MUST, SHOULD, DON’T CARE: TCP Conformance in the Wild

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Yet another TCP study

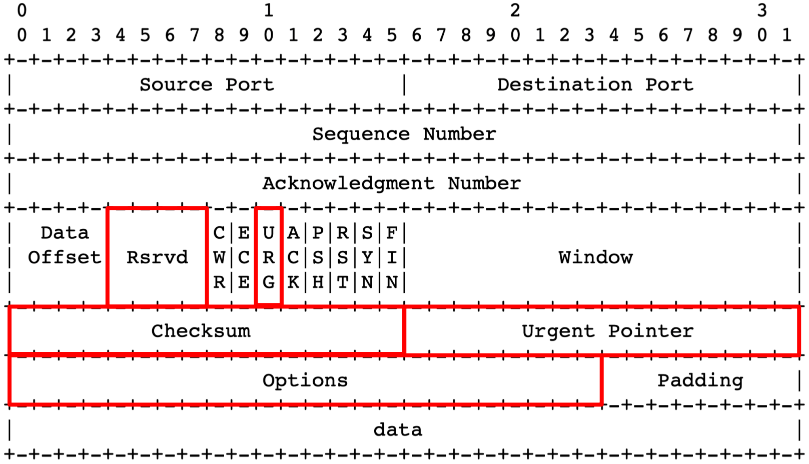
- TCP in the Wild has been thoroughly analyzed in the past decades
  - Stack behavior
    - Tunings, e.g., IW Configuration
    - Extensions, e.g., SACK, ECN, TFO, MPTCP
  - Middlebox Interference
    - TCPExposure
    - Tracebox
    - PATHspider

Conformance to
minimum requirements?

- Approach: Active Scanning
  - Controlled Testbed environment
  - Large scale measurement campaign
  - Tracebox approach to detect Middlebox Interference

Test Cases

- RFC 793bis-Draft14
- Checksum
  - Validation
- Options
  - Ignore unknown
- MSS
  - Used defaults
  - Effective Send MSS
- Reserved Flags
  - Ignore and Zero
- Urgent Pointer
  - Arbitrary Length Segment Processing



```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Source Port          |       Destination Port        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Sequence Number                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Acknowledgment Number                      |
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|  Data |       |C|E|U|A|P|R|S|F|                               |
| Offset| Rsrvd |W|C|R|C|S|S|Y|I|            Window             |
|       |       |R|E|G|K|H|T|N|N|                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Checksum            |         Urgent Pointer        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Options                    |    Padding    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             data                              |
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```
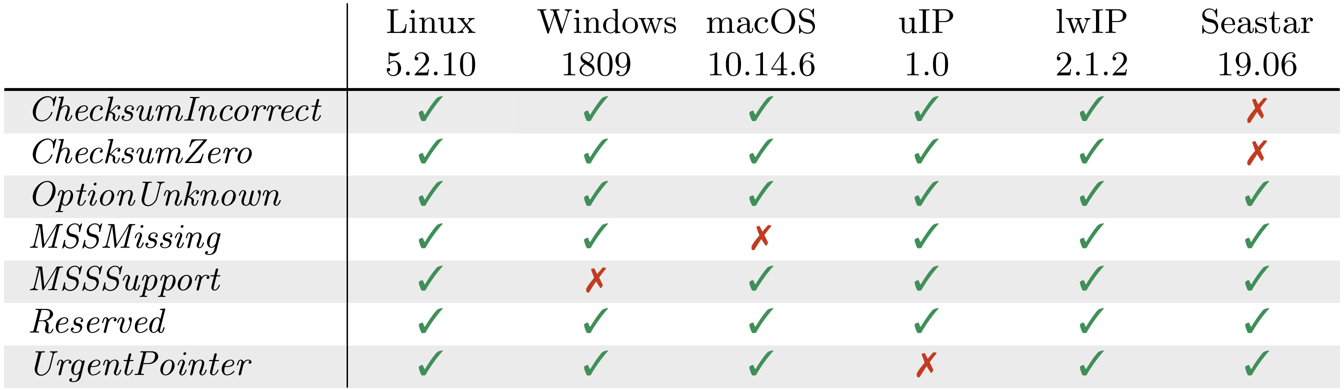

Controlled Testbed Measurements



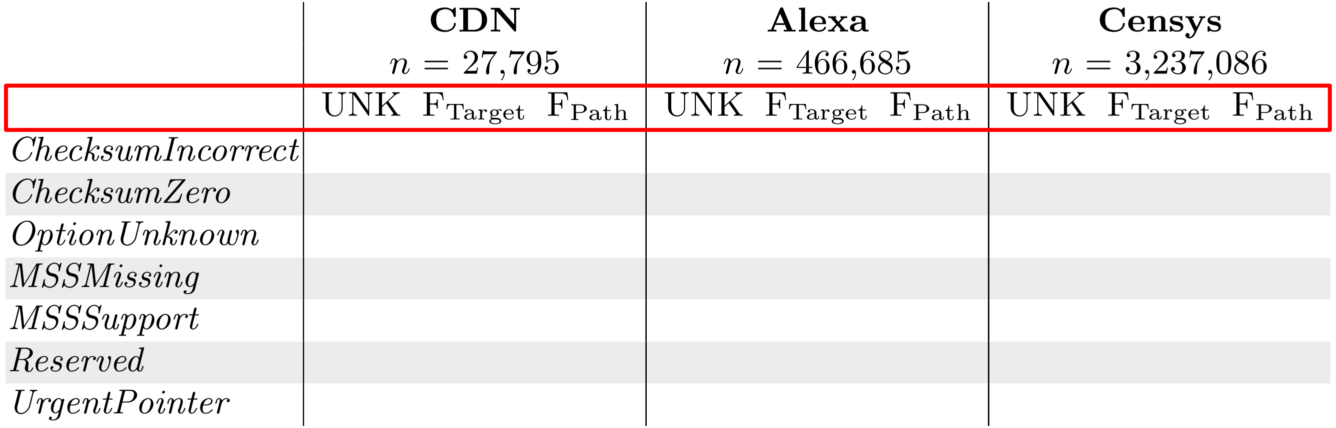
	Linux 5.2.10	Windows 1809	macOS 10.14.6	uIP 1.0	lwIP 2.1.2	Seastar 19.06
ChecksumIncorrect	✓	✓	✓	✓	✓	✗
ChecksumZero	✓	✓	✓	✓	✓	✗
OptionUnknown	✓	✓	✓	✓	✓	✓
MSSMissing	✓	✓	✗	✓	✓	✓
MSSSupport	✓	✗	✓	✓	✓	✓
Reserved	✓	✓	✓	✓	✓	✓
UrgentPointer	✓	✓	✓	✗	✓	✓

- Windows 10 1809: RFC MSS defaults as lower bound
- macOS 10.14.6: 1024 bytes MSS regardless of IP Version
- uIP 1.0: crashes on urgent data pointing beyond the segment’s size (Pull Request merged)
  - Contiki-OS and Contiki-NG are also vulnerable
- Seastar 19.06: Host OS support of offloaded Checksum is not verified (Issue reported)
  - Hardware offloading is enabled by default, software checksumming is supported

TCP Conformance in the Wild – Target Hosts

- HTTP Archive
  - Sampled CDN tagged URLs
  - ~28k unique target hosts
- Alexa 1M
  - ~467k unique target hosts
- Censys
  - Internet-wide port scans
  - ~3.2m unique target hosts

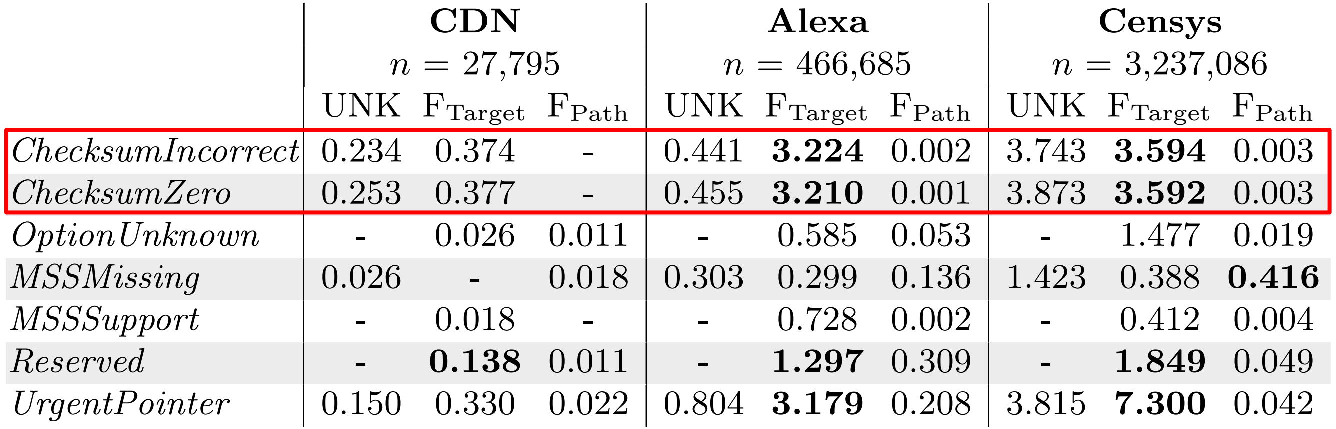
TCP Conformance in the Wild – Results (1)



	CDN			**Alexa**			**Censys**		
	$n = 27{,}795$			$n = 466{,}685$			$n = 3{,}237{,}086$		
	UNK	$\mathrm{F}_{\mathrm{Target}}$	$\mathrm{F}_{\mathrm{Path}}$	UNK	$\mathrm{F}_{\mathrm{Target}}$	$\mathrm{F}_{\mathrm{Path}}$	UNK	$\mathrm{F}_{\mathrm{Target}}$	$\mathrm{F}_{\mathrm{Path}}$
ChecksumIncorrect									
ChecksumZero									
OptionUnknown									
MSSMissing									
MSSSupport									
Reserved									
UrgentPointer									

- UNK
  - not clearly determinable results
- $\mathrm{F}_{\mathrm{Target}}$
  - non-conformities raised by Targets
- $\mathrm{F}_{\mathrm{Path}}$
  - non-conformities raised by Middleboxes

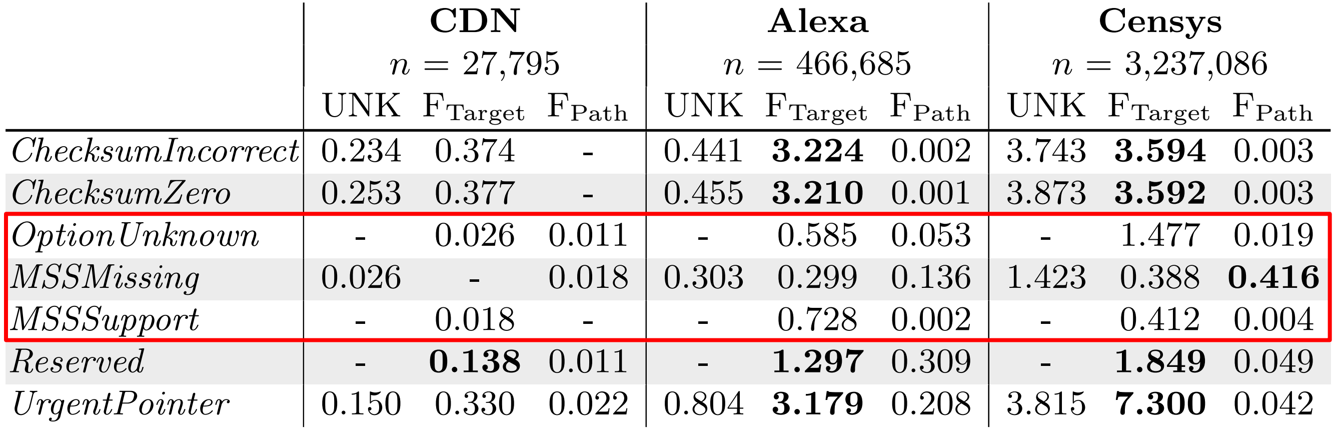
TCP Conformance in the Wild – Results (1)



	CDN			**Alexa**			**Censys**		
	$n = 27{,}795$			$n = 466{,}685$			$n = 3{,}237{,}086$		
	UNK	$\mathrm{F}_{\mathrm{Target}}$	$\mathrm{F}_{\mathrm{Path}}$	UNK	$\mathrm{F}_{\mathrm{Target}}$	$\mathrm{F}_{\mathrm{Path}}$	UNK	$\mathrm{F}_{\mathrm{Target}}$	$\mathrm{F}_{\mathrm{Path}}$
ChecksumIncorrect	0.234	0.374	-	0.441	**3.224**	0.002	3.743	**3.594**	0.003
ChecksumZero	0.253	0.377	-	0.455	**3.210**	0.001	3.873	**3.592**	0.003
OptionUnknown	-	0.026	0.011	-	0.585	0.053	-	1.477	0.019
MSSMissing	0.026	-	0.018	0.303	0.299	0.136	1.423	0.388	**0.416**
MSSSupport	-	0.018	-	-	0.728	0.002	-	0.412	0.004
Reserved	-	**0.138**	0.011	-	**1.297**	0.309	-	**1.849**	0.049
UrgentPointer	0.150	0.330	0.022	0.804	**3.179**	0.208	3.815	**7.300**	0.042

- Checksum
  - CDN shows low failure rates and no on-path modifications
  - Alexa and Censys each show around 3% Target Failure

TCP Conformance in the Wild – Results (2)



	CDN			Alexa			Censys		
	n = 27,795			n = 466,685			n = 3,237,086		
	UNK	F_{Target}	F_{Path}	UNK	F_{Target}	F_{Path}	UNK	F_{Target}	F_{Path}
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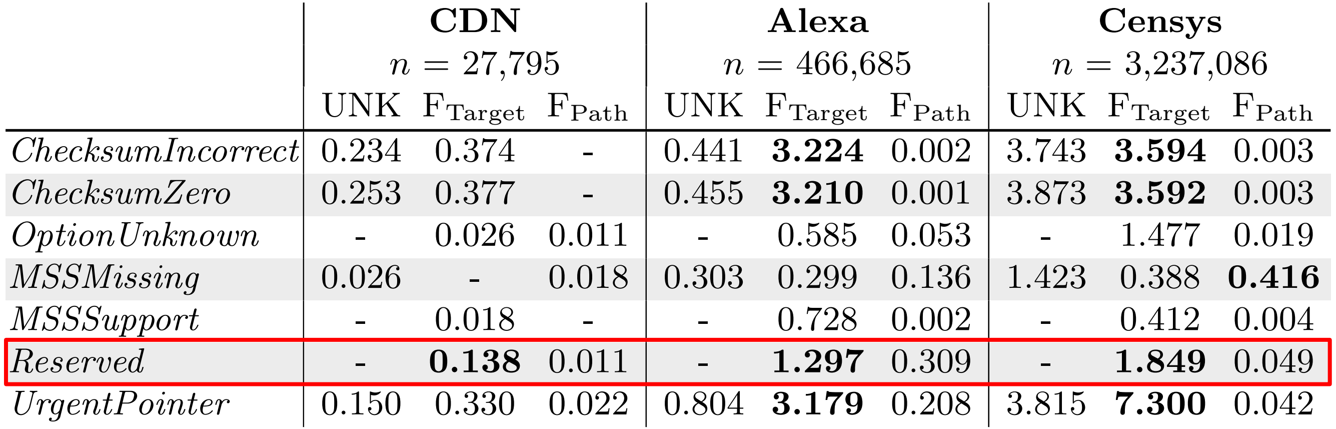
UrgentPointer	0.150	0.330	0.022	0.804	**3.179**	0.208	3.815	**7.300**	0.042

- Option Unknown
  - No single AS stands out, highest Failure rates are within ISP networks
- MSS
  - Censys F_{Path} are primarily located in ISP networks
  - MSS is inserted, likely due to PPPoE encapsulation by access routers

TCP Conformance in the Wild – Results (3)



	CDN			**Alexa**			**Censys**		
	n = 27,795			n = 466,685			n = 3,237,086		
	UNK	$\mathrm{F}_{\mathrm{Target}}$	$\mathrm{F}_{\mathrm{Path}}$	UNK	$\mathrm{F}_{\mathrm{Target}}$	$\mathrm{F}_{\mathrm{Path}}$	UNK	$\mathrm{F}_{\mathrm{Target}}$	$\mathrm{F}_{\mathrm{Path}}$
ChecksumIncorrect	0.234	0.374	-	0.441	**3.224**	0.002	3.743	**3.594**	0.003
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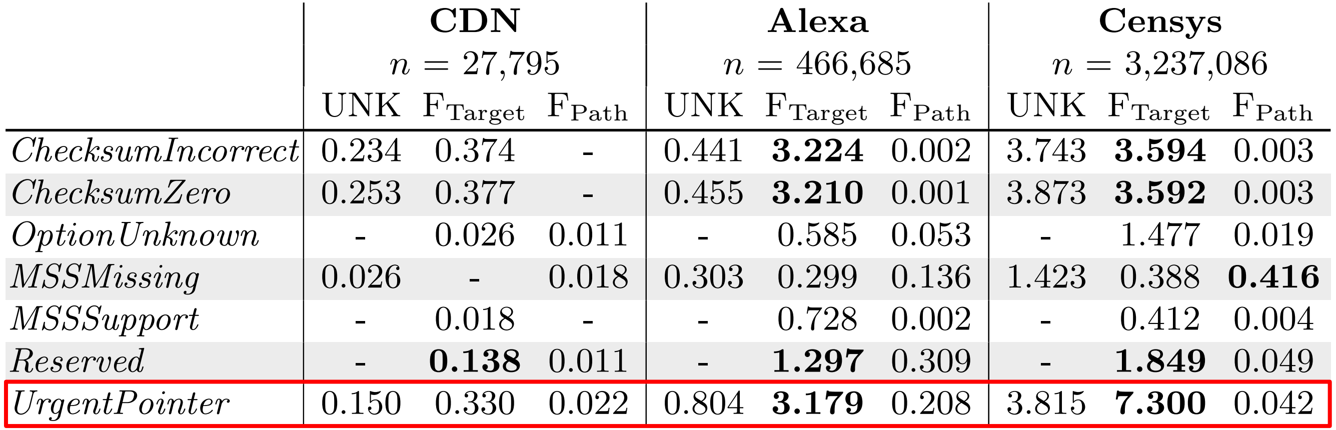
Reserved	-	**0.138**	0.011	-	**1.297**	0.309	-	**1.849**	0.049
UrgentPointer	0.150	0.330	0.022	0.804	**3.179**	0.208	3.815	**7.300**	0.042

- Reserved
  - ~1.2% $\mathrm{F}_{\mathrm{Target}}$ on Alexa, ~1.8% $\mathrm{F}_{\mathrm{Target}}$ on Censys
  - No response to our probing packets
  - Extendibility is limited
  - Ignoring and zeroing Reserved Flags is no formal **MUST** requirement
    - Proposed to add a formal **MUST** within RFC 793bis

TCP Conformance in the Wild – Results (4)



	CDN			**Alexa**			**Censys**		
	n = 27,795			n = 466,685			n = 3,237,086		
	UNK	F_{Target}	F_{Path}	UNK	F_{Target}	F_{Path}	UNK	F_{Target}	F_{Path}
ChecksumIncorrect	0.234	0.374	-	0.441	**3.224**	0.002	3.743	**3.594**	0.003
ChecksumZero	0.253	0.377	-	0.455	**3.210**	0.001	3.873	**3.592**	0.003
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Reserved	-	**0.138**	0.011	-	**1.297**	0.309	-	**1.849**	0.049
UrgentPointer	0.150	0.330	0.022	0.804	**3.179**	0.208	3.815	**7.300**	0.042

- Urgent Pointer
  - Overall highest Failure rates with ~3.2% F_{Target} on Alexa and ~7.3% F_{Target} on Censys
  - Censys Fails are Primarily located in ISP networks, 98.8% of silently discarded the data
  - RFC states that the usage is discouraged, but implementation is mandatory
    - Remove the mandatory implementation requirement to reflect its deprecation?

Thanks

Paper

shorturl.at/bdrFU

Dataset

shorturl.at/cDFN8

Code

shorturl.at/hoyW7

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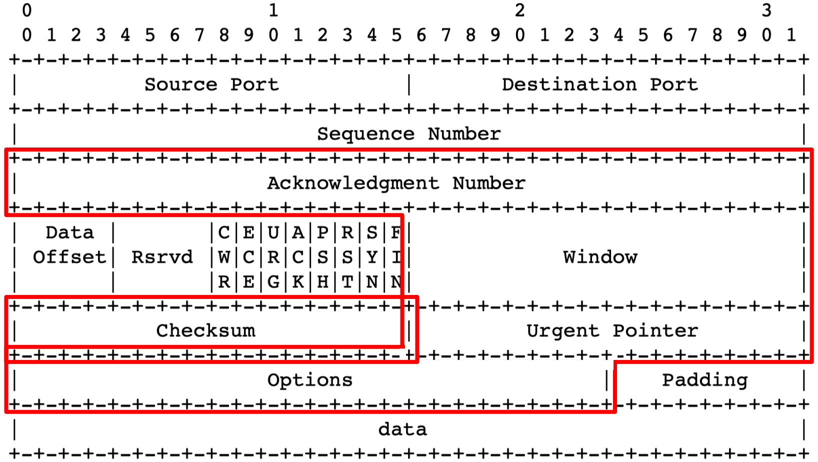
Backup

Methodology

- Middlebox Interference
  - Tracebox approach
  - TTL encoded in multiple fields (e.g., TCP #ACK, Window Size, Urgent Pointer, NOOP Options)
  - Listen for ICMP time exceeded messages
  - Test case specific
- Test cases
  - RFC 793bis-Draft14 features 69 MUSTs
  - Majority addresses internal state handling
  - Requirements must be observable
  - Critical to interoperability, security, performance, or extensibility



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 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Source Port          |       Destination Port        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Sequence Number                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Acknowledgment Number                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Data |       |C|E|U|A|P|R|S|F|                               |
| Offset| Rsrvd |W|C|R|C|S|S|Y|I|            Window             |
|       |       |R|E|G|K|H|T|N|N|                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Checksum            |         Urgent Pointer        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Options                    |    Padding    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             data                              |
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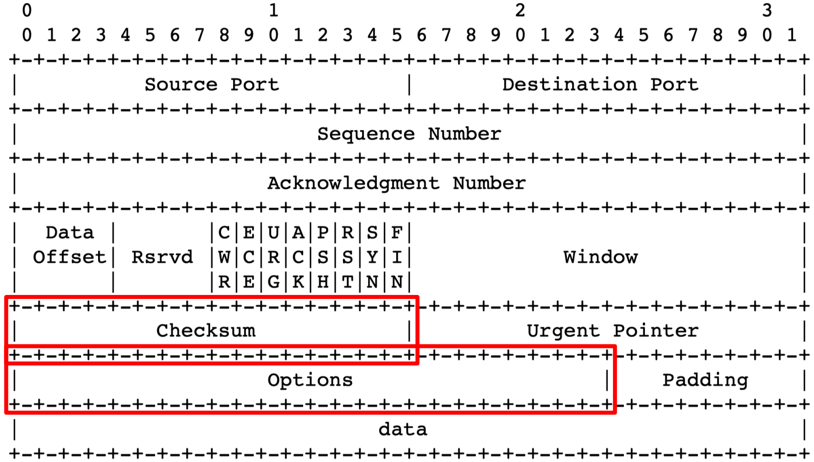
Test Cases (1)

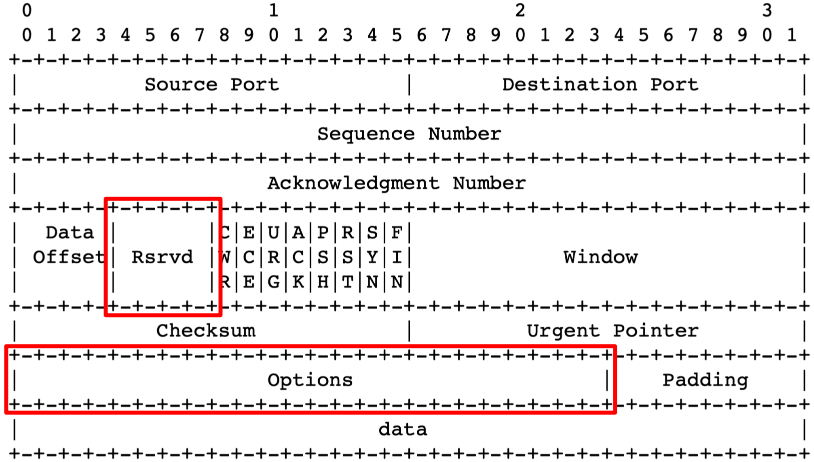


```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Source Port          |       Destination Port        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Sequence Number                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Acknowledgment Number                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Data |       |C|E|U|A|P|R|S|F|                               |
| Offset| Rsrvd |W|C|R|C|S|S|Y|I|            Window             |
|       |       |R|E|G|K|H|T|N|N|                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Checksum            |         Urgent Pointer        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Options                    |    Padding    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             data                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

- Checksum
  - Computationally expensive
  - Most Layer 2 protocols already protect against segment corruption
  - *When sending a SYN or an ACK segment with an incorrect/zeroed checksum, a target must respond with a RST segment or ignore it.*
- Options
  - Up to 40 bytes of options for future extensibility
  - Most critical to extensibility are unassigned options
  - *When sending a SYN segment with an unassigned option, a target must respond with a SYN/ACK segment.*

Test Cases (2)

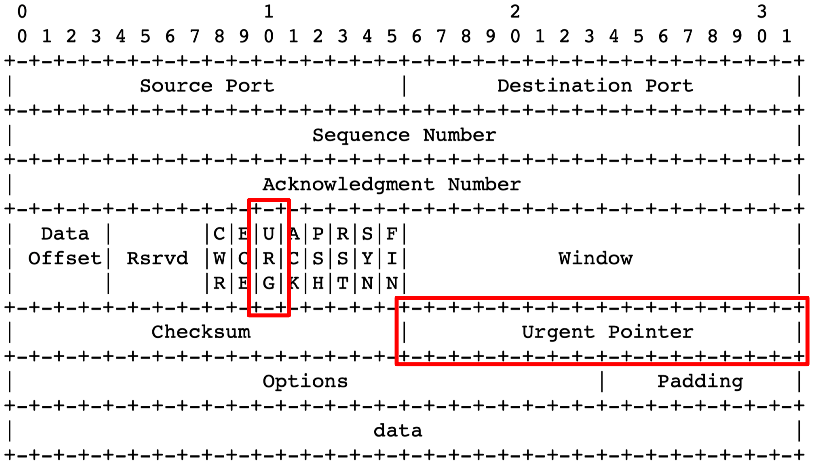
- MSS Missing
  - *When sending a SYN segment without an MSS, a target must not send segments exceeding 536 byte (IPv4) or 1220 byte (IPv6).*
- MSS Support
  - *When sending a SYN segment with an MSS of 515 byte, a target must not send segments exceeding 515 byte.*
- Reserved Flags
  - *When sending a SYN segment with a reserved flag set, a target must respond with a SYN/ACK segment with zeroed reserved flags.*
  - *Subsequently, when sending an ACK segment with a reserved flag set, a target must not retransmit the SYN/ACK segment.*



```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Source Port          |       Destination Port        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Sequence Number                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Acknowledgment Number                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Data |       |C|E|U|A|P|R|S|F|                               |
| Offset| Rsrvd |W|C|R|C|S|S|Y|I|            Window             |
|       |       |R|E|G|K|H|T|N|N|                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Checksum            |         Urgent Pointer        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Options                    |    Padding    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             data                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

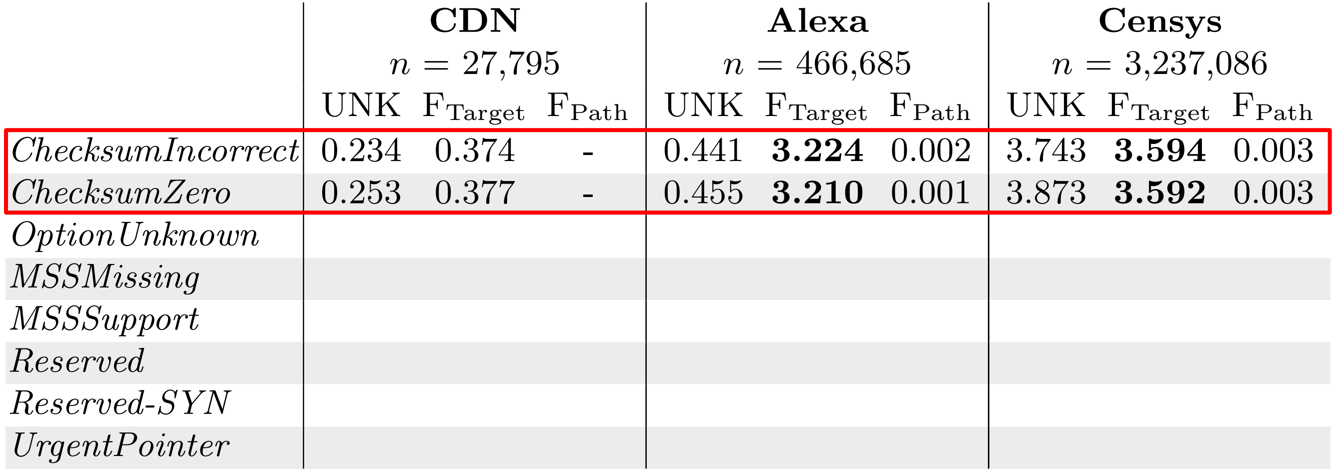
Test Cases (3)

- Urgent Pointer
  - Usage is discouraged for new applications
  - TCP implementations must still include support for arbitrary length
  - *When sending a sequence of segments flagged as urgent, a target must acknowledge them with an ACK segment.*



```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Source Port          |       Destination Port        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Sequence Number                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Acknowledgment Number                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Data |       |C|E|U|A|P|R|S|F|                               |
| Offset| Rsrvd |W|C|R|C|S|S|Y|I|            Window             |
|       |       |R|E|G|K|H|T|N|N|                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Checksum            |         Urgent Pointer        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Options                    |    Padding    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             data                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

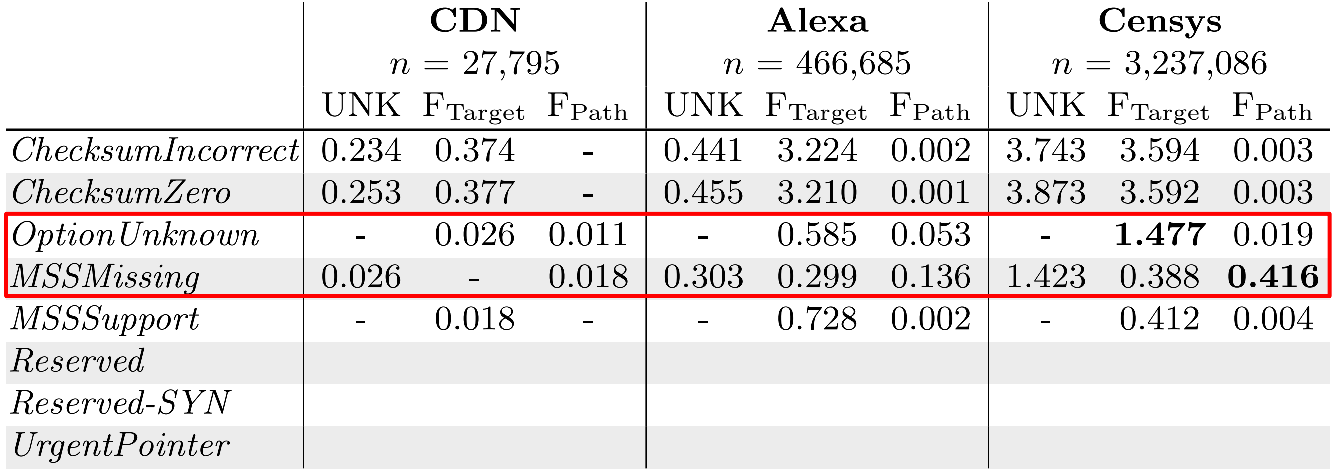
TCP Conformance in the Wild – Results (1)



	CDN			**Alexa**			**Censys**		
	n = 27,795			n = 466,685			n = 3,237,086		
	UNK	F_{Target}	F_{Path}	UNK	F_{Target}	F_{Path}	UNK	F_{Target}	F_{Path}
ChecksumIncorrect	0.234	0.374	-	0.441	**3.224**	0.002	3.743	**3.594**	0.003
ChecksumZero	0.253	0.377	-	0.455	**3.210**	0.001	3.873	**3.592**	0.003
OptionUnknown									
MSSMissing									
MSSSupport									
Reserved									
Reserved-SYN									
UrgentPointer									

- F_{Target} Alexa and Censys
  - 1st AS class: ~7% of hosts fail both tests (e.g., Amazon), hinting at purpose build high-performance VMs for, e.g., TCP-terminating proxies
  - 2nd AS class: Nearly all hosts fail both tests (e.g., QRATOR AS), hinting at purpose build stack for DDoS protection

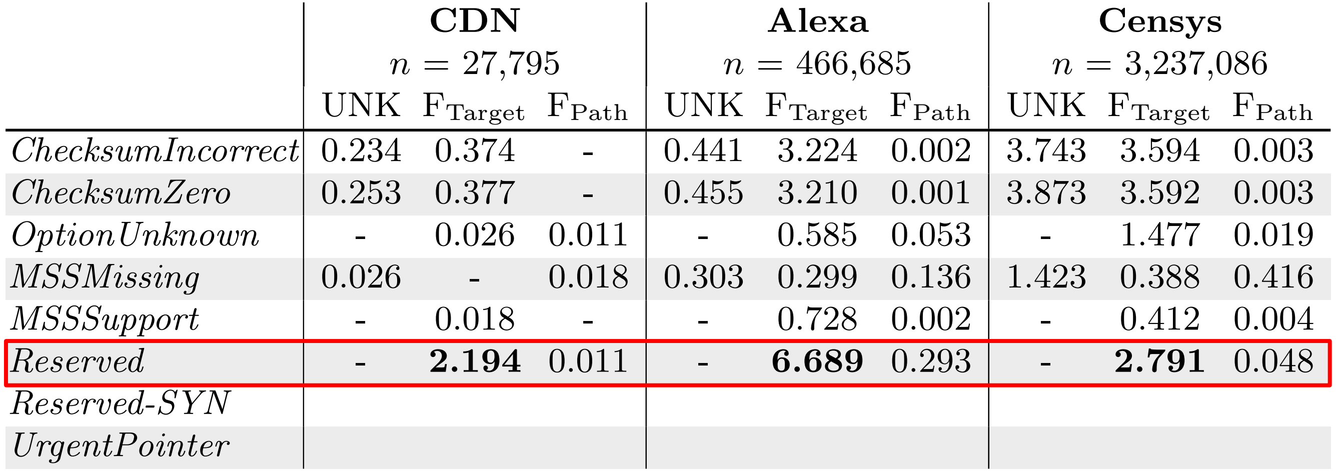
TCP Conformance in the Wild – Results (2)



	CDN			**Alexa**			**Censys**		
	n = 27,795			n = 466,685			n = 3,237,086		
	UNK	$\mathrm{F}_{\mathrm{Target}}$	$\mathrm{F}_{\mathrm{Path}}$	UNK	$\mathrm{F}_{\mathrm{Target}}$	$\mathrm{F}_{\mathrm{Path}}$	UNK	$\mathrm{F}_{\mathrm{Target}}$	$\mathrm{F}_{\mathrm{Path}}$
ChecksumIncorrect	0.234	0.374	-	0.441	3.224	0.002	3.743	3.594	0.003
ChecksumZero	0.253	0.377	-	0.455	3.210	0.001	3.873	3.592	0.003
OptionUnknown	-	0.026	0.011	-	0.585	0.053	-	**1.477**	0.019
MSSMissing	0.026	-	0.018	0.303	0.299	0.136	1.423	0.388	**0.416**
MSSSupport	-	0.018	-	-	0.728	0.002	-	0.412	0.004
Reserved									
Reserved-SYN									
UrgentPointer									

- Option Unknown
  - No single AS stands out, highest failure rates are within ISP networks
- MSS Missing
  - Censys $\mathrm{F}_{\mathrm{Path}}$ are primarily located in ISP networks
  - MSS is inserted, likely due to PPPoE encapsulation by access routers

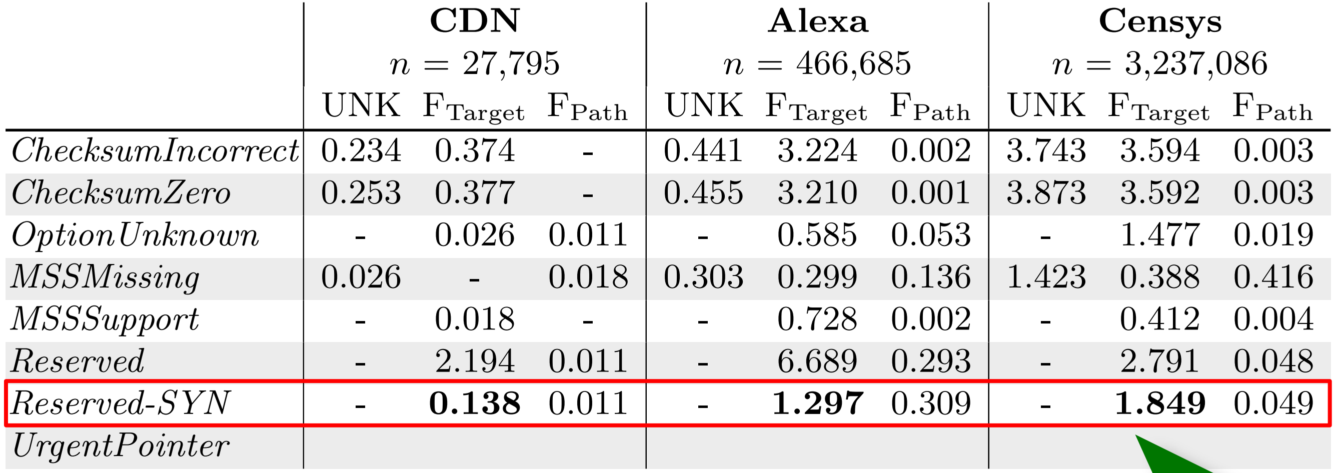
TCP Conformance in the Wild – Results (3)



	CDN			**Alexa**			**Censys**		
	n = 27,795			n = 466,685			n = 3,237,086		
	UNK	F_{Target}	F_{Path}	UNK	F_{Target}	F_{Path}	UNK	F_{Target}	F_{Path}
ChecksumIncorrect	0.234	0.374	-	0.441	3.224	0.002	3.743	3.594	0.003
ChecksumZero	0.253	0.377	-	0.455	3.210	0.001	3.873	3.592	0.003
OptionUnknown	-	0.026	0.011	-	0.585	0.053	-	1.477	0.019
MSSMissing	0.026	-	0.018	0.303	0.299	0.136	1.423	0.388	0.416
MSSSupport	-	0.018	-	-	0.728	0.002	-	0.412	0.004
Reserved	-	**2.194**	0.011	-	**6.689**	0.293	-	**2.791**	0.048
Reserved-SYN									
UrgentPointer									

- High F_{Target} across all datasets
  - No response to our probing packets
  - 10% of targeted Akamai hosts on CDN failed
    - Flags on probing SYN were correctly ignored
    - Tests failed on probing ACK by retransmitting the SYN/ACK → TCP_DEFER_ACCEPT

TCP Conformance in the Wild – Results (4)

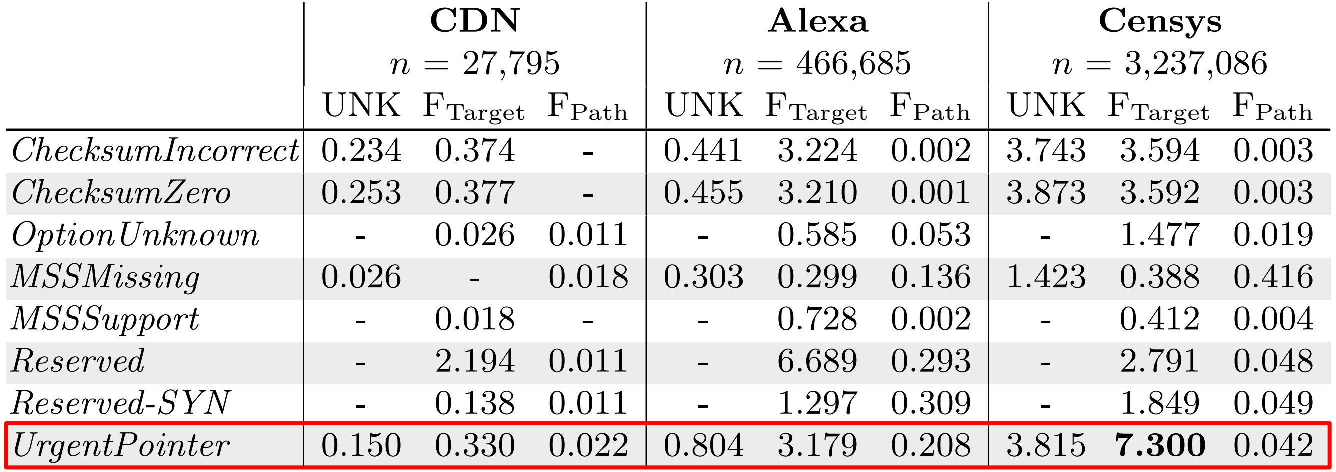


	CDN			Alexa			Censys		
	n = 27,795			n = 466,685			n = 3,237,086		
	UNK	F_{Target}	F_{Path}	UNK	F_{Target}	F_{Path}	UNK	F_{Target}	F_{Path}
ChecksumIncorrect	0.234	0.374	-	0.441	3.224	0.002	3.743	3.594	0.003
ChecksumZero	0.253	0.377	-	0.455	3.210	0.001	3.873	3.592	0.003
OptionUnknown	-	0.026	0.011	-	0.585	0.053	-	1.477	0.019
MSSMissing	0.026	-	0.018	0.303	0.299	0.136	1.423	0.388	0.416
MSSSupport	-	0.018	-	-	0.728	0.002	-	0.412	0.004
Reserved	-	2.194	0.011	-	6.689	0.293	-	2.791	0.048
Reserved-SYN	-	**0.138**	0.011	-	**1.297**	0.309	-	**1.849**	0.049
UrgentPointer									

Connectivity IS impaired

- Reserved-SYN
  - Extendibility is limited
- Recap: No formal MUST requirement
  - Started a discussion within the IETF to add a formal MUST
  - Proposed a new MUST requirement to remove ambiguities regarding Reserved Flags

TCP Conformance in the Wild – Results (5)



	CDN			Alexa			Censys		
	n = 27,795			n = 466,685			n = 3,237,086		
	UNK	$\mathrm{F}_{\mathrm{Target}}$	$\mathrm{F}_{\mathrm{Path}}$	UNK	$\mathrm{F}_{\mathrm{Target}}$	$\mathrm{F}_{\mathrm{Path}}$	UNK	$\mathrm{F}_{\mathrm{Target}}$	$\mathrm{F}_{\mathrm{Path}}$
ChecksumIncorrect	0.234	0.374	-	0.441	3.224	0.002	3.743	3.594	0.003
ChecksumZero	0.253	0.377	-	0.455	3.210	0.001	3.873	3.592	0.003
OptionUnknown	-	0.026	0.011	-	0.585	0.053	-	1.477	0.019
MSSMissing	0.026	-	0.018	0.303	0.299	0.136	1.423	0.388	0.416
MSSSupport	-	0.018	-	-	0.728	0.002	-	0.412	0.004
Reserved	-	2.194	0.011	-	6.689	0.293	-	2.791	0.048
Reserved-SYN	-	0.138	0.011	-	1.297	0.309	-	1.849	0.049
UrgentPointer	0.150	0.330	0.022	0.804	3.179	0.208	3.815	**7.300**	0.042

- $\mathrm{F}_{\mathrm{Target}}$ Censys
  - Primarily located in ISP networks
  - 98.8% of failures silently discarded the data
- Recap: Usage is discouraged, but implementation is mandatory
  - We posit to remove the mandatory implementation requirement to reflect its deprecation

Connectivity
IS impaired

Conclusion

- Most Internet hosts and paths do adhere to basic requirements
- TCP options show the highest level of conformance
  - Access routers in ISP networks are problematic
- Only two out of six TCP stacks are fully conformant
  - Found and fixed/reported implementation bugs
- Using Reserved Flags or setting the Urgent Pointer can limit connectivity

Conformance to mandatory features should not be taken for granted