KU EECS 800
Survivable, Resilient, and DT Networking
Transport Layer

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Transport Layer
Layer/Plane Cube Model

L7  application
L5  session
L4  transport
L3  network
L2  link
L2- MAC
L1  physical

transport layer in data plane & control plane
management control plane
data plane
Transport Layer
Ideal Network Model and Motivation

- Ideal network model
  - zero end-to-end delay
  - unlimited end-to-end bandwidth
  - perfect end-to-end transmission (no errors)

- Real networks not ideal
  - need an end-to-end protocol
Transport association between end systems

- transport connection in the case of connection state
- may be point-to-point or multipoint
- recall: the network is translucent: delay, errors, loss
Transport Layer
End-to-End Protocol

- Transport protocol
  - is responsible for end-to-end transfer of a TPDU
Transport Layer
Service and Interfaces

- Transport layer is E2E analog of HBH link layer
  - link layer (L2) transfers packets HBH
  - network layer (L3) determines the path of hops
- Transport layer (L4) service to application layer (L7)
  - transfer PDU E2E (end-to-end)
    - sender: encapsulate ADU into TPDU and transmit
    - receiver: receive TPDU and decapsulate into ADU
  - multiplexing to application on end system
  - optional reliability: error checking/correction/retransmission
    - recall end-to-end arguments:
      E2E reliability with HBH error control only for performance
    - may be done by application (A2A: application-to-application)
  - flow control and assistance for network congestion control
- **Transport PDU** encapsulates *application data unit*
  - ADU – application data unit
  - TPDU – transport protocol data unit
  - TPDU = header + ADU + optional trailer (protocol dependent)
Transport Layer
Functional Placement

- Transport layer functionality only in end system
  - end system: host software or network interface (NIC)
Transport Layer

Hop-by-Hop vs. End-to-End Semantics

- Hop-by-hop functions
  - link layer protocols
  - link compression and FEC
  - network forwarding
  - link / subnet error control
  - embedded protocols (e.g. protocol boosters)

- End-to-end functions
  - transport protocols
  - source routing
  - end-to-end encryption
  - session protocols
  - application protocols
Transport Layer
End-to-End Argument

• Hop-by-hop function composition ≠ end-to-end

• Examples
  - HBH encryption has data in clear inside network nodes
  - HBH link error control doesn’t cover network layer errors

End-to-End Argument

*Functions required by communicating applications can be correctly and completely implemented only with the knowledge and help of the applications themselves. Providing these functions as features within the network itself is not possible.*
Transport Layer
Hop-by-Hop Performance Enhancement

- E2E functions replicated HBH if performance benefit
- Example
  - per link error control in high bandwidth-x-delay networks reduce E2E control loop when error

Hop-by-Hop Performance Enhancement Corollary

It is beneficial to duplicate an end-to-end function hop-by-hop if the result is an overall (end-to-end) improvement in performance.
Resilience Strategy
End-to-End Resilience & Disruption Tolerance

• Introduction to survivability and disruption tolerance

• Resilience strategy
  – network survivability and resilience
    1. maintain survivable connectivity when possible
    2. survivable communication even when not connected
    3. resilient network mechanisms
    4. technologies to enhance survivability
  – end-to-end resilience and disruption tolerance
  – disruption-tolerant user-controlled adaptive applications

• Summary
E2E Survivability and DT
Internet Transport Protocols

• Current transport protocols assume
  – strongly connected stable end-to-end paths
  – symmetric path
  – reliable medium

• TCP and SCTP
  – combined feedback error+flow+congestion control
    • reliable ACK stream required for self-clocking
  – unable to discriminate channel loss from congestion
    • congestion indicated by loss (switch drops)
    • channel loss results in throttling source
      – wrong response in uncongested network
E2E Survivability and DT

Knobs and Dials

- Transport protocols should interact with network
  - *dials* feed back topology and path characteristics
  - *knobs* influence lower layer parameters and behaviour
  - example: error control based on loss characteristics
E2E Survivability and DT

Asymmetric Paths

- Asymmetric channels result from
  - asymmetric transmission power
    - intentional (LPD) or available power
  - antenna characteristics and directionality
  - terrain and location

- Unidirectional channels result from
  - asymmetric transmission power
  - radio silence

- Path connectivity may be episodic

- Asymmetric and unidirectional E2E
  - concatenation of channels
  - forward and reverse may follow different paths
Asymmetric end-to-end path challenges
- how to find best paths through network
- how to characterise entire path
E2E Survivability and DT

Bidirectional Paths

- Bidirectional path required for
  - pairwise synchronisation
    - signalling messages
  - bidirectional data communication
    - application issue
  - closed-loop feedback control
    - ACKs for reliable data transfer
    - even if data transfer unidirectional
Open Loop Control

- Survivability with asymmetric channels needs:
  - open-loop control
  - with feedback only when necessary

- Open-loop rate control
  - congestion feedback from network only when necessary
E2E Survivability and DT

Open Loop Error Control

- Open-loop error control: FEC
  - unreliable transfer
    - optional per link FEC
  - quasi-reliable transfer
    - FEC for probabilistic reliability
  - reliable transfer
    - requires bi-directional path
    - infrequent adaptive selective ACKs
    - distinct from:
      - flow control (E2E)
      - congestion control

note: SCTP does none of this
E2E Survivability and DT
End-to-End Transport Mechanisms

• Flow control
  - rate that receiver can accept
  - purely end-to-end

• Congestion control
  - rate that network can accept without congesting
  - network feedback to end systems

• Error control
  - retransmission of corrupt and lost packets
  - link and network-based error characteristics
  - application-dependent reliability requirements
E2E Survivability and DT
Explicit Loss/Congestion/Delay Discrimination

- Absence of expected packet or ACK arrival
  - three *distinct* and unrelated causes:

  1. Congestion: packet dropped in network
     - congestion control: queue overflow (tail drop)
     - congestion avoidance: intentional packet drop

  2. Corruption: packet lost or delivered corrupted
     - channel error causing bit errors

  3. Delay: packet arrival later than expected
     - store-and-forward delays in disruption tolerant network
     - long path
       - speed-of-light delay in delay-tolerant network
       - very long path around disruption
E2E Survivability and DT

Discrimination and Explicit Notification

- Discrimination and proper response essential:
  - congestion $\Rightarrow$ back off
  - corruption $\Rightarrow$ retransmit
  - delay $\Rightarrow$ wait or retransmit via lower delay path

- Explicit notification
  - ECN: explicit congestion notification
  - ELN: explicit loss notification (due to corruption)
  - ELN cannot be determined from ECN (and vice versa)
    - packet that first causes congestion may then be corrupted
E2E Survivability and DT

Error Control Mechanisms

• Mechanisms
  - observation that error has occurred (detection)
  - notification of error
  - decision on what response to take
  - action to correct error

• Taxonomy of mechanisms
  - each mechanism may have different implementations…
    ...(e.g. E2E vs. HBH)…
    …but they are frequently related

• ETEN: explicit transport error notification
ETEN Taxonomy

Determinism and Granularity

- Determinism
  - deterministic (take action based on specific corruptions)
  - probabilistic (e.g. throttle source $x\%$ of the time)

- Granularity
  - PETEN: per packet response
  - CETEN: cumulative error rate response

- Control feedback …
- Control locus …
- Control band …
- Control direction …
ETEN Taxonomy

Control Feedback

- Closed loop feedback from notifier nodes \{n,N\}
  - \(\text{(N)ACK}\) from end system or switch (e.g. congestion drop)

- Open loop
  - Unreliable or FEC for statistical reliability, rate control

- Hybrid open + closed loop
  - FEC for statistical reliability + (N)ACKs as needed
ETEN Taxonomy

Control Locus

- **End-to-end**
  - no changes to network infrastructure

- **Some hop-by-hop**
  - deployed as needed (e.g. optional n at wireless access links)

- **All hop-by-hop**  (N indicates *required* notifier functionality)
  - deployment challenges: impractical for Internet as a whole
ETEN Taxonomy

Control Band

- **Out-of-band**
  - ETEN signalling messages
    - may be forward or backward

- **In-band**
  - ETEN information carried by packets; options:
    - corrupted packets not dropped but marked (violates RFC 1812)
    - carried by subsequent packets in flow (header field or option)
ETEN Taxonomy

Control Direction

• Backward
  - ETEN messages returned by switches
    • out-of-band unless inserted in reverse flow
    • requires HBH ETEN

• Forward
  - ETEN forwarded to receiver; turned back to sender
    • may be in- or out-of band
    • longer delay in response for interactive over high bw-×-delay
ETEN Simulation
TCP with Oracle ETEN

• TCP Oracle ETEN
  - instantaneous notification of corruption-based loss
  - perfect per packet loss discrimination
  - perfect response: retransmit rather than throttle
    • if loss within RTO
  - upper bound of possible benefit for bulk traffic
    • does *not* cause immediate retransmission:
      would matter for transactions but not for bulk transfer

• Simulation
  - ns-2 FullTcpSack
  - 536B segments, 30 min. runs
ETEN Simulation
TCP with Oracle ETEN

- LTN: 250ms 1-way 1.5Mb/s single flow
- 30 min. run 536B segment 2400 seg window

Graph showing Goodput [B/s] vs. Bit Error Rate with two lines representing Oracle and SACK.
ETEN Simulation
TCP with Oracle ETEN

LTN:
250ms 1-way
1.5Mb/s

competing:
4×UDP
CBR 0.25Mb/s
on/off
exp mean 0.5s

30 min. run
536B segment
2400 seg window

Goodput [B/s] vs. Bit Error Rate
Assignment for Next Class

- Follow references in [KS+2004]
- Continue researching scenarios and past failures
  - e.g. NE power failure, 9/11, SBB, Hinsdale CO, others
- Begin to think about area of interest
- Office hours: TR 11:00–12:00 Eaton 3036
  - others needed?
- Makeup class Wed. 7 Aug. 09:30
  - semester schedule to be discussed Tue. 6 Aug.
End of Foils