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# TCP Extended Statistics MIB

## Status of This Memo



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## Abstract

This document describes extended performance statistics for TCP. They are designed to use TCP's ideal vantage point to diagnose performance problems in both the network and the application. If a network-based application is performing poorly, TCP can determine if the bottleneck is in the sender, the receiver, or the network itself. If the bottleneck is in the network, TCP can provide specific information about its nature.

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## 1. Introduction

This document describes extended performance statistics for TCP. They are designed to use TCP's ideal vantage point to diagnose performance problems in both the network and the application. If a network-based application is performing poorly, TCP can determine if the bottleneck is in the sender, the receiver, or the network itself. If the bottleneck is in the network, TCP can provide specific information about its nature.

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

The Simple Network Management Protocol (SNMP) objects defined in this document extend TCP MIB, as specified in RFC 4022 [RFC4022]. In addition to several new scalars and other objects, it augments two tables and makes one clarification to RFC 4022. Existing management stations for the TCP MIB are expected to be fully compatible with these clarifications.

## 2. The Internet-Standard Management Framework

For a detailed overview of the documents that describe the current Internet-Standard Management Framework, please refer to section 7 of RFC 3410 [RFC3410].

Managed objects are accessed via a virtual information store, termed the Management Information Base or MIB. MIB objects are generally accessed through the Simple Network Management Protocol (SNMP). Objects in the MIB are defined using the mechanisms defined in the Structure of Management Information (SMI). This memo specifies a MIB module that is compliant to the SMIv2, which is described in STD 58, RFC 2578 [RFC2578], STD 58, RFC 2579 [RFC2579] and STD 58, RFC 2580 [RFC2580].

## 3. Overview

The TCP-ESTATS-MIB defined in this memo consists of two groups of scalars, seven tables, and two notifications:

* The first group of scalars contain statistics of the TCP protocol engine not covered in RFC 4022. This group consists of the single scalar tcpEStatsListenerTableLastChange, which provides management stations with an easier mechanism to validate their listener caches.

* The second group of scalars consist of knobs to enable and disable information collection by the tables containing connection-related statistics/information. For example, the tcpEStatsControlPath object controls the activation of the tcpEStatsPathTable. The tcpEStatsConnTableLatency object determines how long connection table rows are retained after a TCP connection transitions into the closed state.

* The tcpEStatsListenerTable augments tcpListenerTable in TCP-MIB [RFC4022] to provide additional information on the active TCP listeners on a device. It supports objects to monitor and diagnose SYN-flood denial-of-service attacks as described below.

* The tcpEStatsConnectIdTable augments the tcpConnectionTable in TCP-MIB [RFC4022] to provide a mapping between connection 4-tuples (which index tcpConnectionTable) and an integer connection index, tcpEStatsConnectIndex. The connection index is used to index into the five remaining tables in this MIB module, and is designed to facilitate rapid polling of multiple objects associated with one TCP connection.

* The tcpEStatsPerfTable contains objects that are useful for measuring TCP performance and first check problem diagnosis.

* The tcpEStatsPathTable contains objects that can be used to infer detailed behavior of the Internet path, such as the extent that there are segment losses or reordering, etc.

* The tcpEStatsStackTable contains objects that are most useful for determining how well the TCP control algorithms are coping with this particular path.

* The tcpEStatsAppTable provides objects that are useful for determining if the application using TCP is limiting TCP performance.

* The tcpEStatsTuneTable provides per-connection controls that can be used to work around a number of common problems that plague TCP over some paths.

* The two notifications defined in this MIB module are tcpEStatsEstablishNotification, indicating that a new connection has been accepted (or established, see below), and tcpEStatsCloseNotification, indicating that an existing connection has recently closed.

### 3.1. MIB Initialization and Persistence

The TCP protocol itself is specifically designed not to preserve any state whatsoever across system reboots, and enforces this by requiring randomized Initial Sequence numbers and ephemeral ports under any conditions where segments from old connections might corrupt new connections following a reboot.

All of the objects in the MIB MUST have the same persistence properties as the underlying TCP implementation. On a reboot, all zero-based counters MUST be cleared, all dynamically created table rows MUST be deleted, and all read-write objects MUST be restored to their default values. It is assumed that all TCP implementation have some initialization code (if nothing else, to set IP addresses) that has the opportunity to adjust tcpEStatsConnTableLatency and other read-write scalars controlling the creation of the various tables, before establishing the first TCP connection. Implementations MAY also choose to make these control scalars persist across reboots.

The ZeroBasedCounter32 and ZeroBasedCounter64 objects in the listener and connection tables are initialized to zero when the table row is created.

The tcpEStatsConnTableLatency object determines how long connection table rows are retained after a TCP connection transitions into the closed state, to permit reading final connection completion statistics. In RFC 4022 (TCP-MIB), the discussion of tcpConnectionTable row latency (page 9) the words "soon after" are understood to mean after tcpEStatsConnTableLatency, such that all rows of all tables associated with one connection are retained at least tcpEStatsConnTableLatency after connection close. This clarification to RFC 4022 only applies when TCP-ESTATS-MIB is implemented. If TCP-ESTATS-MIB is not implemented, RFC 4022 permits an unspecified delay between connection close and row deletion.

### 3.2. Relationship to TCP Standards

There are more than 70 RFCs and other documents that specify various aspects of the Transmission Control Protocol (TCP) [RFC4614]. While most protocols are completely specified in one or two documents, this has not proven to be feasible for TCP. TCP implements a reliable end-to-end data transport service over a very weakly constrained IP datagram service. The essential problem that TCP has to solve is balancing the applications need for fast and reliable data transport against the need to make fair, efficient, and equitable use of network resources, with only sparse information about the state of the network or its capabilities.

TCP maintains this balance through the use of many estimators and heuristics that regulate various aspects of the protocol. For example, RFC 2988 describes how to calculate the retransmission timer (RTO) from the average and variance of the network round-trip-time (RTT), as estimated from the round-trip time sampled on some data segments. Although these algorithms are standardized, they are a compromise which is optimal for only common Internet environments. Other estimators might yield better results (higher performance or more efficient use of the network) in some environments, particularly under uncommon conditions.

It is the consensus of the community that nearly all of the estimators and heuristics used in TCP might be improved through further research and development. For this reason, nearly all TCP documents leave some latitude for future improvements, for example, by the use of "SHOULD" instead of "MUST" [RFC2119]. Even standard algorithms that are required because they critically effect fairness or the dynamic stability of Internet congestion control, include some latitude for evolution. As a consequence, there is considerable diversity in the details of the TCP implementations actually in use today.

The fact that the underlying algorithms are not uniform makes it difficult to tightly specify a MIB. We could have chosen the point of view that the MIB should publish precisely defined metrics of the network path, even if they are different from the estimators in use by TCP. This would make the MIB more useful as a measurement tool, but less useful for understanding how any specific TCP implementation is interacting with the network path and upper protocol layers. We chose instead to have the MIB expose the estimators and important states variables of the algorithms in use, without constraining the TCP implementation.

As a consequence, the MIB objects are defined in terms of fairly abstract descriptions (e.g., round-trip time), but are intended to expose the actual estimators or other state variables as they are used in TCP implementations, possibly transformed (e.g., scaled or otherwise adjusted) to match the spirit of the object descriptions in this document.

This may mean that MIB objects may not be exactly comparable between two different TCP implementations. A general management station can only assume the abstract descriptions, which are useful for a general assessment of how TCP is functioning. To a TCP implementer with detailed knowledge about the TCP implementation on a specific host, this MIB might be useful for debugging or evaluating the algorithms in their implementation.

Under no conditions is this MIB intended to constrain TCP to use (or exclude) any particular estimator, heuristic, algorithm, or implementation.

### 3.3. Diagnosing SYN-Flood Denial-of-Service Attacks

The tcpEStatsListenerTable is specifically designed to provide information that is useful for diagnosing SYN-flood Denial-of-Service attacks, where a server is overwhelmed by forged or otherwise malicious connection attempts. There are several different techniques that can be used to defend against SYN-flooding but none are standardized [Edd06]. These different techniques all have the same basic characteristics that are instrumentable with a common set of objects, even though the techniques differ greatly in the details.

All SYN-flood defenses avoid allocating significant resources (memory or CPU) to incoming (passive open) connections until the connections meet some liveness criteria (to defend against forged IP source addresses) and the server has sufficient resources to process the incoming request. Note that allocating resources is an implementation-specific event that may not correspond to an observable protocol event (e.g., segments on the wire). There are two general concepts that can be applied to all known SYN-flood defenses. There is generally a well-defined event when a connection is allocated full resources, and a "backlog" -- a queue of embryonic connections that have been allocated only partial resources.

In many implementations, incoming TCP connections are allocated resources as a side effect of the POSIX [POSIX] accept() call. For this reason we use the terminology "accepting a connection" to refer to this event: committing sufficient network resources to process the incoming request. Accepting a connection typically entails allocating memory for the protocol control block [RFC793], the per-connection table rows described in this MIB and CPU resources, such as process table entries or threads.

Note that it is not useful to accept connections before they are ESTABLISHED, because this would create an easy opportunity for Denial-of-Service attacks, using forged source IP addresses.

The backlog consists of connections that are in SYN-RCVD or ESTABLISHED states, that have not been accepted. For purposes of this MIB, we assume that these connections have been allocated some resources (e.g., an embryonic protocol control block), but not full resources (e.g., do not yet have MIB table rows).

Note that some SYN-Flood defenses dispense with explicit SYN-RCVD state by cryptographically encoding the state in the ISS (initial sequence number sent) of the SYN-ACK (sometimes called a syn-cookie), and then using the sequence number of the first ACK to reconstruct the SYN-RCVD state before transitioning to the ESTABLISHED state. For these implementations there is no explicit representation of the SYN-RCVD state, and the backlog only consists of connections that are ESTABLISHED and are waiting to be ACCEPTED.

Furthermore, most SYN-flood defenses have some mechanism to throttle connections that might otherwise overwhelm this endpoint. They generally use some combination of discarding incoming SYNs and discarding connections already in the backlog. This does not cause all connections from legitimate clients to fail, as long as the clients retransmit the SYN or first ACK as specified in RFC 793. Most diversity in SYN flood defenses arise from variations in these algorithms to limit load, and therefore cannot be instrumented with a common standard MIB.

The Listen Table instruments all passively opened TCP connections in terms of observable protocol events (e.g., sent and received segments) and resource allocation events (entering the backlog and being accepted). This approach eases generalization to SYN-flood mechanisms that use alternate TCP state transition diagrams and implicit mechanisms to encode some states.

## 4. TCP Extended Statistics MIB

This MIB module IMPORTS definitions from [RFC2578], [RFC2579], [RFC2580], [RFC2856], [RFC4022], and [RFC4502]. It uses REFERENCE clauses to refer to [RFC791], [RFC793], [RFC1122], [RFC1191], [RFC1323], [RFC2018], [RFC2581], [RFC2861], [RFC2883], [RFC2988], [RFC3168], [RFC3260], [RFC3517], [RFC3522], and [RFC3742].

```
TCP-ESTATS-MIB DEFINITIONS ::= BEGIN
IMPORTS
       MODULE-IDENTITY, Counter32, Integer32, Unsigned32,
       Gauge32, OBJECT-TYPE, mib-2,
       NOTIFICATION-TYPE
           FROM SNMPv2-SMI                 -- [RFC2578]
       MODULE-COMPLIANCE, OBJECT-GROUP, NOTIFICATION-GROUP
           FROM SNMPv2-CONF                -- [RFC2580]
       ZeroBasedCounter32
           FROM RMON2-MIB                  -- [RFC4502]
       ZeroBasedCounter64
           FROM HCNUM-TC                   -- [RFC2856]
       TEXTUAL-CONVENTION,
       DateAndTime, TruthValue, TimeStamp
```

```
            FROM SNMPv2-TC                  -- [RFC2579]
        tcpListenerEntry, tcpConnectionEntry
            FROM TCP-MIB;                   -- [RFC4022]

   tcpEStatsMIB MODULE-IDENTITY
       LAST-UPDATED "200705180000Z"    -- 18 May 2007
       ORGANIZATION "IETF TSV Working Group"
       CONTACT-INFO
           "Matt Mathis
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           Web100 Project
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           Stow, MA 01775
           Phone: 617-201-2655
           Email: saperia@jdscons.com "
       DESCRIPTION
           "Documentation of TCP Extended Performance Instrumentation
            variables from the Web100 project.  [Web100]

            All of the objects in this MIB MUST have the same
            persistence properties as the underlying TCP implementation.
            On a reboot, all zero-based counters MUST be cleared, all
            dynamically created table rows MUST be deleted, and all
            read-write objects MUST be restored to their default values.

            It is assumed that all TCP implementation have some
            initialization code (if nothing else to set IP addresses)
            that has the opportunity to adjust tcpEStatsConnTableLatency
            and other read-write scalars controlling the creation of the
            various tables, before establishing the first TCP
            connection.  Implementations MAY also choose to make these
            control scalars persist across reboots.

            Copyright (C) The IETF Trust (2007).  This version
            of this MIB module is a part of RFC 4898; see the RFC
            itself for full legal notices."
```

```
        REVISION "200705180000Z"    -- 18 May 2007
        DESCRIPTION
            "Initial version, published as RFC 4898."
            ::= { mib-2 156 }

    tcpEStatsNotifications OBJECT IDENTIFIER ::= { tcpEStatsMIB 0 }
    tcpEStatsMIBObjects    OBJECT IDENTIFIER ::= { tcpEStatsMIB 1 }
    tcpEStatsConformance   OBJECT IDENTIFIER ::= { tcpEStatsMIB 2 }
    tcpEStats             OBJECT IDENTIFIER ::= { tcpEStatsMIBObjects 1 }
    tcpEStatsControl      OBJECT IDENTIFIER ::= { tcpEStatsMIBObjects 2 }
    tcpEStatsScalar       OBJECT IDENTIFIER ::= { tcpEStatsMIBObjects 3 }

    --
    -- Textual Conventions
    --

    TcpEStatsNegotiated  ::= TEXTUAL-CONVENTION
       STATUS             current
       DESCRIPTION
           "Indicates if some optional TCP feature was negotiated.

            Enabled(1) indicates that the feature was successfully
            negotiated on, which generally requires both hosts to agree
            to use the feature.

            selfDisabled(2) indicates that the local host refused the
            feature because it is not implemented, configured off, or
            refused for some other reason, such as the lack of
            resources.

            peerDisabled(3) indicates that the local host was willing
            to negotiate the feature, but the remote host did not
            do so."
       SYNTAX INTEGER {
                    enabled(1),
                    selfDisabled(2),
                    peerDisabled(3)
            }

    --
    -- TCP Extended statistics scalars
    --

    tcpEStatsListenerTableLastChange OBJECT-TYPE
        SYNTAX     TimeStamp
        MAX-ACCESS read-only
        STATUS     current
        DESCRIPTION
```

```
            "The value of sysUpTime at the time of the last
             creation or deletion of an entry in the tcpListenerTable.
             If the number of entries has been unchanged since the
             last re-initialization of the local network management
             subsystem, then this object contains a zero value."
        ::= { tcpEStatsScalar 3 }

    -- ================================================================
    --
    -- The tcpEStatsControl Group
    --

    -- The scalar objects in this group are used to control the
    -- activation and deactivation of the TCP Extended Statistics
    -- tables and notifications in this module.
    --

    tcpEStatsControlPath  OBJECT-TYPE
        SYNTAX          TruthValue
        MAX-ACCESS      read-write
        STATUS          current
        DESCRIPTION
            "Controls the activation of the TCP Path Statistics
            table.

            A value 'true' indicates that the TCP Path Statistics
            table is active, while 'false' indicates that the
            table is inactive."
        DEFVAL          { false }
        ::= { tcpEStatsControl 1 }

    tcpEStatsControlStack  OBJECT-TYPE
        SYNTAX          TruthValue
        MAX-ACCESS      read-write
        STATUS          current
        DESCRIPTION
            "Controls the activation of the TCP Stack Statistics
            table.

            A value 'true' indicates that the TCP Stack Statistics
            table is active, while 'false' indicates that the
            table is inactive."
        DEFVAL          { false }
        ::= { tcpEStatsControl 2 }

    tcpEStatsControlApp  OBJECT-TYPE
        SYNTAX          TruthValue
        MAX-ACCESS      read-write
```

```
        STATUS          current
        DESCRIPTION
            "Controls the activation of the TCP Application
            Statistics table.

            A value 'true' indicates that the TCP Application
            Statistics table is active, while 'false' indicates
            that the table is inactive."
        DEFVAL          { false }
        ::= { tcpEStatsControl 3 }

    tcpEStatsControlTune  OBJECT-TYPE
        SYNTAX          TruthValue
        MAX-ACCESS      read-write
        STATUS          current
        DESCRIPTION
            "Controls the activation of the TCP Tuning table.

            A value 'true' indicates that the TCP Tuning
            table is active, while 'false' indicates that the
            table is inactive."
        DEFVAL          { false }
        ::= { tcpEStatsControl 4 }

    tcpEStatsControlNotify  OBJECT-TYPE
        SYNTAX          TruthValue
        MAX-ACCESS      read-write
        STATUS          current
        DESCRIPTION
            "Controls the generation of all notifications defined in
            this MIB.

            A value 'true' indicates that the notifications
            are active, while 'false' indicates that the
            notifications are inactive."
        DEFVAL          { false }
        ::= { tcpEStatsControl 5 }

    tcpEStatsConnTableLatency OBJECT-TYPE
        SYNTAX          Unsigned32
        UNITS           "seconds"
        MAX-ACCESS      read-write
        STATUS          current
        DESCRIPTION
            "Specifies the number of seconds that the entity will
             retain entries in the TCP connection tables, after the
             connection first enters the closed state.  The entity
             SHOULD provide a configuration option to enable
```

```
            customization of this value.  A value of 0
            results in entries being removed from the tables as soon as
            the connection enters the closed state.  The value of
            this object pertains to the following tables:
              tcpEStatsConnectIdTable
              tcpEStatsPerfTable
              tcpEStatsPathTable
              tcpEStatsStackTable
              tcpEStatsAppTable
              tcpEStatsTuneTable"
        DEFVAL { 0 }
        ::= { tcpEStatsControl 6 }

    -- ================================================================
    --
    -- Listener Table
    --

    tcpEStatsListenerTable OBJECT-TYPE
        SYNTAX      SEQUENCE OF TcpEStatsListenerEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "This table contains information about TCP Listeners,
            in addition to the information maintained by the
            tcpListenerTable RFC 4022."
        ::= { tcpEStats 1 }

    tcpEStatsListenerEntry OBJECT-TYPE
        SYNTAX       TcpEStatsListenerEntry
        MAX-ACCESS   not-accessible
        STATUS       current
        DESCRIPTION
            "Each entry in the table contains information about
            a specific TCP Listener."
        AUGMENTS { tcpListenerEntry }
        ::= { tcpEStatsListenerTable 1 }

    TcpEStatsListenerEntry ::= SEQUENCE {
            tcpEStatsListenerStartTime         TimeStamp,
            tcpEStatsListenerSynRcvd           ZeroBasedCounter32,
            tcpEStatsListenerInitial           ZeroBasedCounter32,
            tcpEStatsListenerEstablished       ZeroBasedCounter32,
            tcpEStatsListenerAccepted          ZeroBasedCounter32,
            tcpEStatsListenerExceedBacklog     ZeroBasedCounter32,
            tcpEStatsListenerHCSynRcvd         ZeroBasedCounter64,
            tcpEStatsListenerHCInitial         ZeroBasedCounter64,
            tcpEStatsListenerHCEstablished     ZeroBasedCounter64,
```

```
          tcpEStatsListenerHCAccepted        ZeroBasedCounter64,
          tcpEStatsListenerHCExceedBacklog   ZeroBasedCounter64,
          tcpEStatsListenerCurConns          Gauge32,
          tcpEStatsListenerMaxBacklog        Unsigned32,
          tcpEStatsListenerCurBacklog        Gauge32,
          tcpEStatsListenerCurEstabBacklog   Gauge32
   }

   tcpEStatsListenerStartTime   OBJECT-TYPE
       SYNTAX     TimeStamp
       MAX-ACCESS read-only
       STATUS     current
       DESCRIPTION
           "The value of sysUpTime at the time this listener was
           established.  If the current state was entered prior to
           the last re-initialization of the local network management
           subsystem, then this object contains a zero value."
       ::= { tcpEStatsListenerEntry 1 }

   tcpEStatsListenerSynRcvd OBJECT-TYPE
       SYNTAX     ZeroBasedCounter32
       MAX-ACCESS read-only
       STATUS     current
       DESCRIPTION
           "The number of SYNs which have been received for this
           listener.  The total number of failed connections for
           all reasons can be estimated to be tcpEStatsListenerSynRcvd
           minus tcpEStatsListenerAccepted and
           tcpEStatsListenerCurBacklog."
       ::= { tcpEStatsListenerEntry 2 }

   tcpEStatsListenerInitial     OBJECT-TYPE
      SYNTAX     ZeroBasedCounter32
      MAX-ACCESS read-only
      STATUS     current
      DESCRIPTION
         "The total number of connections for which the Listener
          has allocated initial state and placed the
          connection in the backlog.  This may happen in the
          SYN-RCVD or ESTABLISHED states, depending on the
          implementation."
       ::= { tcpEStatsListenerEntry 3 }

   tcpEStatsListenerEstablished OBJECT-TYPE
       SYNTAX     ZeroBasedCounter32
       MAX-ACCESS read-only
       STATUS     current
       DESCRIPTION
```

```
            "The number of connections that have been established to
            this endpoint (e.g., the number of first ACKs that have
            been received for this listener)."
        ::= { tcpEStatsListenerEntry 4 }

    tcpEStatsListenerAccepted    OBJECT-TYPE
       SYNTAX     ZeroBasedCounter32
       MAX-ACCESS read-only
       STATUS     current
       DESCRIPTION
          "The total number of connections for which the Listener
           has successfully issued an accept, removing the connection
           from the backlog."
        ::= { tcpEStatsListenerEntry 5 }

    tcpEStatsListenerExceedBacklog OBJECT-TYPE
       SYNTAX     ZeroBasedCounter32
       MAX-ACCESS read-only
       STATUS     current
       DESCRIPTION
          "The total number of connections dropped from the
          backlog by this listener due to all reasons.  This
          includes all connections that are allocated initial
          resources, but are not accepted for some reason."
        ::= { tcpEStatsListenerEntry 6 }

    tcpEStatsListenerHCSynRcvd OBJECT-TYPE
        SYNTAX     ZeroBasedCounter64
        MAX-ACCESS read-only
        STATUS     current
        DESCRIPTION
            "The number of SYNs that have been received for this
            listener on systems that can process (or reject) more
            than 1 million connections per second.  See
            tcpEStatsListenerSynRcvd."
        ::= { tcpEStatsListenerEntry 7 }

    tcpEStatsListenerHCInitial     OBJECT-TYPE
       SYNTAX     ZeroBasedCounter64
       MAX-ACCESS read-only
       STATUS     current
       DESCRIPTION
          "The total number of connections for which the Listener
           has allocated initial state and placed the connection
           in the backlog on systems that can process (or reject)
           more than 1 million connections per second.  See
           tcpEStatsListenerInitial."
        ::= { tcpEStatsListenerEntry 8 }
```

```
   tcpEStatsListenerHCEstablished OBJECT-TYPE
       SYNTAX     ZeroBasedCounter64
       MAX-ACCESS read-only
       STATUS     current
       DESCRIPTION
           "The number of connections that have been established to
           this endpoint on systems that can process (or reject) more
           than 1 million connections per second.  See
           tcpEStatsListenerEstablished."
       ::= { tcpEStatsListenerEntry 9 }

   tcpEStatsListenerHCAccepted    OBJECT-TYPE
      SYNTAX     ZeroBasedCounter64
      MAX-ACCESS read-only
      STATUS     current
      DESCRIPTION
         "The total number of connections for which the Listener
          has successfully issued an accept, removing the connection
          from the backlog on systems that can process (or reject)
          more than 1 million connections per second.  See
          tcpEStatsListenerAccepted."
       ::= { tcpEStatsListenerEntry 10 }

   tcpEStatsListenerHCExceedBacklog OBJECT-TYPE
      SYNTAX     ZeroBasedCounter64
      MAX-ACCESS read-only
      STATUS     current
      DESCRIPTION
         "The total number of connections dropped from the
         backlog by this listener due to all reasons on
         systems that can process (or reject) more than
         1 million connections per second.  See
         tcpEStatsListenerExceedBacklog."
       ::= { tcpEStatsListenerEntry 11 }

   tcpEStatsListenerCurConns   OBJECT-TYPE
      SYNTAX     Gauge32
      MAX-ACCESS read-only
      STATUS     current
      DESCRIPTION
         "The current number of connections in the ESTABLISHED
          state, which have also been accepted.  It excludes
          connections that have been established but not accepted
          because they are still subject to being discarded to
          shed load without explicit action by either endpoint."
       ::= { tcpEStatsListenerEntry 12 }

   tcpEStatsListenerMaxBacklog OBJECT-TYPE
```

```
      SYNTAX     Unsigned32
      MAX-ACCESS read-only
      STATUS     current
      DESCRIPTION
         "The maximum number of connections allowed in the
          backlog at one time."
       ::= { tcpEStatsListenerEntry 13 }

   tcpEStatsListenerCurBacklog OBJECT-TYPE
      SYNTAX     Gauge32
      MAX-ACCESS read-only
      STATUS     current
      DESCRIPTION
         "The current number of connections that are in the backlog.
          This gauge includes connections in ESTABLISHED or
          SYN-RECEIVED states for which the Listener has not yet
          issued an accept.

          If this listener is using some technique to implicitly
          represent the SYN-RECEIVED states (e.g., by
          cryptographically encoding the state information in the
          initial sequence number, ISS), it MAY elect to exclude
          connections in the SYN-RECEIVED state from the backlog."
       ::= { tcpEStatsListenerEntry 14 }

   tcpEStatsListenerCurEstabBacklog OBJECT-TYPE
      SYNTAX     Gauge32
      MAX-ACCESS read-only
      STATUS     current
      DESCRIPTION
         "The current number of connections in the backlog that are
          in the ESTABLISHED state, but for which the Listener has
          not yet issued an accept."
       ::= { tcpEStatsListenerEntry 15 }


   -- ================================================================
   --
   -- TCP Connection ID Table
   --

   tcpEStatsConnectIdTable    OBJECT-TYPE
       SYNTAX      SEQUENCE OF TcpEStatsConnectIdEntry
       MAX-ACCESS  not-accessible
       STATUS      current
       DESCRIPTION
           "This table maps information that uniquely identifies
           each active TCP connection to the connection ID used by
```

```
            other tables in this MIB Module.  It is an extension of
            tcpConnectionTable in RFC 4022.

            Entries are retained in this table for the number of
            seconds indicated by the tcpEStatsConnTableLatency
            object, after the TCP connection first enters the closed
            state."
        ::= { tcpEStats 2 }

    tcpEStatsConnectIdEntry  OBJECT-TYPE
        SYNTAX       TcpEStatsConnectIdEntry
        MAX-ACCESS   not-accessible
        STATUS       current
        DESCRIPTION
            "Each entry in this table maps a TCP connection
            4-tuple to a connection index."
        AUGMENTS { tcpConnectionEntry }
        ::= { tcpEStatsConnectIdTable 1 }

    TcpEStatsConnectIdEntry ::= SEQUENCE {
            tcpEStatsConnectIndex             Unsigned32
    }

    tcpEStatsConnectIndex  OBJECT-TYPE
        SYNTAX          Unsigned32 (1..4294967295)
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
            "A unique integer value assigned to each TCP Connection
            entry.

            The RECOMMENDED algorithm is to begin at 1 and increase to
            some implementation-specific maximum value and then start
            again at 1 skipping values already in use."
        ::= { tcpEStatsConnectIdEntry 1 }

    -- ================================================================
    --
    -- Basic TCP Performance Statistics
    --

    tcpEStatsPerfTable    OBJECT-TYPE
        SYNTAX      SEQUENCE OF TcpEStatsPerfEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION

            "This table contains objects that are useful for
```

```
            measuring TCP performance and first line problem
            diagnosis.  Most objects in this table directly expose
            some TCP state variable or are easily implemented as
            simple functions (e.g., the maximum value) of TCP
            state variables.

            Entries are retained in this table for the number of
            seconds indicated by the tcpEStatsConnTableLatency
            object, after the TCP connection first enters the closed
            state."
        ::= { tcpEStats 3 }

    tcpEStatsPerfEntry  OBJECT-TYPE
        SYNTAX       TcpEStatsPerfEntry
        MAX-ACCESS   not-accessible
        STATUS       current
        DESCRIPTION
            "Each entry in this table has information about the
            characteristics of each active and recently closed TCP
            connection."
       INDEX { tcpEStatsConnectIndex }
       ::= { tcpEStatsPerfTable 1 }

    TcpEStatsPerfEntry ::= SEQUENCE {

            tcpEStatsPerfSegsOut                ZeroBasedCounter32,
            tcpEStatsPerfDataSegsOut            ZeroBasedCounter32,
            tcpEStatsPerfDataOctetsOut          ZeroBasedCounter32,
            tcpEStatsPerfHCDataOctetsOut        ZeroBasedCounter64,
            tcpEStatsPerfSegsRetrans            ZeroBasedCounter32,
            tcpEStatsPerfOctetsRetrans          ZeroBasedCounter32,
            tcpEStatsPerfSegsIn                 ZeroBasedCounter32,
            tcpEStatsPerfDataSegsIn             ZeroBasedCounter32,
            tcpEStatsPerfDataOctetsIn           ZeroBasedCounter32,
            tcpEStatsPerfHCDataOctetsIn         ZeroBasedCounter64,
            tcpEStatsPerfElapsedSecs            ZeroBasedCounter32,
            tcpEStatsPerfElapsedMicroSecs       ZeroBasedCounter32,
            tcpEStatsPerfStartTimeStamp         DateAndTime,
            tcpEStatsPerfCurMSS                 Gauge32,
            tcpEStatsPerfPipeSize               Gauge32,
            tcpEStatsPerfMaxPipeSize            Gauge32,
            tcpEStatsPerfSmoothedRTT            Gauge32,
            tcpEStatsPerfCurRTO                 Gauge32,
            tcpEStatsPerfCongSignals            ZeroBasedCounter32,
            tcpEStatsPerfCurCwnd                Gauge32,
            tcpEStatsPerfCurSsthresh            Gauge32,
            tcpEStatsPerfTimeouts               ZeroBasedCounter32,
            tcpEStatsPerfCurRwinSent            Gauge32,
```

```
            tcpEStatsPerfMaxRwinSent            Gauge32,
            tcpEStatsPerfZeroRwinSent           ZeroBasedCounter32,
            tcpEStatsPerfCurRwinRcvd            Gauge32,
            tcpEStatsPerfMaxRwinRcvd            Gauge32,
            tcpEStatsPerfZeroRwinRcvd           ZeroBasedCounter32,
            tcpEStatsPerfSndLimTransRwin        ZeroBasedCounter32,
            tcpEStatsPerfSndLimTransCwnd        ZeroBasedCounter32,
            tcpEStatsPerfSndLimTransSnd         ZeroBasedCounter32,
            tcpEStatsPerfSndLimTimeRwin         ZeroBasedCounter32,
            tcpEStatsPerfSndLimTimeCwnd         ZeroBasedCounter32,
            tcpEStatsPerfSndLimTimeSnd          ZeroBasedCounter32
        }

    --
    --  The following objects provide statistics on aggregate
    --  segments and data sent on a connection.  These provide a
    --  direct measure of the Internet capacity consumed by a
    --  connection.
    --

    tcpEStatsPerfSegsOut  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The total number of segments sent."
        ::= { tcpEStatsPerfEntry 1 }

    tcpEStatsPerfDataSegsOut  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of segments sent containing a positive length
            data segment."
        ::= { tcpEStatsPerfEntry 2 }

    tcpEStatsPerfDataOctetsOut  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of octets of data contained in transmitted
            segments, including retransmitted data.  Note that this does
            not include TCP headers."
        ::= { tcpEStatsPerfEntry 3 }
```

```
   tcpEStatsPerfHCDataOctetsOut  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter64
       UNITS           "octets"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The number of octets of data contained in transmitted
           segments, including retransmitted data, on systems that can
           transmit more than 10 million bits per second.  Note that
           this does not include TCP headers."
       ::= { tcpEStatsPerfEntry 4 }

   tcpEStatsPerfSegsRetrans  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter32
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The number of segments transmitted containing at least some
           retransmitted data."
       REFERENCE
          "RFC 793, Transmission Control Protocol"
       ::= { tcpEStatsPerfEntry 5 }

   tcpEStatsPerfOctetsRetrans  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter32
       UNITS           "octets"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The number of octets retransmitted."
       REFERENCE
          "RFC 793, Transmission Control Protocol"
       ::= { tcpEStatsPerfEntry 6 }

   tcpEStatsPerfSegsIn  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter32
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The total number of segments received."
       ::= { tcpEStatsPerfEntry 7 }

   tcpEStatsPerfDataSegsIn  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter32
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The number of segments received containing a positive
```

```
            length data segment."
        ::= { tcpEStatsPerfEntry 8 }

    tcpEStatsPerfDataOctetsIn  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of octets contained in received data segments,
            including retransmitted data.  Note that this does not
            include TCP headers."
        ::= { tcpEStatsPerfEntry 9 }

    tcpEStatsPerfHCDataOctetsIn  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter64
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of octets contained in received data segments,
            including retransmitted data, on systems that can receive
            more than 10 million bits per second.  Note that this does
            not include TCP headers."
        ::= { tcpEStatsPerfEntry 10 }

    tcpEStatsPerfElapsedSecs  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        UNITS           "seconds"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The seconds part of the time elapsed between
            tcpEStatsPerfStartTimeStamp and the most recent protocol
            event (segment sent or received)."
        ::= { tcpEStatsPerfEntry 11 }

    tcpEStatsPerfElapsedMicroSecs  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        UNITS           "microseconds"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The micro-second part of time elapsed between
            tcpEStatsPerfStartTimeStamp to the most recent protocol
            event (segment sent or received).  This may be updated in
            whatever time granularity is the system supports."
        ::= { tcpEStatsPerfEntry 12 }
```

```
   tcpEStatsPerfStartTimeStamp  OBJECT-TYPE
       SYNTAX          DateAndTime
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "Time at which this row was created and all
           ZeroBasedCounters in the row were initialized to zero."
       ::= { tcpEStatsPerfEntry 13 }

   --
   --  The following objects can be used to fit minimal
   --  performance models to the TCP data rate.
   --

   tcpEStatsPerfCurMSS  OBJECT-TYPE
       SYNTAX          Gauge32
       UNITS           "octets"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The current maximum segment size (MSS), in octets."
       REFERENCE
          "RFC 1122, Requirements for Internet Hosts - Communication
           Layers"
       ::= { tcpEStatsPerfEntry 14 }

   tcpEStatsPerfPipeSize  OBJECT-TYPE
       SYNTAX          Gauge32
       UNITS           "octets"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The TCP senders current estimate of the number of
           unacknowledged data octets in the network.

           While not in recovery (e.g., while the receiver is not
           reporting missing data to the sender), this is precisely the
           same as 'Flight size' as defined in RFC 2581, which can be
           computed as SND.NXT minus SND.UNA. [RFC793]

           During recovery, the TCP sender has incomplete information
           about the state of the network (e.g., which segments are
           lost vs reordered, especially if the return path is also
           dropping TCP acknowledgments).  Current TCP standards do not
           mandate any specific algorithm for estimating the number of
           unacknowledged data octets in the network.

           RFC 3517 describes a conservative algorithm to use SACK
```

```
            information to estimate the number of unacknowledged data
            octets in the network. tcpEStatsPerfPipeSize object SHOULD
            be the same as 'pipe' as defined in RFC 3517 if it is
            implemented. (Note that while not in recovery the pipe
            algorithm yields the same values as flight size).

            If RFC 3517 is not implemented, the data octets in flight
            SHOULD be estimated as SND.NXT minus SND.UNA adjusted by
            some measure of the data that has left the network and
            retransmitted data.  For example, with Reno or NewReno style
            TCP, the number of duplicate acknowledgment is used to
            count the number of segments that have left the network.
            That is,
            PipeSize=SND.NXT-SND.UNA+(retransmits-dupacks)*CurMSS"
        REFERENCE
           "RFC 793, RFC 2581, RFC 3517"
        ::= { tcpEStatsPerfEntry 15 }

    tcpEStatsPerfMaxPipeSize  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The maximum value of tcpEStatsPerfPipeSize, for this
            connection."
        REFERENCE
           "RFC 793, RFC 2581, RFC 3517"
        ::= { tcpEStatsPerfEntry 16 }

    tcpEStatsPerfSmoothedRTT  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "milliseconds"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The smoothed round trip time used in calculation of the
            RTO. See SRTT in [RFC2988]."
        REFERENCE
           "RFC 2988, Computing TCP's Retransmission Timer"
        ::= { tcpEStatsPerfEntry 17 }

    tcpEStatsPerfCurRTO  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "milliseconds"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
```

```
          "The current value of the retransmit timer RTO."
       REFERENCE
          "RFC 2988, Computing TCP's Retransmission Timer"
       ::= { tcpEStatsPerfEntry 18 }

   tcpEStatsPerfCongSignals  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter32
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The number of multiplicative downward congestion window
           adjustments due to all forms of congestion signals,
           including Fast Retransmit, Explicit Congestion Notification
           (ECN), and timeouts.  This object summarizes all events that
           invoke the MD portion of Additive Increase Multiplicative
           Decrease (AIMD) congestion control, and as such is the best
           indicator of how a cwnd is being affected by congestion.

           Note that retransmission timeouts multiplicatively reduce
           the window implicitly by setting ssthresh, and SHOULD be
           included in tcpEStatsPerfCongSignals.  In order to minimize
           spurious congestion indications due to out-of-order
           segments, tcpEStatsPerfCongSignals SHOULD be incremented in
           association with the Fast Retransmit algorithm."
       REFERENCE
          "RFC 2581, TCP Congestion Control"
       ::= { tcpEStatsPerfEntry 19 }

   tcpEStatsPerfCurCwnd  OBJECT-TYPE
       SYNTAX          Gauge32
       UNITS           "octets"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The current congestion window, in octets."
       REFERENCE
          "RFC 2581, TCP Congestion Control"
       ::= { tcpEStatsPerfEntry 20 }

   tcpEStatsPerfCurSsthresh  OBJECT-TYPE
       SYNTAX          Gauge32
       UNITS           "octets"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The current slow start threshold in octets."
       REFERENCE
          "RFC 2581, TCP Congestion Control"
```

```
        ::= { tcpEStatsPerfEntry 21 }

    tcpEStatsPerfTimeouts  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of times the retransmit timeout has expired when
            the RTO backoff multiplier is equal to one."
        REFERENCE
           "RFC 2988, Computing TCP's Retransmission Timer"
        ::= { tcpEStatsPerfEntry 22 }

    --
    --  The following objects instrument receiver window updates
    --  sent by the local receiver to the remote sender.  These can
    --  be used to determine if the local receiver is exerting flow
    --  control back pressure on the remote sender.
    --

    tcpEStatsPerfCurRwinSent  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The most recent window advertisement sent, in octets."
        REFERENCE
           "RFC 793, Transmission Control Protocol"
        ::= { tcpEStatsPerfEntry 23 }

    tcpEStatsPerfMaxRwinSent  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The maximum window advertisement sent, in octets."
        REFERENCE
           "RFC 793, Transmission Control Protocol"
        ::= { tcpEStatsPerfEntry 24 }

    tcpEStatsPerfZeroRwinSent  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of acknowledgments sent announcing a zero
```

```
            receive window, when the previously announced window was
            not zero."
        REFERENCE
           "RFC 793, Transmission Control Protocol"
        ::= { tcpEStatsPerfEntry 25 }

    --
    --  The following objects instrument receiver window updates
    --  from the far end-system to determine if the remote receiver
    --  has sufficient buffer space or is exerting flow-control
    --  back pressure on the local sender.
    --

    tcpEStatsPerfCurRwinRcvd  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The most recent window advertisement received, in octets."
        REFERENCE
           "RFC 793, Transmission Control Protocol"
        ::= { tcpEStatsPerfEntry 26 }

    tcpEStatsPerfMaxRwinRcvd  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The maximum window advertisement received, in octets."
        REFERENCE
           "RFC 793, Transmission Control Protocol"
        ::= { tcpEStatsPerfEntry 27 }

    tcpEStatsPerfZeroRwinRcvd  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of acknowledgments received announcing a zero
            receive window, when the previously announced window was
            not zero."
        REFERENCE
           "RFC 793, Transmission Control Protocol"
        ::= { tcpEStatsPerfEntry 28 }

    --
```

```
   --  The following optional objects can be used to quickly
   --  identify which subsystems are limiting TCP performance.
   --  There are three parallel pairs of instruments that measure
   --  the extent to which TCP performance is limited by the
   --  announced receiver window (indicating a receiver
   --  bottleneck), the current congestion window or
   --  retransmission timeout (indicating a path bottleneck) and
   --  all others events (indicating a sender bottleneck).
   --
   --  These instruments SHOULD be updated every time the TCP
   --  output routine stops sending data.  The elapsed time since
   --  the previous stop is accumulated into the appropriate
   --  object as determined by the previous stop reason (e.g.,
   --  stop state).  The current stop reason determines which timer
   --  will be updated the next time TCP output stops.
   --
   --  Since there is no explicit stop at the beginning of a
   --  timeout, it is necessary to retroactively reclassify the
   --  previous stop as 'Congestion Limited'.
   --

   tcpEStatsPerfSndLimTransRwin  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter32
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The number of transitions into the 'Receiver Limited' state
           from either the 'Congestion Limited' or 'Sender Limited'
           states.  This state is entered whenever TCP transmission
           stops because the sender has filled the announced receiver
           window, i.e., when SND.NXT has advanced to SND.UNA +
           SND.WND - 1 as described in RFC 793."
       REFERENCE
          "RFC 793, Transmission Control Protocol"
       ::= { tcpEStatsPerfEntry 31 }

   tcpEStatsPerfSndLimTransCwnd  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter32
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The number of transitions into the 'Congestion Limited'
           state from either the 'Receiver Limited' or 'Sender
           Limited' states.  This state is entered whenever TCP
           transmission stops because the sender has reached some
           limit defined by congestion control (e.g., cwnd) or other
           algorithms (retransmission timeouts) designed to control
           network traffic.  See the definition of 'CONGESTION WINDOW'
```

```
            in RFC 2581."
        REFERENCE
           "RFC 2581, TCP Congestion Control"
        ::= { tcpEStatsPerfEntry 32 }

    tcpEStatsPerfSndLimTransSnd  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of transitions into the 'Sender Limited' state
            from either the 'Receiver Limited' or 'Congestion Limited'
            states.  This state is entered whenever TCP transmission
            stops due to some sender limit such as running out of
            application data or other resources and the Karn algorithm.
            When TCP stops sending data for any reason, which cannot be
            classified as Receiver Limited or Congestion Limited, it
            MUST be treated as Sender Limited."
        ::= { tcpEStatsPerfEntry 33 }

    tcpEStatsPerfSndLimTimeRwin  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        UNITS           "milliseconds"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The cumulative time spent in the 'Receiver Limited' state.
            See tcpEStatsPerfSndLimTransRwin."
        ::= { tcpEStatsPerfEntry 34 }

    tcpEStatsPerfSndLimTimeCwnd  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        UNITS           "milliseconds"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The cumulative time spent in the 'Congestion Limited'
            state.  See tcpEStatsPerfSndLimTransCwnd.  When there is a
            retransmission timeout, it SHOULD be counted in
            tcpEStatsPerfSndLimTimeCwnd (and not the cumulative time
            for some other state.)"
        ::= { tcpEStatsPerfEntry 35 }

    tcpEStatsPerfSndLimTimeSnd  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        UNITS           "milliseconds"
        MAX-ACCESS      read-only
        STATUS          current
```

```
        DESCRIPTION
           "The cumulative time spent in the 'Sender Limited' state.
            See tcpEStatsPerfSndLimTransSnd."
        ::= { tcpEStatsPerfEntry 36 }

    -- ================================================================
    --
    -- Statistics for diagnosing path problems
    --

    tcpEStatsPathTable    OBJECT-TYPE
        SYNTAX      SEQUENCE OF TcpEStatsPathEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "This table contains objects that can be used to infer
            detailed behavior of the Internet path, such as the
            extent that there is reordering, ECN bits, and if
            RTT fluctuations are correlated to losses.

            Entries are retained in this table for the number of
            seconds indicated by the tcpEStatsConnTableLatency
            object, after the TCP connection first enters the closed
            state."
        ::= { tcpEStats 4 }

    tcpEStatsPathEntry  OBJECT-TYPE
        SYNTAX       TcpEStatsPathEntry
        MAX-ACCESS   not-accessible
        STATUS       current
        DESCRIPTION
            "Each entry in this table has information about the
            characteristics of each active and recently closed TCP
            connection."
       INDEX { tcpEStatsConnectIndex }
       ::= { tcpEStatsPathTable 1 }

    TcpEStatsPathEntry ::= SEQUENCE {

            tcpEStatsPathRetranThresh           Gauge32,
            tcpEStatsPathNonRecovDAEpisodes     ZeroBasedCounter32,
            tcpEStatsPathSumOctetsReordered     ZeroBasedCounter32,
            tcpEStatsPathNonRecovDA             ZeroBasedCounter32,
            tcpEStatsPathSampleRTT              Gauge32,
            tcpEStatsPathRTTVar                 Gauge32,
            tcpEStatsPathMaxRTT                 Gauge32,
            tcpEStatsPathMinRTT                 Gauge32,
            tcpEStatsPathSumRTT                 ZeroBasedCounter32,
```

```
            tcpEStatsPathHCSumRTT               ZeroBasedCounter64,
            tcpEStatsPathCountRTT               ZeroBasedCounter32,
            tcpEStatsPathMaxRTO                 Gauge32,
            tcpEStatsPathMinRTO                 Gauge32,
            tcpEStatsPathIpTtl                  Unsigned32,
            tcpEStatsPathIpTosIn                OCTET STRING,
            tcpEStatsPathIpTosOut               OCTET STRING,
            tcpEStatsPathPreCongSumCwnd         ZeroBasedCounter32,
            tcpEStatsPathPreCongSumRTT          ZeroBasedCounter32,
            tcpEStatsPathPostCongSumRTT         ZeroBasedCounter32,
            tcpEStatsPathPostCongCountRTT       ZeroBasedCounter32,
            tcpEStatsPathECNsignals             ZeroBasedCounter32,
            tcpEStatsPathDupAckEpisodes         ZeroBasedCounter32,
            tcpEStatsPathRcvRTT                 Gauge32,
            tcpEStatsPathDupAcksOut             ZeroBasedCounter32,
            tcpEStatsPathCERcvd                 ZeroBasedCounter32,
            tcpEStatsPathECESent                ZeroBasedCounter32
        }

    --
    --  The following optional objects can be used to infer segment
    --  reordering on the path from the local sender to the remote
    --  receiver.
    --

    tcpEStatsPathRetranThresh  OBJECT-TYPE
        SYNTAX          Gauge32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of duplicate acknowledgments required to trigger
            Fast Retransmit.  Note that although this is constant in
            traditional Reno TCP implementations, it is adaptive in
            many newer TCPs."
        REFERENCE
           "RFC 2581, TCP Congestion Control"
        ::= { tcpEStatsPathEntry 1 }

    tcpEStatsPathNonRecovDAEpisodes  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of duplicate acknowledgment episodes that did
            not trigger a Fast Retransmit because ACK advanced prior to
            the number of duplicate acknowledgments reaching
            RetranThresh.
```

```
            In many implementations this is the number of times the
            'dupacks' counter is set to zero when it is non-zero but
            less than RetranThresh.

            Note that the change in tcpEStatsPathNonRecovDAEpisodes
            divided by the change in tcpEStatsPerfDataSegsOut is an
            estimate of the frequency of data reordering on the forward
            path over some interval."
        REFERENCE
           "RFC 2581, TCP Congestion Control"
        ::= { tcpEStatsPathEntry 2 }

    tcpEStatsPathSumOctetsReordered  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The sum of the amounts SND.UNA advances on the
            acknowledgment which ends a dup-ack episode without a
            retransmission.

            Note the change in tcpEStatsPathSumOctetsReordered divided
            by the change in tcpEStatsPathNonRecovDAEpisodes is an
            estimates of the average reordering distance, over some
            interval."
        ::= { tcpEStatsPathEntry 3 }

    tcpEStatsPathNonRecovDA  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "Duplicate acks (or SACKS) that did not trigger a Fast
            Retransmit because ACK advanced prior to the number of
            duplicate acknowledgments reaching RetranThresh.

            In many implementations, this is the sum of the 'dupacks'
            counter, just before it is set to zero because ACK advanced
            without a Fast Retransmit.

            Note that the change in tcpEStatsPathNonRecovDA divided by
            the change in tcpEStatsPathNonRecovDAEpisodes is an
            estimate of the average reordering distance in segments
            over some interval."
        REFERENCE
           "RFC 2581, TCP Congestion Control"
        ::= { tcpEStatsPathEntry 4 }
```

```
   --
   --  The following optional objects instrument the round trip
   --  time estimator and the retransmission timeout timer.
   --

   tcpEStatsPathSampleRTT  OBJECT-TYPE
       SYNTAX          Gauge32
       UNITS           "milliseconds"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The most recent raw round trip time measurement used in
           calculation of the RTO."
       REFERENCE
          "RFC 2988, Computing TCP's Retransmission Timer"
       ::= { tcpEStatsPathEntry 11 }

   tcpEStatsPathRTTVar  OBJECT-TYPE
       SYNTAX          Gauge32
       UNITS           "milliseconds"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The round trip time variation used in calculation of the
           RTO.  See RTTVAR in [RFC2988]."
       REFERENCE
          "RFC 2988, Computing TCP's Retransmission Timer"
       ::= { tcpEStatsPathEntry 12 }

   tcpEStatsPathMaxRTT  OBJECT-TYPE
       SYNTAX          Gauge32
       UNITS           "milliseconds"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The maximum sampled round trip time."
       REFERENCE
          "RFC 2988, Computing TCP's Retransmission Timer"
       ::= { tcpEStatsPathEntry 13 }

   tcpEStatsPathMinRTT  OBJECT-TYPE
       SYNTAX          Gauge32
       UNITS           "milliseconds"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The minimum sampled round trip time."
       REFERENCE
```

```
          "RFC 2988, Computing TCP's Retransmission Timer"
       ::= { tcpEStatsPathEntry 14 }

   tcpEStatsPathSumRTT  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter32
       UNITS           "milliseconds"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The sum of all sampled round trip times.

           Note that the change in tcpEStatsPathSumRTT divided by the
           change in tcpEStatsPathCountRTT is the mean RTT, uniformly
           averaged over an enter interval."
       REFERENCE
          "RFC 2988, Computing TCP's Retransmission Timer"
       ::= { tcpEStatsPathEntry 15 }

   tcpEStatsPathHCSumRTT  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter64
       UNITS           "milliseconds"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The sum of all sampled round trip times, on all systems
           that implement multiple concurrent RTT measurements.

           Note that the change in tcpEStatsPathHCSumRTT divided by
           the change in tcpEStatsPathCountRTT is the mean RTT,
           uniformly averaged over an enter interval."
       REFERENCE
          "RFC 2988, Computing TCP's Retransmission Timer"
       ::= { tcpEStatsPathEntry 16 }

   tcpEStatsPathCountRTT  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter32
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The number of round trip time samples included in
           tcpEStatsPathSumRTT and tcpEStatsPathHCSumRTT."
       REFERENCE
          "RFC 2988, Computing TCP's Retransmission Timer"
       ::= { tcpEStatsPathEntry 17 }

   tcpEStatsPathMaxRTO  OBJECT-TYPE
       SYNTAX          Gauge32
       UNITS           "milliseconds"
```

```
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The maximum value of the retransmit timer RTO."
        REFERENCE
           "RFC 2988, Computing TCP's Retransmission Timer"
        ::= { tcpEStatsPathEntry 18 }

    tcpEStatsPathMinRTO  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "milliseconds"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The minimum value of the retransmit timer RTO."
        REFERENCE
           "RFC 2988, Computing TCP's Retransmission Timer"
        ::= { tcpEStatsPathEntry 19 }

    --
    --  The following optional objects provide information about
    --  how TCP is using the IP layer.
    --

    tcpEStatsPathIpTtl  OBJECT-TYPE
        SYNTAX          Unsigned32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The value of the TTL field carried in the most recently
            received IP header.  This is sometimes useful to detect
            changing or unstable routes."
        REFERENCE
           "RFC 791, Internet Protocol"
        ::= { tcpEStatsPathEntry 20 }

    tcpEStatsPathIpTosIn  OBJECT-TYPE
        SYNTAX          OCTET STRING (SIZE(1))
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The value of the IPv4 Type of Service octet, or the IPv6
            traffic class octet, carried in the most recently received
            IP header.

            This is useful to diagnose interactions between TCP and any
            IP layer packet scheduling and delivery policy, which might
            be in effect to implement Diffserv."
```

```
        REFERENCE
           "RFC 3260, New Terminology and Clarifications for Diffserv"
        ::= { tcpEStatsPathEntry 21 }

    tcpEStatsPathIpTosOut  OBJECT-TYPE
        SYNTAX          OCTET STRING (SIZE(1))
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The value of the IPv4 Type Of Service octet, or the IPv6
            traffic class octet, carried in the most recently
            transmitted IP header.

            This is useful to diagnose interactions between TCP and any
            IP layer packet scheduling and delivery policy, which might
            be in effect to implement Diffserv."
        REFERENCE
           "RFC 3260, New Terminology and Clarifications for Diffserv"
        ::= { tcpEStatsPathEntry 22 }

    --
    --  The following optional objects characterize the congestion
    --  feedback signals by collecting statistics on how the
    --  congestion events are correlated to losses, changes in RTT
    --  and other protocol events.
    --

    tcpEStatsPathPreCongSumCwnd  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The sum of the values of the congestion window, in octets,
            captured each time a congestion signal is received.  This
            MUST be updated each time tcpEStatsPerfCongSignals is
            incremented, such that the change in
            tcpEStatsPathPreCongSumCwnd divided by the change in
            tcpEStatsPerfCongSignals is the average window (over some
            interval) just prior to a congestion signal."
        ::= { tcpEStatsPathEntry 23 }

    tcpEStatsPathPreCongSumRTT  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        UNITS           "milliseconds"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
```

```
            "Sum of the last sample of the RTT (tcpEStatsPathSampleRTT)
             prior to the received congestion signals.  This MUST be
             updated each time tcpEStatsPerfCongSignals is incremented,
             such that the change in tcpEStatsPathPreCongSumRTT divided by
             the change in tcpEStatsPerfCongSignals is the average RTT
             (over some interval) just prior to a congestion signal."
         ::= { tcpEStatsPathEntry 24 }

    tcpEStatsPathPostCongSumRTT  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "Sum of the first sample of the RTT (tcpEStatsPathSampleRTT)
            following each congestion signal.  Such that the change in
            tcpEStatsPathPostCongSumRTT divided by the change in
            tcpEStatsPathPostCongCountRTT is the average RTT (over some
            interval) just after a congestion signal."
        ::= { tcpEStatsPathEntry 25 }

    tcpEStatsPathPostCongCountRTT  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        UNITS           "milliseconds"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of RTT samples included in
            tcpEStatsPathPostCongSumRTT such that the change in
            tcpEStatsPathPostCongSumRTT divided by the change in
            tcpEStatsPathPostCongCountRTT is the average RTT (over some
            interval) just after a congestion signal."
        ::= { tcpEStatsPathEntry 26 }

    --
    --  The following optional objects can be used to detect other
    --  types of non-loss congestion signals such as source quench
    --  or ECN.
    --

    tcpEStatsPathECNsignals  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of congestion signals delivered to the TCP
            sender via explicit congestion notification (ECN).  This is
            typically the number of segments bearing Echo Congestion
```

```
            Experienced (ECE) bits, but
            should also include segments failing the ECN nonce check or
            other explicit congestion signals."
        REFERENCE
           "RFC 3168, The Addition of Explicit Congestion Notification
            (ECN) to IP"
        ::= { tcpEStatsPathEntry 27 }

    --
    --  The following optional objects are receiver side
    --  instruments of the path from the sender to the receiver.  In
    --  general, the receiver has less information about the state
    --  of the path because the receiver does not have a robust
    --  mechanism to infer the sender's actions.
    --

    tcpEStatsPathDupAckEpisodes  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of Duplicate Acks Sent when prior Ack was not
            duplicate.  This is the number of times that a contiguous
            series of duplicate acknowledgments have been sent.

            This is an indication of the number of data segments lost
            or reordered on the path from the remote TCP endpoint to
            the near TCP endpoint."
        REFERENCE
           "RFC 2581, TCP Congestion Control"
        ::= { tcpEStatsPathEntry 28 }

    tcpEStatsPathRcvRTT  OBJECT-TYPE
        SYNTAX          Gauge32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The receiver's estimate of the Path RTT.

            Adaptive receiver window algorithms depend on the receiver
            to having a good estimate of the path RTT."
        ::= { tcpEStatsPathEntry 29 }

    tcpEStatsPathDupAcksOut  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
```

```
            "The number of duplicate ACKs sent.  The ratio of the change
             in tcpEStatsPathDupAcksOut to the change in
             tcpEStatsPathDupAckEpisodes is an indication of reorder or
             recovery distance over some interval."
        REFERENCE
           "RFC 2581, TCP Congestion Control"
        ::= { tcpEStatsPathEntry 30 }

    tcpEStatsPathCERcvd  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of segments received with IP headers bearing
            Congestion Experienced (CE) markings."
        REFERENCE
           "RFC 3168, The Addition of Explicit Congestion Notification
            (ECN) to IP"
        ::= { tcpEStatsPathEntry 31 }

    tcpEStatsPathECESent  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "Number of times the Echo Congestion Experienced (ECE) bit
            in the TCP header has been set (transitioned from 0 to 1),
            due to a Congestion Experienced (CE) marking on an IP
            header.  Note that ECE can be set and reset only once per
            RTT, while CE can be set on many segments per RTT."
        REFERENCE
           "RFC 3168, The Addition of Explicit Congestion Notification
            (ECN) to IP"
        ::= { tcpEStatsPathEntry 32 }

    -- ================================================================
    --
    -- Statistics for diagnosing stack algorithms
    --

    tcpEStatsStackTable    OBJECT-TYPE
        SYNTAX      SEQUENCE OF TcpEStatsStackEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "This table contains objects that are most useful for
            determining how well some of the TCP control
            algorithms are coping with this particular
```

```
            path.

            Entries are retained in this table for the number of
            seconds indicated by the tcpEStatsConnTableLatency
            object, after the TCP connection first enters the closed
            state."
        ::= { tcpEStats 5 }

    tcpEStatsStackEntry  OBJECT-TYPE
        SYNTAX       TcpEStatsStackEntry
        MAX-ACCESS   not-accessible
        STATUS       current
        DESCRIPTION
            "Each entry in this table has information about the
            characteristics of each active and recently closed TCP
            connection."
       INDEX { tcpEStatsConnectIndex }
       ::= { tcpEStatsStackTable 1 }

    TcpEStatsStackEntry ::= SEQUENCE {

            tcpEStatsStackActiveOpen            TruthValue,
            tcpEStatsStackMSSSent               Unsigned32,
            tcpEStatsStackMSSRcvd               Unsigned32,
            tcpEStatsStackWinScaleSent          Integer32,
            tcpEStatsStackWinScaleRcvd          Integer32,
            tcpEStatsStackTimeStamps            TcpEStatsNegotiated,
            tcpEStatsStackECN                   TcpEStatsNegotiated,
            tcpEStatsStackWillSendSACK          TcpEStatsNegotiated,
            tcpEStatsStackWillUseSACK           TcpEStatsNegotiated,
            tcpEStatsStackState                 INTEGER,
            tcpEStatsStackNagle                 TruthValue,
            tcpEStatsStackMaxSsCwnd             Gauge32,
            tcpEStatsStackMaxCaCwnd             Gauge32,
            tcpEStatsStackMaxSsthresh           Gauge32,
            tcpEStatsStackMinSsthresh           Gauge32,
            tcpEStatsStackInRecovery            INTEGER,
            tcpEStatsStackDupAcksIn             ZeroBasedCounter32,
            tcpEStatsStackSpuriousFrDetected    ZeroBasedCounter32,
            tcpEStatsStackSpuriousRtoDetected   ZeroBasedCounter32,
            tcpEStatsStackSoftErrors            ZeroBasedCounter32,
            tcpEStatsStackSoftErrorReason       INTEGER,
            tcpEStatsStackSlowStart             ZeroBasedCounter32,
            tcpEStatsStackCongAvoid             ZeroBasedCounter32,
            tcpEStatsStackOtherReductions       ZeroBasedCounter32,
            tcpEStatsStackCongOverCount         ZeroBasedCounter32,
            tcpEStatsStackFastRetran            ZeroBasedCounter32,
            tcpEStatsStackSubsequentTimeouts    ZeroBasedCounter32,
```

```
            tcpEStatsStackCurTimeoutCount       Gauge32,
            tcpEStatsStackAbruptTimeouts        ZeroBasedCounter32,
            tcpEStatsStackSACKsRcvd             ZeroBasedCounter32,
            tcpEStatsStackSACKBlocksRcvd        ZeroBasedCounter32,
            tcpEStatsStackSendStall             ZeroBasedCounter32,
            tcpEStatsStackDSACKDups             ZeroBasedCounter32,
            tcpEStatsStackMaxMSS                Gauge32,
            tcpEStatsStackMinMSS                Gauge32,
            tcpEStatsStackSndInitial            Unsigned32,
            tcpEStatsStackRecInitial            Unsigned32,
            tcpEStatsStackCurRetxQueue          Gauge32,
            tcpEStatsStackMaxRetxQueue          Gauge32,
            tcpEStatsStackCurReasmQueue         Gauge32,
            tcpEStatsStackMaxReasmQueue         Gauge32
        }

    --
    --  The following objects reflect TCP options carried on the
    --  SYN or SYN-ACK.  These options are used to provide
    --  additional protocol parameters or to enable various
    --  optional TCP features or algorithms.
    --
    --  Except as noted, the TCP protocol does not permit these
    --  options to change after the SYN exchange.
    --

    tcpEStatsStackActiveOpen  OBJECT-TYPE
        SYNTAX          TruthValue
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "True(1) if the local connection traversed the SYN-SENT
            state, else false(2)."
        REFERENCE
           "RFC 793, Transmission Control Protocol"
        ::= { tcpEStatsStackEntry 1 }

    tcpEStatsStackMSSSent  OBJECT-TYPE
        SYNTAX          Unsigned32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The value sent in an MSS option, or zero if none."
        REFERENCE
           "RFC 1122, Requirements for Internet Hosts - Communication
            Layers"
        ::= { tcpEStatsStackEntry 2 }
```

```
   tcpEStatsStackMSSRcvd  OBJECT-TYPE
       SYNTAX          Unsigned32
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The value received in an MSS option, or zero if none."
       REFERENCE
          "RFC 1122, Requirements for Internet Hosts - Communication
           Layers"
       ::= { tcpEStatsStackEntry 3 }

   tcpEStatsStackWinScaleSent  OBJECT-TYPE
       SYNTAX          Integer32 (-1..14)
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The value of the transmitted window scale option if one was
           sent; otherwise, a value of -1.

           Note that if both tcpEStatsStackWinScaleSent and
           tcpEStatsStackWinScaleRcvd are not -1, then Rcv.Wind.Scale
           will be the same as this value and used to scale receiver
           window announcements from the local host to the remote
           host."
       REFERENCE
          "RFC 1323, TCP Extensions for High Performance"
       ::= { tcpEStatsStackEntry 4 }

   tcpEStatsStackWinScaleRcvd  OBJECT-TYPE
       SYNTAX          Integer32 (-1..14)
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The value of the received window scale option if one was
           received; otherwise, a value of -1.

           Note that if both tcpEStatsStackWinScaleSent and
           tcpEStatsStackWinScaleRcvd are not -1, then Snd.Wind.Scale
           will be the same as this value and used to scale receiver
           window announcements from the remote host to the local
           host."
       REFERENCE
          "RFC 1323, TCP Extensions for High Performance"
       ::= { tcpEStatsStackEntry 5 }

   tcpEStatsStackTimeStamps  OBJECT-TYPE
       SYNTAX          TcpEStatsNegotiated
       MAX-ACCESS      read-only
```

```
        STATUS          current
        DESCRIPTION
           "Enabled(1) if TCP timestamps have been negotiated on,
            selfDisabled(2) if they are disabled or not implemented on
            the local host, or peerDisabled(3) if not negotiated by the
            remote hosts."
        REFERENCE
           "RFC 1323, TCP Extensions for High Performance"
        ::= { tcpEStatsStackEntry 6 }

    tcpEStatsStackECN  OBJECT-TYPE
        SYNTAX          TcpEStatsNegotiated
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "Enabled(1) if Explicit Congestion Notification (ECN) has
            been negotiated on, selfDisabled(2) if it is disabled or
            not implemented on the local host, or peerDisabled(3) if
            not negotiated by the remote hosts."
        REFERENCE
           "RFC 3168, The Addition of Explicit Congestion Notification
            (ECN) to IP"
        ::= { tcpEStatsStackEntry 7 }

    tcpEStatsStackWillSendSACK  OBJECT-TYPE
        SYNTAX          TcpEStatsNegotiated
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "Enabled(1) if the local host will send SACK options,
            selfDisabled(2) if SACK is disabled or not implemented on
            the local host, or peerDisabled(3) if the remote host did
            not send the SACK-permitted option.

            Note that SACK negotiation is not symmetrical.  SACK can
            enabled on one side of the connection and not the other."
        REFERENCE
           "RFC 2018, TCP Selective Acknowledgement Options"
        ::= { tcpEStatsStackEntry 8 }

    tcpEStatsStackWillUseSACK  OBJECT-TYPE
        SYNTAX          TcpEStatsNegotiated
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "Enabled(1) if the local host will process SACK options,
            selfDisabled(2) if SACK is disabled or not implemented on
            the local host, or peerDisabled(3) if the remote host sends
```

```
            duplicate ACKs without SACK options, or the local host
            otherwise decides not to process received SACK options.

            Unlike other TCP options, the remote data receiver cannot
            explicitly indicate if it is able to generate SACK options.
            When sending data, the local host has to deduce if the
            remote receiver is sending SACK options.  This object can
            transition from Enabled(1) to peerDisabled(3) after the SYN
            exchange.

            Note that SACK negotiation is not symmetrical.  SACK can
            enabled on one side of the connection and not the other."
        REFERENCE
           "RFC 2018, TCP Selective Acknowledgement Options"
        ::= { tcpEStatsStackEntry 9 }

    --
    --  The following two objects reflect the current state of the
    --  connection.
    --

    tcpEStatsStackState  OBJECT-TYPE
        SYNTAX          INTEGER {
           tcpESStateClosed(1),
           tcpESStateListen(2),
           tcpESStateSynSent(3),
           tcpESStateSynReceived(4),
           tcpESStateEstablished(5),
           tcpESStateFinWait1(6),
           tcpESStateFinWait2(7),
           tcpESStateCloseWait(8),
           tcpESStateLastAck(9),
           tcpESStateClosing(10),
           tcpESStateTimeWait(11),
           tcpESStateDeleteTcb(12)
        }
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "An integer value representing the connection state from the
            TCP State Transition Diagram.

            The value listen(2) is included only for parallelism to the
            old tcpConnTable, and SHOULD NOT be used because the listen
            state in managed by the tcpListenerTable.

            The value DeleteTcb(12) is included only for parallelism to
            the tcpConnTable mechanism for terminating connections,
```

```
            although this table does not permit writing."
        REFERENCE
           "RFC 793, Transmission Control Protocol"
        ::= { tcpEStatsStackEntry 10 }

    tcpEStatsStackNagle  OBJECT-TYPE
        SYNTAX          TruthValue
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "True(1) if the Nagle algorithm is being used, else
            false(2)."
        REFERENCE
           "RFC 1122, Requirements for Internet Hosts - Communication
            Layers"
        ::= { tcpEStatsStackEntry 11 }

    --
    --  The following objects instrument the overall operation of
    --  TCP congestion control and data retransmissions.  These
    --  instruments are sufficient to fit the actual performance to
    --  an updated macroscopic performance model [RFC2581] [Mat97]
    --  [Pad98].
    --

    tcpEStatsStackMaxSsCwnd  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The maximum congestion window used during Slow Start, in
            octets."
        REFERENCE
           "RFC 2581, TCP Congestion Control"
        ::= { tcpEStatsStackEntry 12 }

    tcpEStatsStackMaxCaCwnd  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The maximum congestion window used during Congestion
            Avoidance, in octets."
        REFERENCE
           "RFC 2581, TCP Congestion Control"
        ::= { tcpEStatsStackEntry 13 }
```

```
   tcpEStatsStackMaxSsthresh  OBJECT-TYPE
       SYNTAX          Gauge32
       UNITS           "octets"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The maximum slow start threshold, excluding the initial
           value."
       REFERENCE
          "RFC 2581, TCP Congestion Control"
       ::= { tcpEStatsStackEntry 14 }

   tcpEStatsStackMinSsthresh  OBJECT-TYPE
       SYNTAX          Gauge32
       UNITS           "octets"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The minimum slow start threshold."
       REFERENCE
          "RFC 2581, TCP Congestion Control"
       ::= { tcpEStatsStackEntry 15 }

   tcpEStatsStackInRecovery  OBJECT-TYPE
       SYNTAX          INTEGER {
          tcpESDataContiguous(1),
          tcpESDataUnordered(2),
          tcpESDataRecovery(3)
       }
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "An integer value representing the state of the loss
           recovery for this connection.

           tcpESDataContiguous(1) indicates that the remote receiver
           is reporting contiguous data (no duplicate acknowledgments
           or SACK options) and that there are no unacknowledged
           retransmissions.

           tcpESDataUnordered(2) indicates that the remote receiver is
           reporting missing or out-of-order data (e.g., sending
           duplicate acknowledgments or SACK options) and that there
           are no unacknowledged retransmissions (because the missing
           data has not yet been retransmitted).

           tcpESDataRecovery(3) indicates that the sender has
           outstanding retransmitted data that is still
```

```
            unacknowledged."
        REFERENCE
           "RFC 2581, TCP Congestion Control"
        ::= { tcpEStatsStackEntry 16 }

    tcpEStatsStackDupAcksIn  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of duplicate ACKs received."
        REFERENCE
           "RFC 2581, TCP Congestion Control"
        ::= { tcpEStatsStackEntry 17 }

    tcpEStatsStackSpuriousFrDetected  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of acknowledgments reporting out-of-order
            segments after the Fast Retransmit algorithm has already
            retransmitted the segments. (For example as detected by the
            Eifel algorithm).'"
        REFERENCE
           "RFC 3522, The Eifel Detection Algorithm for TCP"
        ::= { tcpEStatsStackEntry 18 }

    tcpEStatsStackSpuriousRtoDetected  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of acknowledgments reporting segments that have
            already been retransmitted due to a Retransmission Timeout."
        ::= { tcpEStatsStackEntry 19 }

    --
    --  The following optional objects instrument unusual protocol
    --  events that probably indicate implementation problems in
    --  the protocol or path.
    --

    tcpEStatsStackSoftErrors  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
```

```
          "The number of segments that fail various consistency tests
           during TCP input processing.  Soft errors might cause the
           segment to be discarded but some do not.  Some of these soft
           errors cause the generation of a TCP acknowledgment, while
           others are silently discarded."
       REFERENCE
          "RFC 793, Transmission Control Protocol"
       ::= { tcpEStatsStackEntry 21 }

   tcpEStatsStackSoftErrorReason  OBJECT-TYPE
       SYNTAX          INTEGER {
          belowDataWindow(1),
          aboveDataWindow(2),
          belowAckWindow(3),
          aboveAckWindow(4),
          belowTSWindow(5),
          aboveTSWindow(6),
          dataCheckSum(7),
          otherSoftError(8)
       }
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "This object identifies which consistency test most recently
           failed during TCP input processing.  This object SHOULD be
           set every time tcpEStatsStackSoftErrors is incremented.  The
           codes are as follows:

           belowDataWindow(1) - All data in the segment is below
           SND.UNA. (Normal for keep-alives and zero window probes).

           aboveDataWindow(2) - Some data in the segment is above
           SND.WND. (Indicates an implementation bug or possible
           attack).

           belowAckWindow(3) - ACK below SND.UNA. (Indicates that the
           return path is reordering ACKs)

           aboveAckWindow(4) - An ACK for data that we have not sent.
           (Indicates an implementation bug or possible attack).

           belowTSWindow(5) - TSecr on the segment is older than the
           current TS.Recent (Normal for the rare case where PAWS
           detects data reordered by the network).

           aboveTSWindow(6) - TSecr on the segment is newer than the
           current TS.Recent. (Indicates an implementation bug or
           possible attack).
```

```
            dataCheckSum(7) - Incorrect checksum.  Note that this value
            is intrinsically fragile, because the header fields used to
            identify the connection may have been corrupted.

            otherSoftError(8) - All other soft errors not listed
            above."
        REFERENCE
           "RFC 793, Transmission Control Protocol"
        ::= { tcpEStatsStackEntry 22 }

    --
    --  The following optional objects expose the detailed
    --  operation of the congestion control algorithms.
    --

    tcpEStatsStackSlowStart  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of times the congestion window has been
            increased by the Slow Start algorithm."
        REFERENCE
           "RFC 2581, TCP Congestion Control"
        ::= { tcpEStatsStackEntry 23 }

    tcpEStatsStackCongAvoid  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of times the congestion window has been
            increased by the Congestion Avoidance algorithm."
        REFERENCE
           "RFC 2581, TCP Congestion Control"
        ::= { tcpEStatsStackEntry 24 }

    tcpEStatsStackOtherReductions  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of congestion window reductions made as a result
            of anything other than AIMD congestion control algorithms.
            Examples of non-multiplicative window reductions include
            Congestion Window Validation [RFC2861] and experimental
            algorithms such as Vegas [Bra94].
```

```
            All window reductions MUST be counted as either
            tcpEStatsPerfCongSignals or tcpEStatsStackOtherReductions."
        REFERENCE
           "RFC 2861, TCP Congestion Window Validation"
        ::= { tcpEStatsStackEntry 25 }

    tcpEStatsStackCongOverCount  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of congestion events that were 'backed out' of
            the congestion control state machine such that the
            congestion window was restored to a prior value.  This can
            happen due to the Eifel algorithm [RFC3522] or other
            algorithms that can be used to detect and cancel spurious
            invocations of the Fast Retransmit Algorithm.

            Although it may be feasible to undo the effects of spurious
            invocation of the Fast Retransmit congestion events cannot
            easily be backed out of tcpEStatsPerfCongSignals and
            tcpEStatsPathPreCongSumCwnd, etc."
        REFERENCE
           "RFC 3522, The Eifel Detection Algorithm for TCP"
        ::= { tcpEStatsStackEntry 26 }

    tcpEStatsStackFastRetran  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of invocations of the Fast Retransmit algorithm."
        REFERENCE
           "RFC 2581, TCP Congestion Control"
        ::= { tcpEStatsStackEntry 27 }

    tcpEStatsStackSubsequentTimeouts  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of times the retransmit timeout has expired after
            the RTO has been doubled.  See Section 5.5 of RFC 2988."
        REFERENCE
           "RFC 2988, Computing TCP's Retransmission Timer"
        ::= { tcpEStatsStackEntry 28 }
```

```
   tcpEStatsStackCurTimeoutCount  OBJECT-TYPE
       SYNTAX          Gauge32
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The current number of times the retransmit timeout has
           expired without receiving an acknowledgment for new data.
           tcpEStatsStackCurTimeoutCount is reset to zero when new
           data is acknowledged and incremented for each invocation of
           Section 5.5 of RFC 2988."
       REFERENCE
          "RFC 2988, Computing TCP's Retransmission Timer"
       ::= { tcpEStatsStackEntry 29 }

   tcpEStatsStackAbruptTimeouts  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter32
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The number of timeouts that occurred without any
           immediately preceding duplicate acknowledgments or other
           indications of congestion.  Abrupt Timeouts indicate that
           the path lost an entire window of data or acknowledgments.

           Timeouts that are preceded by duplicate acknowledgments or
           other congestion signals (e.g., ECN) are not counted as
           abrupt, and might have been avoided by a more sophisticated
           Fast Retransmit algorithm."
       REFERENCE
          "RFC 2581, TCP Congestion Control"
       ::= { tcpEStatsStackEntry 30 }

   tcpEStatsStackSACKsRcvd  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter32
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The number of SACK options received."
       REFERENCE
          "RFC 2018, TCP Selective Acknowledgement Options"
       ::= { tcpEStatsStackEntry 31 }

   tcpEStatsStackSACKBlocksRcvd  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter32
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The number of SACK blocks received (within SACK options)."
```

```
        REFERENCE
           "RFC 2018, TCP Selective Acknowledgement Options"
        ::= { tcpEStatsStackEntry 32 }

    tcpEStatsStackSendStall  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of interface stalls or other sender local
            resource limitations that are treated as congestion
            signals."
        ::= { tcpEStatsStackEntry 33 }

    tcpEStatsStackDSACKDups  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of duplicate segments reported to the local host
            by D-SACK blocks."
        REFERENCE
           "RFC 2883, An Extension to the Selective Acknowledgement
            (SACK) Option for TCP"
        ::= { tcpEStatsStackEntry 34 }

    --
    --  The following optional objects instrument path MTU
    --  discovery.
    --

    tcpEStatsStackMaxMSS  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The maximum MSS, in octets."
        REFERENCE
           "RFC 1191, Path MTU discovery"
        ::= { tcpEStatsStackEntry 35 }

    tcpEStatsStackMinMSS  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
```

```
            "The minimum MSS, in octets."
        REFERENCE
            "RFC 1191, Path MTU discovery"
        ::= { tcpEStatsStackEntry 36 }

    --
    --  The following optional initial value objects are useful for
    --  conformance testing instruments on application progress and
    --  consumed network resources.
    --

    tcpEStatsStackSndInitial  OBJECT-TYPE
        SYNTAX          Unsigned32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
            "Initial send sequence number.  Note that by definition
             tcpEStatsStackSndInitial never changes for a given
             connection."
        REFERENCE
            "RFC 793, Transmission Control Protocol"
        ::= { tcpEStatsStackEntry 37 }

    tcpEStatsStackRecInitial  OBJECT-TYPE
        SYNTAX          Unsigned32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
            "Initial receive sequence number.  Note that by definition
             tcpEStatsStackRecInitial never changes for a given
             connection."
        REFERENCE
            "RFC 793, Transmission Control Protocol"
        ::= { tcpEStatsStackEntry 38 }

    --
    --  The following optional objects instrument the senders
    --  buffer usage, including any buffering in the application
    --  interface to TCP and the retransmit queue.  All 'buffer
    --  memory' instruments are assumed to include OS data
    --  structure overhead.
    --

    tcpEStatsStackCurRetxQueue  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
```

```
        DESCRIPTION
           "The current number of octets of data occupying the
            retransmit queue."
        ::= { tcpEStatsStackEntry 39 }

    tcpEStatsStackMaxRetxQueue  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The maximum number of octets of data occupying the
            retransmit queue."
        ::= { tcpEStatsStackEntry 40 }

    tcpEStatsStackCurReasmQueue  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The current number of octets of sequence space spanned by
            the reassembly queue.  This is generally the difference
            between rcv.nxt and the sequence number of the right most
            edge of the reassembly queue."
        ::= { tcpEStatsStackEntry 41 }

    tcpEStatsStackMaxReasmQueue  OBJECT-TYPE
        SYNTAX          Gauge32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The maximum value of tcpEStatsStackCurReasmQueue"
        ::= { tcpEStatsStackEntry 42 }

    -- ================================================================
    --
    -- Statistics for diagnosing interactions between
    -- applications and TCP.
    --

    tcpEStatsAppTable    OBJECT-TYPE
        SYNTAX      SEQUENCE OF TcpEStatsAppEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "This table contains objects that are useful for
            determining if the application using TCP is
```

```
            limiting TCP performance.

            Entries are retained in this table for the number of
            seconds indicated by the tcpEStatsConnTableLatency
            object, after the TCP connection first enters the closed
            state."
        ::= { tcpEStats 6 }

    tcpEStatsAppEntry  OBJECT-TYPE
        SYNTAX       TcpEStatsAppEntry
        MAX-ACCESS   not-accessible
        STATUS       current
        DESCRIPTION
            "Each entry in this table has information about the
            characteristics of each active and recently closed TCP
            connection."
       INDEX { tcpEStatsConnectIndex }
       ::= { tcpEStatsAppTable 1 }

    TcpEStatsAppEntry ::= SEQUENCE {

            tcpEStatsAppSndUna                  Counter32,
            tcpEStatsAppSndNxt                  Unsigned32,
            tcpEStatsAppSndMax                  Counter32,
            tcpEStatsAppThruOctetsAcked         ZeroBasedCounter32,
            tcpEStatsAppHCThruOctetsAcked       ZeroBasedCounter64,
            tcpEStatsAppRcvNxt                  Counter32,
            tcpEStatsAppThruOctetsReceived      ZeroBasedCounter32,
            tcpEStatsAppHCThruOctetsReceived    ZeroBasedCounter64,
            tcpEStatsAppCurAppWQueue            Gauge32,
            tcpEStatsAppMaxAppWQueue            Gauge32,
            tcpEStatsAppCurAppRQueue            Gauge32,
            tcpEStatsAppMaxAppRQueue            Gauge32
        }

    --
    --  The following objects provide throughput statistics for the
    --  connection including sequence numbers and elapsed
    --  application data.  These permit direct observation of the
    --  applications progress, in terms of elapsed data delivery
    --  and elapsed time.
    --

    tcpEStatsAppSndUna  OBJECT-TYPE
        SYNTAX          Counter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
```

```
          "The value of SND.UNA, the oldest unacknowledged sequence
           number.

           Note that SND.UNA is a TCP state variable that is congruent
           to Counter32 semantics."
       REFERENCE
          "RFC 793, Transmission Control Protocol"
       ::= { tcpEStatsAppEntry 1 }

   tcpEStatsAppSndNxt  OBJECT-TYPE
       SYNTAX          Unsigned32
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The value of SND.NXT, the next sequence number to be sent.
           Note that tcpEStatsAppSndNxt is not monotonic (and thus not
           a counter) because TCP sometimes retransmits lost data by
           pulling tcpEStatsAppSndNxt back to the missing data."
       REFERENCE
          "RFC 793, Transmission Control Protocol"
       ::= { tcpEStatsAppEntry 2 }

   tcpEStatsAppSndMax  OBJECT-TYPE
       SYNTAX          Counter32
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The farthest forward (right most or largest) SND.NXT value.
           Note that this will be equal to tcpEStatsAppSndNxt except
           when tcpEStatsAppSndNxt is pulled back during recovery."
       REFERENCE
          "RFC 793, Transmission Control Protocol"
       ::= { tcpEStatsAppEntry 3 }

   tcpEStatsAppThruOctetsAcked  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter32
       UNITS           "octets"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The number of octets for which cumulative acknowledgments
           have been received.  Note that this will be the sum of
           changes to tcpEStatsAppSndUna."
       ::= { tcpEStatsAppEntry 4 }

   tcpEStatsAppHCThruOctetsAcked  OBJECT-TYPE
       SYNTAX          ZeroBasedCounter64
       UNITS           "octets"
```

```
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of octets for which cumulative acknowledgments
            have been received, on systems that can receive more than
            10 million bits per second.  Note that this will be the sum
            of changes in tcpEStatsAppSndUna."
        ::= { tcpEStatsAppEntry 5 }

    tcpEStatsAppRcvNxt  OBJECT-TYPE
        SYNTAX          Counter32
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The value of RCV.NXT.  The next sequence number expected on
            an incoming segment, and the left or lower edge of the
            receive window.

            Note that RCV.NXT is a TCP state variable that is congruent
            to Counter32 semantics."
        REFERENCE
           "RFC 793, Transmission Control Protocol"
        ::= { tcpEStatsAppEntry 6 }

    tcpEStatsAppThruOctetsReceived  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of octets for which cumulative acknowledgments
            have been sent.  Note that this will be the sum of changes
            to tcpEStatsAppRcvNxt."
        ::= { tcpEStatsAppEntry 7 }

    tcpEStatsAppHCThruOctetsReceived  OBJECT-TYPE
        SYNTAX          ZeroBasedCounter64
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The number of octets for which cumulative acknowledgments
            have been sent, on systems that can transmit more than 10
            million bits per second.  Note that this will be the sum of
            changes in tcpEStatsAppRcvNxt."
        ::= { tcpEStatsAppEntry 8 }

    tcpEStatsAppCurAppWQueue  OBJECT-TYPE
```

```
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The current number of octets of application data buffered
            by TCP, pending first transmission, i.e., to the left of
            SND.NXT or SndMax.  This data will generally be transmitted
            (and SND.NXT advanced to the left) as soon as there is an
            available congestion window (cwnd) or receiver window
            (rwin).  This is the amount of data readily available for
            transmission, without scheduling the application.  TCP
            performance may suffer if there is insufficient queued
            write data."
        ::= { tcpEStatsAppEntry 11 }

    tcpEStatsAppMaxAppWQueue  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The maximum number of octets of application data buffered
            by TCP, pending first transmission.  This is the maximum
            value of tcpEStatsAppCurAppWQueue.  This pair of objects can
            be used to determine if insufficient queued data is steady
            state (suggesting insufficient queue space) or transient
            (suggesting insufficient application performance or
            excessive CPU load or scheduler latency)."
        ::= { tcpEStatsAppEntry 12 }

    tcpEStatsAppCurAppRQueue  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "The current number of octets of application data that has
            been acknowledged by TCP but not yet delivered to the
            application."
        ::= { tcpEStatsAppEntry 13 }

    tcpEStatsAppMaxAppRQueue  OBJECT-TYPE
        SYNTAX          Gauge32
        UNITS           "octets"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
```

```
          "The maximum number of octets of application data that has
           been acknowledged by TCP but not yet delivered to the
           application."
       ::= { tcpEStatsAppEntry 14 }

   -- ================================================================
   --
   -- Controls for Tuning TCP
   --

   tcpEStatsTuneTable    OBJECT-TYPE
       SYNTAX      SEQUENCE OF TcpEStatsTuneEntry
       MAX-ACCESS  not-accessible
       STATUS      current
       DESCRIPTION
           "This table contains per-connection controls that can
           be used to work around a number of common problems that
           plague TCP over some paths.  All can be characterized as
           limiting the growth of the congestion window so as to
           prevent TCP from overwhelming some component in the
           path.

           Entries are retained in this table for the number of
           seconds indicated by the tcpEStatsConnTableLatency
           object, after the TCP connection first enters the closed
           state."
       ::= { tcpEStats 7 }

   tcpEStatsTuneEntry  OBJECT-TYPE
       SYNTAX       TcpEStatsTuneEntry
       MAX-ACCESS   not-accessible
       STATUS       current
       DESCRIPTION
           "Each entry in this table is a control that can be used to
           place limits on each active TCP connection."
      INDEX { tcpEStatsConnectIndex }
      ::= { tcpEStatsTuneTable 1 }

   TcpEStatsTuneEntry ::= SEQUENCE {

           tcpEStatsTuneLimCwnd                Unsigned32,
           tcpEStatsTuneLimSsthresh            Unsigned32,
           tcpEStatsTuneLimRwin                Unsigned32,
           tcpEStatsTuneLimMSS                 Unsigned32
       }

   tcpEStatsTuneLimCwnd  OBJECT-TYPE
       SYNTAX          Unsigned32
```

```
        UNITS           "octets"
        MAX-ACCESS      read-write
        STATUS          current
        DESCRIPTION
           "A control to set the maximum congestion window that may be
            used, in octets."
        REFERENCE
           "RFC 2581, TCP Congestion Control"
        ::= { tcpEStatsTuneEntry 1 }

    tcpEStatsTuneLimSsthresh  OBJECT-TYPE
        SYNTAX          Unsigned32
        UNITS           "octets"
        MAX-ACCESS      read-write
        STATUS          current
        DESCRIPTION
           "A control to limit the maximum queue space (in octets) that
            this TCP connection is likely to occupy during slowstart.

            It can be implemented with the algorithm described in
            RFC 3742 by setting the max_ssthresh parameter to twice
            tcpEStatsTuneLimSsthresh.

            This algorithm can be used to overcome some TCP performance
            problems over network paths that do not have sufficient
            buffering to withstand the bursts normally present during
            slowstart."
        REFERENCE
           "RFC 3742, Limited Slow-Start for TCP with Large Congestion
            Windows"
        ::= { tcpEStatsTuneEntry 2 }

    tcpEStatsTuneLimRwin  OBJECT-TYPE
        SYNTAX          Unsigned32
        UNITS           "octets"
        MAX-ACCESS      read-write
        STATUS          current
        DESCRIPTION
           "A control to set the maximum window advertisement that may
            be sent, in octets."
        REFERENCE
           "RFC 793, Transmission Control Protocol"
        ::= { tcpEStatsTuneEntry 3 }

    tcpEStatsTuneLimMSS  OBJECT-TYPE
        SYNTAX          Unsigned32
        UNITS           "octets"
        MAX-ACCESS      read-write
```

```
        STATUS          current
        DESCRIPTION
           "A control to limit the maximum segment size in octets, that
            this TCP connection can use."
        REFERENCE
           "RFC 1191, Path MTU discovery"
        ::= { tcpEStatsTuneEntry 4 }

    -- ================================================================
    --
    -- TCP Extended Statistics Notifications Group
    --

    tcpEStatsEstablishNotification NOTIFICATION-TYPE
        OBJECTS     {
                      tcpEStatsConnectIndex
                    }
        STATUS      current
        DESCRIPTION
            "The indicated connection has been accepted
            (or alternatively entered the established state)."
        ::= { tcpEStatsNotifications 1 }

    tcpEStatsCloseNotification NOTIFICATION-TYPE
        OBJECTS     {
                      tcpEStatsConnectIndex
                    }
        STATUS      current
        DESCRIPTION
            "The indicated connection has left the
            established state"
        ::= { tcpEStatsNotifications 2 }

    -- ================================================================
    --
    -- Conformance Definitions
    --

       tcpEStatsCompliances   OBJECT IDENTIFIER
            ::= { tcpEStatsConformance 1 }
       tcpEStatsGroups        OBJECT IDENTIFIER
            ::= { tcpEStatsConformance 2 }

    --
    -- Compliance Statements
    --

      tcpEStatsCompliance MODULE-COMPLIANCE
```

```
        STATUS current
        DESCRIPTION
            "Compliance statement for all systems that implement TCP
            extended statistics."
        MODULE -- this module
            MANDATORY-GROUPS {
                               tcpEStatsListenerGroup,
                               tcpEStatsConnectIdGroup,
                               tcpEStatsPerfGroup,
                               tcpEStatsPathGroup,
                               tcpEStatsStackGroup,
                               tcpEStatsAppGroup
                             }
            GROUP tcpEStatsListenerHCGroup
            DESCRIPTION
                "This group is mandatory for all systems that can
                 wrap the values of the 32-bit counters in
                 tcpEStatsListenerGroup in less than one hour."

            GROUP tcpEStatsPerfOptionalGroup
            DESCRIPTION
                "This group is optional for all systems."

            GROUP tcpEStatsPerfHCGroup
            DESCRIPTION
                "This group is mandatory for systems that can
                wrap the values of the 32-bit counters in
                tcpEStatsPerfGroup in less than one hour.

                Note that any system that can attain 10 Mb/s
                can potentially wrap 32-Bit Octet counters in
                under one hour."

            GROUP tcpEStatsPathOptionalGroup
            DESCRIPTION
                "This group is optional for all systems."

            GROUP tcpEStatsPathHCGroup
            DESCRIPTION
                "This group is mandatory for systems that can
                wrap the values of the 32-bit counters in
                tcpEStatsPathGroup in less than one hour.

                Note that any system that can attain 10 Mb/s
                can potentially wrap 32-Bit Octet counters in
                under one hour."

            GROUP tcpEStatsStackOptionalGroup
```

```
            DESCRIPTION
                "This group is optional for all systems."

            GROUP tcpEStatsAppHCGroup
            DESCRIPTION
                "This group is mandatory for systems that can
                wrap the values of the 32-bit counters in
                tcpEStatsStackGroup in less than one hour.

                Note that any system that can attain 10 Mb/s
                can potentially wrap 32-Bit Octet counters in
                under one hour."

            GROUP tcpEStatsAppOptionalGroup
            DESCRIPTION
                "This group is optional for all systems."

            GROUP tcpEStatsTuneOptionalGroup
            DESCRIPTION
                "This group is optional for all systems."

            GROUP tcpEStatsNotificationsGroup
            DESCRIPTION
                "This group is optional for all systems."

            GROUP tcpEStatsNotificationsCtlGroup
            DESCRIPTION
                "This group is mandatory for systems that include the
                 tcpEStatsNotificationGroup."

        ::= { tcpEStatsCompliances 1 }

    -- ================================================================
    --
    -- Units of Conformance
    --
        tcpEStatsListenerGroup  OBJECT-GROUP
            OBJECTS {
                 tcpEStatsListenerTableLastChange,
                 tcpEStatsListenerStartTime,
                 tcpEStatsListenerSynRcvd,
                 tcpEStatsListenerInitial,
                 tcpEStatsListenerEstablished,
                 tcpEStatsListenerAccepted,
                 tcpEStatsListenerExceedBacklog,
                 tcpEStatsListenerCurConns,
                 tcpEStatsListenerMaxBacklog,
                 tcpEStatsListenerCurBacklog,
```

```
                tcpEStatsListenerCurEstabBacklog
          }
          STATUS current
          DESCRIPTION
                "The tcpEStatsListener group includes objects that
                provide valuable statistics and debugging
                information for TCP Listeners."
        ::= { tcpEStatsGroups 1 }

      tcpEStatsListenerHCGroup  OBJECT-GROUP
          OBJECTS {
                tcpEStatsListenerHCSynRcvd,
                tcpEStatsListenerHCInitial,
                tcpEStatsListenerHCEstablished,
                tcpEStatsListenerHCAccepted,
                tcpEStatsListenerHCExceedBacklog
          }
          STATUS current
          DESCRIPTION
                "The tcpEStatsListenerHC group includes 64-bit
                 counters in tcpEStatsListenerTable."
        ::= { tcpEStatsGroups 2 }

      tcpEStatsConnectIdGroup  OBJECT-GROUP
          OBJECTS {
                tcpEStatsConnTableLatency,
                tcpEStatsConnectIndex
          }
          STATUS current
          DESCRIPTION
                "The tcpEStatsConnectId group includes objects that
                identify TCP connections and control how long TCP
                connection entries are retained in the tables."
        ::= { tcpEStatsGroups 3 }

      tcpEStatsPerfGroup  OBJECT-GROUP
          OBJECTS {
                tcpEStatsPerfSegsOut, tcpEStatsPerfDataSegsOut,
                tcpEStatsPerfDataOctetsOut,
                tcpEStatsPerfSegsRetrans,
                tcpEStatsPerfOctetsRetrans, tcpEStatsPerfSegsIn,
                tcpEStatsPerfDataSegsIn,
                tcpEStatsPerfDataOctetsIn,
                tcpEStatsPerfElapsedSecs,
                tcpEStatsPerfElapsedMicroSecs,
                tcpEStatsPerfStartTimeStamp, tcpEStatsPerfCurMSS,
                tcpEStatsPerfPipeSize, tcpEStatsPerfMaxPipeSize,
                tcpEStatsPerfSmoothedRTT, tcpEStatsPerfCurRTO,
```

```
                tcpEStatsPerfCongSignals, tcpEStatsPerfCurCwnd,
                tcpEStatsPerfCurSsthresh, tcpEStatsPerfTimeouts,
                tcpEStatsPerfCurRwinSent,
                tcpEStatsPerfMaxRwinSent,
                tcpEStatsPerfZeroRwinSent,
                tcpEStatsPerfCurRwinRcvd,
                tcpEStatsPerfMaxRwinRcvd,
                tcpEStatsPerfZeroRwinRcvd
           }
           STATUS current
           DESCRIPTION
                "The tcpEStatsPerf group includes those objects that
                provide basic performance data for a TCP connection."
      ::= { tcpEStatsGroups 4 }

    tcpEStatsPerfOptionalGroup  OBJECT-GROUP
           OBJECTS {
                tcpEStatsPerfSndLimTransRwin,
                tcpEStatsPerfSndLimTransCwnd,
                tcpEStatsPerfSndLimTransSnd,
                tcpEStatsPerfSndLimTimeRwin,
                tcpEStatsPerfSndLimTimeCwnd,
                tcpEStatsPerfSndLimTimeSnd
           }
           STATUS current
           DESCRIPTION
                "The tcpEStatsPerf group includes those objects that
                provide basic performance data for a TCP connection."
      ::= { tcpEStatsGroups 5 }

    tcpEStatsPerfHCGroup  OBJECT-GROUP
           OBJECTS {
                tcpEStatsPerfHCDataOctetsOut,
                tcpEStatsPerfHCDataOctetsIn
           }
           STATUS current
           DESCRIPTION
                "The tcpEStatsPerfHC group includes 64-bit
                counters in the tcpEStatsPerfTable."
      ::= { tcpEStatsGroups 6 }


    tcpEStatsPathGroup  OBJECT-GROUP
           OBJECTS {
                tcpEStatsControlPath,
                tcpEStatsPathRetranThresh,
                tcpEStatsPathNonRecovDAEpisodes,
                tcpEStatsPathSumOctetsReordered,
```

```
                tcpEStatsPathNonRecovDA
            }
            STATUS current
            DESCRIPTION
                "The tcpEStatsPath group includes objects that
                control the creation of the tcpEStatsPathTable,
                and provide information about the path
                for each TCP connection."
        ::= { tcpEStatsGroups 7 }

      tcpEStatsPathOptionalGroup  OBJECT-GROUP
            OBJECTS {
                tcpEStatsPathSampleRTT, tcpEStatsPathRTTVar,
                tcpEStatsPathMaxRTT, tcpEStatsPathMinRTT,
                tcpEStatsPathSumRTT, tcpEStatsPathCountRTT,
                tcpEStatsPathMaxRTO, tcpEStatsPathMinRTO,
                tcpEStatsPathIpTtl, tcpEStatsPathIpTosIn,
                tcpEStatsPathIpTosOut,
                tcpEStatsPathPreCongSumCwnd,
                tcpEStatsPathPreCongSumRTT,
                tcpEStatsPathPostCongSumRTT,
                tcpEStatsPathPostCongCountRTT,
                tcpEStatsPathECNsignals,
                tcpEStatsPathDupAckEpisodes, tcpEStatsPathRcvRTT,
                tcpEStatsPathDupAcksOut, tcpEStatsPathCERcvd,
                tcpEStatsPathECESent
            }
            STATUS current
            DESCRIPTION
                "The tcpEStatsPath group includes objects that
                provide additional information about the path
                for each TCP connection."
        ::= { tcpEStatsGroups 8 }

     tcpEStatsPathHCGroup  OBJECT-GROUP
            OBJECTS {
                tcpEStatsPathHCSumRTT
            }
            STATUS current
            DESCRIPTION
                "The tcpEStatsPathHC group includes 64-bit
                counters in the tcpEStatsPathTable."
        ::= { tcpEStatsGroups 9 }

      tcpEStatsStackGroup  OBJECT-GROUP
            OBJECTS {
                tcpEStatsControlStack,
                tcpEStatsStackActiveOpen, tcpEStatsStackMSSSent,
```

```
                tcpEStatsStackMSSRcvd, tcpEStatsStackWinScaleSent,
                tcpEStatsStackWinScaleRcvd,
                tcpEStatsStackTimeStamps, tcpEStatsStackECN,
                tcpEStatsStackWillSendSACK,
                tcpEStatsStackWillUseSACK, tcpEStatsStackState,
                tcpEStatsStackNagle, tcpEStatsStackMaxSsCwnd,
                tcpEStatsStackMaxCaCwnd,
                tcpEStatsStackMaxSsthresh,
                tcpEStatsStackMinSsthresh,
                tcpEStatsStackInRecovery, tcpEStatsStackDupAcksIn,
                tcpEStatsStackSpuriousFrDetected,
                tcpEStatsStackSpuriousRtoDetected
            }
            STATUS current
            DESCRIPTION
                "The tcpEStatsConnState group includes objects that
                control the creation of the tcpEStatsStackTable,
                and provide information about the operation of
                algorithms used within TCP."
        ::= { tcpEStatsGroups 10 }

    tcpEStatsStackOptionalGroup  OBJECT-GROUP
            OBJECTS {
                tcpEStatsStackSoftErrors,
                tcpEStatsStackSoftErrorReason,
                tcpEStatsStackSlowStart, tcpEStatsStackCongAvoid,
                tcpEStatsStackOtherReductions,
                tcpEStatsStackCongOverCount,
                tcpEStatsStackFastRetran,
                tcpEStatsStackSubsequentTimeouts,
                tcpEStatsStackCurTimeoutCount,
                tcpEStatsStackAbruptTimeouts,
                tcpEStatsStackSACKsRcvd,
                tcpEStatsStackSACKBlocksRcvd,
                tcpEStatsStackSendStall, tcpEStatsStackDSACKDups,
                tcpEStatsStackMaxMSS, tcpEStatsStackMinMSS,
                tcpEStatsStackSndInitial,
                tcpEStatsStackRecInitial,
                tcpEStatsStackCurRetxQueue,
                tcpEStatsStackMaxRetxQueue,
                tcpEStatsStackCurReasmQueue,
                tcpEStatsStackMaxReasmQueue
            }
            STATUS current
            DESCRIPTION
                "The tcpEStatsConnState group includes objects that
                provide additional information about the operation of
                algorithms used within TCP."
```

```
        ::= { tcpEStatsGroups 11 }

      tcpEStatsAppGroup  OBJECT-GROUP
           OBJECTS {
                tcpEStatsControlApp,
                tcpEStatsAppSndUna, tcpEStatsAppSndNxt,
                tcpEStatsAppSndMax, tcpEStatsAppThruOctetsAcked,
                tcpEStatsAppRcvNxt,
                tcpEStatsAppThruOctetsReceived
           }
           STATUS current
           DESCRIPTION
                "The tcpEStatsConnState group includes objects that
                control the creation of the tcpEStatsAppTable,
                and provide information about the operation of
                algorithms used within TCP."
        ::= { tcpEStatsGroups 12 }

    tcpEStatsAppHCGroup  OBJECT-GROUP
           OBJECTS {
                tcpEStatsAppHCThruOctetsAcked,
                tcpEStatsAppHCThruOctetsReceived
           }
           STATUS current
           DESCRIPTION
                "The tcpEStatsStackHC group includes 64-bit
                counters in the tcpEStatsStackTable."
        ::= { tcpEStatsGroups 13 }

      tcpEStatsAppOptionalGroup  OBJECT-GROUP
           OBJECTS {
                tcpEStatsAppCurAppWQueue,
                tcpEStatsAppMaxAppWQueue,
                tcpEStatsAppCurAppRQueue,
                tcpEStatsAppMaxAppRQueue
           }
           STATUS current
           DESCRIPTION
                "The tcpEStatsConnState group includes objects that
                provide additional information about how applications
                are interacting with each TCP connection."
        ::= { tcpEStatsGroups 14 }

      tcpEStatsTuneOptionalGroup  OBJECT-GROUP
           OBJECTS {
                tcpEStatsControlTune,
                tcpEStatsTuneLimCwnd, tcpEStatsTuneLimSsthresh,
                tcpEStatsTuneLimRwin, tcpEStatsTuneLimMSS
```

```
            }
            STATUS current
            DESCRIPTION
                 "The tcpEStatsConnState group includes objects that
                 control the creation of the tcpEStatsConnectionTable,
                 which can be used to set tuning parameters
                 for each TCP connection."
          ::= { tcpEStatsGroups 15 }

        tcpEStatsNotificationsGroup      NOTIFICATION-GROUP
            NOTIFICATIONS {
                          tcpEStatsEstablishNotification,
                          tcpEStatsCloseNotification
            }
            STATUS   current
            DESCRIPTION
                "Notifications sent by a TCP extended statistics agent."
          ::= { tcpEStatsGroups 16 }

        tcpEStatsNotificationsCtlGroup  OBJECT-GROUP
            OBJECTS {
                          tcpEStatsControlNotify
            }
            STATUS   current
            DESCRIPTION
                "The tcpEStatsNotificationsCtl group includes the
                 object that controls the creation of the events
                 in the tcpEStatsNotificationsGroup."
          ::= { tcpEStatsGroups 17 }

       END
```

## 5. Security Considerations

There are a number of management objects defined in this MIB module with a MAX-ACCESS clause of read-write and/or read-create. Such objects may be considered sensitive or vulnerable in some network environments. The support for SET operations in a non-secure environment without proper protection can have a negative effect on network operations. These are the tables and objects and their sensitivity/vulnerability:

* Changing tcpEStatsConnTableLatency or any of the control objects in the tcpEStatsControl group (tcpEStatsControlPath, tcpEStatsControlStack, tcpEStatsControlApp, tcpEStatsControlTune) may affect the correctness of other management applications accessing this MIB. Generally, local policy should only permit limited write access to these controls (e.g., only by one management station or only during system configuration).

* The objects in the tcpEStatsControlTune group (tcpEStatsTuneLimCwnd, tcpEStatsTuneLimSsthresh, tcpEStatsTuneLimRwin) can be used to limit resources consumed by TCP connections or to limit TCP throughput. An attacker might manipulate these objects to reduce performance to levels below the minimum acceptable for a particular application.

Some of the readable objects in this MIB module (i.e., objects with a MAX-ACCESS other than not-accessible) may be considered sensitive or vulnerable in some network environments. It is thus important to control even GET and/or NOTIFY access to these objects and possibly to even encrypt the values of these objects when sending them over the network via SNMP. These are the tables and objects and their sensitivity/vulnerability:

* All objects which expose TCP sequence numbers (tcpEStatsAppSndUna, tcpEStatsAppSndNxt, tcpEStatsAppSndMax, tcpEStatsStackSndInitial, tcpEStatsAppRcvNxt, and tcpEStatsStackRecInitial) might make it easier for an attacker to forge in sequence TCP segments to disrupt TCP connections.

* Nearly all objects in this (or any other) MIB may be used to estimate traffic volumes, which may reveal unanticipated information about an organization to the outside world.

SNMP versions prior to SNMPv3 did not include adequate security. Even if the network itself is secure (for example by using IPsec), even then, there is no control as to who on the secure network is allowed to access and GET/SET (read/change/create/delete) the objects in this MIB module.

It is RECOMMENDED that implementers consider the security features as provided by the SNMPv3 framework (see [RFC3410], section 8), including full support for the SNMPv3 cryptographic mechanisms (for authentication and privacy).

Further, deployment of SNMP versions prior to SNMPv3 is NOT RECOMMENDED. Instead, it is RECOMMENDED to deploy SNMPv3 and to enable cryptographic security. It is then a customer/operator responsibility to ensure that the SNMP entity giving access to an instance of this MIB module is properly configured to give access to the objects only to those principals (users) that have legitimate rights to indeed GET or SET (change/create/delete) them.

## 6. IANA Considerations

The MIB module in this document uses the following IANA-assigned OBJECT IDENTIFIER values recorded in the SMI Numbers registry:

| Descriptor | OBJECT IDENTIFIER value |
|---|---|
| tcpEStatsMIB | { mib-2 156 } |

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## 9. Contributors

The following people contributed text that was incorporated into this document:

Jon Saperia <saperia@jdscons.com> converted Web100 internal documentation into a true MIB.

Some of the objects in this document were moved from an early version of the TCP-MIB by Bill Fenner, et al.

Some of the object descriptions are based on an earlier unpublished document by Jeff Semke.

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