Is it Still Possible to Extend TCP?

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Motivation

- Extending TCP addresses many issues in the Internet
  - Inability to use multi-homing and mobility
    - Multipath TCP uses multiple paths in the connection and supports mobility
  - Security and privacy
    - TcpCrypt encrypts all the TCP traffic

- All of these would be great, but

  IS IT STILL POSSIBLE TO EXTEND TCP?

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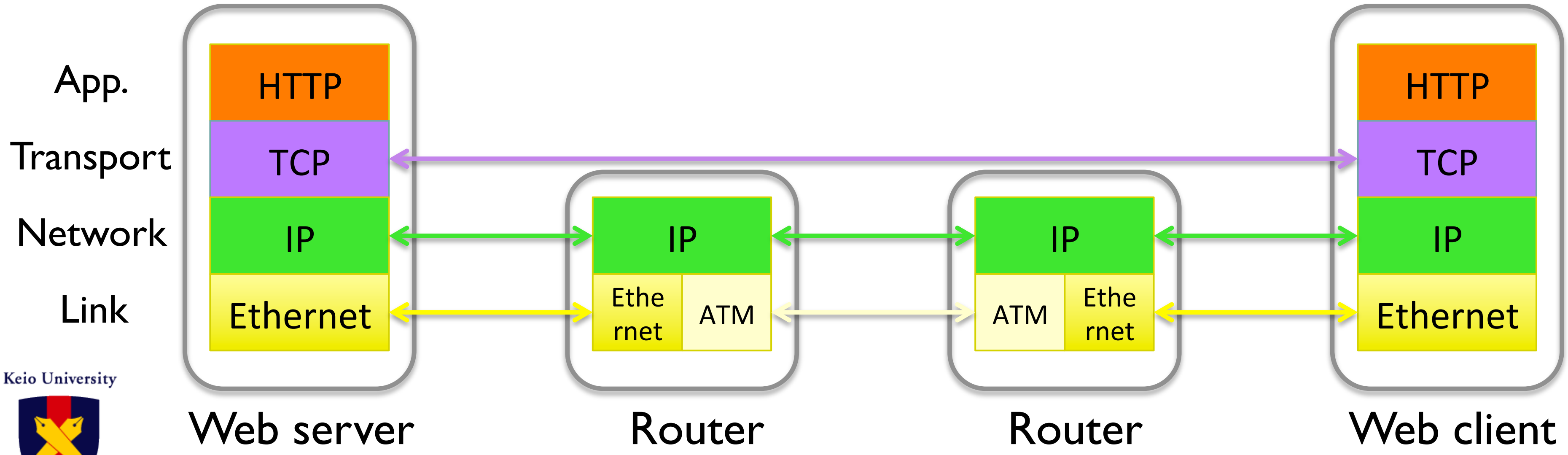
The Original Internet

- Protocol layering
  - Routers look at IP headers to decide how to route a packet
  - TCP provides reliability via retransmission
  - Application uses OS's TCP API to do its job



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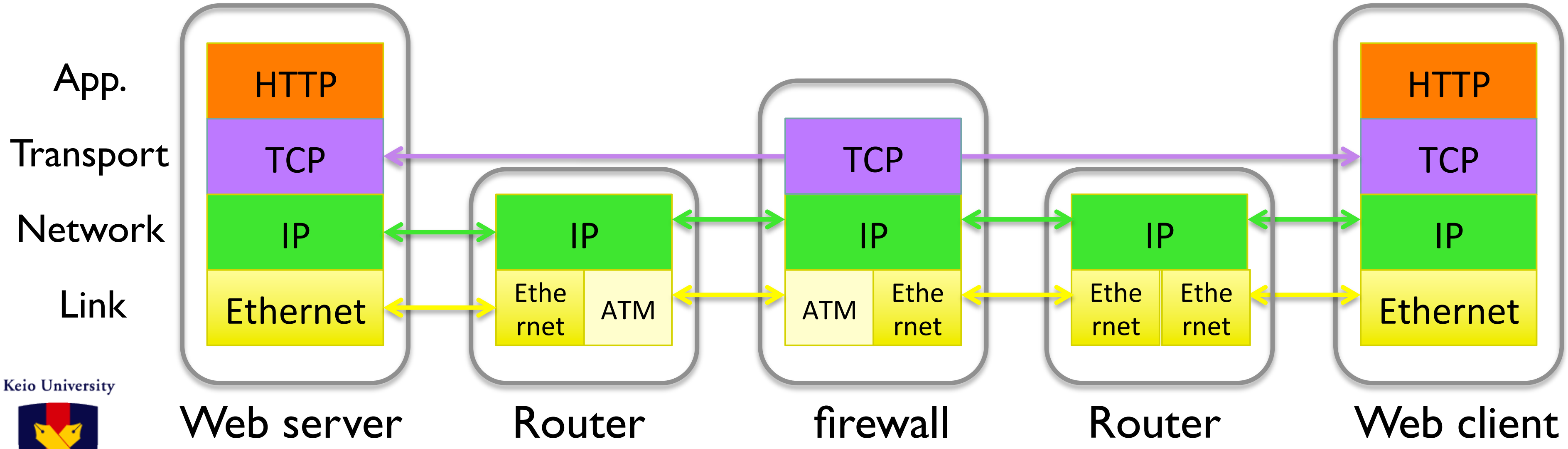
The real Internet

- Networks look beyond the IP header
  - Middleboxes (firewalls, performance-enhancing proxies, traffic normalizer etc)
    - Optimization, security enhancement



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Extending TCP: the reality

- Extending TCP in the original Internet was easy
  - Specify what the new extension should do at end systems
- Extending TCP today is much more complicated
  - Really need to understand what middleboxes do

Problem:

We don't really know what middleboxes do in the Internet!

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Contributions

- This paper remedies this problem
  - We run a thorough study of middlebox behaviors that are relevant for TCP extensions
  - We examined the design implications for newly proposed TCP extensions
- **IS IT STILL POSSIBLE TO EXTEND TCP?**
  - **Yes,** but we need to design very carefully

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Measurement Methodology

- We need to control both endpoints
  - One-sided measurements are not enough
    - Mimic TCP extensions
      - e.g., negotiating the undefined option
    - Monitor test TCP traffic at both ends
      - e.g., whether TCP options are removed
- We developed two tools that generate test TCP traffic:
  - Responder – runs at the server
  - Initiator – runs at the client

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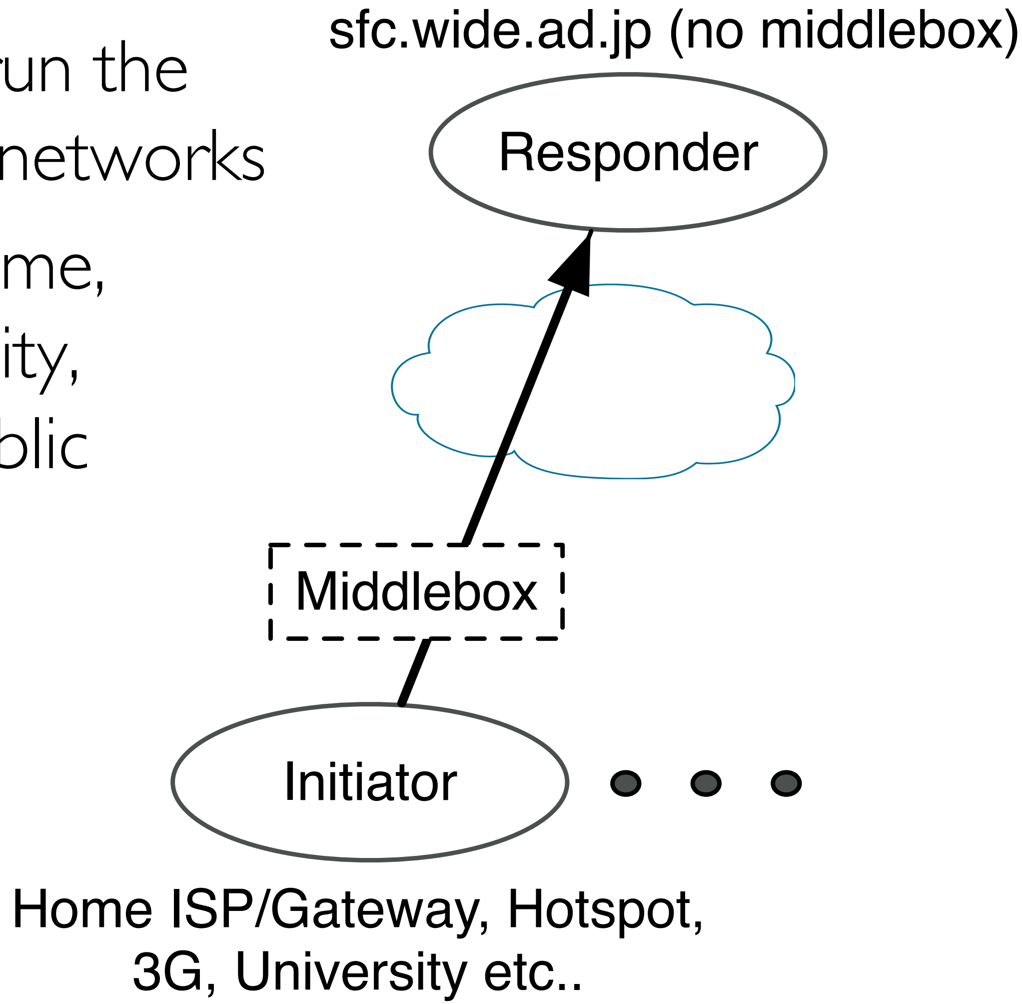
Experimental Setup

- The responder tool runs in the middlebox-free network
- Contributors and we run the initiator tool in access networks
- 142 paths including home, enterprise, 3G, university, hosting service and public hotspots from 24 countries



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Our Tests

- **TCP Option**
- Sequence Number Modification
- **Sequence Number Hole**
- Proxy-Acknowledgment
- Inconsistent Retransmission
- **Segment Splitting and Coalescing**
- **Intelligent NICs**

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Middlebox behaviors depend on the port number

- We performed every experiment using three server ports:
  - 80 (http)
  - 443 (https)
  - 34343 (unregistered)

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TCP Option Tests

- Are new options removed from TCP packets?
  - Benign, but need to understand how often this happens
- Are packets with new TCP options dropped?
  - If yes, fallback to regular TCP is hard!
- If options are negotiated in the SYN exchange, will options in data segments also pass?
  - If no, we need option negotiation with data segments after that in SYN exchange

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TCP Option Test Results

- No path dropped a packet containing the new option
  - Smooth fallback to regular TCP is possible
- 4 % of paths for port 34343, 14 % for port 80 of paths removed the SYN option
  - For port 80, ubiquitous deployment of TCP extensions might be hard
- All the paths removing options from data segments also removed the SYN option
  - SYN option exchange is reasonable to test if options in data segments pass

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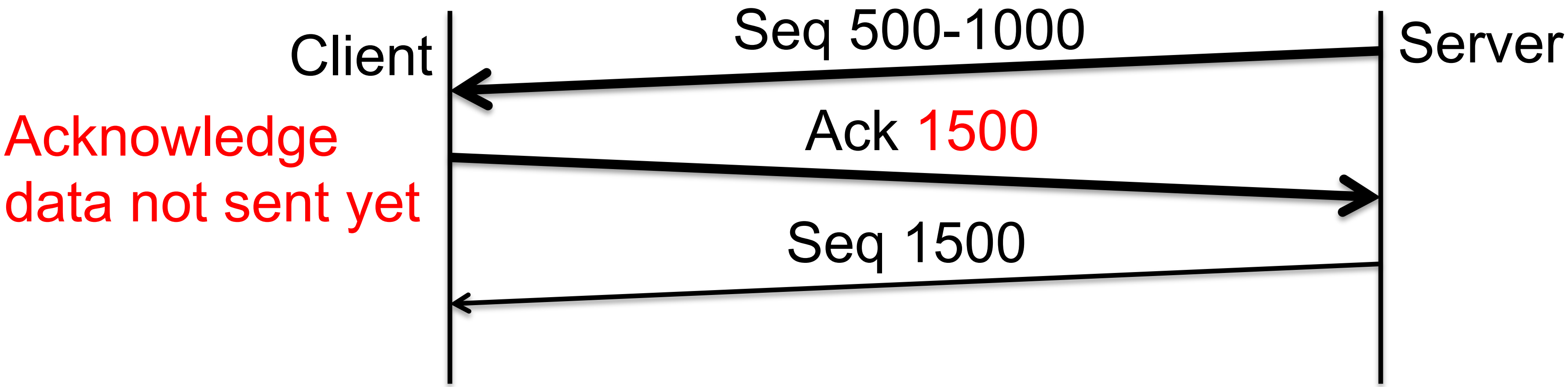
How TCP options are removed

- For port 34343, 5 out of 6 paths just “eliminated options”
- For port 80, 16 out of 20 paths exhibited “proxy” behavior
  - The middlebox generates SYN/ACK, and options are removed as a side-effect
  - Transparently split the TCP connection
    - Split/coalesce segments, indirectly ack packets, cache segments
    - We found more such paths in 3G networks

Sequence Number Hole Test

- Can we leave holes in sequence number consistency?
  - How to skip retransmission of stale data? (e.g., for VoIP)



- Leaving sequence holes is a bad idea
  - 24% of paths (28% on port 80) do strange things

Segment Splitting/Coalescing Test

- Can we assume that segments arrive without being resegmented?
  - TCP gives a bytestream to apps
  - But TCP extensions often assume segments are not resegmented
    - TcpCrypt, MD5
- 1- 7 % of paths split/coalesce segments
  - Mostly proxies (one is not, but it does not split/coalesce when options are present)
- If options are passed in SYN exchange, we can assume packets containing options are not resegmented

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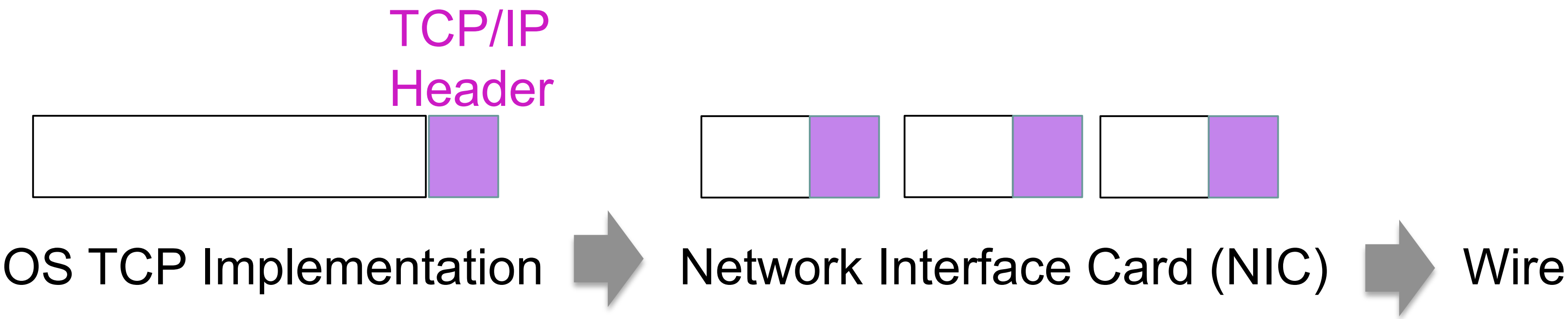
Intelligent NICs

- TCP Segmentation Offload (TSO) is very common – "middlebox" resegmenting packets



- How TCP options are treated?
- We tested 12 NICs from 4 vendors
- All the NICs copied the option to all the split segments
  - Duplicated options must be assumed

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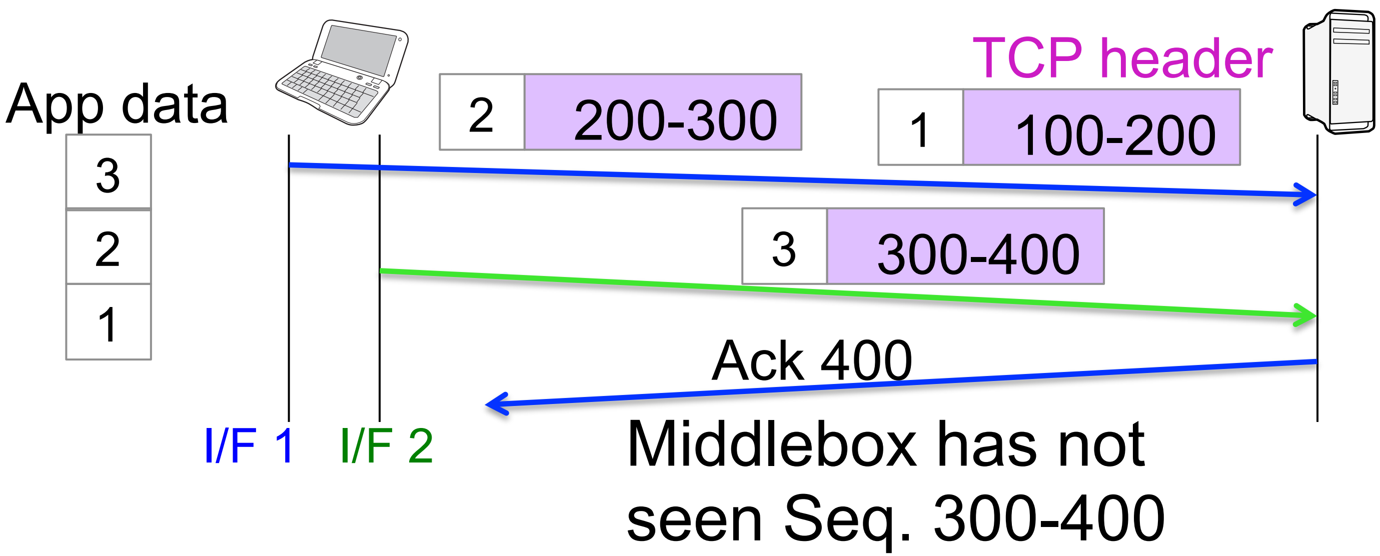
Design Implications: Multipath TCP

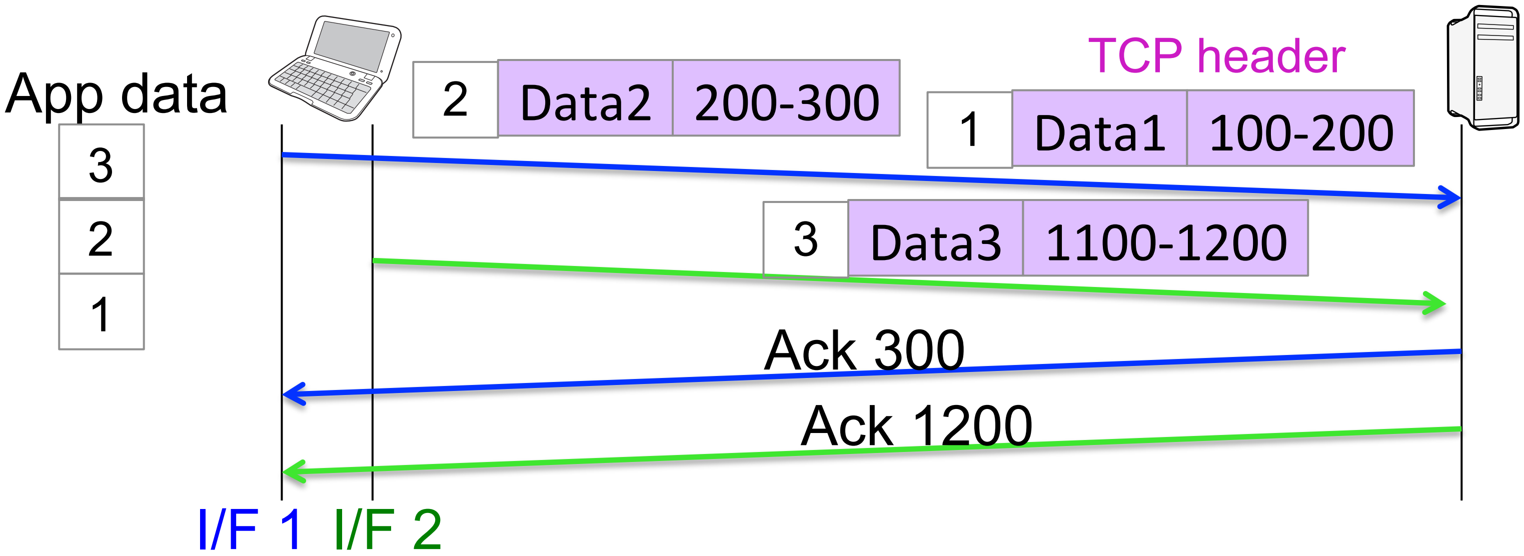
- Transmit segments across more than one path
  - Multi-homed nodes are common
- What sequence numbers should we use?
  - Option 1: reuse regular TCP sequence numbers across multiple paths



- We cannot leave a hole in sequence space on each path

Design Implications: Multipath TCP

- Need separate sequence spaces for "on-path" and "app data"
  - Regular sequence numbers are used for on-path sequence numbers
  - App data sequence number is embedded in the option



Design Implications: TcpCrypt

- TcpCrypt operation:
  - Negotiate keys
  - Encrypt payload of each segment
  - Add TCP option with MAC
- TcpCrypt is safe, but performance penalty
  - Resegmentation doesn't happen after options are negotiated
  - TCP Segmentation Offload (TSO) must be disabled

Design Implications: TCP Extended Option Space

- TCP Extended Option Space:
  - Use a part of payload as an extended option space
  - An option in the TCP header specifies "actual" data offset
- TCP Extended Option Space is unsafe
  - we cannot use different options on retransmissions

  - TSO copies the option specifying the actual data offset to all the split segments

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Design Guidelines for TCP Extensions

- Negotiate new features on the SYN exchange before use
- If options are removed, don't assume message boundaries will be preserved
- Assume segments will be split by TSO and options duplicated on these segments

Design Guidelines for TCP Extensions

- Don't assume sequence numbers arrive unmodified
  - i.e. Initial Sequence Number randomization
- Don't leave gaps in the sequence space
- Retransmitting inconsistent information is a bit risky
- Proxies are common, especially on port 80, and will strip TCP options, and resegment packets

Conclusion

- **We can still extend TCP, but extensions' design is very constrained**
- Future work
  - New tests, wider coverage
- Please join the measurement!
  - http://www.sfc.wide.ad.jp/~micchie/middlebox/cfc.html
  - Download self-contained python script, run one command, and post a result (15 min. experiment)!
  - You will see the summary of results after posting log files!

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