



TCP Connections

The High-Level View

UDP Problems

- Packets have to be resent
- Packets arrive duplicated or out of order
- Have to split data across packets
- Can overwhelm connection



...there is a better way

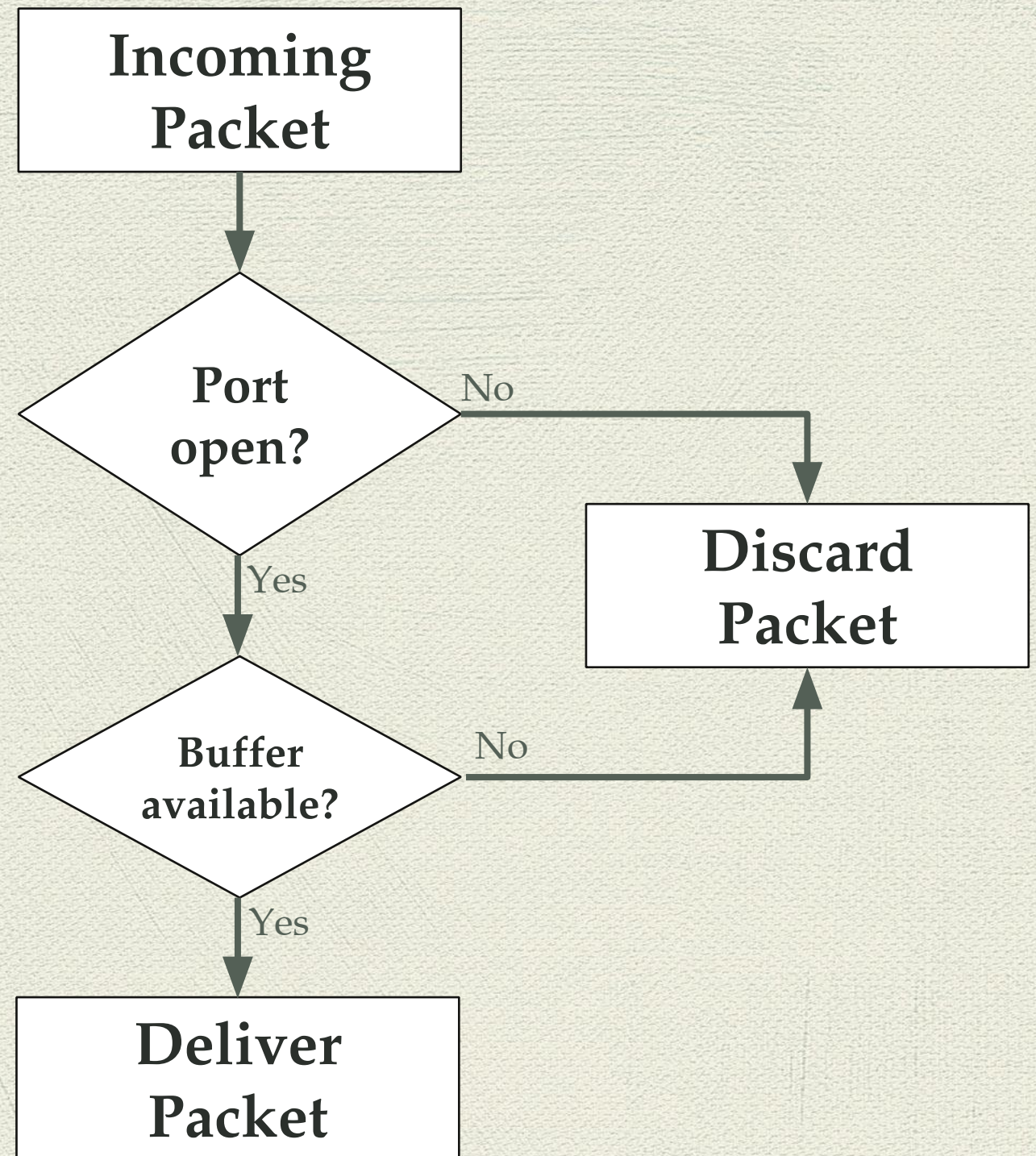
TCP Solutions

- Packets are promised to arrive
- Duplicate/out-of-order packets dropped
- Data stream split into packets automatically
- Packets are throttled to not overload network

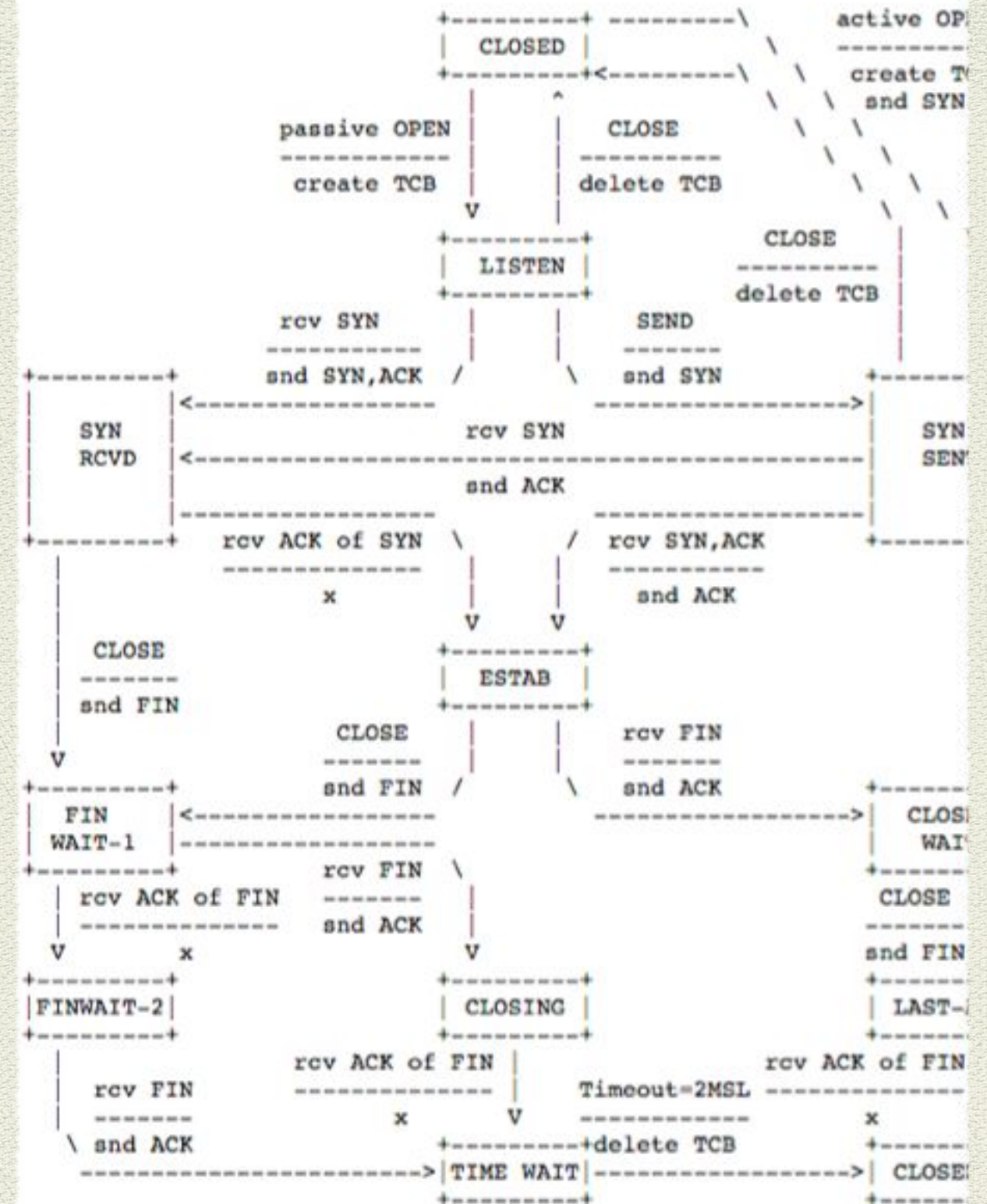
Why Not?

- Not all packets equally valuable
- Duplicate packets are a warning sign
- Your data may be pre-segmented
- Games can afford to be bad citizens

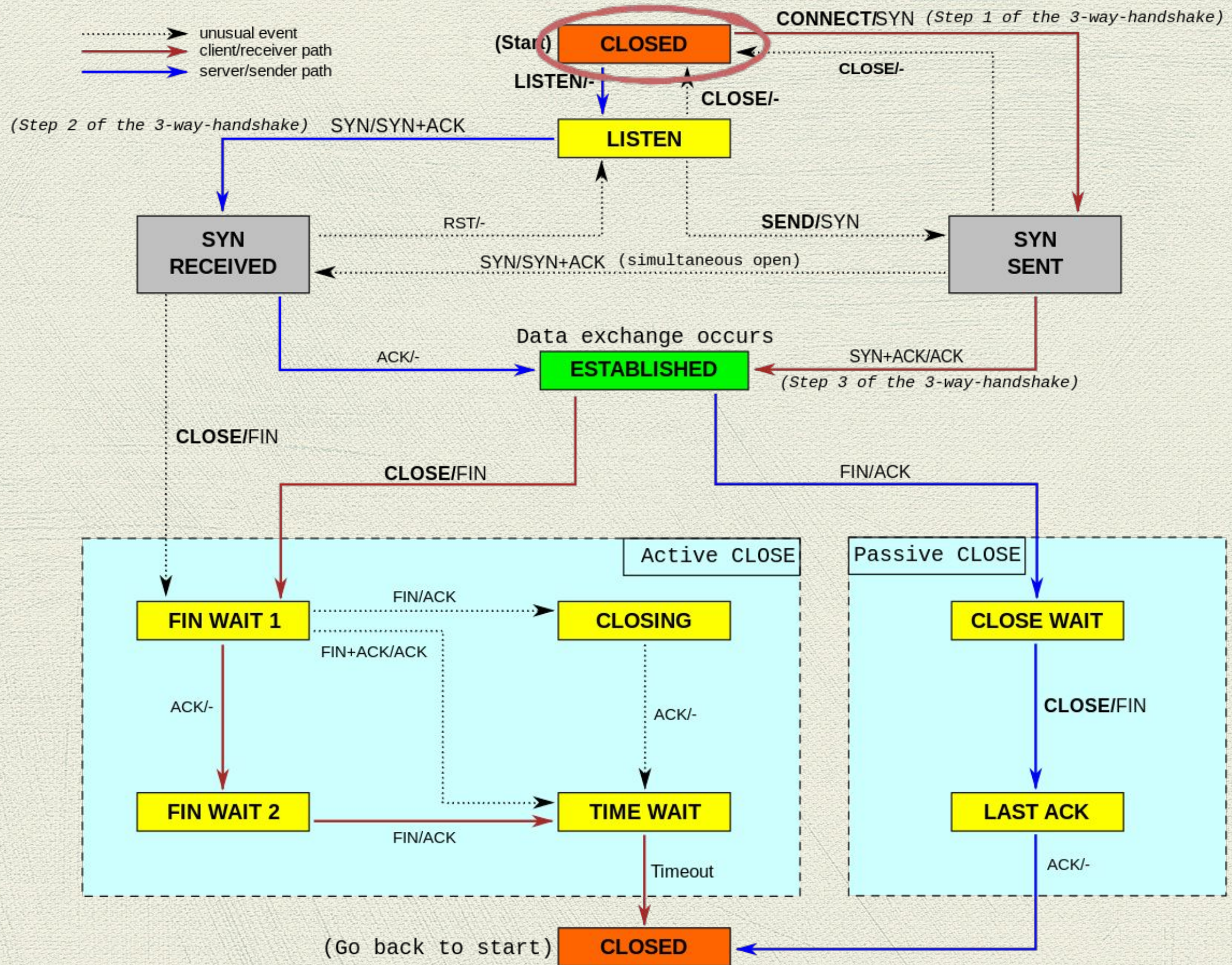
UDP State Machine



TCP State Machine



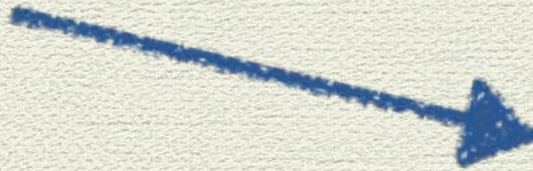
TCP Connection State Diagram
Figure 6.



Server

Client

Send message & start timer

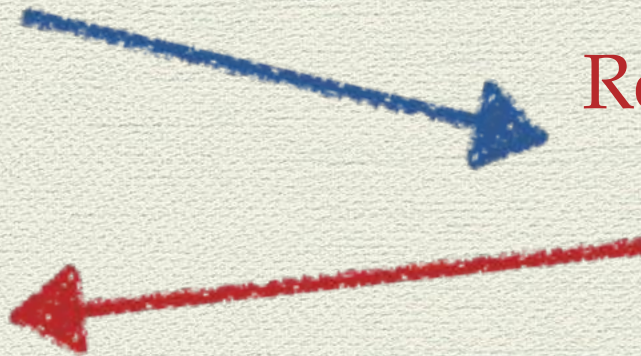


Server

Send message & start timer

Client

Receive message
Send ACK



Server

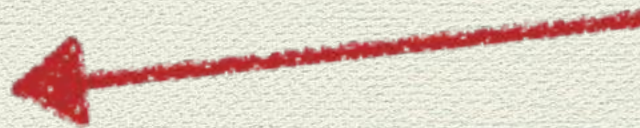
Send message & start timer

ACK received!

Send message & start timer

Client

Receive message
Send ACK



Server

Send message & start timer

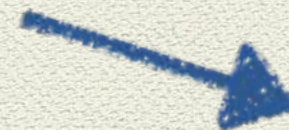
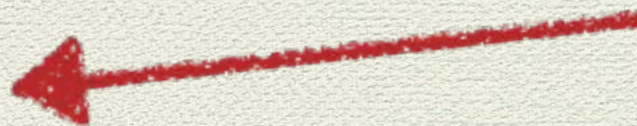
ACK received!

Send message & start timer

Timer expired

Client

Receive message
Send ACK



Server

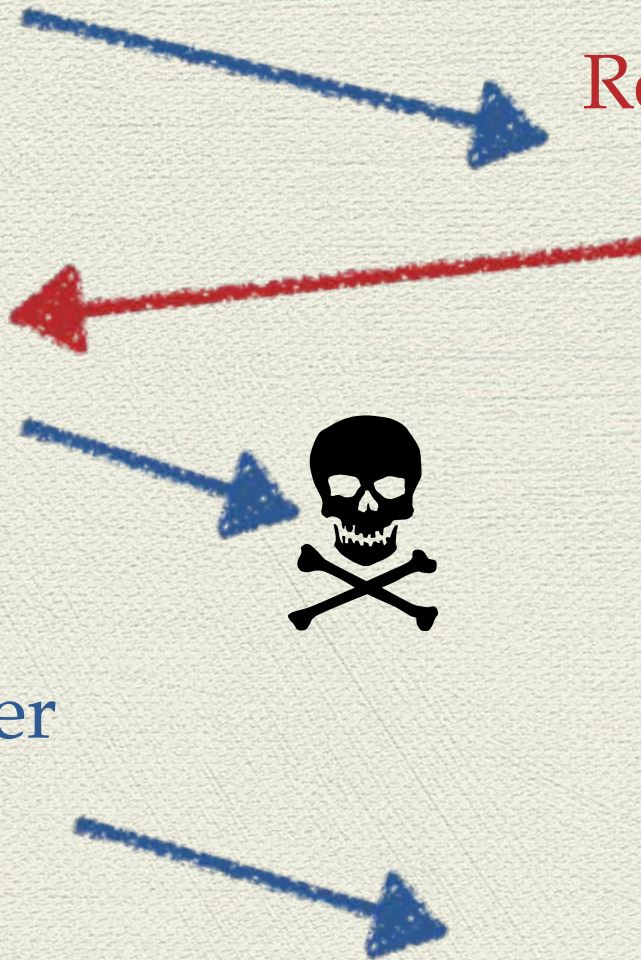
Client

Send message & start timer

Receive message
Send ACK

ACK received!
Send message & start timer

Timer expired
Resend message & restart timer



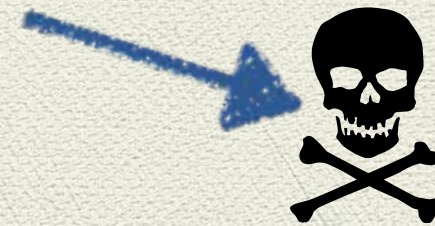
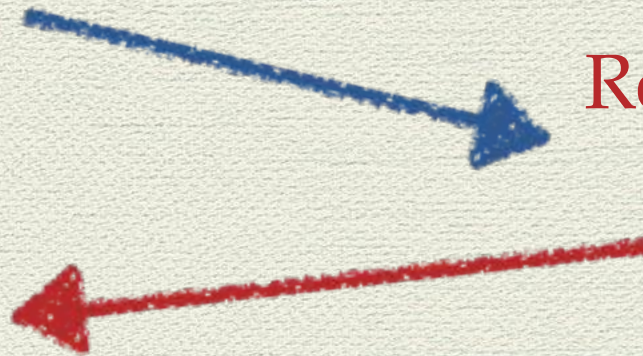
Server

Client

Send message & start timer

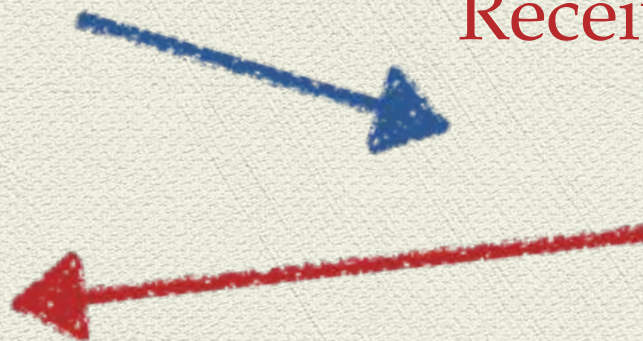
Receive message
Send ACK

ACK received!
Send message & start timer



Timer expired
Resend message & restart timer

Receive re-sent message
Send ACK



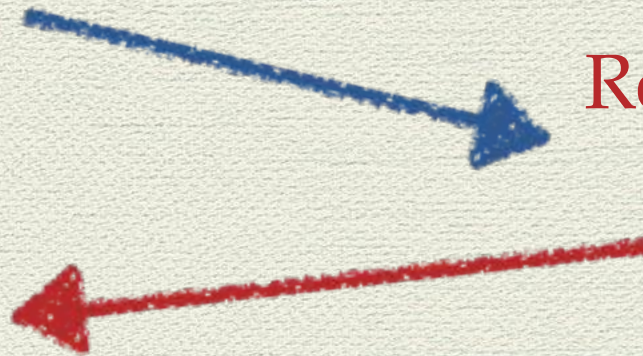
Server

Client

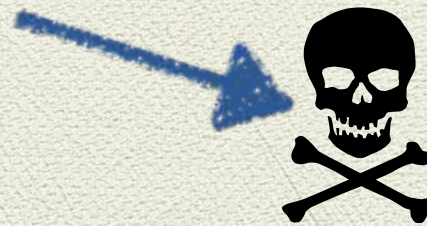
Send message & start timer

Receive message
Send ACK

ACK received!
Send message & start timer

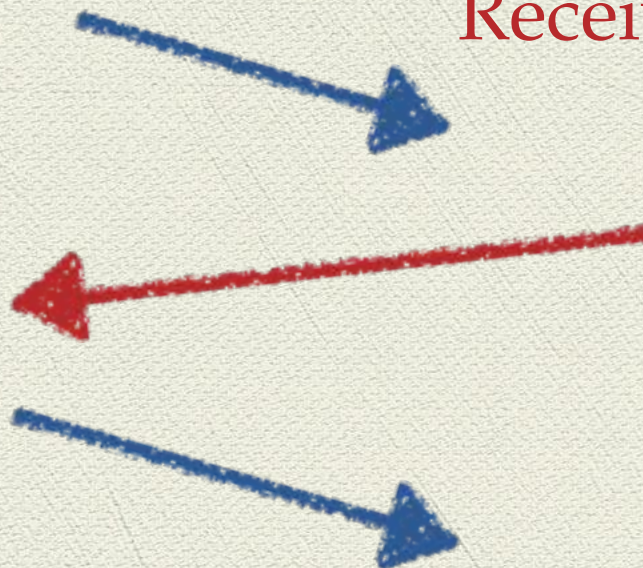


Timer expired
Resend message & restart timer



Receive re-sent message
Send ACK

ACK received!
Send message & start timer



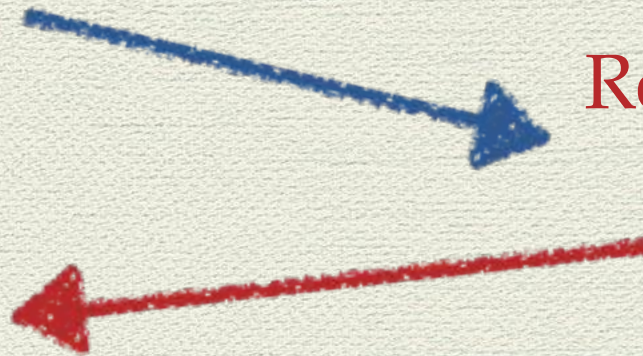
Server

Client

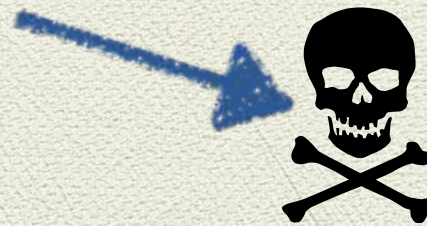
Send message & start timer

Receive message
Send ACK

ACK received!
Send message & start timer

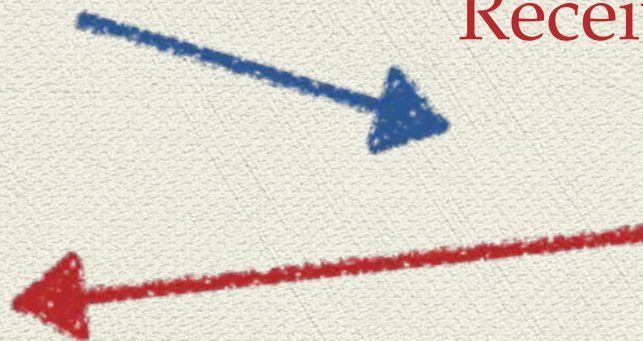


Timer expired
Resend message & restart timer



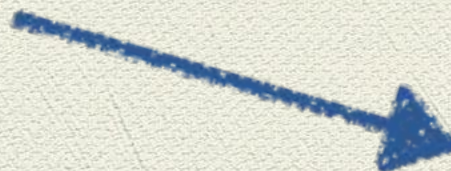
Receive re-sent message
Send ACK

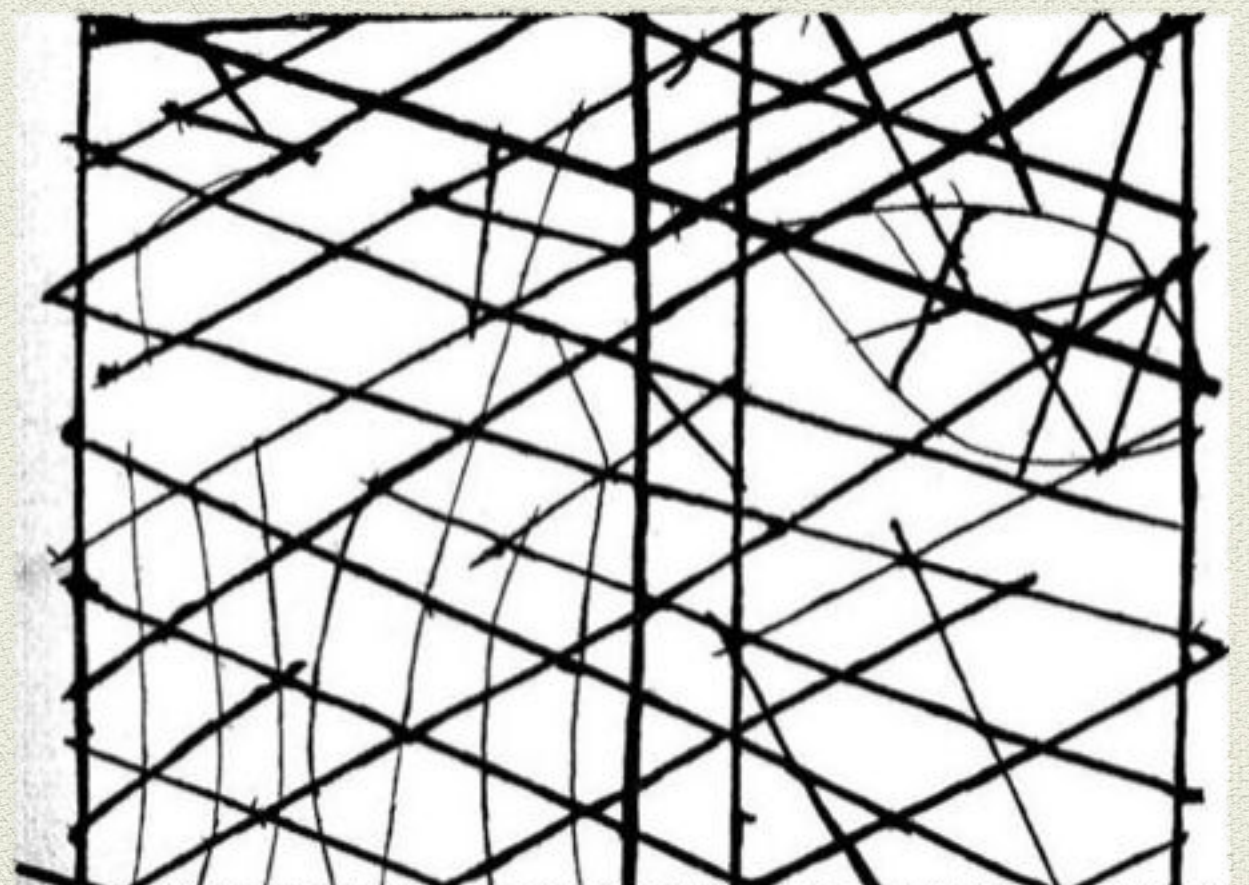
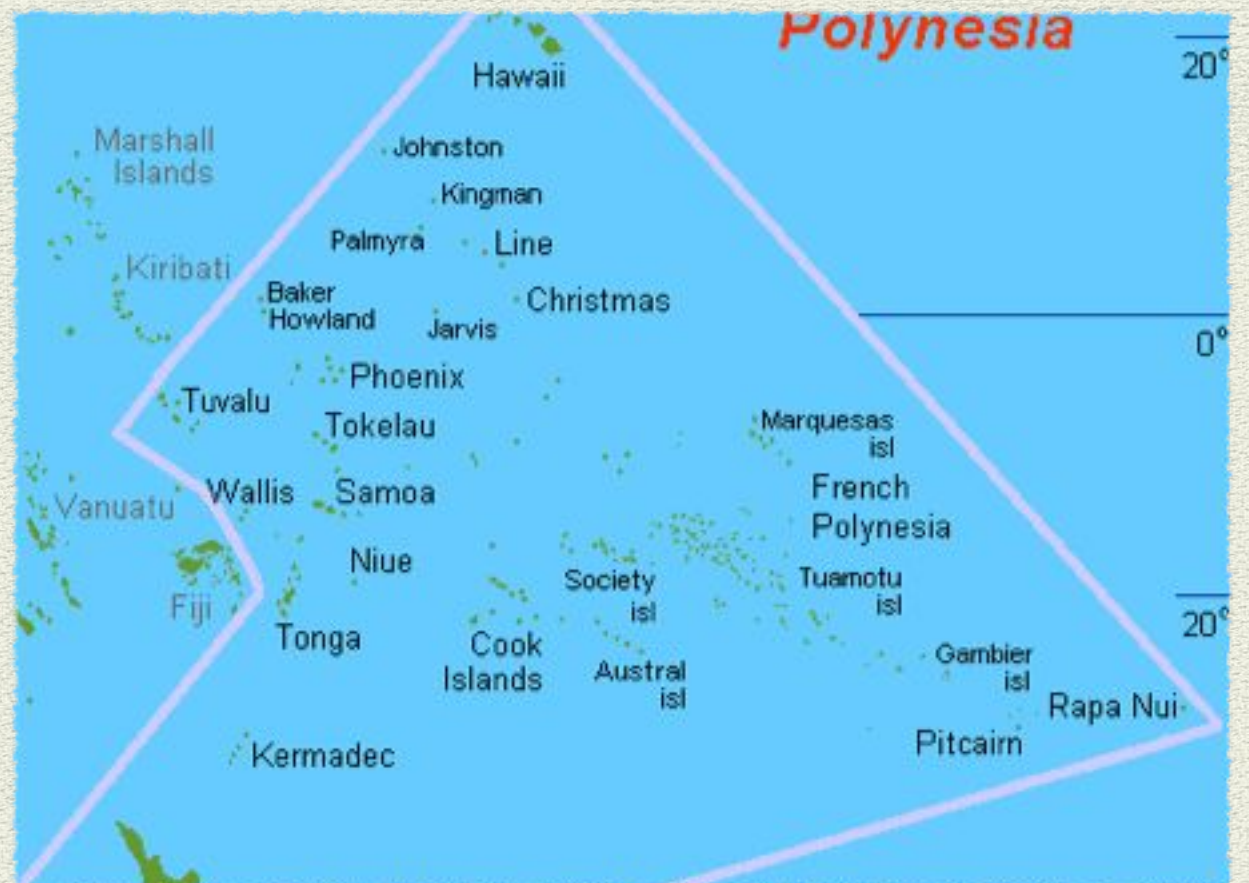
ACK received!
Send message & start timer



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Little's Law

(John Little, MIT, 1954)

- Occupancy = Latency x Throughput
- count = count/time x time
- $O = L \times T \iff L = O / T \iff T = O / L$

Server

Send message 1

Client



Server

Send message 1

Send message 2

Client

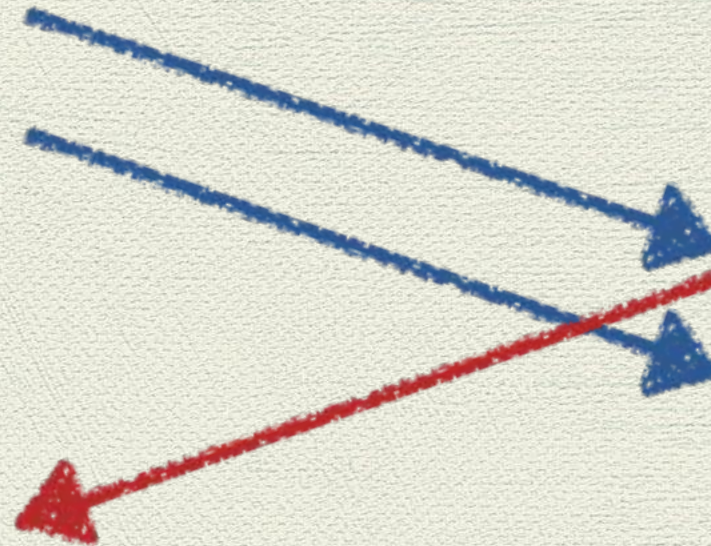


Server

Send message 1
Send message 2

Client

Receive & ACK 1

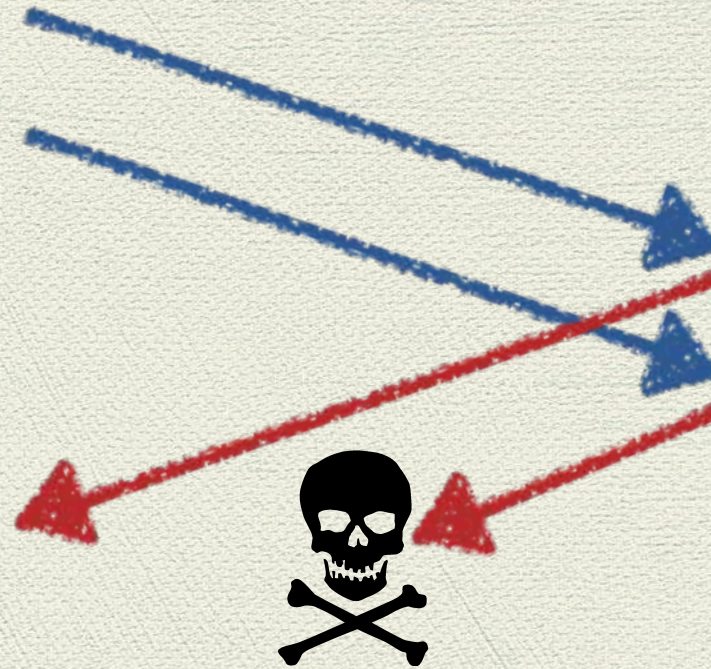


Server

Send message 1
Send message 2

Client

Receive & ACK 1
Receive & ACK 2



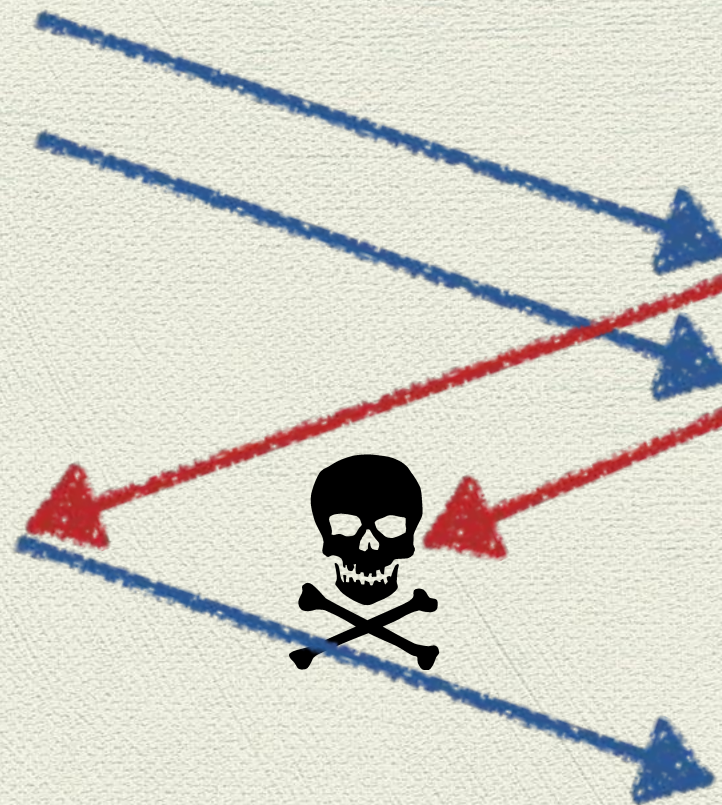
Server

Send message 1
Send message 2

1 ACKed; send 3

Client

Receive & ACK 1
Receive & ACK 2



Server

Send message 1
Send message 2

1 ACKed; send 3

2 TIME; resend 2

Client

Receive & ACK 1
Receive & ACK 2



Server

Send message 1
Send message 2

1 ACKed; send 3

2 TIME; resend 2

Client

Receive & ACK 1
Receive & ACK 2

Receive & ACK 3



Server

Send message 1

Send message 2

1 ACKed; send 3

2 TIME; resend 2

Client

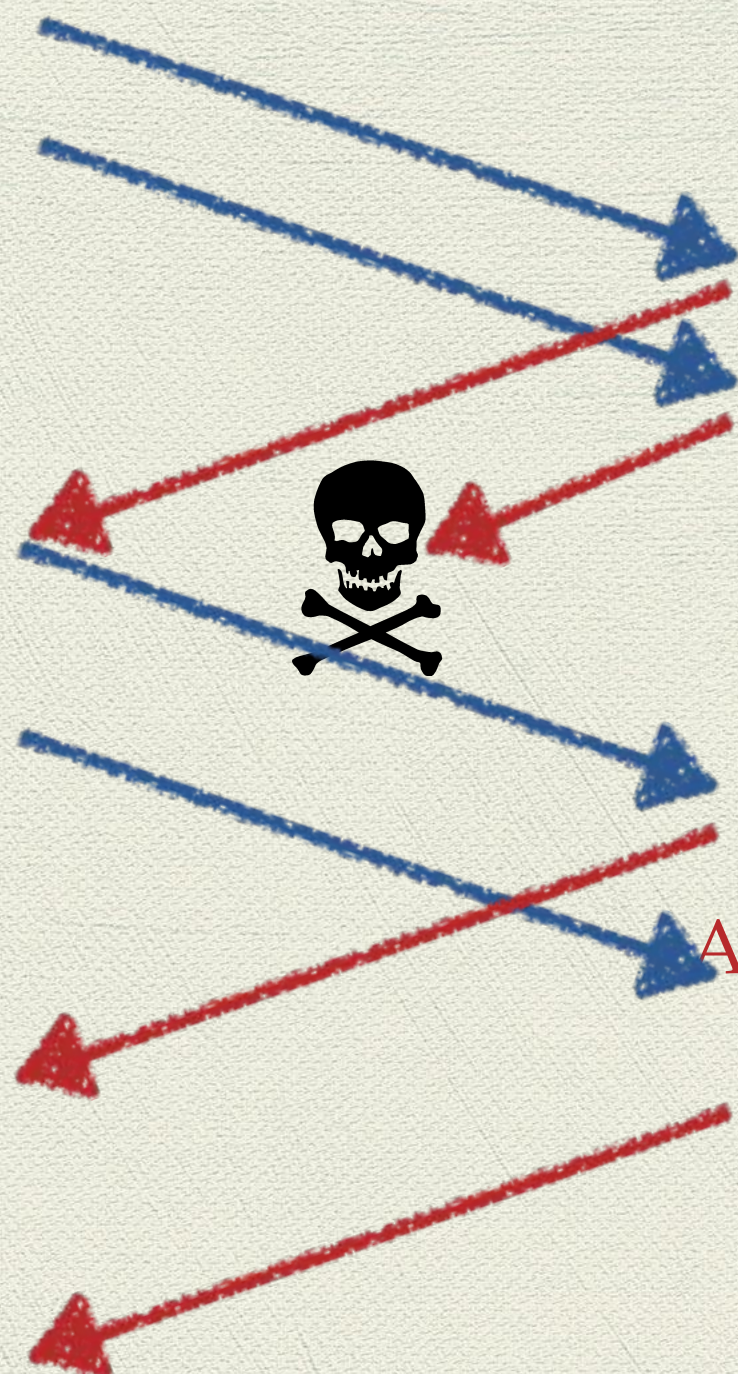
Receive & ACK 1

Receive & ACK 2

Receive & ACK 3

⋮

ACK 3 (&2); LIMIT=1



Server

Send message 1
Send message 2

1 ACKed; send 3

2 TIME; resend 2

3 & 2 ACKed; send 4
Send 5

Client

Receive & ACK 1
Receive & ACK 2

Receive & ACK 3

:(
ACK 3 (&2); LIMIT=1



Server

Send message 1
Send message 2

1 ACKed; send 3

2 TIME; resend 2

3 & 2 ACKed; send 4

Send 5

Set new LIMIT=1

Client

Receive & ACK 1

Receive & ACK 2

Receive & ACK 3

:(

ACK 3 (&2); LIMIT=1



Server

Send message 1
Send message 2

1 ACKed; send 3

2 TIME; resend 2

3 & 2 ACKed; send 4

Send 5

Set new LIMIT=1

Client

Receive & ACK 1

Receive & ACK 2

Receive & ACK 3

:(

ACK 3 (&2); LIMIT=1

Receive & ACK 4



Server

Send message 1
Send message 2

1 ACKed; send 3

2 TIME; resend 2

3 & 2 ACKed; send 4
Send 5

Set new LIMIT=1

4 ACKed; limit
reached; wait

Client

Receive & ACK 1
Receive & ACK 2

Receive & ACK 3

:(
ACK 3 (&2); LIMIT=1

Receive & ACK 4



- Packets sent and ACKed

- Packets not yet sent and invalid to send

										1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	
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ΓΣΛΓΕΙ
Network Access

Internet ΓΣΛΓΕΙ

Transport ΓΣΛΓΕΙ

Application ΓΣΛΓΕΙ

Sequence Numbers

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Sliding Windows

Congestion Control



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TCP Connections

The Deep Dive

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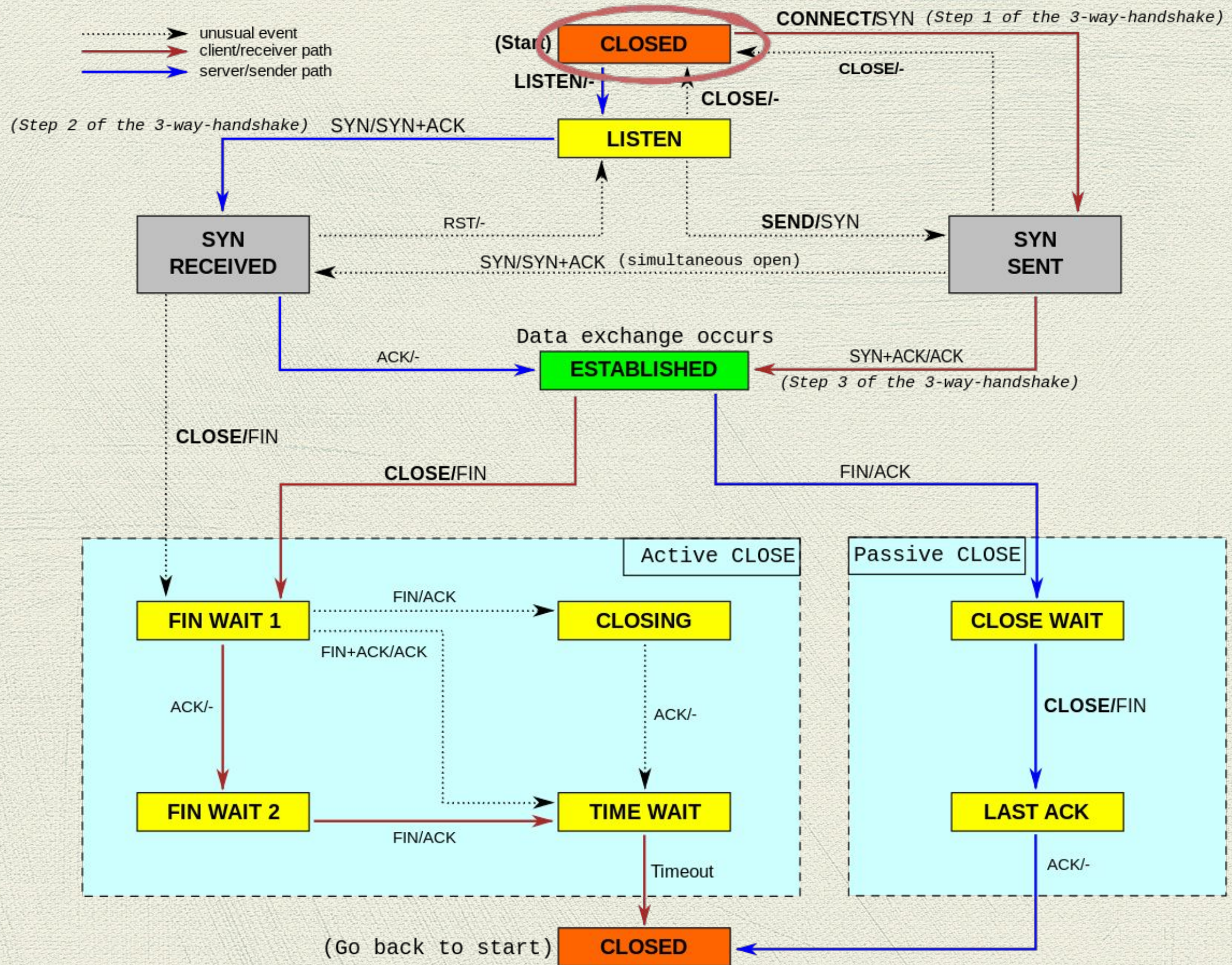
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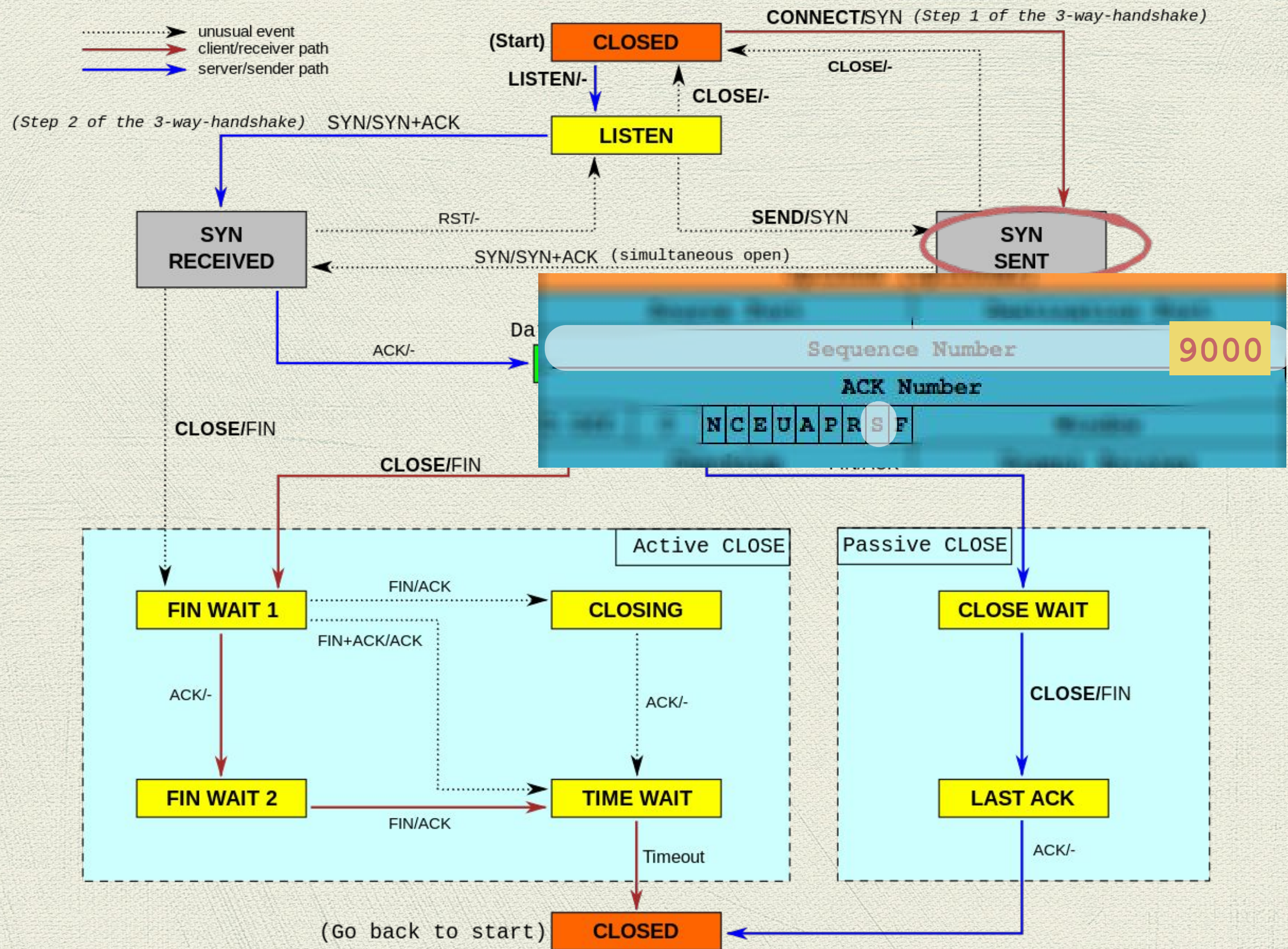
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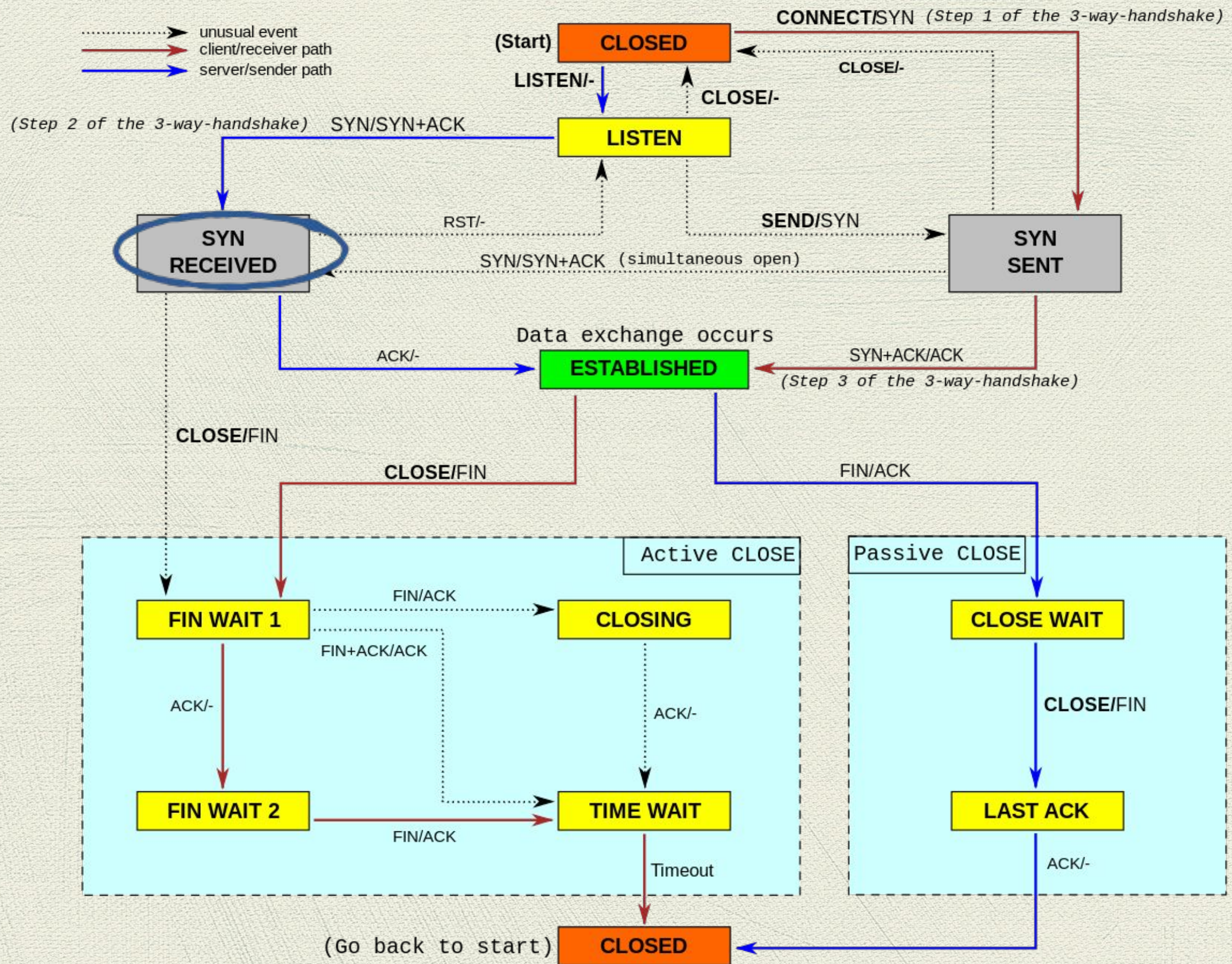
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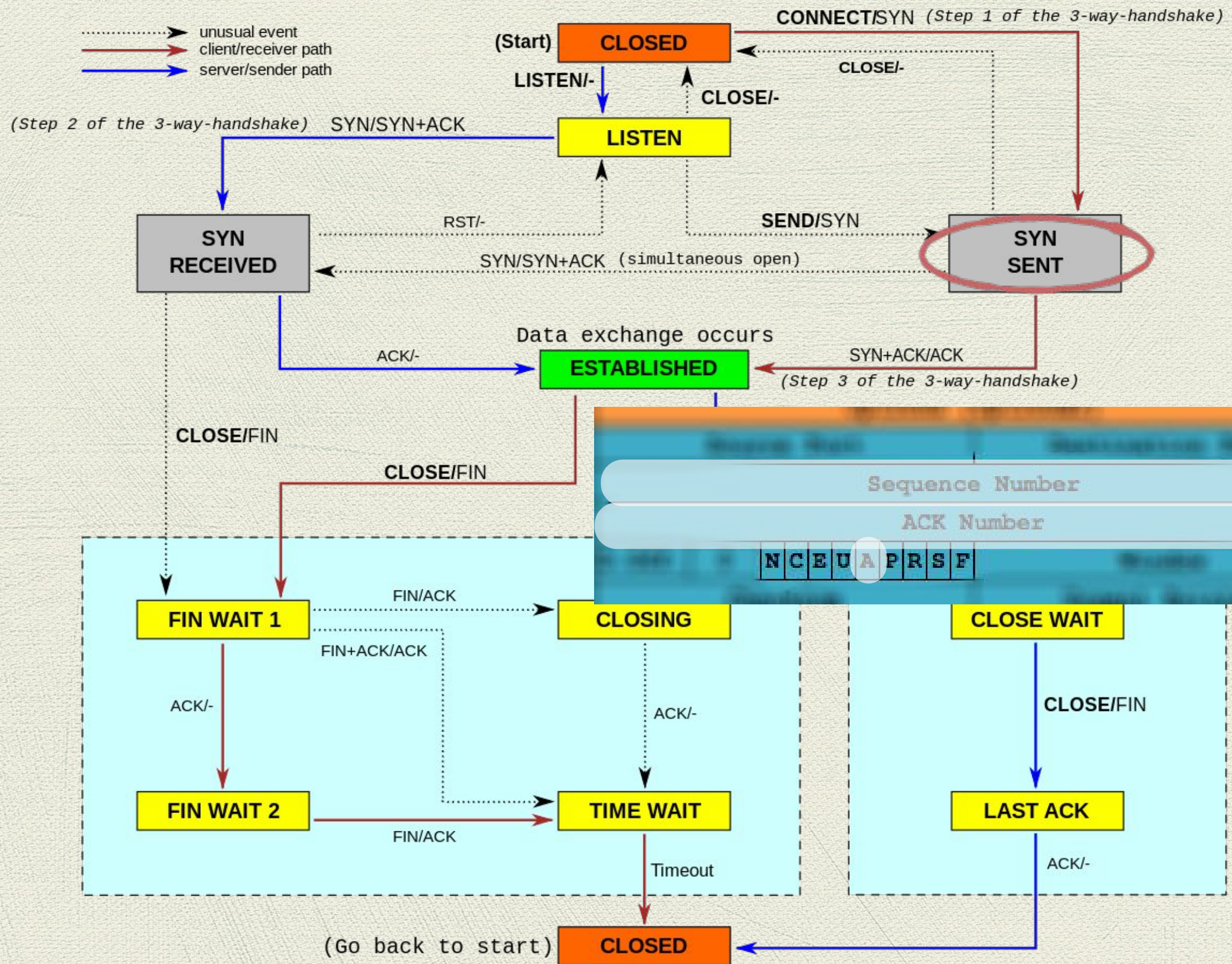
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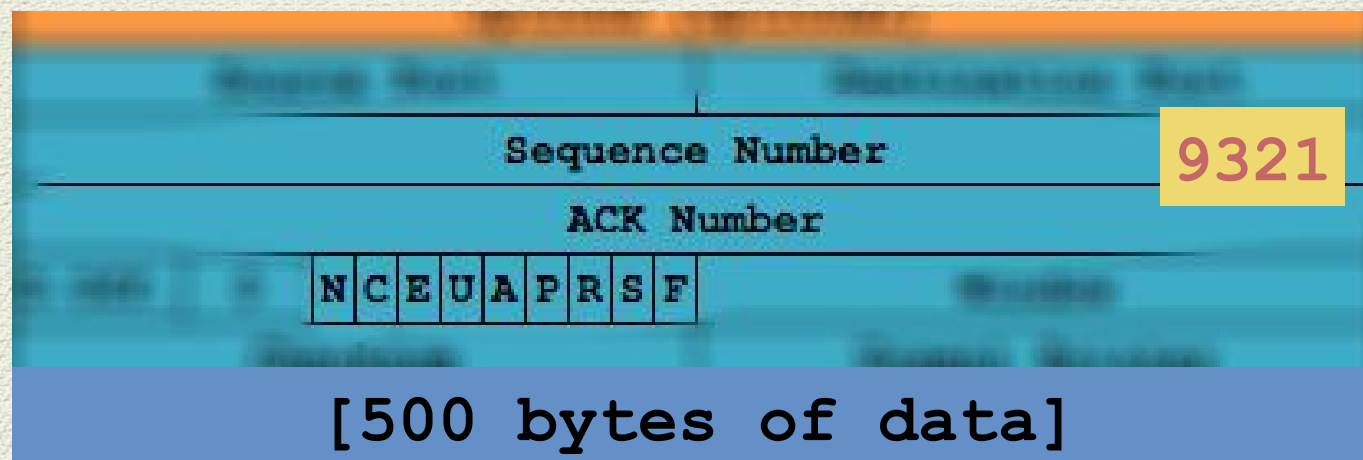
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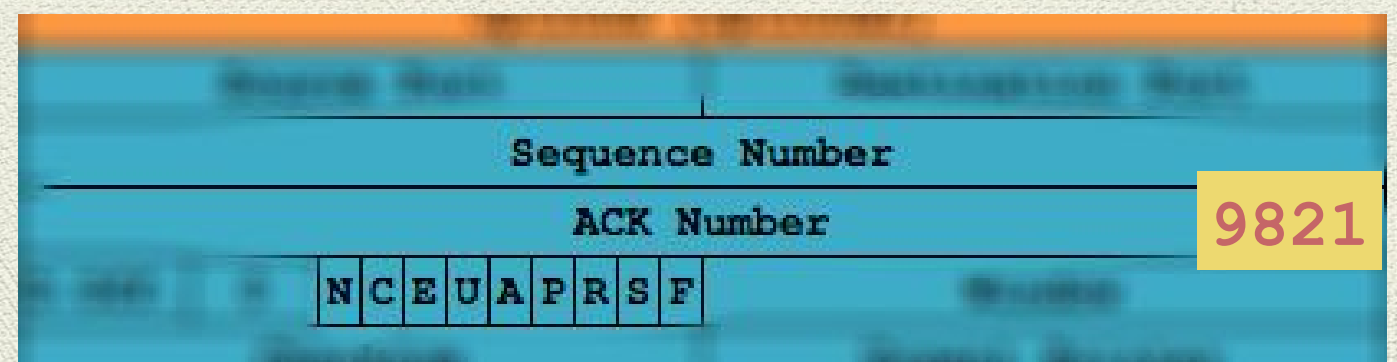






~~Packets~~

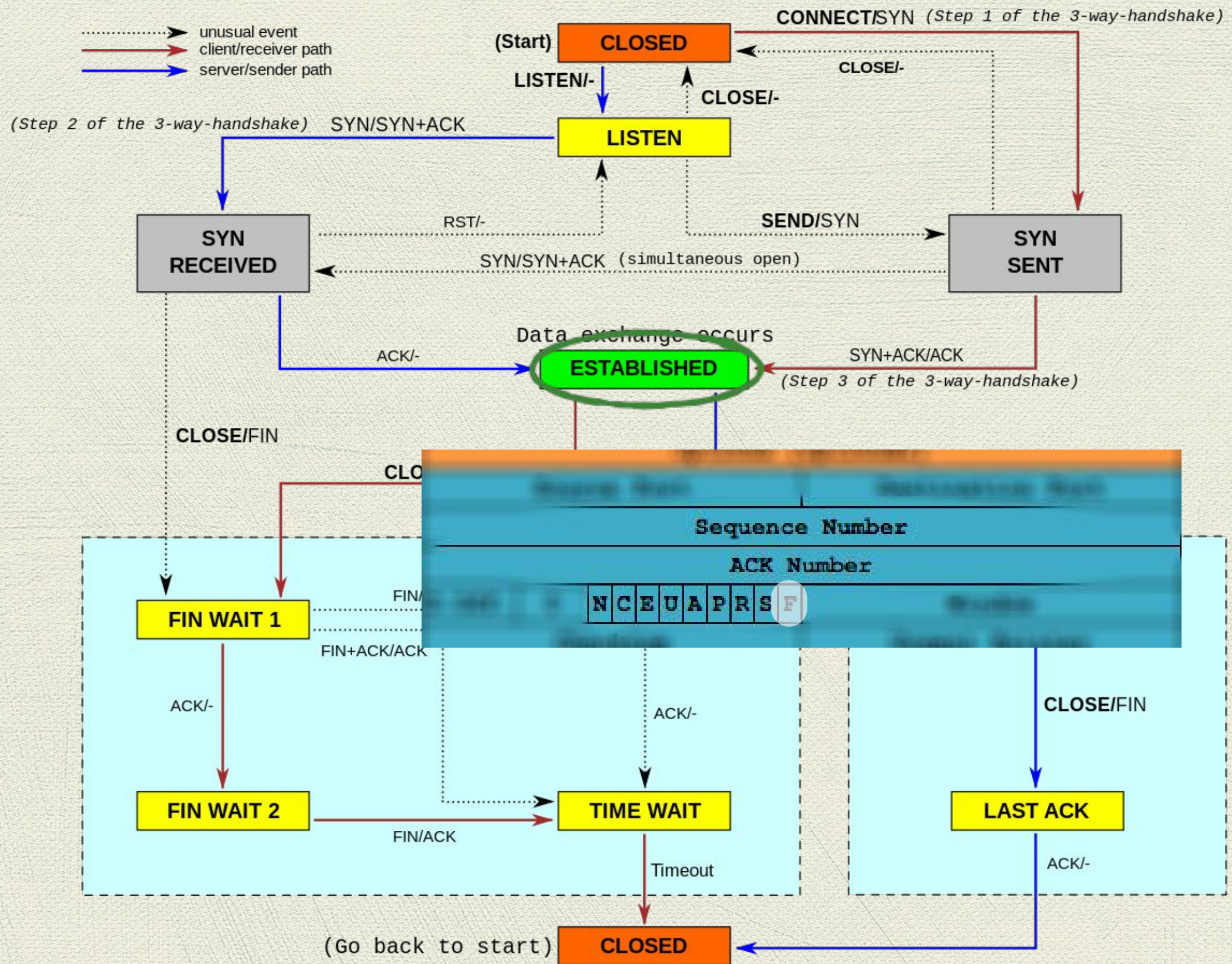
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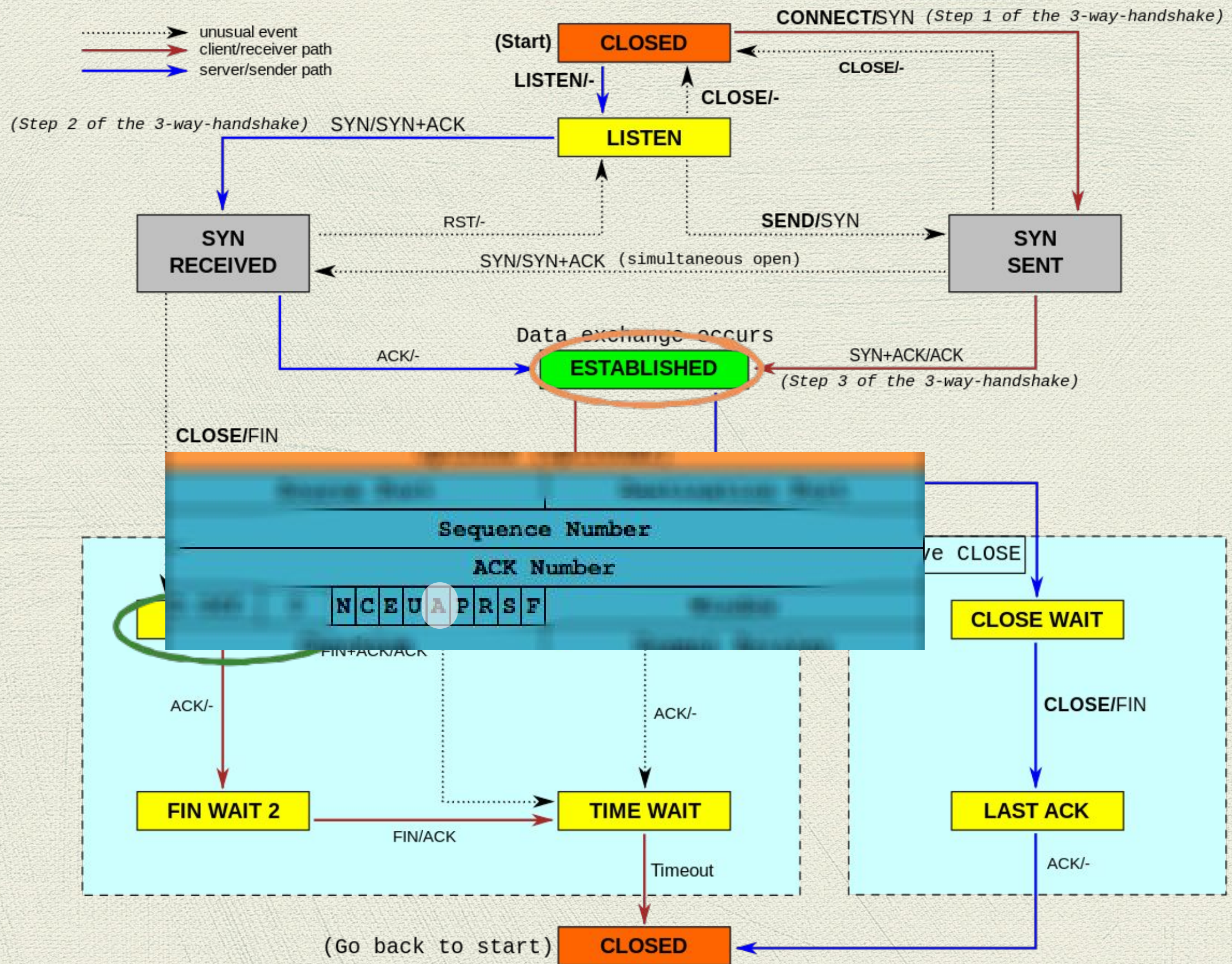


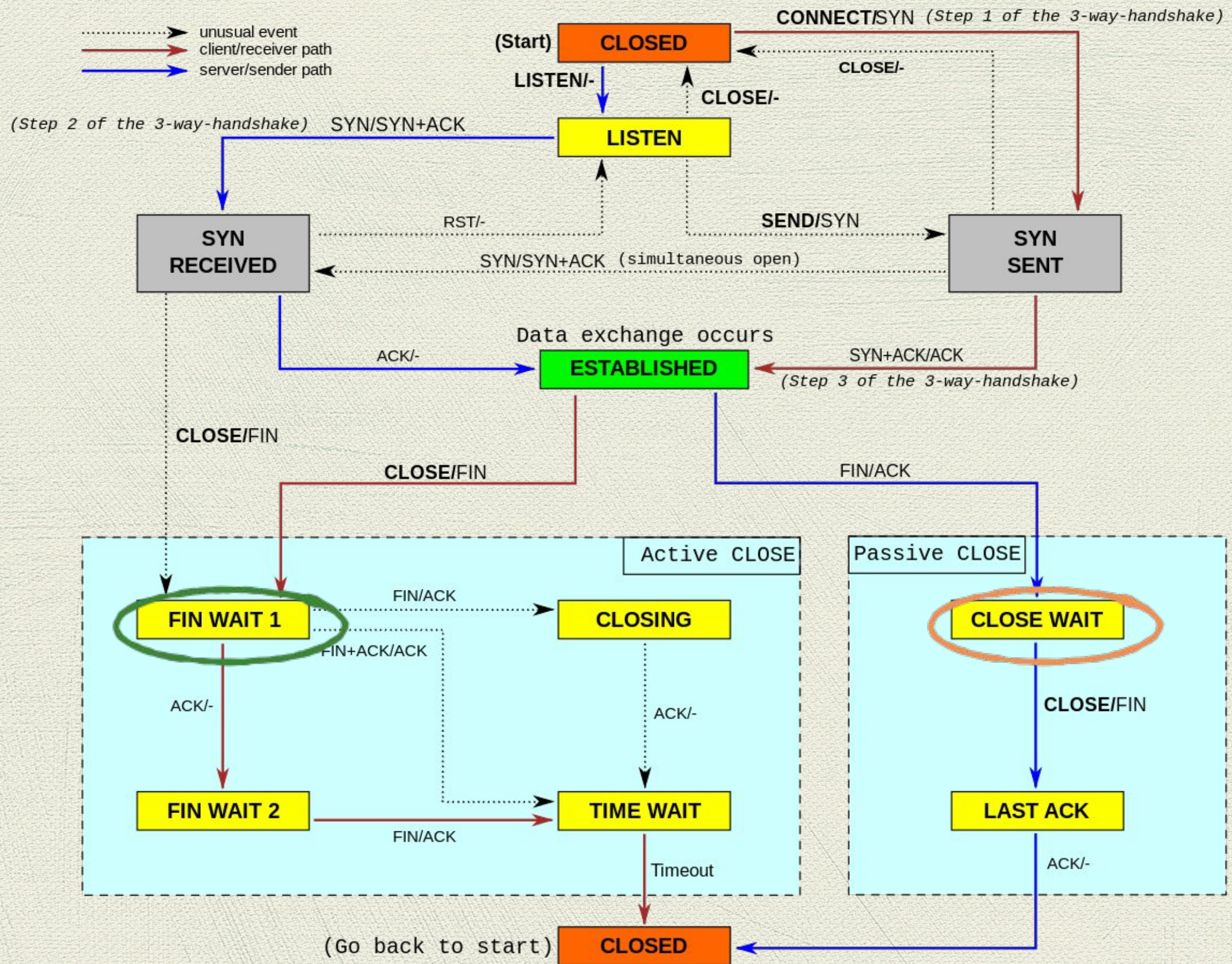
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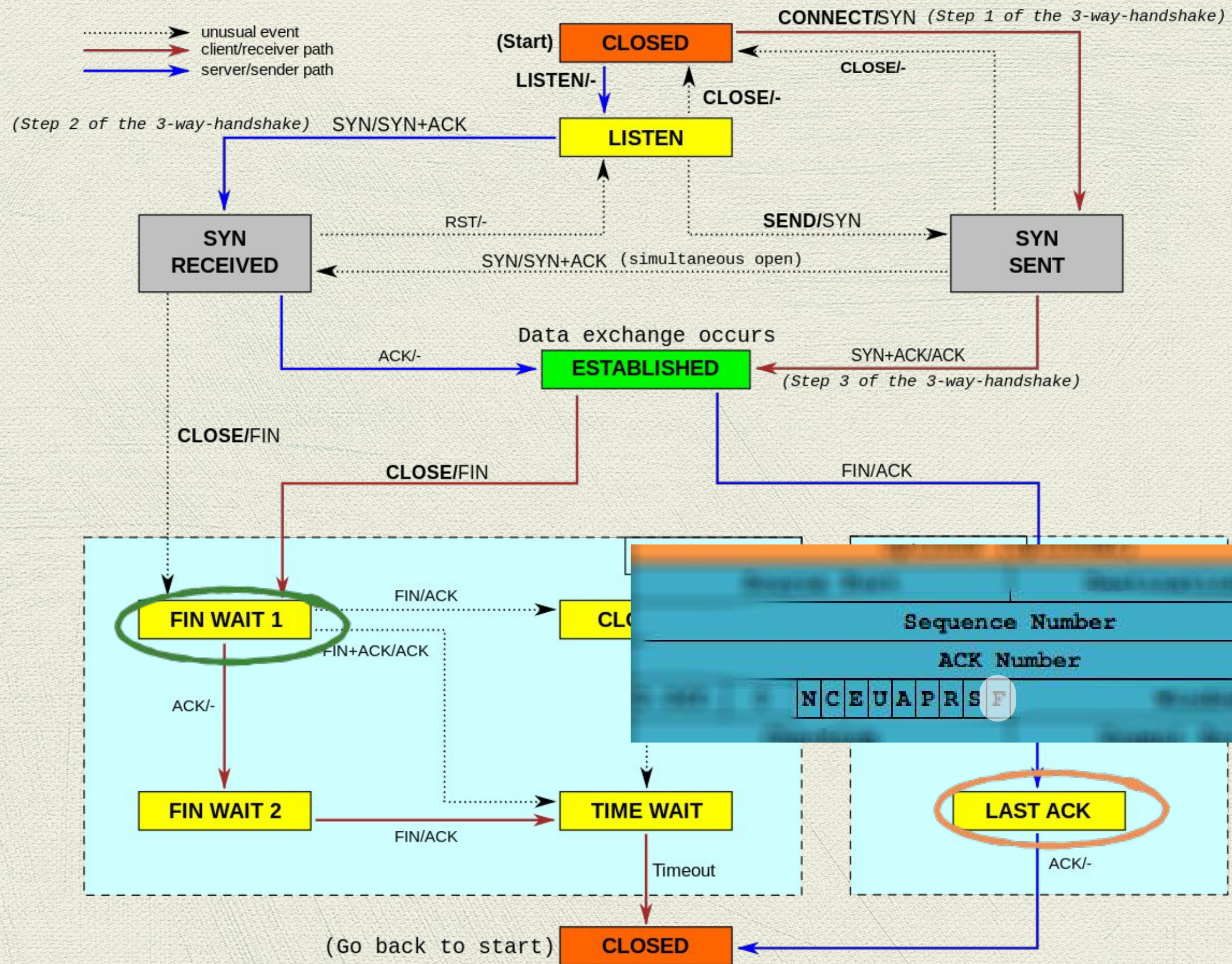
Flow Control Tricks

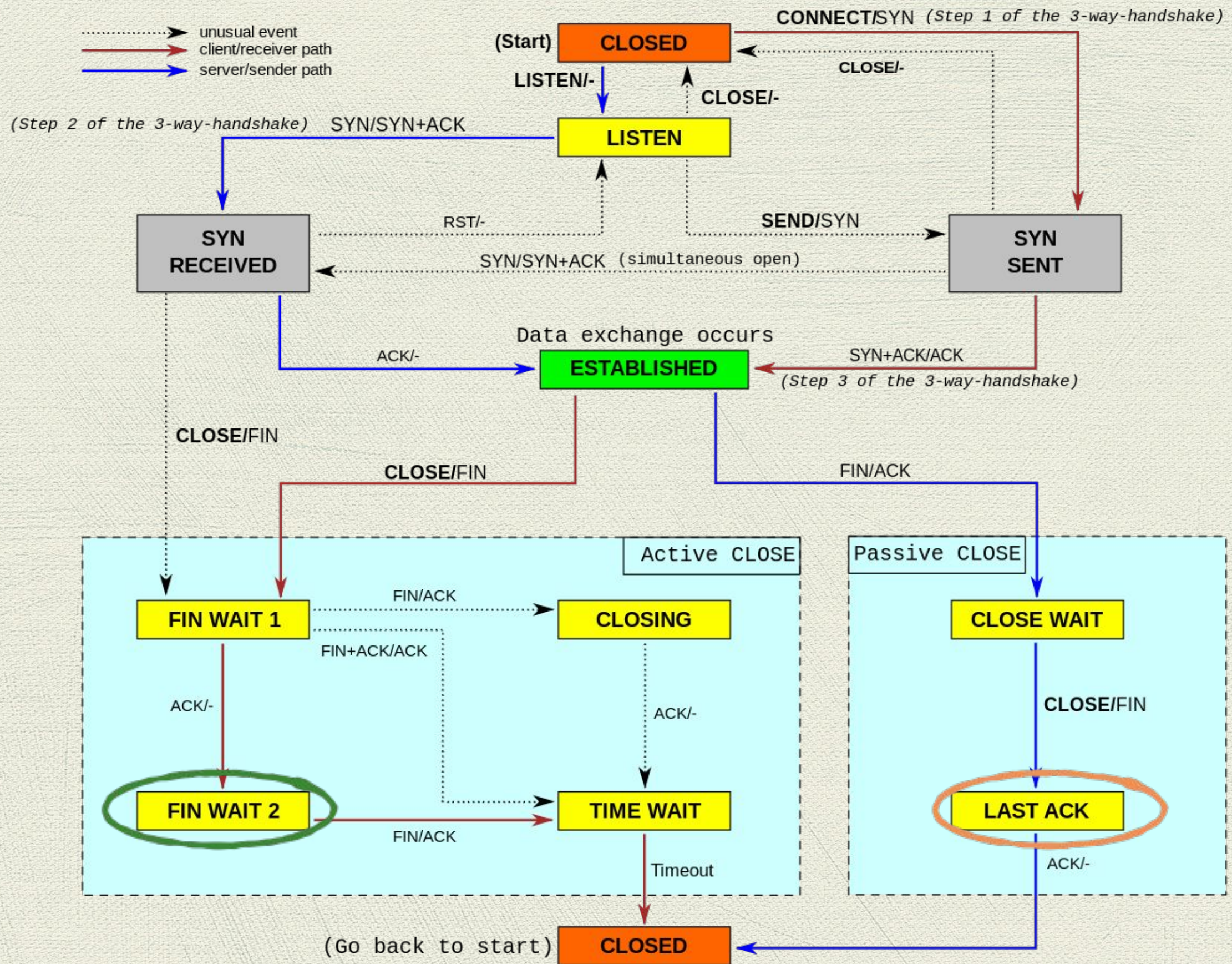
- Selective Acknowledgement
[RFC1072 & RFC2018]
- Karn's Algorithm
[RFC2988 & RFC6298]
- Slow Start, Congestion Avoidance, Fast Retransmit, Fast Recovery
[RFC2581]
- Nagle's Algorithm
[RFC896]
- Explicit Congestion Notification
[RFC3168 and RFC3540]

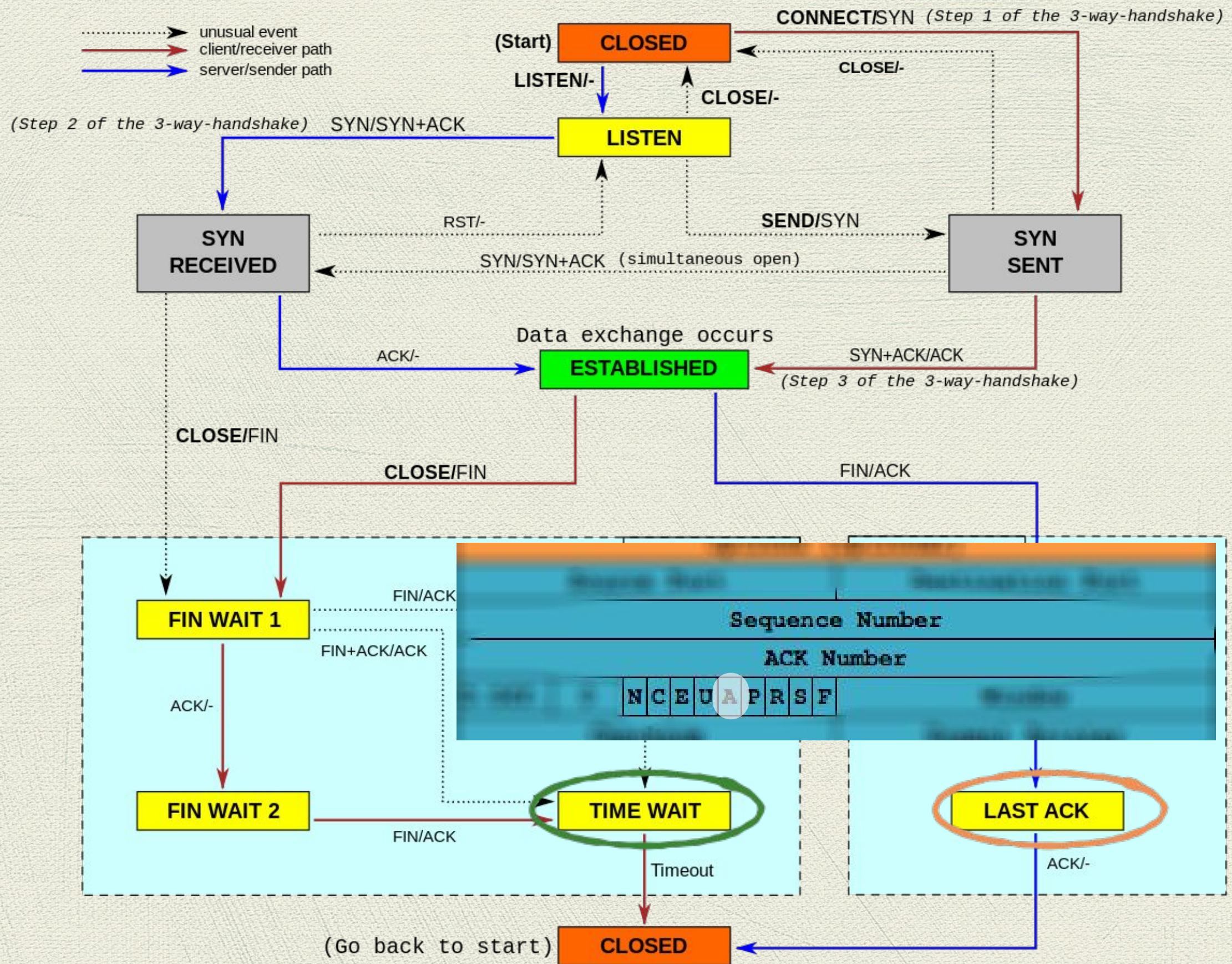


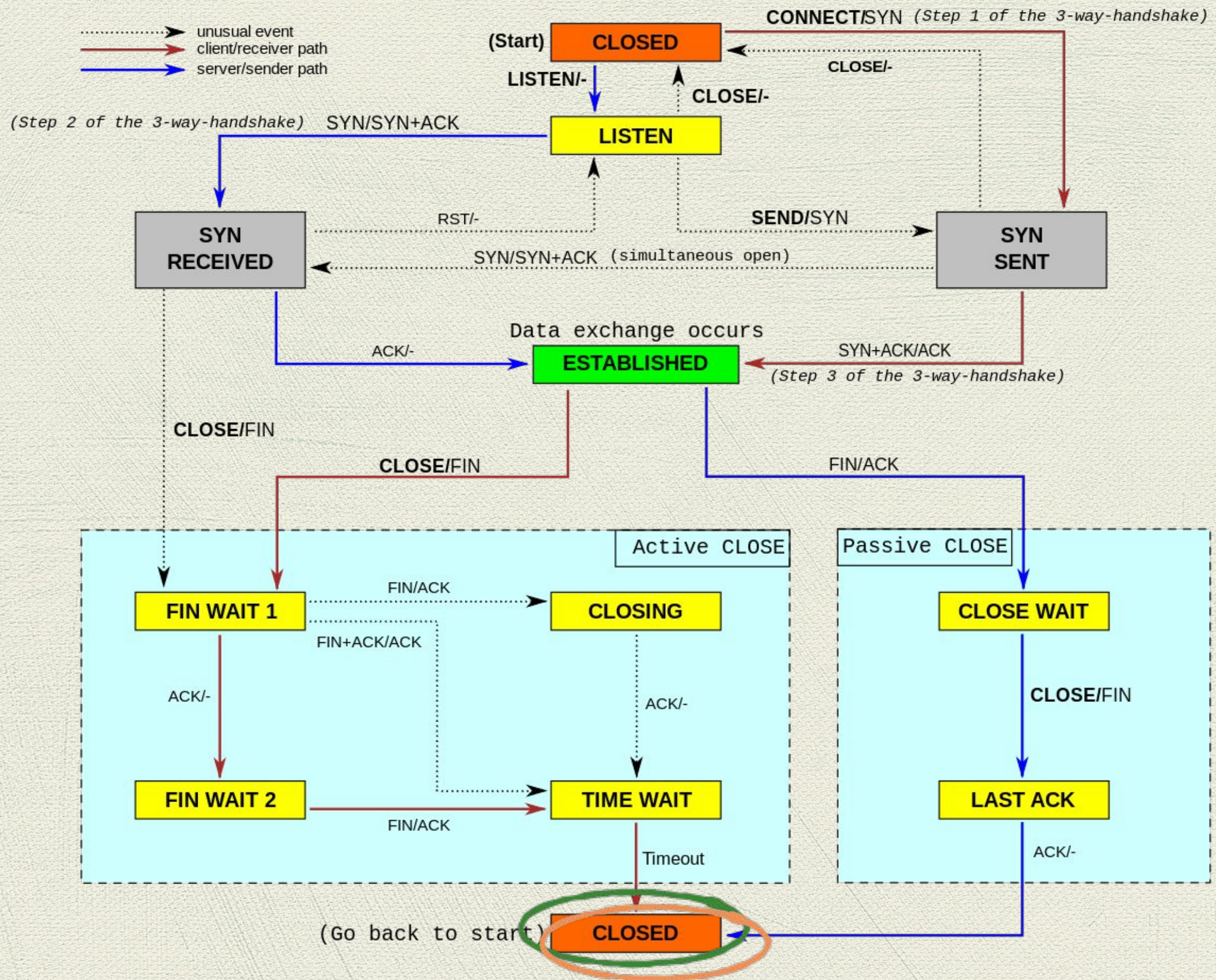












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0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1				
Vers				Hdr Sz				Service								Datagram Len																			
Identifier																Flags				Fragmentation Offset															
Time to Live								Protocol								Header Checksum																			
Source Address																																			
Destination Address																																			
Options [optional]																																			
Source Port																Destination Port																			
Sequence Number																																			
ACK Number																																			
D.Off.				0	N	C	E	U	A	P	R	S	F	Window																					
Checksum																Urgent Pointer																			
Options [optional]																																			
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