Misbehaviors in TCP SACK Generation

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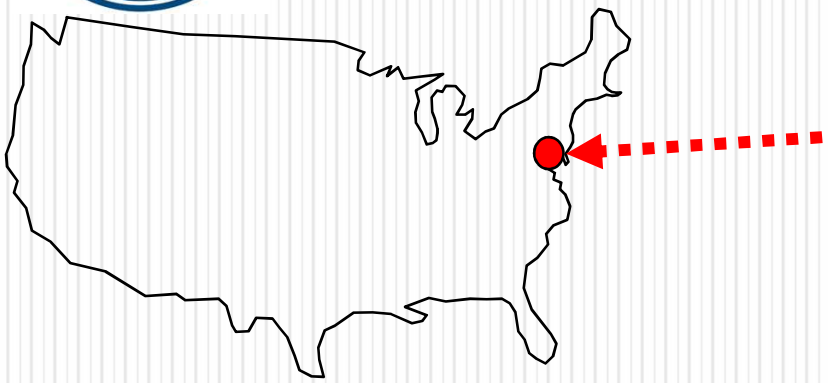

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OUTLINE

1. Introduction
2. Experimental design
3. 7 SACK misbehaviors
4. Results
5. Summary

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TCP acknowledgements

- cumulative ACK *n* (for ordered data)

  bytes [*… to n-1*] [RFC 793]

- selective ACK (SACK) *m-n* (for out-of-order data)

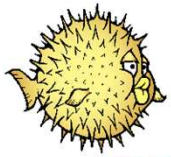
  bytes [*m* to *n-1*] [RFC 2018]

  - prevents unnecessary retransmissions during loss recovery
  - improves throughput when multiple losses in same window (SACK-based loss recovery [RFC 3517])

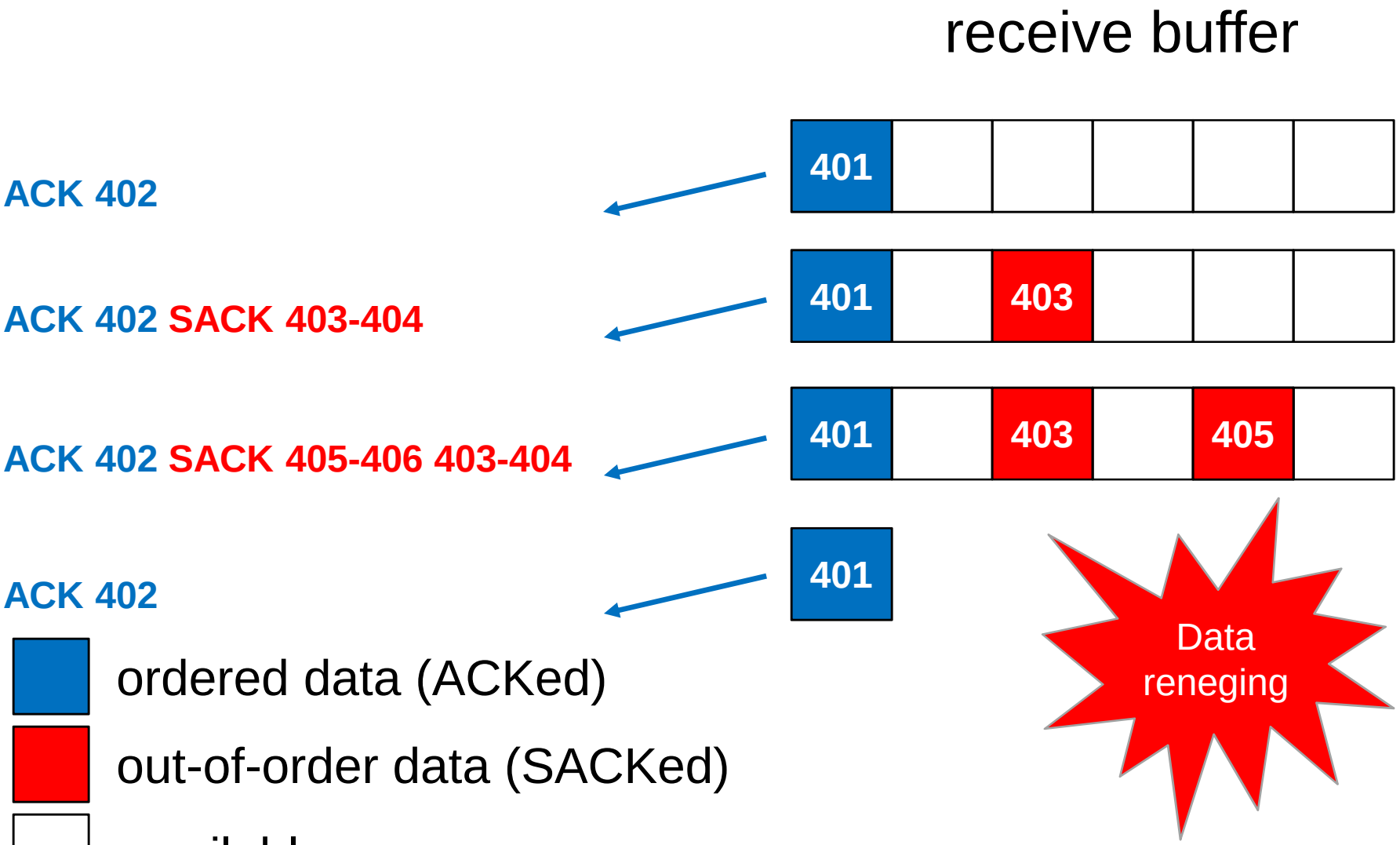
Deployment of SACK

- 2001: 41% of web servers do SACK
- 2005: 68% of web servers do SACK
- 2010: All recent versions of OSes do SACK
  - FreeBSD
  - Linux
  - Mac OS X
  - OpenBSD
  - Open Solaris
  - Solaris
  - Windows



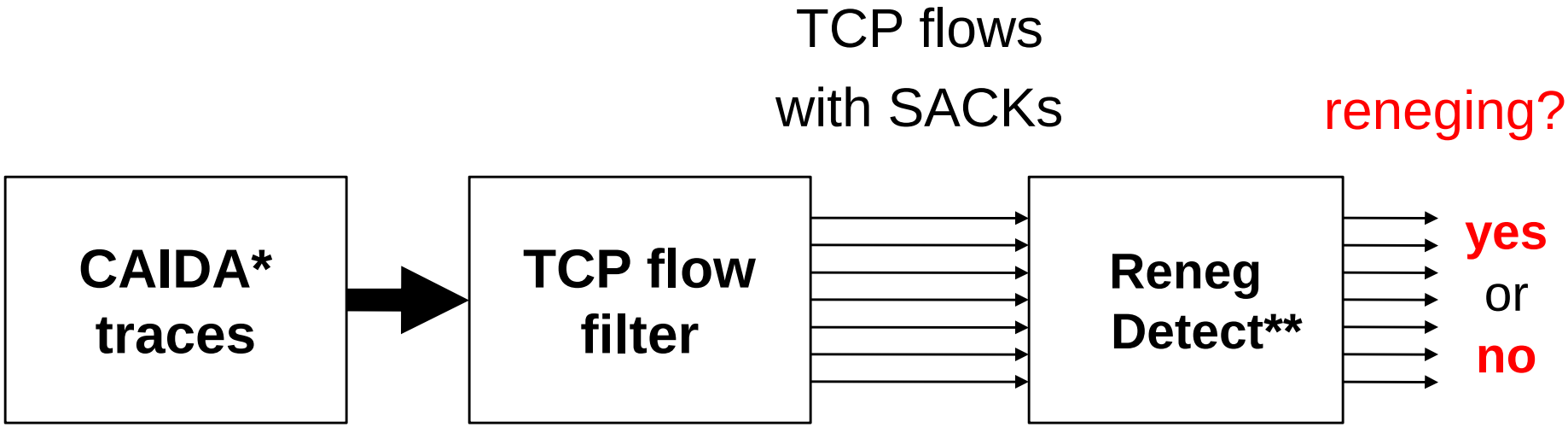
Data reneging



Data reneging

- TCP is designed to tolerate reneging
  - [RFC 2018]: “The SACK option is *advisory*, in that, while it notifies the data sender that the data receiver has received the indicated segments, the data receiver is permitted to later *discard* data which have been reported in a SACK option.”
  - TCP data sender retains copies of all SACKed data until ACKed

RenegDetect



* Cooperative Association for Internet Data Analysis

** Nasif Ekiz, Paul D. Amer, **"*A model for detecting transport layer data reneging*"**, PFLDNeT 2010, Lancaster, PA, 11/10

RenegDetect

- RenegDetect was tested with real TCP flows
  - at first, reneging seemed to occur frequently
  - on closer inspection, we found many unexpected behaviors !
    - sometimes SACKs that should have been sent were not
    - sometimes the wrong SACKs were sent
- these SACK misbehaviors wrongly gave the impression that data reneging was occurring

Research goal

- verify TCP SACK for a wide-range of OSes
- not measure degraded performance
  - misbehaviors can reduce the effectiveness of SACKs

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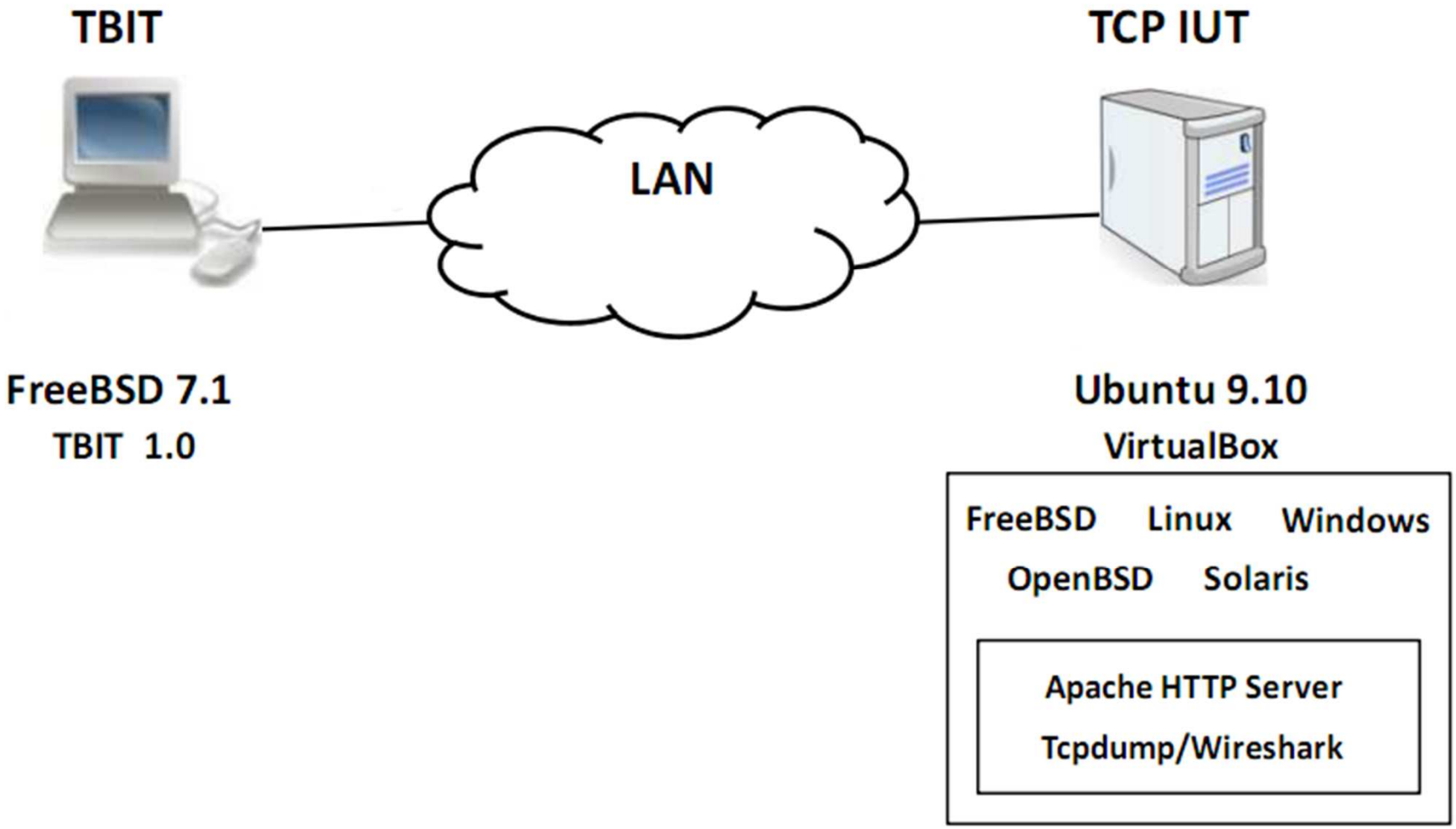
Experimental design

TCP Behavior Inference Tool

TCP Implementation Under Test



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MISBEHAVIOR

A

Misbehavior A:
fewer than maximum number of reported SACKs

- RFC 2018 section 3
  - "*the data receiver SHOULD include as many distinct SACK blocks possible in the SACK option,*" and
  - "*the 40 bytes available for TCP options can specify a maximum of four SACK blocks*"

- for some TCP flows, only 2 or 3 SACK blocks are reported even when 4 are possible

Misbehavior A:
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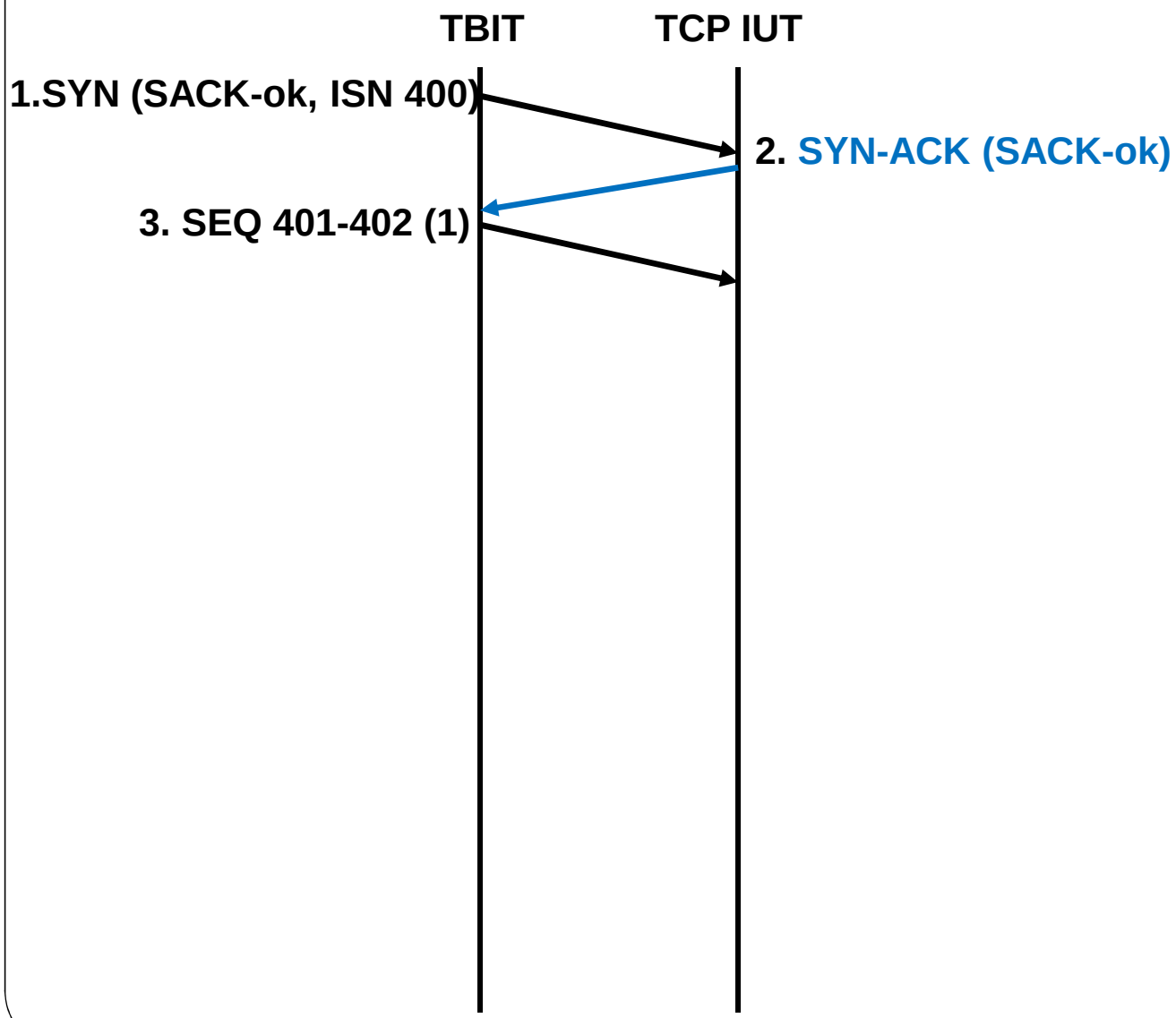

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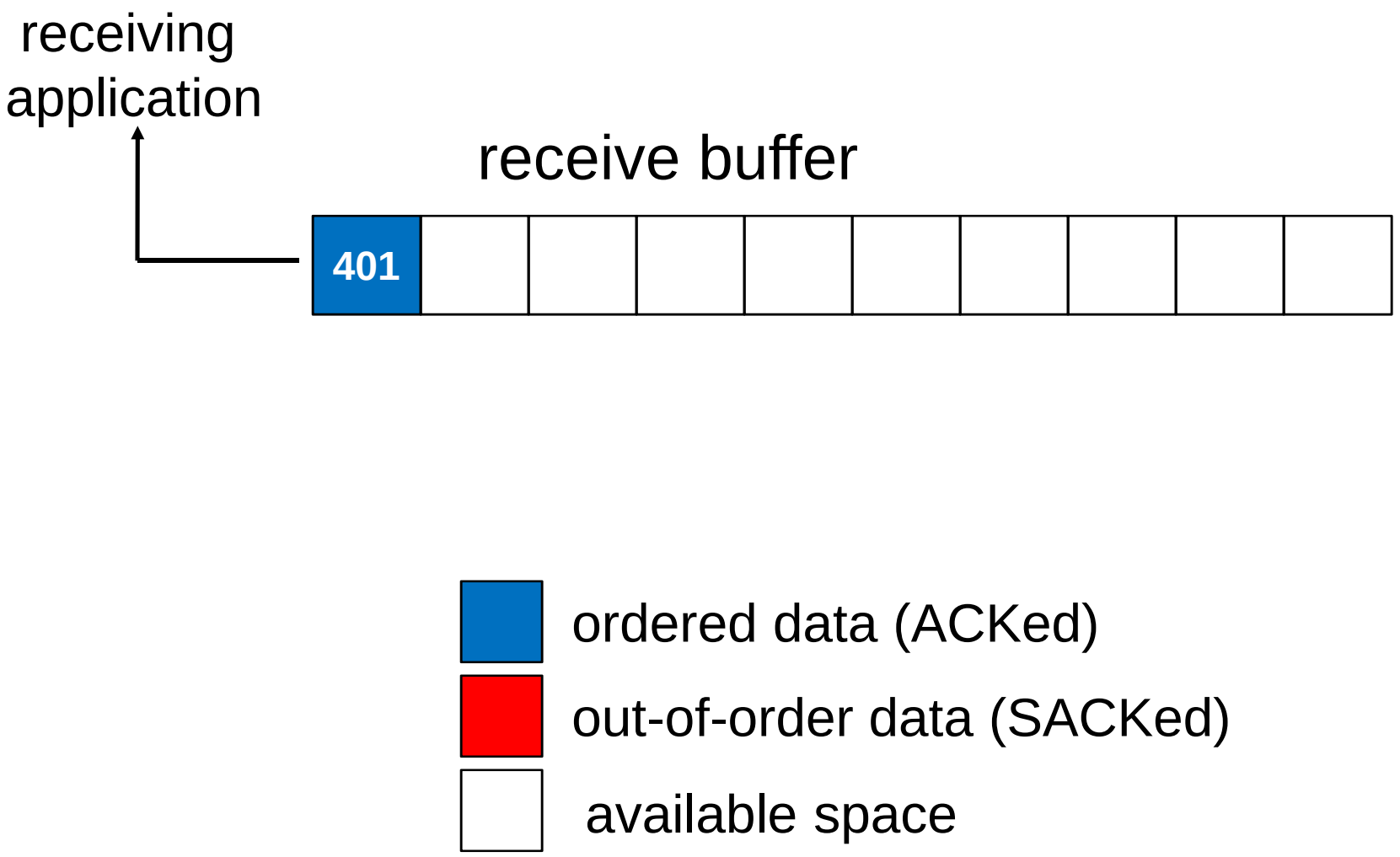

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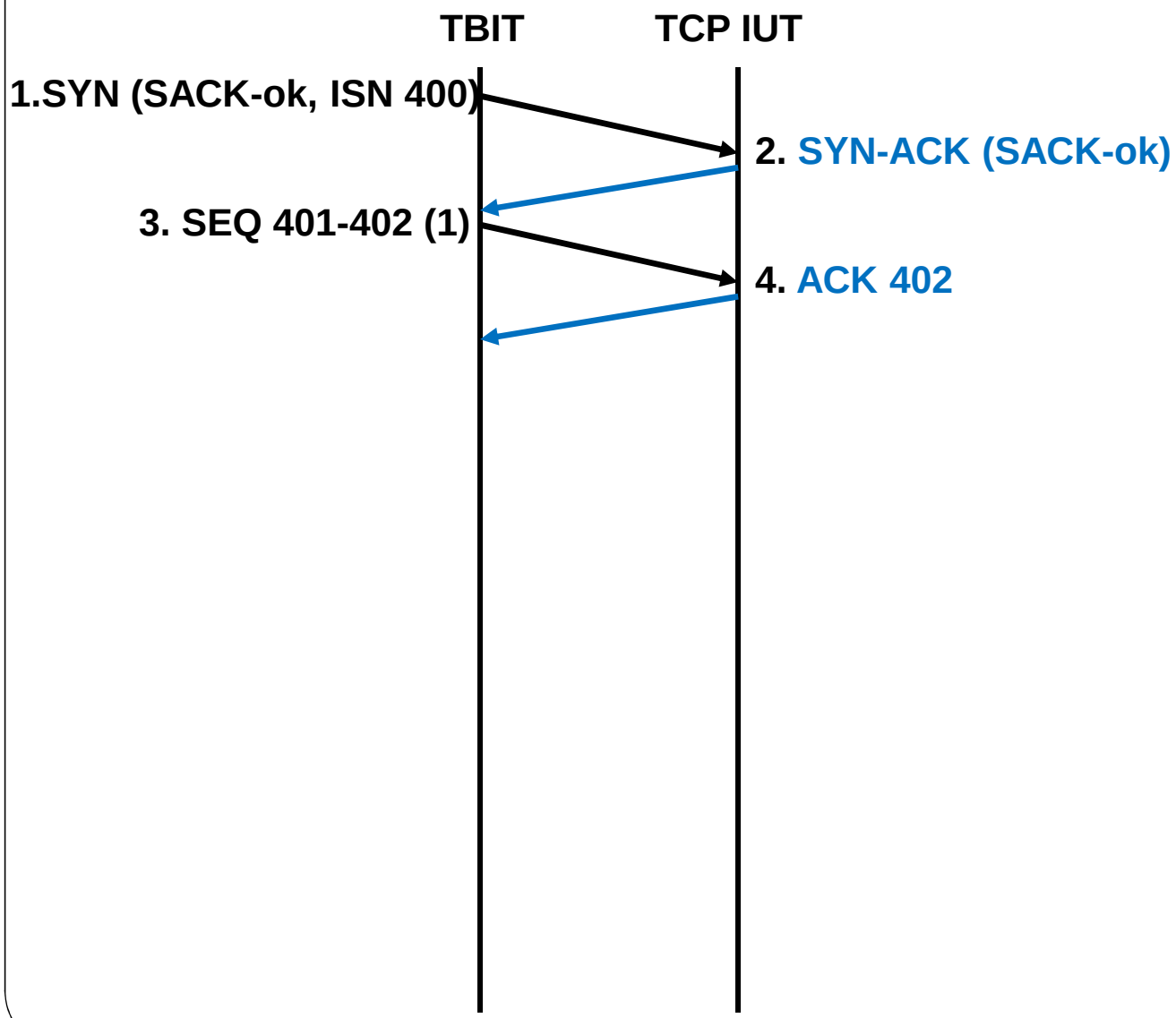

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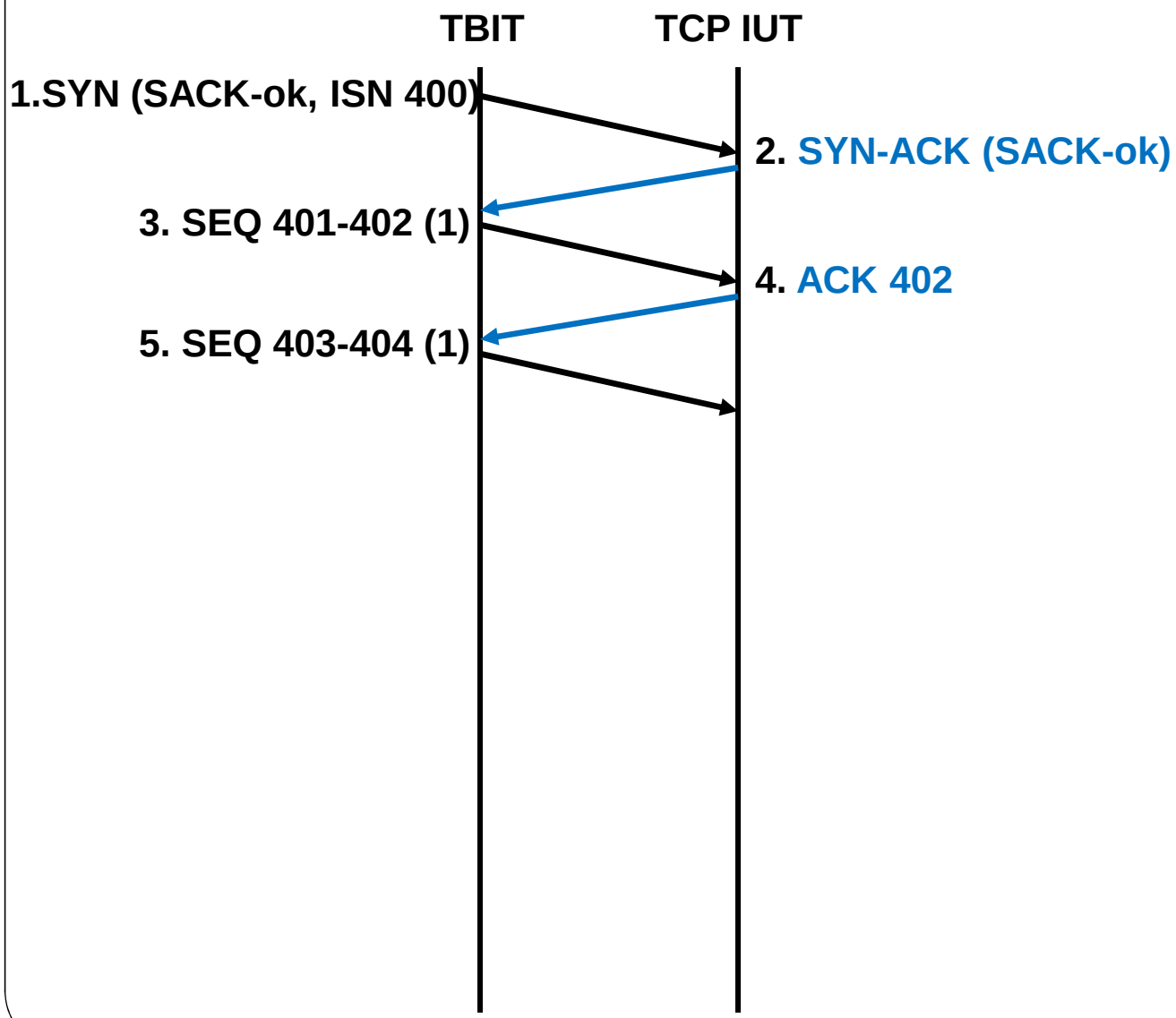

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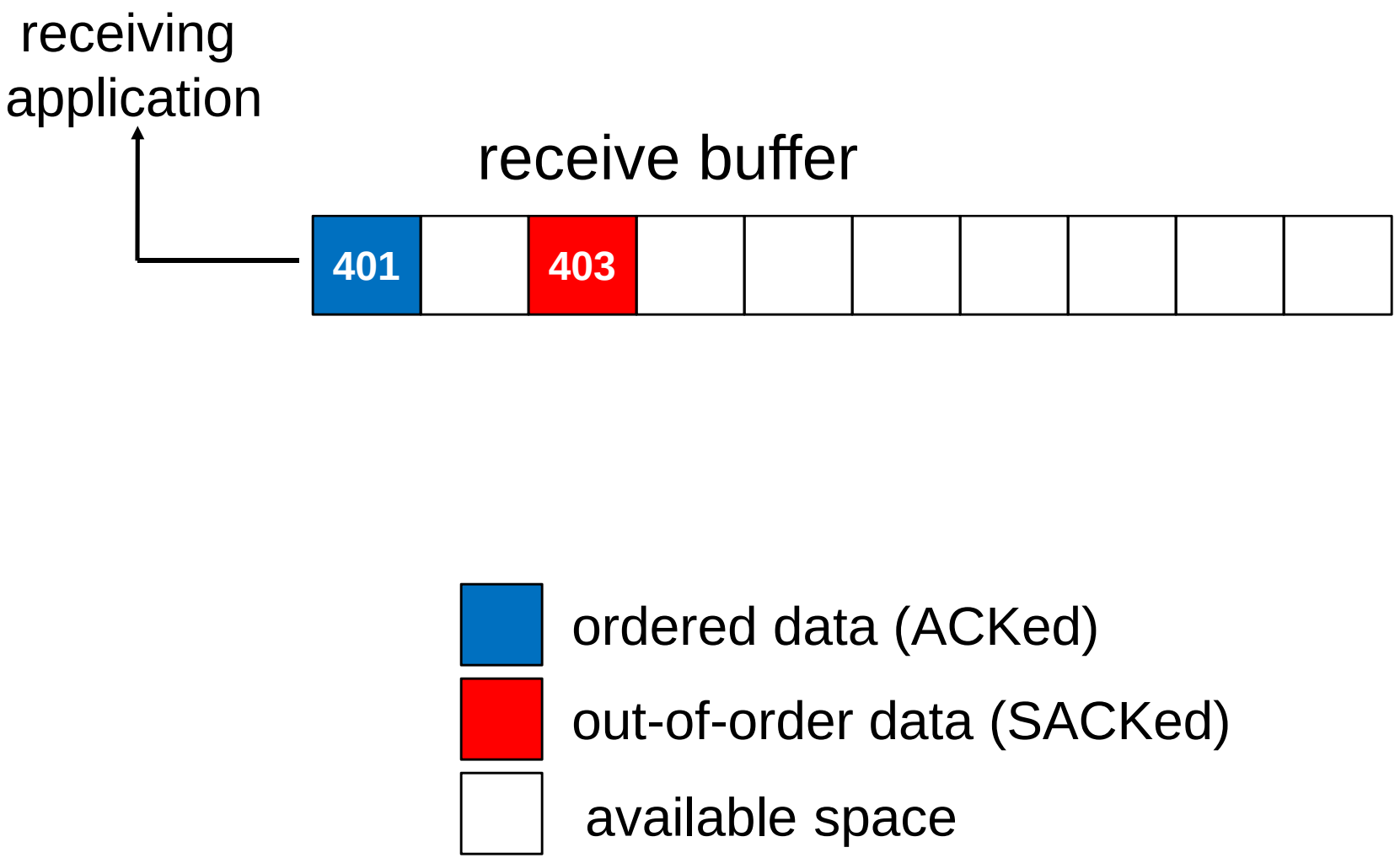

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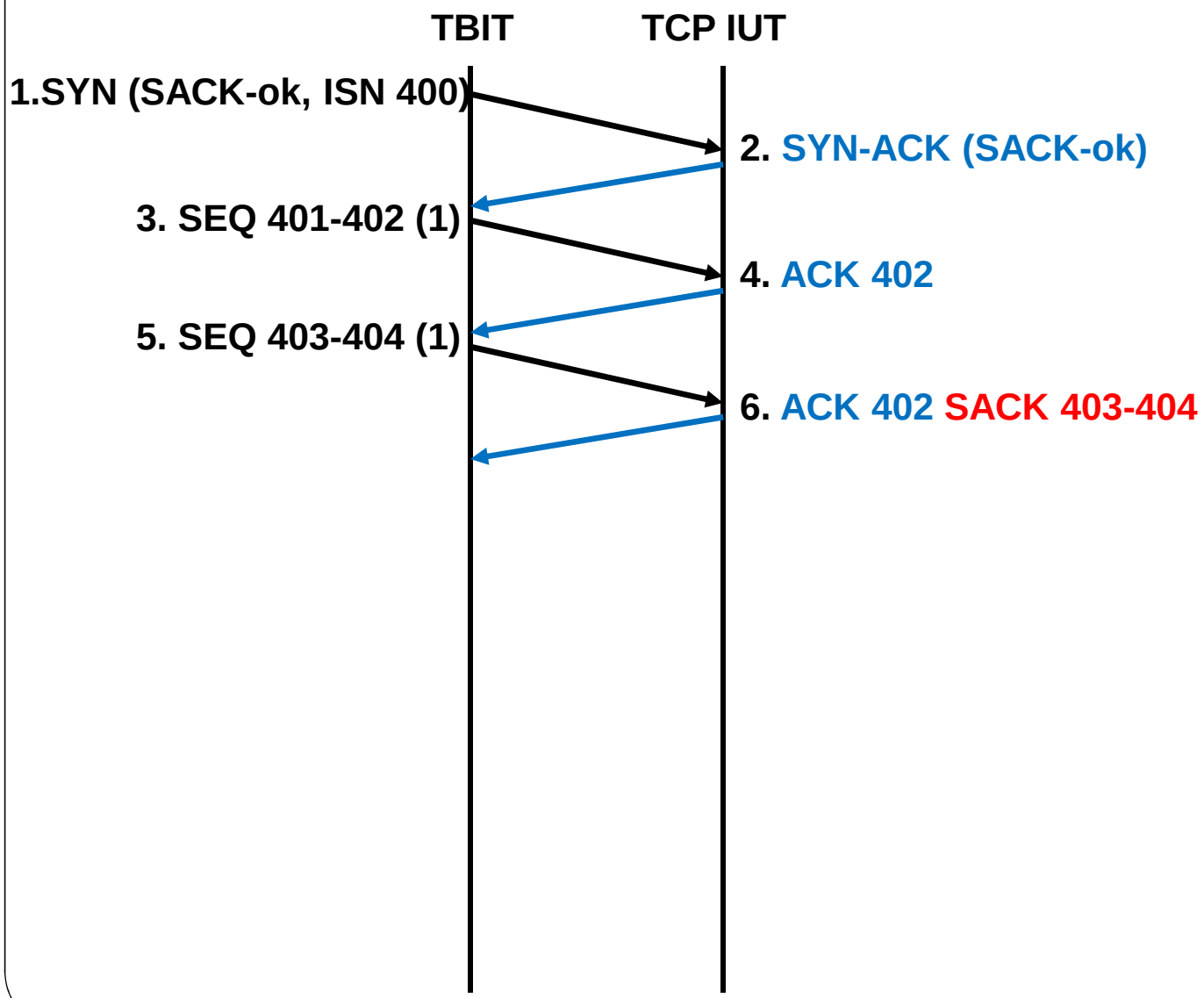

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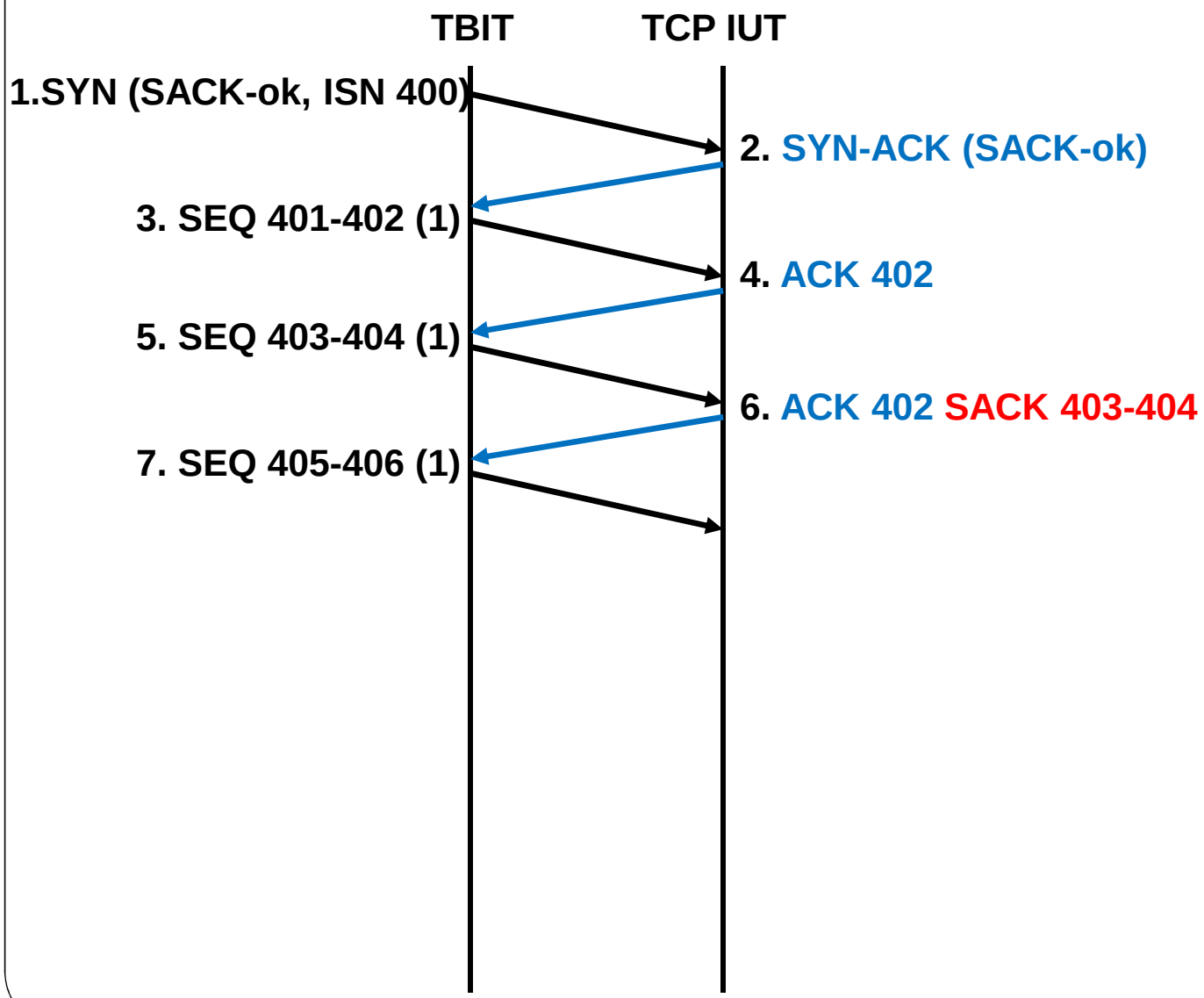

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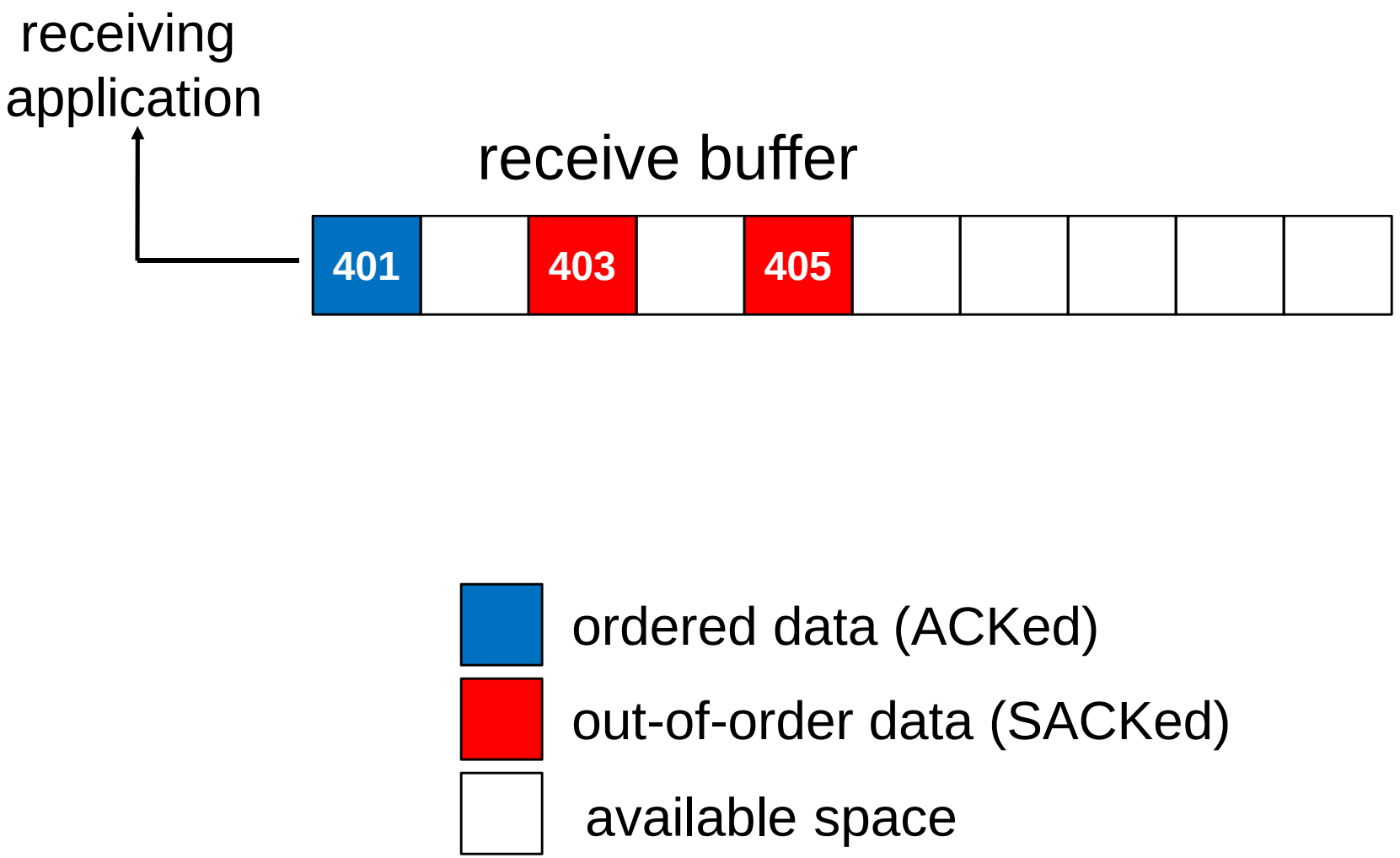

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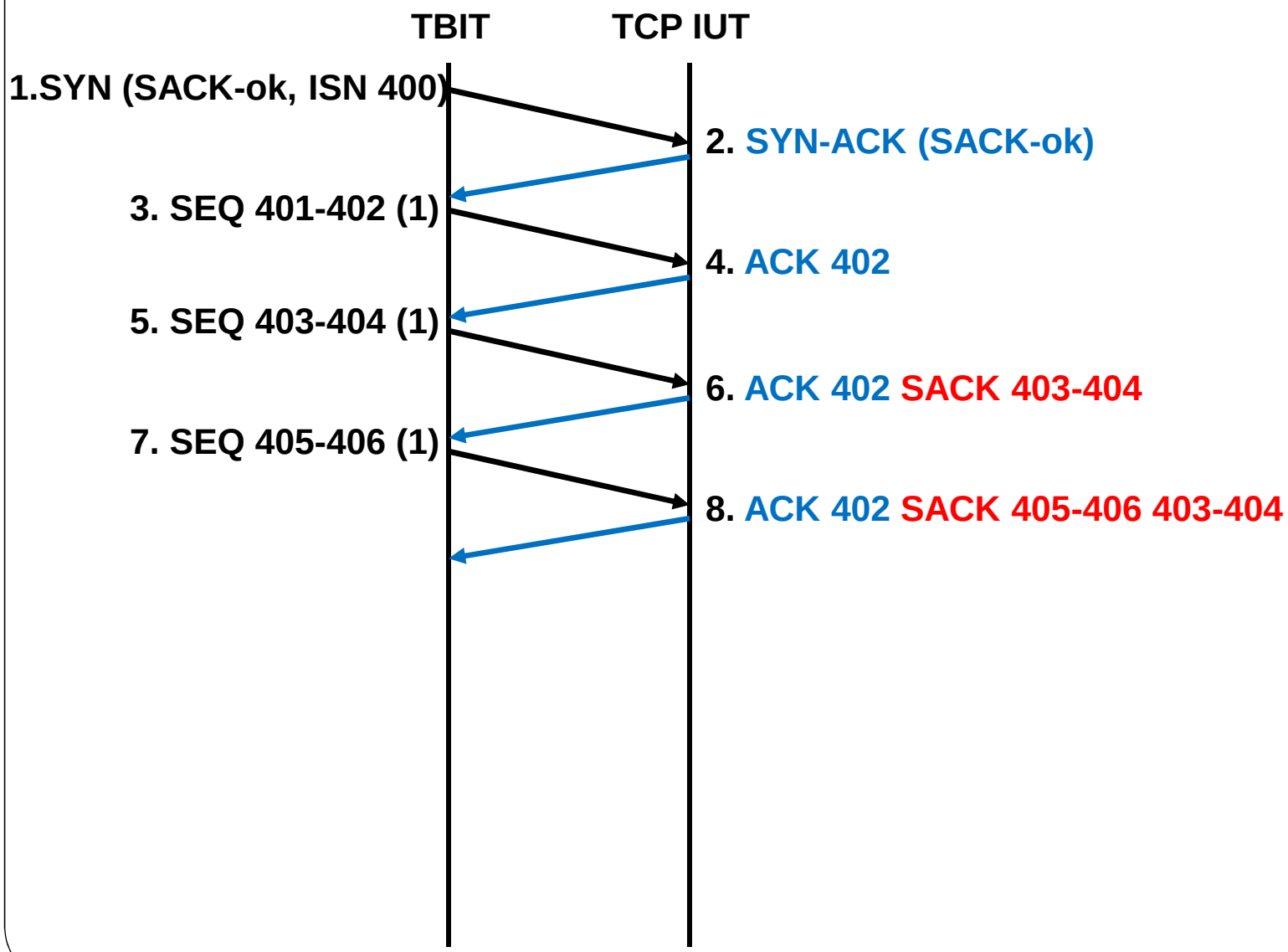

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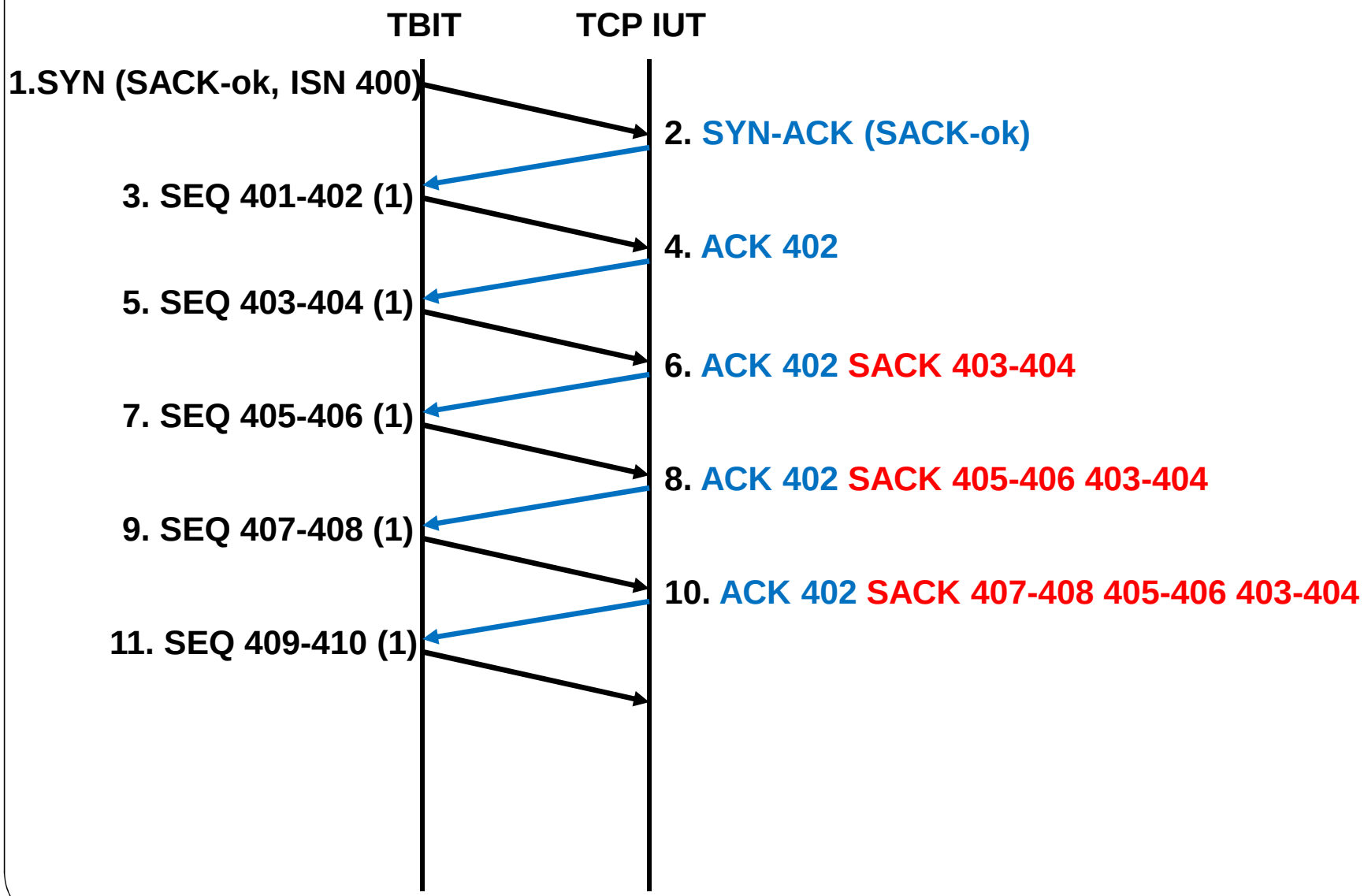

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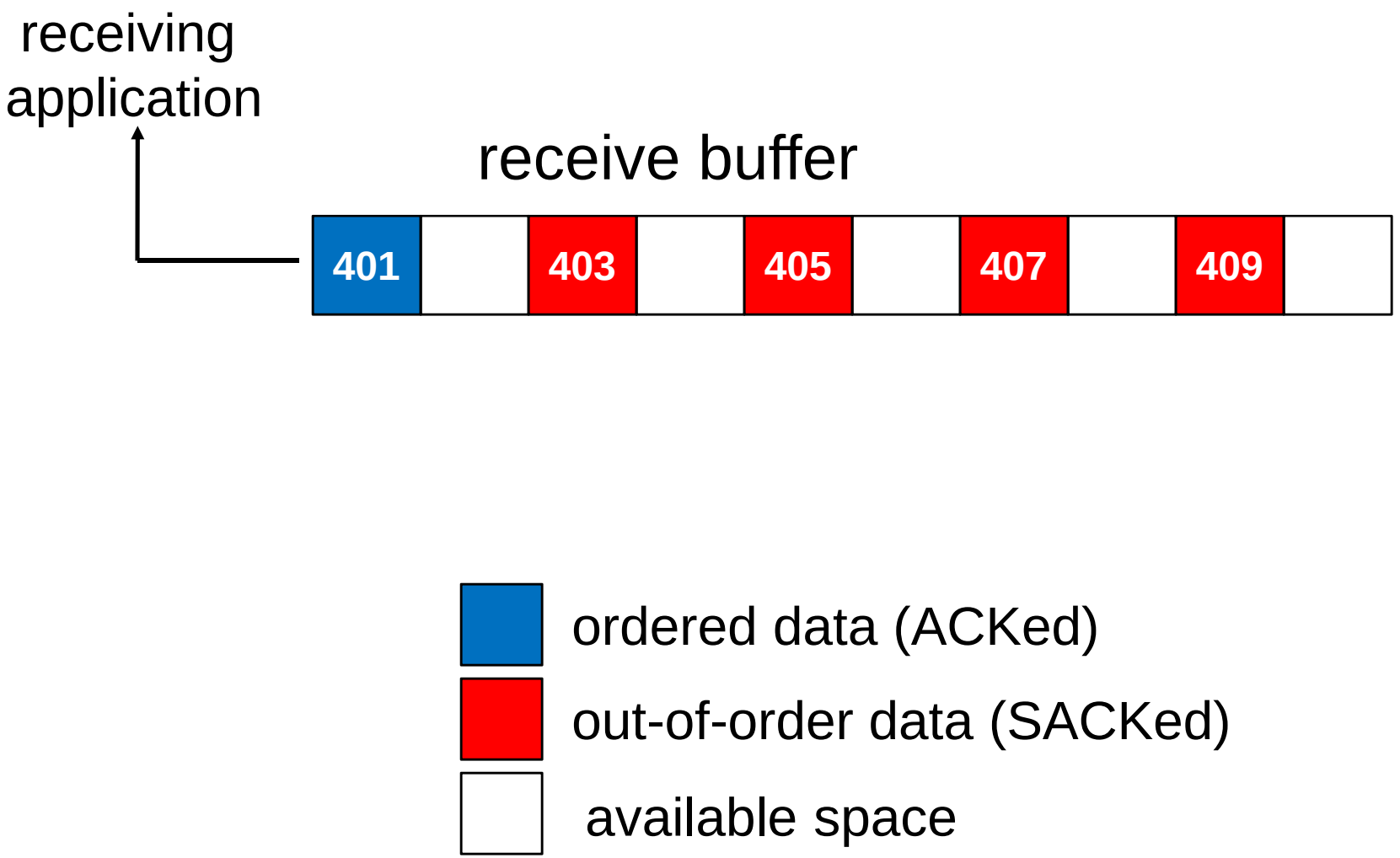

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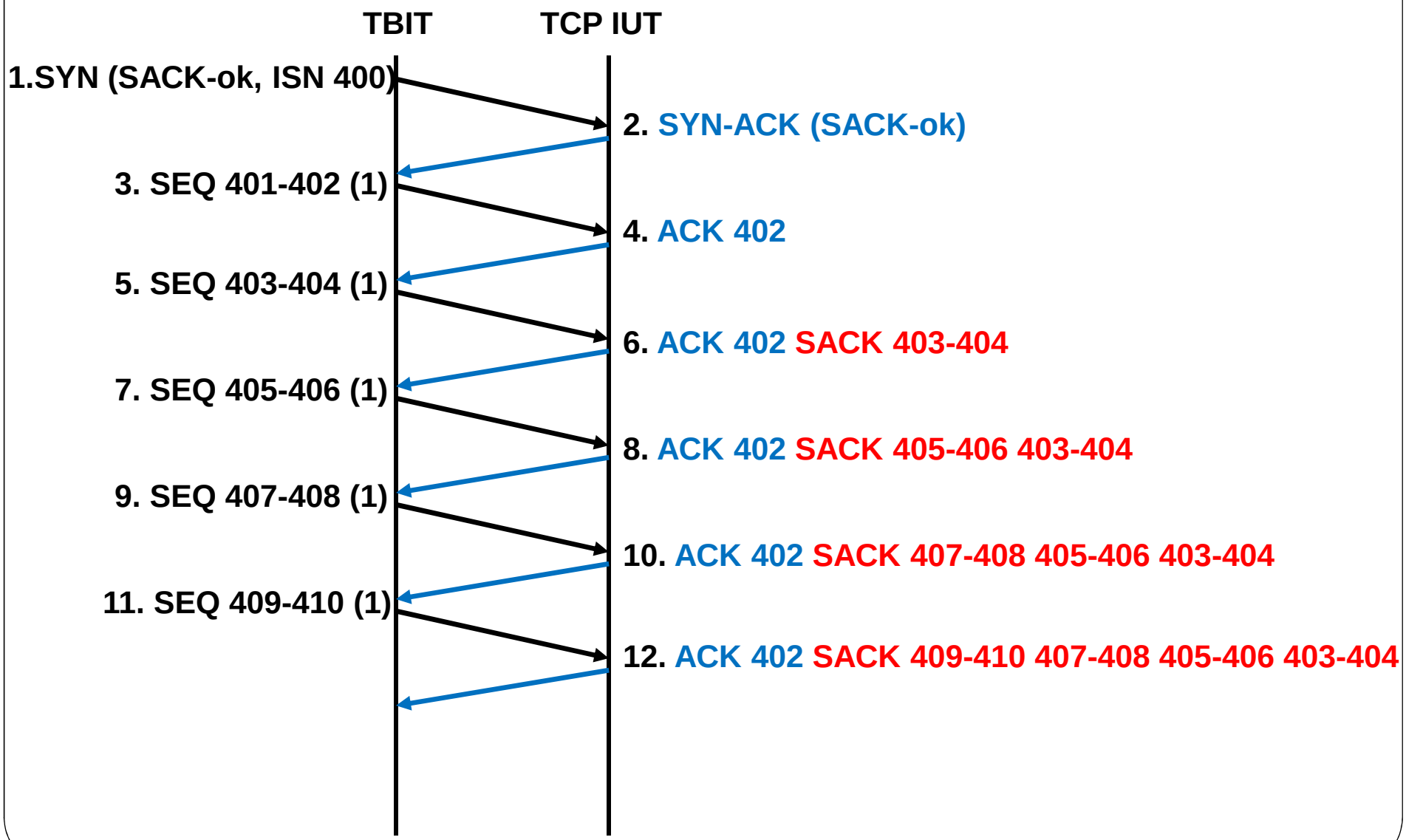

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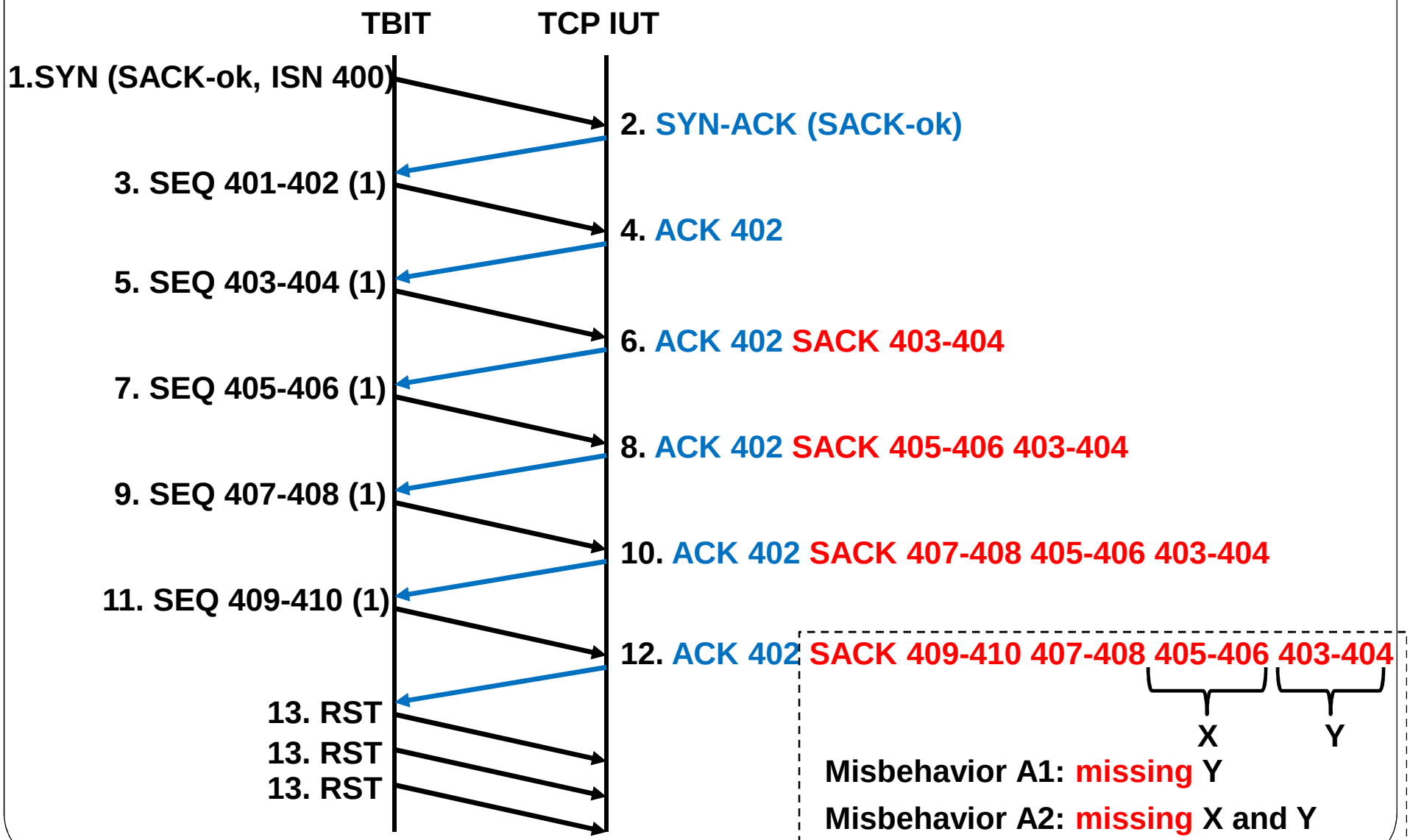

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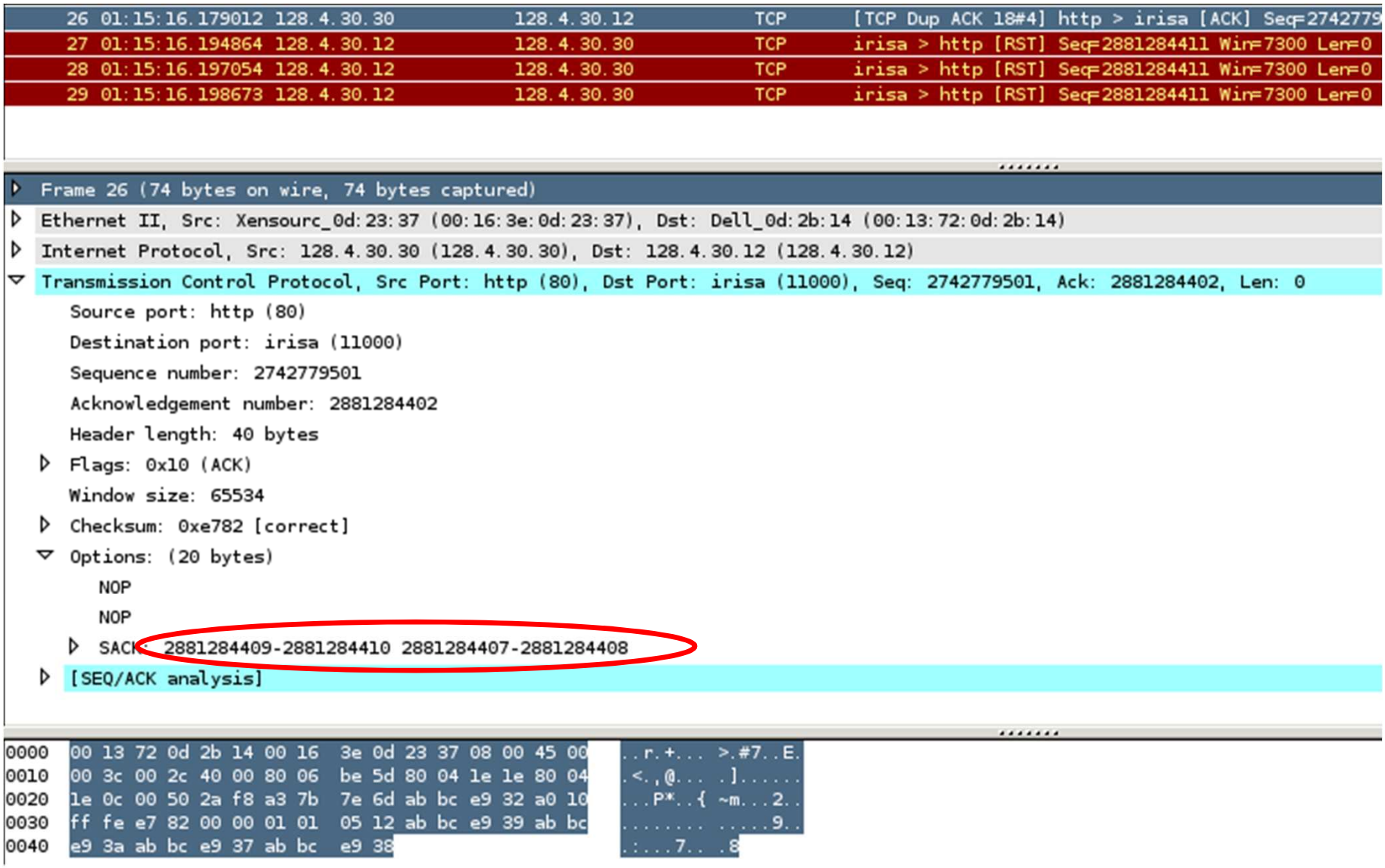

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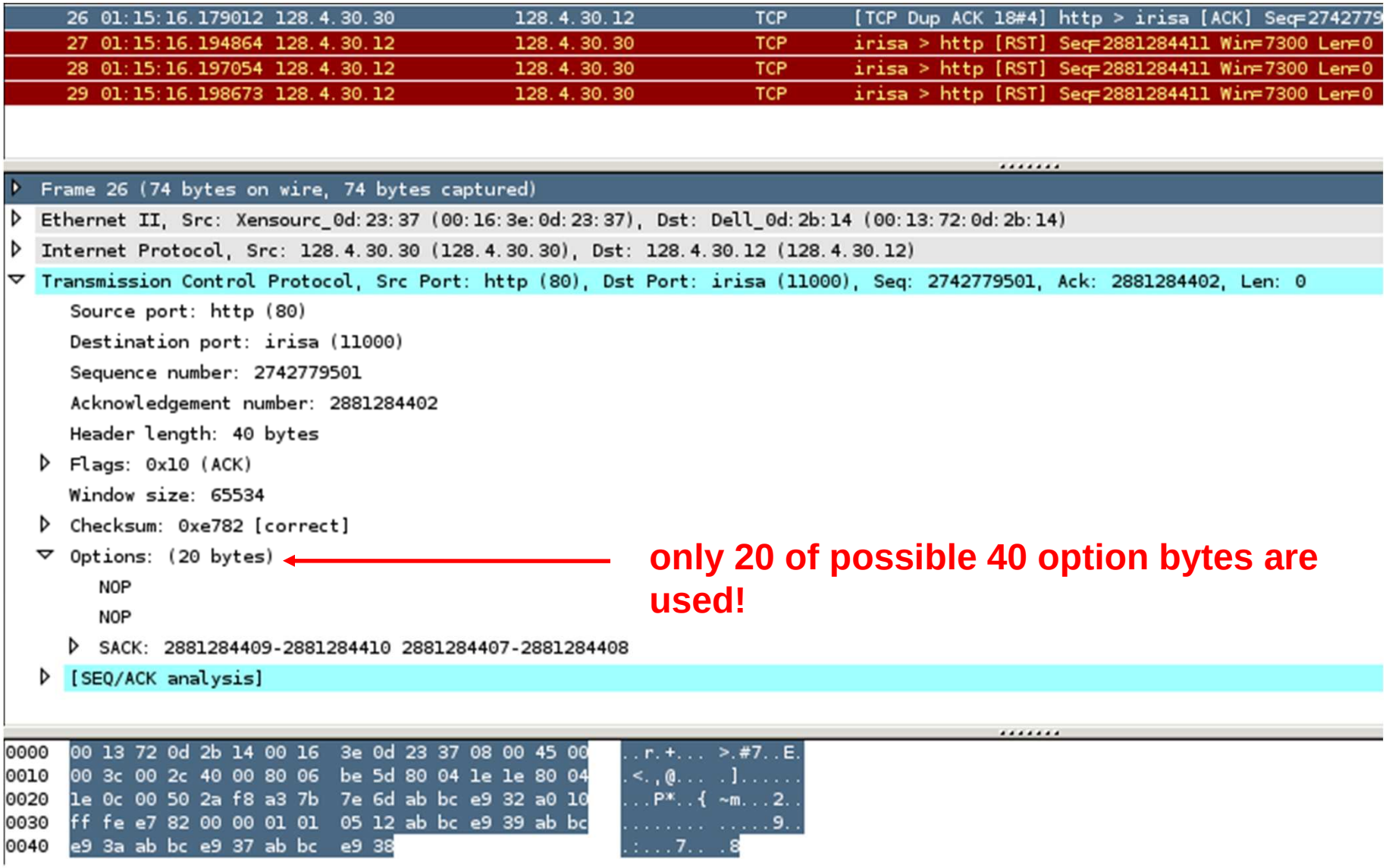
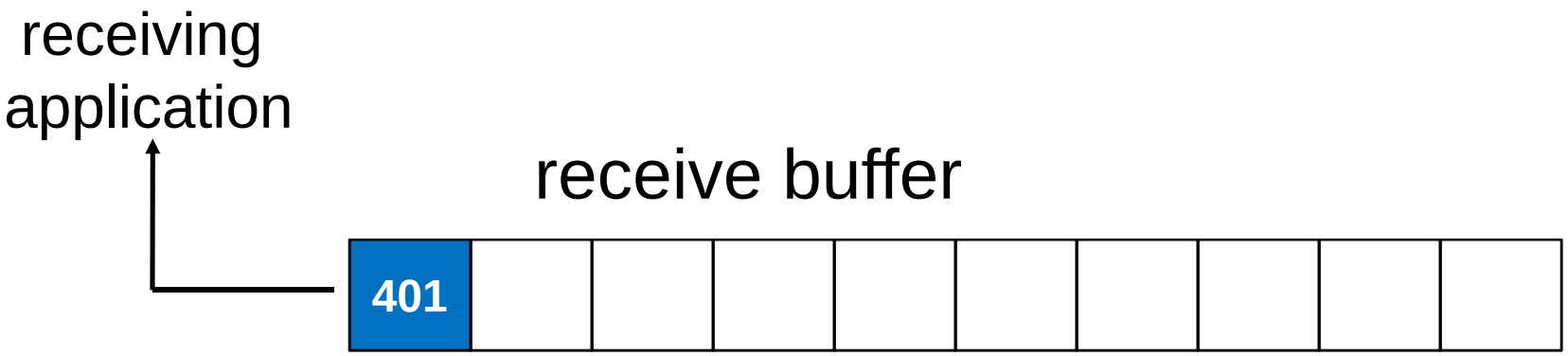


MISBEHAVIOR

B

Misbehavior B:
filling gap between Cum ACK and first SACK



ordered data (ACKed)

out-of-order data (SACKed)

available space

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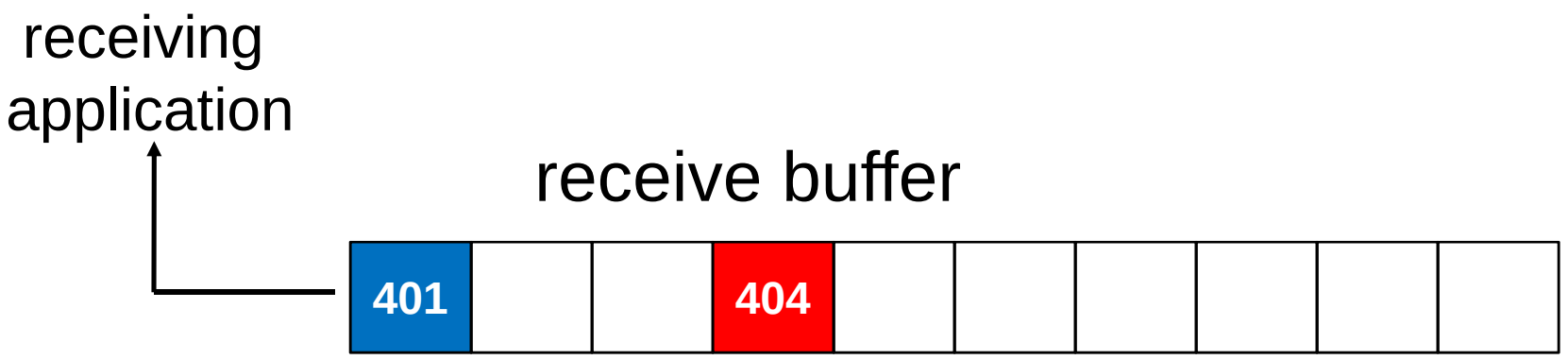

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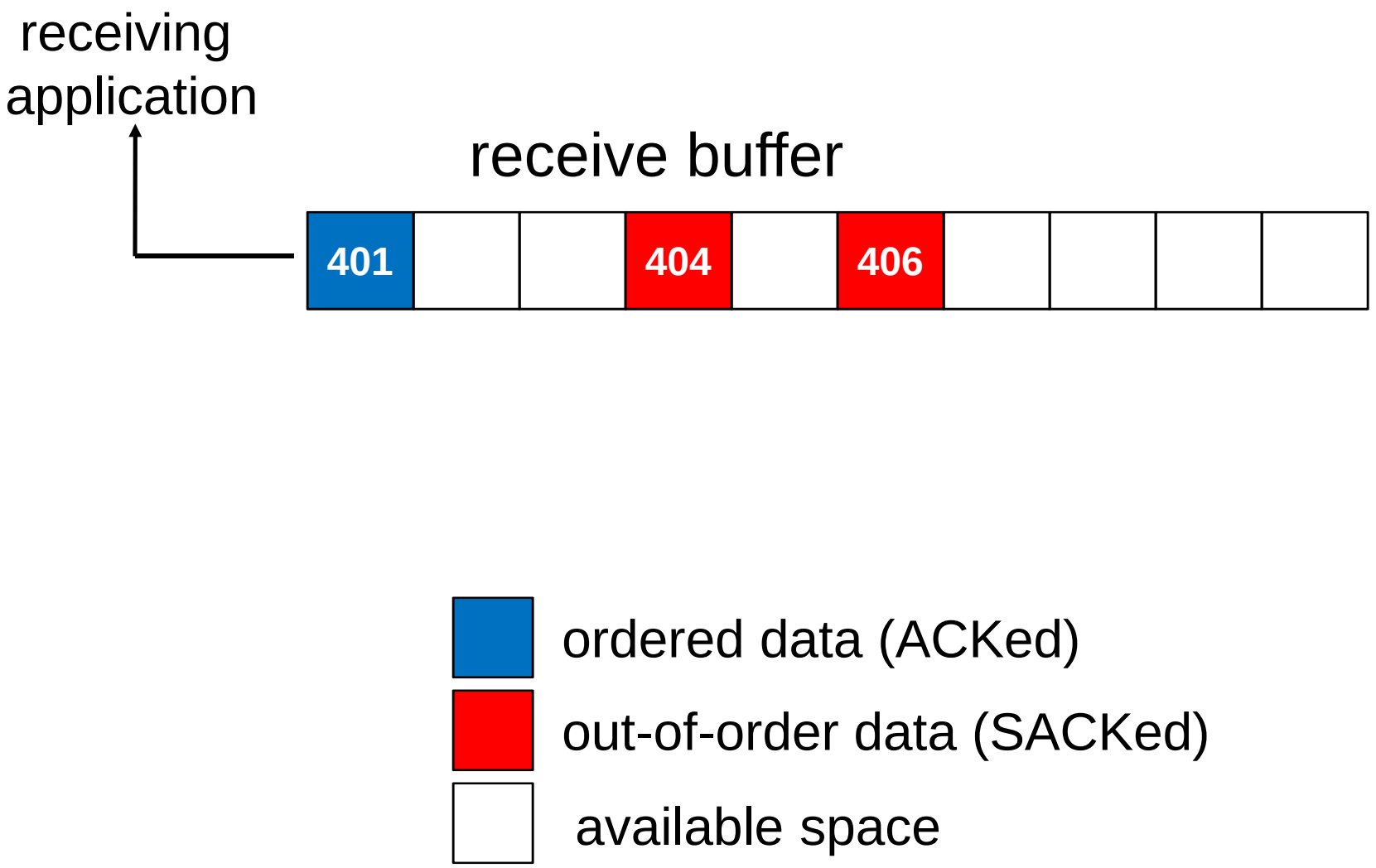

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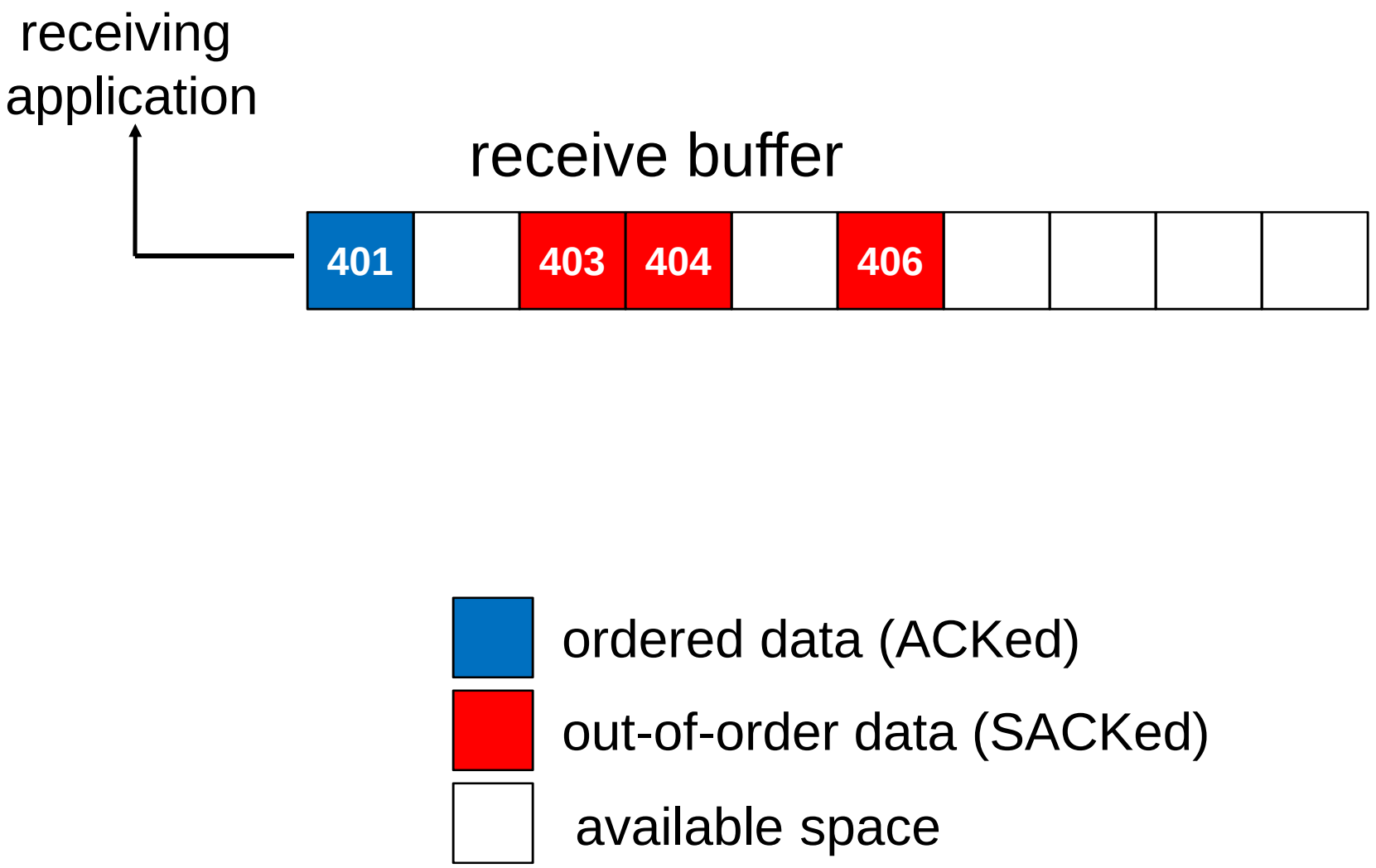

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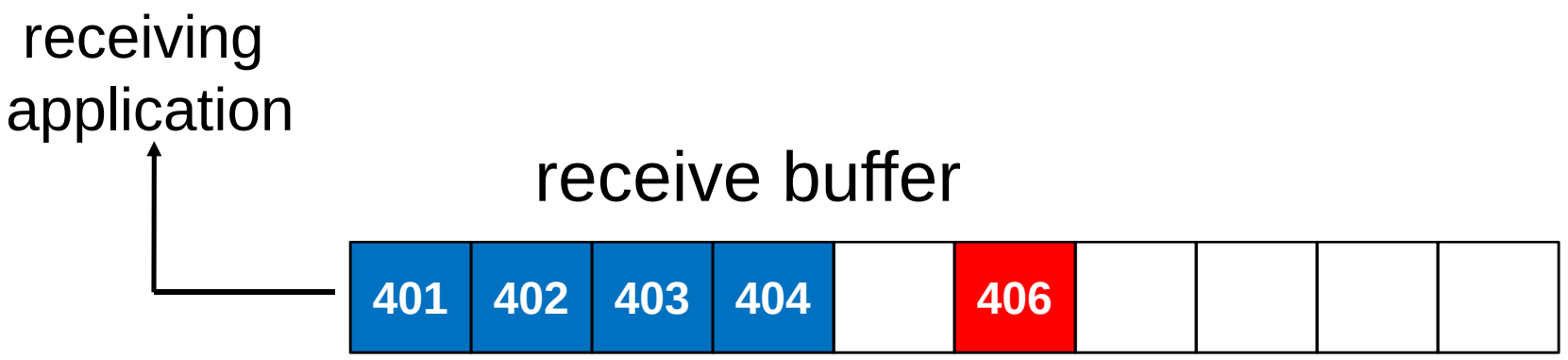

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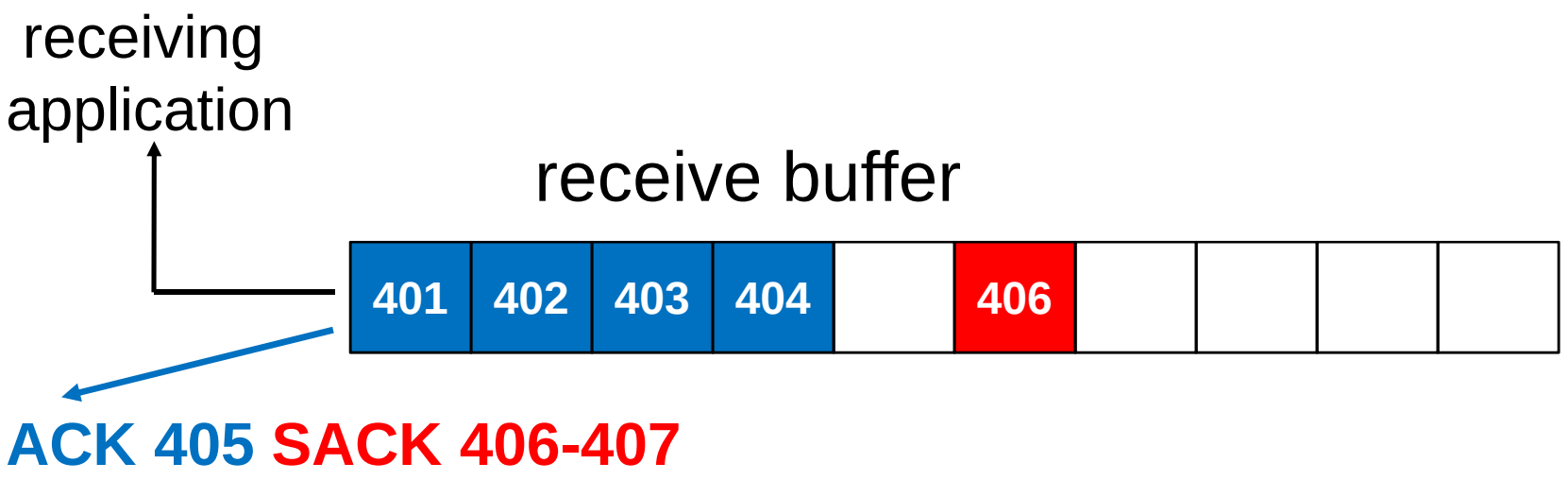

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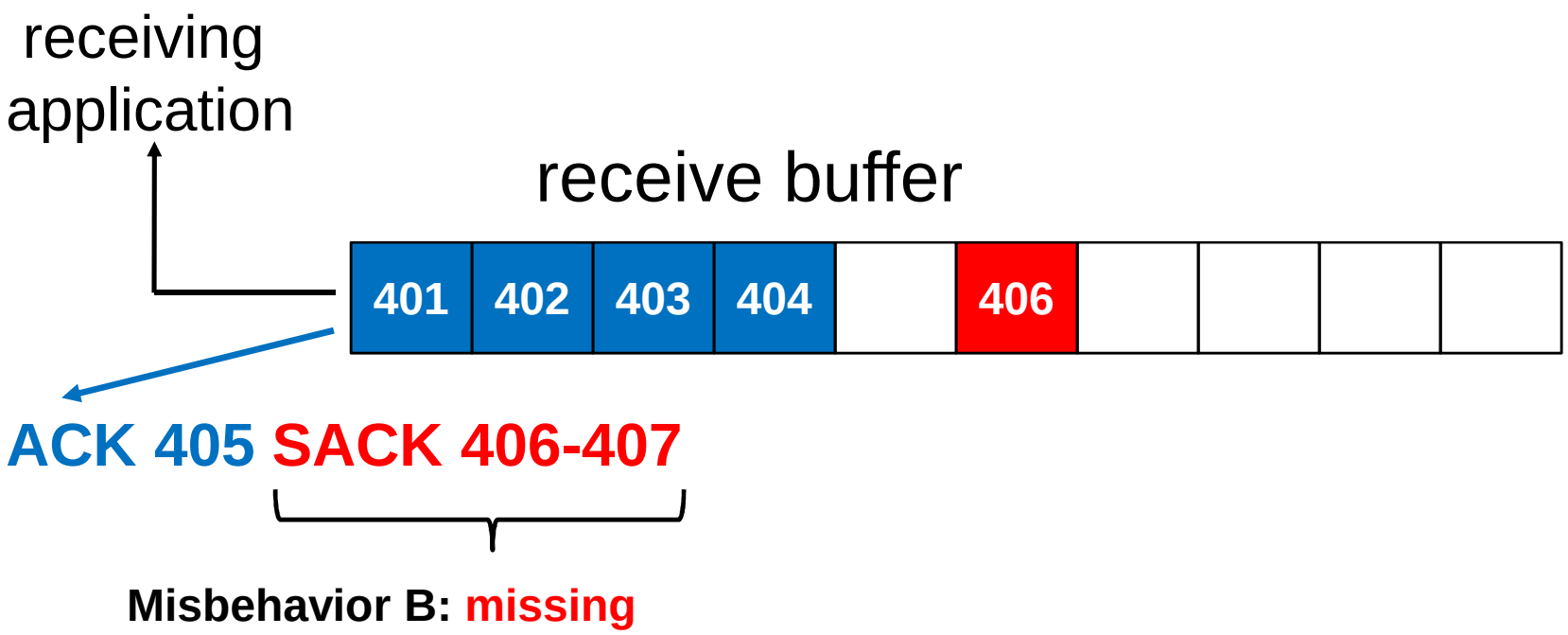
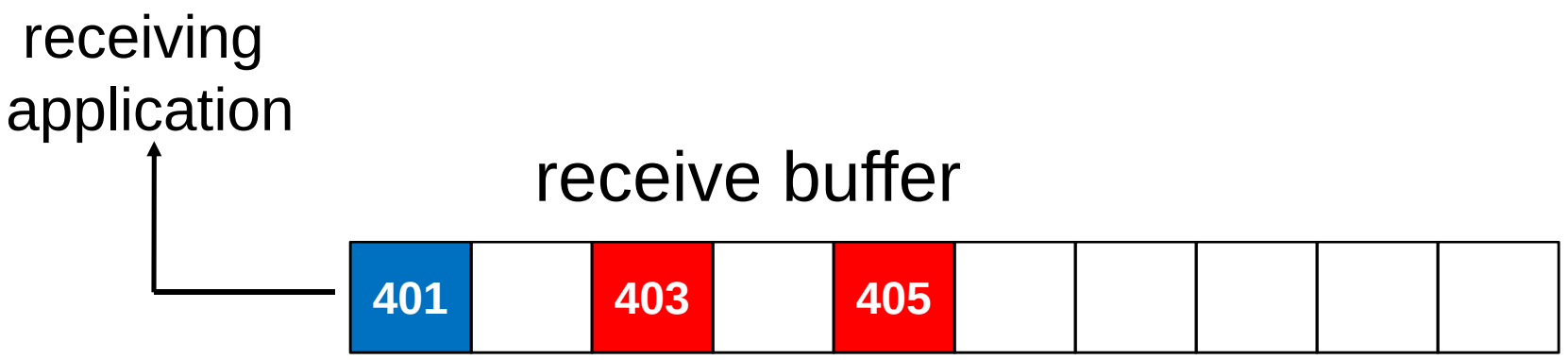


MISBEHAVIOR

C

Misbehavior C:

filling gap between two previously reported SACKs



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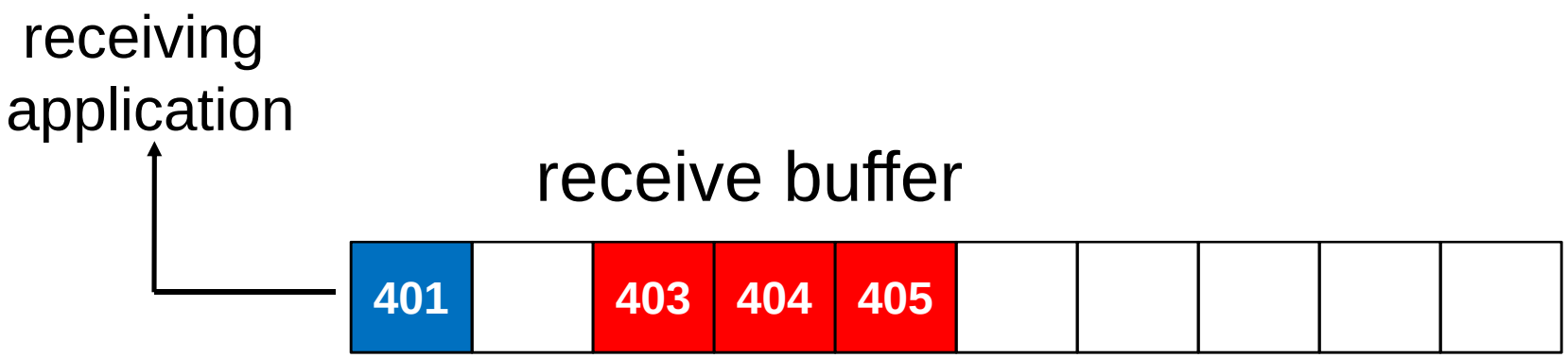

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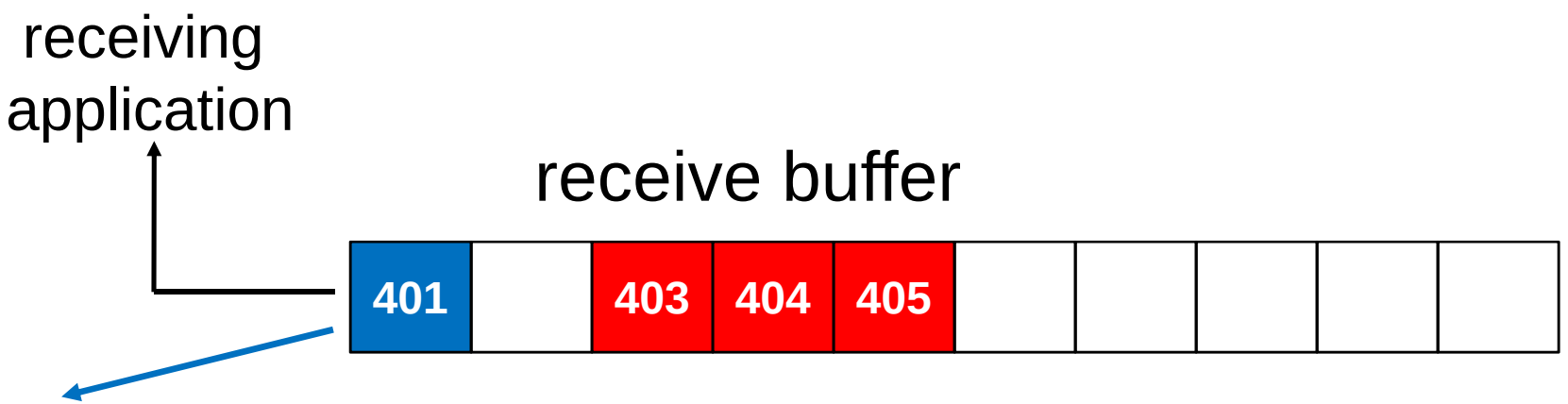

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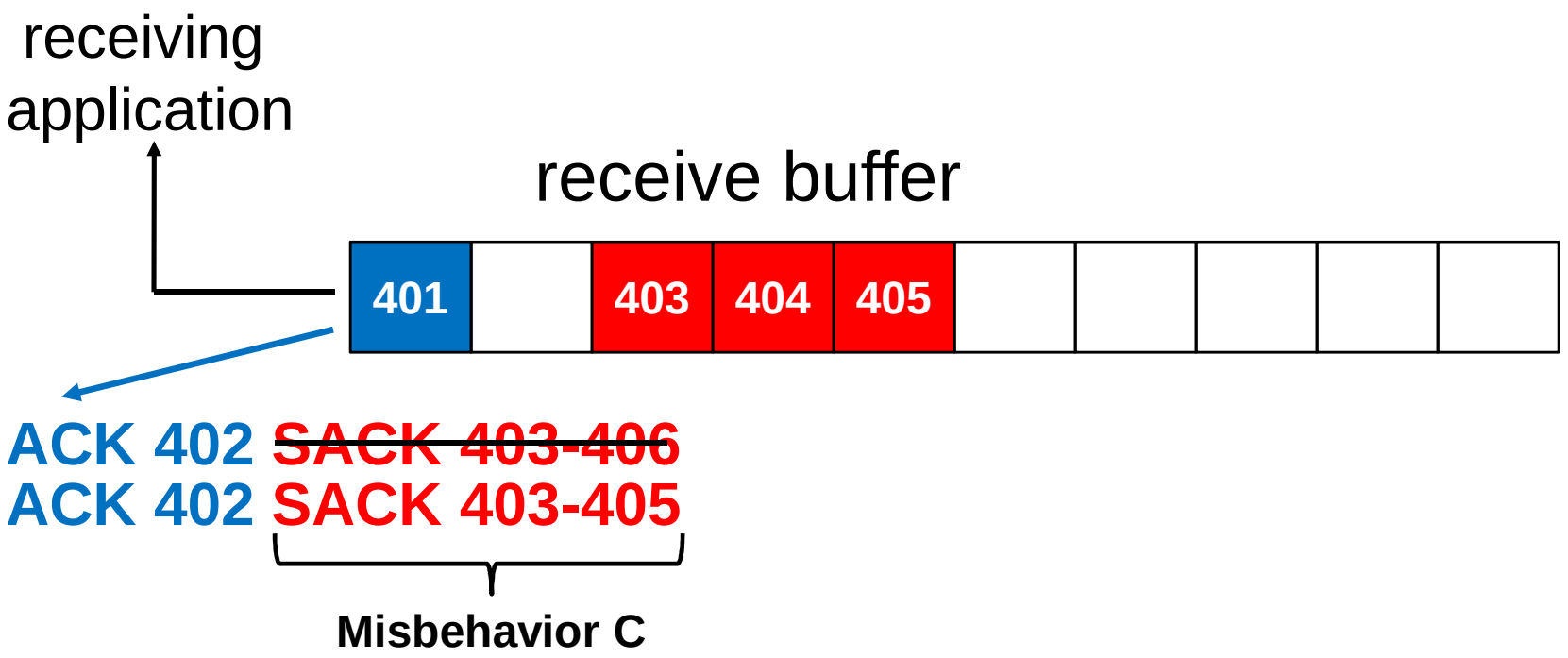
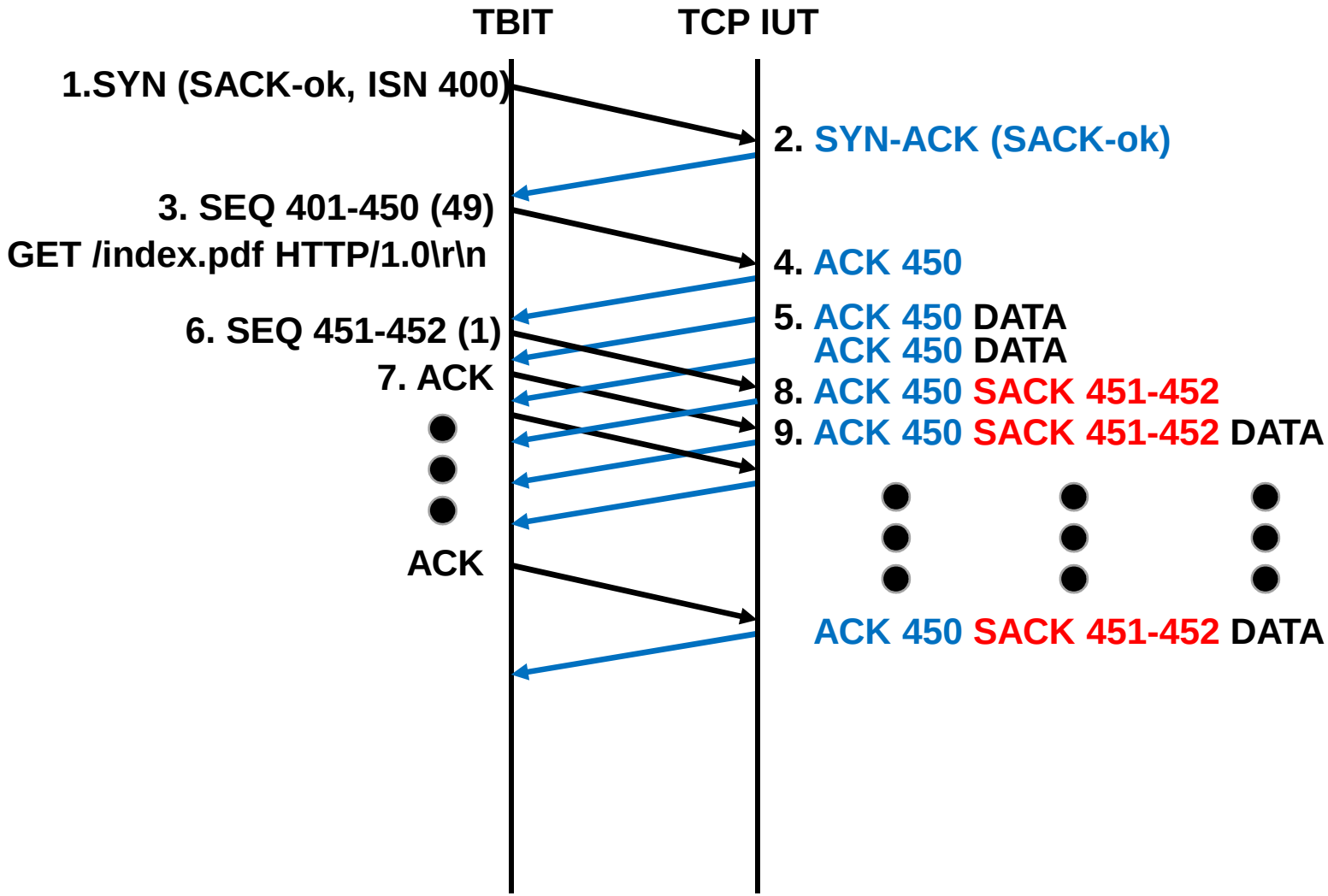


MISBEHAVIOR

D

Misbehavior D:

failure to report SACKs in FIN segments



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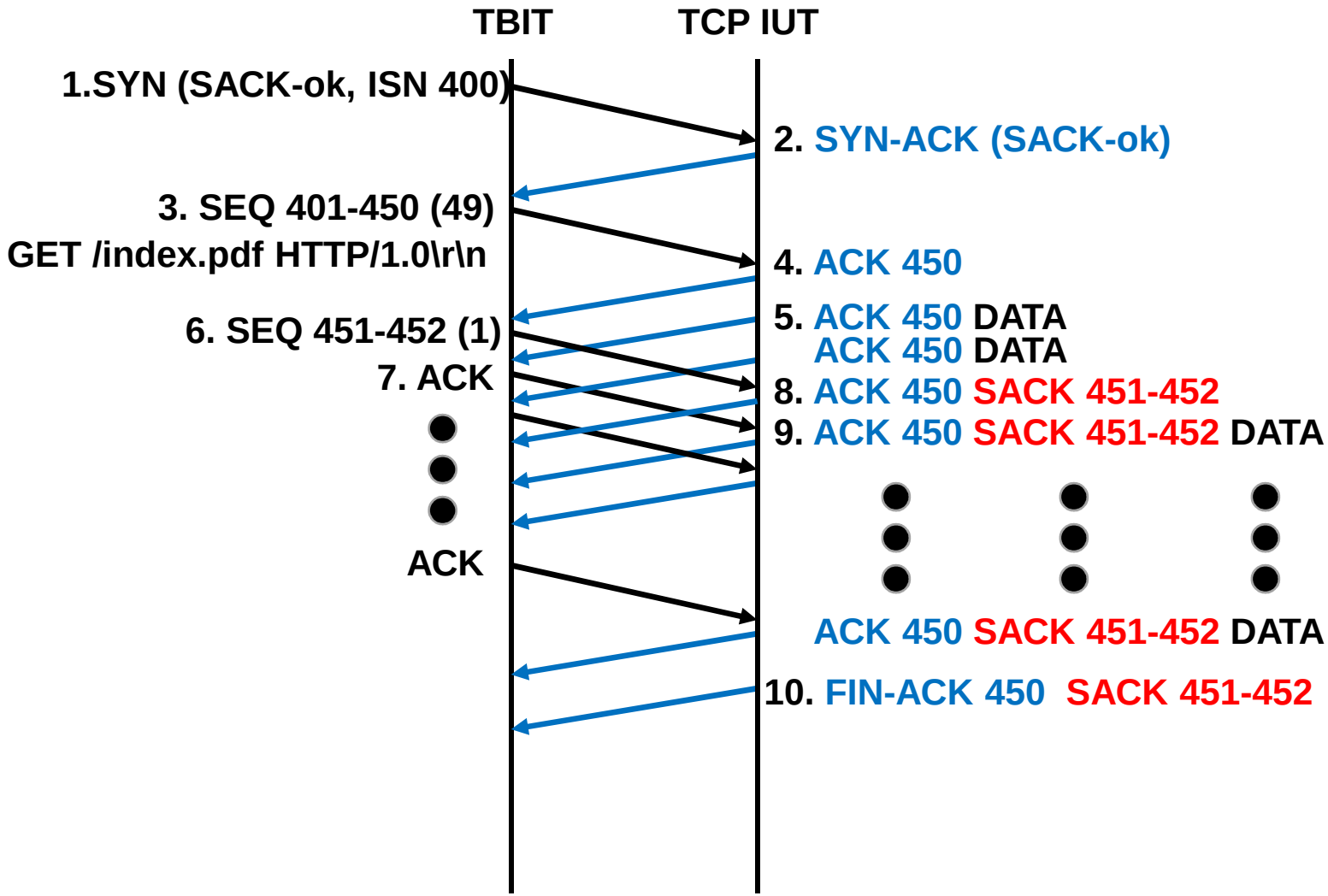

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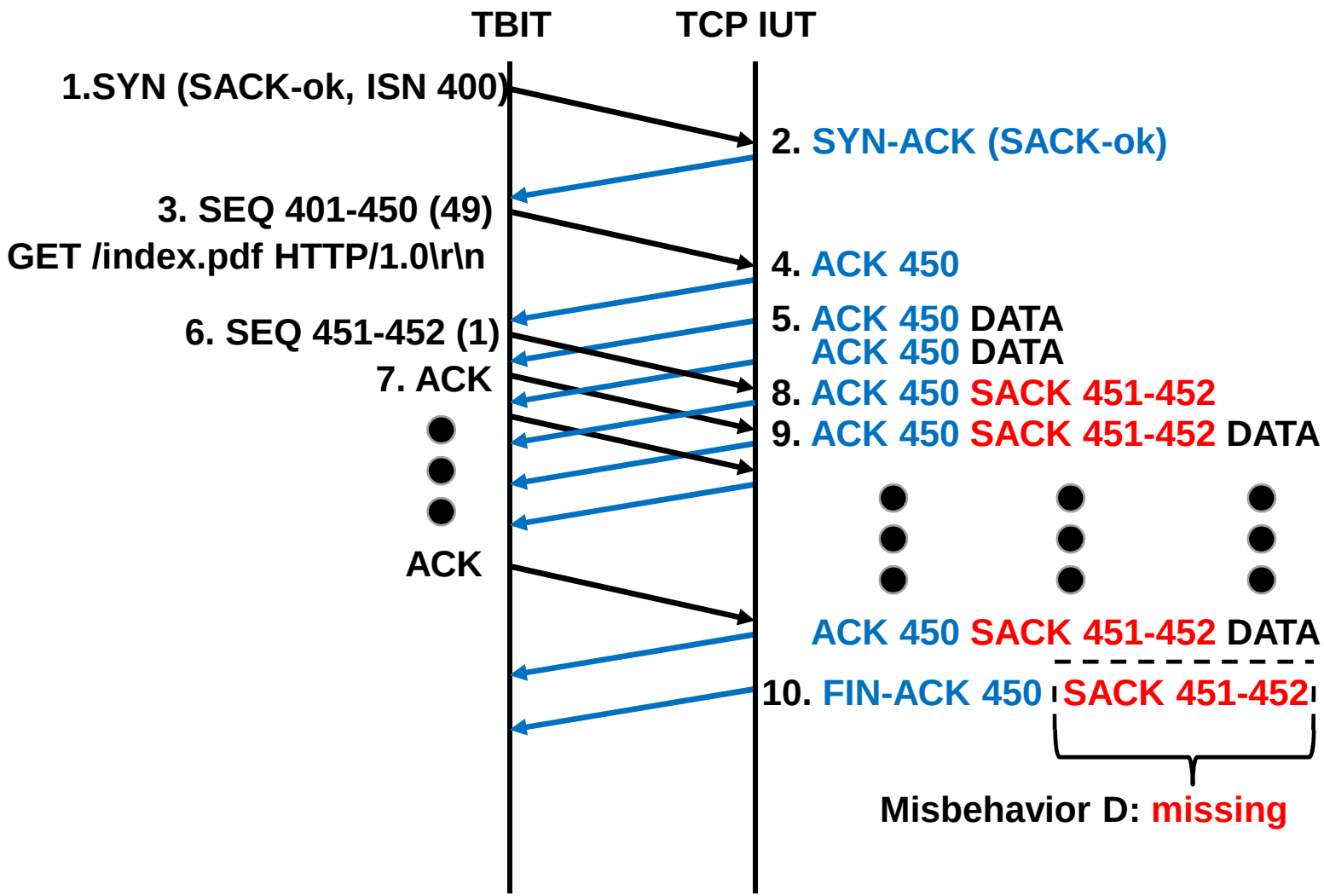
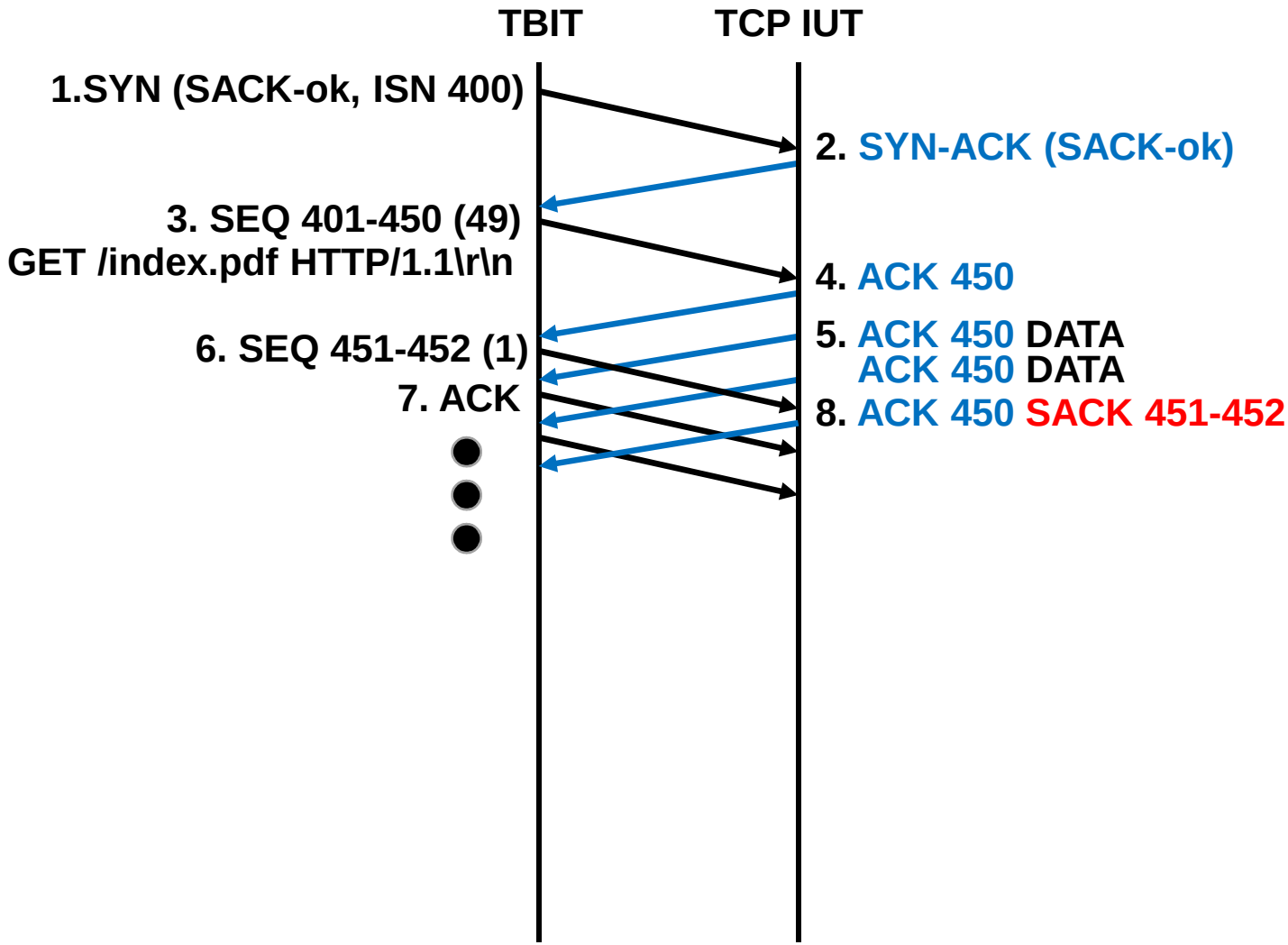


MISBEHAVIOR

E

Misbehavior E:

failure to report SACKs in bidirectional data flow



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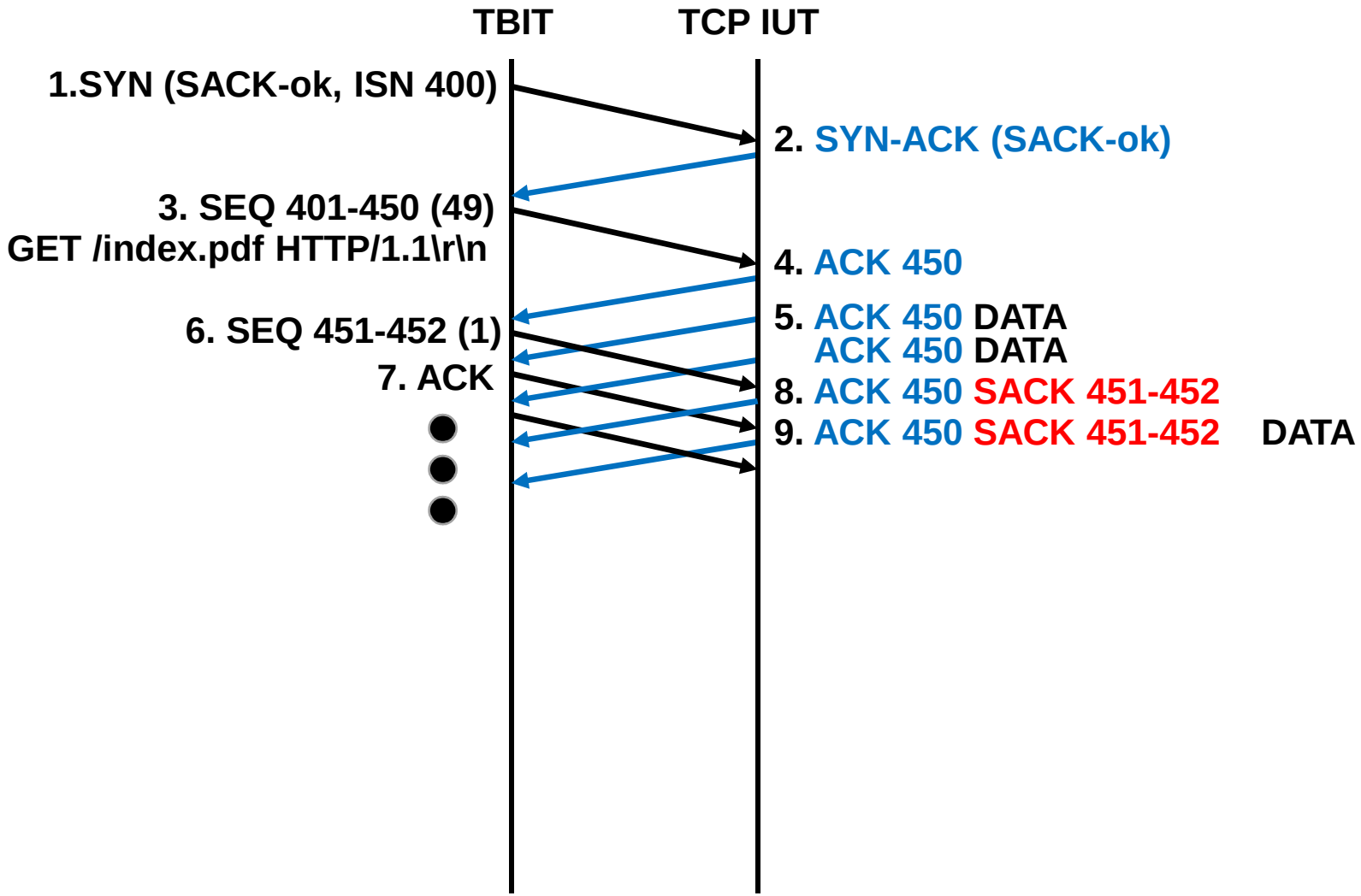

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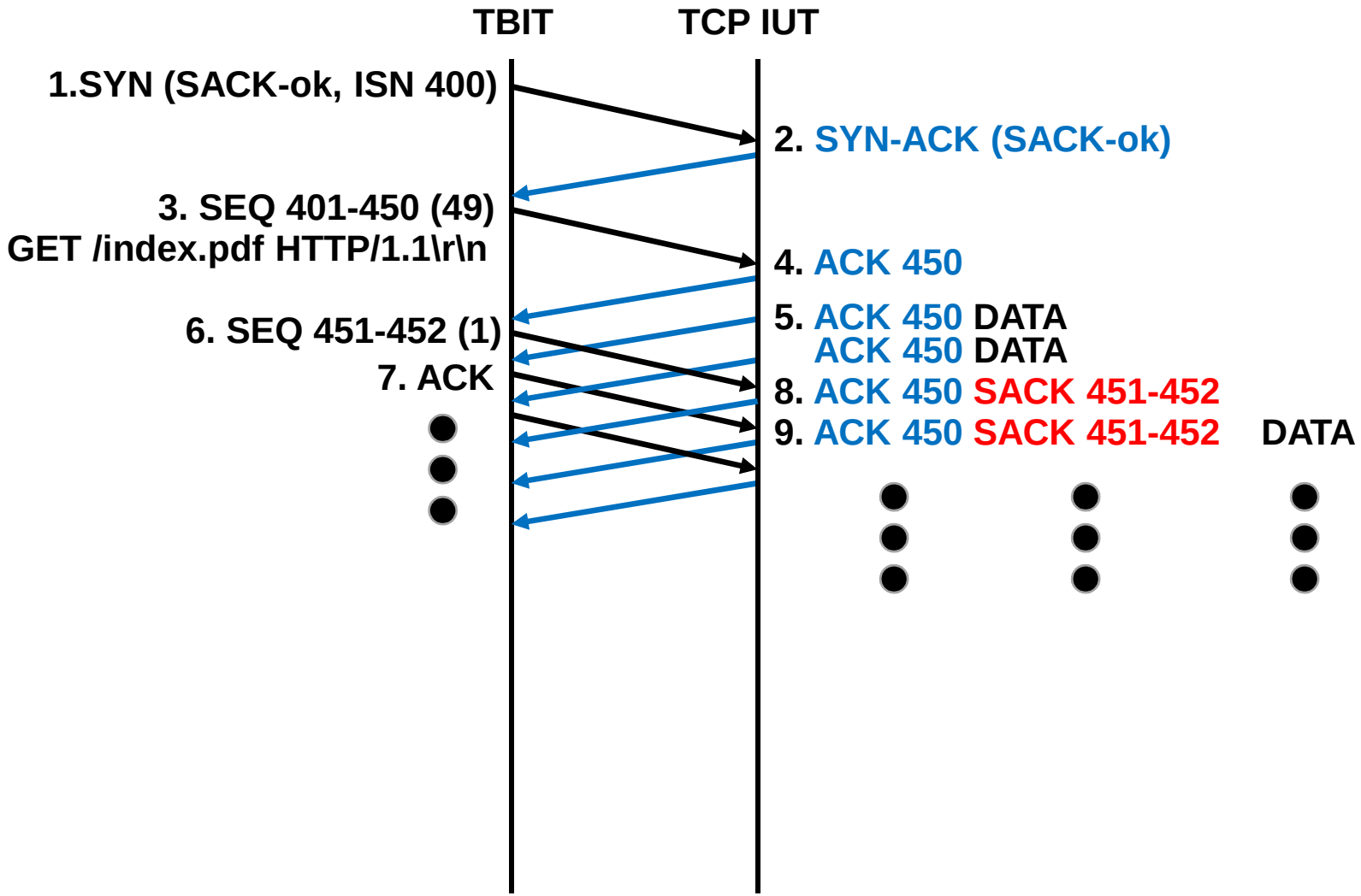

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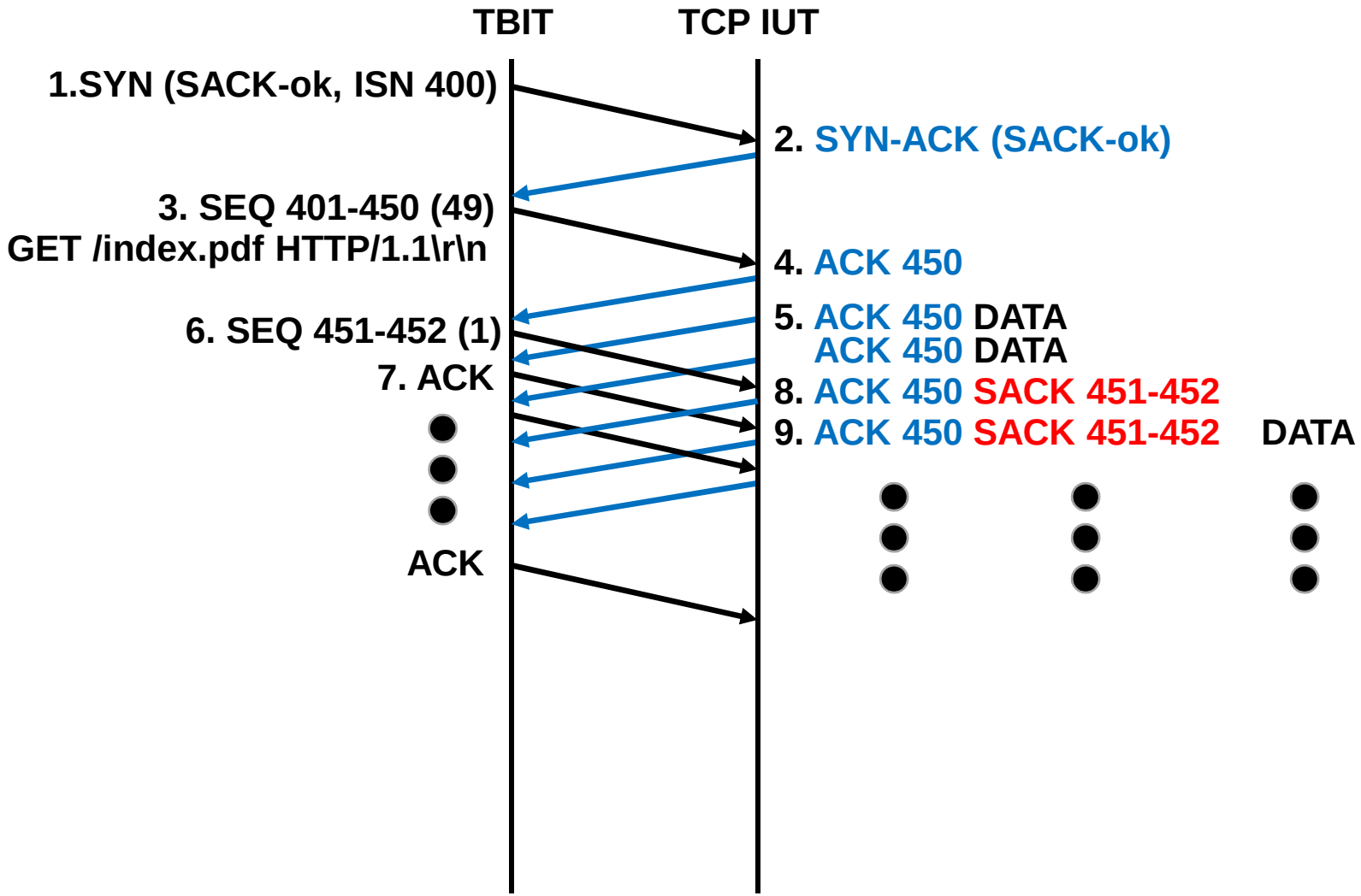

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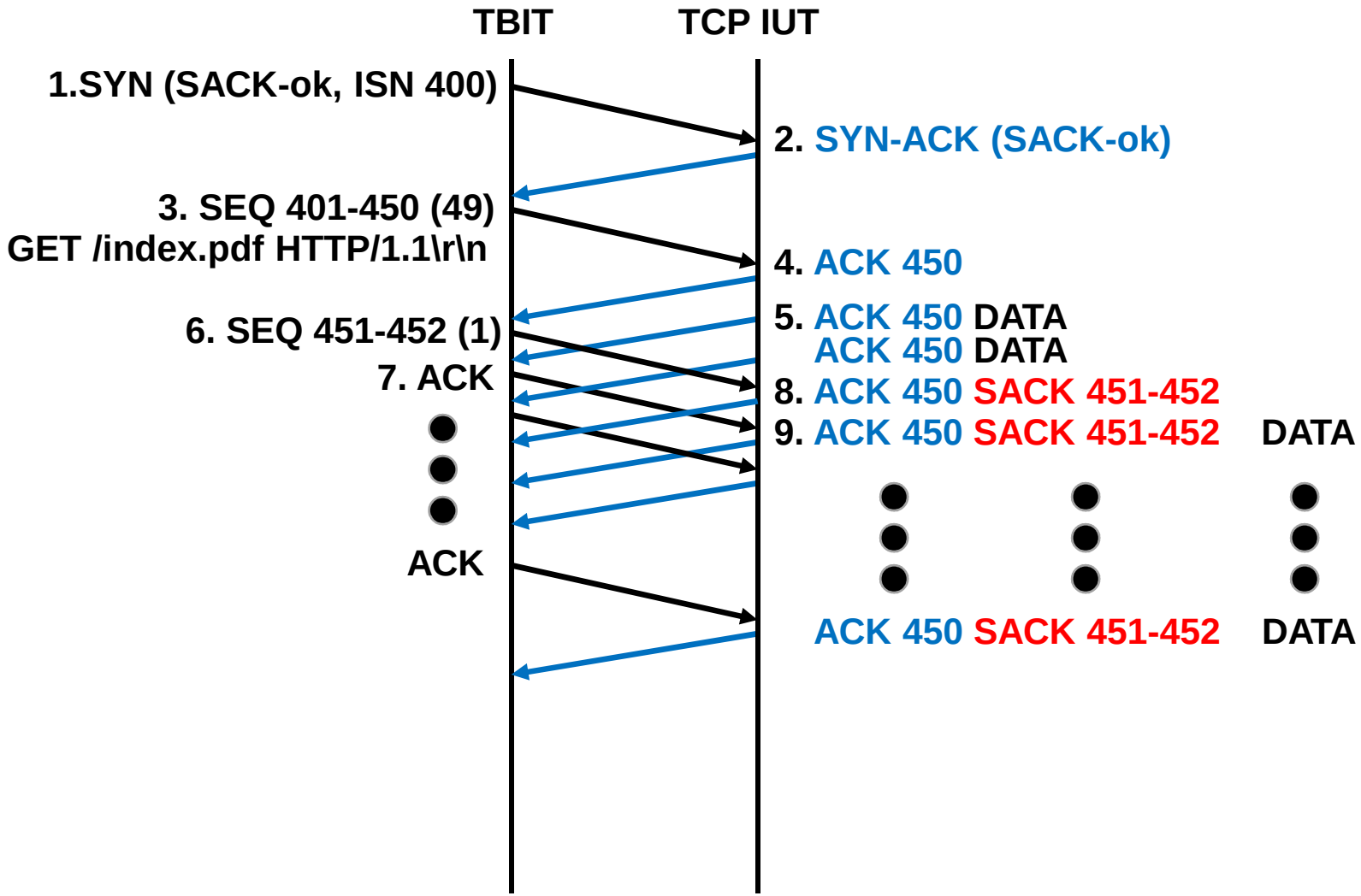

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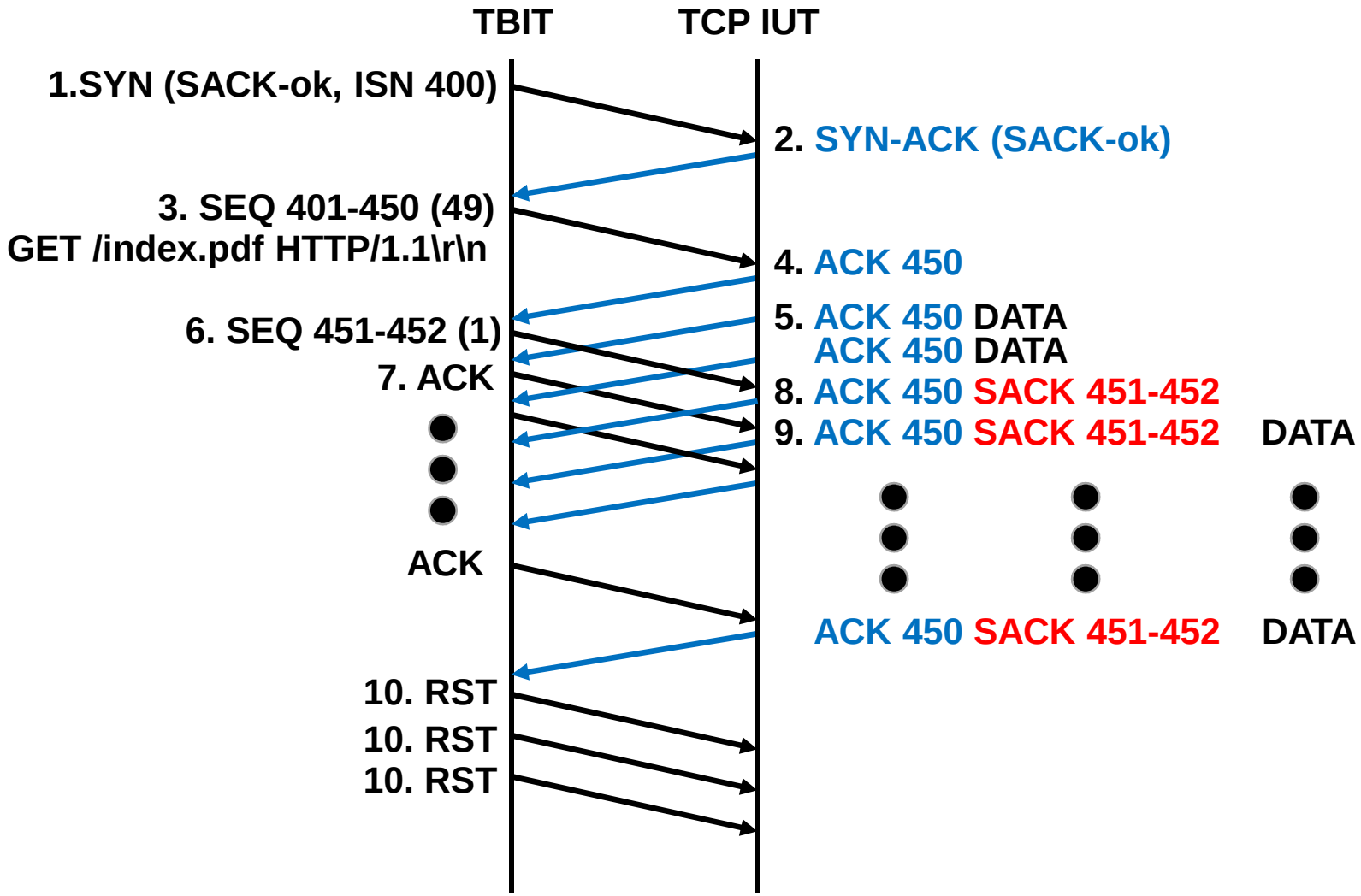

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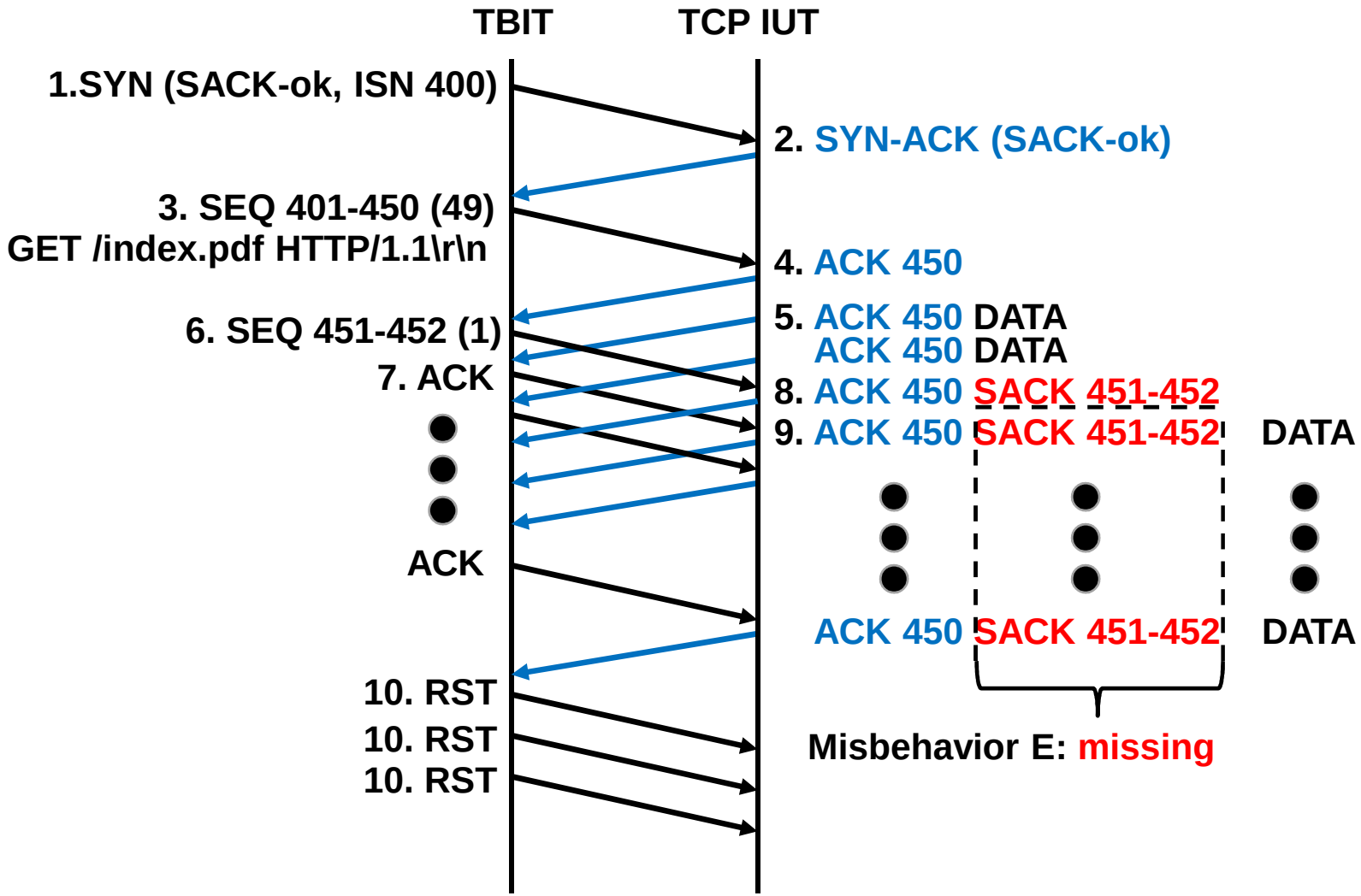
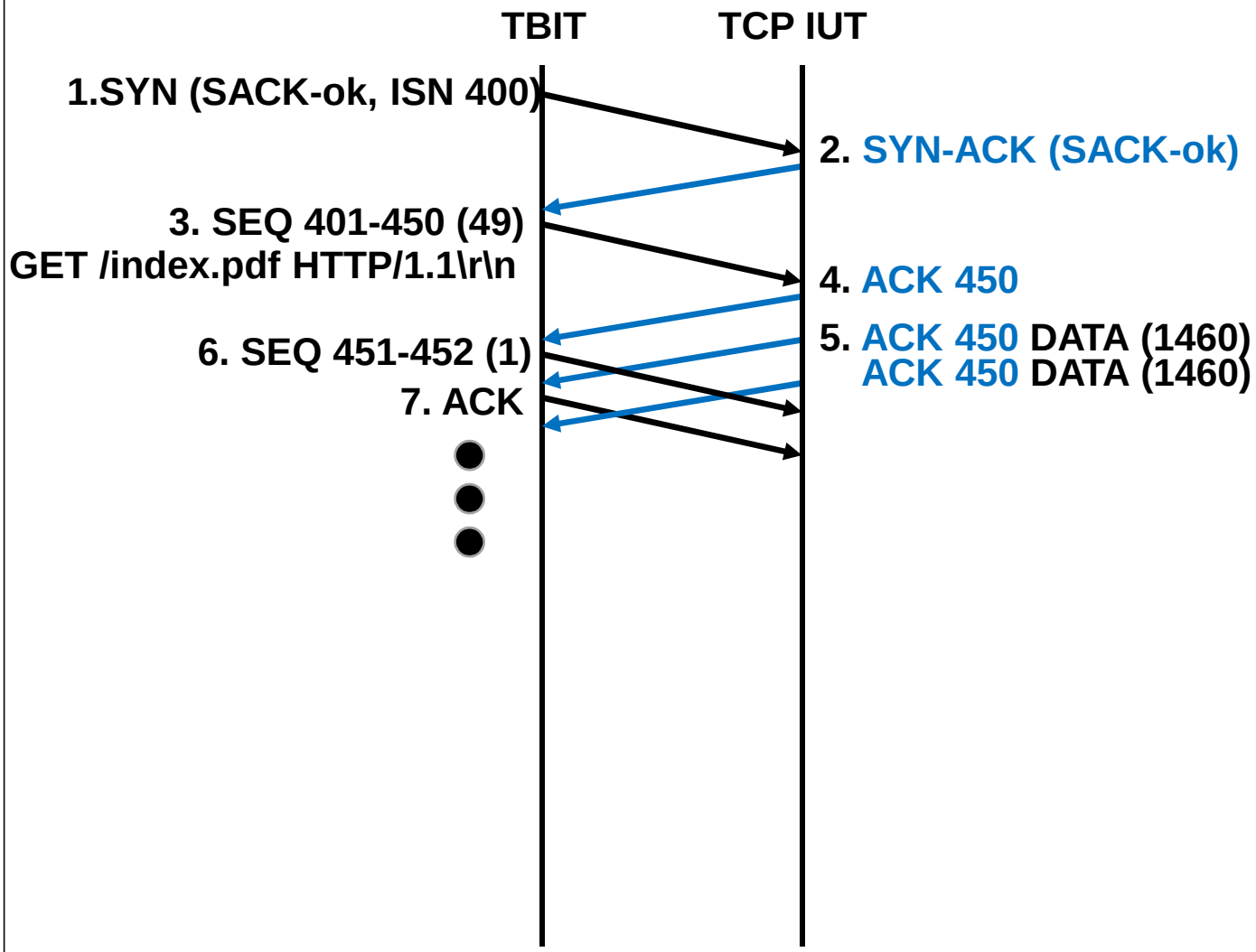


MISBEHAVIOR

F

Misbehavior F:

mishandling of data due to SACK processing



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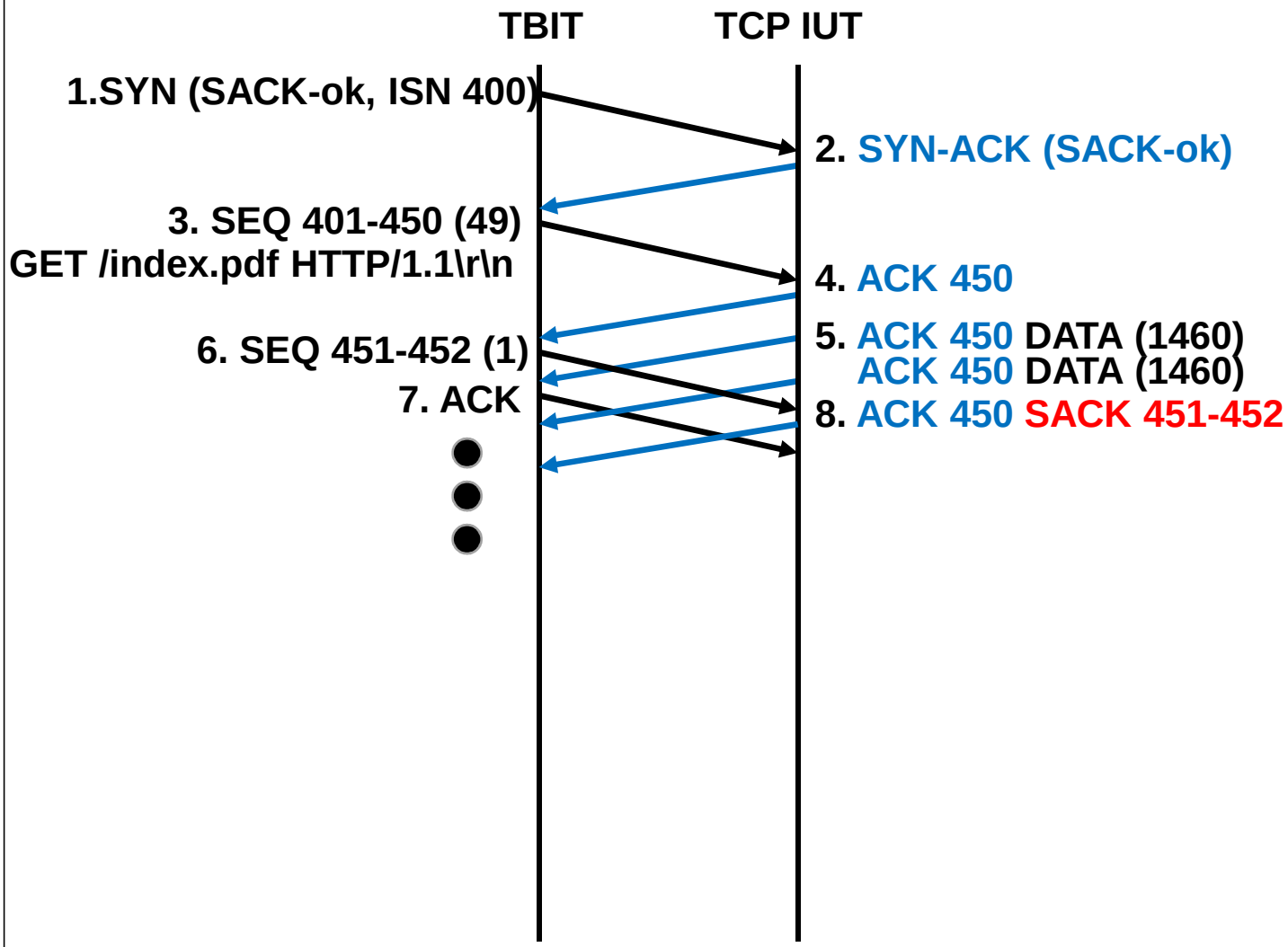

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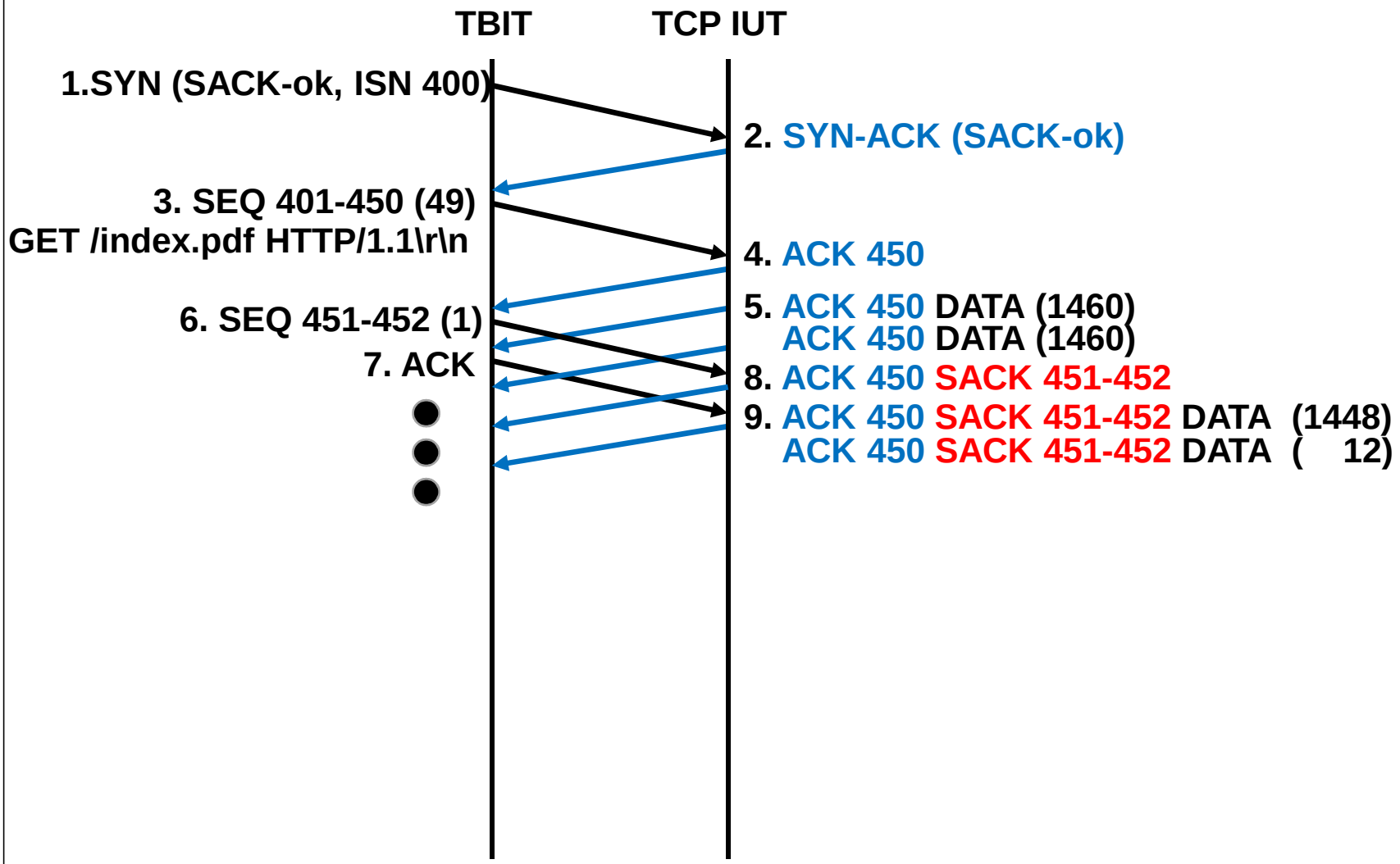

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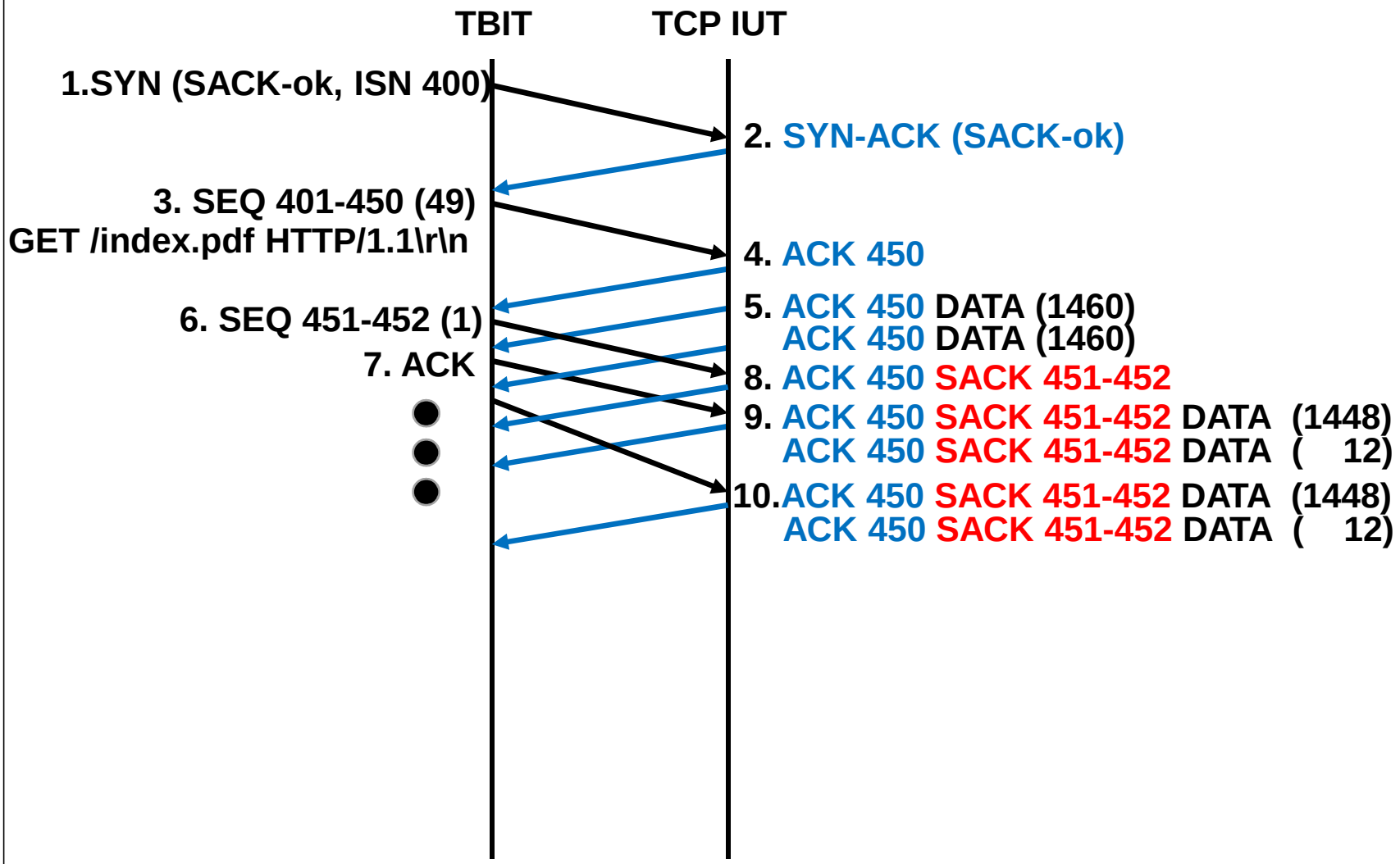

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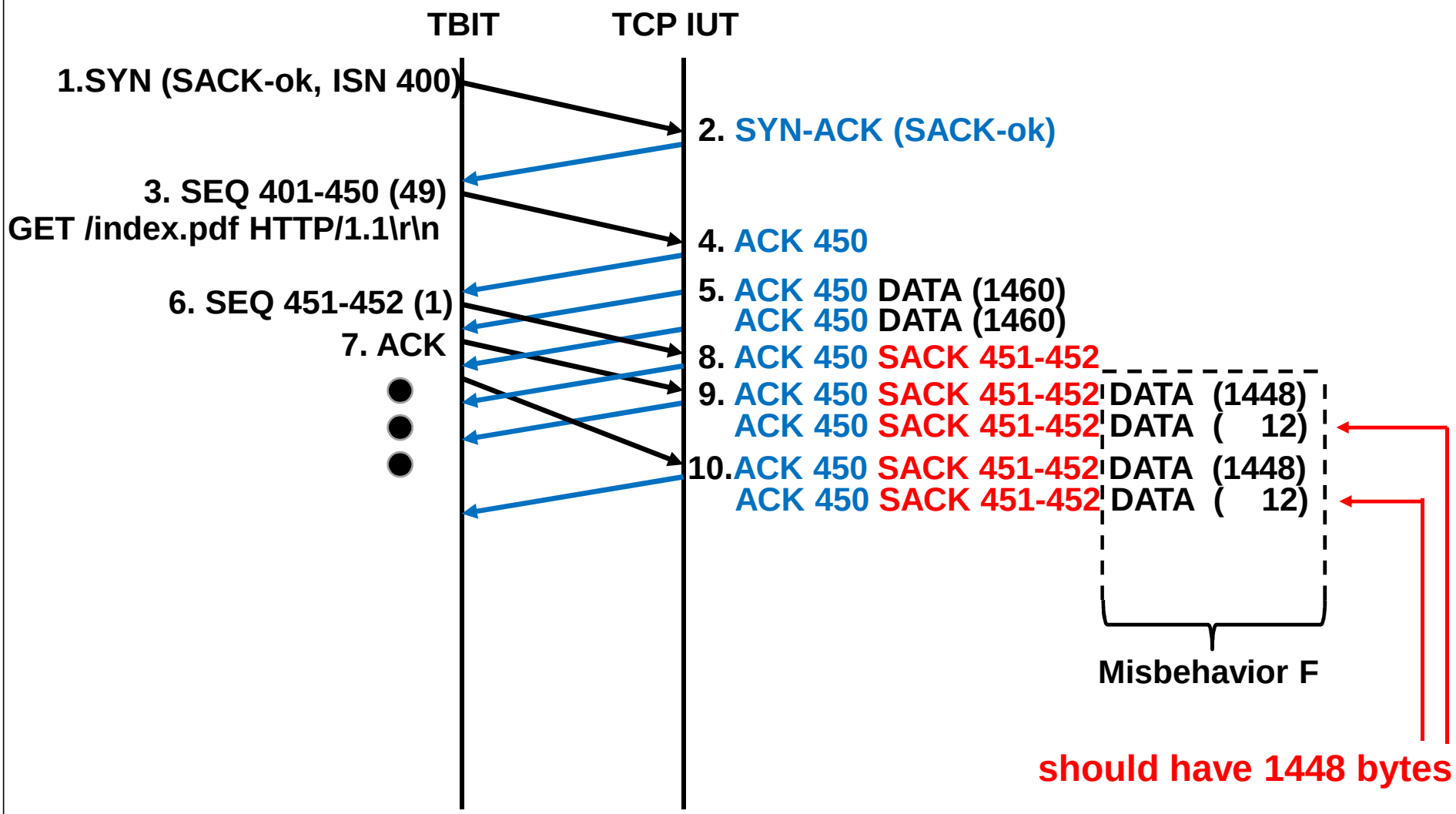
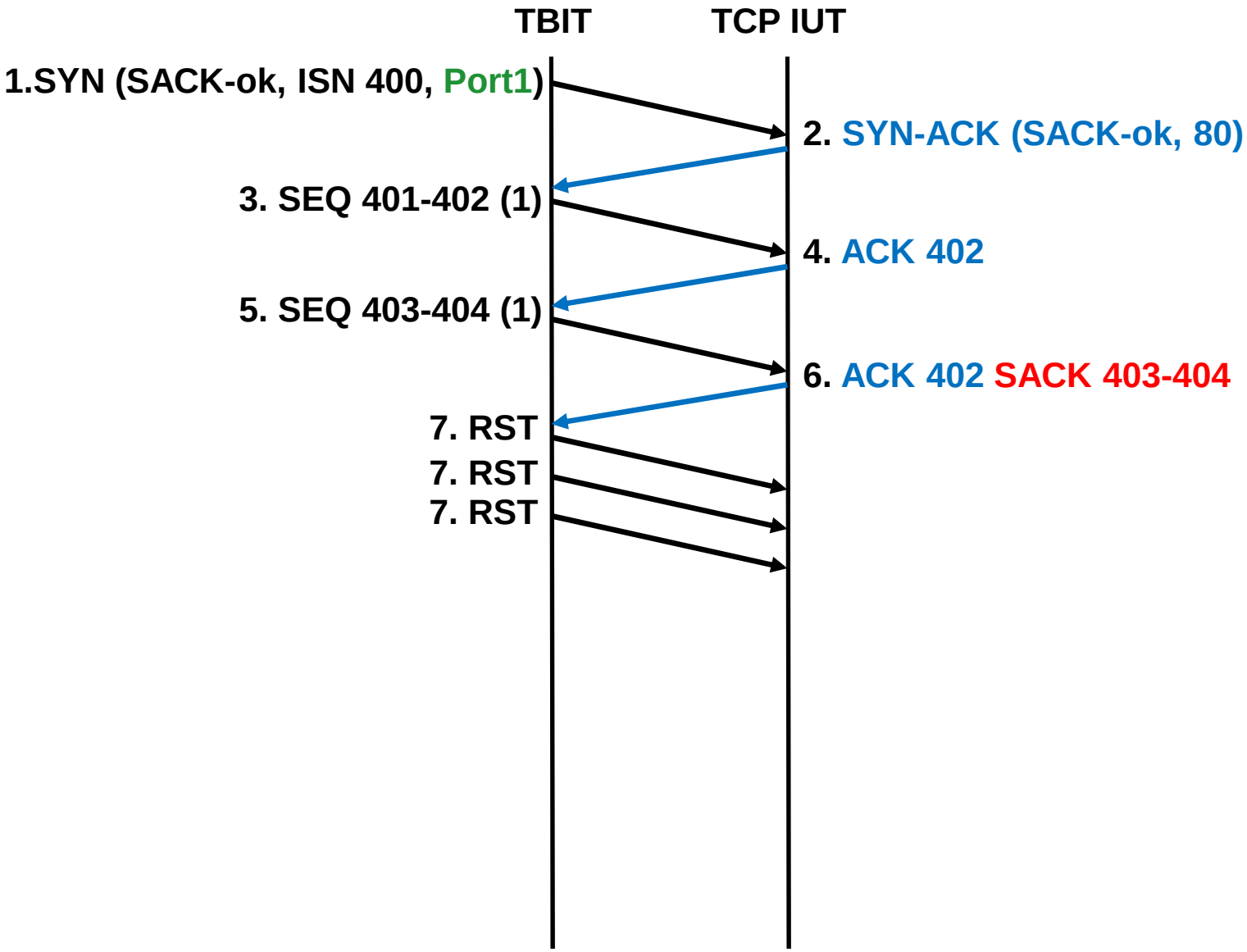


MISBEHAVIOR

G

Misbehavior G:

SACK reappearance in consecutive connections



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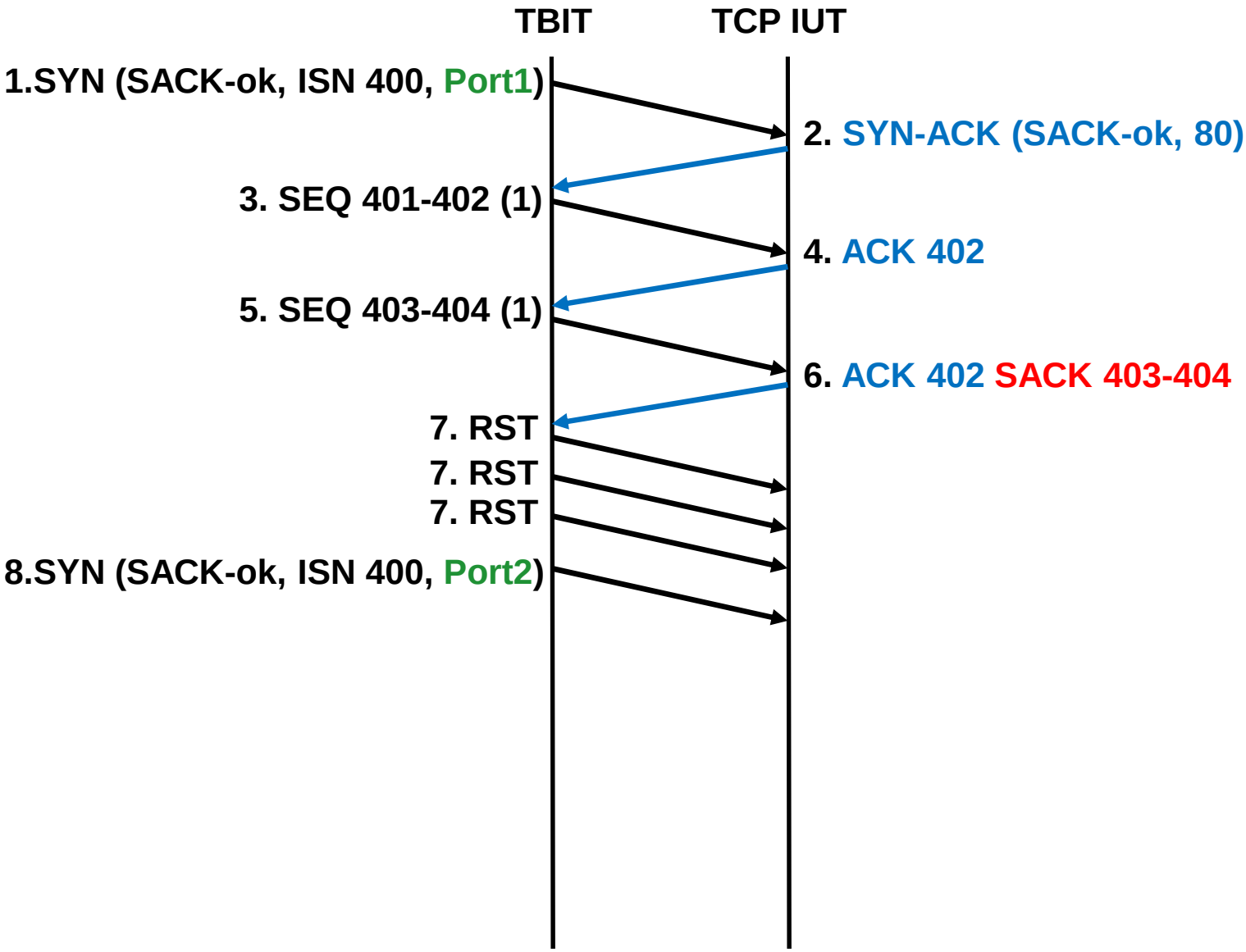
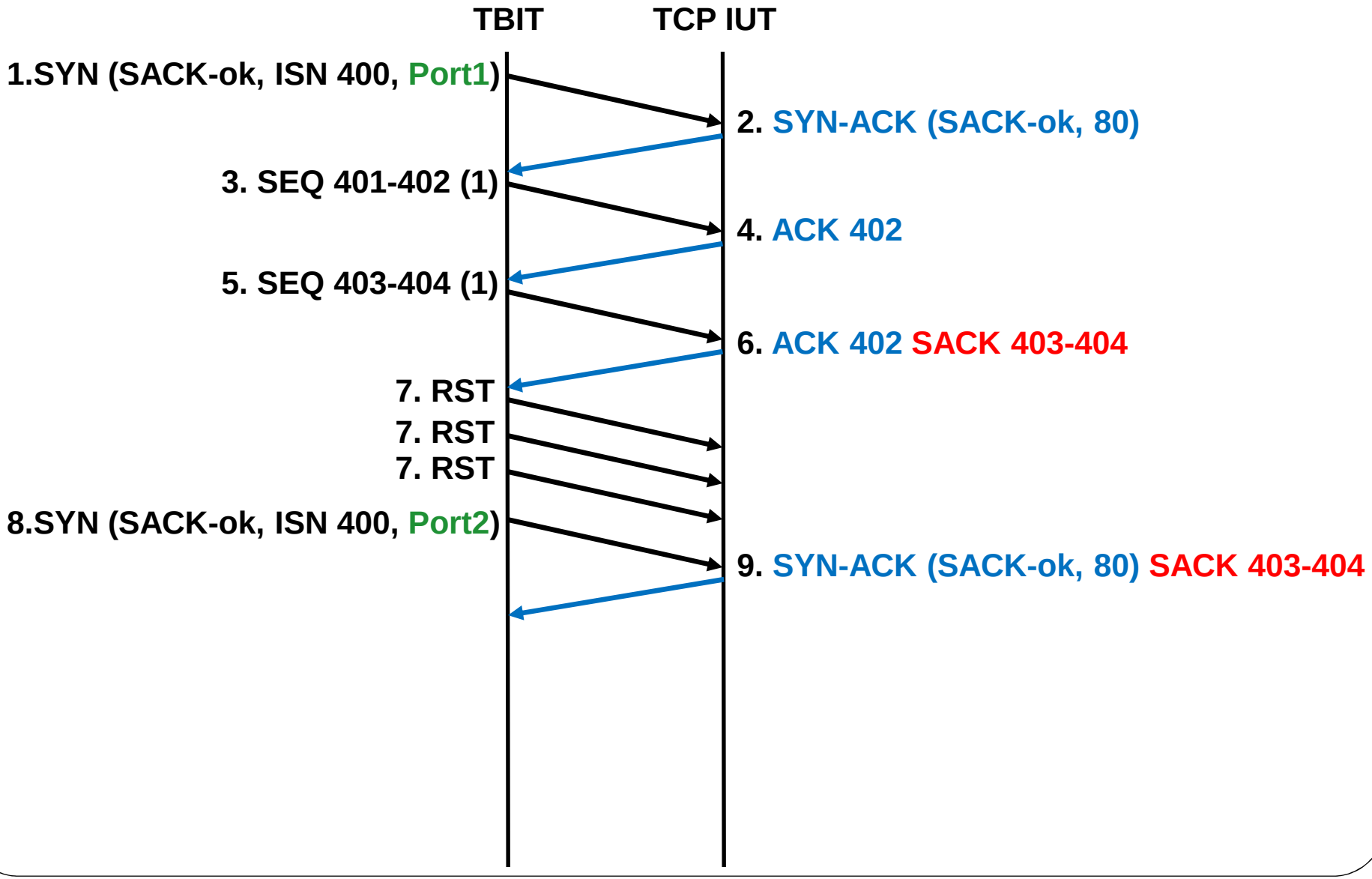


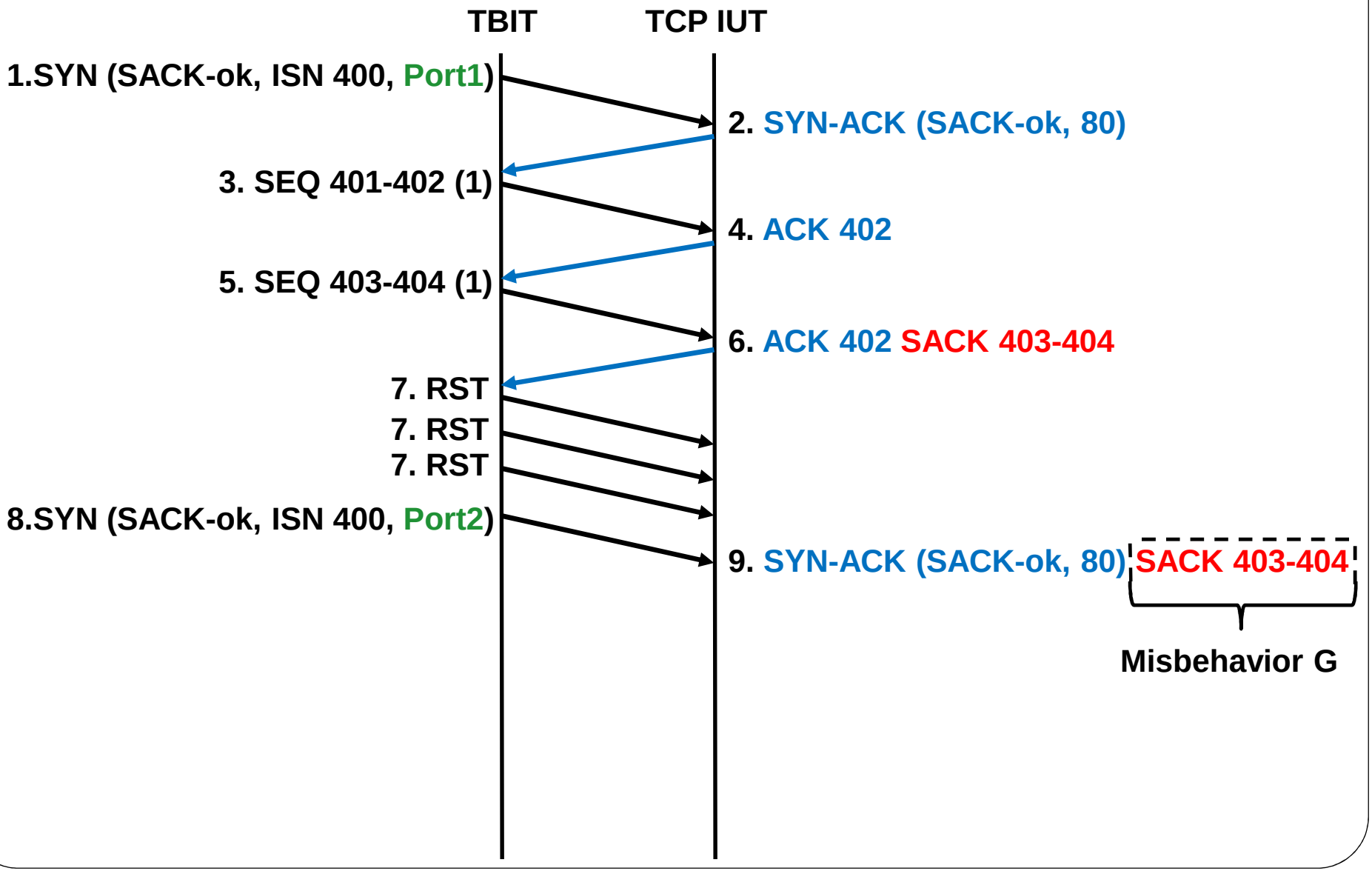
Misbehavior G:

SACK reappearance in consecutive connections



Misbehavior G:

SACK reappearance in consecutive connections



OUTLINE

1. Introduction
2. Experimental design
3. 7 SACK misbehaviors
4. Results
5. Summary

Results

Operating System	Misbehavior						
	A	*B*	*C*	*D*	*E*	*F*	*G*
FreeBSD 5.3, 5.4	Y			Y			
Linux 2.2.20 (Debian 3)						Y	
Linux 2.4.18 (Red Hat 8)						Y	
Linux 2.4.22 (Fedora 1)						Y	
Linux 2.6.12 (Ubuntu 5.10)						Y	
Linux 2.6.15 (Ubuntu 6.06)						Y	
Linux 2.6.18 (Debian 4)						Y	
OpenBSD 4.2, 4.5, 4.6, 4.7	Y			Y			
OpenSolaris 2008.05						Y	Y
OpenSolaris 2009.06						Y	Y
Solaris 10							Y
Solaris 11						Y	
Windows 2000	Y	Y	Y	Y	Y		
Windows XP	Y	Y	Y	Y	Y		
Windows Server 2003	Y	Y	Y	Y	Y		
Windows Vista				Y	Y		
Windows Server 2008				Y	Y		
Windows 7				Y	Y		

Results

Operating System	Misbehavior						
	A	***B***	***C***	***D***	***E***	***F***	***G***
FreeBSD 6.0							
FreeBSD 7.3							
FreeBSD 8.0							
Linux 2.6.31 (Ubuntu 9.10)							
Mac OS X 10.5							
Mac OS X 10.6							

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Summary

- we accidentally discovered 7 unexpected SACK behaviors while researching reneging
- we designed a methodology using TBIT to identify OSes exhibiting these misbehaviors
- we applied the methodology on 29 OSes
  - found at least one OS for each misbehavior
- Conclusion: SACKs - simple in concept; complex to implement

Nasif Ekiz, Abuthahir Rahman, Paul Amer
"***Misbehaviors in TCP SACK Generation***"
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Questions?