IK1550 & IK1552 Internetworking/Internetteknik

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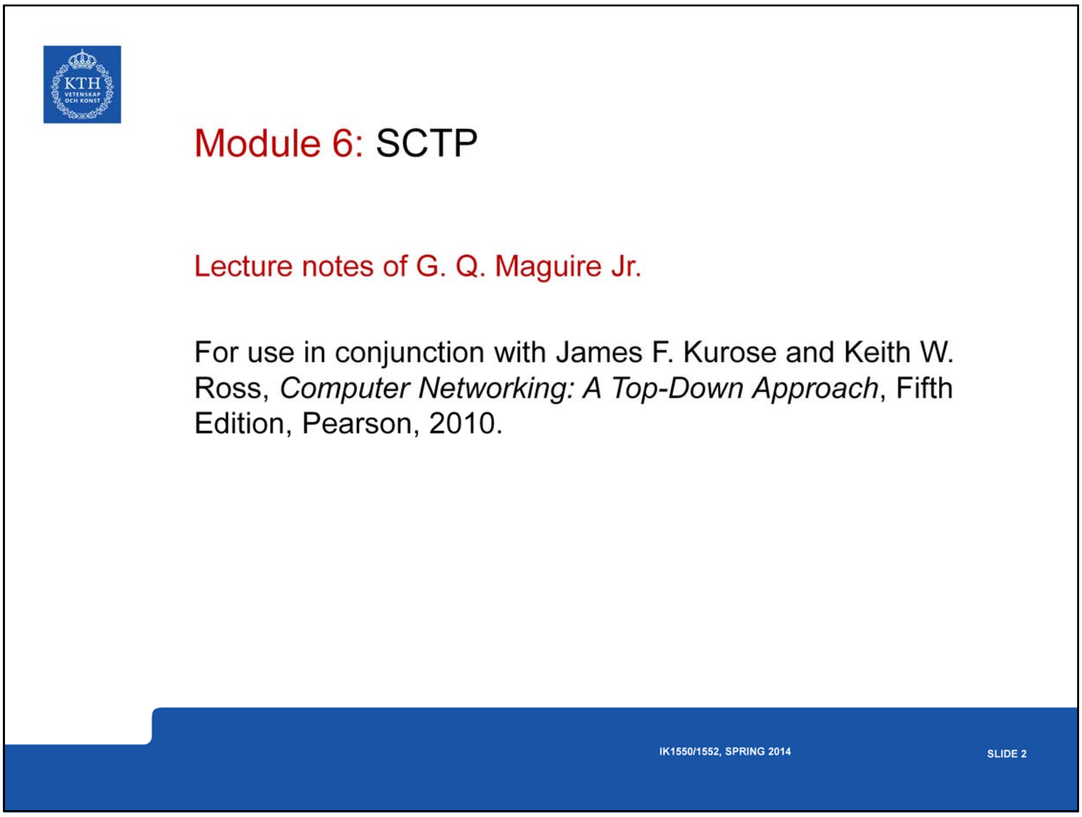
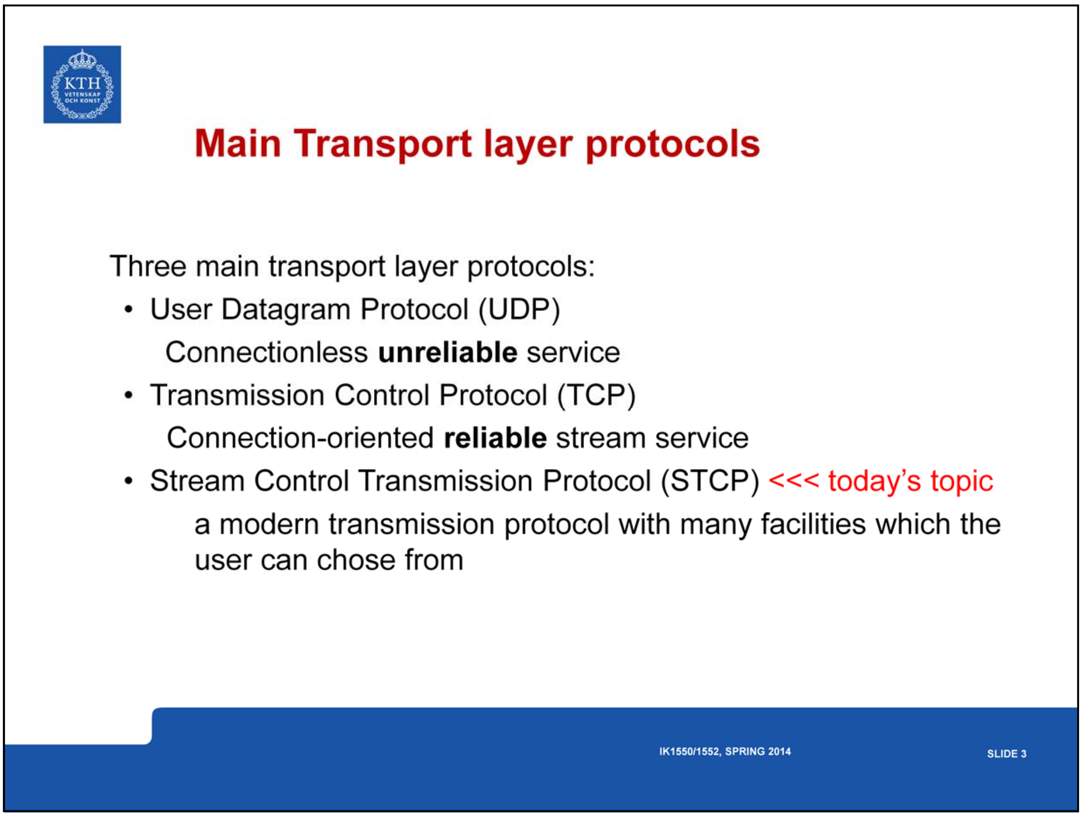
IK1550/IK1552 Spring 2014, Period 4 2014.03.31



Module 6: SCTP

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with James F. Kurose and Keith W. Ross, *Computer Networking: A Top-Down Approach*, Fifth Edition, Pearson, 2010.



Main Transport layer protocols

Three main transport layer protocols:

- User Datagram Protocol (UDP)

  Connectionless **unreliable** service
- Transmission Control Protocol (TCP)

  Connection-oriented **reliable** stream service
- Stream Control Transmission Protocol (STCP) <<< today's topic

  a modern transmission protocol with many facilities which the user can chose from

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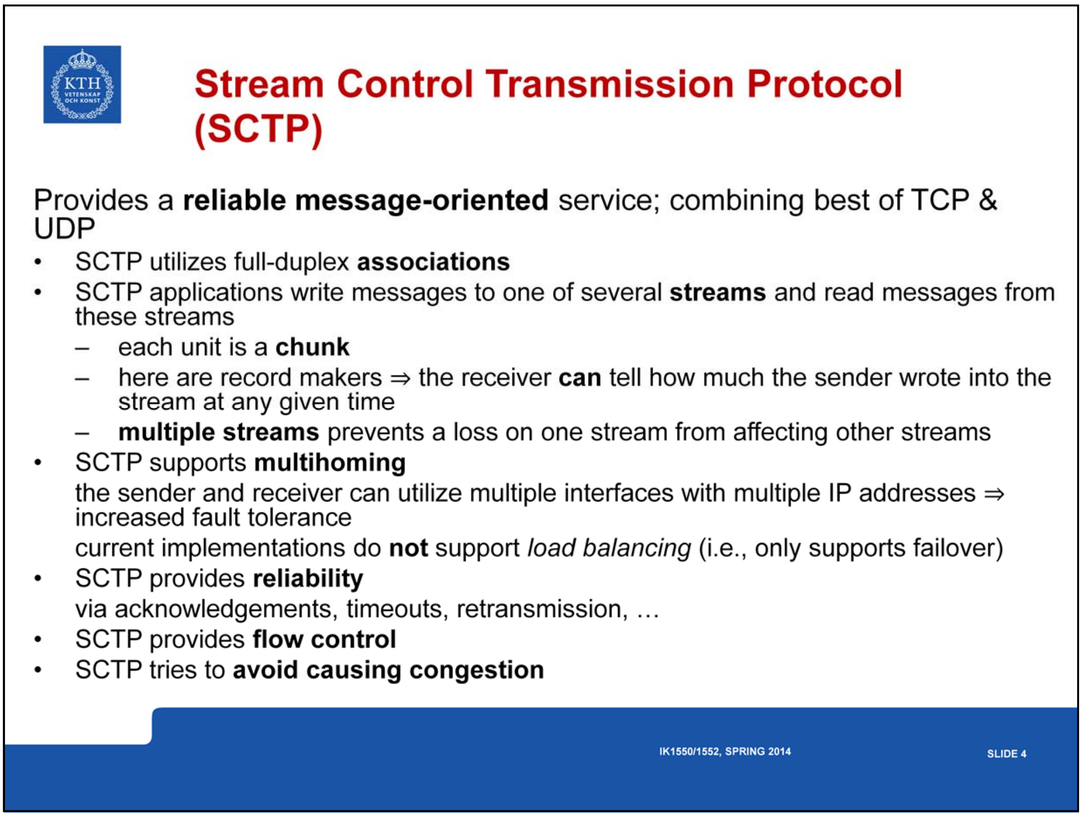
Andreas Jungmaier, “A Gentle Introduction to SCTP”, 19th Chaos Communications Congress, Berlin, 2002 *http://tdrwww.exp-math.uni-essen.de/inhalt/forschung/19ccc2002/html/slide_1.html*



Stream Control Transmission Protocol (SCTP)

Provides a **reliable message-oriented** service; combining best of TCP & UDP

- SCTP utilizes full-duplex **associations**
- SCTP applications write messages to one of several **streams** and read messages from these streams
  - each unit is a **chunk**
  - here are record makers ⇒ the receiver **can** tell how much the sender wrote into the stream at any given time
  - **multiple streams** prevents a loss on one stream from affecting other streams
- SCTP supports **multihoming**

  the sender and receiver can utilize multiple interfaces with multiple IP addresses ⇒ increased fault tolerance

  current implementations do **not** support *load balancing* (i.e., only supports failover)
- SCTP provides **reliability**

  via acknowledgements, timeouts, retransmission, …
- SCTP provides **flow control**
- SCTP tries to **avoid causing congestion**

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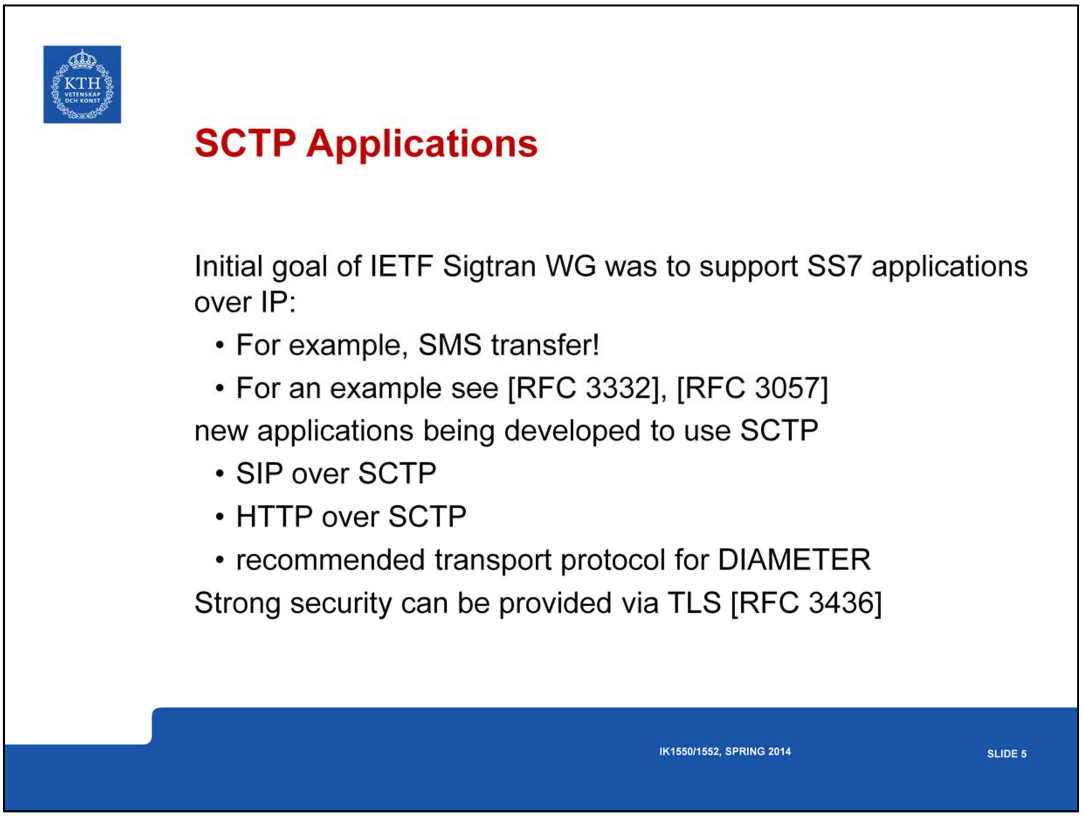
R. Stewart, Q. Xie, K. Morneault, C. Sharp, H. Schwarzbauer, T. Taylor, I. Rytina, M. Kalla, L. Zhang, and V. Paxson, “Stream Control Transmission Protocol”, IETF RFC 2960, October 2000 *http://www.ietf.org/rfc/rfc2960.txt*

Randall R. Stewart and Qiaobing Xie, “Stream Control Transmission Protocol: A Reference Guide”, Addison-Wesley, 2002, ISBN 0-201-72186-4.

R. Stewart, ‘Stream Control Transmission Protocol’, *Internet Request for Comments*, vol. RFC 4960 (Proposed Standard), Sep. 2007 [Online]. Available: http://www.rfc-editor.org/rfc/rfc4960.txt



SCTP Applications

Initial goal of IETF Sigtran WG was to support SS7 applications over IP:

- For example, SMS transfer!
- For an example see [RFC 3332], [RFC 3057]

new applications being developed to use SCTP

- SIP over SCTP
- HTTP over SCTP
- recommended transport protocol for DIAMETER

Strong security can be provided via TLS [RFC 3436]

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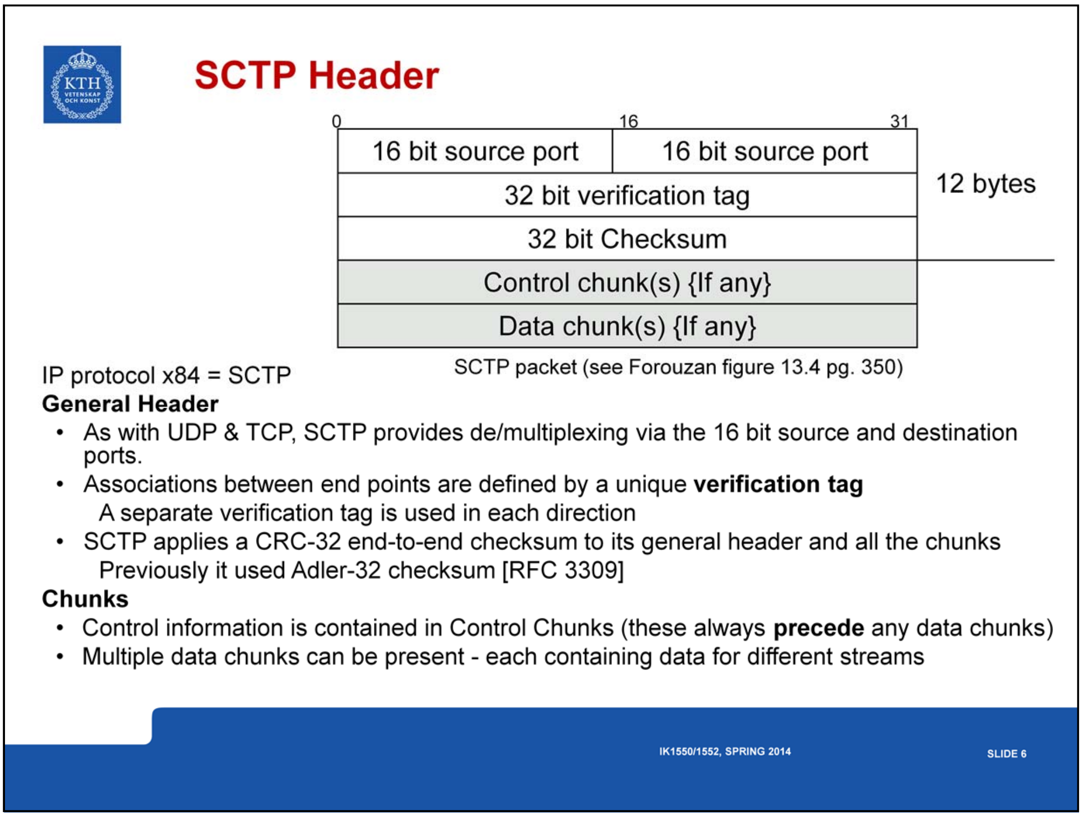
G. Sidebottom, K. Morneault, and J. Pastor-Balbas, ‘Signaling System 7 (SS7) Message Transfer Part 3 (MTP3) - User Adaptation Layer (M3UA)’, *Internet Request for Comments*, vol. RFC 3332 (Proposed Standard), Sep. 2002 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3332.txt

K. Morneault and J. Pastor-Balbas, ‘Signaling System 7 (SS7) Message Transfer Part 3 (MTP3) - User Adaptation Layer (M3UA)’, *Internet Request for Comments*, vol. RFC 4666 (Proposed Standard), Sep. 2006 [Online]. Available: http://www.rfc-editor.org/rfc/rfc4666.txt

K. Morneault, S. Rengasami, M. Kalla, and G. Sidebottom, ‘ISDN Q.921-User Adaptation Layer’, *Internet Request for Comments*, vol. RFC 3057 (Proposed Standard), Feb. 2001 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3057.txt

A. Jungmaier, E. Rescorla, and M. Tuexen, ‘Transport Layer Security over Stream Control Transmission Protocol’, *Internet Request for Comments*, vol. RFC 3436 (Proposed Standard), Dec. 2002 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3436.txt



SCTP Header

0	16	31
16 bit source port	16 bit source port	12 bytes
32 bit verification tag		
32 bit Checksum		
Control chunk(s) {If any}		
Data chunk(s) {If any}		

SCTP packet (see Forouzan figure 13.4 pg. 350)

IP protocol x84 = SCTP

General Header

- As with UDP & TCP, SCTP provides de/multiplexing via the 16 bit source and destination ports.
- Associations between end points are defined by a unique **verification tag**
  A separate verification tag is used in each direction
- SCTP applies a CRC-32 end-to-end checksum to its general header and all the chunks
  Previously it used Adler-32 checksum [RFC 3309]

Chunks

- Control information is contained in Control Chunks (these always **precede** any data chunks)
- Multiple data chunks can be present - each containing data for different streams

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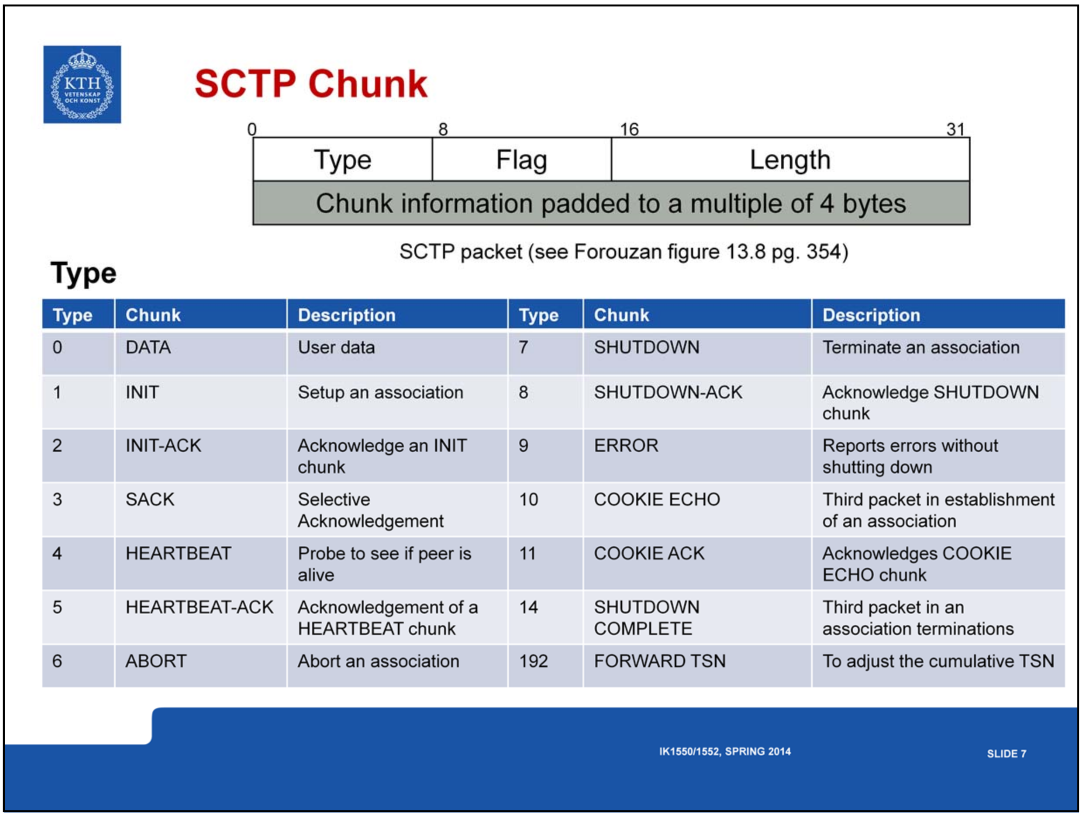
J. Stone, R. Stewart, and D. Otis, ‘Stream Control Transmission Protocol (SCTP) Checksum Change’, *Internet Request for Comments*, vol. RFC 3309 (Proposed Standard), Sep. 2002 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3309.txt



SCTP Chunk

0
8
16
31
Type
Flag
Length
Chunk information padded to a multiple of 4 bytes

SCTP packet (see Forouzan figure 13.8 pg. 354)

Type

Type	Chunk	Description	Type	Chunk	Description
0	DATA	User data	7	SHUTDOWN	Terminate an association
1	INIT	Setup an association	8	SHUTDOWN-ACK	Acknowledge SHUTDOWN chunk
2	INIT-ACK	Acknowledge an INIT chunk	9	ERROR	Reports errors without shutting down
3	SACK	Selective Acknowledgement	10	COOKIE ECHO	Third packet in establishment of an association
4	HEARTBEAT	Probe to see if peer is alive	11	COOKIE ACK	Acknowledges COOKIE ECHO chunk
5	HEARTBEAT-ACK	Acknowledgement of a HEARTBEAT chunk	14	SHUTDOWN COMPLETE	Third packet in an association terminations
6	ABORT	Abort an association	192	FORWARD TSN	To adjust the cumulative TSN

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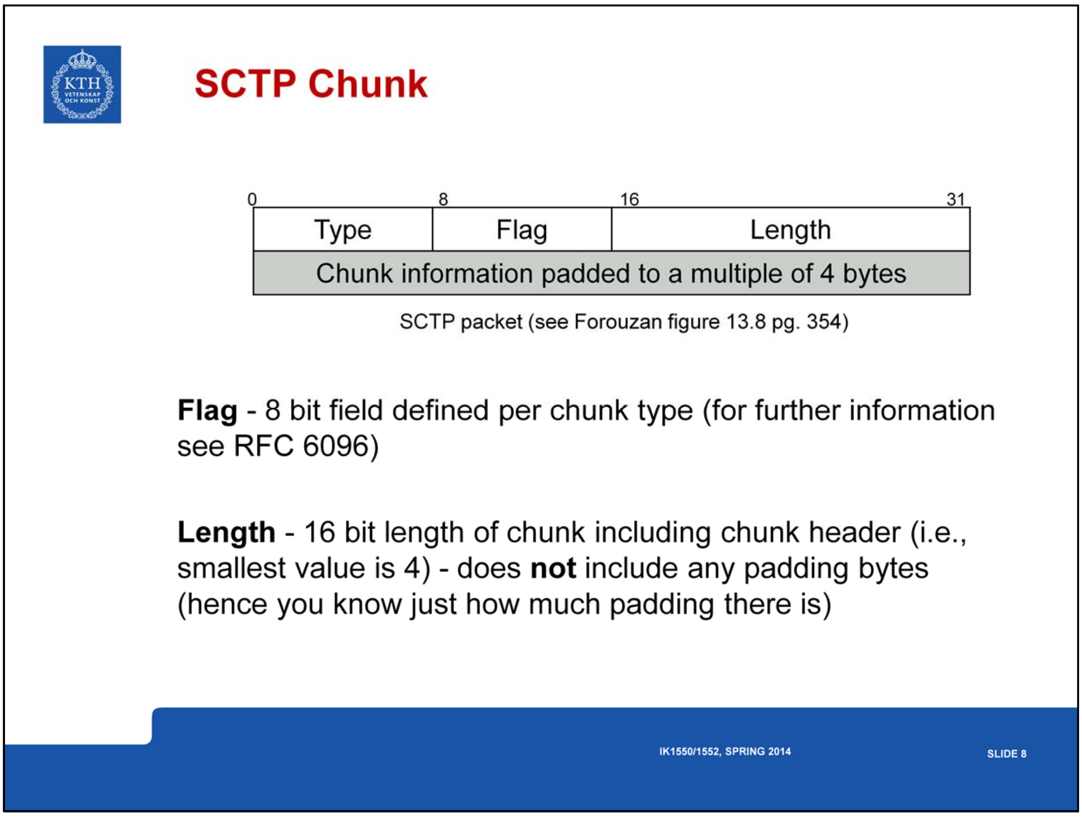

SCTP Chunk

0 8 16 31

Type	Flag	Length
Chunk information padded to a multiple of 4 bytes		

SCTP packet (see Forouzan figure 13.8 pg. 354)

Flag - 8 bit field defined per chunk type (for further information see RFC 6096)

Length - 16 bit length of chunk including chunk header (i.e., smallest value is 4) - does **not** include any padding bytes (hence you know just how much padding there is)

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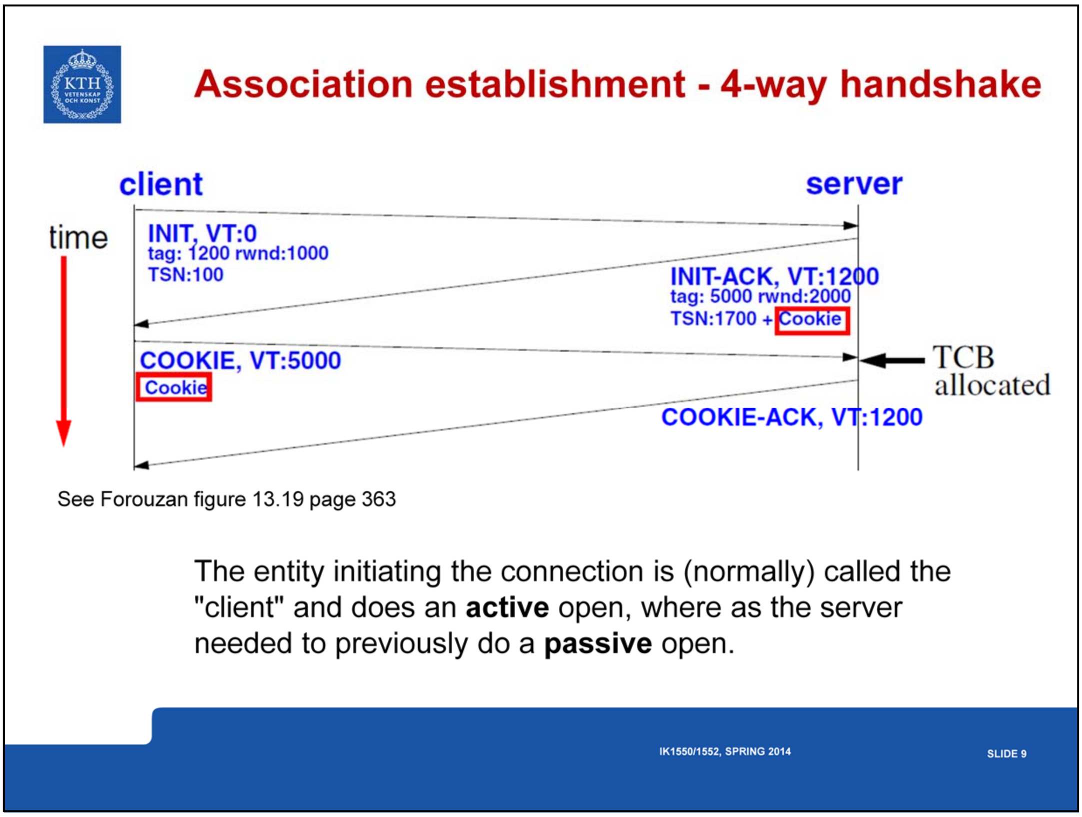
M. Tuexen and R. Stewart, ‘Stream Control Transmission Protocol (SCTP) Chunk Flags Registration’, *Internet Request for Comments*, vol. RFC 6096 (Proposed Standard), Jan. 2011 [Online]. Available: http://www.rfc-editor.org/rfc/rfc6096.txt



Association establishment - 4-way handshake

client

server

time

INIT, VT:0
tag: 1200 rwnd:1000
TSN:100

INIT-ACK, VT:1200
tag: 5000 rwnd:2000
TSN:1700 + Cookie

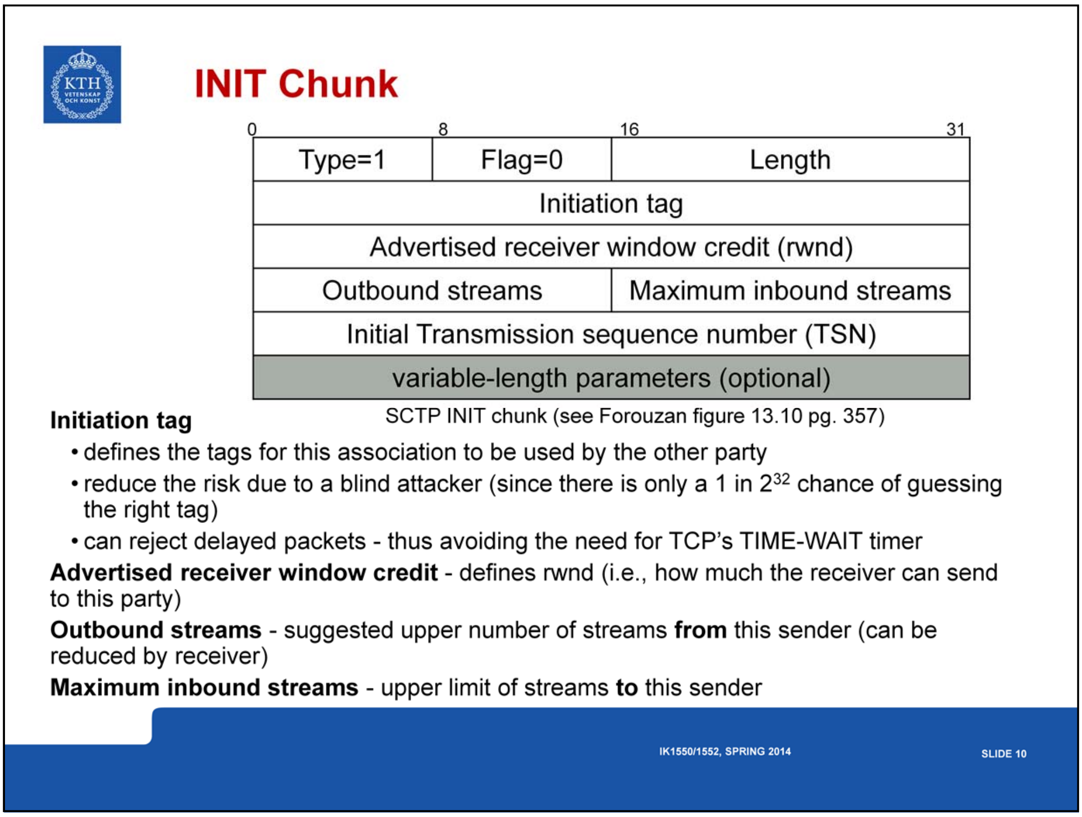
COOKIE, VT:5000
Cookie

TCB
allocated

COOKIE-ACK, VT:1200

See Forouzan figure 13.19 page 363

The entity initiating the connection is (normally) called the "client" and does an **active** open, where as the server needed to previously do a **passive** open.



INIT Chunk

<table>
<tr><th>0</th><th>8</th><th>16</th><th>31</th></tr>
<tr><td>Type=1</td><td>Flag=0</td><td colspan="2">Length</td></tr>
<tr><td colspan="4">Initiation tag</td></tr>
<tr><td colspan="4">Advertised receiver window credit (rwnd)</td></tr>
<tr><td colspan="2">Outbound streams</td><td colspan="2">Maximum inbound streams</td></tr>
<tr><td colspan="4">Initial Transmission sequence number (TSN)</td></tr>
<tr><td colspan="4">variable-length parameters (optional)</td></tr>
</table>

SCTP INIT chunk (see Forouzan figure 13.10 pg. 357)

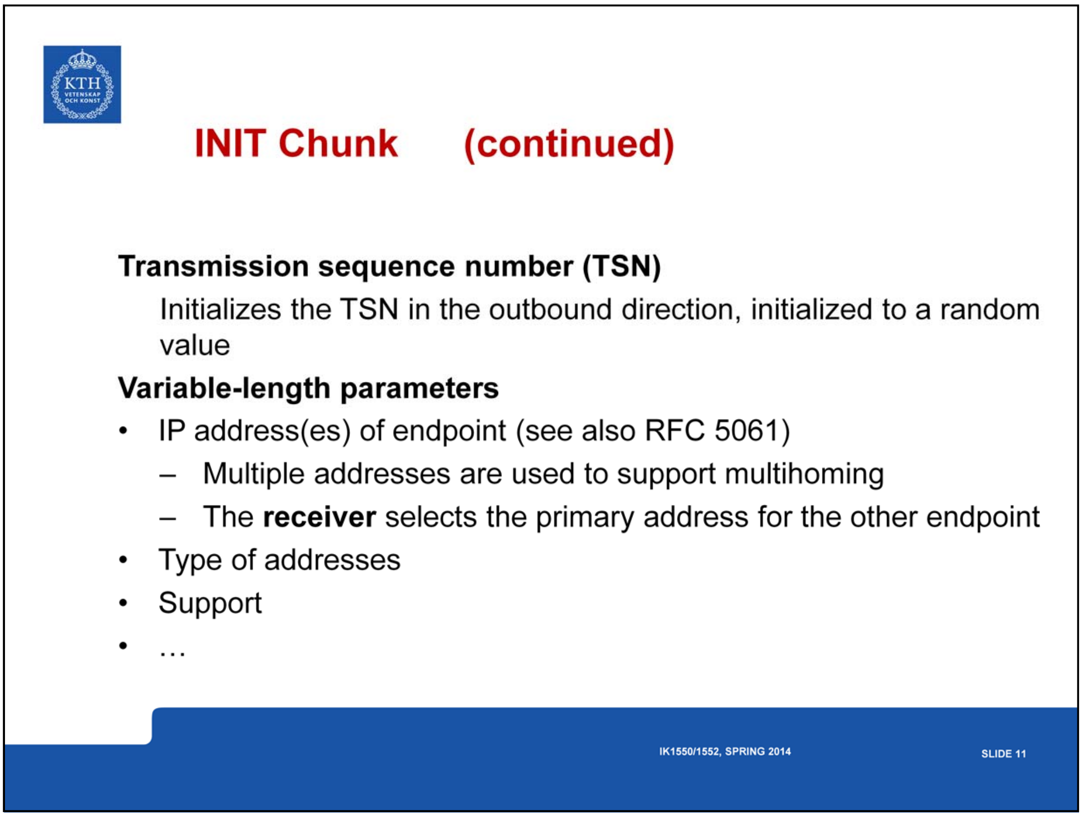
Initiation tag

- defines the tags for this association to be used by the other party
- reduce the risk due to a blind attacker (since there is only a 1 in 2^{32} chance of guessing the right tag)
- can reject delayed packets - thus avoiding the need for TCP's TIME-WAIT timer

Advertised receiver window credit - defines rwnd (i.e., how much the receiver can send to this party)

Outbound streams - suggested upper number of streams **from** this sender (can be reduced by receiver)

Maximum inbound streams - upper limit of streams **to** this sender



INIT Chunk (continued)

Transmission sequence number (TSN)

Initializes the TSN in the outbound direction, initialized to a random value

Variable-length parameters

- IP address(es) of endpoint (see also RFC 5061)
  - Multiple addresses are used to support multihoming
  - The **receiver** selects the primary address for the other endpoint
- Type of addresses
- Support
- …

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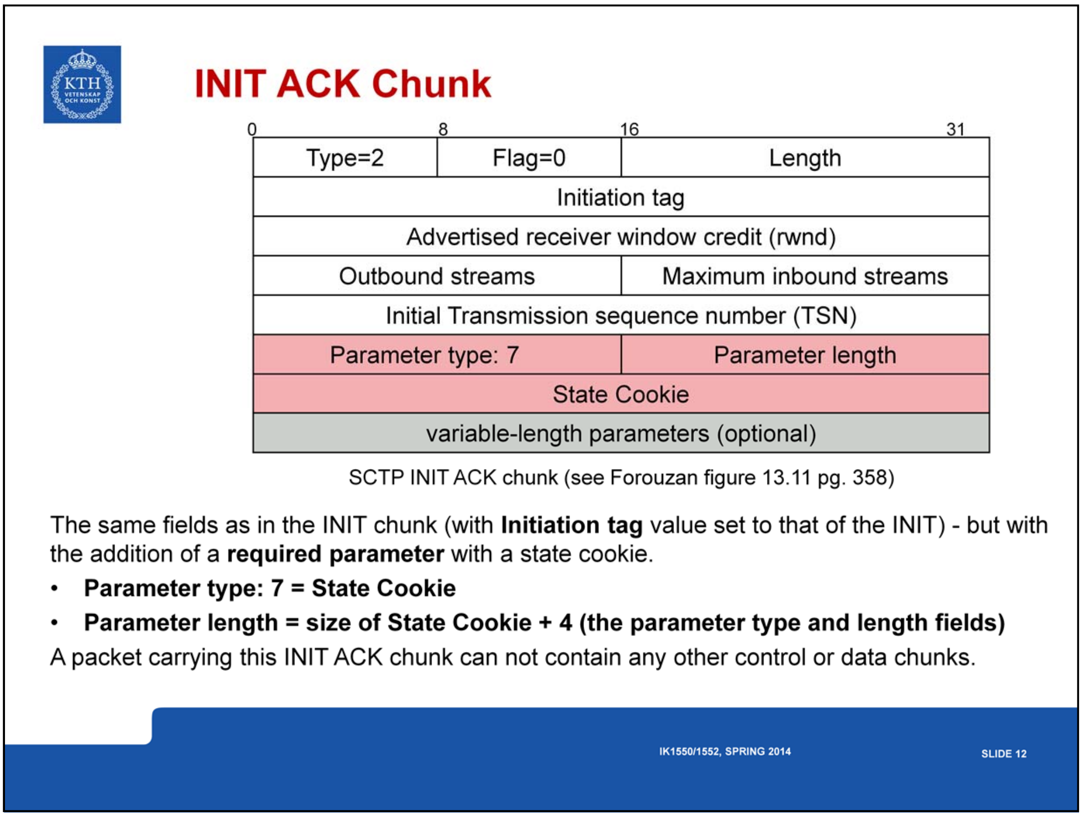
R. Stewart, Q. Xie, M. Tuexen, S. Maruyama, and M. Kozuka, ‘Stream Control Transmission Protocol (SCTP) Dynamic Address Reconfiguration’, *Internet Request for Comments*, vol. RFC 5061 (Proposed Standard), Sep. 2007 [Online]. Available: http://www.rfc-editor.org/rfc/rfc5061.txt



INIT ACK Chunk

0	8	16	31
Type=2	Flag=0	Length	
Initiation tag			
Advertised receiver window credit (rwnd)			
Outbound streams		Maximum inbound streams	
Initial Transmission sequence number (TSN)			
Parameter type: 7		Parameter length	
State Cookie			
variable-length parameters (optional)			

SCTP INIT ACK chunk (see Forouzan figure 13.11 pg. 358)

The same fields as in the INIT chunk (with **Initiation tag** value set to that of the INIT) - but with the addition of a **required parameter** with a state cookie.

- **Parameter type: 7 = State Cookie**
- **Parameter length = size of State Cookie + 4 (the parameter type and length fields)**

A packet carrying this INIT ACK chunk can not contain any other control or data chunks.

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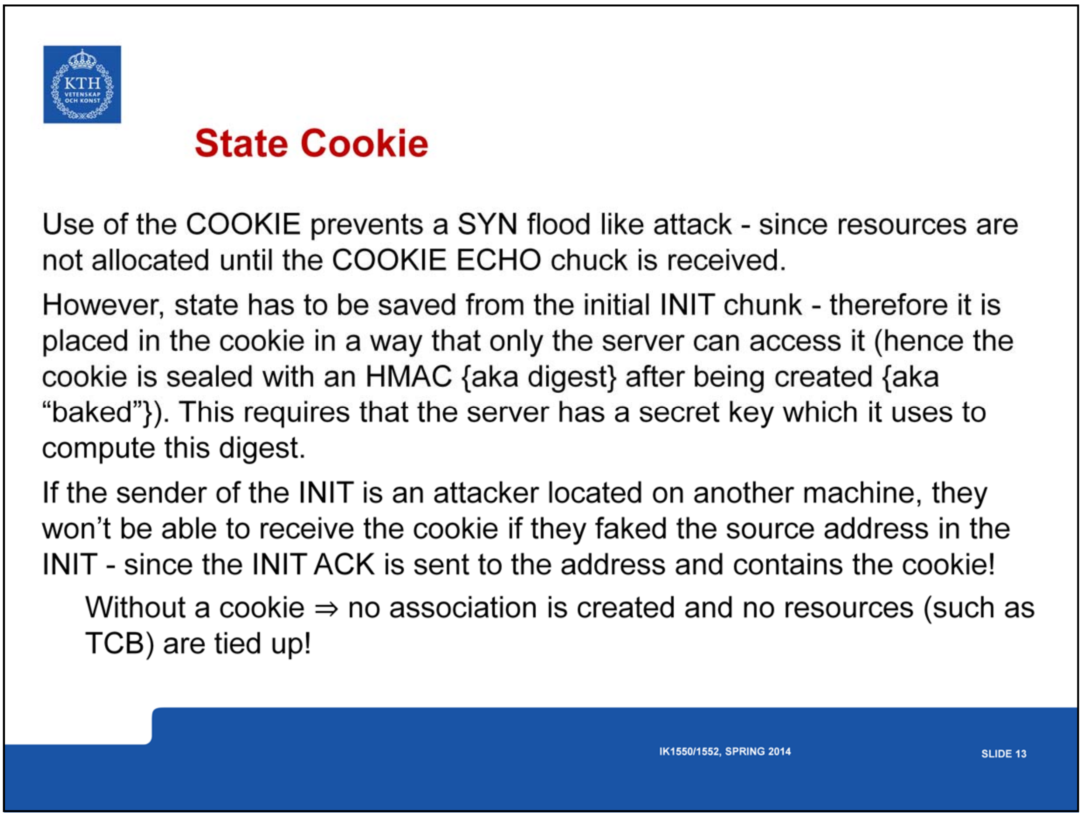


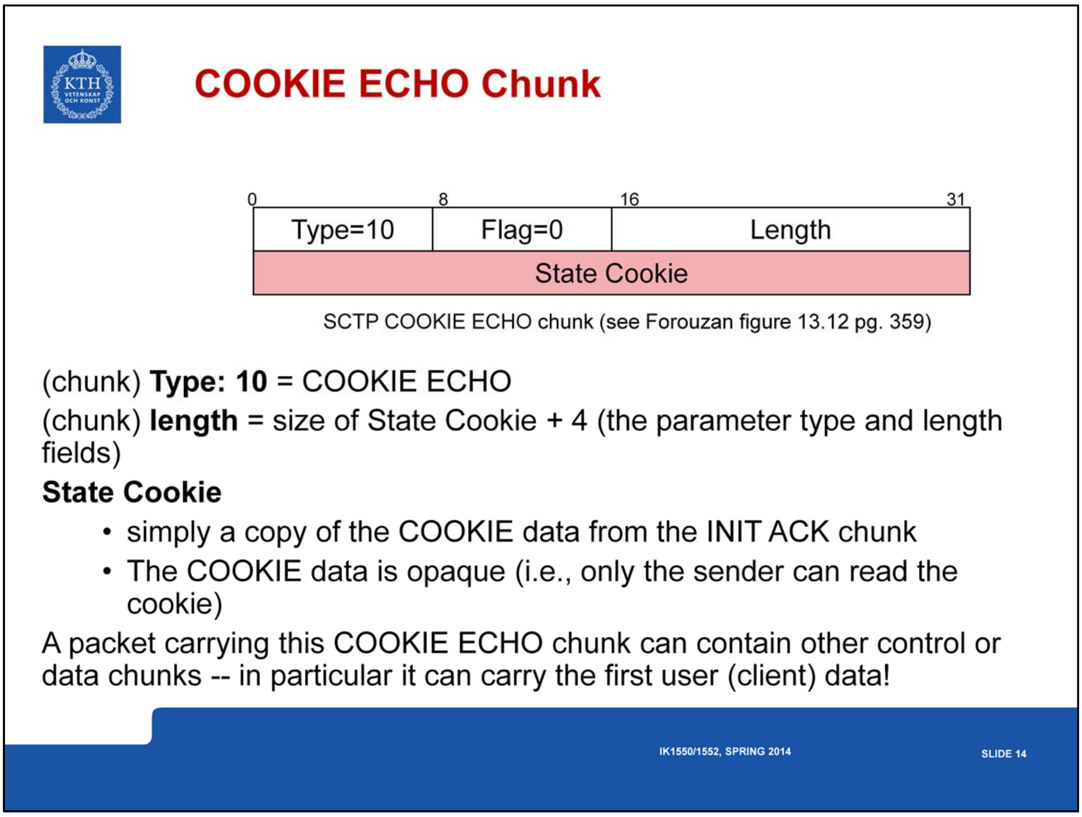
State Cookie

Use of the COOKIE prevents a SYN flood like attack - since resources are not allocated until the COOKIE ECHO chuck is received.

However, state has to be saved from the initial INIT chunk - therefore it is placed in the cookie in a way that only the server can access it (hence the cookie is sealed with an HMAC {aka digest} after being created {aka “baked”}). This requires that the server has a secret key which it uses to compute this digest.

If the sender of the INIT is an attacker located on another machine, they won’t be able to receive the cookie if they faked the source address in the INIT - since the INIT ACK is sent to the address and contains the cookie!

- Without a cookie ⇒ no association is created and no resources (such as TCB) are tied up!



COOKIE ECHO Chunk

0	8	16 31
Type=10	Flag=0	Length
State Cookie		

SCTP COOKIE ECHO chunk (see Forouzan figure 13.12 pg. 359)

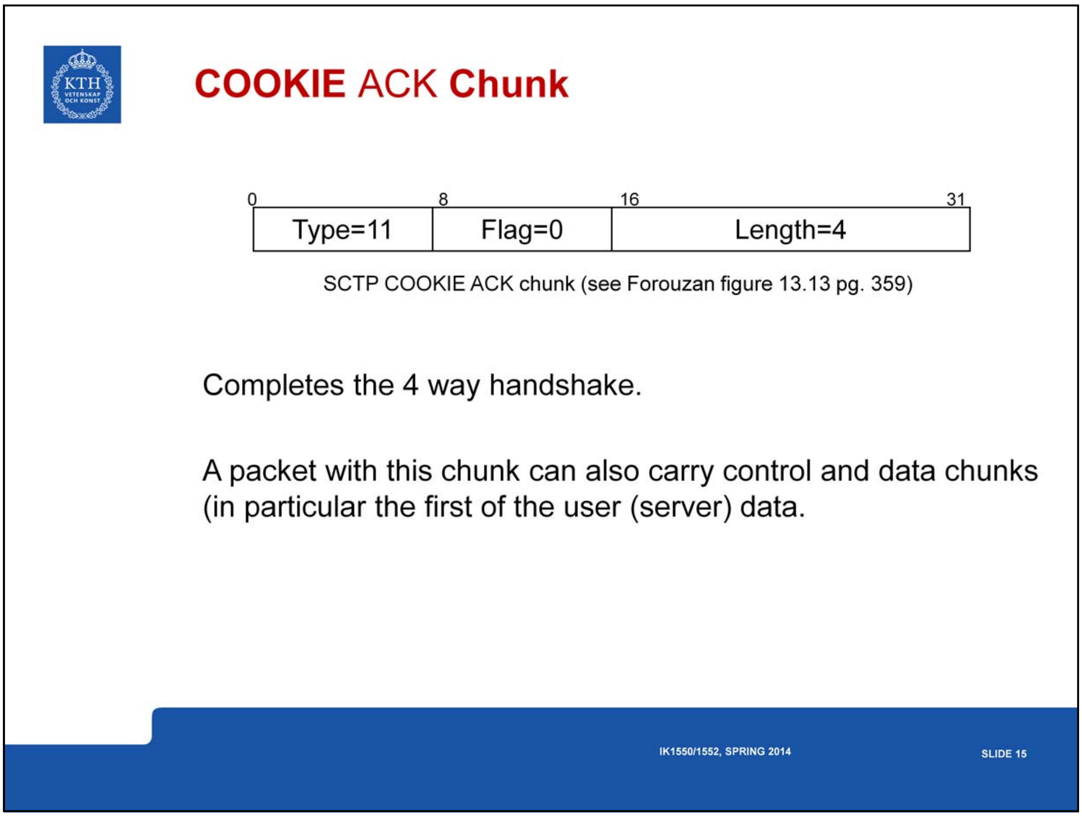
(chunk) **Type: 10** = COOKIE ECHO

(chunk) **length** = size of State Cookie + 4 (the parameter type and length fields)

State Cookie

- simply a copy of the COOKIE data from the INIT ACK chunk
- The COOKIE data is opaque (i.e., only the sender can read the cookie)

A packet carrying this COOKIE ECHO chunk can contain other control or data chunks -- in particular it can carry the first user (client) data!



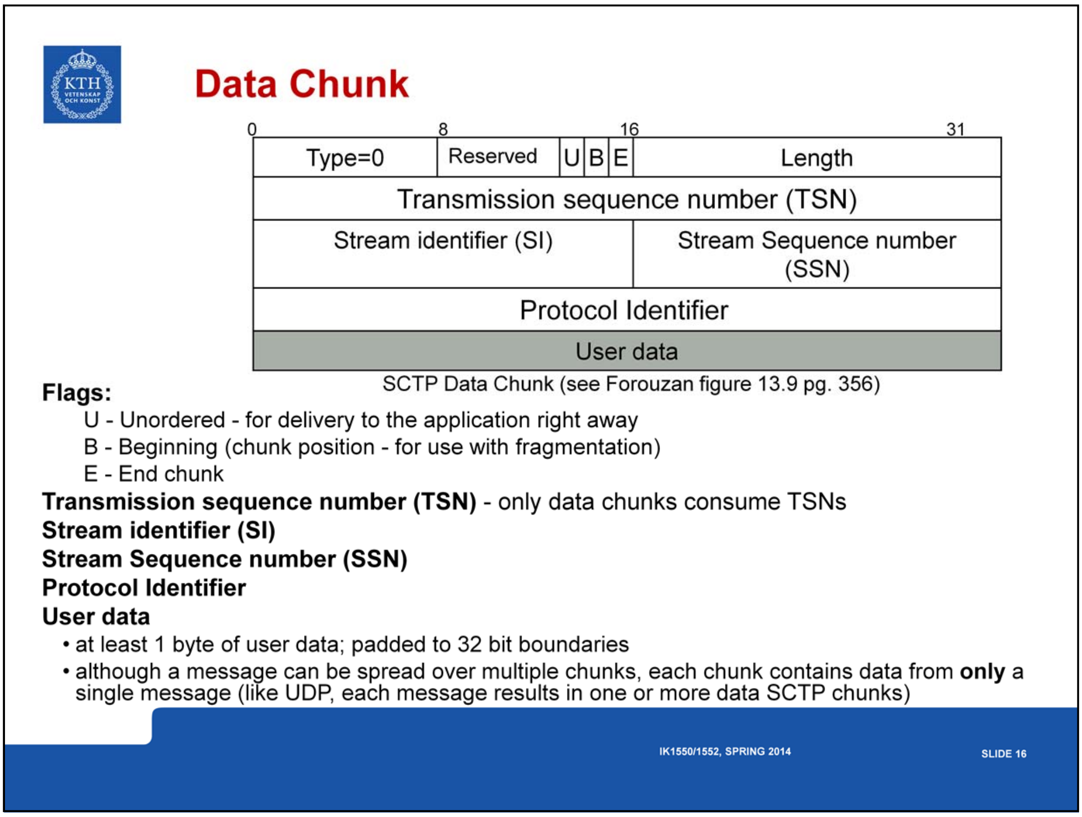
COOKIE ACK Chunk

0	8	16 31
Type=11	Flag=0	Length=4

SCTP COOKIE ACK chunk (see Forouzan figure 13.13 pg. 359)

Completes the 4 way handshake.

A packet with this chunk can also carry control and data chunks (in particular the first of the user (server) data.



Data Chunk

0	8				16 31
Type=0	Reserved	U	B	E	Length
Transmission sequence number (TSN)					
Stream identifier (SI)					Stream Sequence number (SSN)
Protocol Identifier					
User data					

SCTP Data Chunk (see Forouzan figure 13.9 pg. 356)

Flags:

U - Unordered - for delivery to the application right away

B - Beginning (chunk position - for use with fragmentation)

E - End chunk

Transmission sequence number (TSN) - only data chunks consume TSNs

Stream identifier (SI)

Stream Sequence number (SSN)

Protocol Identifier

User data

- at least 1 byte of user data; padded to 32 bit boundaries
- although a message can be spread over multiple chunks, each chunk contains data from **only** a single message (like UDP, each message results in one or more data SCTP chunks)

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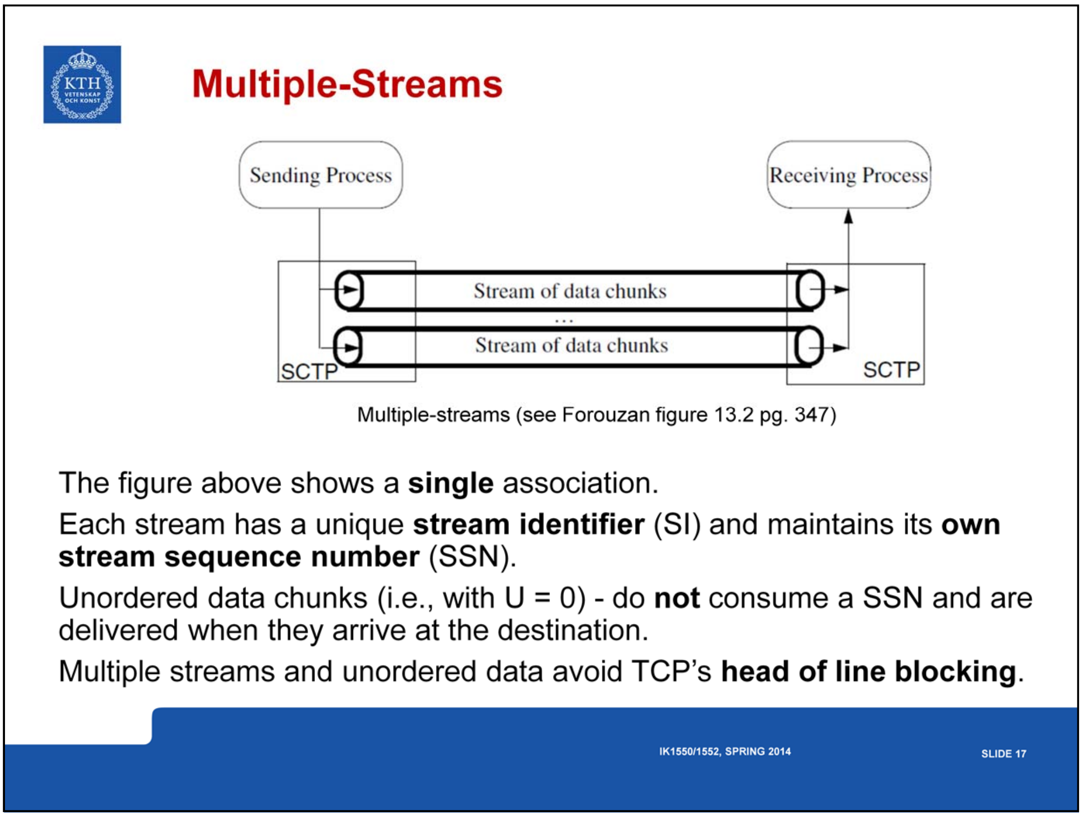


Multiple-Streams

Sending Process
Receiving Process
Stream of data chunks
...
Stream of data chunks
SCTP
SCTP

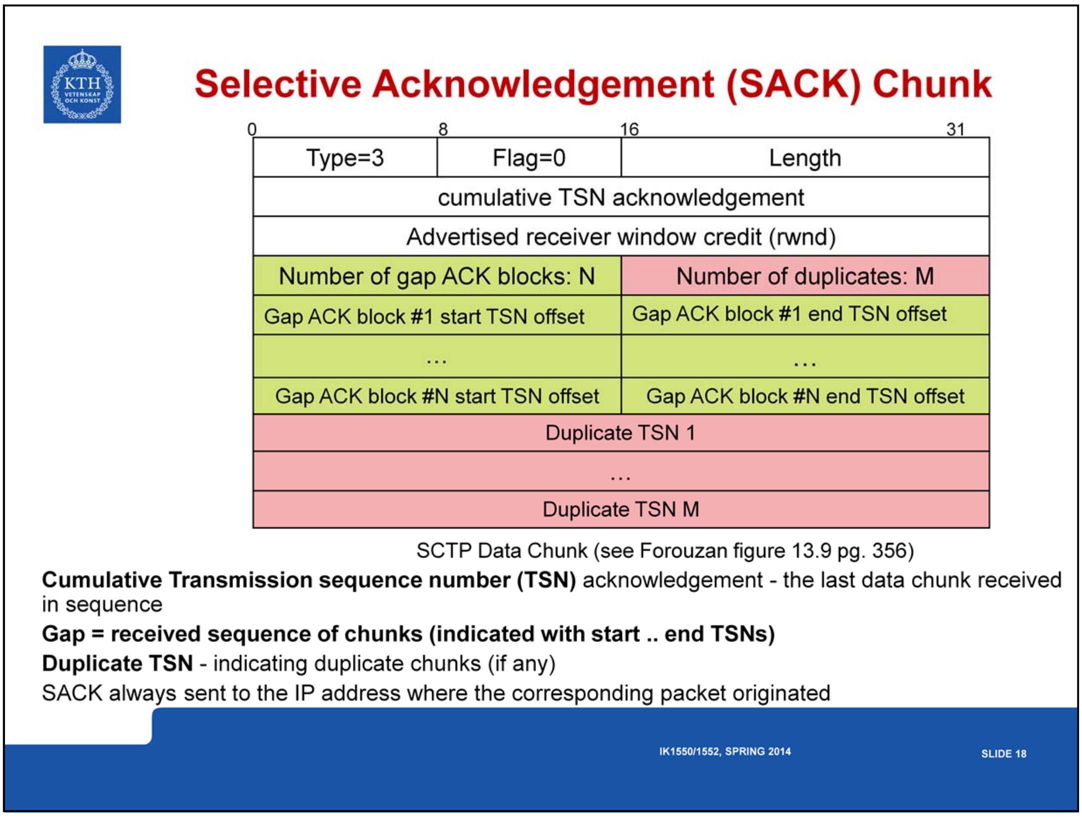
Multiple-streams (see Forouzan figure 13.2 pg. 347)

The figure above shows a **single** association.

Each stream has a unique **stream identifier** (SI) and maintains its **own stream sequence number** (SSN).

Unordered data chunks (i.e., with U = 0) - do **not** consume a SSN and are delivered when they arrive at the destination.

Multiple streams and unordered data avoid TCP’s **head of line blocking**.



Selective Acknowledgement (SACK) Chunk

0 8 16 31

<table>
<tr><td>Type=3</td><td>Flag=0</td><td colspan="2">Length</td></tr>
<tr><td colspan="4">cumulative TSN acknowledgement</td></tr>
<tr><td colspan="4">Advertised receiver window credit (rwnd)</td></tr>
<tr><td colspan="2">Number of gap ACK blocks: N</td><td colspan="2">Number of duplicates: M</td></tr>
<tr><td colspan="2">Gap ACK block #1 start TSN offset</td><td colspan="2">Gap ACK block #1 end TSN offset</td></tr>
<tr><td colspan="2">…</td><td colspan="2">…</td></tr>
<tr><td colspan="2">Gap ACK block #N start TSN offset</td><td colspan="2">Gap ACK block #N end TSN offset</td></tr>
<tr><td colspan="4">Duplicate TSN 1</td></tr>
<tr><td colspan="4">…</td></tr>
<tr><td colspan="4">Duplicate TSN M</td></tr>
</table>

SCTP Data Chunk (see Forouzan figure 13.9 pg. 356)

Cumulative Transmission sequence number (TSN) acknowledgement - the last data chunk received in sequence

Gap = received sequence of chunks (indicated with start .. end TSNs)

Duplicate TSN - indicating duplicate chunks (if any)

SACK always sent to the IP address where the corresponding packet originated

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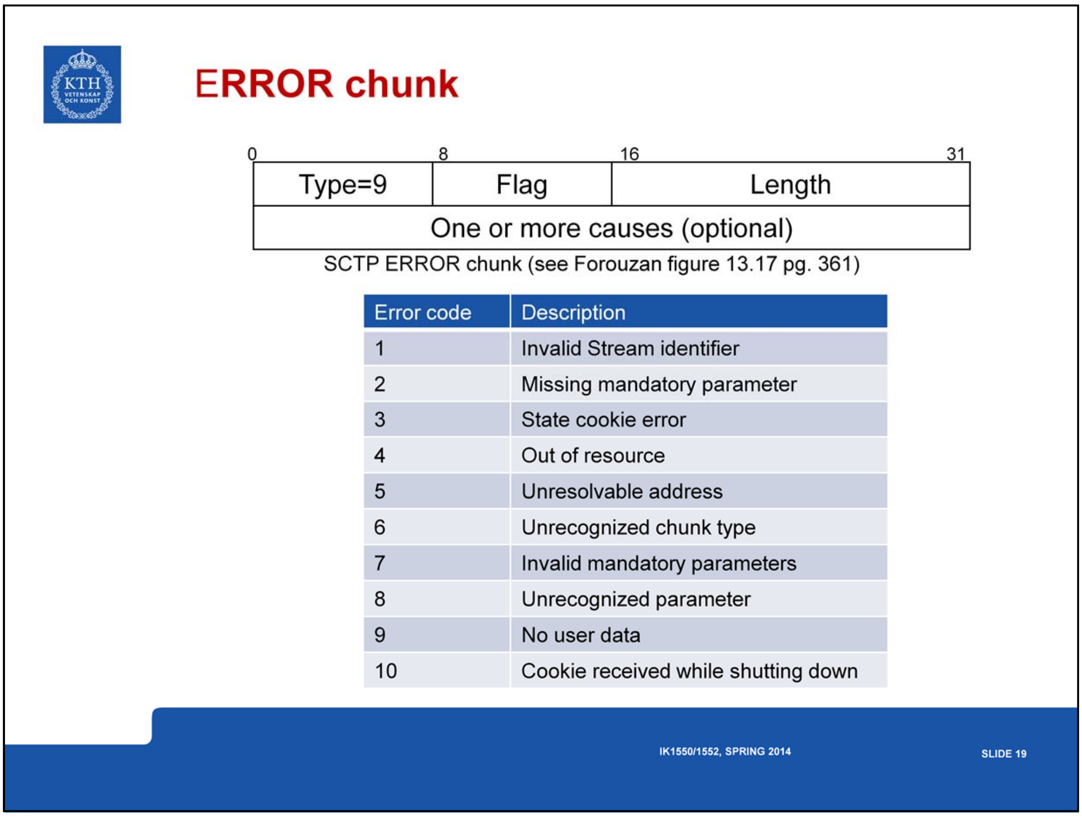

ERROR chunk

0	8	16 31
Type=9	Flag	Length
One or more causes (optional)		

SCTP ERROR chunk (see Forouzan figure 13.17 pg. 361)

Error code	Description
1	Invalid Stream identifier
2	Missing mandatory parameter
3	State cookie error
4	Out of resource
5	Unresolvable address
6	Unrecognized chunk type
7	Invalid mandatory parameters
8	Unrecognized parameter
9	No user data
10	Cookie received while shutting down

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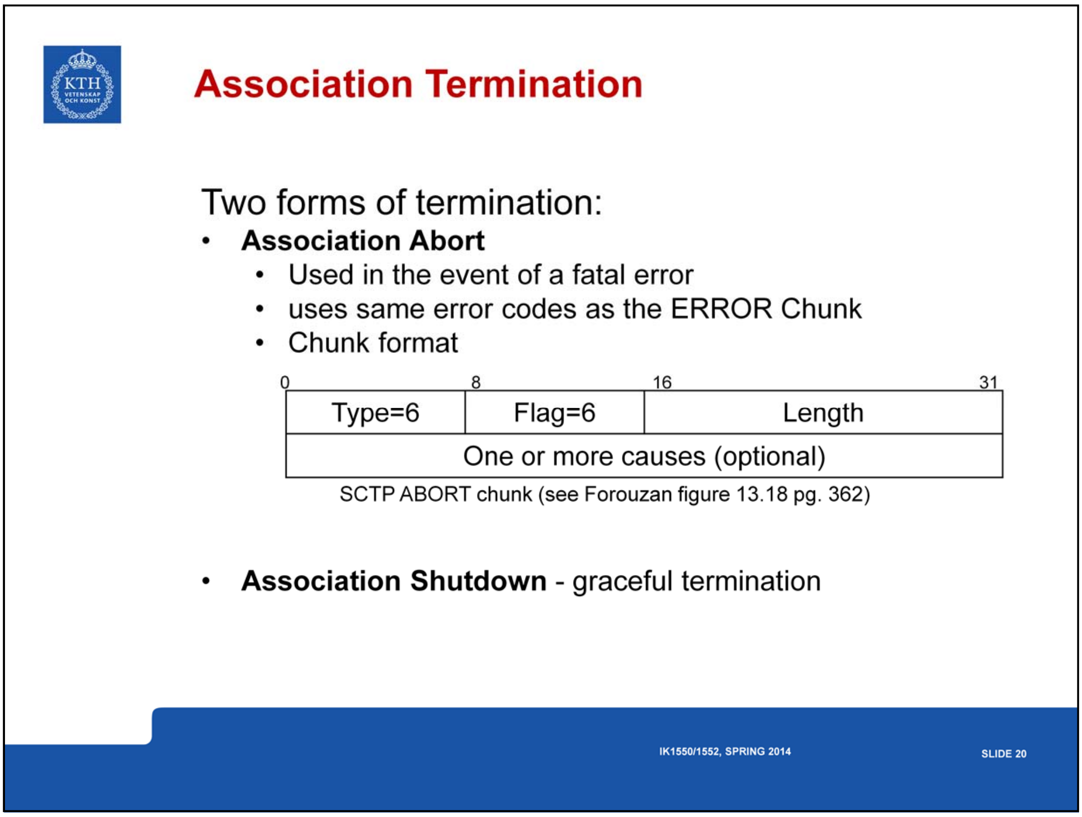


Association Termination

Two forms of termination:

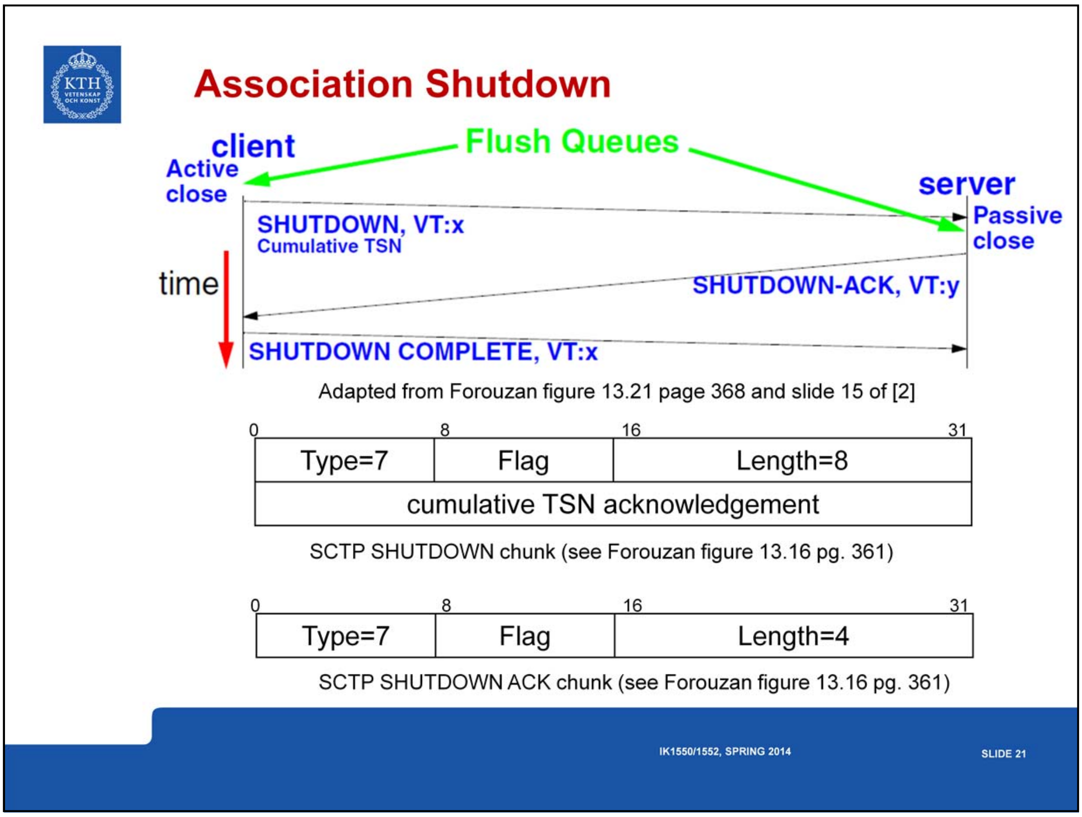
- **Association Abort**
  - Used in the event of a fatal error
  - uses same error codes as the ERROR Chunk
  - Chunk format

0 8 16 31

Type=6	Flag=6	Length
One or more causes (optional)		

SCTP ABORT chunk (see Forouzan figure 13.18 pg. 362)

- **Association Shutdown** - graceful termination



Association Shutdown

client
Active close

Flush Queues

server
Passive close

SHUTDOWN, VT:x
Cumulative TSN

time

SHUTDOWN-ACK, VT:y

SHUTDOWN COMPLETE, VT:x

Adapted from Forouzan figure 13.21 page 368 and slide 15 of [2]

0	8	16 31
Type=7	Flag	Length=8
cumulative TSN acknowledgement		

SCTP SHUTDOWN chunk (see Forouzan figure 13.16 pg. 361)

0	8	16 31
Type=7	Flag	Length=4

SCTP SHUTDOWN ACK chunk (see Forouzan figure 13.16 pg. 361)

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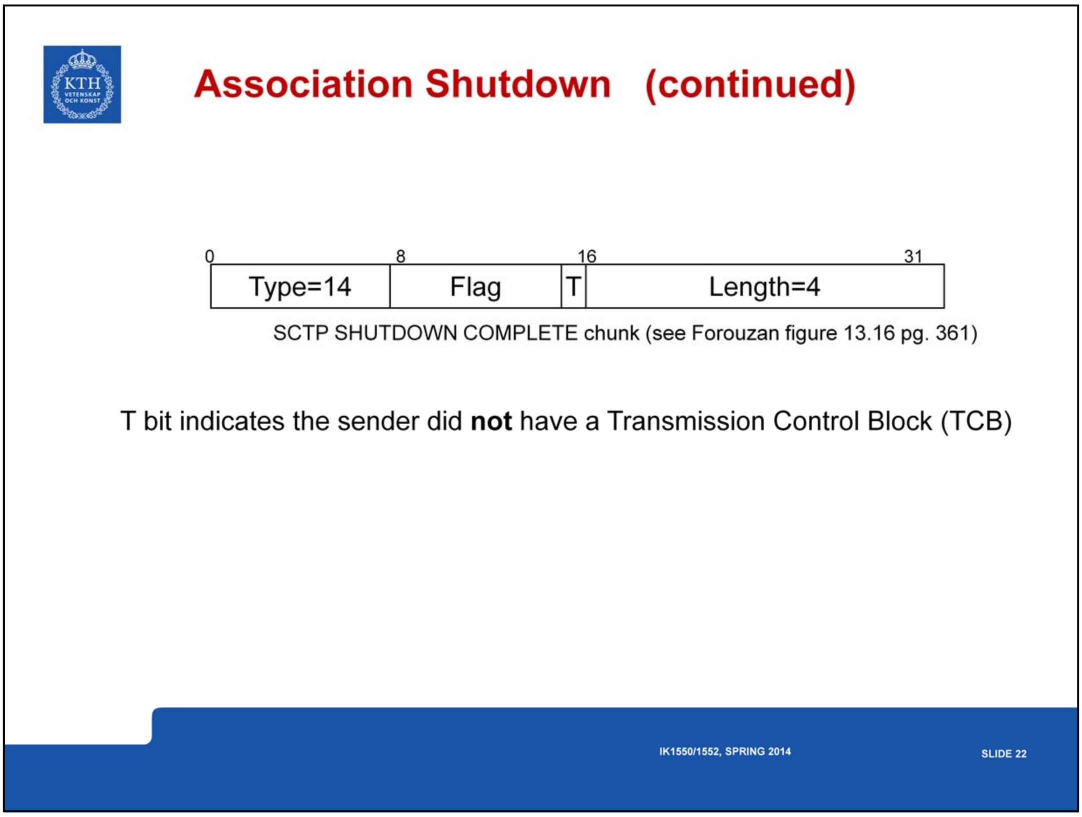
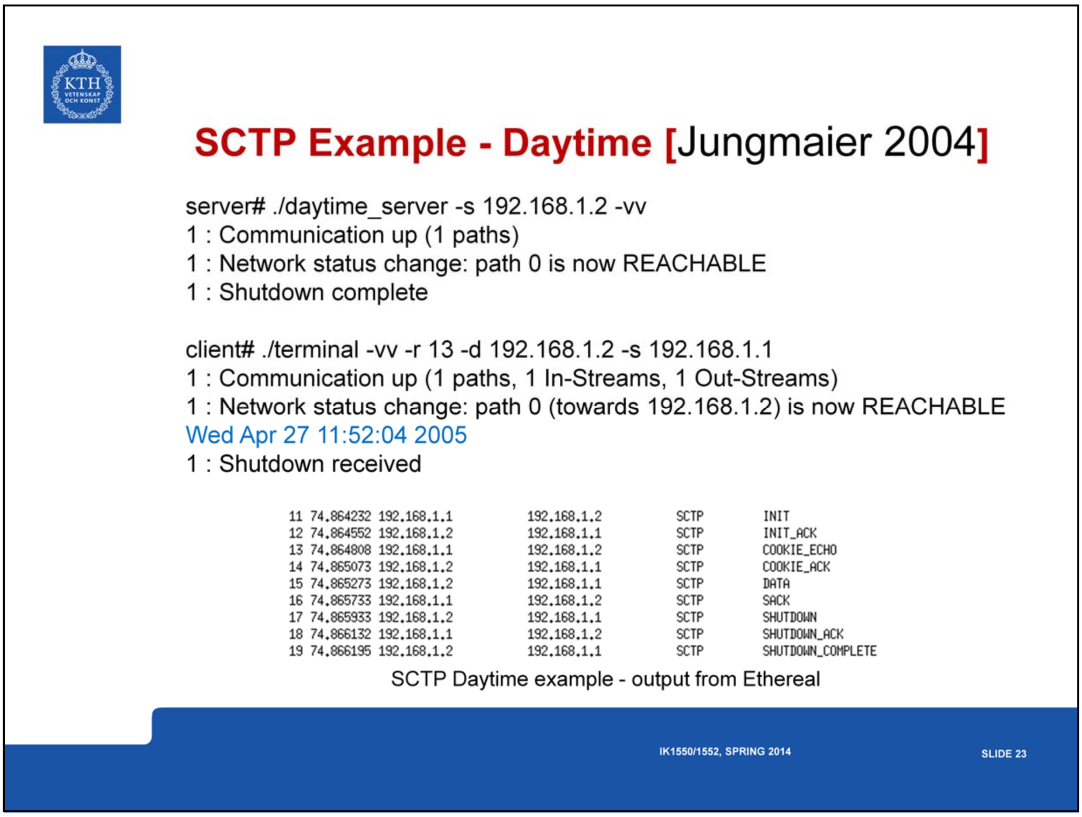


Association Shutdown (continued)

0	8	16	31
Type=14	Flag	T	Length=4

SCTP SHUTDOWN COMPLETE chunk (see Forouzan figure 13.16 pg. 361)

T bit indicates the sender did **not** have a Transmission Control Block (TCB)



SCTP Example - Daytime [Jungmaier 2004]

```
server# ./daytime_server -s 192.168.1.2 -vv
1 : Communication up (1 paths)
1 : Network status change: path 0 is now REACHABLE
1 : Shutdown complete

client# ./terminal -vv -r 13 -d 192.168.1.2 -s 192.168.1.1
1 : Communication up (1 paths, 1 In-Streams, 1 Out-Streams)
1 : Network status change: path 0 (towards 192.168.1.2) is now REACHABLE
Wed Apr 27 11:52:04 2005
1 : Shutdown received
```

```
11 74.864232 192.168.1.1        192.168.1.2        SCTP       INIT
12 74.864552 192.168.1.2        192.168.1.1        SCTP       INIT_ACK
13 74.864808 192.168.1.1        192.168.1.2        SCTP       COOKIE_ECHO
14 74.865073 192.168.1.2        192.168.1.1        SCTP       COOKIE_ACK
15 74.865273 192.168.1.2        192.168.1.1        SCTP       DATA
16 74.865733 192.168.1.1        192.168.1.2        SCTP       SACK
17 74.865933 192.168.1.2        192.168.1.1        SCTP       SHUTDOWN
18 74.866132 192.168.1.1        192.168.1.2        SCTP       SHUTDOWN_ACK
19 74.866195 192.168.1.2        192.168.1.1        SCTP       SHUTDOWN_COMPLETE
```

SCTP Daytime example - output from Ethereal

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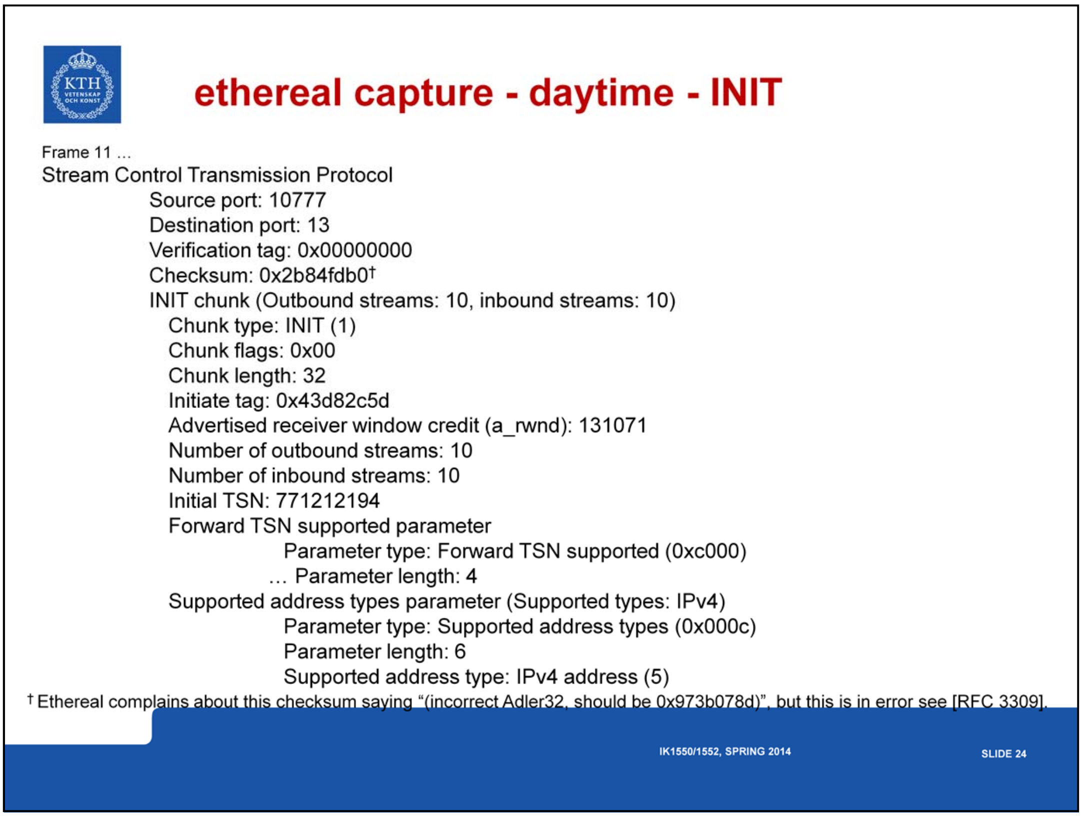
Andreas Jungmaier , Herbert Hölzlwimmer, Michael Tüxen , and Thomas Dreibholz, "sctplib-1.0.2", Siemens AG and the Institute of Computer Networking Technology, University of Essen, Germany, August 2004 http://www.sctp.de/sctp-download.html {Note that a later version 1.0.3 was released March 4th, 2005}



ethereal capture - daytime - INIT

```
Frame 11 …
Stream Control Transmission Protocol
            Source port: 10777
            Destination port: 13
            Verification tag: 0x00000000
            Checksum: 0x2b84fdb0†
            INIT chunk (Outbound streams: 10, inbound streams: 10)
              Chunk type: INIT (1)
              Chunk flags: 0x00
              Chunk length: 32
              Initiate tag: 0x43d82c5d
              Advertised receiver window credit (a_rwnd): 131071
              Number of outbound streams: 10
              Number of inbound streams: 10
              Initial TSN: 771212194
              Forward TSN supported parameter
                          Parameter type: Forward TSN supported (0xc000)
                        … Parameter length: 4
              Supported address types parameter (Supported types: IPv4)
                          Parameter type: Supported address types (0x000c)
                          Parameter length: 6
                          Supported address type: IPv4 address (5)
```

† Ethereal complains about this checksum saying “(incorrect Adler32, should be 0x973b078d)”, but this is in error see [RFC 3309].

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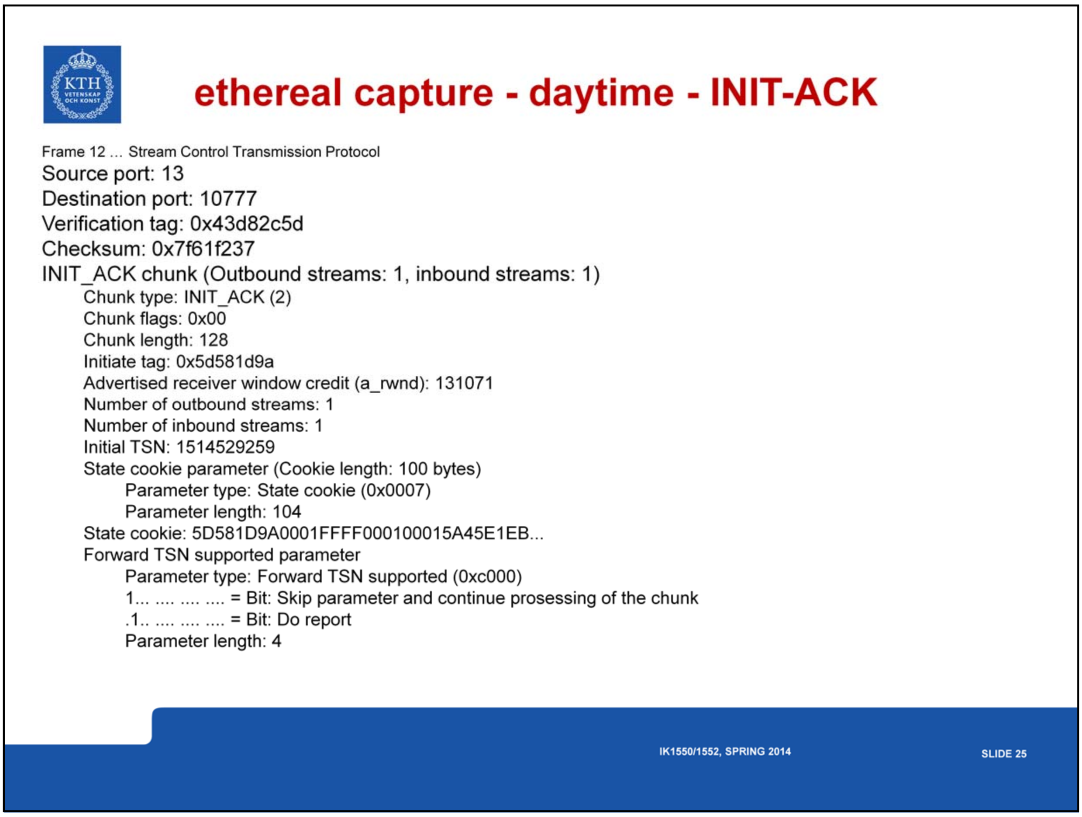
J. Stone, R. Stewart, and D. Otis, ‘Stream Control Transmission Protocol (SCTP) Checksum Change’, *Internet Request for Comments*, vol. RFC 3309 (Proposed Standard), Sep. 2002 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3309.txt



ethereal capture - daytime - INIT-ACK

```
Frame 12 … Stream Control Transmission Protocol
Source port: 13
Destination port: 10777
Verification tag: 0x43d82c5d
Checksum: 0x7f61f237
INIT_ACK chunk (Outbound streams: 1, inbound streams: 1)
    Chunk type: INIT_ACK (2)
    Chunk flags: 0x00
    Chunk length: 128
    Initiate tag: 0x5d581d9a
    Advertised receiver window credit (a_rwnd): 131071
    Number of outbound streams: 1
    Number of inbound streams: 1
    Initial TSN: 1514529259
    State cookie parameter (Cookie length: 100 bytes)
        Parameter type: State cookie (0x0007)
        Parameter length: 104
    State cookie: 5D581D9A0001FFFF000100015A45E1EB...
    Forward TSN supported parameter
        Parameter type: Forward TSN supported (0xc000)
        1... .... .... .... = Bit: Skip parameter and continue prosessing of the chunk
        .1.. .... .... .... = Bit: Do report
        Parameter length: 4
```

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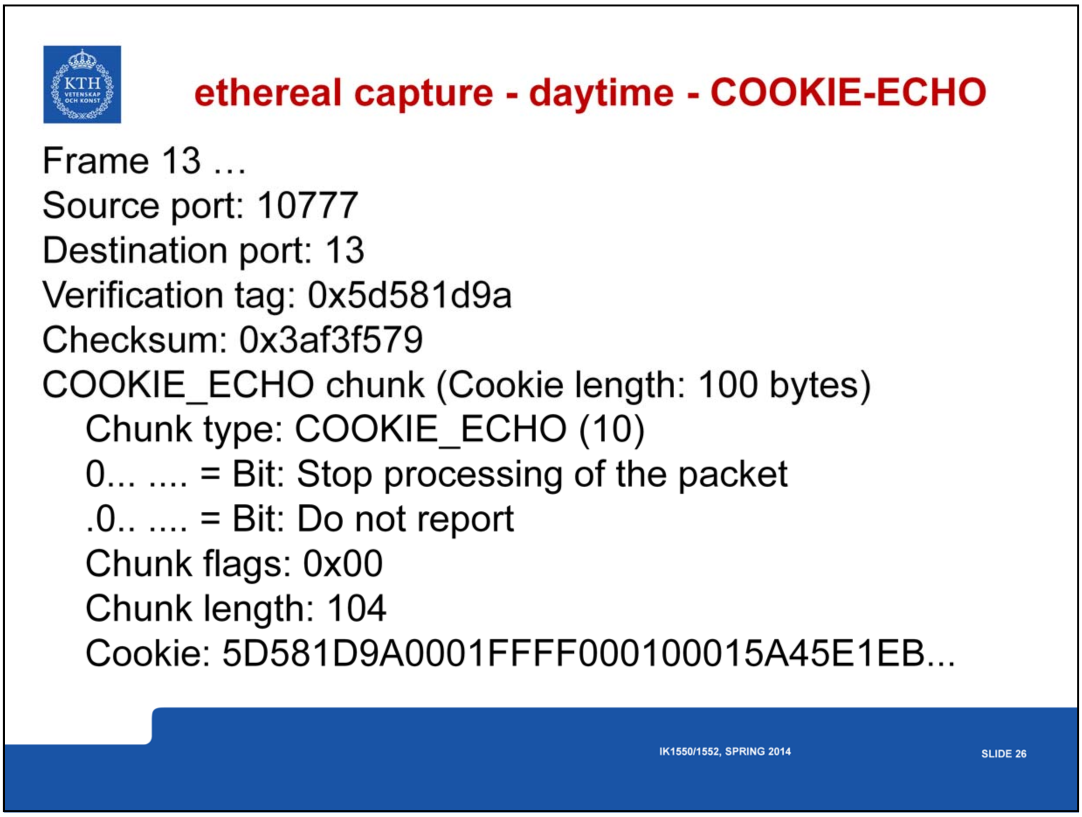
J. Stone, R. Stewart, and D. Otis, ‘Stream Control Transmission Protocol (SCTP) Checksum Change’, *Internet Request for Comments*, vol. RFC 3309 (Proposed Standard), Sep. 2002 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3309.txt



ethereal capture - daytime - COOKIE-ECHO

```
Frame 13 …
Source port: 10777
Destination port: 13
Verification tag: 0x5d581d9a
Checksum: 0x3af3f579
COOKIE_ECHO chunk (Cookie length: 100 bytes)
    Chunk type: COOKIE_ECHO (10)
    0... .... = Bit: Stop processing of the packet
    .0.. .... = Bit: Do not report
    Chunk flags: 0x00
    Chunk length: 104
    Cookie: 5D581D9A0001FFFF000100015A45E1EB...
```

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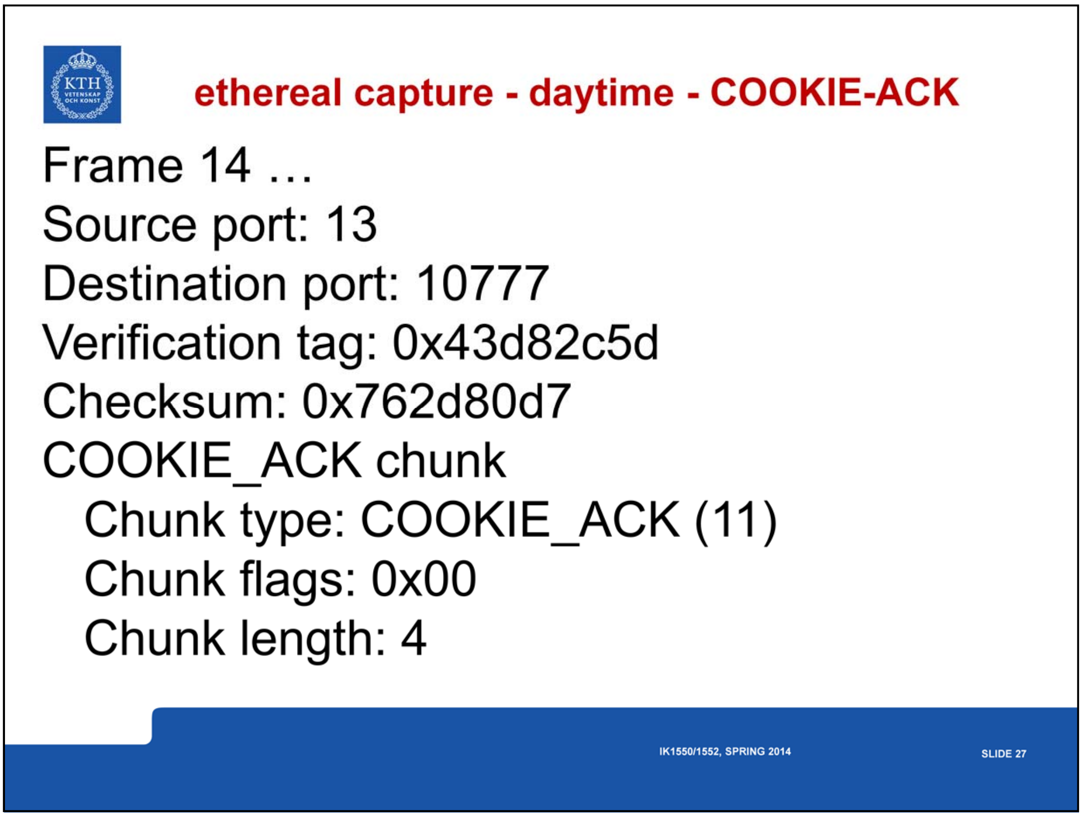
J. Stone, R. Stewart, and D. Otis, ‘Stream Control Transmission Protocol (SCTP) Checksum Change’, *Internet Request for Comments*, vol. RFC 3309 (Proposed Standard), Sep. 2002 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3309.txt



ethereal capture - daytime - COOKIE-ACK

Frame 14 …
Source port: 13
Destination port: 10777
Verification tag: 0x43d82c5d
Checksum: 0x762d80d7
COOKIE_ACK chunk
    Chunk type: COOKIE_ACK (11)
    Chunk flags: 0x00
    Chunk length: 4

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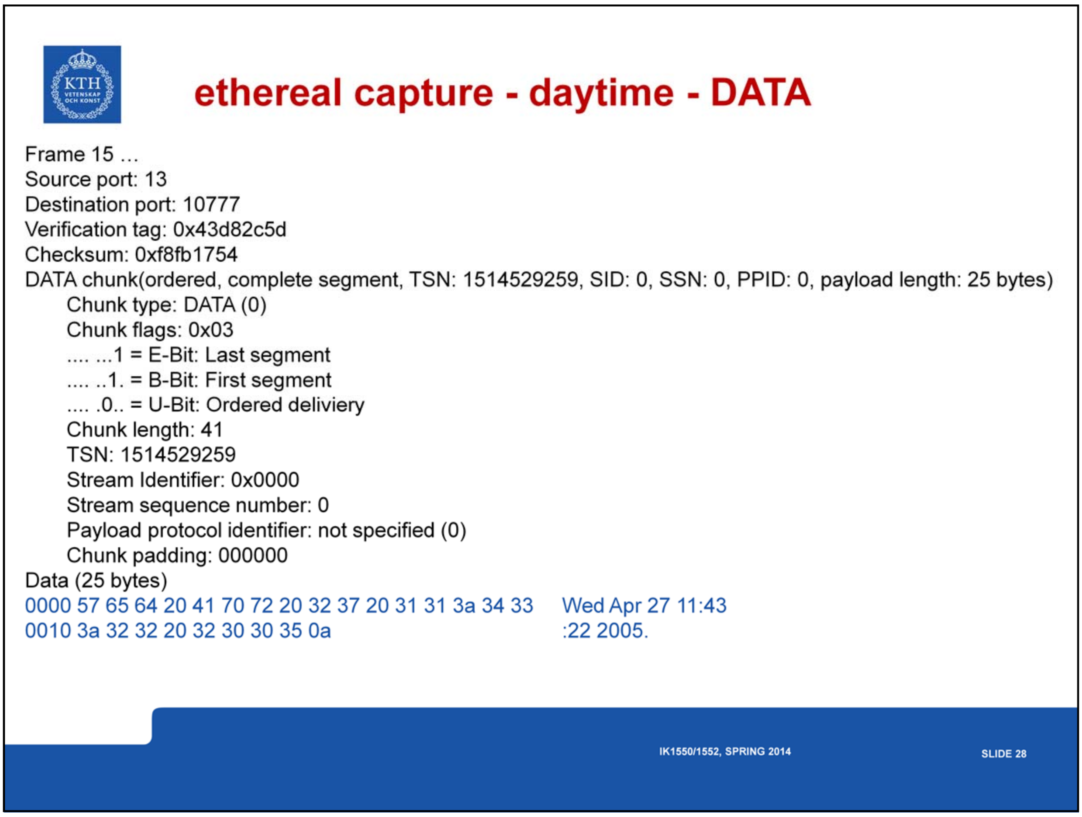
J. Stone, R. Stewart, and D. Otis, ‘Stream Control Transmission Protocol (SCTP) Checksum Change’, *Internet Request for Comments*, vol. RFC 3309 (Proposed Standard), Sep. 2002 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3309.txt



ethereal capture - daytime - DATA

```
Frame 15 …
Source port: 13
Destination port: 10777
Verification tag: 0x43d82c5d
Checksum: 0xf8fb1754
DATA chunk(ordered, complete segment, TSN: 1514529259, SID: 0, SSN: 0, PPID: 0, payload length: 25 bytes)
      Chunk type: DATA (0)
      Chunk flags: 0x03
      .... ...1 = E-Bit: Last segment
      .... ..1. = B-Bit: First segment
      .... .0.. = U-Bit: Ordered deliviery
      Chunk length: 41
      TSN: 1514529259
      Stream Identifier: 0x0000
      Stream sequence number: 0
      Payload protocol identifier: not specified (0)
      Chunk padding: 000000
Data (25 bytes)
0000 57 65 64 20 41 70 72 20 32 37 20 31 31 3a 34 33    Wed Apr 27 11:43
0010 3a 32 32 20 32 30 30 35 0a                         :22 2005.
```

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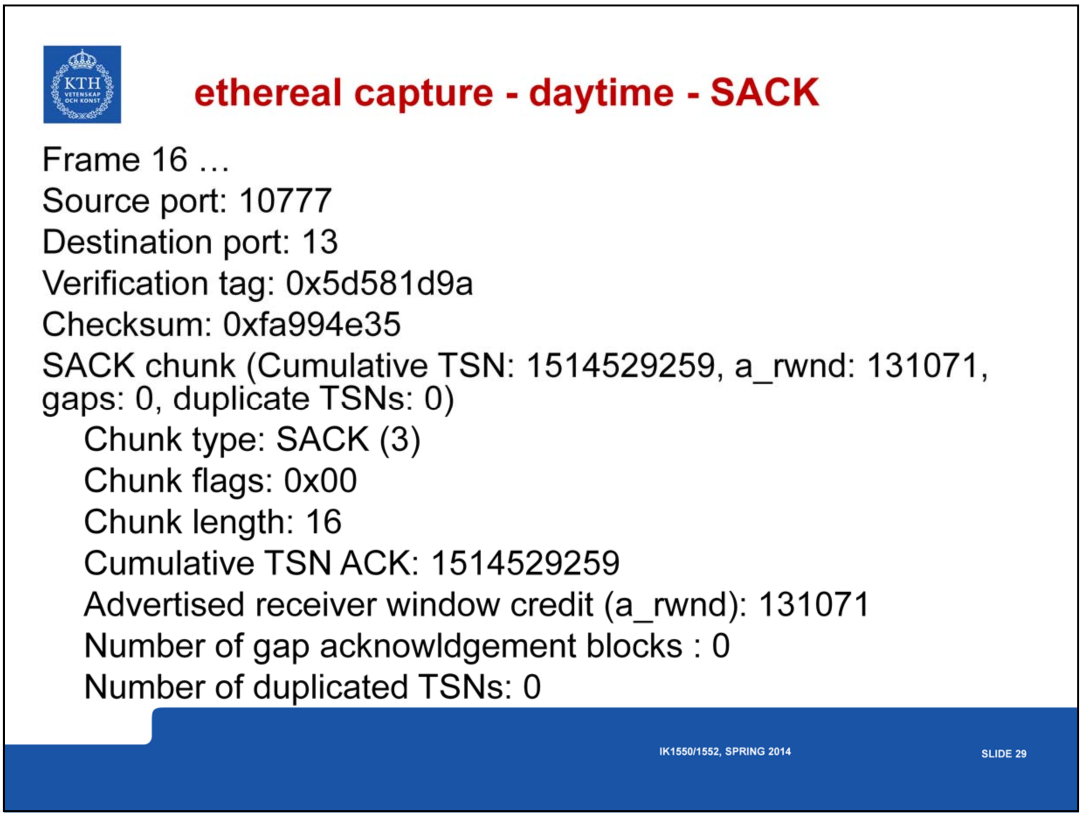
J. Stone, R. Stewart, and D. Otis, ‘Stream Control Transmission Protocol (SCTP) Checksum Change’, *Internet Request for Comments*, vol. RFC 3309 (Proposed Standard), Sep. 2002 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3309.txt



ethereal capture - daytime - SACK

```
Frame 16 …
Source port: 10777
Destination port: 13
Verification tag: 0x5d581d9a
Checksum: 0xfa994e35
SACK chunk (Cumulative TSN: 1514529259, a_rwnd: 131071,
gaps: 0, duplicate TSNs: 0)
    Chunk type: SACK (3)
    Chunk flags: 0x00
    Chunk length: 16
    Cumulative TSN ACK: 1514529259
    Advertised receiver window credit (a_rwnd): 131071
    Number of gap acknowldgement blocks : 0
    Number of duplicated TSNs: 0
```

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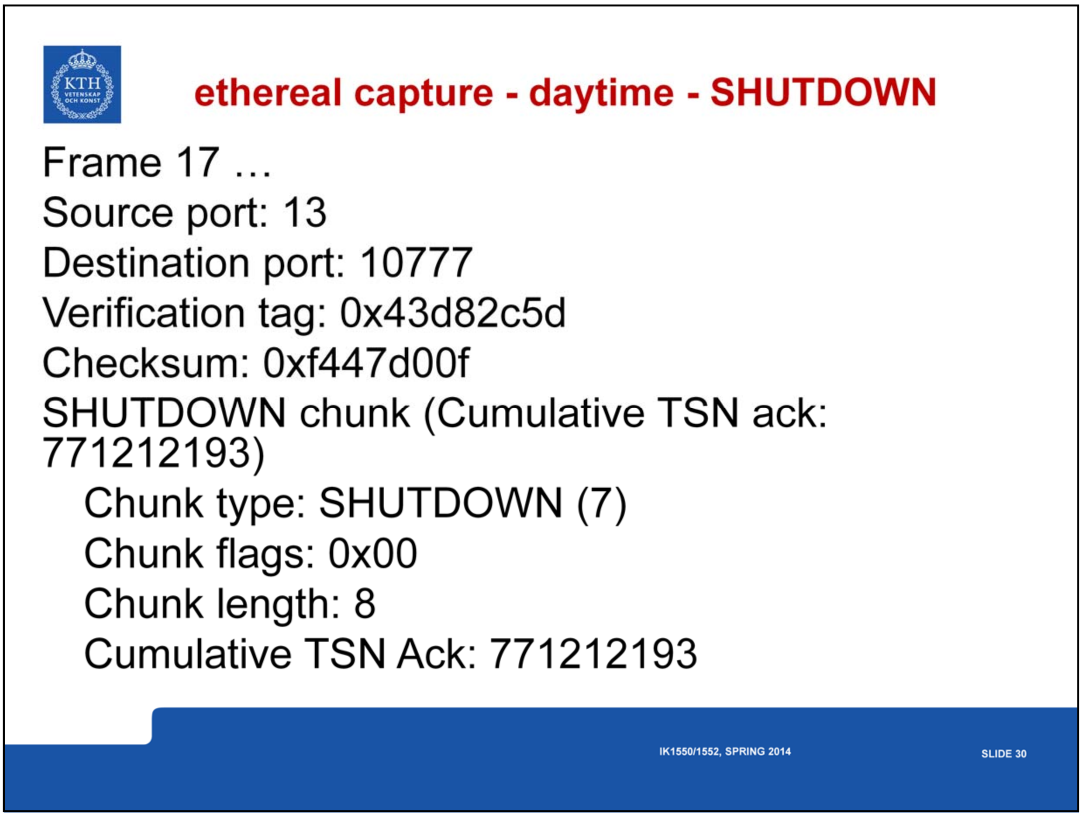
J. Stone, R. Stewart, and D. Otis, ‘Stream Control Transmission Protocol (SCTP) Checksum Change’, *Internet Request for Comments*, vol. RFC 3309 (Proposed Standard), Sep. 2002 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3309.txt



ethereal capture - daytime - SHUTDOWN

Frame 17 …

Source port: 13

Destination port: 10777

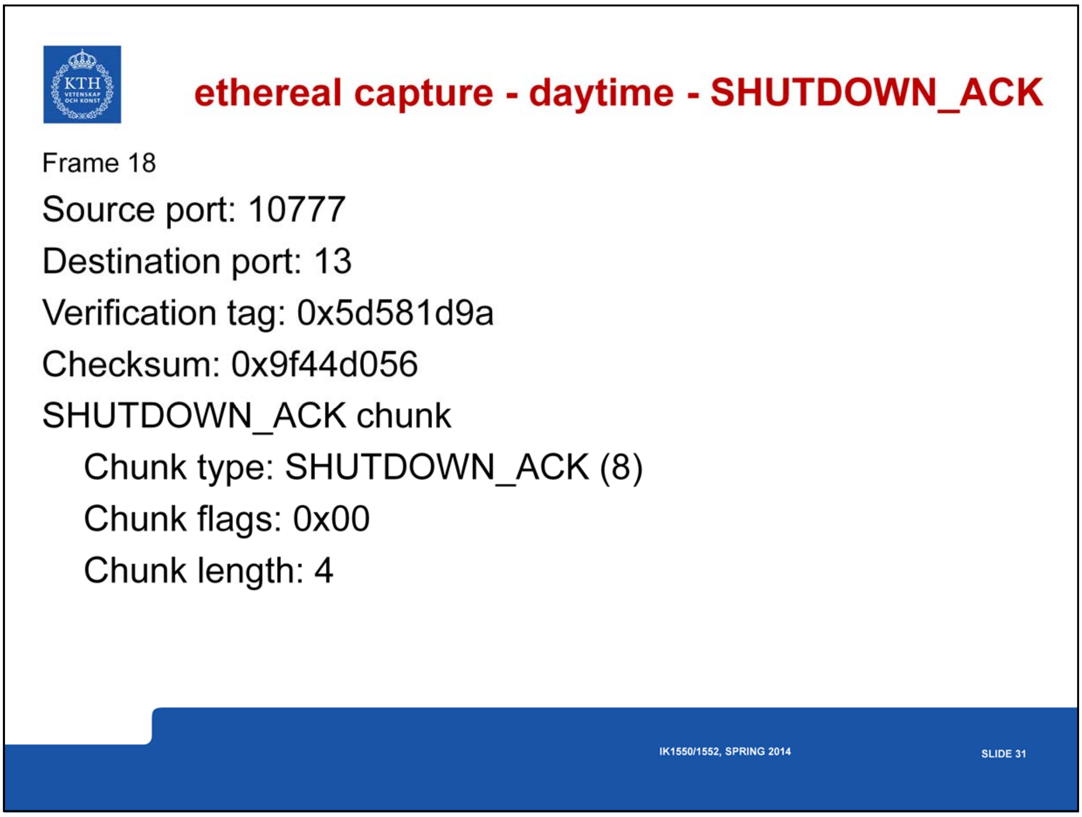
Verification tag: 0x43d82c5d

Checksum: 0xf447d00f

SHUTDOWN chunk (Cumulative TSN ack: 771212193)

- Chunk type: SHUTDOWN (7)
- Chunk flags: 0x00
- Chunk length: 8
- Cumulative TSN Ack: 771212193

J. Stone, R. Stewart, and D. Otis, ‘Stream Control Transmission Protocol (SCTP) Checksum Change’, *Internet Request for Comments*, vol. RFC 3309 (Proposed Standard), Sep. 2002 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3309.txt



ethereal capture - daytime - SHUTDOWN_ACK

Frame 18

Source port: 10777

Destination port: 13

Verification tag: 0x5d581d9a

Checksum: 0x9f44d056

SHUTDOWN_ACK chunk

- Chunk type: SHUTDOWN_ACK (8)
- Chunk flags: 0x00
- Chunk length: 4

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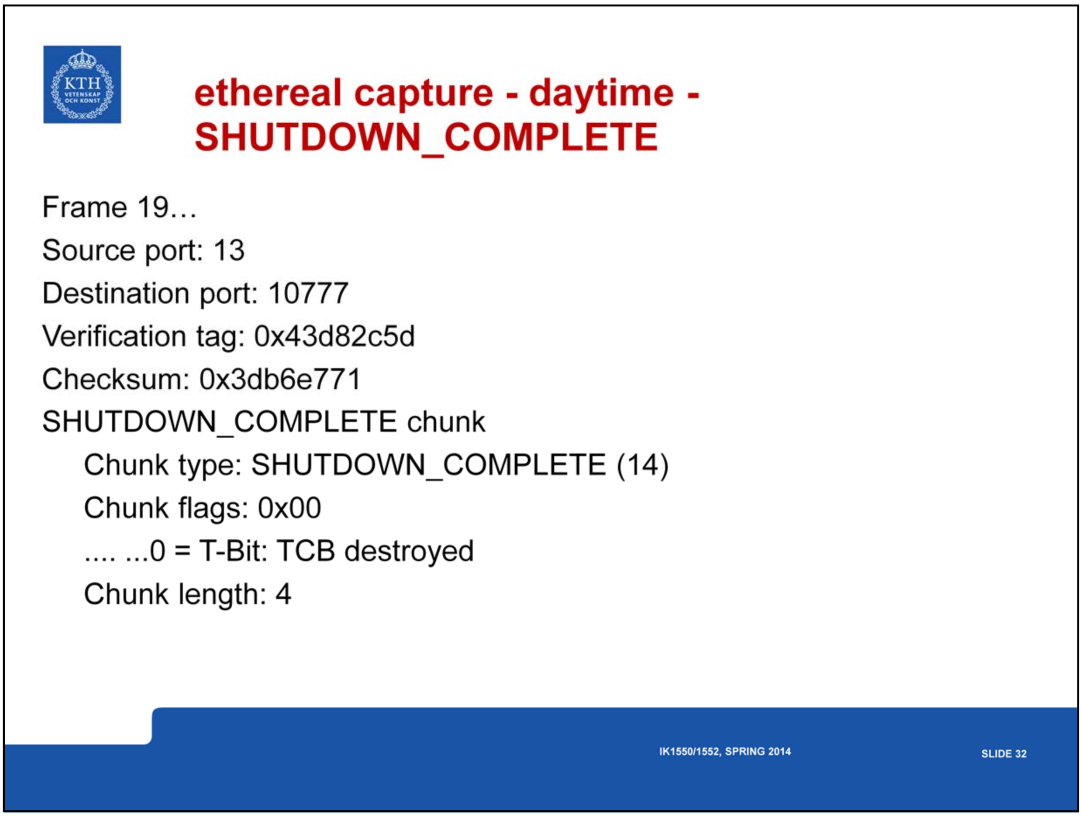
J. Stone, R. Stewart, and D. Otis, ‘Stream Control Transmission Protocol (SCTP) Checksum Change’, *Internet Request for Comments*, vol. RFC 3309 (Proposed Standard), Sep. 2002 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3309.txt



ethereal capture - daytime - SHUTDOWN_COMPLETE

Frame 19…

Source port: 13

Destination port: 10777

Verification tag: 0x43d82c5d

Checksum: 0x3db6e771

SHUTDOWN_COMPLETE chunk

- Chunk type: SHUTDOWN_COMPLETE (14)
- Chunk flags: 0x00
- ....0 = T-Bit: TCB destroyed
- Chunk length: 4

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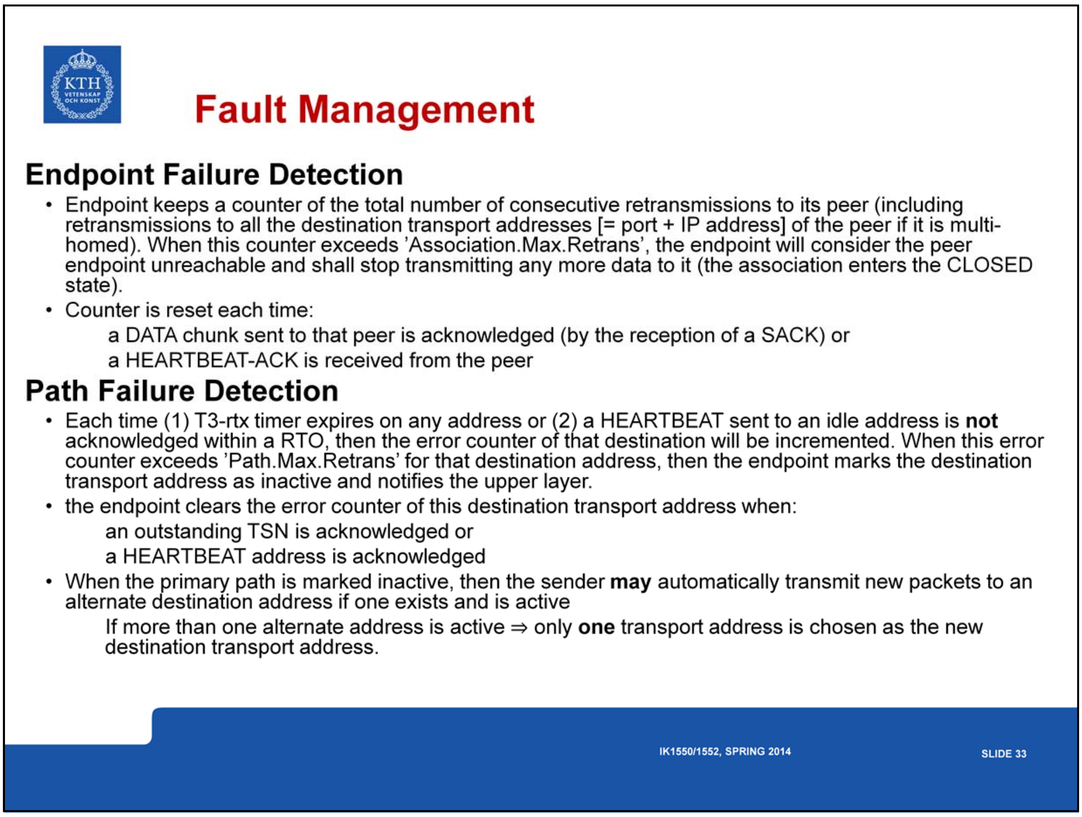
J. Stone, R. Stewart, and D. Otis, ‘Stream Control Transmission Protocol (SCTP) Checksum Change’, *Internet Request for Comments*, vol. RFC 3309 (Proposed Standard), Sep. 2002 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3309.txt



Fault Management

Endpoint Failure Detection

- Endpoint keeps a counter of the total number of consecutive retransmissions to its peer (including retransmissions to all the destination transport addresses [= port + IP address] of the peer if it is multi-homed). When this counter exceeds 'Association.Max.Retrans', the endpoint will consider the peer endpoint unreachable and shall stop transmitting any more data to it (the association enters the CLOSED state).
- Counter is reset each time:
  - a DATA chunk sent to that peer is acknowledged (by the reception of a SACK) or
  - a HEARTBEAT-ACK is received from the peer

Path Failure Detection

- Each time (1) T3-rtx timer expires on any address or (2) a HEARTBEAT sent to an idle address is **not** acknowledged within a RTO, then the error counter of that destination will be incremented. When this error counter exceeds 'Path.Max.Retrans' for that destination address, then the endpoint marks the destination transport address as inactive and notifies the upper layer.
- the endpoint clears the error counter of this destination transport address when:
  - an outstanding TSN is acknowledged or
  - a HEARTBEAT address is acknowledged
- When the primary path is marked inactive, then the sender **may** automatically transmit new packets to an alternate destination address if one exists and is active
  - If more than one alternate address is active ⇒ only **one** transport address is chosen as the new destination transport address.

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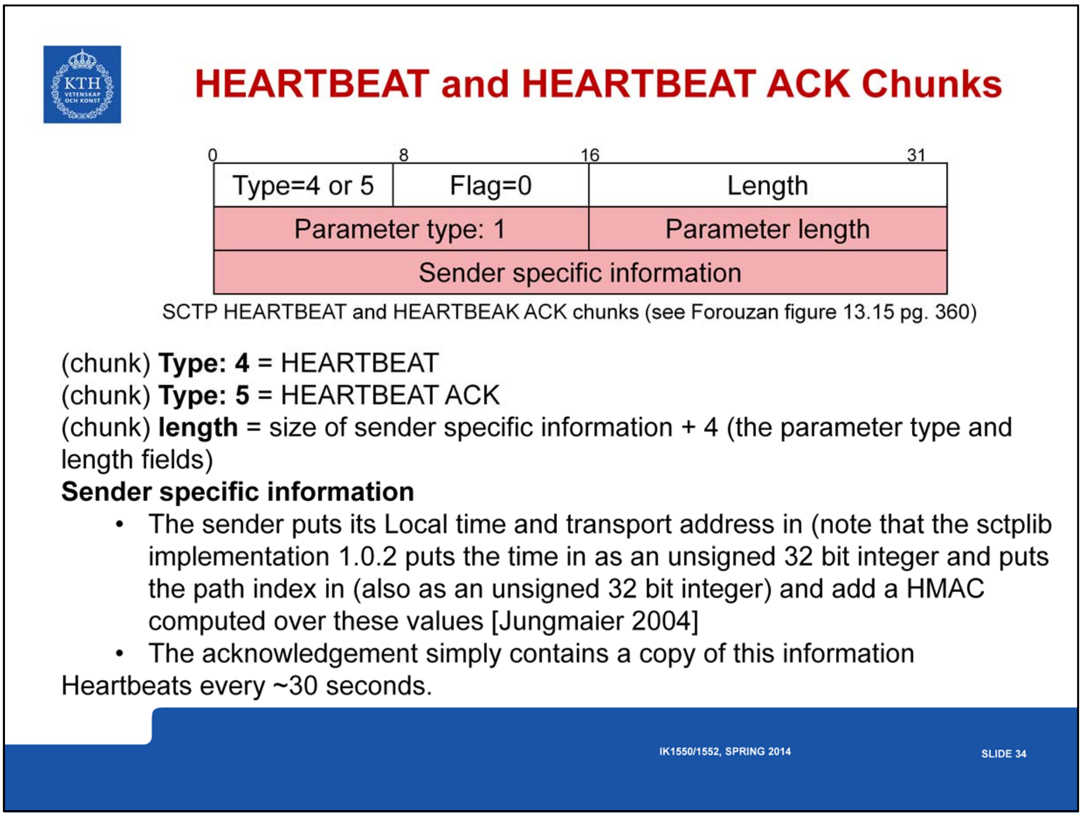

HEARTBEAT and HEARTBEAT ACK Chunks

<table>
<tr><th>0</th><th>8</th><th>16</th><th>31</th></tr>
<tr><td>Type=4 or 5</td><td>Flag=0</td><td colspan="2">Length</td></tr>
<tr><td colspan="2">Parameter type: 1</td><td colspan="2">Parameter length</td></tr>
<tr><td colspan="4">Sender specific information</td></tr>
</table>

SCTP HEARTBEAT and HEARTBEAK ACK chunks (see Forouzan figure 13.15 pg. 360)

(chunk) **Type: 4** = HEARTBEAT
(chunk) **Type: 5** = HEARTBEAT ACK
(chunk) **length** = size of sender specific information + 4 (the parameter type and length fields)
Sender specific information

- The sender puts its Local time and transport address in (note that the sctplib implementation 1.0.2 puts the time in as an unsigned 32 bit integer and puts the path index in (also as an unsigned 32 bit integer) and add a HMAC computed over these values [Jungmaier 2004]
- The acknowledgement simply contains a copy of this information

Heartbeats every ~30 seconds.

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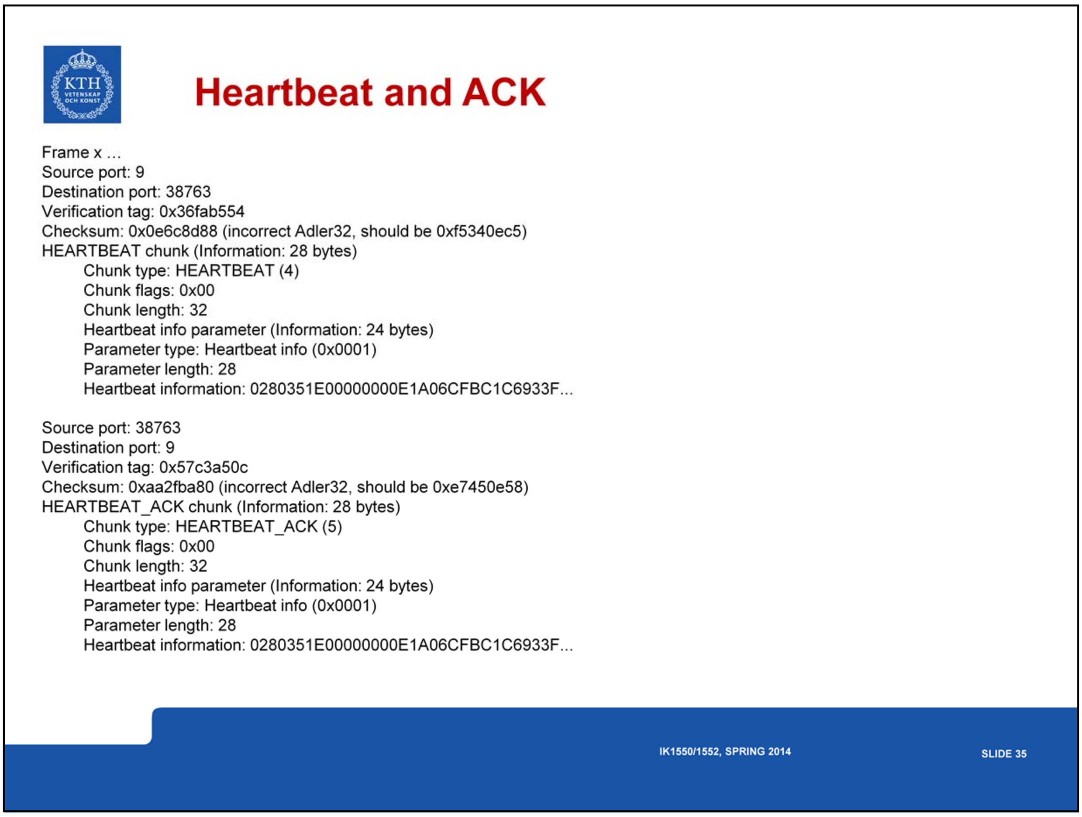
Andreas Jungmaier , Herbert Hölzlwimmer, Michael Tüxen , and Thomas Dreibholz, "sctplib-1.0.2", Siemens AG and the Institute of Computer Networking Technology, University of Essen, Germany, August 2004 http://www.sctp.de/sctp-download.html {Note that a later version 1.0.3 was released March 4th, 2005}



Heartbeat and ACK

```
Frame x …
Source port: 9
Destination port: 38763
Verification tag: 0x36fab554
Checksum: 0x0e6c8d88 (incorrect Adler32, should be 0xf5340ec5)
HEARTBEAT chunk (Information: 28 bytes)
        Chunk type: HEARTBEAT (4)
        Chunk flags: 0x00
        Chunk length: 32
        Heartbeat info parameter (Information: 24 bytes)
        Parameter type: Heartbeat info (0x0001)
        Parameter length: 28
        Heartbeat information: 0280351E00000000E1A06CFBC1C6933F…

Source port: 38763
Destination port: 9
Verification tag: 0x57c3a50c
Checksum: 0xaa2fba80 (incorrect Adler32, should be 0xe7450e58)
HEARTBEAT_ACK chunk (Information: 28 bytes)
        Chunk type: HEARTBEAT_ACK (5)
        Chunk flags: 0x00
        Chunk length: 32
        Heartbeat info parameter (Information: 24 bytes)
        Parameter type: Heartbeat info (0x0001)
        Parameter length: 28
        Heartbeat information: 0280351E00000000E1A06CFBC1C6933F…
```

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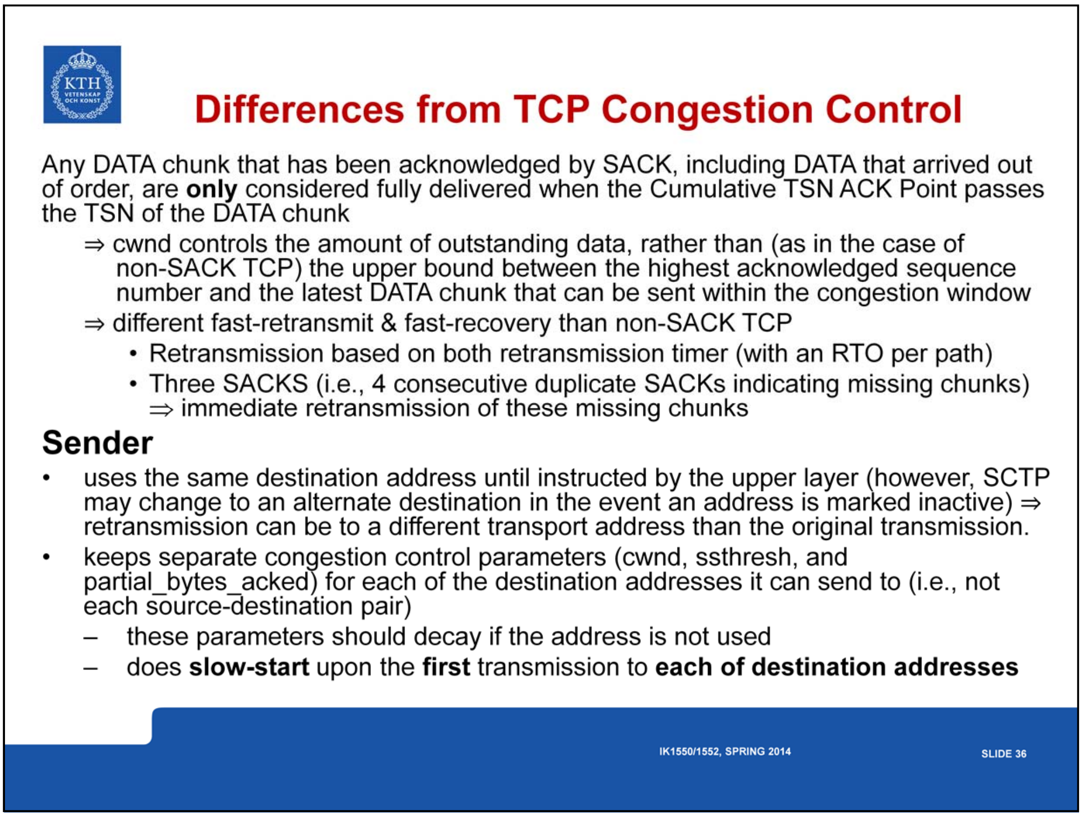
J. Stone, R. Stewart, and D. Otis, ‘Stream Control Transmission Protocol (SCTP) Checksum Change’, *Internet Request for Comments*, vol. RFC 3309 (Proposed Standard), Sep. 2002 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3309.txt



Differences from TCP Congestion Control

Any DATA chunk that has been acknowledged by SACK, including DATA that arrived out of order, are **only** considered fully delivered when the Cumulative TSN ACK Point passes the TSN of the DATA chunk

⇒ cwnd controls the amount of outstanding data, rather than (as in the case of non-SACK TCP) the upper bound between the highest acknowledged sequence number and the latest DATA chunk that can be sent within the congestion window

⇒ different fast-retransmit & fast-recovery than non-SACK TCP

- Retransmission based on both retransmission timer (with an RTO per path)
- Three SACKS (i.e., 4 consecutive duplicate SACKs indicating missing chunks) ⇒ immediate retransmission of these missing chunks

Sender

- uses the same destination address until instructed by the upper layer (however, SCTP may change to an alternate destination in the event an address is marked inactive) ⇒ retransmission can be to a different transport address than the original transmission.
- keeps separate congestion control parameters (cwnd, ssthresh, and partial_bytes_acked) for each of the destination addresses it can send to (i.e., not each source-destination pair)
  - these parameters should decay if the address is not used
  - does **slow-start** upon the **first** transmission to **each of destination addresses**

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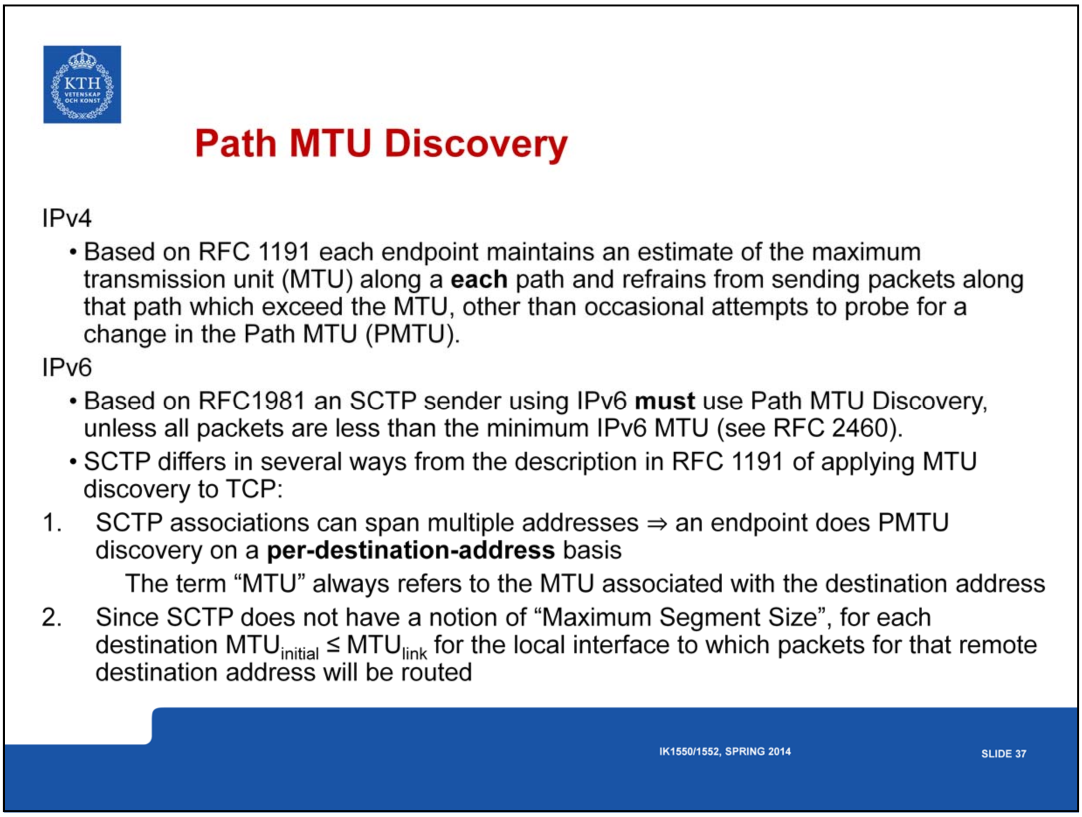

Path MTU Discovery

IPv4

- Based on RFC 1191 each endpoint maintains an estimate of the maximum transmission unit (MTU) along a **each** path and refrains from sending packets along that path which exceed the MTU, other than occasional attempts to probe for a change in the Path MTU (PMTU).

IPv6

- Based on RFC1981 an SCTP sender using IPv6 **must** use Path MTU Discovery, unless all packets are less than the minimum IPv6 MTU (see RFC 2460).
- SCTP differs in several ways from the description in RFC 1191 of applying MTU discovery to TCP:

1. SCTP associations can span multiple addresses ⇒ an endpoint does PMTU discovery on a **per-destination-address** basis

   The term “MTU” always refers to the MTU associated with the destination address
2. Since SCTP does not have a notion of “Maximum Segment Size”, for each destination $\mathrm{MTU}_{\mathrm{initial}} \leq \mathrm{MTU}_{\mathrm{link}}$ for the local interface to which packets for that remote destination address will be routed

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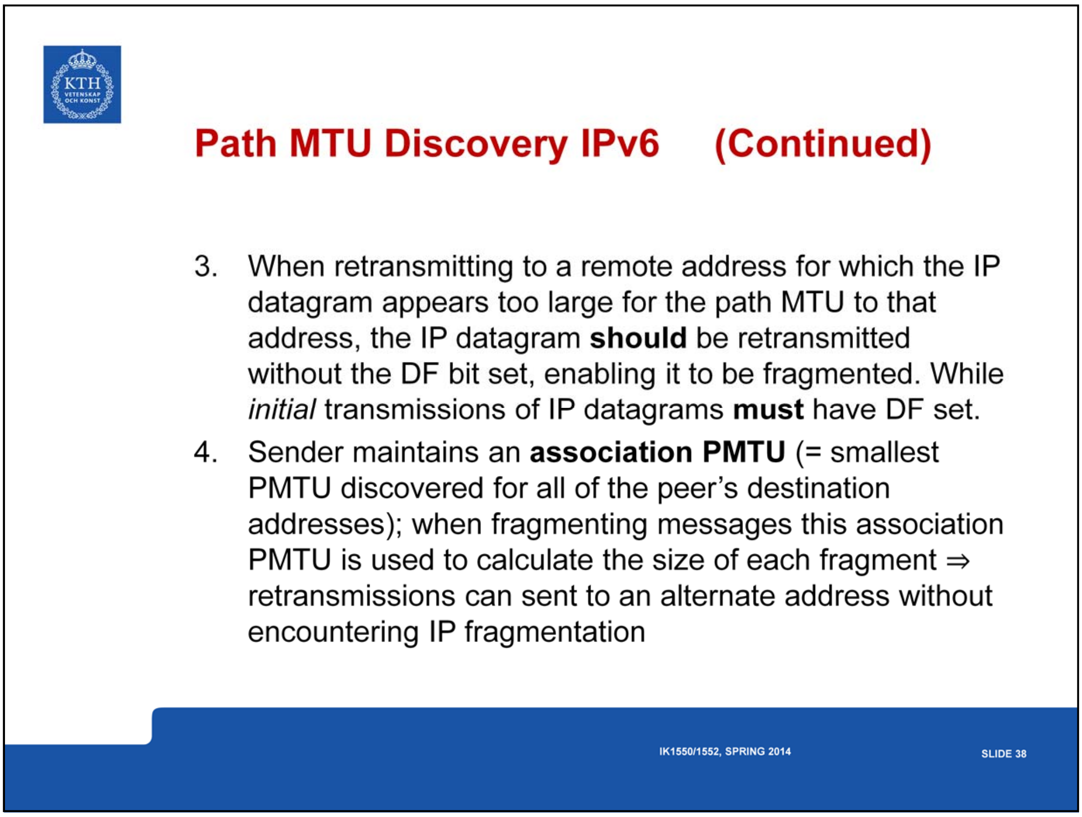
J. C. Mogul and S. E. Deering, ‘Path MTU discovery’, *Internet Request for Comments*, vol. RFC 1191 (Draft Standard), Nov. 1990 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1191.txt

J. McCann, S. Deering, and J. Mogul, ‘Path MTU Discovery for IP version 6’, *Internet Request for Comments*, vol. RFC 1981 (Draft Standard), Aug. 1996 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1981.txt

S. Deering and R. Hinden, ‘Internet Protocol, Version 6 (IPv6) Specification’, *Internet Request for Comments*, vol. RFC 2460 (Draft Standard), Dec. 1998 [Online]. Available: http://www.rfc-editor.org/rfc/rfc2460.txt



Path MTU Discovery IPv6 (Continued)

3. When retransmitting to a remote address for which the IP datagram appears too large for the path MTU to that address, the IP datagram **should** be retransmitted without the DF bit set, enabling it to be fragmented. While *initial* transmissions of IP datagrams **must** have DF set.
4. Sender maintains an **association PMTU** (= smallest PMTU discovered for all of the peer's destination addresses); when fragmenting messages this association PMTU is used to calculate the size of each fragment ⇒ retransmissions can sent to an alternate address without encountering IP fragmentation

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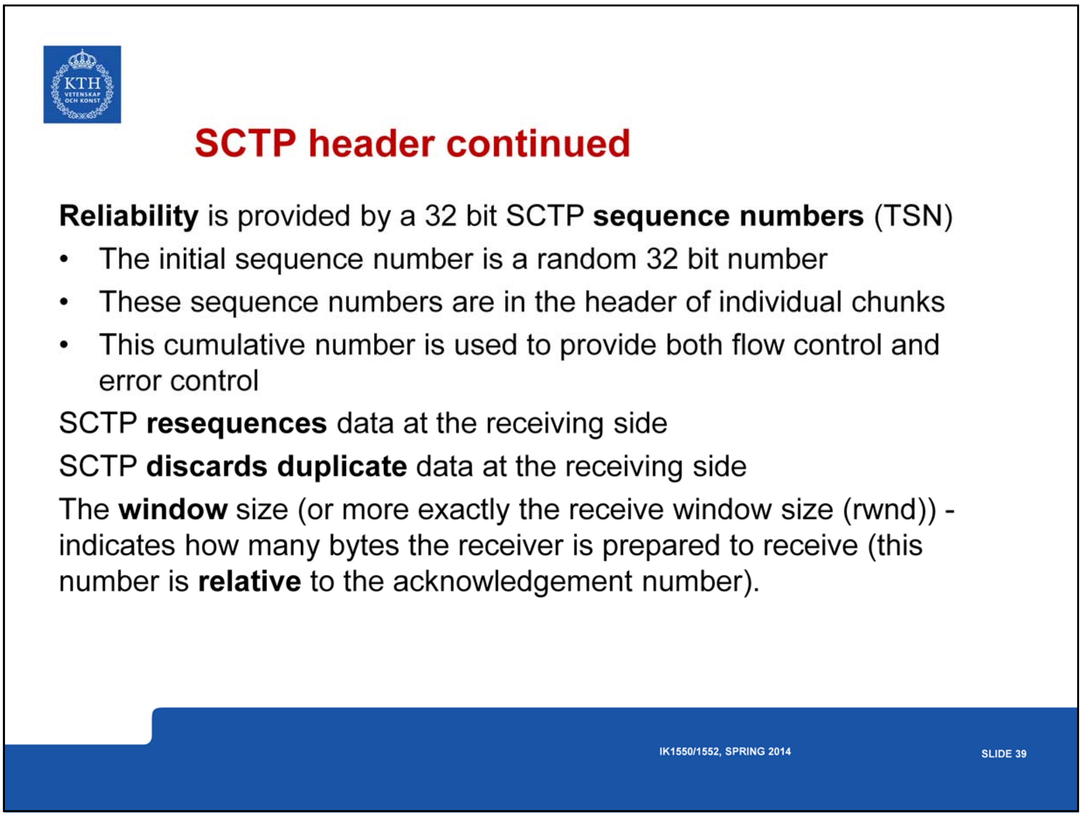

SCTP header continued

Reliability is provided by a 32 bit SCTP **sequence numbers** (TSN)

- The initial sequence number is a random 32 bit number
- These sequence numbers are in the header of individual chunks
- This cumulative number is used to provide both flow control and error control

SCTP **resequences** data at the receiving side

SCTP **discards duplicate** data at the receiving side

The **window** size (or more exactly the receive window size (rwnd)) - indicates how many bytes the receiver is prepared to receive (this number is **relative** to the acknowledgement number).

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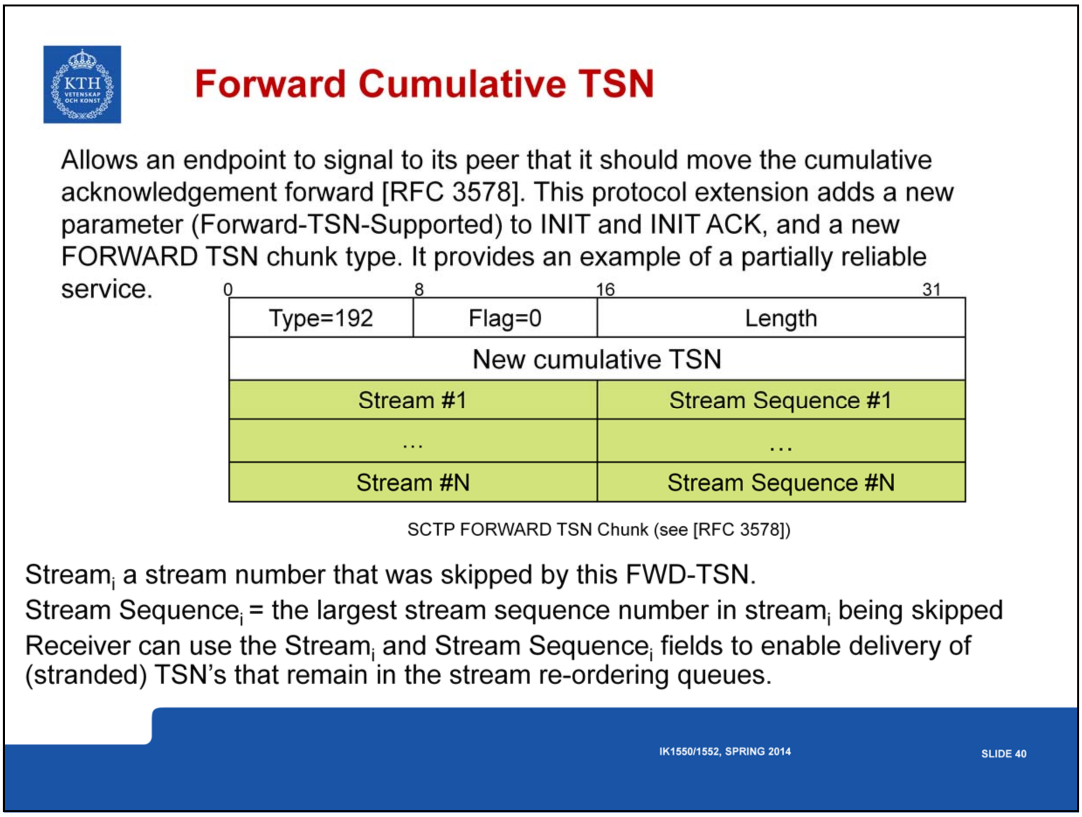

Forward Cumulative TSN

Allows an endpoint to signal to its peer that it should move the cumulative acknowledgement forward [RFC 3578]. This protocol extension adds a new parameter (Forward-TSN-Supported) to INIT and INIT ACK, and a new FORWARD TSN chunk type. It provides an example of a partially reliable service.

<table>
<tr><th>0</th><th>8</th><th colspan="2">16 31</th></tr>
<tr><td>Type=192</td><td>Flag=0</td><td colspan="2">Length</td></tr>
<tr><td colspan="4">New cumulative TSN</td></tr>
<tr><td colspan="2">Stream #1</td><td colspan="2">Stream Sequence #1</td></tr>
<tr><td colspan="2">…</td><td colspan="2">…</td></tr>
<tr><td colspan="2">Stream #N</td><td colspan="2">Stream Sequence #N</td></tr>
</table>

SCTP FORWARD TSN Chunk (see [RFC 3578])

Stream$_i$ a stream number that was skipped by this FWD-TSN.

Stream Sequence$_i$ = the largest stream sequence number in stream$_i$ being skipped

Receiver can use the Stream$_i$ and Stream Sequence$_i$ fields to enable delivery of (stranded) TSN's that remain in the stream re-ordering queues.

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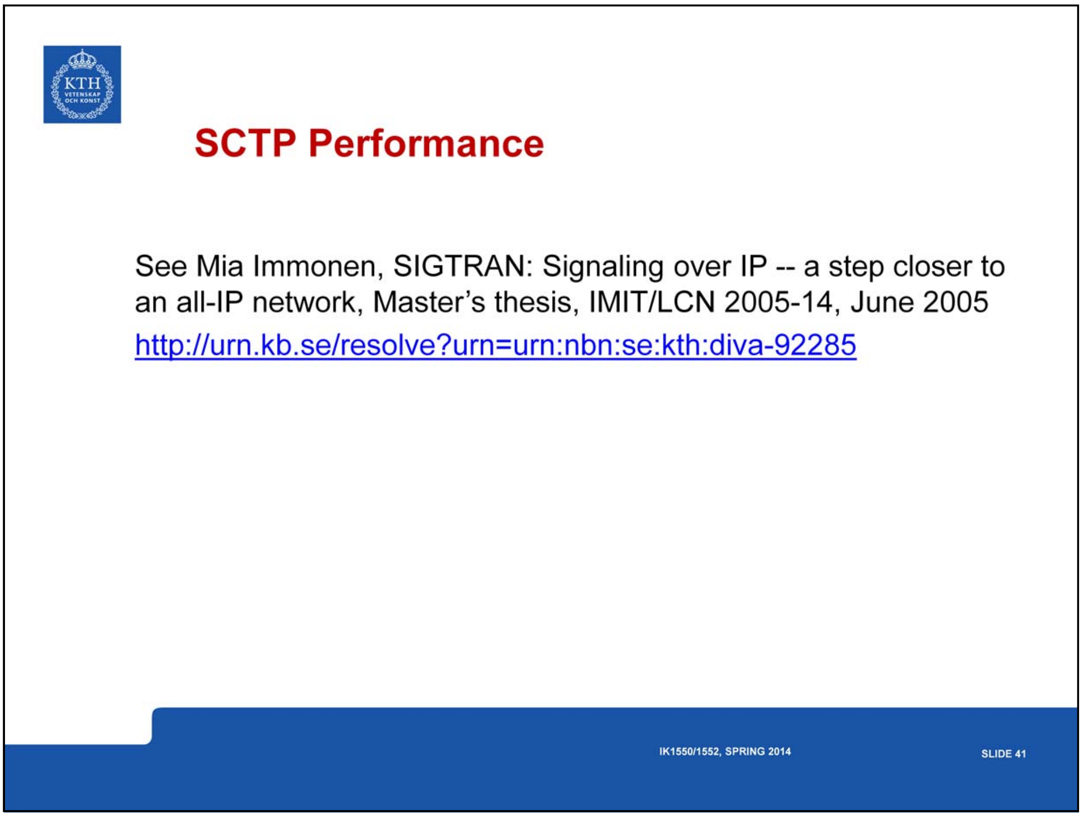
R. Stewart, M. Ramalho, Q. Xie, M. Tuexen, and P. Conrad, ‘Stream Control Transmission Protocol (SCTP) Partial Reliability Extension’, *Internet Request for Comments*, vol. RFC 3758 (Proposed Standard), May 2004 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3758.txt



SCTP Performance

See Mia Immonen, SIGTRAN: Signaling over IP -- a step closer to an all-IP network, Master’s thesis, IMIT/LCN 2005-14, June 2005

http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-92285

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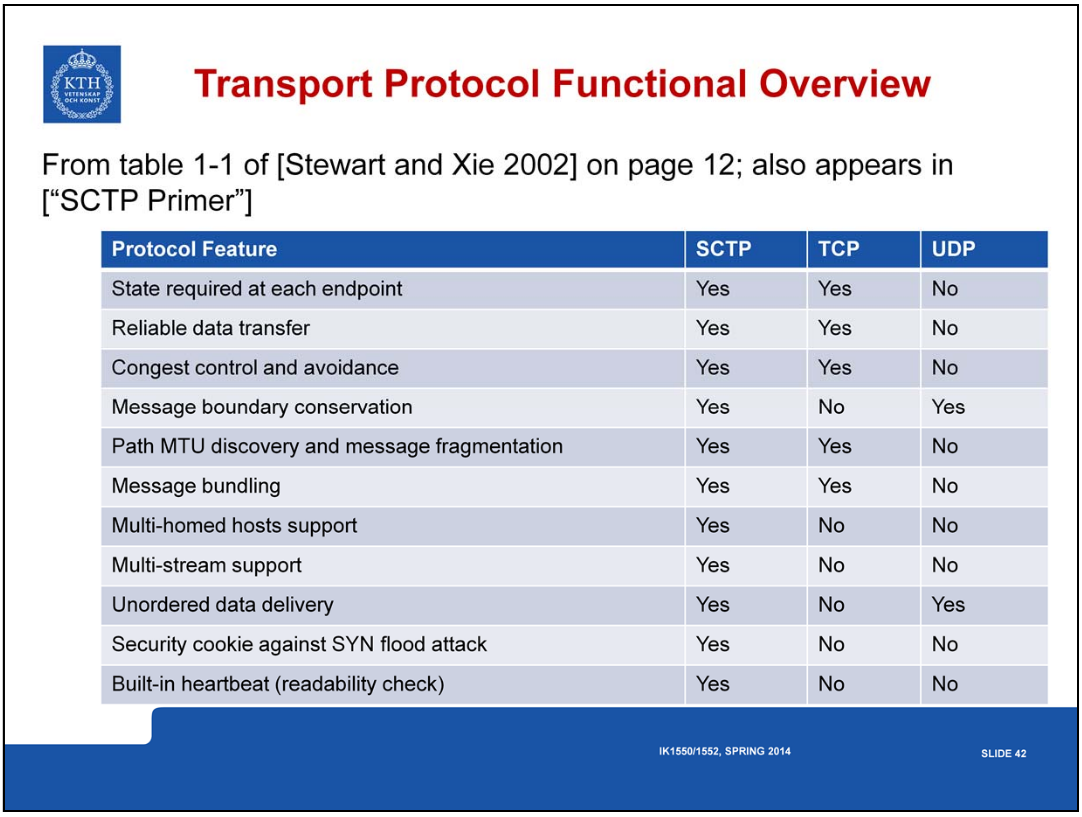
See Mia Immonen, SIGTRAN: Signaling over IP -- a step closer to an all-IP network, Master’s thesis, KTH Royal Institute of Technology, Institutionen för Mikroelektronik och Informationsteknik, IMIT/LCN 2005-14, June 2005

http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-92285



Transport Protocol Functional Overview

From table 1-1 of [Stewart and Xie 2002] on page 12; also appears in ["SCTP Primer"]

Protocol Feature	SCTP	TCP	UDP
State required at each endpoint	Yes	Yes	No
Reliable data transfer	Yes	Yes	No
Congest control and avoidance	Yes	Yes	No
Message boundary conservation	Yes	No	Yes
Path MTU discovery and message fragmentation	Yes	Yes	No
Message bundling	Yes	Yes	No
Multi-homed hosts support	Yes	No	No
Multi-stream support	Yes	No	No
Unordered data delivery	Yes	No	Yes
Security cookie against SYN flood attack	Yes	No	No
Built-in heartbeat (readability check)	Yes	No	No

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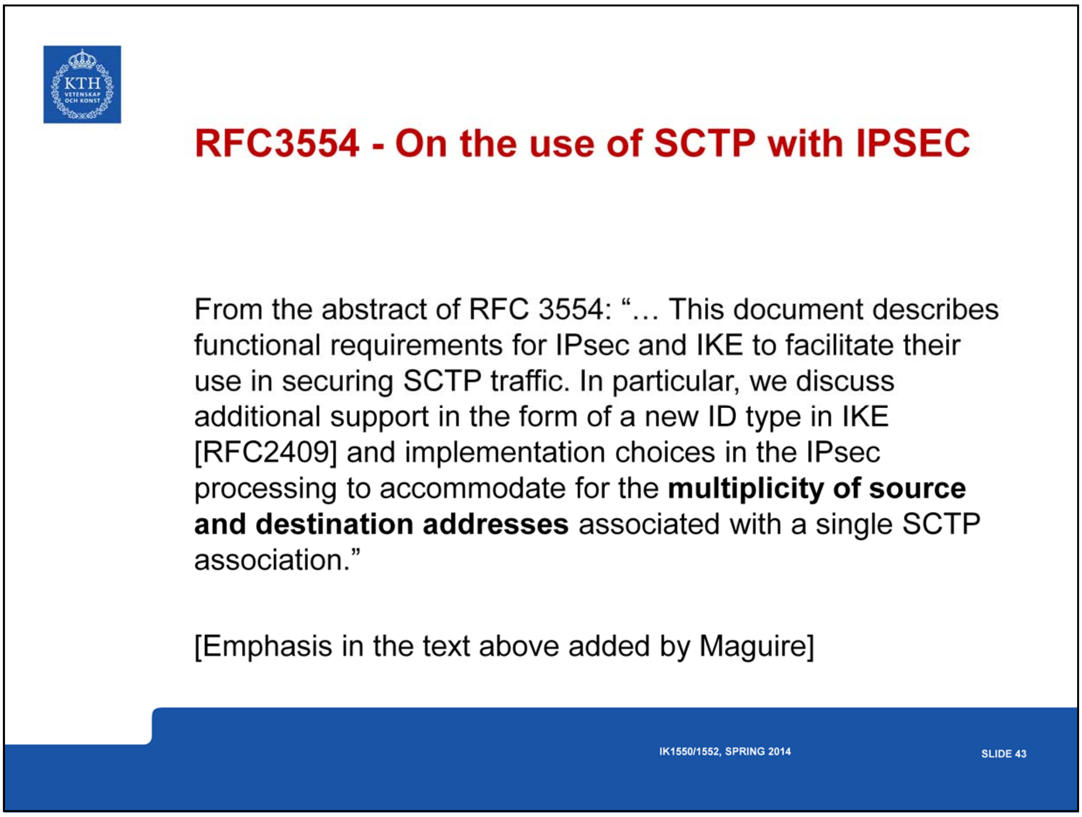
Randall R. Stewart and Qiaobing Xie, “Stream Control Transmission Protocol: A Reference Guide”, Addison-Wesley, 2002, ISBN 0-201-72186-4.

“SCTP Primer”, Mon, Mar 1, 2004 03:35:54 PM
http://datatag.web.cern.ch/datatag/WP3/sctp/primer.htm



RFC3554 - On the use of SCTP with IPSEC

From the abstract of RFC 3554: "… This document describes functional requirements for IPsec and IKE to facilitate their use in securing SCTP traffic. In particular, we discuss additional support in the form of a new ID type in IKE [RFC2409] and implementation choices in the IPsec processing to accommodate for the **multiplicity of source and destination addresses** associated with a single SCTP association."

[Emphasis in the text above added by Maguire]

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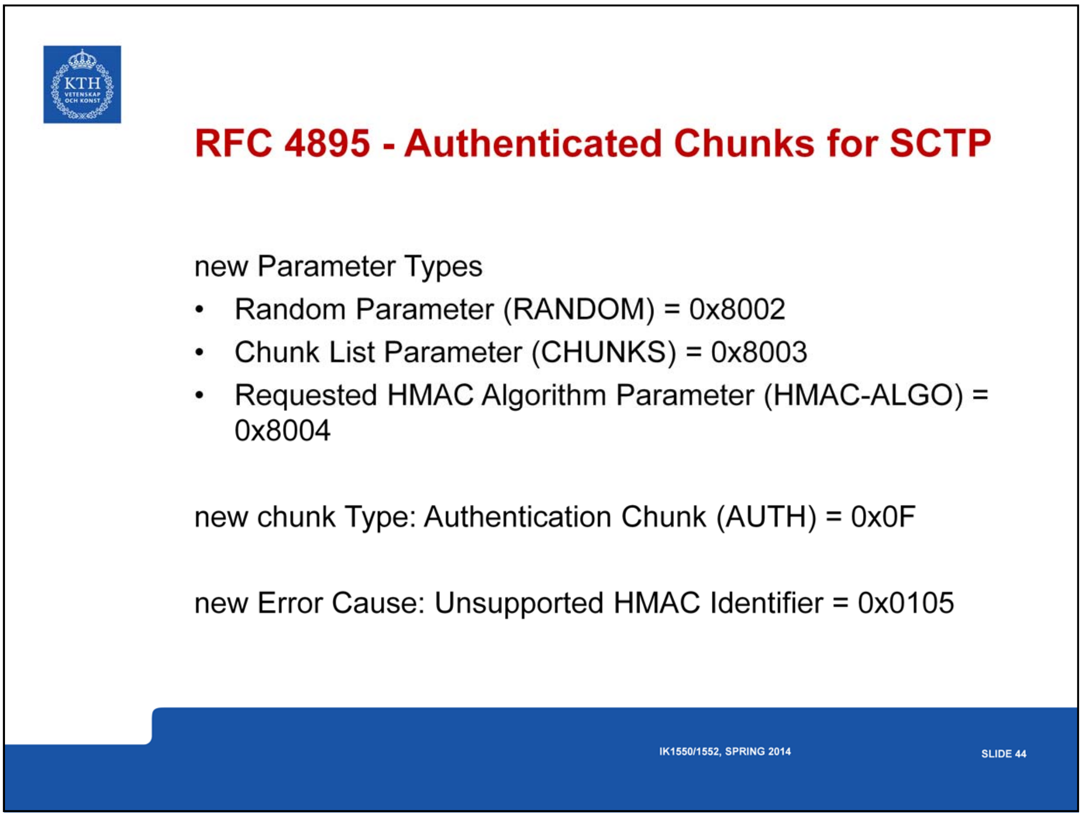
S. Bellovin, J. Ioannidis, A. Keromytis, and R. Stewart, 'On the Use of Stream Control Transmission Protocol (SCTP) with IPsec', *Internet Request for Comments*, vol. RFC 3554 (Proposed Standard), Jul. 2003 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3554.txt

D. Harkins and D. Carrel, 'The Internet Key Exchange (IKE)', *Internet Request for Comments*, vol. RFC 2409 (Proposed Standard), Nov. 1998 [Online]. Available: http://www.rfc-editor.org/rfc/rfc2409.txt



RFC 4895 - Authenticated Chunks for SCTP

new Parameter Types

- Random Parameter (RANDOM) = 0x8002
- Chunk List Parameter (CHUNKS) = 0x8003
- Requested HMAC Algorithm Parameter (HMAC-ALGO) = 0x8004

new chunk Type: Authentication Chunk (AUTH) = 0x0F

new Error Cause: Unsupported HMAC Identifier = 0x0105

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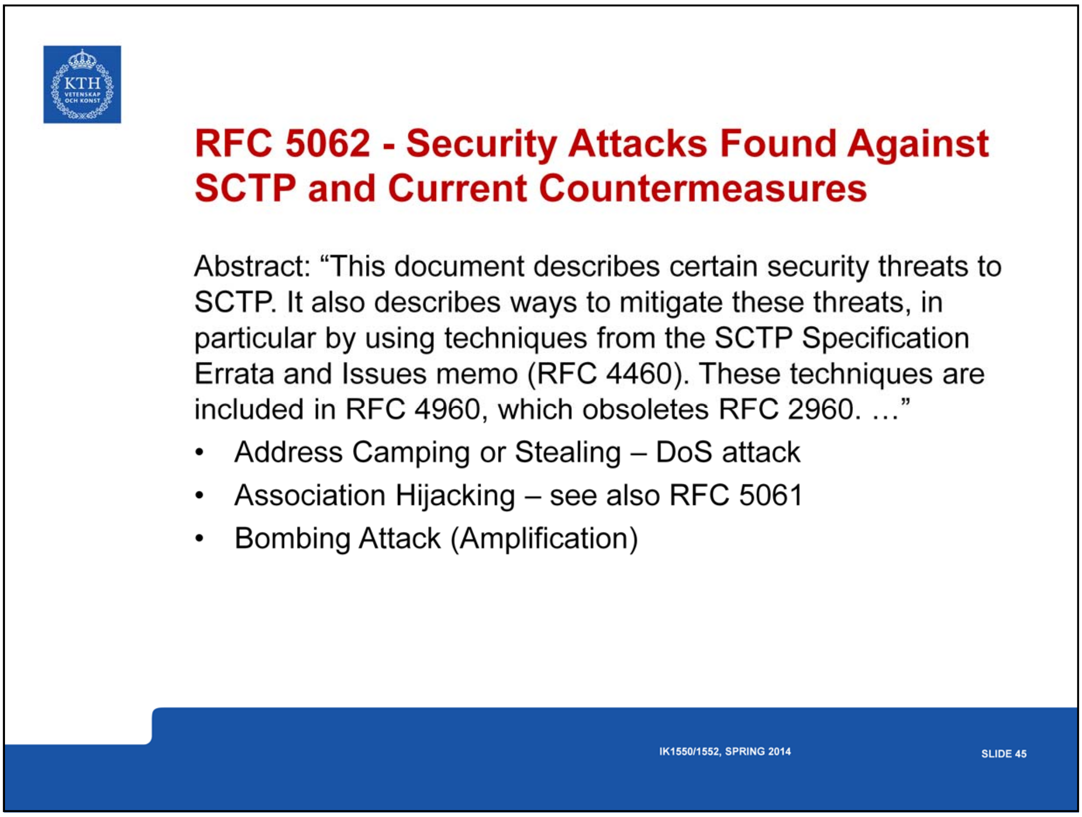
M. Tuexen, R. Stewart, P. Lei, and E. Rescorla, ‘Authenticated Chunks for the Stream Control Transmission Protocol (SCTP)’, *Internet Request for Comments*, vol. RFC 4895 (Proposed Standard), Aug. 2007 [Online]. Available: http://www.rfc-editor.org/rfc/rfc4895.txt



RFC 5062 - Security Attacks Found Against SCTP and Current Countermeasures

Abstract: “This document describes certain security threats to SCTP. It also describes ways to mitigate these threats, in particular by using techniques from the SCTP Specification Errata and Issues memo (RFC 4460). These techniques are included in RFC 4960, which obsoletes RFC 2960. …”

- Address Camping or Stealing – DoS attack
- Association Hijacking – see also RFC 5061
- Bombing Attack (Amplification)

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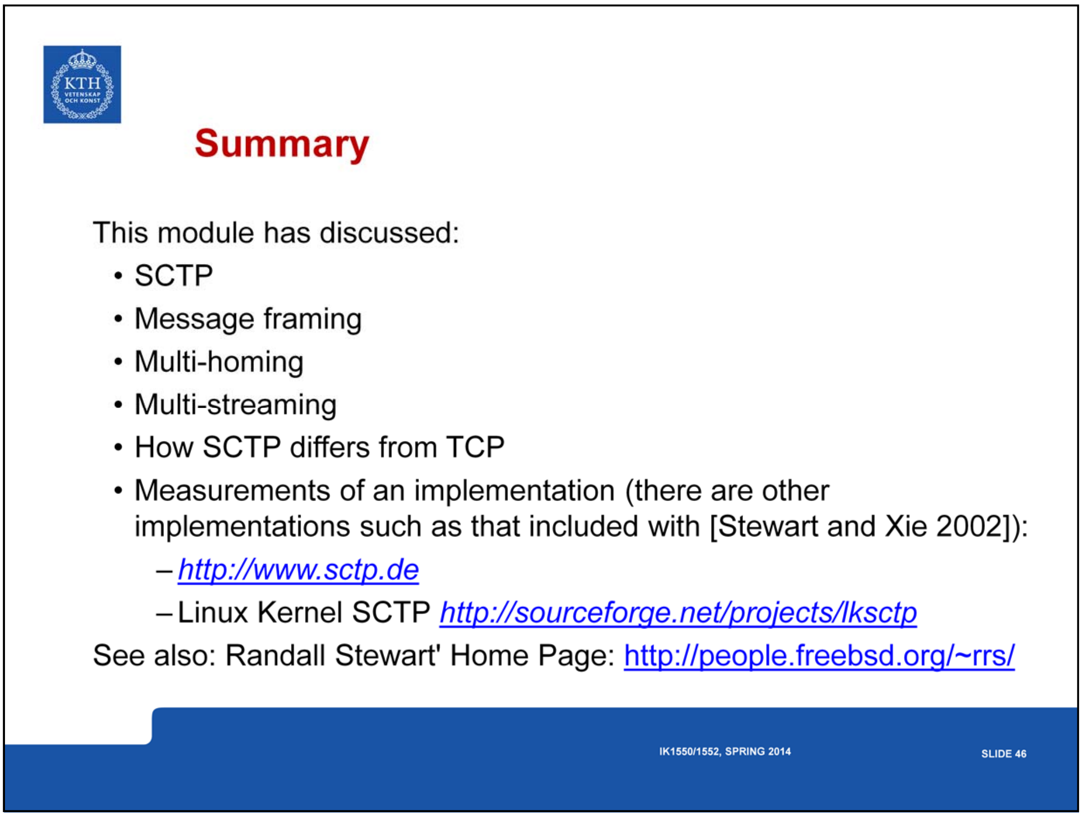
R. Stewart, M. Tuexen, and G. Camarillo, ‘Security Attacks Found Against the Stream Control Transmission Protocol (SCTP) and Current Countermeasures’, *Internet Request for Comments*, vol. RFC 5062 (Informational), Sep. 2007 [Online]. Available: http://www.rfc-editor.org/rfc/rfc5062.txt

R. Stewart, I. Arias-Rodriguez, K. Poon, A. Caro, and M. Tuexen, ‘Stream Control Transmission Protocol (SCTP) Specification Errata and Issues’, *Internet Request for Comments*, vol. RFC 4460 (Informational), Apr. 2006 [Online]. Available: http://www.rfc-editor.org/rfc/rfc4460.txt

R. Stewart, ‘Stream Control Transmission Protocol’, *Internet Request for Comments*, vol. RFC 4960 (Proposed Standard), Sep. 2007 [Online]. Available: http://www.rfc-editor.org/rfc/rfc4960.txt

R. Stewart, Q. Xie, M. Tuexen, S. Maruyama, and M. Kozuka, ‘Stream Control Transmission Protocol (SCTP) Dynamic Address Reconfiguration’, *Internet Request for Comments*, vol. RFC 5061 (Proposed Standard), Sep. 2007 [Online]. Available: http://www.rfc-editor.org/rfc/rfc5061.txt



Summary

This module has discussed:

- SCTP
- Message framing
- Multi-homing
- Multi-streaming
- How SCTP differs from TCP
- Measurements of an implementation (there are other implementations such as that included with [Stewart and Xie 2002]):
  - http://www.sctp.de
  - Linux Kernel SCTP http://sourceforge.net/projects/lksctp

See also: Randall Stewart' Home Page: http://people.freebsd.org/~rrs/

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Randall R. Stewart and Qiaobing Xie, “Stream Control Transmission Protocol: A Reference Guide”, Addison-Wesley, 2002, ISBN 0-201-72186-4.

¿Questions?