure:



Figure 18: Format of the Message Header

The message header fields are as follows:

Message Type: Indicates the type of the message as per [Table 2](#) below. Encoded values are listed in [Section 9.5](#).

Name	Code	Description
SESS_INIT	0x07	Contains the session parameter inputs from one of the entities, as described in Section 4.6 .
SESS_TERM	0x05	Indicates that one of the entities participating in the session wishes to cleanly terminate the session, as described in Section 6.1 .
XFER_SEGMENT	0x01	Indicates the transmission of a segment of bundle data, as described in Section 5.2.2 .
XFER_ACK	0x02	Acknowledges reception of a data segment, as described in Section 5.2.3 .
XFER_REFUSE	0x03	Indicates that the transmission of the current bundle SHALL be stopped, as described in Section 5.2.4 .
KEEPALIVE	0x04	Used to keep TCPCL session active, as described in Section 5.1.1 .
MSG_REJECT	0x06	Contains a TCPCL message rejection, as described in Section 5.1.2 .

Table 2: TCPCL Message Types

4.6. Session Initialization Message (SESS_INIT)

Before a session is established and ready to transfer bundles, the session parameters are negotiated between the connected entities. The SESS_INIT message is used to convey the per-entity parameters which are used together to negotiate the per-session parameters as described in [Section 4.7](#).

The format of a SESS_INIT message is as follows in [Figure 19](#).

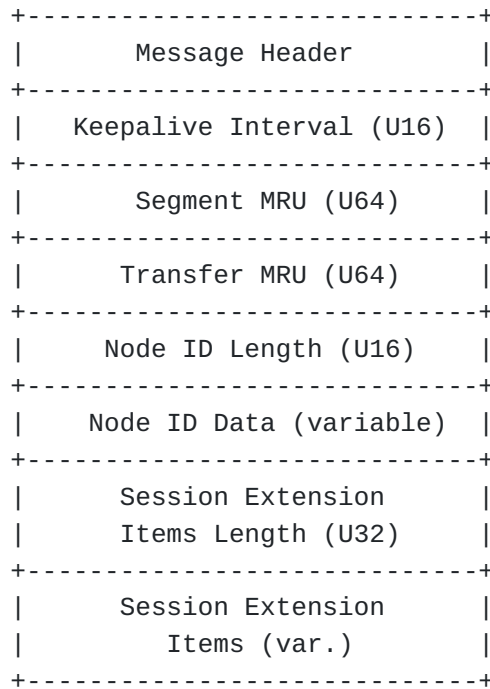


Figure 19: SESS_INIT Format

The fields of the SESS_INIT message are:

Keepalive Interval: A 16-bit unsigned integer indicating the minimum interval, in seconds, to negotiate as the Session Keepalive using the method of [Section 4.7](#).

Segment MRU: A 64-bit unsigned integer indicating the largest allowable single-segment data payload size to be received in this session. Any XFER_SEGMENT sent to this peer SHALL have a data payload no longer than the peer's Segment MRU. The two entities of a single session MAY have different Segment MRUs, and no relation between the two is required.

Transfer MRU: A 64-bit unsigned integer indicating the largest allowable total-bundle data size to be received in this session. Any bundle transfer sent to this peer SHALL have a Total Bundle Length payload no longer than the peer's Transfer MRU. This value can be used to perform proactive bundle fragmentation. The two entities of a single session MAY have different Transfer MRUs, and no relation between the two is required.

Node ID Length and Node ID Data: Together these fields represent a variable-length text string. The Node ID Length is a 16-bit unsigned integer indicating the number of octets of Node ID Data to follow. A zero-length Node ID SHALL be used to indicate the lack of Node ID rather than a truly empty Node ID. This case allows an entity to avoid exposing Node ID information on an

untrusted network. A non-zero-length Node ID Data SHALL contain the UTF-8 encoded Node ID of the Entity which sent the SESS_INIT message. Every Node ID SHALL be a URI consistent with the requirements of [RFC3986] and the URI schemes of the IANA "Bundle Protocol URI Scheme Type" registry [IANA-BUNDLE]. The Node ID itself can be authenticated as described in [Section 4.4.4](#).

Session Extension Length and Session Extension Items: Together these fields represent protocol extension data not defined by this specification. The Session Extension Length is the total number of octets to follow which are used to encode the Session Extension Item list. The encoding of each Session Extension Item is within a consistent data container as described in [Section 4.8](#). The full set of Session Extension Items apply for the duration of the TCPCL session to follow. The order and multiplicity of these Session Extension Items is significant, as defined in the associated type specification(s). If the content of the Session Extension Items data disagrees with the Session Extension Length (e.g., the last Item claims to use more octets than are present in the Session Extension Length), the reception of the SESS_INIT is considered to have failed.

If an entity receives a peer Node ID which is not authenticated (by the procedure of [Section 4.4.4.3](#)) that Node ID SHOULD NOT be used by a BP agent for any discovery or routing functions. Trusting an unauthenticated Node ID can lead to the threat described in [Section 8.9](#).

When the active entity initiates a TCPCL session, it is likely based on routing information which binds a Node ID to CL parameters used to initiate the session. If the active entity receives a SESS_INIT with different Node ID than was intended for the TCPCL session, the session MAY be allowed to be established. If allowed, such a session SHALL be associated with the Node ID provided in the SESS_INIT message rather than any intended value.

4.7. Session Parameter Negotiation

An entity calculates the parameters for a TCPCL session by negotiating the values from its own preferences (conveyed by the SESS_INIT it sent to the peer) with the preferences of the peer entity (expressed in the SESS_INIT that it received from the peer). The negotiated parameters defined by this specification are described in the following paragraphs.

Transfer MTU and Segment MTU: The maximum transmit unit (MTU) for whole transfers and individual segments are identical to the Transfer MRU and Segment MRU, respectively, of the received SESS_INIT message. A transmitting peer can send individual

segments with any size smaller than the Segment MTU, depending on local policy, dynamic network conditions, etc. Determining the size of each transmitted segment is an implementation matter. If either the Transfer MRU or Segment MRU is unacceptable, the entity SHALL terminate the session with a reason code of "Contact Failure".

Session Keepalive: Negotiation of the Session Keepalive parameter is performed by taking the minimum of the two Keepalive Interval values from the two SESS_INIT messages. The Session Keepalive interval is a parameter for the behavior described in [Section 5.1.1](#). If the Session Keepalive interval is unacceptable, the entity SHALL terminate the session with a reason code of "Contact Failure". Note: a negotiated Session Keepalive of zero indicates that KEEPALIVES are disabled.

Once this process of parameter negotiation is completed, this protocol defines no additional mechanism to change the parameters of an established session; to effect such a change, the TCPCL session MUST be terminated and a new session established.

4.8. Session Extension Items

Each of the Session Extension Items SHALL be encoded in an identical Type-Length-Value (TLV) container form as indicated in [Figure 20](#).

The fields of the Session Extension Item are:

Item Flags: A one-octet field containing generic bit flags about the Item, which are listed in [Table 3](#). All reserved header flag bits SHALL be set to 0 by the sender. All reserved header flag bits SHALL be ignored by the receiver. If a TCPCL entity receives a Session Extension Item with an unknown Item Type and the CRITICAL flag of 1, the entity SHALL terminate the TCPCL session with SESS_TERM reason code of "Contact Failure". If the CRITICAL flag is 0, an entity SHALL skip over and ignore any item with an unknown Item Type.

Item Type: A 16-bit unsigned integer field containing the type of the extension item. This specification does not define any extension types directly, but does create an IANA registry for such codes (see [Section 9.3](#)).

Item Length: A 16-bit unsigned integer field containing the number of Item Value octets to follow.

Item Value: A variable-length data field which is interpreted according to the associated Item Type. This specification places no restrictions on an extension's use of available Item Value data. Extension specifications SHOULD avoid the use of large data

lengths, as no bundle transfers can begin until the full extension data is sent.

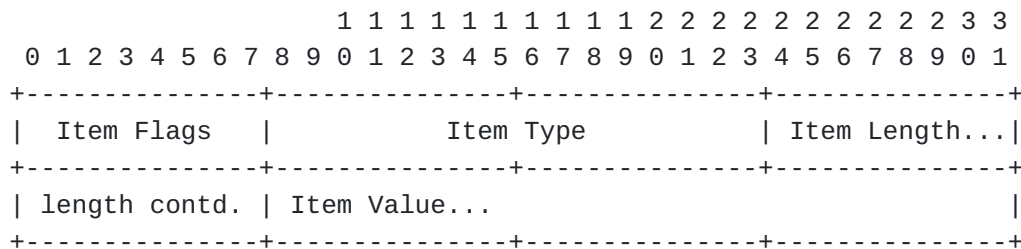


Figure 20: Session Extension Item Format

Name	Code	Description
CRITICAL	0x01	If bit is set, indicates that the receiving peer must handle the extension item.
Reserved	others	

Table 3: Session Extension Item Flags

5. Established Session Operation

This section describes the protocol operation for the duration of an established session, including the mechanism for transmitting bundles over the session.

5.1. Upkeep and Status Messages

5.1.1. Session Upkeep (KEEPALIVE)

The protocol includes a provision for transmission of KEEPALIVE messages over the TCPCL session to help determine if the underlying TCP connection has been disrupted.

As described in [Section 4.3](#), a negotiated parameter of each session is the Session Keepalive interval. If the negotiated Session Keepalive is zero (i.e., one or both SESS_INIT messages contains a zero Keepalive Interval), then the keepalive feature is disabled. There is no logical minimum value for the keepalive interval (within the minimum imposed by the positive-value encoding), but when used for many sessions on an open, shared network a short interval could lead to excessive traffic. For shared network use, entities SHOULD choose a keepalive interval no shorter than 30 seconds. There is no logical maximum value for the keepalive interval (within the maximum imposed by the fixed-size encoding), but an idle TCP connection is liable for closure by the host operating system if the keepalive time is longer than tens-of-minutes. Entities SHOULD choose a keepalive interval no longer than 10 minutes (600 seconds).

Note: The Keepalive Interval SHOULD NOT be chosen too short as TCP retransmissions MAY occur in case of packet loss. Those will have to be triggered by a timeout (TCP retransmission timeout (RTO)), which is dependent on the measured RTT for the TCP connection so that KEEPALIVE messages can experience noticeable latency.

The format of a KEEPALIVE message is a one-octet message type code of KEEPALIVE (as described in [Table 2](#)) with no additional data. Both sides SHALL send a KEEPALIVE message whenever the negotiated interval has elapsed with no transmission of any message (KEEPALIVE or other).

If no message (KEEPALIVE or other) has been received in a session after some implementation-defined time duration, then the entity SHALL terminate the session by transmitting a SESS_TERM message (as described in [Section 6.1](#)) with reason code "Idle Timeout". If configurable, the idle timeout duration SHOULD be no shorter than twice the keepalive interval. If not configurable, the idle timeout duration SHOULD be exactly twice the keepalive interval.

5.1.2. Message Rejection (MSG_REJECT)

This message type is not expected to be seen in a well-functioning session. Its purpose is to aid in troubleshooting bad entity behavior by allowing the peer to observe why an entity is not responding as expected to its messages.

If a TCPCL entity receives a message type which is unknown to it (possibly due to an unhandled protocol version mismatch or a incorrectly-negotiated session extension which defines a new message type), the entity SHALL send a MSG_REJECT message with a Reason Code of "Message Type Unknown" and close the TCP connection. If a TCPCL entity receives a message type which is known but is inappropriate for the negotiated session parameters (possibly due to incorrectly-negotiated session extension), the entity SHALL send a MSG_REJECT message with a Reason Code of "Message Unsupported". If a TCPCL entity receives a message which is inappropriate for the current session state (e.g., a SESS_INIT after the session has already been established or an XFER_ACK message with an unknown Transfer ID), the entity SHALL send a MSG_REJECT message with a Reason Code of "Message Unexpected".

The format of a MSG_REJECT message is as follows in [Figure 21](#).

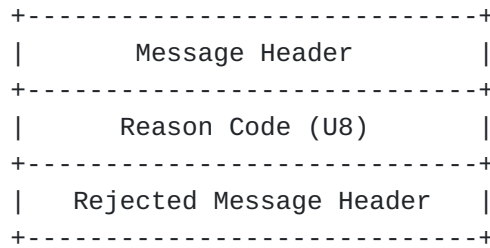


Figure 21: Format of MSG_REJECT Messages

The fields of the MSG_REJECT message are:

Reason Code: A one-octet refusal reason code interpreted according to the descriptions in [Table 4](#).

Rejected Message Header: The Rejected Message Header is a copy of the Message Header to which the MSG_REJECT message is sent as a response.

Name	Code	Description
Message Type Unknown	0x01	A message was received with a Message Type code unknown to the TCPCL entity.
Message Unsupported	0x02	A message was received but the TCPCL entity cannot comply with the message contents.
Message Unexpected	0x03	A message was received while the session is in a state in which the message is not expected.

Table 4: MSG_REJECT Reason Codes

5.2. Bundle Transfer

All of the messages in this section are directly associated with transferring a bundle between TCPCL entities.

A single TCPCL transfer results in a bundle (handled by the convergence layer as opaque data) being exchanged from one entity to the other. In TCPCL a transfer is accomplished by dividing a single bundle up into "segments" based on the receiving-side Segment MRU (see [Section 4.2](#)). The choice of the length to use for segments is an implementation matter, but each segment MUST NOT be larger than the receiving entity's maximum receive unit (MRU) (see the field Segment MRU of [Section 4.2](#)). The first segment for a bundle is indicated by the 'START' flag and the last segment is indicated by the 'END' flag.

A single transfer (and by extension a single segment) SHALL NOT contain data of more than a single bundle. This requirement is imposed on the agent using the TCPCL rather than TCPCL itself.

If multiple bundles are transmitted on a single TCPCL connection, they MUST be transmitted consecutively without interleaving of segments from multiple bundles.

5.2.1. Bundle Transfer ID

Each of the bundle transfer messages contains a Transfer ID which is used to correlate messages (from both sides of a transfer) for each bundle. A Transfer ID does not attempt to address uniqueness of the bundle data itself and has no relation to concepts such as bundle fragmentation. Each invocation of TCPCL by the bundle protocol agent, requesting transmission of a bundle (fragmentary or otherwise), results in the initiation of a single TCPCL transfer. Each transfer entails the sending of a sequence of some number of XFER_SEGMENT and XFER_ACK messages; all are correlated by the same Transfer ID. The sending entity originates a transfer ID and the receiving entity uses that same Transfer ID in acknowledgements.

Transfer IDs from each entity SHALL be unique within a single TCPCL session. Upon exhaustion of the entire 64-bit Transfer ID space, the sending entity SHALL terminate the session with SESS_TERM reason code "Resource Exhaustion". For bidirectional bundle transfers, a TCPCL entity SHOULD NOT rely on any relation between Transfer IDs originating from each side of the TCPCL session.

Although there is not a strict requirement for Transfer ID initial values or ordering (see [Section 8.13](#)), in the absence of any other mechanism for generating Transfer IDs an entity SHALL use the following algorithm: The initial Transfer ID from each entity is zero and subsequent Transfer ID values are incremented from the prior Transfer ID value by one.

5.2.2. Data Transmission (XFER_SEGMENT)

Each bundle is transmitted in one or more data segments. The format of a XFER_SEGMENT message follows in [Figure 22](#).

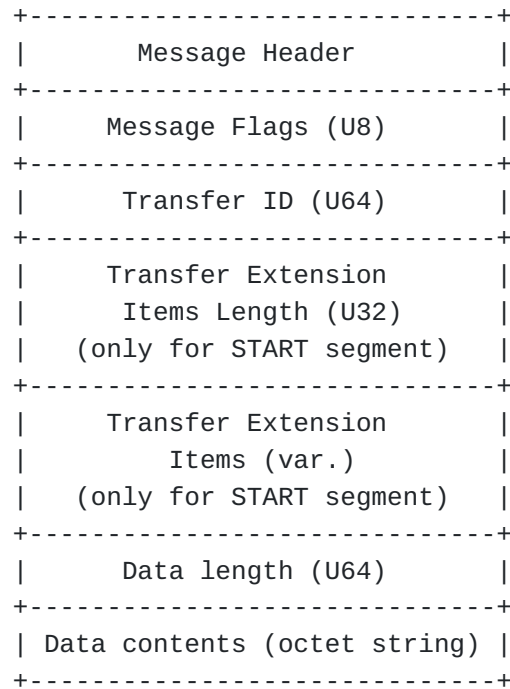


Figure 22: Format of XFER_SEGMENT Messages

The fields of the XFER_SEGMENT message are:

Message Flags: A one-octet field of single-bit flags, interpreted according to the descriptions in [Table 5](#). All reserved header flag bits SHALL be set to 0 by the sender. All reserved header flag bits SHALL be ignored by the receiver.

Transfer ID: A 64-bit unsigned integer identifying the transfer being made.

Transfer Extension Length and Transfer Extension Items: Together these fields represent protocol extension data for this specification. The Transfer Extension Length and Transfer Extension Item fields SHALL only be present when the 'START' flag is set to 1 on the message. The Transfer Extension Length is the total number of octets to follow which are used to encode the Transfer Extension Item list. The encoding of each Transfer Extension Item is within a consistent data container as described in [Section 5.2.5](#). The full set of transfer extension items apply only to the associated single transfer. The order and multiplicity of these transfer extension items is significant, as defined in the associated type specification(s). If the content of the Transfer Extension Items data disagrees with the Transfer Extension Length (e.g., the last Item claims to use more octets than are present in the Transfer Extension Length), the reception of the XFER_SEGMENT is considered to have failed.

Data length:

A 64-bit unsigned integer indicating the number of octets in the Data contents to follow.

Data contents: The variable-length data payload of the message.

Name	Code	Description
END	0x01	If bit is set, indicates that this is the last segment of the transfer.
START	0x02	If bit is set, indicates that this is the first segment of the transfer.
Reserved	others	

Table 5: XFER_SEGMENT Flags

The flags portion of the message contains two flag values in the two low-order bits, denoted 'START' and 'END' in [Table 5](#). The 'START' flag SHALL be set to 1 when transmitting the first segment of a transfer. The 'END' flag SHALL be set to 1 when transmitting the last segment of a transfer. In the case where an entire transfer is accomplished in a single segment, both the 'START' and 'END' flags SHALL be set to 1.

Once a transfer of a bundle has commenced, the entity MUST only send segments containing sequential portions of that bundle until it sends a segment with the 'END' flag set to 1. No interleaving of multiple transfers from the same entity is possible within a single TCPCL session. Simultaneous transfers between two entities MAY be achieved using multiple TCPCL sessions.

5.2.3. Data Acknowledgments (XFER_ACK)

Although the TCP transport provides reliable transfer of data between transport peers, the typical BSD sockets interface provides no means to inform a sending application of when the receiving application has processed some amount of transmitted data. Thus, after transmitting some data, the TCPCL needs an additional mechanism to determine whether the receiving agent has successfully received and fully processed the segment. To this end, the TCPCL protocol provides feedback messaging whereby a receiving entity transmits acknowledgments of reception of data segments.

The format of an XFER_ACK message follows in [Figure 23](#).

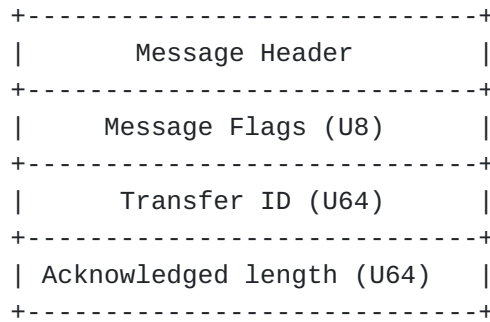


Figure 23: Format of XFER_ACK Messages

The fields of the XFER_ACK message are:

Message Flags: A one-octet field of single-bit flags, interpreted according to the descriptions in [Table 5](#). All reserved header flag bits SHALL be set to 0 by the sender. All reserved header flag bits SHALL be ignored by the receiver.

Transfer ID: A 64-bit unsigned integer identifying the transfer being acknowledged.

Acknowledged length: A 64-bit unsigned integer indicating the total number of octets in the transfer which are being acknowledged.

A receiving TCPCL entity SHALL send an XFER_ACK message in response to each received XFER_SEGMENT message after the segment has been fully processed. The flags portion of the XFER_ACK header SHALL be set to match the corresponding XFER_SEGMENT message being acknowledged (including flags not decodable to the entity). The acknowledged length of each XFER_ACK contains the sum of the data length fields of all XFER_SEGMENT messages received so far in the course of the indicated transfer. The sending entity SHOULD transmit multiple XFER_SEGMENT messages without waiting for the corresponding XFER_ACK responses. This enables pipelining of messages on a transfer stream.

For example, suppose the sending entity transmits four segments of bundle data with lengths 100, 200, 500, and 1000, respectively. After receiving the first segment, the entity sends an acknowledgment of length 100. After the second segment is received, the entity sends an acknowledgment of length 300. The third and fourth acknowledgments are of length 800 and 1800, respectively.

5.2.4. Transfer Refusal (XFER_REFUSE)

The TCPCL supports a mechanism by which a receiving entity can indicate to the sender that it does not want to receive the corresponding bundle. To do so, upon receiving an XFER_SEGMENT message, the entity MAY transmit a XFER_REFUSE message. As data

segments and acknowledgments can cross on the wire, the bundle that is being refused SHALL be identified by the Transfer ID of the refusal.

There is no required relation between the Transfer MRU of a TCPCL entity (which is supposed to represent a firm limitation of what the entity will accept) and sending of a XFER_REFUSE message. A XFER_REFUSE can be used in cases where the agent's bundle storage is temporarily depleted or somehow constrained. A XFER_REFUSE can also be used after the bundle header or any bundle data is inspected by an agent and determined to be unacceptable.

A transfer receiver MAY send an XFER_REFUSE message as soon as it receives any XFER_SEGMENT message. The transfer sender MUST be prepared for this and MUST associate the refusal with the correct bundle via the Transfer ID fields.

The TCPCL itself does not have any required behavior to respond to an XFER_REFUSE based on its Reason Code; the refusal is passed up as an indication to the BP agent that the transfer has been refused. If a transfer refusal has a Reason Code which is not decodable to the BP agent, the agent SHOULD treat the refusal as having an Unknown reason.

The format of the XFER_REFUSE message is as follows in [Figure 24](#).

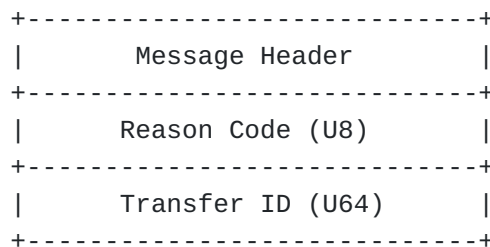


Figure 24: Format of XFER_REFUSE Messages

The fields of the XFER_REFUSE message are:

Reason Code: A one-octet refusal reason code interpreted according to the descriptions in [Table 6](#).

Transfer ID: A 64-bit unsigned integer identifying the transfer being refused.

Name	Code	Description
Unknown	0x00	Reason for refusal is unknown or not specified.
Completed	0x01	

Name	Code	Description
		The receiver already has the complete bundle. The sender MAY consider the bundle as completely received.
No Resources	0x02	The receiver's resources are exhausted. The sender SHOULD apply reactive bundle fragmentation before retrying.
Retransmit	0x03	The receiver has encountered a problem that requires the bundle to be retransmitted in its entirety.
Not Acceptable	0x04	Some issue with the bundle data or the transfer extension data was encountered. The sender SHOULD NOT retry the same bundle with the same extensions.
Extension Failure	0x05	A failure processing the Transfer Extension Items has occurred.
Session Terminating	0x06	The receiving entity is in the process of terminating the session. The sender MAY retry the same bundle at a later time in a different session.

Table 6: XFER_REFUSE Reason Codes

The receiver MUST, for each transfer preceding the one to be refused, have either acknowledged all XFER_SEGMENT messages or refused the bundle transfer.

The bundle transfer refusal MAY be sent before an entire data segment is received. If a sender receives a XFER_REFUSE message, the sender MUST complete the transmission of any partially sent XFER_SEGMENT message. There is no way to interrupt an individual TCPCL message partway through sending it. The sender MUST NOT commence transmission of any further segments of the refused bundle subsequently. Note, however, that this requirement does not ensure that an entity will not receive another XFER_SEGMENT for the same bundle after transmitting a XFER_REFUSE message since messages can cross on the wire; if this happens, subsequent segments of the bundle SHALL also be refused with a XFER_REFUSE message.

Note: If a bundle transmission is aborted in this way, the receiver does not receive a segment with the 'END' flag set to 1 for the aborted bundle. The beginning of the next bundle is identified by the 'START' flag set to 1, indicating the start of a new transfer, and with a distinct Transfer ID value.

5.2.5. Transfer Extension Items

Each of the Transfer Extension Items SHALL be encoded in an identical Type-Length-Value (TLV) container form as indicated in [Figure 25](#).

The fields of the Transfer Extension Item are:

Item Flags: A one-octet field containing generic bit flags about the Item, which are listed in [Table 7](#). All reserved header flag bits SHALL be set to 0 by the sender. All reserved header flag bits SHALL be ignored by the receiver. If a TCPCL entity receives a Transfer Extension Item with an unknown Item Type and the CRITICAL flag is 1, the entity SHALL refuse the transfer with an XFER_REFUSE reason code of "Extension Failure". If the CRITICAL flag is 0, an entity SHALL skip over and ignore any item with an unknown Item Type.

Item Type: A 16-bit unsigned integer field containing the type of the extension item. This specification creates an IANA registry for such codes (see [Section 9.4](#)).

Item Length: A 16-bit unsigned integer field containing the number of Item Value octets to follow.

Item Value: A variable-length data field which is interpreted according to the associated Item Type. This specification places no restrictions on an extension's use of available Item Value data. Extension specifications SHOULD avoid the use of large data lengths, as the associated transfer cannot begin until the full extension data is sent.

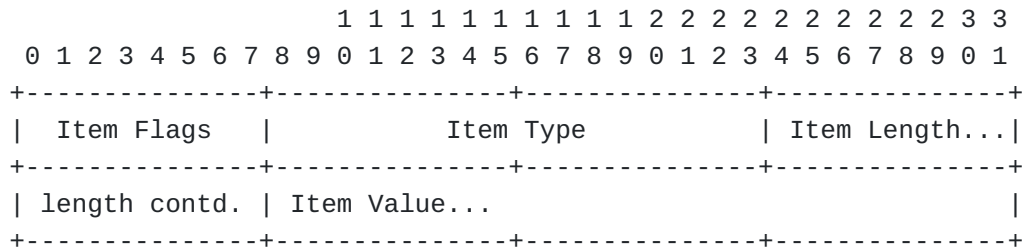


Figure 25: Transfer Extension Item Format

Name	Code	Description
CRITICAL	0x01	If bit is set, indicates that the receiving peer must handle the extension item.
Reserved	others	

Table 7: Transfer Extension Item Flags

5.2.5.1. Transfer Length Extension

The purpose of the Transfer Length extension is to allow entities to preemptively refuse bundles that would exceed their resources or to prepare storage on the receiving entity for the upcoming bundle data.

Multiple Transfer Length extension items SHALL NOT occur within the same transfer. The lack of a Transfer Length extension item in any transfer SHALL NOT imply anything about the potential length of the transfer. The Transfer Length extension SHALL be assigned transfer extension type ID 0x0001.

If a transfer occupies exactly one segment (i.e., both START and END flags are 1) the Transfer Length extension SHOULD NOT be present. The extension does not provide any additional information for single-segment transfers.

The format of the Transfer Length data is as follows in [Figure 26](#).

```
+-----+
| Total Length (U64) |
+-----+
```

Figure 26: Format of Transfer Length data

The fields of the Transfer Length extension are:

Total Length: A 64-bit unsigned integer indicating the size of the data-to-be-transferred. The Total Length field SHALL be treated as authoritative by the receiver. If, for whatever reason, the actual total length of bundle data received differs from the value indicated by the Total Length value, the receiver SHALL treat the transmitted data as invalid and send an XFER_REFUSE with a Reason Code of "Not Acceptable".

6. Session Termination

This section describes the procedures for terminating a TCPCL session. The purpose of terminating a session is to allow transfers to complete before the TCP connection is closed but not allow any new transfers to start. A session state change is necessary for this to happen because transfers can be in-progress in either direction (transfer stream) within a session. Waiting for a transfer to complete in one direction does not control or influence the possibility of a transfer in the other direction. Either peer of a session can terminate an established session at any time.

6.1. Session Termination Message (SESS_TERM)

To cleanly terminate a session, a SESS_TERM message SHALL be transmitted by either entity at any point following complete transmission of any other message. When sent to initiate a termination, the REPLY flag of a SESS_TERM message SHALL be 0. Upon receiving a SESS_TERM message after not sending a SESS_TERM message in the same session, an entity SHALL send an acknowledging SESS_TERM

message. When sent to acknowledge a termination, a SESS_TERM message SHALL have identical data content from the message being acknowledged except for the REPLY flag, which is set to 1 to indicate acknowledgement.

Once a SESS_TERM message is sent the state of that TCPCL session changes to Ending. While the session is in the Ending state, an entity MAY finish an in-progress transfer in either direction. While the session is in the Ending state, an entity SHALL NOT begin any new outgoing transfer for the remainder of the session. While the session is in the Ending state, an entity SHALL NOT accept any new incoming transfer for the remainder of the session. If a new incoming transfer is attempted while in the Ending state, the receiving entity SHALL send an XFER_REFUSE with a Reason Code of "Session Terminating".

There are circumstances where an entity has an urgent need to close a TCP connection associated with a TCPCL session, without waiting for transfers to complete but also in a way which doesn't force timeouts to occur; for example, due to impending shutdown of the underlying data link layer. Instead of following a clean termination sequence, after transmitting a SESS_TERM message an entity MAY perform an unclean termination by immediately closing the associated TCP connection. When performing an unclean termination, an entity SHOULD acknowledge all received XFER_SEGMENTS with an XFER_ACK before closing the TCP connection. Not acknowledging received segments can result in unnecessary bundle or bundle fragment retransmission. Any delay between request to close the TCP connection and actual closing of the connection (a "half-closed" state) MAY be ignored by the TCPCL entity. If the underlying TCP connection is closed during a transmission (in either transfer stream), the transfer SHALL be indicated to the BP agent as failed (see the transmission failure and reception failure indications of [Section 3.1](#)).

The TCPCL itself does not have any required behavior to respond to an SESS_TERM based on its Reason Code; the termination is passed up as an indication to the BP agent that the session state has changed. If a termination has a Reason Code which is not decodable to the BP agent, the agent SHOULD treat the termination as having an Unknown reason.

The format of the SESS_TERM message is as follows in [Figure 27](#).

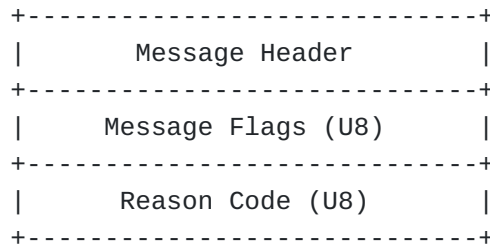


Figure 27: Format of SESS_TERM Messages

The fields of the SESS_TERM message are:

Message Flags: A one-octet field of single-bit flags, interpreted according to the descriptions in [Table 8](#). All reserved header flag bits SHALL be set to 0 by the sender. All reserved header flag bits SHALL be ignored by the receiver.

Reason Code: A one-octet refusal reason code interpreted according to the descriptions in [Table 9](#).

Name	Code	Description
REPLY	0x01	If bit is set, indicates that this message is an acknowledgement of an earlier SESS_TERM message.
Reserved	others	

Table 8: SESS_TERM Flags

Name	Code	Description
Unknown	0x00	A termination reason is not available.
Idle timeout	0x01	The session is being terminated due to idleness.
Version mismatch	0x02	The entity cannot conform to the specified TCPCL protocol version.
Busy	0x03	The entity is too busy to handle the current session.
Contact Failure	0x04	The entity cannot interpret or negotiate a Contact Header or SESS_INIT option.
Resource Exhaustion	0x05	The entity has run into some resource limit and cannot continue the session.

Table 9: SESS_TERM Reason Codes

The earliest a TCPCL session termination MAY occur is immediately after transmission of a Contact Header (and prior to any further message transmit). This can, for example, be used to notify that the entity is currently not able or willing to communicate. However, an entity MUST always send the Contact Header to its peer before sending a SESS_TERM message.

Termination of the TCP connection MAY occur prior to receiving the Contact header as discussed in [Section 4.1](#). If reception of the Contact Header itself somehow fails (e.g., an invalid "magic string" is received), an entity SHALL close the TCP connection without sending a SESS_TERM message.

If a session is to be terminated before a protocol message has completed being sent, then the entity MUST NOT transmit the SESS_TERM message but still SHALL close the TCP connection. Each TCPCL message is contiguous in the octet stream and has no ability to be cut short and/or preempted by an other message. This is particularly important when large segment sizes are being transmitted; either entire XFER_SEGMENT is sent before a SESS_TERM message or the connection is simply terminated mid-XFER_SEGMENT.

6.2. Idle Session Shutdown

The protocol includes a provision for clean termination of idle sessions. Determining the length of time to wait before terminating idle sessions, if they are to be terminated at all, is an implementation and configuration matter.

If there is a configured time to terminate idle sessions and if no TCPCL messages (other than KEEPALIVE messages) has been received for at least that amount of time, then either entity MAY terminate the session by transmitting a SESS_TERM message indicating the reason code of "Idle timeout" (as described in [Table 9](#)).

7. Implementation Status

This section is to be removed before publishing as an RFC.

[NOTE to the RFC Editor: please remove this section before publication, as well as the reference to [\[RFC7942\]](#), [\[github-dtn-demo-agent\]](#), and [\[github-dtn-wireshark\]](#).]

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 [\[RFC7942\]](#). 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 can exist.

An example implementation of the this draft of TCPCLv4 has been created as a GitHub project [[github-dtn-demo-agent](#)] and is intended to use as a proof-of-concept and as a possible source of interoperability testing. This example implementation uses D-Bus as the CL-BP Agent interface, so it only runs on hosts which provide the Python "dbus" library.

A wireshark dissector for TCPCLv4 has been created as a GitHub project [[github-dtn-wireshark](#)] and has been kept in-sync with the latest encoding of this specification.

8. Security Considerations

This section separates security considerations into threat categories based on guidance of BCP 72 [[RFC3552](#)].

8.1. Threat: Passive Leak of Node Data

When used without TLS security, the TCPCL exposes the Node ID and other configuration data to passive eavesdroppers. This occurs even when no transfers occur within a TCPCL session. This can be avoided by always using TLS, even if authentication is not available (see [Section 8.12](#)).

8.2. Threat: Passive Leak of Bundle Data

TCPCL can be used to provide point-to-point transport security, but does not provide security of data-at-rest and does not guarantee end-to-end bundle security. The bundle security mechanisms defined in [[I-D.ietf-dtn-bpsec](#)] are to be used instead.

When used without TLS security, the TCPCL exposes all bundle data to passive eavesdroppers. This can be avoided by always using TLS, even if authentication is not available (see [Section 8.12](#)).

8.3. Threat: TCPCL Version Downgrade

When a TCPCL entity supports multiple versions of the protocol it is possible for a malicious or misconfigured peer to use an older version of TCPCL which does not support transport security. A on-path attacker can also manipulate a Contact Header to present a lower protocol version than desired.

It is up to security policies within each TCPCL entity to ensure that the negotiated TCPCL version meets transport security requirements.

8.4. Threat: Transport Security Stripping

When security policy allows non-TLS sessions, TCPCL does not protect against active network attackers. It is possible for a on-path attacker to set the CAN_TLS flag to 0 on either side of the Contact Header exchange, which will cause the negotiation of [Section 4.3](#) to disable TLS. This leads to the "SSL Stripping" attack described in [\[RFC7457\]](#).

The purpose of the CAN_TLS flag is to allow the use of TCPCL on entities which simply do not have a TLS implementation available. When TLS is available on an entity, it is strongly encouraged that the security policy disallow non-TLS sessions. This requires that the TLS handshake occurs, regardless of the policy-driven parameters of the handshake and policy-driven handling of the handshake outcome.

One mechanism to mitigate the possibility of TLS stripping is the use of DNS-based Authentication of Named Entities (DANE) [\[RFC6698\]](#) toward the passive peer. This mechanism relies on DNS and is unidirectional, so it doesn't help with applying policy toward the active peer, but it can be useful in an environment using opportunistic security. The configuration and use of DANE are outside of the scope of this document.

The negotiated use of TLS is identical behavior to STARTTLS use in [\[RFC2595\]](#), [\[RFC4511\]](#), and others.

8.5. Threat: Weak TLS Configurations

Even when using TLS to secure the TCPCL session, the actual ciphersuite negotiated between the TLS peers can be insecure. Recommendations for ciphersuite use are included in BCP 195 [\[RFC7525\]](#). It is up to security policies within each TCPCL entity to ensure that the negotiated TLS ciphersuite meets transport security requirements.

8.6. Threat: Untrusted End-Entity Certificate

The profile in [Section 4.4.4](#) uses end-entity certificates chained up to a trusted root CA. During TLS handshake, either entity can send a certificate set which does not contain the full chain, possibly excluding intermediate or root CAs. In an environment where peers are known to already contain needed root and intermediate CAs there is no need to include those CAs, but this has a risk of an entity not actually having one of the needed CAs.

8.7. Threat: Certificate Validation Vulnerabilities

Even when TLS itself is operating properly an attacker can attempt to exploit vulnerabilities within certificate check algorithms or configuration to establish a secure TCPCL session using an invalid certificate. A BP agent treats the peer Node ID within a TCPCL session as authoritative and an invalid certificate exploit could lead to bundle data leaking and/or denial of service to the Node ID being impersonated.

There are many reasons, described in [[RFC5280](#)] and [[RFC6125](#)], why a certificate can fail to validate, including using the certificate outside of its valid time interval, using purposes for which it was not authorized, or using it after it has been revoked by its CA. Validating a certificate is a complex task and can require network connectivity outside of the primary TCPCL network path(s) if a mechanism such as OCSP [[RFC6960](#)] is used by the CA. The configuration and use of particular certificate validation methods are outside of the scope of this document.

8.8. Threat: Symmetric Key Limits

Even with a secure block cipher and securely-established session keys, there are limits to the amount of plaintext which can be safely encrypted with a given set of keys as described in [[AEAD-LIMITS](#)]. When permitted by the negotiated TLS version (see [[RFC8446](#)]), it is advisable to take advantage of session key updates to avoid those limits.

8.9. Threat: BP Node Impersonation

The certificates exchanged by TLS enable authentication of peer DNS name and Node ID, but it is possible that a peer either not provide a valid certificate or that the certificate does not validate either the DNS-ID/IPADDR-ID or NODE-ID of the peer (see [Section 3.4](#)). Having a CA-validated certificate does not alone guarantee the identity of the network host or BP node from which the certificate is provided; additional validation procedures in [Section 4.4.3](#) bind the DNS-ID/IPADDR-ID or NODE-ID based on the contents of the certificate.

The DNS-ID/IPADDR-ID validation is a weaker form of authentication, because even if a peer is operating on an authenticated network DNS name or IP address it can provide an invalid Node ID and cause bundles to be "leaked" to an invalid node. Especially in DTN environments, network names and addresses of nodes can be time-variable so binding a certificate to a Node ID is a more stable identity.

NODE-ID validation ensures that the peer to which a bundle is transferred is in fact the node which the BP Agent expects it to be. In circumstances where certificates can only be issued to DNS names, Node ID validation is not possible but it could be reasonable to assume that a trusted host is not going to present an invalid Node ID. Determining when a DNS-ID/IPADDR-ID authentication can be trusted to validate a Node ID is also a policy matter outside of the scope of this document.

One mitigation to arbitrary entities with valid PKIX certificates impersonating arbitrary Node IDs is the use of the PKIX Extended Key Usage key purpose id-kp-bundleSecurity (see [Section 4.4.2.1](#)). When this Extended Key Usage is present in the certificate, it represents a stronger assertion that the private key holder should in fact be trusted to operate as a DTN Node.

8.10. Threat: Denial of Service

The behaviors described in this section all amount to a potential denial-of-service to a TCPCL entity. The denial-of-service could be limited to an individual TCPCL session, could affect other well-behaving sessions on an entity, or could affect all sessions on a host.

A malicious entity can continually establish TCPCL sessions and delay sending of protocol-required data to trigger timeouts. The victim entity can block TCP connections from network peers which are thought to be incorrectly behaving within TCPCL.

An entity can send a large amount of data over a TCPCL session, requiring the receiving entity to handle the data. The victim entity can attempt to stop the flood of data by sending an XFER_REFUSE message, or forcibly terminate the session.

There is the possibility of a "data dribble" attack in which an entity presents a very small Segment MRU which causes transfers to be split among an large number of very small segments and causes the segmentation overhead to overwhelm the actual bundle data segments. Similarly, an entity can present a very small Transfer MRU which will cause resources to be wasted on establishment and upkeep of a TCPCL session over which a bundle could never be transferred. The victim entity can terminate the session during the negotiation of [Section 4.7](#) if the MRUs are unacceptable.

The keepalive mechanism can be abused to waste throughput within a network link which would otherwise be usable for bundle transmissions. Due to the quantization of the Keepalive Interval parameter the smallest Session Keepalive is one second, which should be long enough to not flood the link. The victim entity can

terminate the session during the negotiation of [Section 4.7](#) if the Keepalive Interval is unacceptable.

Finally, an attacker or a misconfigured entity can cause issues at the TCP connection which will cause unnecessary TCP retransmissions or connection resets, effectively denying the use of the overlying TCPCL session.

8.11. Mandatory-to-Implement TLS

Following IETF best current practice, TLS is mandatory to implement for all TCPCL implementations but TLS is optional to use for a given TCPCL session. The recommended configuration of [Section 4.2](#) is to always enable TLS, but entities are permitted to disable TLS based on local configuration. The configuration to enable or disable TLS for an entity or a session is outside of the scope of this document. The configuration to disable TLS is different from the threat of TLS stripping described in [Section 8.4](#).

8.12. Alternate Uses of TLS

This specification makes use of PKIX certificate validation and authentication within TLS. There are alternate uses of TLS which are not necessarily incompatible with the security goals of this specification, but are outside of the scope of this document. The following subsections give examples of alternate TLS uses.

8.12.1. TLS Without Authentication

In environments where PKI is available but there are restrictions on the issuance of certificates (including the contents of certificates), it may be possible to make use of TLS in a way which authenticates only the passive entity of a TCPCL session or which does not authenticate either entity. Using TLS in a way which does not successfully authenticate some claim of both peer entities of a TCPCL session is outside of the scope of this document but does have similar properties to the opportunistic security model of [[RFC7435](#)].

8.12.2. Non-Certificate TLS Use

In environments where PKI is unavailable, alternate uses of TLS which do not require certificates such as pre-shared key (PSK) authentication [[RFC5489](#)] and the use of raw public keys [[RFC7250](#)] are available and can be used to ensure confidentiality within TCPCL. Using non-PKI node authentication methods is outside of the scope of this document.

8.13. Predictability of Transfer IDs

The only requirement on Transfer IDs is that they be unique with each session from the sending peer only. The trivial algorithm of the first transfer starting at zero and later transfers incrementing by one causes absolutely predictable Transfer IDs. Even when a TCPCL session is not TLS secured and there is a on-path attacker causing denial of service with XFER_REFUSE messages, it is not possible to preemptively refuse a transfer so there is no benefit in having unpredictable Transfer IDs within a session.

9. IANA Considerations

Registration procedures referred to in this section are defined in [\[RFC8126\]](#).

Some of the registries have been defined as version specific to TCPCLv4, and imports some or all codepoints from TCPCLv3. This was done to disambiguate the use of these codepoints between TCPCLv3 and TCPCLv4 while preserving the semantics of some of the codepoints.

9.1. Port Number

Within the port registry of [\[IANA-PORTS\]](#), TCP port number 4556 has been previously assigned as the default port for the TCP convergence layer in [\[RFC7242\]](#). This assignment is unchanged by TCPCL version 4, but the assignment reference is updated to this specification. Each TCPCL entity identifies its TCPCL protocol version in its initial contact (see [Section 9.2](#)), so there is no ambiguity about what protocol is being used. The related assignments for UDP and DCCP port 4556 (both registered by [\[RFC7122\]](#)) are unchanged.

Parameter	Value
Service Name:	dtn-bundle
Transport Protocol(s):	TCP
Assignee:	IESG <iesg@ietf.org>
Contact:	IESG <iesg@ietf.org>
Description:	DTN Bundle TCP CL Protocol
Reference:	This specification.
Port Number:	4556

Table 10

9.2. Protocol Versions

IANA has created, under the "Bundle Protocol" registry [\[IANA-BUNDLE\]](#), a sub-registry titled "Bundle Protocol TCP Convergence-Layer Version Numbers". The version number table is updated to include this specification. The registration procedure is RFC Required.

Value	Description	Reference
0	Reserved	[RFC7242]
1	Reserved	[RFC7242]
2	Reserved	[RFC7242]
3	TCPCL	[RFC7242]
4	TCPCLv4	This specification.
5-255	Unassigned	

Table 11

9.3. Session Extension Types

EDITOR NOTE: sub-registry to-be-created upon publication of this specification.

IANA will create, under the "Bundle Protocol" registry [[IANA-BUNDLE](#)], a sub-registry titled "Bundle Protocol TCP Convergence-Layer Version 4 Session Extension Types" and initialize it with the contents of [Table 12](#). The registration procedure is Expert Review within the lower range 0x0001--0x7FFF. Values in the range 0x8000--0xFFFF are reserved for use on private networks for functions not published to the IANA.

Specifications of new session extension types need to define the encoding of the Item Value data as well as any meaning or restriction on the number of or order of instances of the type within an extension item list. Specifications need to define how the extension functions when no instance of the new extension type is received during session negotiation.

Expert(s) are encouraged to be biased towards approving registrations unless they are abusive, frivolous, or actively harmful (not merely aesthetically displeasing, or architecturally dubious).

Code	Session Extension Type
0x0000	Reserved
0x0001--0x7FFF	Unassigned
0x8000--0xFFFF	Private/Experimental Use

Table 12: Session Extension Type Codes

9.4. Transfer Extension Types

EDITOR NOTE: sub-registry to-be-created upon publication of this specification.

IANA will create, under the "Bundle Protocol" registry [[IANA-BUNDLE](#)], a sub-registry titled "Bundle Protocol TCP Convergence-Layer Version 4 Transfer Extension Types" and initialize it with the

contents of [Table 13](#). The registration procedure is Expert Review within the lower range 0x0001--0x7FFF. Values in the range 0x8000--0xFFFF are reserved for use on private networks for functions not published to the IANA.

Specifications of new transfer extension types need to define the encoding of the Item Value data as well as any meaning or restriction on the number of or order of instances of the type within an extension item list. Specifications need to define how the extension functions when no instance of the new extension type is received in a transfer.

Expert(s) are encouraged to be biased towards approving registrations unless they are abusive, frivolous, or actively harmful (not merely aesthetically displeasing, or architecturally dubious).

Code	Transfer Extension Type
0x0000	Reserved
0x0001	Transfer Length Extension
0x0002--0x7FFF	Unassigned
0x8000--0xFFFF	Private/Experimental Use

Table 13: Transfer Extension Type Codes

9.5. Message Types

EDITOR NOTE: sub-registry to-be-created upon publication of this specification.

IANA will create, under the "Bundle Protocol" registry [[IANA-BUNDLE](#)], a sub-registry titled "Bundle Protocol TCP Convergence-Layer Version 4 Message Types" and initialize it with the contents of [Table 14](#). The registration procedure is RFC Required within the lower range 0x01--0xEF. Values in the range 0xF0--0xFF are reserved for use on private networks for functions not published to the IANA.

Specifications of new message types need to define the encoding of the message data as well as the purpose and relationship of the new message to existing session/transfer state within the baseline message sequencing. The use of new message types need to be negotiated between TCPCL entities within a session (using the session extension mechanism) so that the receiving entity can properly decode all message types used in the session.

Expert(s) are encouraged to favor new session/transfer extension types over new message types. TCPCL messages are not self-delimiting, so care must be taken in introducing new message types. If an entity receives an unknown message type the only thing that

can be done is to send a MSG_REJECT and close the TCP connection; not even a clean termination can be done at that point.

Code	Message Type
0x00	Reserved
0x01	XFER_SEGMENT
0x02	XFER_ACK
0x03	XFER_REFUSE
0x04	KEEPALIVE
0x05	SESS_TERM
0x06	MSG_REJECT
0x07	SESS_INIT
0x08--0xEF	Unassigned
0xF0--0xFF	Private/Experimental Use

Table 14: Message Type Codes

9.6. XFER_REFUSE Reason Codes

EDITOR NOTE: sub-registry to-be-created upon publication of this specification.

IANA will create, under the "Bundle Protocol" registry [[IANA-BUNDLE](#)], a sub-registry titled "Bundle Protocol TCP Convergence-Layer Version 4 XFER_REFUSE Reason Codes" and initialize it with the contents of [Table 15](#). The registration procedure is Specification Required within the lower range 0x00--0xEF. Values in the range 0xF0--0xFF are reserved for use on private networks for functions not published to the IANA.

Specifications of new XFER_REFUSE reason codes need to define the meaning of the reason and disambiguate it with pre-existing reasons. Each refusal reason needs to be usable by the receiving BP Agent to make retransmission or re-routing decisions.

Expert(s) are encouraged to be biased towards approving registrations unless they are abusive, frivolous, or actively harmful (not merely aesthetically displeasing, or architecturally dubious).

Code	Refusal Reason
0x00	Unknown
0x01	Completed
0x02	No Resources
0x03	Retransmit
0x04	Not Acceptable
0x05	Extension Failure
0x06	Session Terminating

Code	Refusal Reason
0x07--0xEF	Unassigned
0xF0--0xFF	Private/Experimental Use

Table 15: XFER_REFUSE Reason Codes

9.7. SESS_TERM Reason Codes

EDITOR NOTE: sub-registry to-be-created upon publication of this specification.

IANA will create, under the "Bundle Protocol" registry [[IANA-BUNDLE](#)], a sub-registry titled "Bundle Protocol TCP Convergence-Layer Version 4 SESS_TERM Reason Codes" and initialize it with the contents of [Table 16](#). The registration procedure is Specification Required within the lower range 0x00--0xEF. Values in the range 0xF0--0xFF are reserved for use on private networks for functions not published to the IANA.

Specifications of new SESS_TERM reason codes need to define the meaning of the reason and disambiguate it with pre-existing reasons. Each termination reason needs to be usable by the receiving BP Agent to make re-connection decisions.

Expert(s) are encouraged to be biased towards approving registrations unless they are abusive, frivolous, or actively harmful (not merely aesthetically displeasing, or architecturally dubious).

Code	Termination Reason
0x00	Unknown
0x01	Idle timeout
0x02	Version mismatch
0x03	Busy
0x04	Contact Failure
0x05	Resource Exhaustion
0x06--0xEF	Unassigned
0xF0--0xFF	Private/Experimental Use

Table 16: SESS_TERM Reason Codes

9.8. MSG_REJECT Reason Codes

EDITOR NOTE: sub-registry to-be-created upon publication of this specification.

IANA will create, under the "Bundle Protocol" registry [[IANA-BUNDLE](#)], a sub-registry titled "Bundle Protocol TCP Convergence-Layer Version 4 MSG_REJECT Reason Codes" and initialize it with the contents of [Table 17](#). The registration procedure is Specification

Required within the lower range 0x01--0xEF. Values in the range 0xF0--0xFF are reserved for use on private networks for functions not published to the IANA.

Specifications of new MSG_REJECT reason codes need to define the meaning of the reason and disambiguate it with pre-existing reasons. Each rejection reason needs to be usable by the receiving TCPCL Entity to make message sequencing and/or session termination decisions.

Expert(s) are encouraged to be biased towards approving registrations unless they are abusive, frivolous, or actively harmful (not merely aesthetically displeasing, or architecturally dubious).

Code	Rejection Reason
0x00	reserved
0x01	Message Type Unknown
0x02	Message Unsupported
0x03	Message Unexpected
0x04--0xEF	Unassigned
0xF0--0xFF	Private/Experimental Use

Table 17: MSG_REJECT Reason Codes

9.9. Object Identifier for PKIX Module Identifier

IANA has created, under the "Structure of Management Information (SMI) Numbers" registry [[IANA-SMI](#)], a sub-registry titled "SMI Security for PKIX Module Identifier". The table is updated to include a row "id-mod-dtn-tcpclv4-2021" for identifying the module in [Appendix B](#) as in the following table.

Decimal	Description	References
MOD-TBD	id-mod-dtn-tcpclv4-2021	This specification.

Table 18

9.10. Object Identifier for PKIX Other Name Forms

IANA has created, under the "Structure of Management Information (SMI) Numbers" registry [[IANA-SMI](#)], a sub-registry titled "SMI Security for PKIX Other Name Forms". The other name forms table is updated to include a row "id-on-bundleEID" for identifying DTN Endpoint IDs as in the following table.

Decimal	Description	References
ON-TBD	id-on-bundleEID	This specification.

Table 19

The formal structure of the associated other name form is in [Appendix B](#). The use of this OID is defined in [Section 4.4.1](#) and [Section 4.4.2](#).

9.11. Object Identifier for PKIX Extended Key Usage

IANA has created, under the "Structure of Management Information (SMI) Numbers" registry [[IANA-SMI](#)], a sub-registry titled "SMI Security for PKIX Extended Key Purpose". The extended key purpose table is updated to include a purpose "id-kp-bundleSecurity" for identifying DTN endpoints as in the following table.

Decimal	Description	References
KP-TBD	id-kp-bundleSecurity	This specification.

Table 20

The formal definition of this EKU is in [Appendix B](#). The use of this OID is defined in [Section 4.4.2](#).

10. Acknowledgments

This specification is based on comments on implementation of [[RFC7242](#)] provided from Scott Burleigh.

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Appendix A. Significant changes from RFC7242

The areas in which changes from [RFC7242] have been made to existing headers and messages are:

- *Split Contact Header into pre-TLS protocol negotiation and SESS_INIT parameter negotiation. The Contact Header is now fixed-length.
- *Changed Contact Header content to limit number of negotiated options.
- *Added session option to negotiate maximum segment size (per each direction).
- *Renamed "Endpoint ID" to "Node ID" to conform with BPv7 terminology.
- *Added session extension capability.
- *Added transfer extension capability. Moved transfer total length into an extension item.
- *Defined new IANA registries for message / type / reason codes to allow renaming some codes for clarity.
- *Segments of all new IANA registries are reserved for private/experimental use.
- *Expanded Message Header to octet-aligned fields instead of bit-packing.
- *Added a bundle transfer identification number to all bundle-related messages (XFER_SEGMENT, XFER_ACK, XFER_REFUSE).
- *Use flags in XFER_ACK to mirror flags from XFER_SEGMENT.
- *Removed all uses of SDNV fields and replaced with fixed-bit-length (network byte order) fields.

- *Renamed SHUTDOWN to SESS_TERM to deconflict term "shutdown" related to TCP connections.

- *Removed the notion of a re-connection delay parameter.

The areas in which extensions from [[RFC7242](#)] have been made as new messages and codes are:

- *Added contact negotiation failure SESS_TERM reason code.

- *Added MSG_REJECT message to indicate an unknown or unhandled message was received.

- *Added TLS connection security mechanism.

- *Added "Not Acceptable", "Extension Failure", and "Session Terminating" XFER_REFUSE reason codes.

- *Added "Resource Exhaustion" SESS_TERM reason code.

Appendix B. ASN.1 Module

The following ASN.1 module formally specifies the BundleEID structure, its Other Name form, and the bundleSecurity Extended Key Usage in the syntax of [[X.680](#)]. This specification uses the ASN.1 definitions from [[RFC5912](#)] with the 2002 ASN.1 notation used in that document.

<CODE BEGINS>

DTN-TCPCLPV4-2021

```
{ iso(1) identified-organization(3) dod(6)
  internet(1) security(5) mechanisms(5) pkix(7) id-mod(0)
  id-mod-dtn-tcpclv4-2021(MOD-TBD) }
```

DEFINITIONS IMPLICIT TAGS ::=

BEGIN

IMPORTS

OTHER-NAME

FROM PKIX1Implicit-2009 -- [RFC5912]

```
{ iso(1) identified-organization(3) dod(6) internet(1)
  security(5) mechanisms(5) pkix(7) id-mod(0)
  id-mod-pkix1-implicit-02(59) }
```

id-pkix

FROM PKIX1Explicit-2009 -- [RFC5912]

```
{ iso(1) identified-organization(3) dod(6) internet(1)
  security(5) mechanisms(5) pkix(7) id-mod(0)
  id-mod-pkix1-explicit-02(51) } ;
```

id-kp OBJECT IDENTIFIER ::= { id-pkix 3 }

id-on OBJECT IDENTIFIER ::= { id-pkix 8 }

DTNOtherNames OTHER-NAME ::= { on-bundleEID, ... }

-- The otherName definition for Bundle EID

```
on-bundleEID OTHER-NAME ::= {
  BundleEID IDENTIFIED BY { id-on-bundleEID }
}
```

id-on-bundleEID OBJECT IDENTIFIER ::= { id-on ON-TBD }

-- Same encoding as GeneralName of uniformResourceIdentifier

BundleEID ::= IA5String

-- The Extended Key Usage key for bundle security

id-kp-bundleSecurity OBJECT IDENTIFIER ::= { id-kp KP-TBD }

END

<CODE ENDS>

Appendix C. Example of the BundleEID Other Name Form

EDITOR NOTE: The encoded hex part "0b" and OID segment "11" are to be replaced by ON-TBD allocated value. It was necessary to choose some OID value, so I chose the first not-allocated code point.

This non-normative example demonstrates an otherName with a name form of BundleEID to encode the Node ID "dtn://example/".

The hexadecimal form of the DER encoding of the otherName is:

a01c06082b0601050507080ba010160e64746e3a2f2f6578616d706c652f

And the text decoding in [Figure 28](#) is an output of Peter Gutmann's "dumpasn1" program.

```
0 28: [0] {
2 8:  OBJECT IDENTIFIER '1 3 6 1 5 5 7 8 11'
12 16:  [0] {
14 14:  IA5String 'dtn://example/'
      :  }
      :  }
```

Figure 28: Visualized decoding of the on-bundleEID

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