Internet Engineering Task Force
INTERNET-DRAFT
draft-kohler-dcp-04.ps

Eddie Kohler
Mark Handley
Sally Floyd
ICIR
Jitendra Padhye
Microsoft Research

19 June 2002
Expires: December 2002

Datagram Congestion Control Protocol (DCCP)

Status of this Document

Abstract

This document specifies the Datagram Congestion Control Protocol (DCCP), which implements a congestion-controlled, unreliable flow of datagrams suitable for use by applications such as streaming media.

Table of Contents

1. Introduction

This document specifies the Datagram Congestion Control Protocol (DCCP). DCCP provides the following features:

- An unreliable flow of datagrams, with acknowledgements.
- A reliable handshake for connection setup and teardown.
- Reliable negotiation of options, including negotiation of a suitable congestion control mechanism.
- Mechanisms allowing a server to avoid holding any state for unacknowledged connection attempts or already-finished connections.
- An optional mechanism that allows the sender to know, with high reliability, which packets reached the receiver.
- Congestion control incorporating Explicit Congestion Notification (ECN) and the ECN Nonce, as per [RFC 3168] and [WES01].
- Path MTU discovery, as per [RFC 1191].

DCCP is intended for applications that require the flow-based semantics of TCP, but which do not want TCP's in-order delivery and reliability semantics, or which would like different congestion control dynamics than TCP. Similarly, DCCP is intended for applications that do not require the features of SCTP [RFC 2960] such as sequenced delivery within multiple streams.

The sort of applications which could make use of DCCP are those which have timing constraints on the delivery of data, such that reliable in-order delivery, when combined with congestion control, is likely to result in some information arriving at the receiver after it is no longer of use. Such applications might include streaming media and Internet telephony.

To date most such applications have used either TCP, with the problems described above, or used UDP and implemented their own congestion control mechanisms (or no congestion control at all). The purpose of DCCP is to provide a standard way to implement congestion control and congestion control negotiation for such applications. One of the motivations for DCCP is to enable the use of ECN, along with conformant end-to-end congestion control, for applications that otherwise would be using UDP. In addition, DCCP implements reliable connection setup, teardown, and feature negotiation.

A DCCP connection contains acknowledgement traffic as well as data traffic. Acknowledgements inform a sender whether its packets arrived, and whether they were ECN marked. Acks are transmitted as reliably as the congestion control mechanism in use requires, possibly up to completely reliably.

Previous drafts of this specification called the protocol DCP, or Datagram Control Protocol. The name was changed to make the acronym sound less like "TCP".

2. Design Rationale

One of the motivations behind the design of DCCP is to make DCCP as low-overhead as possible, in terms both of the size of the packet header and in terms of the state and CPU overhead required at the end hosts. In particular, DCCP is designed to minimize the state maintained by the data sender. DCCP is intended to be used by applications that currently now use UDP without end-to-end congestion control. The desire is for many applications to have little reason not to use DCCP instead of UDP, once DCCP is deployed.

This desire for minimal overhead results in the design decision to add only the minimal necessary functionality to DCCP, and to leave other functionality such as FEC or semireliability to the application, to be layered on top of DCCP as desired. The desire for minimal overhead is also one of the reasons to propose DCCP instead of just proposing an unreliable version of SCTP for applications currently using UDP.

Mechanisms for multi-homing and mobility are the one area of additional functionality that can not necessarily be layered cleanly and effectively on top of DCCP. Thus, the one outstanding design decision with DCCP concerns whether to incorporate mechanisms for multi-homing and mobility into DCCP itself.

A second motivation behind the design of DCCP is to allow applications to choose an alternative to the current TCP-style congestion control that halves the congestion window in response to a congestion indication. Thus, DCCP is designed to allow applications to choose between several forms of congestion control. The first, TCP-like congestion control, halves the congestion window in response to a packet drop or mark, as in TCP. A second alternative, TFRC (TCP-Friendly Rate Control), is a form of equation-based congestion control that minimized abrupt changes in the sending rate, while maintaining longer-term fairness with TCP.

In proposing a new transport protocol, it is necessary to justify the design decision not to require the use of the Congestion Manager, as well as the design decision to add a new transport protocol to the current family of UDP, TCP, and SCTP. The Congestion Manager [RFC3124] allows multiple concurrent streams between the same sender and receiver to share congestion control. However, the current Congestion Manager can only be used by applications that have their own end-to-end feedback about packet losses, and this is not the case for many of the applications currently using UDP. In addition, the current Congestion Manager does not lend itself to the use of forms of TFRC where the state about past packet drops or marks is maintained at the receiver rather than at the sender. In addition, while we would like for DCCP to be able to make use of CM where desired by the application, we do not see any benefit in making the deployment of DCCP contingent on the deployment of CM itself.

3. Concepts and Terminology

3.1. Anatomy of a DCCP Connection

Each DCCP connection runs between two endpoints, which we often name DCCP A and DCCP B. Data may pass over the connection in either or both directions. The DCCP connection between DCCP A and DCCP B consists of four sets of packets, as follows:

(1) Data packets from DCCP A to DCCP B.

(2) Acknowledgements from DCCP B to DCCP A.

(3) Data packets from DCCP B to DCCP A.

(4) Acknowledgements from DCCP A to DCCP B.

We use the following terms to refer to subsets and endpoints of a DCCP connection.

Subflows
A subflow consists of either data or acknowledgement packets, sent in one direction (from DCCP A to DCCP B, say). Each of the four sets of packets above is a subflow. (Subflows may overlap to some extent, since acknowledgements may be piggybacked on data packets.)

Sequences
A sequence consists of all packets sent in one direction, regardless of whether they are data or acknowledgements. The sets 1+4 and 2+3, from above, are each

sequences. Each packet on a sequence has a different sequence number.

Half-connections

A half-connection consists of the data packets sent in one direction, plus the corresponding acknowledgements. The sets 1+2 and 3+4, from above, are each half-connections. Half-connections are named after the direction of data flow, so the A-to-B half-connection contains the data packets from A to B and the acknowledgements from B to A.

HC-Sender and HC-Receiver

In the context of a single half-connection, the HC-Sender is the endpoint sending data, while the HC-Receiver is the endpoint sending acknowledgements. For example, in the A-to-B half-connection, DCCP A is the HC-Sender and DCCP B is the HC-Receiver.

3.2. Congestion Control

Each half-connection is managed by a congestion control mechanism. The endpoints negotiate these mechanisms at connection setup; the mechanisms for the two half-connections need not be the same, but they must both be TCP-compatible.

Conformant congestion control mechanisms correspond to single-byte congestion control identifiers, or CCIDs. The CCID for a half-connection describes how the HC-Sender limits data packet rates in a TCP-friendly manner; how it maintains necessary parameters, such as congestion windows; how the HC-Receiver sends congestion feedback via acknowledgements; and how it manages the acknowledgement rate. Section 6 introduces the currently allocated CCIDs, which are defined in separate profile documents.

3.3. Connection Initiation and Termination

Every DCCP connection is actively initiated by one DCCP, which connects to a DCCP socket in the passive listening state. We refer to the active endpoint as "the client" and the passive endpoint as "the server". Most of the DCCP specification is indifferent to whether a DCCP is client or server. However, only the server may generate a DCCP-CloseReq packet. (A DCCP-CloseReq packet forces the receiving DCCP to close the connection and maintain connection state for a reasonable time, allowing old packets to clear the network.) This means that the client cannot force the server to maintain connection state after the connection is closed.

DCCP does not support TCP-style simultaneous open. In particular, a host MUST NOT respond to a DCCP-Request packet with a DCCP-Response packet unless the destination port specified in the DCCP-Request corresponds to a local socket opened for listening.

DCCP also does not support half-open connections. That is, DCCP shuts down both half-connections as a unit. However, DCCP SHOULD allow applications to declare that they are no longer interested in receiving data. This would allow DCCP implementations to streamline state for certain half-connections. See Section 7.8, the Buffer Closed Drops option, for more information.

3.4. Features

DCCP uses a generic mechanism to negotiate connection properties, such as the CCIDs active on the two half-connections. These properties are called features. (We reserve the term "option" for a collection of bytes in some DCCP header.) A feature name, such as "CCID", generally corresponds to two features, one per half-connection. For instance, there are two CCIDs per connection. The endpoint in charge of a particular feature is called its feature location.

The Change, Prefer, and Confirm options negotiate feature values. (These options were formerly called Ask, Choose, and Answer, respectively.) Change is sent to a feature location, asking it to change its value for the feature. The feature location may respond with Prefer, which asks the other endpoint to Change again with different values, or it may change the feature value and acknowledge the request with Confirm. Retransmissions make feature negotiation reliable. Section 5.3 describes these options further.

4. DCCP Packets

DCCP has nine different packet types:

- DCCP-Request
- DCCP-Response
- DCCP-Data
- DCCP-Ack
- DCCP-DataAck
- DCCP-CloseReq
- DCCP-Close
- DCCP-Reset
- DCCP-Move

Only the first eight types commonly occur. The DCCP-Move packet is used to support multihoming and mobility.

The progress of a typical DCCP connection is as follows.

(1) The client sends the server a DCCP-Request packet specifying the client and server ports, the service that is being requested, and any features that are being negotiated, including the CCID that the client would like the server to use. The client MAY optionally piggyback some data on the DCCP-Request packet---an application-level request, say---which the server MAY ignore.

(2) The server sends the client a DCCP-Response packet indicating that it is willing to communicate with the client. The response indicates any features and options that the server agrees to, whether an application request in the DCCP-request was actually passed to the application, and optionally an Init Cookie that wraps up all this information and which MUST be returned by the client for the connection to complete.

(3) The client sends the server a DCCP-Ack packet that acknowledges the DCCP-Response packet. This acknowledges the server's initial sequence number and returns the Init Cookie if there was one in the DCCP-Response. It may also continue feature negotiation.

(4) Next comes zero or more DCCP-Ack exchanges as required to finalize feature negotiation. The client may piggyback an application-level request on its final ack, producing a DCCP-DataAck packet.

(5) The server and client then exchange DCCP-Data packets, DCCP-Ack packets acknowledging that data, and, optionally, DCCP-DataAck packets containing piggybacked data and acknowledgements. If the client has no data to send, then the server will send DCCP-Data and DCCP-DataAck packets, while the client will send DCCP-Acks exclusively.

(6) The server sends a DCCP-CloseReq packet requesting a close.

(7) The client sends a DCCP-Close packet acknowledging the close.

(8) The server sends a DCCP-Reset packet and clears its connection state.

(9) The client receives the DCCP-Reset packet and holds state for a reasonable interval of time to allow any remaining packets to clear the network.

An alternative connection closedown sequence is initiated by the client:

(6) The client sends a DCCP-Close packet closing the connection.

(7) The server sends a DCCP-Reset packet and clears its connection state.

(8) The client receives the DCCP-Reset packet and holds state for a reasonable interval of time to allow any remaining packets to clear the network.

This arrangement of setup and teardown handshakes permits the server to decline to hold any state until the handshake with the client has completed, and ensures that the client must hold the TimeWait state at connection closedown.

4.1. Examples of DCCP Congestion Control

Before giving the detailed specifications of DCCP, we first give two more detailed examples on DCCP congestion control in operation.

4.1.1. DCCP with TCP-like Congestion Control

The first example is of a connection where both half-connections use TCP-like Congestion Control, specified by CCID 2 [CCID 2 PROFILE]. In this example, the client sends an application-level request to the server, and the server responds with a stream of data packets. This example is of a connection using ECN.

(1) The client sends the DCCP-Request, which includes a Change option asking the server to use CCID 2 for the server's data packets, and a Prefer option informing the server that the client would like to use CCID 2 for the its data packets.

(2) The server sends a DCCP-Response, including a Confirm option indicating that the server agrees to use CCID 2 for its data packets, and a Change option indicating that the server agrees to the client's suggestion of CCID 2 for the client's data packets.

(3) The client responds with a DCCP-DataAck acknowledging the server's initial sequence number, and including a Confirm option finalizing the negotiation of the client-to-server CCID, and an application-level request for data. We will not discuss the client-to-server half-connection further in this example.

(4) The server sends DCCP-Data packets, where the number of packets sent is governed by a congestion window cwnd, as in TCP. The details of the congestion window are defined in the profile for CCID 2, which is a separate document [CCID 2 PROFILE]. The server also sends Ack Ratio feature options specifying the number of server data packets to be covered by an Ack packet from the client.

Some of these data packets are DCCP-DataAcks acknowledging packets from the client.

(5) The client sends a DCCP-Ack packet acknowledging the data packets for every Ack Ratio data packets transmitted by the server. Each DCCP-Ack packet uses a sequence number and contains an Ack Vector, as defined in Section 7 on Acknowledgements. These packets also include Confirm options answering any Ack Ratio requests from the server.

(6) The server continues sending DCCP-Data packets as controlled by the congestion window. Upon receiving DCCP-Ack packets, the server examines the Ack Vector to learn about marked or dropped data packets, and adjusts its congestion window accordingly, as described in [CCID 2 PROFILE]. Because this is unreliable transfer, the server does not retransmit dropped packets.

(7) Because DCCP-Ack packets use sequence numbers, the server has direct information about the fraction of loss or marked DCCP-Ack packets. The server responds to lost or marked DCCP-Ack packets by modifying the Ack Ratio sent to the client, as described in [CCID 2 PROFILE]. Under certain conditions, the server must acknowledge some of the client's acknowledgements; see Section 7.1 for more information.

(8) The server estimates round-trip times and calculates a TimeOut (TO) value much as the RTO (Retransmit Timeout) is calculated in TCP. Again, the specification for this is in [CCID 2 PROFILE]. The TO is used to determine when a new DCCP-Data packet can be transmitted when the server has been limited by the congestion window and no feedback has been received from the client.

(9) Each DCCP-Data, DCCP-DataAck, and DCCP-Ack packet is sent as ECN-Capable, with either the ECT(0) or the ECT(1) codepoint set, as described in [WES01]. The client echoes the accumulated ECN Nonce for the server's packets along with its Ack Vector options.

(10) The DCCP-CloseReq, DCCP-Close, and DCCP-Reset packets to close the connection are as in the example above.

4.1.2. DCCP with TFRC Congestion Control

This example is of a connection where both half-connections use TFRC Congestion Control, specified by CCID 3 The specification for CCID 3 is in a separate profile [CCID 3 PROFILE]; the purpose of this example is to illustrate the range of uses for DCCP.

(1) The DCCP-Request and DCCP-Response packets specifying the use of CCID 3 and the initial DCCP-DataAck packet are similar to those in the TCP-like example above.

(2) The server sends DCCP-Data packets, where the number of packets sent is governed by an allowed transmit rate, as in TFRC. The details of the allowed transmit rate are defined in the profile for CCID 3, which is a separate document [CCID 3 PROFILE]. Each DCCP-Data packet has a sequence number and a window counter option.

Some of these data packets are DCCP-DataAck packets acknowledging packets from the client, but for simplicity we will not discuss the half-connection of data from the client to the server in this example.

(3) The receiver sends DCCP-Ack packets at least once per round-trip time acknowledging the data packets, unless the server is sending at a rate of less than one packet per RTT, as specified by CITE CCID3 . These acknowledgements may be piggybacked on data packets, producing DCCP-DataAck packets. Each DCCP-Ack packet uses a sequence number and identifies the most recent packet received from the server. Each DCCP-Ack packet includes feedback about the loss event rate calculated by the client, as specified by [CCID 3 PROFILE].

(4) The server continues sending DCCP-Data packets as controlled by the allowed transmit rate. Upon receiving DCCP-Ack packets, the server updates its allowed transmit rate as specified by [CCID 3 PROFILE].

(5) The server estimates round-trip times and calculates a TimeOut (TO) value much as the RTO (Retransmit Timeout) is calculated in TCP. Again, the specification for this is in [CCID 3 PROFILE].

(6) The use of ECN follows TCP-like Congestion Control, above, and is described further in [CCID 3 PROFILE].

(7) The DCCP-CloseReq, DCCP-Close, and DCCP-Reset packets to close the connection are as in the examples above.

4.2. DCCP Generic Packet Header

All DCCP packets begin with a generic DCCP packet header:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Source Port          |           Dest Port           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Type  |  Res  |               Sequence Number                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Data Offset  | # NDP | Cslen |           Checksum            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Source and Destination Ports: 16 bits each

These fields identify the connection. Packets sent on the other sequence switch the source and destination port values.

Type: 4 bits

The type field specifies the type of the DCCP message. The following values are defined:

0 DCCP-Request packet.

1 DCCP-Response packet.

2 DCCP-Data packet.

3 DCCP-Ack packet.

4 DCCP-DataAck packet.

5 DCCP-CloseReq packet.

6 DCCP-Close packet.

7 DCCP-Reset packet.

8 DCCP-Move packet.

Reserved (Res): 4 bits

This field is reserved for future expansion. The version of DCCP specified here MUST set the field to all zeroes on generated packets, and ignore its value on received packets.

Sequence Number: 24 bits

The sequence number field is initialized by a DCCP-Request or DCCP-Response packet, and increases by one (modulo 16777216) with every packet sent. The receiver uses this information to determine whether packet losses have occurred. Even packets containing no data update the sequence number. Sequence numbers also provide some protection against old and malicious packets. Section 4.3 discusses sequence number validity.

Data Offset: 8 bits

The offset from the start of the DCCP header to the beginning of the packet's payload, measured in 32-bit words.

Number of Non-Data Packets (# NDP): 4 bits

DCCP sets this field to the number of non-data packets it has sent so far on its sequence, modulo 16. A non-data packet is simply any packet not containing user data; DCCP-Ack packets are the canonical example. When sending a non-data packet, DCCP increments the # NDP counter before storing its value in the packet header.

This field can help the receiving DCCP decide whether a lost packet contained any user data. (An application may want to know when it has lost data. DCCP could report every packet loss as a potential data loss, but that would cause false loss reports when non-data packets were lost.) For example, say that packet 10 had # NDP set to 5; packet 11 was lost; and packet 12 had # NDP set to 5. Then the receiving DCCP could deduce that packet 11 contained data, since # NDP did not change. Likewise, if # NDP had gone up to 6 (and packets 10 and 12 contained user data), then packet 11 must not have contained any data.

Checksum Length (Cslen): 4 bits

The checksum length field specifies what parts of the packet are covered by the checksum field. The checksum always covers at least the DCCP header, DCCP options, and a pseudoheader taken from the network-layer header (see below). If the checksum length field is zero, that is all the checksum covers. If the field is 15, the checksum covers the packet's payload as well, possibly with 8 bits of zero padding on the right to pad the payload to an even number of bytes. Values between 1 and 14, inclusive, indicate that the checksum additionally covers the indicated number of initial 32-bit words of the packet's payload, padded on the right with zeros as necessary. Any value other than 15 specifies that corruption is acceptable in some or all of the DCCP packet's payload, and that partially corrupted data packets may be received and counted for congestion control purposes. The meaning of values other than 0 and 15 should be considered experimental.

Checksum: 16 bits

DCCP uses the TCP/IP checksum algorithm. The checksum field equals the 16 bit one's complement of the one's complement sum of all 16 bit words in the DCCP header, DCCP options, a pseudoheader taken from the network-layer header, and, depending on the value of the checksum length field, some or all of the payload. When calculating the checksum, the checksum field itself is treated as 0. If a packet contains an odd number of header and text octets to be checksummed, the last octet is padded on the right with zeros to form a 16 bit word for checksum purposes. The pad is not transmitted as part of the packet.

The pseudoheader is calculated as for TCP. For IPv4, it is 96 bits long, and consists of the IPv4 source and destination addresses, the IP protocol number for DCCP (padded on the left with 8 zero bits), and the DCCP length (the length of the DCCP header with options, plus the length of any data); see Section 3.1 of [RFC 793]. For IPv6, it is 320 bits long, and consists of the IPv6 source and destination addresses, the DCCP length as a 32-bit quantity, and the IP protocol number for DCCP (padded on the left with 24 zero bits); see Section 8.1 of [RFC 2460].

4.3. Sequence Number Validity

DCCP should ignore packets with invalid sequence numbers, which may arise if the network delivers a very old packet or an attacker attempts to hijack a connection. TCP solves this problem with its window. In DCCP, however, the definition of "unreasonable sequence number" is complicated because sequence numbers change with each packet sent. Thus, a loss event that dropped many consecutive packets could cause two DCCPs to get out of sync relative to any window.

DCCP uses Loss Window and Connection Nonce mechanisms to determine whether a given packet's sequence number is valid. Each HC-Sender gives the corresponding HC-Receiver a *loss window width* W; see Section 5.9. This reflects how many packets the sender expects to be in flight. Only the sender can anticipate this number. One good guideline is to set it to about 3 or 4 times the maximum number of packets the sender expects to send in any round-trip time. Too-small values increase the risk of the endpoints getting out sync after bursts of loss; too-large values increase the risk of connection hijacking. W defaults to 1000. The Connection Nonces are used to get back into sync when more than W consecutive packets are lost.

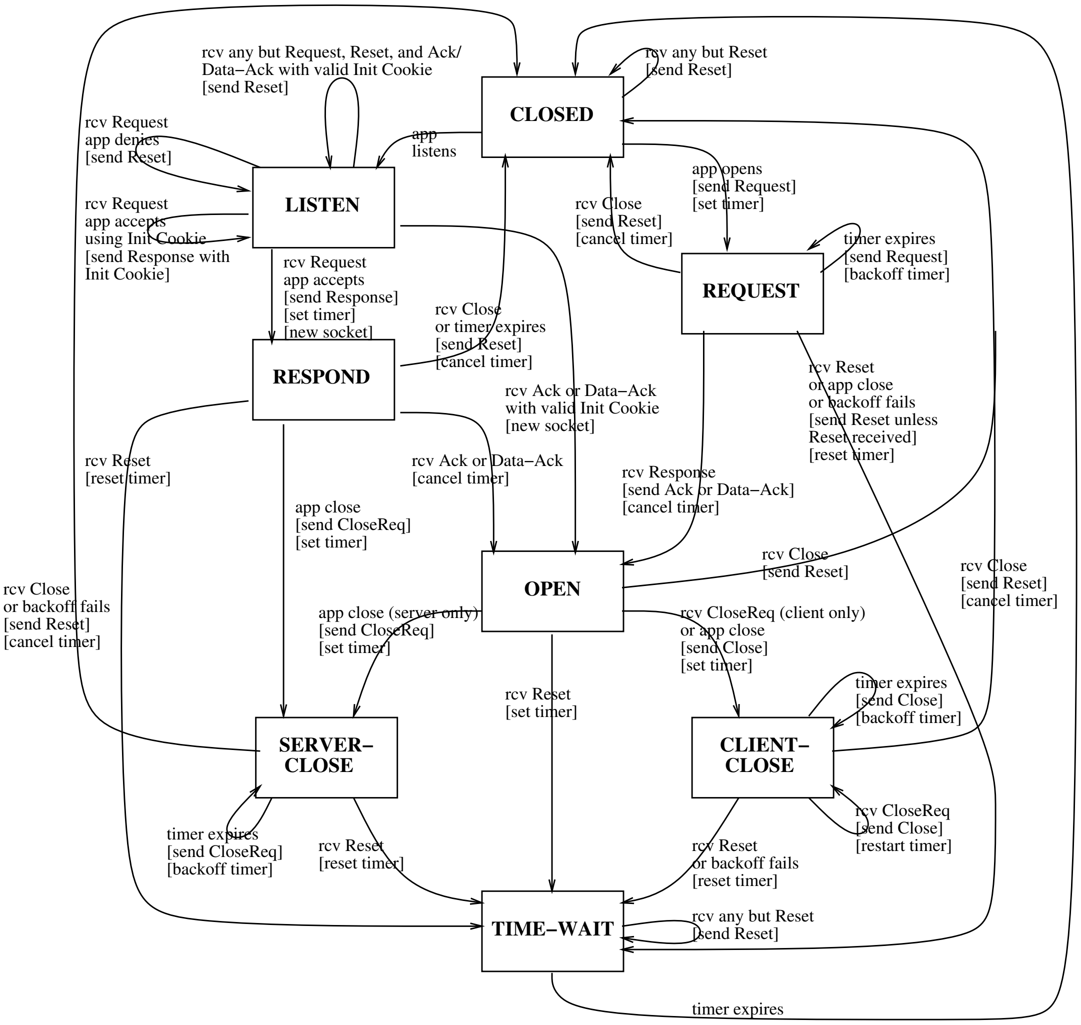
The HC-Receiver sets up a loss window of W consecutive sequence numbers containing GSN, the Greatest Sequence Number it has received on any valid packet from the sender. ("Consecutive" and "greatest" are measured in circular sequence space. The receiver may center the loss window on GSN, or arrange it asymmetrically.) Sequence numbers outside this loss window are invalid. Packets with invalid sequence numbers are themselves invalid, *unless* their sequence numbers are greater than GSN and their acknowledgement numbers are correct (within a loss window of the last packets sent from the receiver), *or* they include correct Connection Proof (Section 5.4.2).

The receiving DCCP SHOULD ignore invalid packets---that is, it should not pass any enclosed data to the application, update its congestion control state, or close the connection. However, the receiving DCCP MAY send a DCCP-Ack packet to the sender, as allowed by the congestion control mechanism in use. This packet should contain the last received valid sequence number and an Identify Yourself option (Section 5.4.3). The other DCCP will send a Connection Proof option to resync. (Such Identify Yourself packets MUST be rate limited.)

We note that resyncing mechanisms may need further research.

4.4. DCCP State Diagram

In this section we present a DCCP state diagram showing how a DCCP connection should progress, and the proper responses for packets or timeout events in various connection states. The state diagram is illustrative; the text should be considered definitive.



All receive events on the diagram represent receipt of valid packets. For example, receiving a Reset with a bad Acknowledgement Number should not cause DCCP to transition to the Time-Wait state. Furthermore, packets without explicit transitions in the state diagram should be treated as invald. DCCP implementations MAY send Resets (or Acks, as described above) in response to invalid packets. Any such responses MUST be rate-limited.

The Open state does not signify that a DCCP connection is ready for data transfer. In particular, incomplete feature negotiations might prevent data transfer. Feature negotiation takes place in parallel with the state transitions on this diagram.

Only the server may take the transition from the OPEN state to the SERVER-CLOSE state. (The server is the DCCP endpoint that began in the LISTEN state.) Similarly, only the client must transition to CLIENT-CLOSE after receiving a CloseReq packet.

4.5. DCCP-Request Packet Format

A DCCP connection is initiated by sending a DCCP-Request packet. The format of a DCCP request packet is:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
/                      Generic DCCP Header                      /
/                          (12 octets)                          /
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Service Name                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Options                    |   [padding]  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             data                              |
|                              ...                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The Service Name field, in combination with the Destination Port, identifies the service to which the sender is trying to connect. Service Names are 32-bit numbers allocated by the IETF; they are meant to correspond to application services and protocols. The host operating system MAY force every DCCP socket, both actively and passively opened, to specify a Service Name. The connection will succeed only if the Destination Port on the receiver has the same Service Name as that given in the packet. If they differ, the receiver will respond with a DCCP-Reset packet.

The DCCP-Request packet initializes the client-to-server sequence number. As in TCP, this sequence number should be chosen randomly to help prevent connection hijacking.

Options

DCCP-Request packets will usually include a "Change(Connection Nonce)" option, to inform the server of the client's connection nonce; see Section 5.4.

4.6. DCCP-Response Packet Format

In the second phase of the three-way handshake, the server sends a DCCP-Response message to the client. The response initializes the server-to-client sequence number. As in TCP, this sequence number should be chosen randomly to help prevent connection hijacking.

In this phase, a server will often specify the options it would like to use, either from among those the client requested, or in addition to those. Among these options is the congestion control mechanism the server expects to use.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
/                      Generic DCCP Header                      /
/                          (12 octets)                          /
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Reserved    |            Acknowledgement Number             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Options                   |   [padding]   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              data                             |
|                               ...                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Acknowledgement Number: 24 bits

The acknowledgement number field acknowledges the *largest* valid sequence number received so far on this connection. (The usual care must be taken in case of wrapped sequence numbers.) In the case of a DCCP-Response packet, the acknowledgement number field will equal the sequence number from the DCCP-Request. Acknowledgement numbers make no attempt to provide precise information about which packets have arrived; options such as the Ack Vector do this.

Reserved: 8 bits

The version of DCCP specified here MUST set this field to all zeroes on generated packets, and ignore its value on received packets.

Options

The Data Discarded and Init Cookie options are particularly designed for DCCP-Response packets (Sections 5.5 and 5.6). In addition, DCCP-Response, or early DCCP-Data or DCCP-Ack packets, will often include "Confirm(Connection Nonce)" and "Change(Connection Nonce)" packets, to further negotiate connection nonces (Section 5.4).

4.7. DCCP-Data, DCCP-Ack, and DCCP-DataAck Packet Formats

The payload data in a DCCP connection is sent in DCCP-Data and DCCP-DataAck packets. DCCP-Data packets look like this:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
/                      Generic DCCP Header                      /
/                          (12 octets)                          /
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Options                   |   [padding]   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              data                             |
|                               ...                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

DCCP-Ack packets dispense with the data, but contain an acknowledgement number:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
/                      Generic DCCP Header                      /
/                          (12 octets)                          /
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Reserved    |            Acknowledgement Number             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Options                   |   [padding]   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

DCCP-DataAck packets contain both data and an acknowledgement number. That is, acknowledgement information is piggybacked on a data packet.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
/                      Generic DCCP Header                      /
/                          (12 octets)                          /
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Reserved    |            Acknowledgement Number             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Options                   |   [padding]   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             data                              |
|                              ...                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

DCCP-Ack and DCCP-DataAck packets may include additional acknowledgement options, such as Ack Vector, as required by the congestion control mechanism in use.

DCCP A sends DCCP-Data and DCCP-DataAck packets to DCCP B due to application events on host A. These packets are congestion-controlled by the CCID for the A-to-B half-connection. In contrast, DCCP-Ack packets sent by DCCP A are controlled by the CCID for the B-to-A half-connection. Generally, DCCP A will piggyback acknowledgement information on data packets when acceptable, creating DCCP-DataAck packets. DCCP-Ack packets are used when there is no data to send from DCCP A to DCCP B, or when the link from A to B is completely congested (so sending data would be inappropriate).

Section 7, below, describes acknowledgements in DCCP.

A DCCP-Data or DCCP-DataAck packet may contain no data if the application sends a zero-length datagram.

4.8. DCCP-CloseReq and DCCP-Close Packet Format

The DCCP-CloseReq and DCCP-Close packets have the same format. However, only the server can send a DCCP-CloseReq packet. Either client or server may send a DCCP-Close packet.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
/                      Generic DCCP Header                      /
/                          (12 octets)                          /
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Reserved    |            Acknowledgement Number             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Options                |   [padding]   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

4.9. DCCP-Reset Packet Format

DCCP-Reset packets unconditionally shut down a connection. Every connection shutdown sequence ends with a DCCP-Reset, but resets may be sent for other reasons, including bad port numbers, bad option behavior, incorrect ECN Nonce Echoes, and so forth. The reason for a reset is represented in the reset itself by a four-byte number, the Reason field.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
/                      Generic DCCP Header                      /
/                          (12 octets)                          /
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Reserved    |            Acknowledgement Number             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Reason                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Options                |   [padding]   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Reason: 32 bits

The Reason field represents the reason that the sender reset the DCCP connection. Particular values for this field will be described in later versions of this document.

4.10. DCCP-Move Packet Format

The DCCP-Move packet type is part of DCCP's support for multihoming and mobility, which is described further in Section 9. DCCP A sends a DCCP-Move packet to DCCP B after changing its IP address and/or port number. The DCCP-Move packet requests that DCCP B start sending its data to the new address and port number. The old address and port are stored explicitly in the DCCP-Move packet header; the new address and port come from the network header and generic DCCP header. The type of address contained in the packet is indicated explicitly by an Old Address Family field. The Sequence Number and Acknowledgement Number fields, and the Connection Proof option, provide some protection against hijacked connections. See Section 9 for more on security and DCCP's mobility support.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
/                      Generic DCCP Header                      /
/                          (12 octets)                          /
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Reserved    |            Acknowledgement Number             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Old Address Family       |           Old Port            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
/                          Old Address                          /
/                                               |   [padding]   /
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Options                   |   [padding]   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             data                              |
|                              ...                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Old Address Family: 16 bits

The Old Address Family field indicates the address family formerly used for this connection, and takes values from the Address Family Numbers registry administered by IANA. Particular values include 1 for IPv4 and 2 for IPv6. The endpoint MUST discard DCCP-Move packets with unrecognized Old Address Family values.

Old Port: 16 bits

The former port number used by DCCP A’s endpoint.

Old Address: at least 32 bits

The former address used by DCCP A’s endpoint, padded on the right to a multiple of 32 bits. The form and size of the address are determined by the Old Address Family field. For instance, if Old Address Family is 1, then Old Address contains an IPv4 address and takes 32 bits; if it is 2, then Old Address contains an IPv6 address and takes 128 bits.

Options

A DCCP-Move packet MUST contain a valid Connection Proof option (see Section 5.4.2). This means that mobile-aware DCCP endpoints MUST inform each other of their Connection Nonces (Section 5.4) during connection setup.

DCCP B should reset the connection if the DCCP-Move packet has valid sequence and acknowledgement numbers, but incorrect Connection Proof. Also, it should reset if neither the Old Address/Old Port combination nor the network address/Source Port combination refers to a currently active DCCP connection.

DCCP B MUST respond to the DCCP-Move packet with a DCCP-Ack or DCCP-DataAck packet acknowledging the move. If this acknowledgement is lost, DCCP A might resend the DCCP-Move packet (using a new sequence number). DCCP B MUST NOT reset these packets, even though the Old Address/Old Port combination no longer refers to a valid DCCP connection. It SHOULD instead send another acknowledgement, as allowed by the congestion control mechanism in use.

We note that DCCP mobility, as provided by DCCP-Move, may not be useful in the context of IPv6, with its mandatory support for Mobile IP.

5. Options and Features

All DCCP packets may contain options which can be used to extend DCCP's functionality. Options occupy space at the end of the DCCP header and are a multiple of 8 bits in length. All options are included in the checksum. An option may begin on any byte boundary.

The first octet of an option is the option type. Options with types 0 through 31 are single-byte options. Other options are followed by an octet indicating the option's length. This length includes the two octets of option-type and option-length as well as the option-data octets.

The following options are currently defined:

```
         Option                            Section
Type     Length     Meaning                Reference
----     ------     -------                ---------
  0         1       Padding                  5.1
  1         1       Data Discarded           5.5
  2         1       Slow Receiver            7.6
  3         1       Identify Yourself        5.4.3
 32         4       Ignored                  5.2
 33      variable   Change                   5.3
 34      variable   Prefer                   5.3
 35      variable   Confirm                  5.3
 36      variable   Init Cookie              5.6
 37      variable   Ack Vector [Nonce 0]     7.5
 38      variable   Ack Vector [Nonce 1]     7.5
 39         3       Receive Buffer Drops     7.7
 40         6       Timestamp                5.7
 41        10       Timestamp Echo           5.8
 42      variable   Connection Proof         5.4.2
 43         3       Buffer Closed Drops      7.8
128-255  variable   CCID-Specific Options    6.4
```

5.1. Padding Option

The padding option, with type 0, is a single byte option used to pad between or after options. It either ensures the payload begins on a 32-bit boundary (as required), or ensures alignment of following options (not mandatory).

5.2. Ignored Option

The Ignored option, with type 32, signals that a DCCP did not understand some option. This can happen, for example, when a conventional DCCP converses with an extended DCCP. Each Ignored option has two octets of payload, the first containing the offending option type and the second containing the first octet of the offending option's payload. (If the offending option had no payload, this octet is 0.)

```
+--------+--------+--------+--------+
|00100000|00000100|Opt Type|Opt Data|
+--------+--------+--------+--------+
 Type=32  Length=4
```

5.3. Feature Negotiation

DCCP contains a mechanism for reliably negotiating features, most notably the congestion control mechanism in use on each half-connection. The motivation was to implement reliable feature negotiation once, so that different options need not reinvent that particular wheel.

Three options, Change, Prefer, and Confirm, implement feature negotiation. Change is sent to a feature's location, asking it to change the feature's value. The feature location may respond with Prefer, which asks the other endpoint to Change again with different values, or it may change the feature value and acknowledge the request with Confirm. (The options were formerly called Ask, Choose, and Answer.)

Features MUST NOT change values apart from feature negotiation, and enforced retransmissions make feature negotiation reliable. This ensures that both endpoints eventually agree on every feature's value.

Some features are non-negotiable, meaning that the feature location MUST set its value to whatever the other endpoint requests. For non-negotiable features, the feature location MUST respond to Change options with Confirm; Prefer is not useful. These features use the feature framework simply to achieve reliability.

5.3.1. Feature Numbers

The first data octet of every Change, Prefer, or Confirm option is a feature number, defining the type of feature being negotiated. The remainder of the data gives one or more values for the feature, and is interpreted according to the feature. The current set of feature numbers is as follows:

Number	Meaning	Neg.?	Section Reference
1	Congestion Control (CC)	Y	6
2	ECN Capable	Y	8.1
3	Ack Ratio	N	7.3
4	Use Ack Vector	Y	7.4
5	Mobility Capable	Y	9.1
6	Loss Window	N	5.9
7	Connection Nonce	N	5.4.1
128-255	CCID-Specific Features	?	6.4

The "Neg.?" column is "Y" for normal features and "N" for non-negotiable features.

5.3.2. Change Option

DCCP B sends a Change option to DCCP A to ask it to change the value of some feature. (DCCP A is the feature location.) DCCP A MUST respond to the Change option with either Prefer or Confirm. DCCP B MUST retransmit the Change option until it receives some relevant response. DCCP B will always generate a Change option in response to a Prefer option; it may also generate a Change option due to some application event.

5.3.3. Prefer Option

DCCP A sends a Prefer option to DCCP B to ask it to confirm the value of some feature. (Again, DCCP A is the feature location.) DCCP B MUST respond to the Prefer option with a Change. DCCP A MUST retransmit the Prefer option until it receives a relevant Change response. DCCP A may generate a Prefer option in response to some Change option, or in response to some application event. Prefer options are not useful for non-negotiable features.

5.3.4. Confirm Option

DCCP A sends a Confirm option to DCCP B to inform it of the current value of some feature. (Again, DCCP A is the feature location.) DCCP A MUST generate Confirm options only in response to Change options. DCCP A need not ever retransmit a Confirm option: DCCP B will retransmit the relevant Change as necessary.

5.3.5. Example Negotiations

This section demonstrates several negotiations of the congestion control feature for the A-to-B half-connection. (This feature is located at DCCP A.) In this sequence of packets, DCCP A is happy with DCCP B's suggestion of CC mechanism 2:

```
B > A    Change(CC, 2)
A > B    Confirm(CC, 2)
```

Here, A and B jointly settle on CC mechanism 5:

```
B > A    Change(CC, 3, 4)
A > B    Prefer(CC, 1, 2, 5)
B > A    Change(CC, 5)
A > B    Confirm(CC, 5)
```

In this sequence, A refuses to use CC mechanism 5. If B requires CC mechanism 5, its only recourse is to abort the connection:

```
B > A    Change(CC, 3, 4, 5)
A > B    Prefer(CC, 1, 2)
B > A    Change(CC, 5)
A > B    Prefer(CC, 1, 2)
```

Here, A elicts agreement from B that it is satisfied with congestion control mechanism 2:

```
A > B    Prefer(CC, 1, 2)
B > A    Change(CC, 2)
A > B    Confirm(CC, 2)
```

5.3.6. Unknown Features

If a DCCP receives a Change or Prefer option referring to a feature number it does not understand, it MUST respond with a corresponding Ignored option. This informs the remote DCCP that the local DCCP does not implement the feature. No other action need be taken. (Ignored may also indicate that the DCCP endpoint could not respond to a CCID-specific feature request because the CCID was in flux; see Section 6.4.)

5.3.7. State Diagram

These state diagrams present the legal transitions in a DCCP feature negotiation. They define DCCP's states and transitions with respect to the negotiation of a single feature it understands. There are two diagrams, corresponding to the two endpoints: the feature location, or DCCP A, and what we call the "feature requester", DCCP B.

Transitions between states are triggered by receiving a packet ("`RECV`") or by an application event ("`APP`"). Received packets are further distinguished by any options relevant to the feature being negotiated. "`RECV -`" means the packet contained no relevant option. "`RECV Chg`" denotes a Change option, "`RECV Pr`" a Prefer option, and "`RECV Con`" a Confirm option. The data contained in an option is given in parentheses when necessary. The "`SEND`" action indicates which option the DCCP will send next. Finally, the "`SET-VALUE`" action causes the DCCP to change its value for the relevant feature.

"`SEND`" does not force DCCP to immediately generate a packet; rather, it says which feature option must be sent on the next packet generated. A DCCP MAY choose to generate a packet in response to some "`SEND`" action. However, it MUST NOT generate a packet if doing so would violate the congestion control mechanism in use.

The requester, DCCP B, has four states: Known, Unknown, Failed, and Changing. Similarly, the feature location, DCCP A, has four states: Known, Unknown, Failed, and Confirming. In both cases, Known denotes a state where the DCCP knows the feature's current value, and believes that the other DCCP agrees. Changing and Confirming denote states where the DCCPs are in the process of negotiating a new value for the feature. The Unknown state can occur only at connection setup time. It denotes a state where the DCCP does not know any value for the feature, and has not yet entered a negotiation to determine its value. Finally, the Failed state represents a state where the other DCCP does not implement the feature under negotiation.

A DCCP may start in either the Unknown or Known state, depending on the feature in question. In particular, some features have a well-known value for new connections, in which case the DCCPs begin the connection in the Known states.

```
                    REQUESTER STATE DIAGRAM (DCCP B)

                        +-----------+
                        |  Unknown  |
                        +-----------+
      +----------+            |                    +-----------+
      |          |RECV -      |RECV -/Pr | APP     |           |RECV Pr/Con
      V          |SEND -      |SEND Chg            V           |SEND Chg
+-----------+    |            |             +------------+     |
|           |----+            +------------>|            |-----+
|   Known   |------------------------------>|  Changing  |
|           |        RECV Pr | APP          |            |-----+
+-----------+          SEND Chg             +------------+     |RECV -
      ^                                          | | ^         |SEND -/Chg
      |                                          | | |         |
      +------------------------------------------+ | +---------+
                       RECV Con(O)                 |          +----------+
                       SEND -                      +---------->|  Failed  |
                       SET-VALUE O                  RECV Ign  +----------+
                                                    SEND -
```

```
                  FEATURE LOCATION STATE DIAGRAM (DCCP A)
(O represents any feature value acceptable to DCCP A; X is not acceptable.)

        RECV Chg(O)
        SEND Con(O)                   RECV -  |  APP
        SET-VALUE O     +-----------+ SEND Pr(O)
   +--------------------|  Unknown  |------------+
   |                    +-----------+            |
   |     +-------+            |                  | +-----------+
   |     |       |RECV -      |RECV Chg(X)       | |           |RECV Chg(X)
   V     V       |SEND -      |SEND Pr(O)        V V           |SEND Pr(O)
+-----------+    |            |             +------------+     |  (need not be
|           |----+            +------------>|            |-----+   the same O)
|   Known   |------------------------------>| Confirming |
|           |----+     RECV Chg  |  APP     |            |-----+
+-----------+    |        SEND Pr(O)        +------------+     |RECV -
   ^     ^       |                               | | ^         |SEND -/Pr(O)
   |     |       |RECV Chg(O)                    | | |         |
   |     |       |SEND Con(O)                    | | +---------+
   |     |       |SET-VALUE O                    | |
   |     +-------+                               | |         +----------+
   +---------------------------------------------+ +--------->|  Failed  |
                  RECV Chg(O)                       RECV Ign +----------+
                  SEND Con(O)                       SEND -
                  SET-VALUE O
```

This specification allows several choices of action in certain states. The implementation will generally use feature-specific information to decide how to respond. For example, DCCP A in the Known state may respond to a Change option with either Confirm or Prefer. If DCCP A is willing to set the feature to the value specified by Change, it will generally send Confirm; but if it would like to negotiate further, it will send Prefer.

DCCP B must retransmit Change options, and DCCP A must retransmit Prefer options, until receiving a relevant response. However, they need not retransmit the option on every packet, as shown by the "`RECV - / SEND -`" transitions in the Changing and Confirming states.

These state diagrams guarantee safety, but not liveness. Namely, no unexpected or erroneous options will be sent, but option negotiation might not terminate. For example, the following infinite negotiation is legal according to this specification.

```
A > B    Prefer(1)
B > A    Change(2)
A > B    Prefer(1)
B > A    Change(2)...
```

Implementations may choose to enforce a maximum length on any negotiation -- for example, by resetting the connection when any negotiation lasts more than some maximum time.

In the Changing and Confirming states, the value of the corresponding feature is in flux. DCCP MAY change its behavior in these states---for example, by refusing to send data until reentering a Known state.

5.4. Connection Nonce Options

Connection nonces are opaque cookies that serve as identities for DCCP endpoints. They may be negotiated at connection setup time, or at any point thereafter. Once set up, they facilitate reconnection after an endpoint moves (Section 9) or a long burst of loss that gets the endpoints out of sync (Section 4.3).

The Connection Nonce feature is used to inform one endpoint of the other endpoint’s connection nonce. The Connection Proof option contains the xor of the two endpoints’ nonces, and thus acts as proof that the sending endpoint knows both nonces. The Identify Yourself option requests that a DCCP send a Connection Proof option on its next packet.

5.4.1. Connection Nonce Feature

Connection Nonce has feature number 7. The Connection Nonce feature located at DCCP B is the value of DCCP A’s connection nonce. Each endpoint must keep track of both its nonce and, via the Connection Nonce feature, the other endpoint’s nonce.

The Connection Nonce feature takes arbitrary values of at least 4 bytes long. A Change or Confirm Connection Nonce option therefore takes at least 6 bytes.

Connection Nonce defaults to a random 8-byte string. To prevent spoofing, this string MUST NOT have any predictable value. For example, it MUST NOT be set deterministically to zero, and it MUST change on every connection.

This feature is non-negotiable.

5.4.2. Connection Proof Option

This option is permitted in any DCCP packet, although it is useful only after the endpoints have informed each other of their connection nonces. The value of the option is the exclusive-or of the two connection nonces. (If one nonce is longer than the other, then the shorter one is padded on the right with zero bytes before the exclusive-or.) The endpoint receiving Connection Proof compares the option value with the xor of the connection nonces, and thus determines whether or not the packet is really part of the connection. Packets with invalid Connection Proof MUST be ignored, except that the receiving DCCP MAY send an Identify Yourself option. (DCCP implementations SHOULD limit the rate of such response packets.)

```
+--------+--------+--------+--------+--------+--------
|00101010|????????|      Connection Proof Value ...
+--------+--------+--------+--------+--------+--------
 Type=42   Length
```

5.4.3. Identify Yourself Option

This option is permitted in any DCCP packet, although it is useful only after the endpoints have informed each other of their connection nonces. The option informs the receiving DCCP that one of its packets was ignored, and that succeeding packets will be ignored until the endpoint sends a correct Connection Proof option. The receiving DCCP SHOULD include a Connection Proof option on the next packet it sends.

```
+--------+
|00000011|
+--------+
 Type=3
```

5.5. Data Discarded Option

This option is permitted in a DCCP-Response packet only. It indicates that the payload of the DCCP-Request packet was discarded by the server, and therefore should be resent in a following DCCP-Data or DCCP-DataAck packet. This option can be set by the server to avoid having to keep state for the connection until the handshake is complete. Doing so causes an additional round-trip time before the server can begin servicing the request. The tradeoff is under the control of local policy at the server.

```
+--------+
|00000010|
+--------+
 Type=2
```

5.6. Init Cookie Option

This option is permitted in DCCP-Response, DCCP-Data, and DCCP-DataAck messages. The option MAY be returned by the server in a DCCP-Response mechanism. If so, then the client MUST echo the same Init Cookie option in its ensuing DCCP-Data or DCCP-DataAck message.

The purpose of this option is to allow a DCCP server to avoid having to hold any state until the three-way connection setup handshake has completed. The server wraps up the service name, server port, and any options it cares about from both the DCCP-Request and DCCP-

Response in a opaque cookie. Typically the cookie will be encrypted using a secret known only to the server and include a cryptographic checksum or magic value so that correct decryption can be verified. When the server receives the cookie back in the response, it can decrypt the cookie and instantiate all the state it avoided keeping.

The precise implementation of the Init Cookie does not need to be specified here as it is only relayed by the client, and does not need to be understood by the client.

```
+--------+--------+--------+--------+--------+--------
|00100100|????????|        Init Cookie Value   ...
+--------+--------+--------+--------+--------+--------
 Type=36   Length
```

5.7. Timestamp Option

This option is permitted in any DCCP packet. The length of the option is 6 bytes.

```
+--------+--------+--------+--------+--------+--------+
|00101000|00000110|          Timestamp Value          |
+--------+--------+--------+--------+--------+--------+
 Type=40  Length=6
```

The four bytes of option data carry the timestamp of this packet, in some undetermined form. A DCCP receiving a Timestamp option SHOULD respond with a Timestamp Echo option on the next packet it sends.

5.8. Timestamp Echo Option

This option is permitted in any DCCP packet, as long as at least one packet carrying the Timestamp option has been received. The length of the option is 10 bytes.

```
+--------+--------+------- ... -------+------- ... -------+
|00101001|00001010|      TS Echo      |      Elapsed      |
+--------+--------+------- ... -------+------- ... -------+
 Type=41   Len=10       (4 bytes)           (4 bytes)
```

The first four bytes of option data, TS Echo, carry a Timestamp Value taken from a preceding received Timestamp option. Usually, this will be the last packet that was received. The final four bytes indicate the amount of time elapsed since receiving the packet whose timestamp is being echoed. This time MUST be in microseconds. We are currently investigating ways to relax the last requirement.

5.9. Loss Window Feature

Loss Window has feature number 6. The Loss Window feature located at DCCP B is the width of the window DCCP B uses to determine whether packets from DCCP A are valid. Packets outside this window will be dropped by DCCP B as old duplicates or spoofing attempts; see Section 4.3 for more information. DCCP A sends a "Change(Loss Window, W)" option to DCCP B to set DCCP B's Loss Window to W.

The Loss Window feature takes 3-byte integer values, like DCCP sequence numbers. Change and Confirm options for Loss Window are therefore 6 bytes long.

Loss Window defaults to 1000 for new connections. The Loss Window value is the total width of the loss window. The receiver may position the loss window asymmetrically around the last sequence number seen -- for example, by allocating 1/4 of the loss window width for older sequence numbers and 3/4 of it for newer sequence numbers.

This feature is non-negotiable.

6. Congestion Control IDs

Each congestion control mechanism supported by DCCP is assigned a congestion control identifier, or CCID: a number from 0 to 255. During connection setup, and optionally thereafter, the endpoints negotiate their congestion control mechanisms by negotiating the values for their Congestion Control features. Congestion Control has feature number 1. The feature located at DCCP A is the CCID in use for the A-to-B half-connection. DCCP B sends an "Change(CC, K)" option to DCCP A to ask A to use CCID K for its data packets.

The data octets of Congestion Control feature negotiation options form a list of acceptable CCIDs, sorted in descending order of priority. For example, the option "Change(CC 1, 2, 3)" asks the sender to use CCID 1, although CCIDs 2 and 3 are also acceptable. (This corresponds to the octets "33, 6, 1, 1, 2, 3": Change option (33), option length (6), feature ID (1), CCIDs (1, 2, 3).) Similarly, "Confirm(CC 1, 2, 3)" tells the receiver that the sender is using CCID 1, but that CCIDs 2 or 3 might also be acceptable.

The CCIDs defined by this document are:

```
CCID   Meaning
----   -------
  0    Reserved
  1    Unspecified Sender-Based Congestion Control
  2    TCP-like Congestion Control
  3    TFRC Congestion Control
```

A new connection starts with CCID 2 for both DCCPs. If this is unacceptable for either DCCP, that DCCP will start in the Unknown state. A DCCP SHOULD NOT send data when its Congestion Control feature is in the Unknown state.

6.1. Unspecified Sender-Based Congestion Control

CCID 1 denotes an unspecified sender-based congestion control mechanism. Separate features negotiate the corresponding congestion acknowledgement options---for example, Ack Vector. This provides a limited, controlled form of interoperability for new IETF-approved CCIDs.

Implementors MUST NOT use CCID 1 in production environments as a proxy for congestion control mechanisms that have not entered the IETF standards process. We intend for the IETF to approve all production uses of CCID 1. Nevertheless, middle boxes MAY choose to treat the use of CCID 1 as experimental or unacceptable.

For example, say that CCID 98, a new sender-based congestion control mechanism using Ack Vector for acknowledgements, has entered the IETF standards process. Now, DCCP A, which understands and would like to use CCID 98, is trying to communicate with DCCP B, which doesn't yet know about CCID 98. DCCP A can simply negotiate use of CCID 1 and, separately, negotiate Use Ack Vector. DCCP B will provide the feedback DCCP A requires for CCID 98, namely Ack Vector, without needing to understand the congestion control mechanism in use.

6.2. TCP-like Congestion Control

CCID 2 denotes Additive Increase, Multiplicative Decrease (AIMD) congestion control with behavior modelled directly on TCP, including congestion window, slow start, timeouts, and so forth. CCID 2 is further described in [CCID 2 PROFILE].

6.3. TFRC Congestion Control

CCID 3 denotes TCP-Friendly Rate Control, an equation-based rate-controlled congestion control mechanism. CCID 3 is further described in [CCID 3 PROFILE].

6.4. CCID-Specific Options and Features

Option and feature numbers 128 through 255 are available for CCID-specific use. CCIDs may often need new option types---for communicating acknowledgement or rate information, for example. CCID-specific option types let them create options at will without polluting the global options space. Option 128 might have different meanings on a half-connection using CCID 4 and a half-connection using CCID 8. CCID-specific options and features will never conflict with global options introduced by later versions of this specification.

Any packet may contain information meant for either half-connection, so CCID-specific option and feature numbers explicitly signal the half-connection to which they apply. Option numbers 128 through 191 are for options sent from the HC-Sender to the HC-Receiver; option numbers 192 through 255 are for options sent from the HC-Receiver to the HC-Sender. Similarly, feature numbers 128 through 191 are for features located at the HC-Sender; feature numbers 192 through 255 are for features located at the HC-Receiver. (Change options for a feature are sent *to* the feature location; Prefer and Confirm options are sent *from* the feature location. Thus, Change(128) options are sent by the HC-Receiver by definition, while Change(192) options are sent by the HC-Sender.)

For example, consider a DCCP connection where the A-to-B half-connection uses CCID 4 and the B-to-A half-connection uses CCID 5. Here is how a sampling of CCID-specific options and features are assigned to half-connections:

```
                                 Relevant    Relevant
Packet   Option                  Half-conn.  CCID
------   ------                  ----------  ----
A > B    128                       A-to-B     4
A > B    192                       B-to-A     5
A > B    Change(128, ...)          B-to-A     5
A > B    Prefer(128, ...)          A-to-B     4
A > B    Confirm(128, ...)         A-to-B     4
A > B    Change(192, ...)          A-to-B     4
A > B    Prefer(192, ...)          B-to-A     5
A > B    Confirm(192, ...)         B-to-A     5
```

CCID-specific options and features have no clear meaning when the relevant CCID is in flux. A DCCP SHOULD respond to CCID-specific options and features with Ignored options during those times.

7. Acknowledgements

Congestion control requires receivers to transmit information about packet losses and ECN marks to senders. DCCP receivers MUST report all congestion they see, as defined by the relevant CCID profile. Each CCID says when acknowledgements should be sent, what options they must use, how they should be congestion controlled, and so on.

Most acknowledgements use DCCP options. For example, on a half-connection with CCID 2 (TCP-like), the receiver reports acknowledgement information using the Ack Vector option. This section describes common acknowledgement options and shows how acks using those options will commonly work. Full descriptions of the acknowledgement mechanisms used for each CCID are laid out in the CCID profile specifications.

Acknowledgement options, such as Ack Vector, are only allowed on DCCP-Ack, DCCP-DataAck, DCCP-Close, and DCCP-CloseReq packets.

7.1. Acks of Acks and Unidirectional Connections

DCCP was designed to work well for both bidirectional and unidirectional flows of data, and for connections that transition between these states. However, acknowledgements required for a unidirectional connection are very different from those required for a bidirectional connection. In particular, unidirectional connections need to worry about acks of acks.

The ack-of-acks problem arises because some acknowledgement mechanisms are reliable. For example, an HC-Receiver using CCID 2, TCP-like Congestion Control, sends Ack Vectors containing completely reliable acknowledgement information. The HC-Sender should occasionally inform the HC-Receiver that it has received an ack. If it did not, the HC-Receiver might resend complete Ack Vector information, going back to the start of the connection, with every DCCP-Ack packet! However, note that acks-of-acks need not be reliable themselves: when an ack-of-acks is lost, the HC-Receiver will simply maintain old acknowledgement-related state for a little longer. Therefore, there is no need for acks of acks of acks.

When communication is bidirectional, any required acks of acks are automatically contained in normal acknowledgements for data packets. On a unidirectional connection, however, the receiver DCCP sends no data, so the sender would not normally send acknowledgements. Therefore, the CCID in force on that half-connection must explicitly say whether, when, and how the HC-Sender should generate acks of acks.

For example, consider a bidirectional connection where both half-connections use the same CCID (either 2 or 3), and where DCCP B goes *quiescent*. This means that the connection becomes unidirectional: DCCP B stops sending data, and sends only sends DCCP-Ack packets to DCCP A. For CCID 2, TCP-like Congestion Control, DCCP B uses Ack Vector to reliably communicate which packets it has received. As described above, DCCP A must occasionally acknowledge a pure acknowledgement from DCCP B, so that DCCP B can free old Ack Vector state. For instance, DCCP A might send a DCCP-DataAck packet every now and then, instead of DCCP-Data. In contrast, for CCID 3, TFRC Congestion Control, DCCP B's acknowledgements need not be reliable, since they contain cumulative loss rates; TFRC works even if every DCCP-Ack is lost. Therefore, DCCP A need never acknowledge an acknowledgement.

When communication is unidirectional, a single CCID---in the example, the A-to-B CCID---controls both DCCPs' acknowledgements, in terms of their content, their frequency, and so forth. For bidirectional connections, the A-to-B CCID governs DCCP B's acknowledgements (including its acks of DCCP A's acks), while the B-to-A CCID governs DCCP A's acknowledgements.

DCCP A switches its ack pattern from bidirectional to unidirectional when it notices that DCCP B has gone quiescent. It switches from unidirectional to bidirectional when it must acknowledge even a single DCCP-Data or DCCP-DataAck packet from DCCP B. (This includes the case where a single DCCP-Data or DCCP-DataAck packet was lost in transit, which is detectable using the # NDP field in the DCCP packet header.)

Each CCID defines how to detect quiescence on that CCID, and how that CCID handles acks-of-acks on unidirectional connections. The B-to-A CCID defines when DCCP B has gone quiescent. Usually, this happens when a period has passed without B sending any data packets. For CCID 2, this period is roughly two round-trip times. The A-to-B CCID defines how DCCP A handles acks-of-acks once DCCP B has gone quiescent.

7.2. Ack Piggybacking

Acknowledgements of A-to-B data MAY be piggybacked on data sent by DCCP B, as long as that does not delay the acknowledgement longer than the A-to-B CCID would find acceptable. However, data acknowledgements often require more than 4 bytes to express. A large set of acknowledgements prepended to a large data packet might exceed the path's MTU. In this case, DCCP B SHOULD send separate DCCP-Data and DCCP-Ack packets, or wait for a smaller datagram (but not too long).

Piggybacking is particularly common at DCCP A when the B-to-A half-connection is quiescent---that is, when DCCP A is just acknowledging DCCP B's acknowledgements, as described above. There are three reasons to acknowledge DCCP B's acknowledgements: to allow DCCP B to free up information about previously acknowledged data packets from A; to shrink the size of future acknowledgements; and to manipulate the rate future acknowledgements are sent. Since these are secondary concerns, DCCP A can generally afford to wait indefinitely for a data packet to piggyback its acknowledgement onto.

Any restrictions on ack piggybacking are described in the relevant CCID's profile.

7.3. Ack Ratio Feature

With Ack Ratio, DCCP A can perform rudimentary congestion control on DCCP B's acknowledgement stream by telling DCCP B how to clock its acks.

Ack Ratio has feature number 3. The Ack Ratio feature located at DCCP B equals the ratio of data packets sent by DCCP A to acknowledgement packets sent back by DCCP B. For example, if it is set to four, then DCCP B will send at least one acknowledgement packet for every four data packets DCCP A sends. DCCP A sends a "Change(Ack Ratio)" option to DCCP B to change DCCP B's ack ratio.

An Ack Ratio option contains two bytes of data: a sixteen-bit integer representing the ratio. A new connection starts with Ack Ratio 2 for both DCCPs.

This feature is non-negotiable.

7.4. Use Ack Vector Feature

The Use Ack Vector feature lets DCCPs negotiate whether they should use Ack Vector options to report congestion. Ack Vector provides detailed loss information, and lets senders report back to their applications whether particular packets were dropped. Use Ack Vector is mandatory for some CCIDs, and optional for others.

Use Ack Vector has feature number 4. The Use Ack Vector feature located at DCCP B specifies whether DCCP B should use the Ack Vector option to report congestion back to DCCP A. DCCP A sends a "Change(Use Ack Vector, 1)" option to DCCP B to ask B to send Ack Vector options as part of its acknowledgement traffic.

A Use Ack Vector option contains a single octet of data. The receiver should send Ack Vector options if and only if this octet is nonzero. A new connection starts with Use Ack Vector 0 for both DCCPs.

7.5. Ack Vector Options

The Ack Vector gives a run-length encoded history of data packets received at the client. Each octet of the vector gives the state of that data packet in the loss history, and the number of preceding packets with the same state. The option's data looks like this:

```
+--------+--------+--------+--------+--------+
|001001??| Length |SSLLLLLL|SSLLLLLL|SSLLLLLL|...
+--------+--------+--------+--------+--------+
Type=37/38         \_________ Vector _________/
```

The two Ack Vector options (option types 37 and 38) differ only in the values they imply for ECN Nonce Echo. Section 8.2 describes this further.

The vector itself consists of a series of octets, each of whose encoding is:

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|St | Run Length|
+-+-+-+-+-+-+-+-+
```

St[ate]: 2 bits

Run Length: 6 bits

State occupies the most significant two bits of each byte, and can have one of four values:

0 Packet received (and not ECN marked).

1 Packet ECN marked.

2 Reserved.

3 Packet not yet received.

The first byte in the first Ack Vector option refers to the packet indicated in the Acknowledgement Number; subsequent bytes refer to older packets. (Ack Vector may not be sent on DCCP-Data packets, which lack an Acknowledgement Number.) If an Ack Vector contains the decimal values 0,192,3,64,5 and the Acknowledgement Number is decimal 100, then:

Packet 100 was received (Acknowledgement Number 100, State 0, Run Length 0).

Packet 99 was lost (State 3, Run Length 0).

Packets 98, 97, 96 and 95 were received (State 0, Run Length 3).

Packet 94 was ECN marked (State 1, Run Length 0).

Packets 93, 92, 91, 90, 89, and 88 were received (State 0, Run Length 5).

Run lengths of more than 64 must be encoded in multiple bytes. A single Ack Vector option can acknowledge up to 16192 data packets. Should more packets need to be acknowledged than can fit in 253 bytes of Ack Vector, then multiple Ack Vector options can be sent. The second Ack Vector option will begin where the first Ack Vector option left off, and so forth.

Packets dropped in the receive buffer should be reported as not received (State 3). The Receive Buffer Drops and Buffer Closed Drops options distinguishes between congestion losses and losses due to receive buffer overflow.

7.5.1. Ack Vector Consistency

A DCCP sender will commonly receive multiple acknowledgements for some of its data packets. For instance, an HC-Sender might receive two DCCP-Acks with Ack Vectors, both of which contained information about sequence number 24. (Because of cumulative acking, information about a sequence number is repeated in every ack until the HC-Sender acknowledges an ack. Perhaps the HC-Receiver is sending acks faster than the HC-Sender is acknowledging them.) In a perfect world, the two Ack Vectors would always be consistent. However, there are many reasons why they might not be:

- The HC-Receiver received packet 24 between sending its acks, so the first ack said 24 was not received (State 3) and the second said it was received or ECN marked (State 0 or 1).
- The HC-Receiver received packet 24 between sending its acks, and the network reordered the acks. In this case, the packet will appear to transition from State 0 or 1 to State 3.
- The network duplicated packet 24, but only one of the duplicates was ECN marked. Depending on the HC-Receiver's implementation, this might show up as a transition between States 0 and 1.

To cope with these situations, HC-Sender DCCP implementations SHOULD combine multiple received Ack Vector states according to this table:

```
                  Received State
                    0   1   3
                  +---+---+---+
                0 | 0 | 1 | 0 |
       Old        +---+---+---+
                1 | 1 | 1 | 1 |
      State       +---+---+---+
                3 | 0 | 1 | 3 |
                  +---+---+---+
```

To read the table, choose the row corresponding to the packet's old state and the column corresponding to the packet's state in the newly received Ack Vector, then read the packet's new state off the table. The table is symmetric about the main diagonal, so it is indifferent to ack reordering.

A HC-Sender MAY choose to throw away old information gleaned from the HC-Receiver's Ack Vectors, in which case it MUST ignore newly received acknowledgements from the HC-Receiver for those old packets. However, it is often kinder to save recent Ack Vector information for a while, so that the HC-Sender can undo its reaction to presumed congestion when a "lost" packet unexpectedly shows up (the transition from State 3 to State 0).

7.5.2. Ack Vector Coverage

We can divide the packets that have been sent from an HC-Sender to an HC-Receiver into four roughly contiguous groups. From oldest to youngest, these are:

(1) Packets already acknowledged by the HC-Receiver, where the HC-Receiver knows that the HC-Sender has definitely received the acknowledgements.

(2) Packets already acknowledged by the HC-Receiver, where the HC-Receiver cannot be sure that the HC-Sender has received the acknowledgements.

(3) Packets not yet acknowledged by the HC-Receiver.

(4) Packets not yet received by the HC-Receiver.

The union of groups 2 and 3 is called the Unacknowledged Window. Generally, every Ack Vector the HC-Receiver sends will cover the whole Unacknowledged Window: Ack Vector acknowledgements are cumulative. (This simplifies Ack Vector maintenance at the HC-Receiver; see Section 7.9, below.) As packets are received, this window both grows on the right and shrinks on the left. It grows because there are more packets, and shrinks because the data packets' Acknowledgement Numbers will acknowledge previous acknowledgements, moving packets from group 2 into group 1.

7.6. Slow Receiver Option

An HC-Receiver sends the Slow Receiver option to its sender to indicate that it is having trouble keeping up with the sender's data. The HC-Sender SHOULD NOT increase its sending rate for approximately one round-trip time after seeing a packet with a Slow Receiver option. However, the Slow Receiver option does not indicate congestion, and the HC-Sender need not reduce its sending rate. (If necessary, the receiver can force the sender to slow down by dropping packets and including Receive Buffer Drops options.) APIs SHOULD let receiver applications set Slow Receiver, and sending applications determine whether or not their receivers are Slow.

The Slow Receiver option takes just one byte:

```
+--------+
|00000010|
+--------+
 Type=2
```

Slow Receiver does not specify why the receiver is having trouble keeping up with the sender. Possible reasons include lack of buffer space, CPU overload, and application quotas. A sending application might react to Slow Receiver by reducing its sending rate or by switching to a lossier compression algorithm. However, a smart sender might actually *increase* its sending rate in response to Slow Receiver, by switching to a less-compressed sending format. (A highly-compressed data format might overwhelm a slow CPU more seriously than the higher memory requirements of a less-compressed data format.) This tension between transfer size (less compression means more congestion) and processing speed (more compression means more processing) cannot be resolved in general.

Slow Receiver implements a portion of TCP's receive window functionality. We believe receiver operating systems and applications will find it much easier to send Slow Receiver when appropriate than they currently find it to correctly set a TCP receive window.

7.7. Receive Buffer Drops Option

The Receive Buffer Drops option indicates that some packets reported as not received were actually dropped at the endpoint, due to insufficient kernel space. The sender will probably react differently to receive buffer drops than congestion losses; for instance, it might not reduce its congestion window. The option's data looks like this:

```
+--------+--------+--------+
|00100111|00000011| Count  |
+--------+--------+--------+
 Type=39  Length=3
```

Count: 8 bits

The Count field says how many acknowledged packets were dropped at the receive buffer, limited to packets acknowledged by the packet containing the option. Count is simply a number between 0 and 255.

Multiple Receive Buffer Drops options are added together, so a single option with Count 2 is equivalent to two options, each with Count 1. A packet's total Receive Buffer Drops count MUST be less than or equal to the number of packets acknowledged by it as "not yet received". For example, assuming Ack Vector, the Receive Buffer Drops count must be less than or equal to the total number of State-3 packets in the Ack Vectors.

If an ECN-marked packet is dropped at the receive buffer, it MUST NOT be included in the Receive Buffer Drops count. Such packets MUST be reported as the equivalent of "dropped by the network". (For Ack Vector, this is "not yet received".)

7.8. Buffer Closed Drops Option

The Buffer Closed Drops option indicates that some packets reported as not received were actually dropped at the endpoint, because the application is no longer listening for data. For example, a server might close its receiving half-connection to new data after receiving a complete request from the client. This would limit the amount of state the server would expend on incoming data, and thus reduce the potential damage from certain denial-of-service attacks. A DCCP receiving a Buffer Closed Drops option MAY report this event to the application.

The semantics of Buffer Closed Drops are similar to those of Receive Buffer Drops.

```
+--------+--------+--------+
|00101011|00000011| Count  |
+--------+--------+--------+
 Type=43  Length=3
```

Count: 8 bits

Like the Count field in Receive Buffer Drops.

Multiple Buffer Closed Drops options are added together, so a single option with Count 2 is equivalent to two options, each with Count 1. A packet's total Buffer Closed Drops count MUST be less than or equal to the number of packets acknowledged by it as "not yet received". If an ECN-marked packet is dropped due to a closed receive buffer, it MUST NOT be included in the Buffer Closed Drops count. Such packets MUST be reported as the equivalent of "dropped by the network". (For Ack Vector, this is "not yet received".) No packet should be included in both the Receive Buffer Drops and Buffer Closed Drops count.

7.9. Ack Vector Implementation Notes

This section discusses the particulars of DCCP acknowledgement handling, in the context of an abstract implementation for Ack Vector. It may safely be skipped.

The first part of our implementation runs at the HC-Receiver, and therefore acknowledges data packets. It generates Ack Vector options. The implementation has the following characteristics:

- At most one byte of state per acknowledged packet.
- O(1) time to update that state when a new packet arrives (normal case).
- Cumulative acknowledgements.
- Quick removal of old state.

The basic data structure is a circular buffer containing information about acknowledged packets. Each byte in this buffer contains a state and run length; the state can be 0 (packet received), 1 (packet ECN marked), or 3 (packet not yet received). The live portion of the buffer is marked off by head and tail pointers; each is further marked with the HC-Sender sequence number to which it corresponds. The buffer grows from right to left. For example:

```
+-------------------------------------------------------------------+
|S,L|S,L|S,L|S,L|S,L|   |   |   |   |S,L|S,L|S,L|S,L|S,L|S,L|S,L|S,L|
+-------------------------------------------------------------------+
                 ^                   ^
              Tail, seqno = T     Head, seqno = H

                <=== Head and Tail move this way <===
```

Each 'S,L' represents a State/Run length byte. We will draw these buffers showing only their live portion; for example, here is another representation for the buffer above:

```
          +---------------------------------------------------+
(Head) H  |S,L|S,L|S,L|S,L|S,L|S,L|S,L|S,L|S,L|S,L|S,L|S,L|S,L| T (Tail)
          +---------------------------------------------------+
```

This smaller Example Buffer contains actual data.

```
             +---------------------------+
          10 |0,0|3,0|3,0|3,0|0,4|1,0|0,0| 0    [Example Buffer]
             +---------------------------+
```

In concrete terms, its meaning is as follows:

Packet 10 was received. (The head of the buffer has sequence number 10, state 0, and run length 0.)

Packets 9, 8, and 7 have not yet been received. (The three bytes preceding the head each have state 3 and run length 0.)

Packets 6, 5, 4, 3, and 2 were received.

Packet 1 was ECN marked.

Packet 0 was received.

7.9.1. New Packets

When a packet arrives whose sequence number is larger than any in the buffer, the HC-Receiver simply moves the Head pointer to the left, increases the head sequence number, and stores a byte representing the packet into the buffer. For example, if HC-Sender packet 11 arrived ECN marked, the Example Buffer above would enter this new state (the change is marked with stars):

```
         +***----------------------------+
      11 |1,0|0,0|3,0|3,0|3,0|0,4|1,0|0,0| 0
         +***----------------------------+
```

If the packet's state equals the state at the head of the buffer, the HC-Receiver may choose to increment its run length (up to the maximum). For example, if HC-Sender packet 11 arrived without ECN marking, the Example Buffer might enter this state instead:

```
             +--*------------------------+
          11 |0,1|3,0|3,0|3,0|0,4|1,0|0,0| 0
             +--*------------------------+
```

Of course, the new packet's sequence number might not equal the expected sequence number. In this case, the HC-Receiver should enter the intervening packets as State 3. If several packets are missing, the HC-Receiver may prefer to enter multiple bytes with run length 0, rather than a single byte with a larger run length; this simplifies table updates when one of the missing packets arrives. For example, if HC-Sender packet 12 arrived, the Example Buffer would enter this state:

```
     +*******----------------------------+
  12 |0,0|3,0|0,1|3,0|3,0|3,0|0,4|1,0|0,0| 0
     +*******----------------------------+
```

When a new packet's sequence number is less than the head sequence number, the HC-Receiver should scan the table for the byte corresponding to that sequence number. (Slightly more complex indexing structures could reduce the complexity of this scan.) Assume that the sequence number was previously lost (State 3), and that it was stored in a byte with run length 0. Then the HC-Receiver can simply change the byte's state. For example, if HC-Sender packet 8 was received, the Example Buffer would enter this state:

```
             +--------*------------------+
          10 |0,0|3,0|0,0|3,0|0,4|1,0|0,0| 0
             +--------*------------------+
```

If the packet is not marked as lost, or if its sequence number is not contained in the table, the packet is probably a duplicate, and should be ignored. (The new packet's ECN marking state might differ from the state in the buffer; Section 7.5.1 describes what to do then.) If the packet's corresponding buffer byte has a non-zero run length, then the buffer might need be reshuffled to make space for one or two new bytes.

Of course, the circular buffer may overflow, either when the HC-Sender is sending data at a very high rate, when the HC-Receiver's acknowledgements are not reaching the HC-Sender, or when the HC-Sender is forgetting to acknowledge those acks (so the HC-Receiver is unable to clean up old state). In this case, the HC-Receiver should either compress the buffer, transfer its state to a larger buffer, or drop all received packets until its buffer shrinks again.

7.9.2. Sending Acknowledgements

Whenever the HC-Receiver needs to generate an acknowledgement, the buffer's contents can simply be copied into one or more Ack Vector options. Copied Ack Vectors might not be maximally compressed; for example, the Example Buffer above contains three adjacent 3,0 bytes that could be combined into a single 3,2 byte. The HC-Receiver might, therefore, choose to compress the buffer in place before sending the option, or to compress the buffer while copying it; either operation is simple.

Every acknowledgement sent by the HC-Receiver should include the entire state of the buffer. That is, acknowledgements are cumulative.

The HC-Receiver should store information about each acknowledgement it sends in another buffer. Specifically, for every acknowledgement it sends, the HC-Receiver should store:

- The HC-Receiver sequence number it used for the ack packet.
- The HC-Sender sequence number it acknowledged (that is, the packet's Acknowledgement Number). Since acknowledgements are cumulative, this single number completely specifies the set of HC-Sender packets acknowledged by this ack packet.

7.9.3. Clearing State

Some of the HC-Sender's packets will include acknowledgement numbers, which ack the HC-Receiver's acknowledgements. When such an ack is received, the HC-Receiver simply finds the HC-Sender sequence number corresponding to that acked HC-Receiver packet, and moves the buffer's Tail pointer up to that sequence number. (It may choose to keep some older information, in case a lost packet shows up late.) For example, say that the HC-Receiver storing the Example Buffer had sent two acknowledgements already:

```
HC-Receiver Ack 59  acknowledged  HC-Sender Seq 3, and
HC-Receiver Ack 60  acknowledged  HC-Sender Seq 10.
```

Say the HC-Receiver then received a DCCP-DataAck packet from the HC-Sender with Acknowledgement Number 59. This informs the HC-Receiver that the HC-Sender received, and processed, all the information in HC-Receiver packet 59. This packet acknowledged HC-Sender packet 3, so the HC-Sender has now received HC-Receiver's acknowledgements for packets 0, 1, 2, and 3. The Example Buffer should enter this state:

```
   +------------------*+ *
10 |0,0|3,0|3,0|3,0|0,2| 4
   +------------------*+ *
```

Note that the tail byte's run length was adjusted, since packet 3 was in the middle of that byte. The HC-Receiver can also throw away the information about HC-Receiver Ack 59.

A careful implementation might also modify its own acknowledgement record to ensure that it is reasonably robust to reordering. Suppose that the Example Buffer is as before, but that packet 9 now arrives, out of sequence. The Example buffer would enter this state:

```
   +----*-----------------------+
10 |0,0|0,0|3,0|3,0|0,4|1,0|0,0| 0
   +----*-----------------------+
```

Now, if the HC-Receiver then received a DCCP-DataAck packet from the HC-Sender with Sequence Number 11 and Acknowledgement Number 60, this might cause the tail pointer to be moved up to packet 10, although packet 9's arrival has not yet been acknowledged. Instead, when packet 9 arrived, the HC-Receiver's acknowledgement record might be modified to:

```
HC-Receiver Ack 59  acknowledged  HC-Sender Seq 3, and
HC-Receiver Ack 60  acknowledged  HC-Sender Seq 8.
```

That is, any HC-Sender sequence number in the acknowledgement record is reduced to at most 8. This would prevent the Tail pointer from moving past packet 9 until the HC-Receiver knows that the HC-Sender has seen an Ack Vector indicating this packets arrival.

7.9.4. Processing Acknowledgements

When the HC-Sender receives an acknowledgement, it generally cares about the number of packets that were dropped and/or ECN marked. It simply reads this off the Ack Vector. Additionally, it may check the ECN Nonce for correctness. (As described in Section 7.5.1, it may want to keep more detailed information about acknowledged packets in case packets change states between acknowledgements, or in case the application queries whether a packet arrived.)

The HC-Sender must also acknowledge the HC-Receiver's acknowledgements so that the HC-Receiver can free old Ack Vector state. (Since Ack Vector acknowledgements are reliable, the HC-Receiver must maintain and resend Ack Vector information until it is sure that the HC-Sender has received that information.) A simple algorithm suffices: since Ack Vector acknowledgements are cumulative, a single acknowledgement number tells HC-Receiver how much ack information has arrived. Assuming that the HC-Receiver sends no data, the HC-Sender can simply ensure that at least once a round-trip time, it sends a DCCP-DataAck packet acknowledging the latest DCCP-Ack packet it has received. Of course, the HC-Sender only needs to acknowledge the HC-Receiver's acknowledgements if the HC-Sender is also sending data. If the HC-Sender is not sending data, then the HC-Receiver's Ack Vector state is stable, and there is no need to shrink it. The HC-Sender must watch for drops and ECN marks on received DCCP-Ack packets so that it can adjust the HC-Receiver's ack-sending rate with Ack Ratio in response to congestion.

If the other half-connection is not quiescent---that is, the HC-Receiver is sending data to the HC-Sender, possibly using another CCID---then the acknowledgements on that half-connection are sufficient for the HC-Receiver to free its state.

8. Explicit Congestion Notification

The DCCP protocol is fully ECN-aware. Every CCID specifies how its endpoints respond to ECN marks. Furthermore, DCCP, unlike TCP, allows senders to control the rate at which acknowledgements are generated (with options like Ack Ratio); this means that acknowledgements are generally congestion-controlled, and may have ECN-Capable Transport set.

Every CCID profile describes how that profile interacts with ECN, both for data traffic and pure-acknowledgement traffic. A sender SHOULD set ECN-Capable Transport on a sent packet whenever the receiver has its ECN Capable feature turned on, and the relevant CCID allows it.

The rest of this section describes the ECN Capable feature, and the interaction of the ECN Nonce with acknowledgement options such as Ack Vector.

8.1. ECN Capable Feature

The ECN Capable feature lets a DCCP inform its partner that it cannot read ECN bits from received IP headers, so the partner must not set ECN-Capable Transport on its packets.

ECN Capable has feature number 2. The ECN Capable feature located at DCCP A indicates whether or not A can successfully read ECN bits from received frames' IP headers. (This is independent of whether it can set ECN bits on sent frames.) DCCP A sends a "Prefer(ECN Capable, 0)" option to DCCP B to inform B that A cannot read ECN bits.

An ECN Capable feature contains a single octet of data. ECN capability is on if and only if this octet is nonzero.

A new connection starts with ECN Capable 1 (that is, ECN capable) for both DCCPs. If a DCCP is not ECN capable, it MUST send "Prefer(ECN Capable, 0)" options to the other endpoint until acknowledged (by "Change(ECN Capable, 0)") or the connection closes. Furthermore, it MUST NOT accept any data until the other endpoint sends "Change(ECN Capable, 0)".

8.2. ECN Nonces

Congestion avoidance will not occur, and the receiver will sometimes get its data faster, when the sender is not told about any congestion events. Thus, the receiver has some incentive to falsify acknowledgement information, reporting that marked or dropped packets were actually received unmarked. This problem is more serious with DCCP than with TCP, since TCP provides reliable transport: it is more difficult with TCP to lie about lost packets without breaking the application.

ECN Nonces are a general mechanism to prevent ECN cheating (or loss cheating). Two values for the two-bit ECN header field indicate ECN-Capable Transport, 01 and 10. The second code point, 10, is the ECN Nonce. In general, a protocol sender chooses between these code points randomly on its output packets, remembering the sequence it chose. The protocol receiver reports, on every acknowledgement, the number of ECN Nonces it has received thus far. This is called the ECN Nonce Echo. Since ECN marking and packet dropping both destroy the ECN Nonce, a receiver that lies about an ECN mark or packet drop has a 50% chance of guessing right and avoiding discipline. The sender may react punitively to an ECN Nonce mismatch, possibly up to dropping the connection. The ECN Nonce Echo field need not be an integer; one bit is enough to catch 50% of infractions.

In DCCP, the ECN Nonce Echo field is encoded in acknowledgement options. For example, the Ack Vector option comes in two forms, Ack Vector [Nonce 0] (option 37) and Ack Vector [Nonce 1] (option 38), corresponding to the two values for a one-bit ECN Nonce Echo. The Nonce Echo for a given Ack Vector equals the base-2 modulus of the number of received ECN Nonce packets represented by that Ack Vector. Only packets marked as State 0 matter for this calculation (that is, received packets that were not ECN marked or dropped in the receive buffer). Every Ack Vector option is detailed enough for the sender to determine what the Nonce Echo should have been. It can check this calculation against the actual Nonce Echo, and complain if there is a mismatch.

(The Ack Vector could conceivably report every ECN Nonce packet, using a separate code point for received ECN Nonces. However, this would limit Ack Vector's compressibility without providing much extra protection.)

Consider a half-connection from DCCP A to DCCP B. DCCP A SHOULD set ECN Nonces on its packets, and remember which packets had nonces, whenever DCCP B reports that it is ECN Capable. An ECN-capable endpoint MUST calculate and use the correct value for ECN Nonce Echo when sending acknowledgement options. An ECN-incapable endpoint, however, SHOULD treat the ECN Nonce Echo as always zero. When a sender detects an ECN Nonce Echo mismatch, it SHOULD behave as if the receiver had reported one or more packets as ECN-marked (instead of unmarked). It MAY take more punitive action, such as resetting the connection.

9. Multihoming and Mobility

DCCP provides primitive support for multihoming and mobility, via a mechanism for transferring a connection endpoint from one IP address to another. The moving endpoint must negotiate mobility support beforehand, and both endpoints must share their Connection Nonces. When the moving endpoint gets a new IP address, it sends a DCCP-Move packet from that address to the stationary endpoint, including proof that it knows both nonces. The stationary endpoint then changes its connection state to use the new IP address.

DCCP's support for mobility is intended to solve only the simplest multihoming and mobility problems. For instance, DCCP has no support for simultaneous moves. Applications requiring more complex mobility semantics, or more stringent security guarantees, should use an existing solution like Mobile IP or Snoeren and Balakrishnan's work [SB00].

9.1. Mobility Capable Feature

A DCCP uses the Mobility Capable feature to inform its partner that it would like to be able to change its IP address and/or port during the course of the connection.

Mobility Capable has feature number 5. The Mobility Capable feature located at DCCP A indicates whether or not A will accept a DCCP-Move packet sent by B. DCCP B sends a "Change(Mobility Capable, 1)" option to DCCP A to inform it that B might like to move later.

A Mobility Capable feature contains a single octet of data. Mobility is allowed if and only if this octet is nonzero. A DCCP MUST reject a DCCP-Move packet referring to a connection when Mobility Capable is 0; however, it MAY reject a valid DCCP-Move packet even when Mobility Capable is 1.

A new connection starts with Mobility Capable 0 (that is, mobility is not allowed) for both DCCPs.

9.2. Security

The DCCP mobility mechanism, like DCCP in general, does not provide cryptographic security guarantees. Nevertheless, DCCP-Move packets must have valid sequence numbers and Connection Proof, providing protection against some classes of attackers. Specifically, an attacker cannot move a DCCP connection to a new IP address unless they know both the Connection Proof and a valid sequence number. If initial sequence numbers and Connection Nonces are chosen well (that is, randomly), this means that attackers must snoop on data packets to get any reasonable probability of success. Section 14 further describes DCCP security considerations.

9.3. Congestion Control State

Once an endpoint has transitioned to a new IP address, the connection is effectively a new connection in terms of its congestion control state: the accumulated information about congestion between the old endpoints no longer applies. Both DCCPs MUST initialize their congestion control state (windows, rates, and so forth) to that of a new connection---that is, they must "slow start"---unless they have high-quality information about actual network conditions between the two new endpoints. Normally, the only way to get this information would be by instrumenting a DCCP connection between the new addresses.

Similarly, the endpoints' configured MTUs (see 10) should be reinitialized, and PMTU discovery performed again, following an IP address change.

9.4. Loss During Transition

(This section is preliminary.) Several loss and delay events may affect the transition of a DCCP connection from one IP address to another. The DCCP-Move packet itself might be lost; the acknowledgement to that packet might be lost, leaving the mobile endpoint unsure of whether the transition has completed; and data from the old endpoint might continue to arrive at the receiver even after the transition.

To protect against lost DCCP-Move packets, the mobile host SHOULD retransmit a DCCP-Move packet if it does not receive an acknowledgement within a reasonable time period. Section 4.10 describes the mechanism used to protect against duplicate DCCP-Move packets.

A receiver MAY drop all data received from the old IP address/port pair, once a DCCP-Move has successfully completed. Alternately, it MAY accept one loss window's worth of this data. Congestion and loss events on this data SHOULD NOT affect the new connection's congestion control state. The receiver MUST NOT accept data with the old IP address/port pair past one loss window, and SHOULD send DCCP-Resets in response to those packets.

During some transition period, acknowledgements from the receiver to the mobile host will contain information about packets sent both from the old IP address/port pair, and from the new IP address/port pair. The mobile DCCP MUST NOT let loss events on packets from the old IP address/port pair affect the new congestion control state.

10. Path MTU Discovery

A DCCP implementation should be capable of performing Path MTU (PMTU) discovery, as described in [RFC 1191]. The API to DCCP SHOULD allow this mechanism to be disabled in cases where IP fragmentation is preferred. The rest of this section assumes PMTU discovery has not been disabled.

A DCCP implementation MUST maintain its idea of the current PMTU for each active DCCP session. The PMTU should be initialized from the interface MTU that will be used to send packets.

To perform PMTU discovery, the DCCP sender sets the IP Don't Fragment (DF) bit. However, it is undersirable for MTU discovery to occur on the initial connection setup handshake, as the connection setup process may not be representative of packet sizes used during the connection, and performing MTU discovery on the initial handshake might unnecessarily delay connection establishment. Thus, DF SHOULD NOT be set on DCCP-Request and DCCP-Response packets. In addition DF SHOULD NOT be set on DCCP-Reset packets, although typically these would be small enough to not be a problem. On all other DCCP packets, DF SHOULD be set.

Any API to DCCP MUST allow the application to discover DCCP's current PMTU. DCCP applications SHOULD use the API to discover the PMTU, and SHOULD NOT send datagrams that are greater than the PMTU; the only exception to this is if the application disables PMTU discovery. If the application tries to send a packet bigger than the PMTU, the DCCP implementation MUST drop the packet and return an appropriate error.

As specified in [RFC 1191], when a router receives a packet with DF set that is larger than the PMTU, it sends an ICMP Destination Unreachable message to the source of the datagram with the Code indicating "fragmentation needed and DF set" (also known as a "Datagram Too Big" message). When a DCCP implementation receives a Datagram Too Big message, it decreases its PMTU to the Next-Hop MTU value given in the ICMP message. If the MTU given in the message is zero, the sender chooses a value for PMTU using the algorithm described in Section 7 of [RFC 1191]. If the MTU given in the message is greater than the current PMTU, the Datagram Too Big message is ignored, as described in [RFC 1191]. (We are aware that this may cause problems for DCCP endpoints behind certain firewalls.)

If the DCCP implementation has decreased the PMTU, and the sending application attempts to send a packet larger than the new MTU, the API MUST cause the send to fail returning an appropriate error to the application, and the application SHOULD then use the API to query the new value of the PMTU. When this occurs, it is possible that the kernel has some packets buffered for transmission that are smaller than the old PMTU, but larger than the new PMTU. The kernel MAY send these packets with the DF bit cleared, or it MAY discard these packets; it MUST NOT transmit these datagrams with the DF bit set.

DCCP currently provides no way to increase the PMTU once it has decreased.

A DCCP sender MAY optionally treat the reception of an ICMP Datagram Too Big message as an indication that the packet being reported was not lost due congestion, and so for the purposes of congestion control it MAY ignore the DCCP receiver’s indication that this packet did not arrive. However, if this is done, then the DCCP sender MUST check the ECN bits of the IP header echoed in the ICMP message, and only perform this optimization if these ECN bits indicate that the packet did not experience congestion prior to reaching the router whose MTU it exceeded.

11. Abstract API

TBA

12. Multiplexing Issues

In contrast to TCP, DCCP does not offer reliable ordered delivery. As a consequence, with DCCP there are no inherent performance penalties in layering functionality above DCCP to multiplex several sub-flows into a single DCCP connection.

However, this approach of multiplexing sub-flows above DCCP will not work in circumstances such as RTP where the RTP subflows require separate port numbers. In this case, if it is desired to share congestion control state among multiple DCCP flows that share the same source and destination addresses, the possibilities are to add DCCP-specific mechanisms to enable this, or to use a generic multiplexing facility like the Congestion Manager [RFC 3124] residing below the transport layer. For some DCCP flows, the ability to specify the congestion control mechanism might be critical, and for these flows the Congestion Manager will only be a viable tool if it allows DCCP to specify the congestion control mechanism used by the Congestion Manager for that flow. Thus, to allow the sharing of congestion control state among multiple DCCP flows, the alternatives seem to be to add DCCP-specific functionality to the Congestion Manager, or to add a similar layer below DCCP that is specific to DCCP. We defer issues of DCCP operating over a revised version of the Congestion Manager, or over a DCCP-specific module for the sharing of congestion control state, to later work.

13. DCCP and RTP

This section discusses the relationship between DCCP and RTP [RFC 1889].

TBA

14. Security Considerations

DCCP does not provide cryptographic security guarantees. Applications desiring hard security should use IPsec or end-to-end security of some kind.

Nevertheless, DCCP is intended to protect against some classes of attackers. Attackers cannot hijack a DCCP connection (close the connection unexpectedly, or cause attacker data to be accepted by an endpoint as if it came from the sender) unless they can guess valid sequence numbers. Thus, as long as endpoints choose initial sequence numbers well, a DCCP attacker must snoop on data packets to get any reasonable probability of success. The sequence number validity (Section 4.3) and mobility (Section 9) mechanisms provide this guarantee.

This section is not in its final state. Further research is needed to ensure that we have met our stated security requirement.

15. IANA Considerations

DCCP introduces five sets of numbers whose values should be allocated by IANA.

- 32-bit Service Names (Section 4.5).
- 32-bit DCCP-Reset Reasons (Section 4.9).
- 8-bit DCCP Option Types (Section 5). The CCID-specific options 128 through 255 need not be allocated by IANA.
- 8-bit DCCP Feature Numbers (Section 5.3). The CCID-specific features 128 through 255 need not be allocated by IANA.
- 8-bit DCCP Congestion Control Identifiers (CCIDs) (Section 6).

In addition, DCCP requires a Protocol Number to be added to the registry of Assigned Internet Protocol Numbers. Experimental implementors should use Protocol Number 33 for DCCP, but this number may change in future.

16. Thanks

There is a wealth of work in this area, including the Congestion Manager. We thank the staff and interns of ICIR and, formerly, ACIRI, the members of the End-to-End Research Group, and the members of the Transport Area Working Group for their feedback on DCCP.

17. References

[CCID 2 PROFILE] S. Floyd and E. Kohler. Profile for DCCP Congestion Control ID 2: TCP-like Congestion Control. Work in progress.

[CCID 3 PROFILE] J. Padhye, S. Floyd, and E. Kohler. Profile for DCCP Congestion Control ID 3: TFRC Congestion Control. Work in progress.

[RFC 793] J. Postol, editor. Transmission Control Protocol. RFC 793.

[RFC 1191] J. C. Mogul and S. E. Deering. Path MTU discovery. RFC 1191.

[RFC 1889] Audio-Video Transport Working Group, H. Schulzrinne, S. Casner, R. Frederick, and V. Jacobson. RTP: A Transport Protocol for Real-Time Applications.

RFC 1889.

[RFC 2026] S. Bradner. The Internet Standards Process---Revision 3. RFC 2026.

[RFC 2460] S. Deering and R. Hinden. Internet Protocol, Version 6 (IPv6) Specification. RFC 2460.

[RFC 2960] R. Stewart, Q. Xie, K. Morneault, C. Sharp, H. Schwarzbauer, T. Taylor, I. Rytina, M. Kalla, L. Zhang, and V. Paxson. Stream Control Transmission Protocol. RFC 2960.

[RFC 3124] H. Balakrishnan and S. Seshan. The Congestion Manager. RFC 3124.

[RFC 3168] K.K. Ramakrishnan, S. Floyd, and D. Black. The Addition of Explicit Congestion Notification (ECN) to IP. RFC 3168. September 2001.

[SB00] Alex C. Snoeren and Hari Balakrishnan. An End-to-End Approach to Host Mobility. Proc. 6th Annual ACM/IEEE International Conference on Mobile Computing and Networking (MOBICOM ’00), August 2000.

[WES01] David Wetherall, David Ely, Neil Spring. Robust ECN Signaling with Nonces. draft-ietf-tsvwg-tcp-nonce-00.txt, work in progress, January 2001.

18. Authors’ Addresses

Eddie Kohler <kohler@icir.org>
Mark Handley <mjh@icir.org>
Sally Floyd <floyd@icir.org>

ICSI Center for Internet Research
1947 Center Street, Suite 600
Berkeley, CA 94704 USA

Jitendra Padhye <padhye@microsoft.com>

Microsoft Research
One Microsoft Way
Redmond, WA 98052 USA