6.1800 Spring 2024

Lecture #11: Reliable Transport

adding reliability while also keeping things efficient and fair

Katrina LaCurts | lacurts@mit.edu | 6.1800 2024

6.1800 in the news

SPECIAL SEMINAR

Reconstructing the History of Incompatible Computing

Lars Brinkhoff and Oscar Vermeulen

ITS Reconstruction Project

MIT Museum Collections Workshop (3rd floor)

(MIT Museum, 314 Main St, Gambrill Center, Cambridge, MA)

April 1, 2024

2:30-4:30 pm

NOTE: The seminar is free and open to all but an MIT ID (or an admission ticket) is required for entry to the museum.

6.1800 in the news

ITS, and the software developed on it, were technically and culturally influential far beyond their core user community. Remote "guest" or "tourist" access was easily available via the early ARPAnet, allowing many interested parties to informally try out features of the operating system and application programs. The wide-open ITS philosophy and collaborative online community were a major influence on the hacker culture, as described in Steven Levy's book *Hackers*,[3] and were the direct forerunners of the free and open-source software, open-design, and Wiki movements.

https://en.wikipedia.org/wiki/Incompatible_Timesharing_System

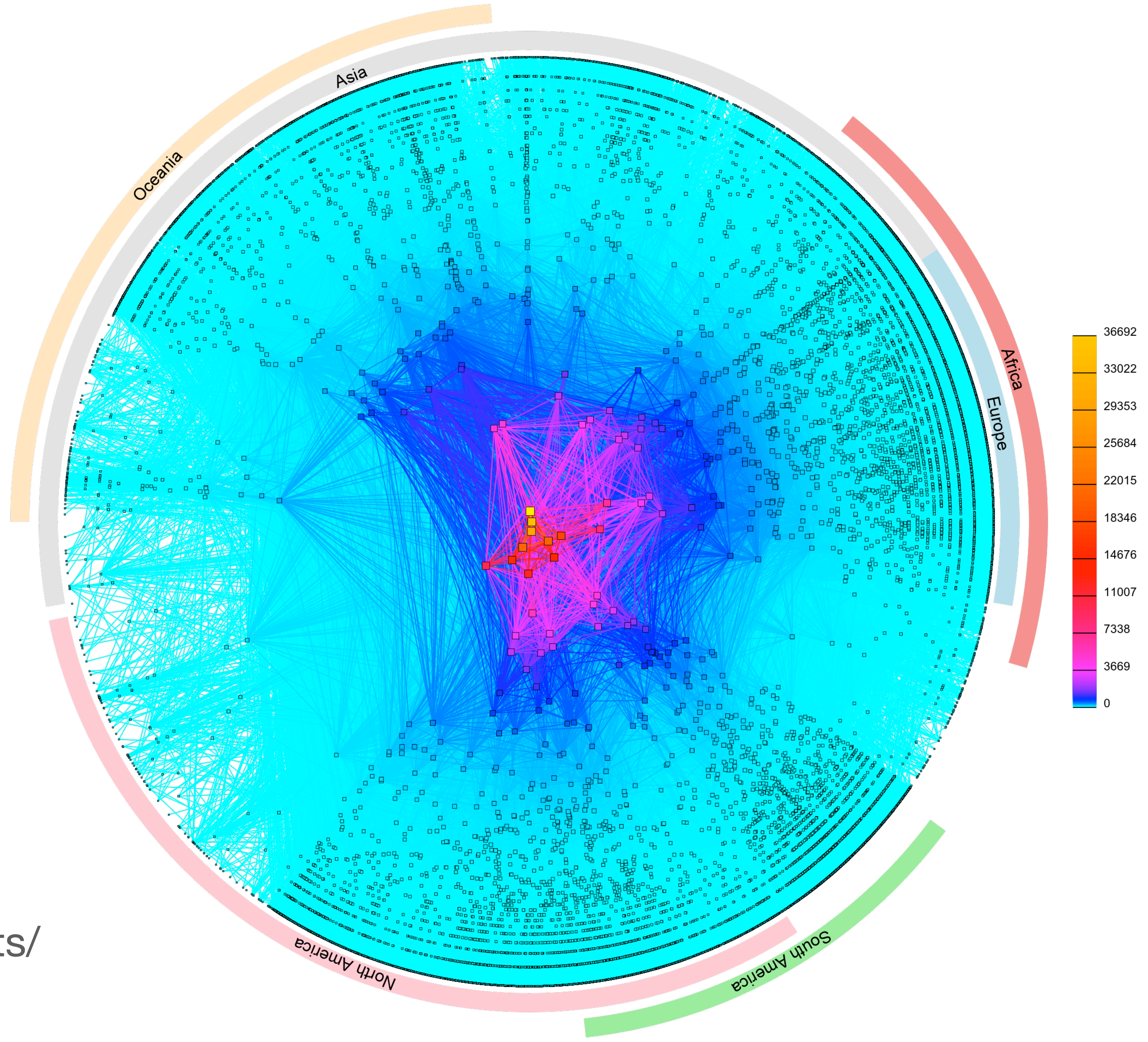
1970s: ARPAnet — hosts.txt

1978: flexibility and layering — distance-vector routing

early 80s: growth → change — **TCP**, UDP; OSPF, EGP, DNS

late 80s: growth → problems — congestion collapse (which led to **congestion control**); policy routing; CIDR

1993: commercialization



CAIDA's IPv4 AS Core, January 2020 (https://www.caida.org/projects/cartography/as-core/2020/)

application	the things that actually generate traffic
transport	sharing the network, reliability (or not) *examples: TCP, UDP*
network	naming, addressing, routing *examples: IP*
link	communication between two directly-connected nodes *examples: ethernet, bluetooth, 802.11 (wifi)*

today: moving up to the transport layer to discuss **reliable transport**

our (first) goal today is to create a **reliable transport protocol**, which delivers each byte of data **exactly once, in-order**, to the receiving application

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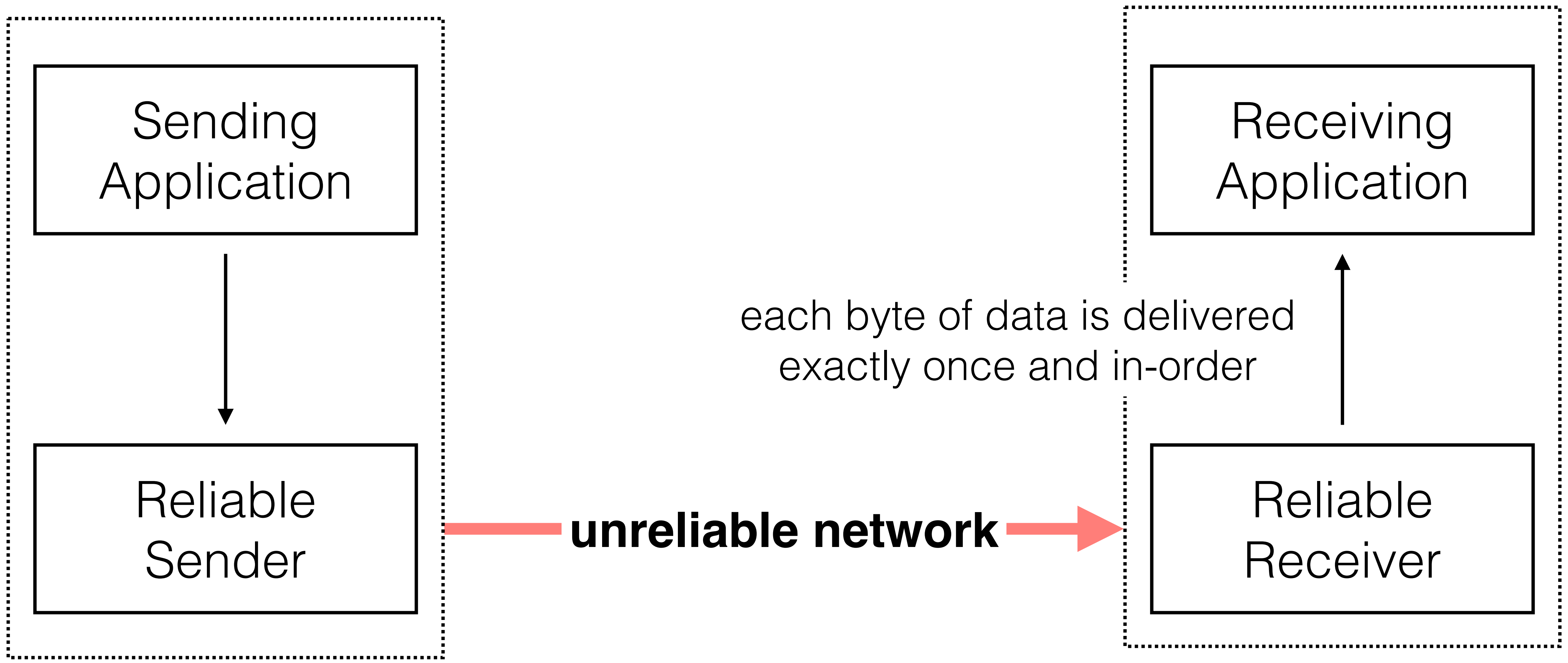

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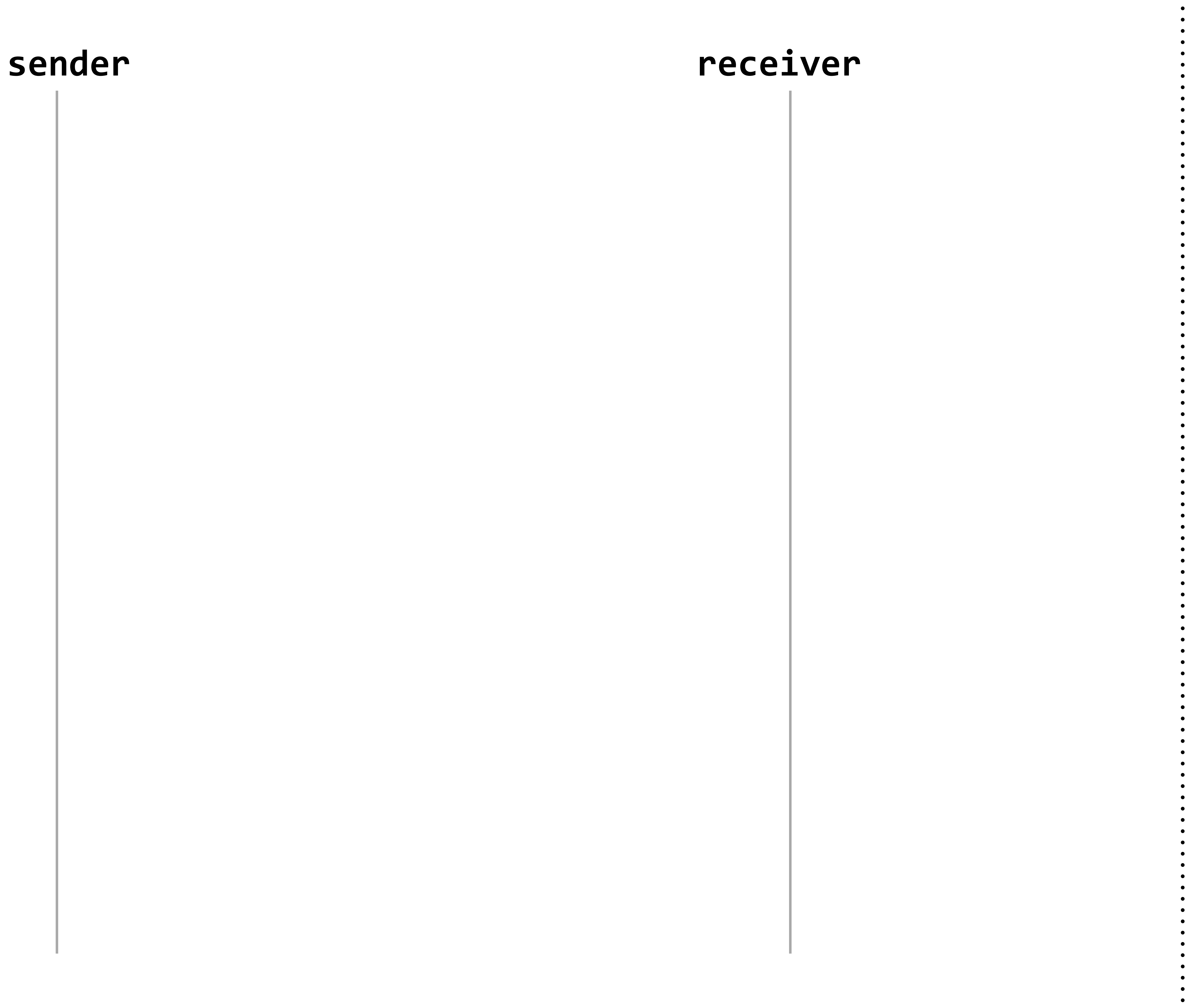

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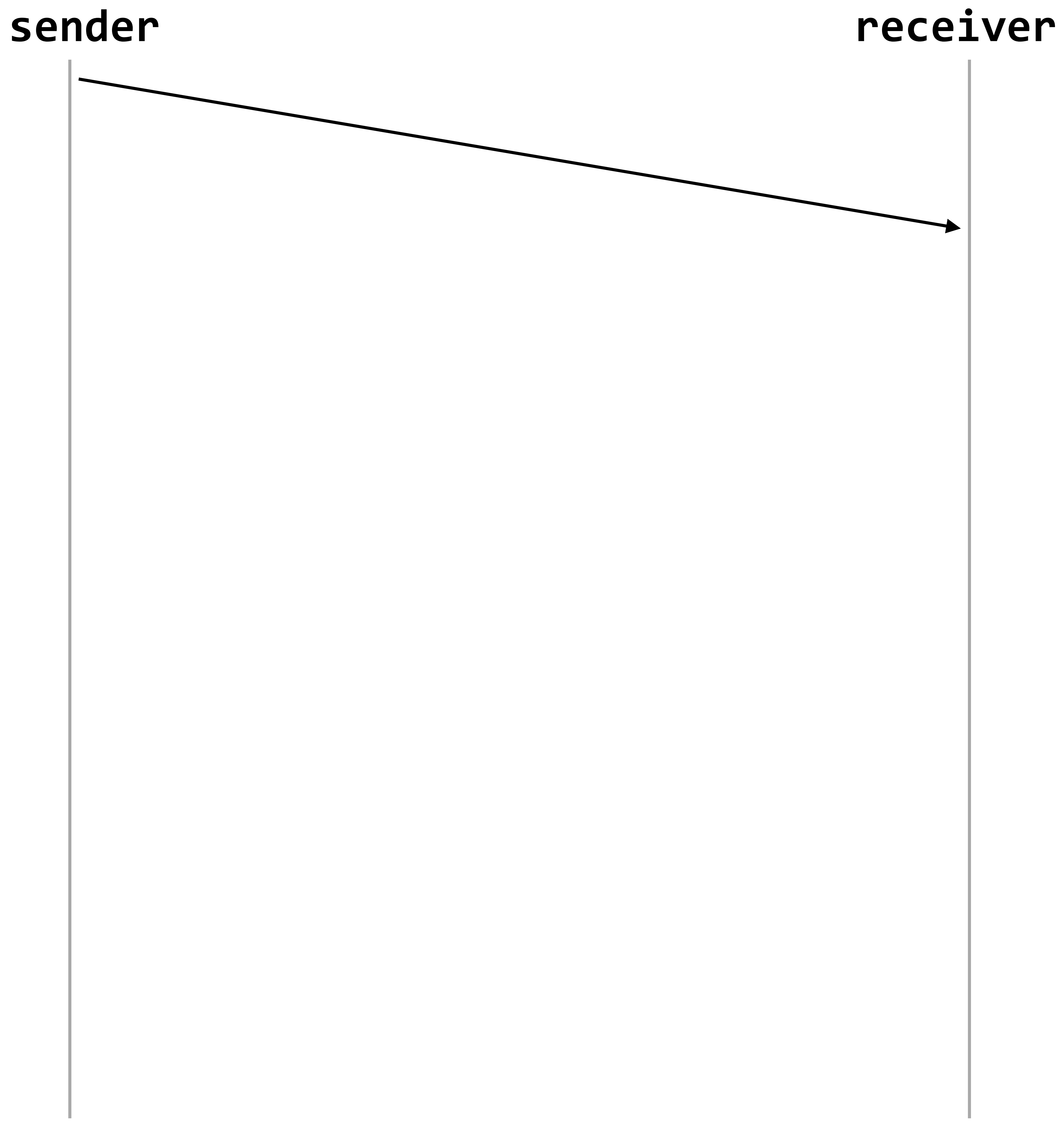

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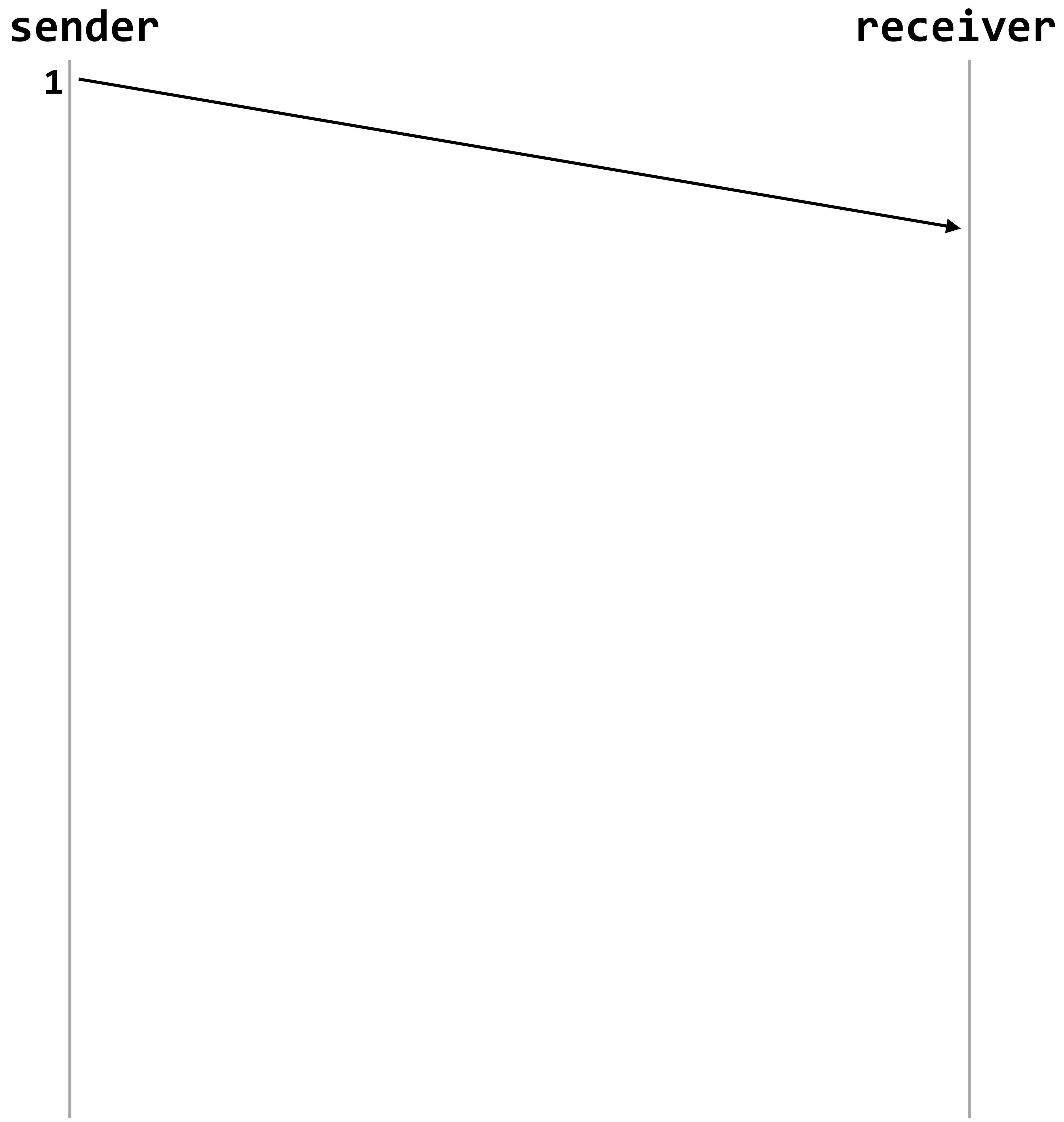

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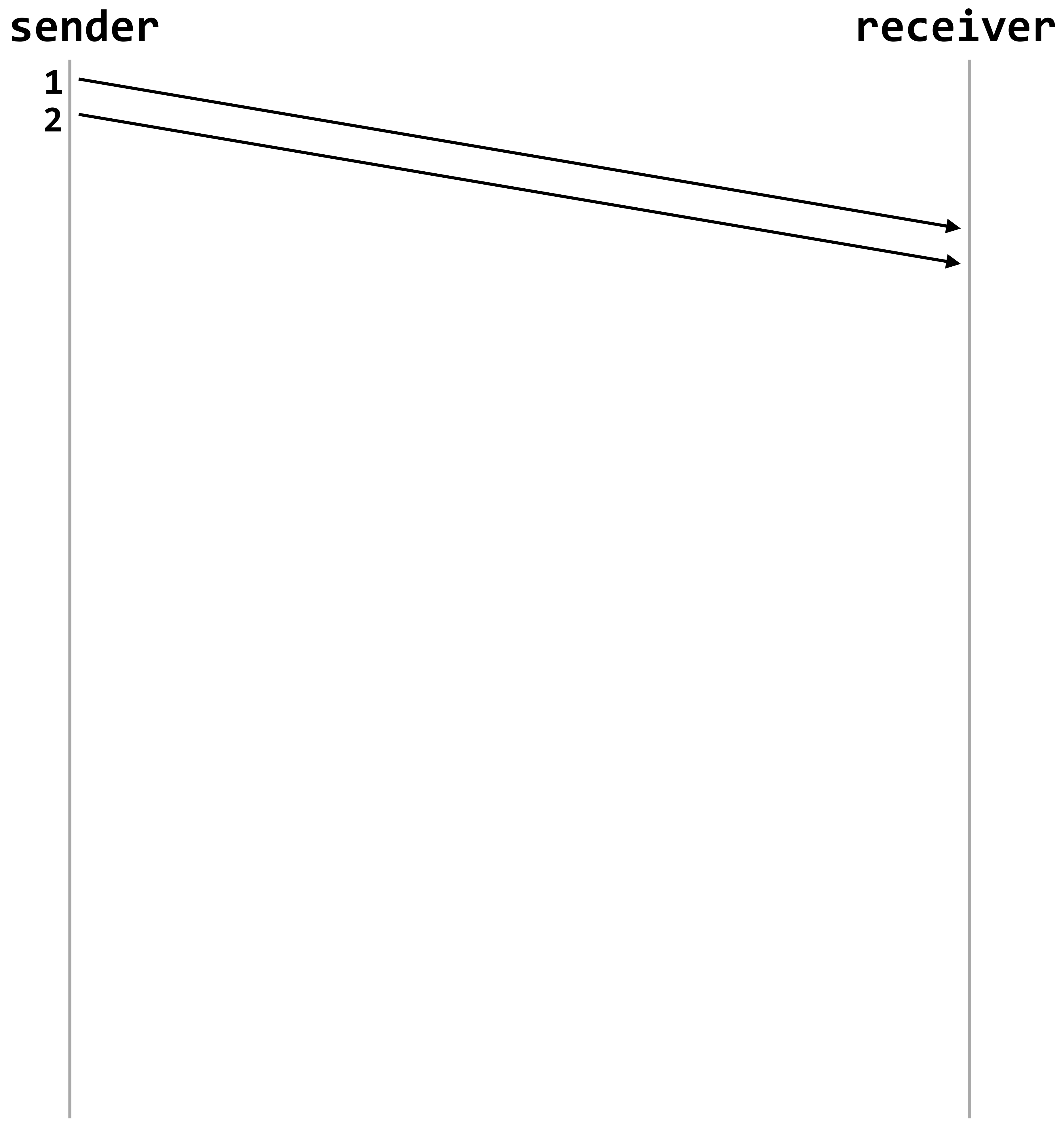

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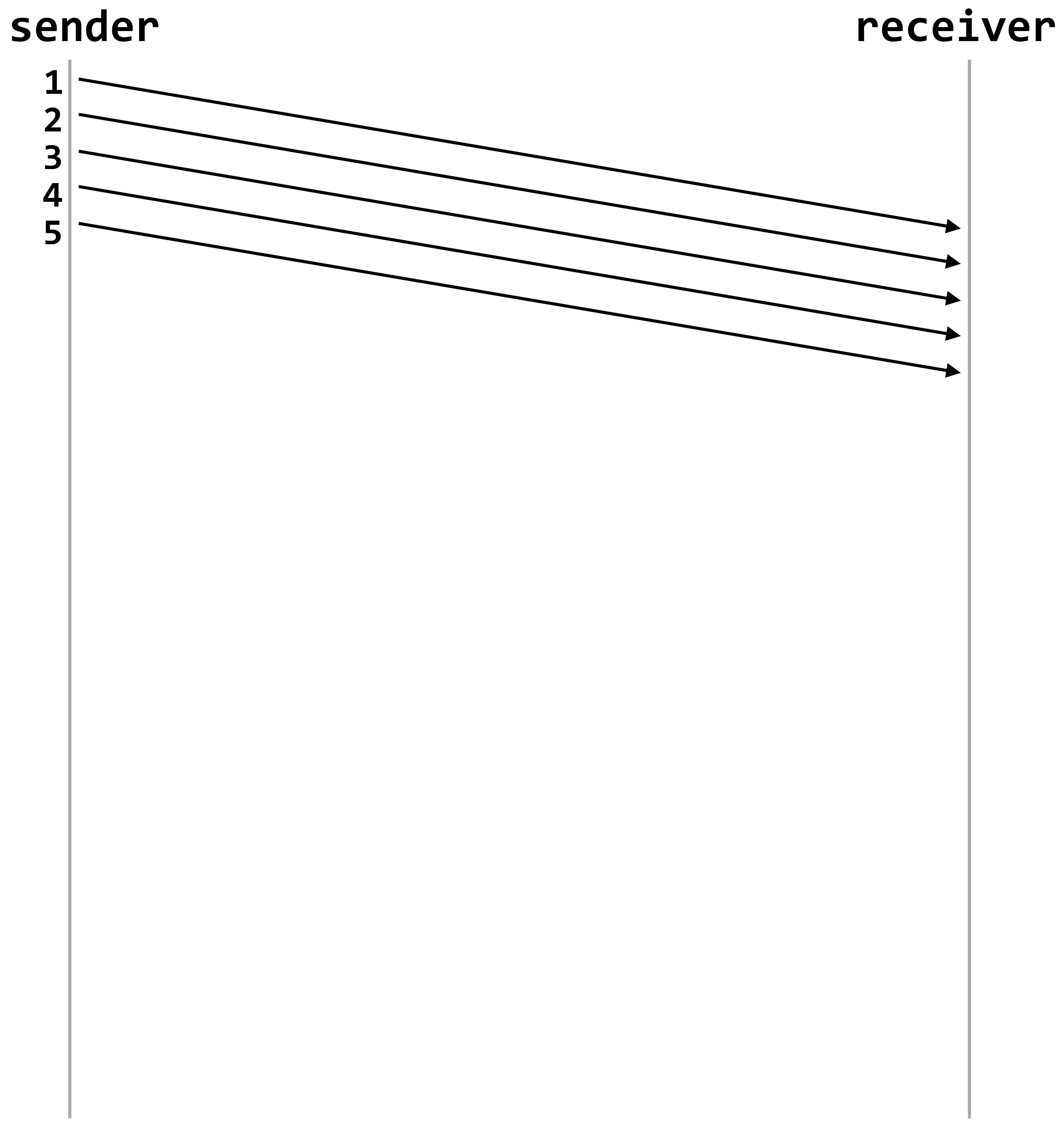

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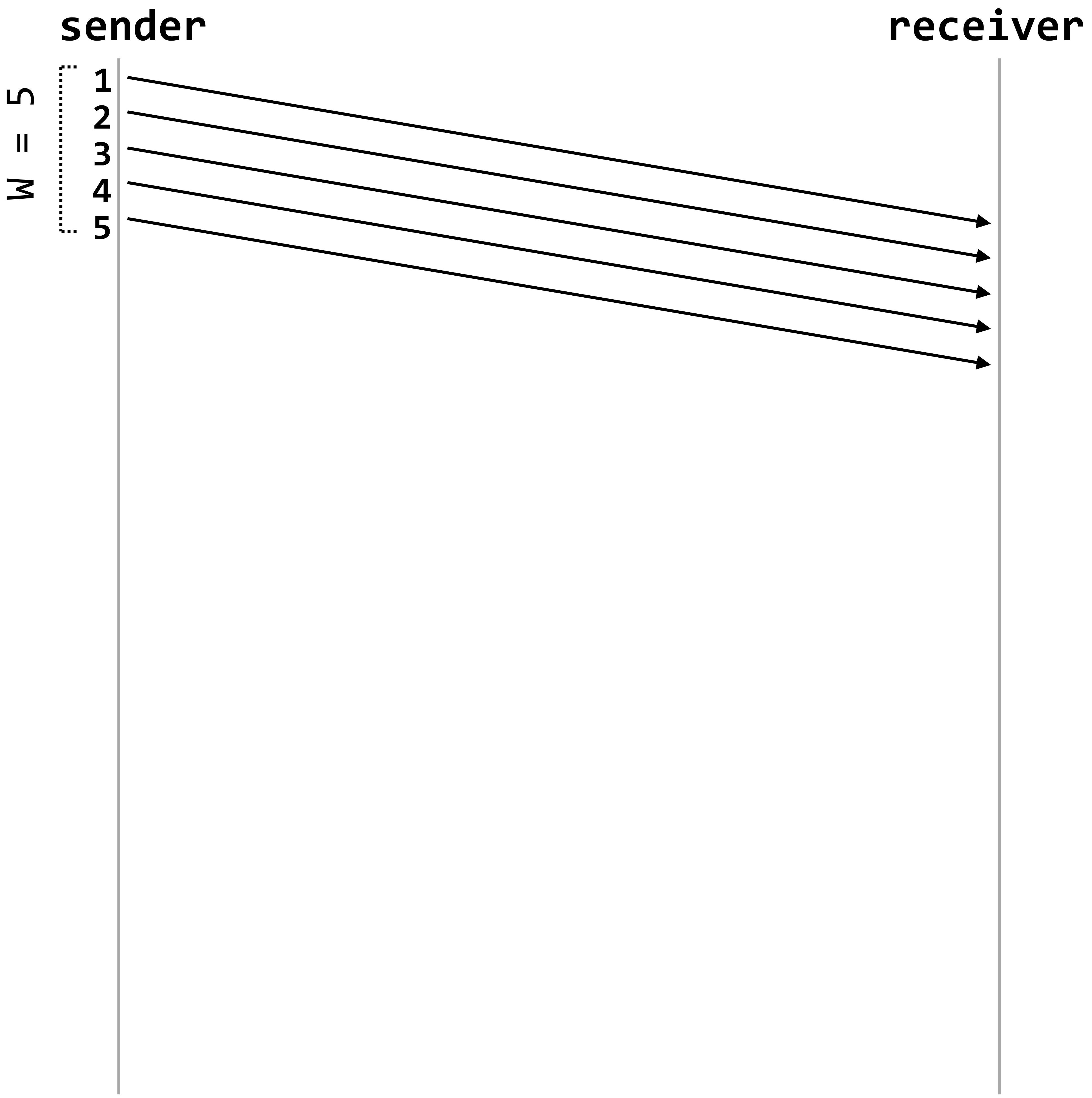

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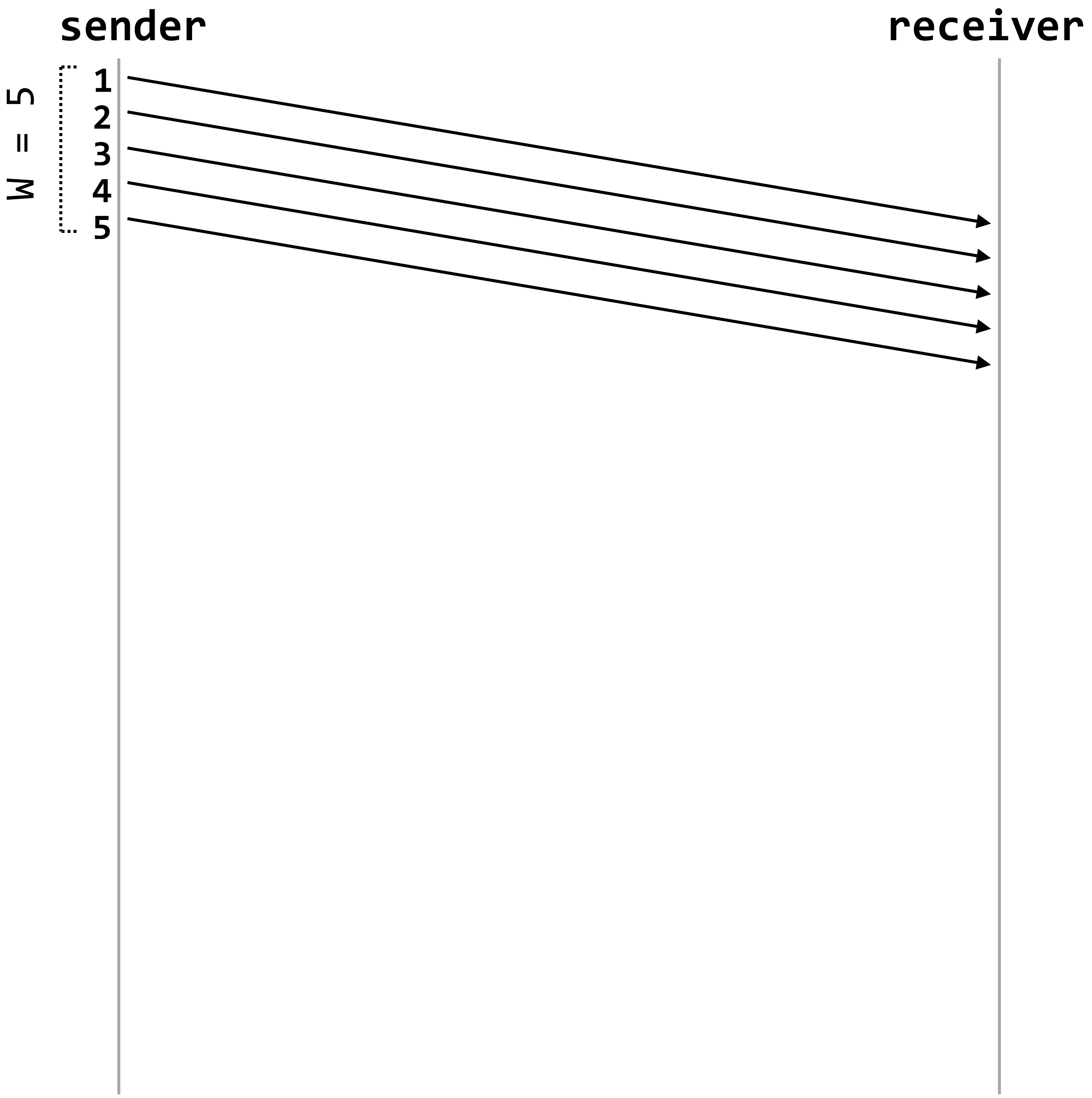

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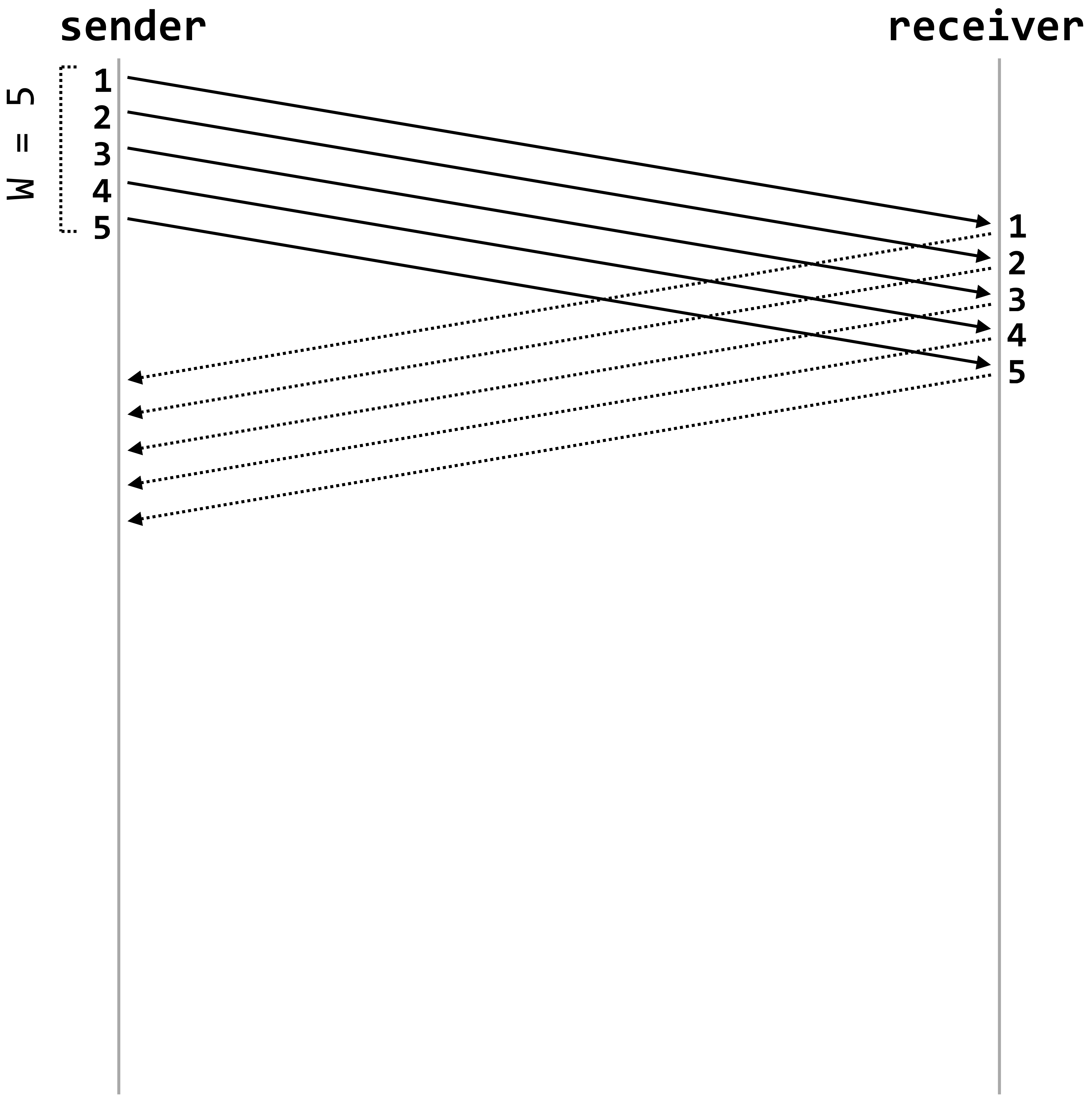

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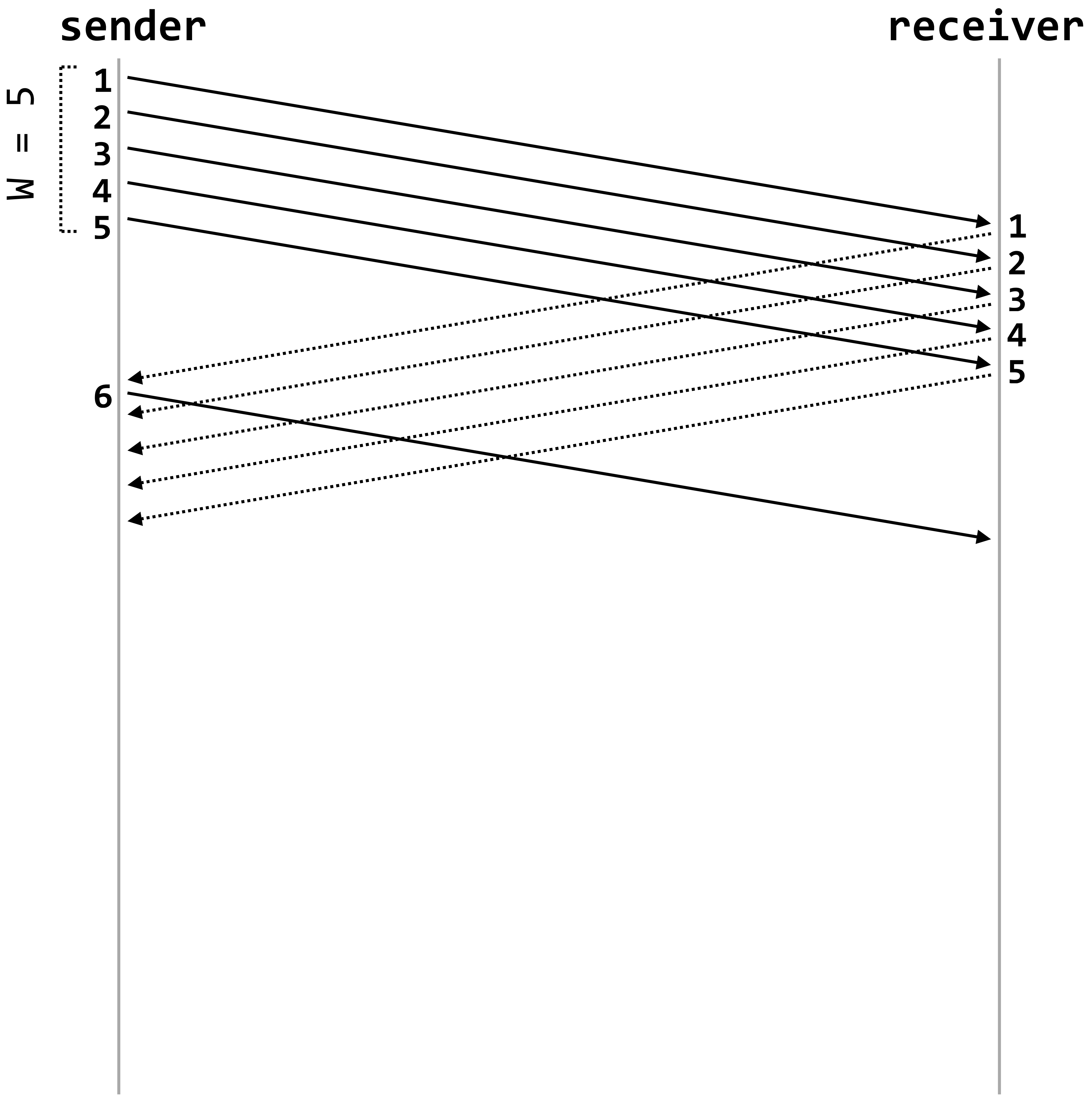

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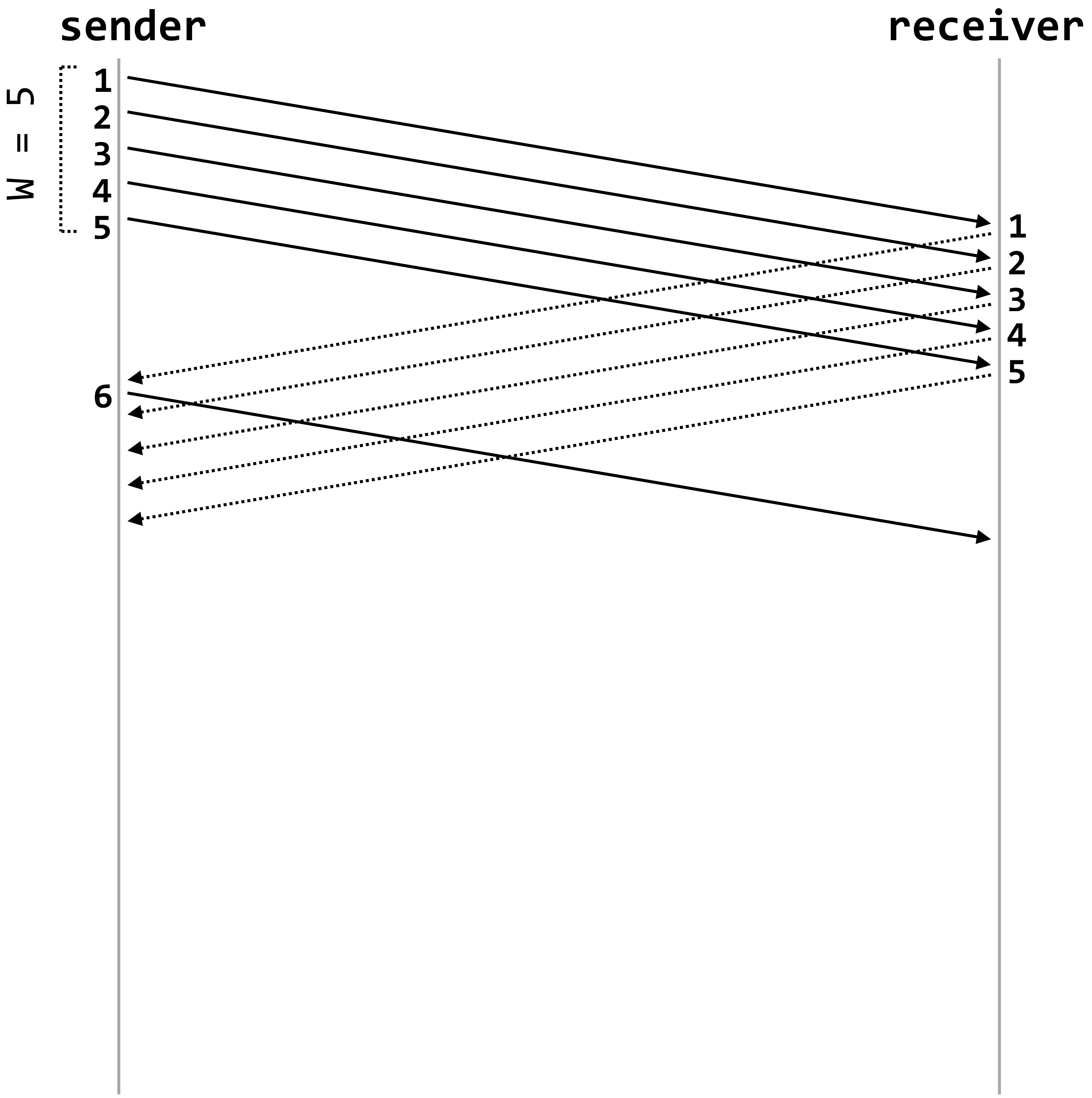

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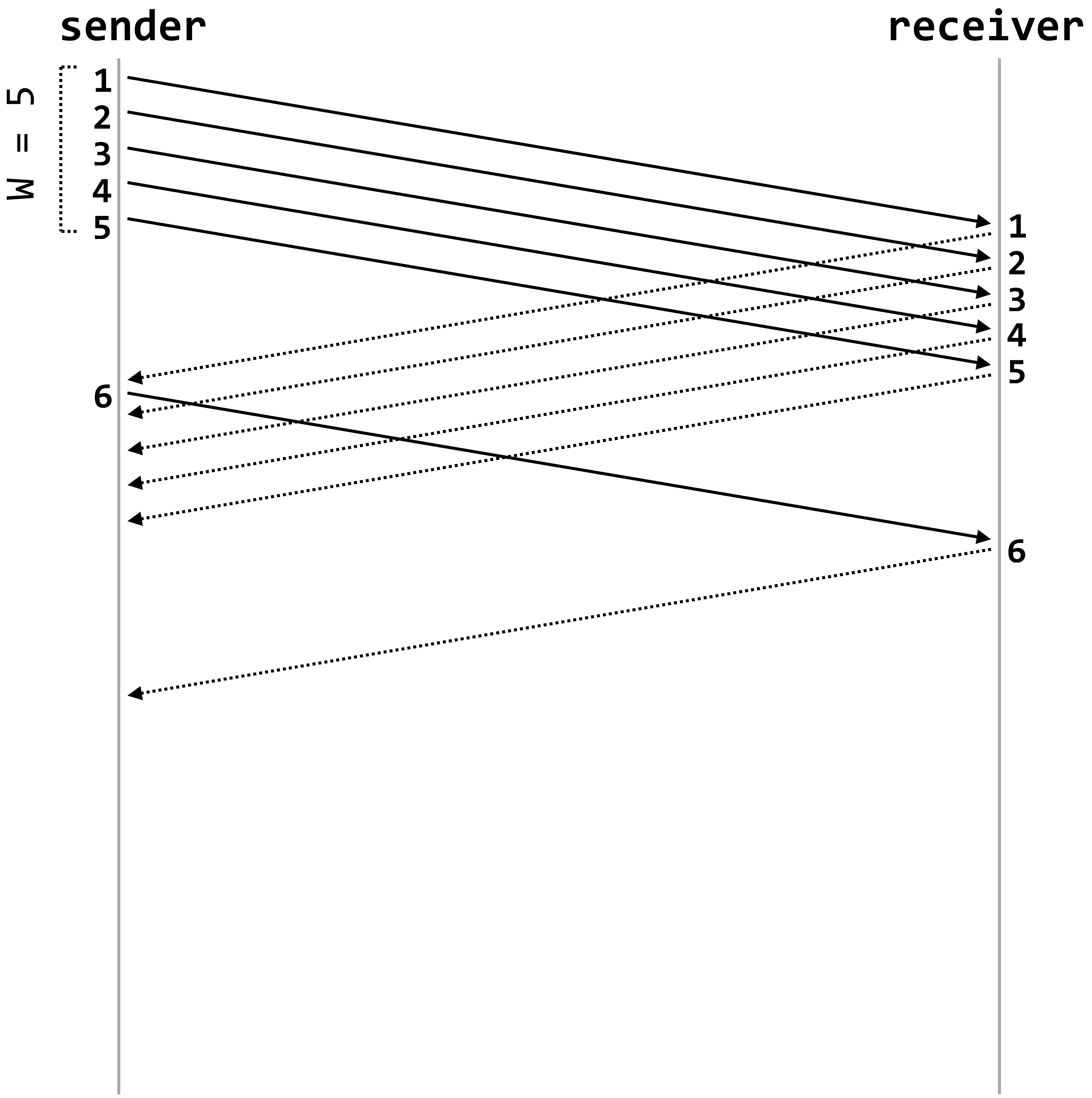

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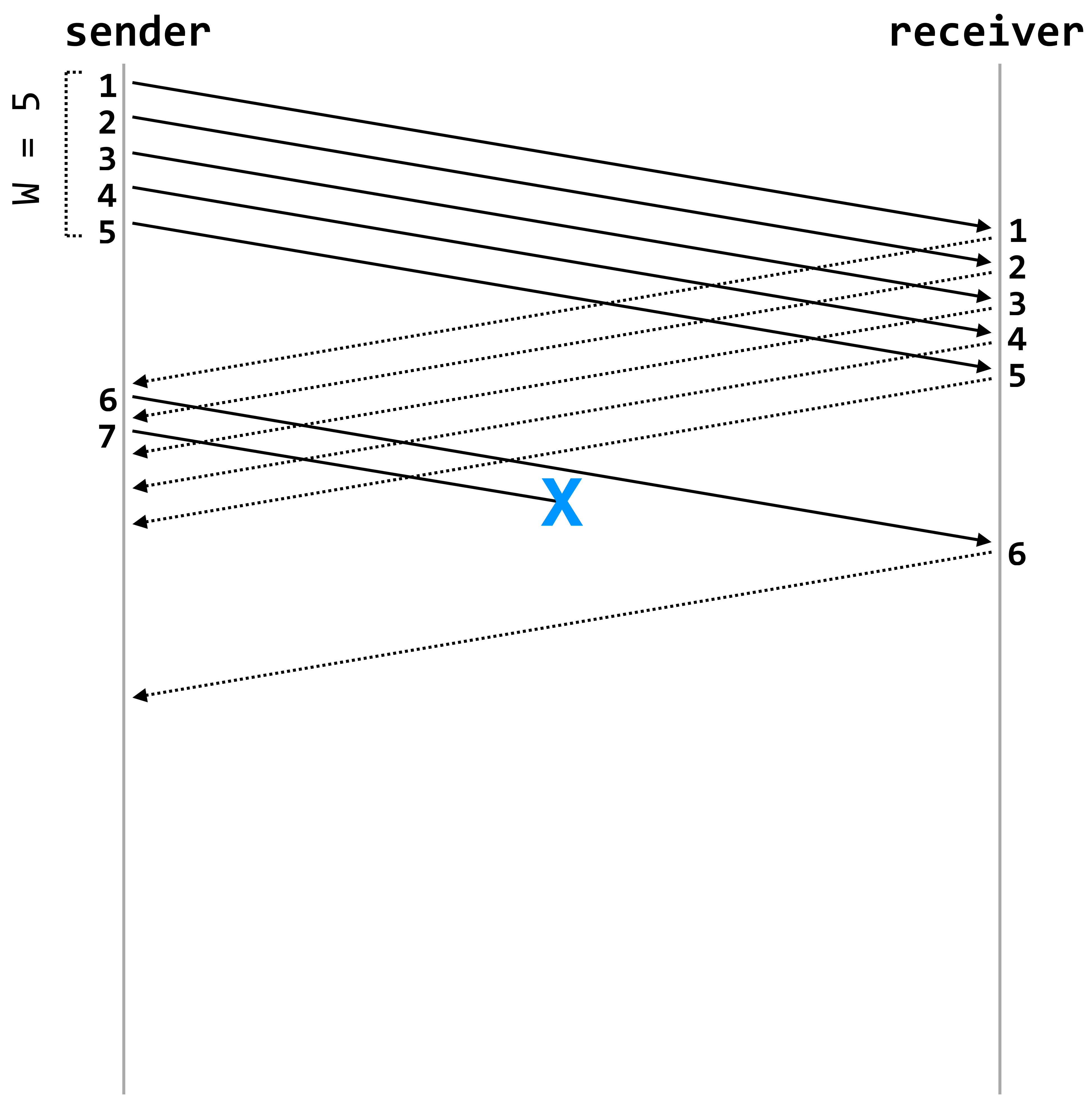

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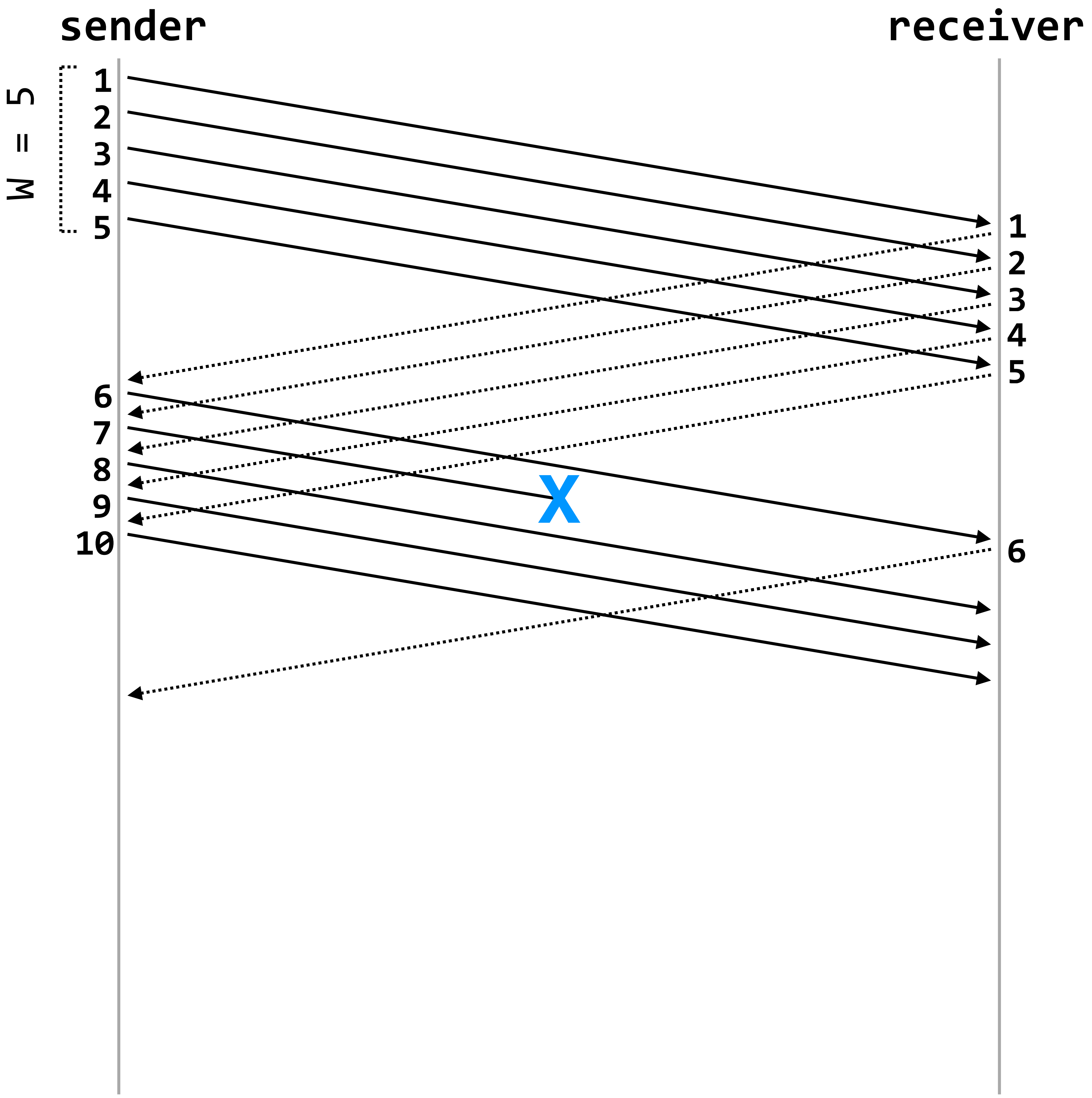

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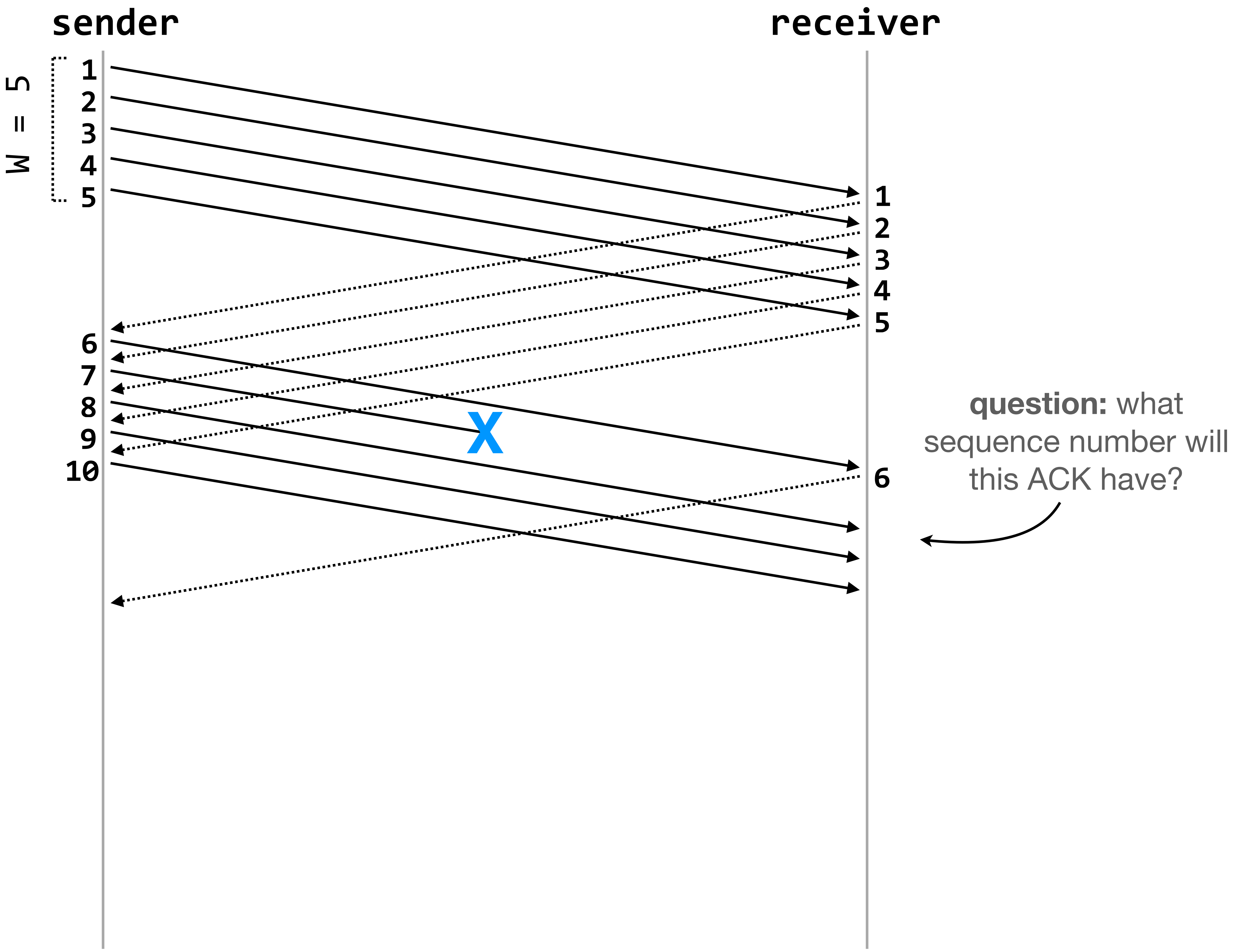

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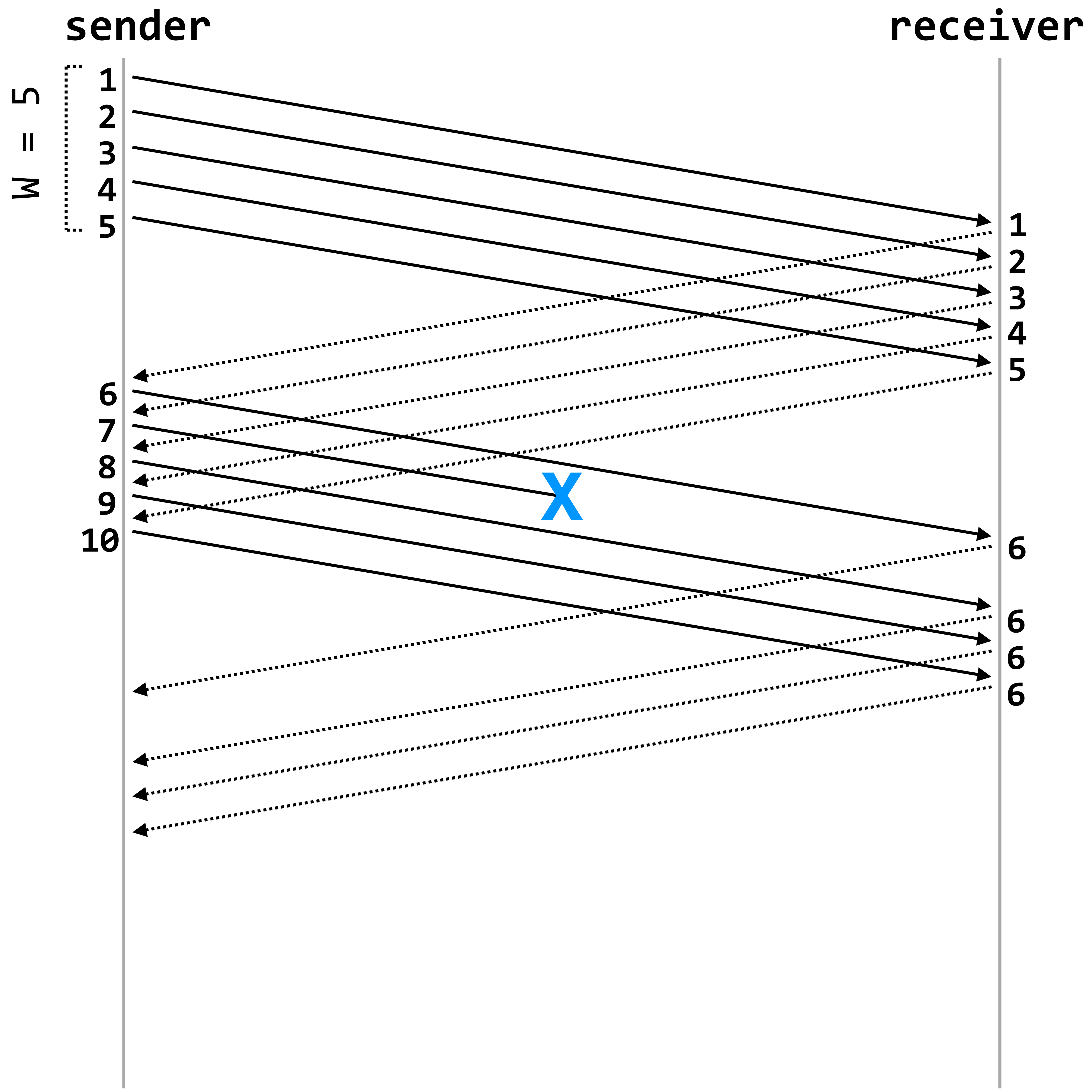

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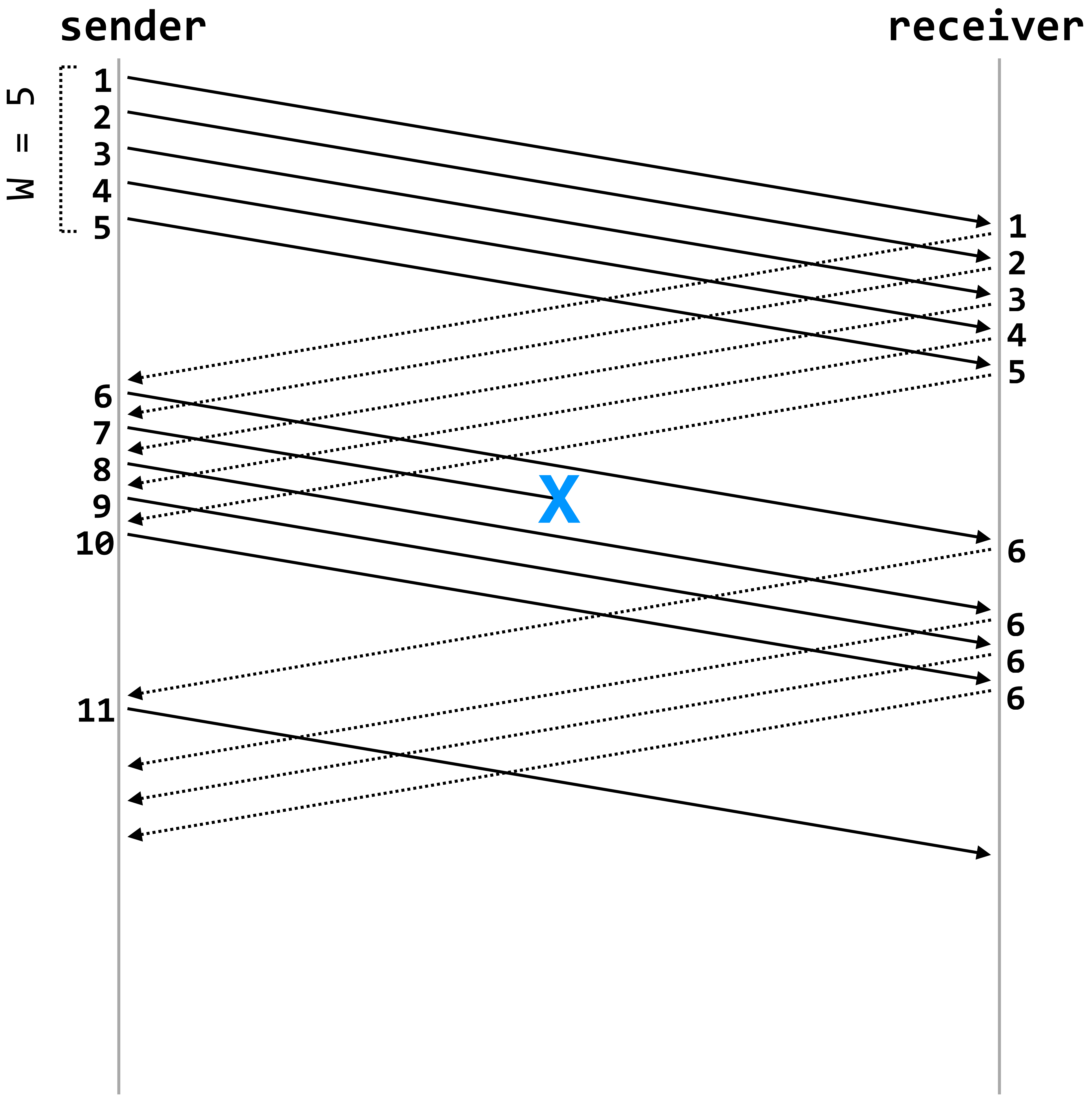

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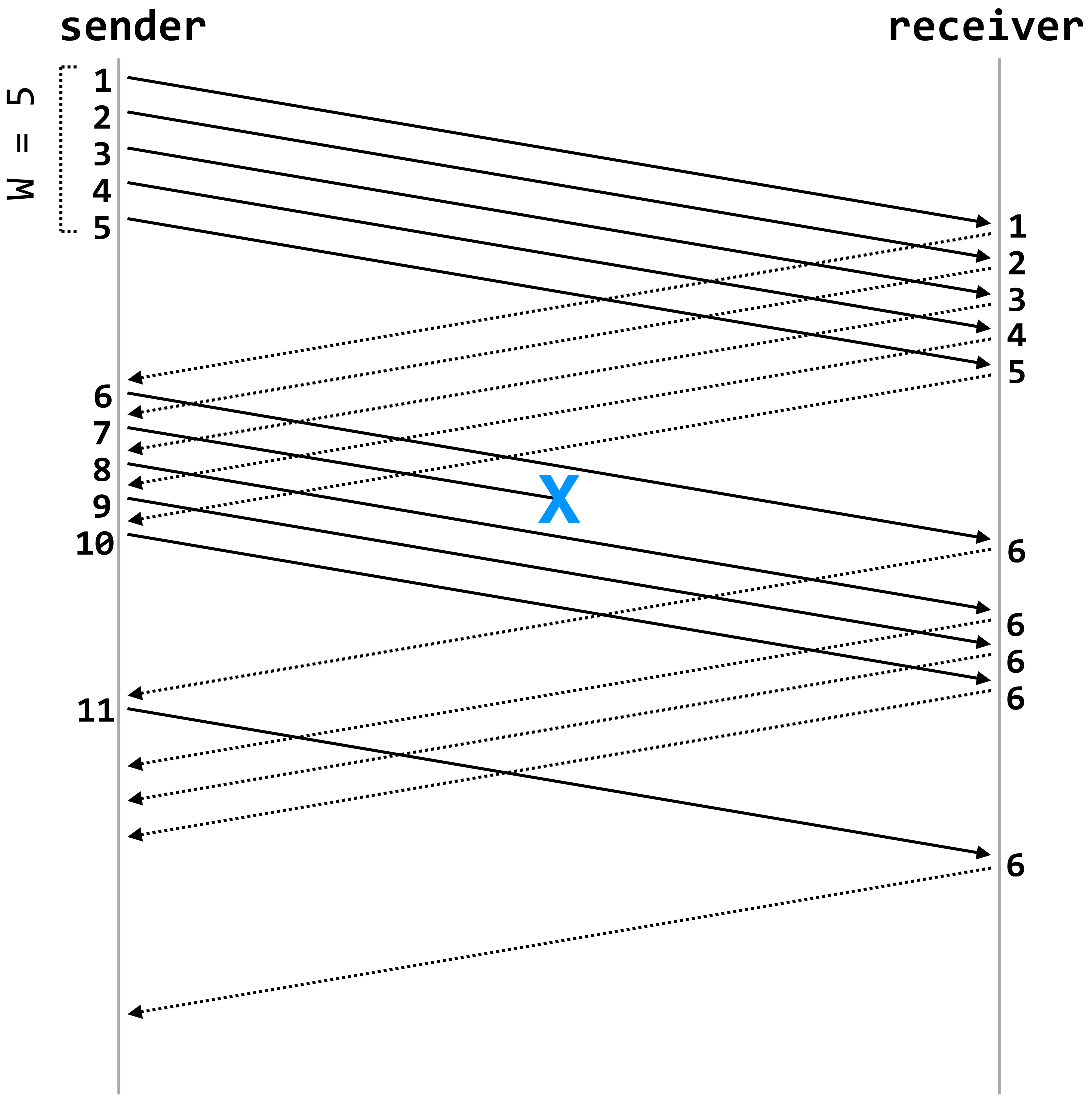

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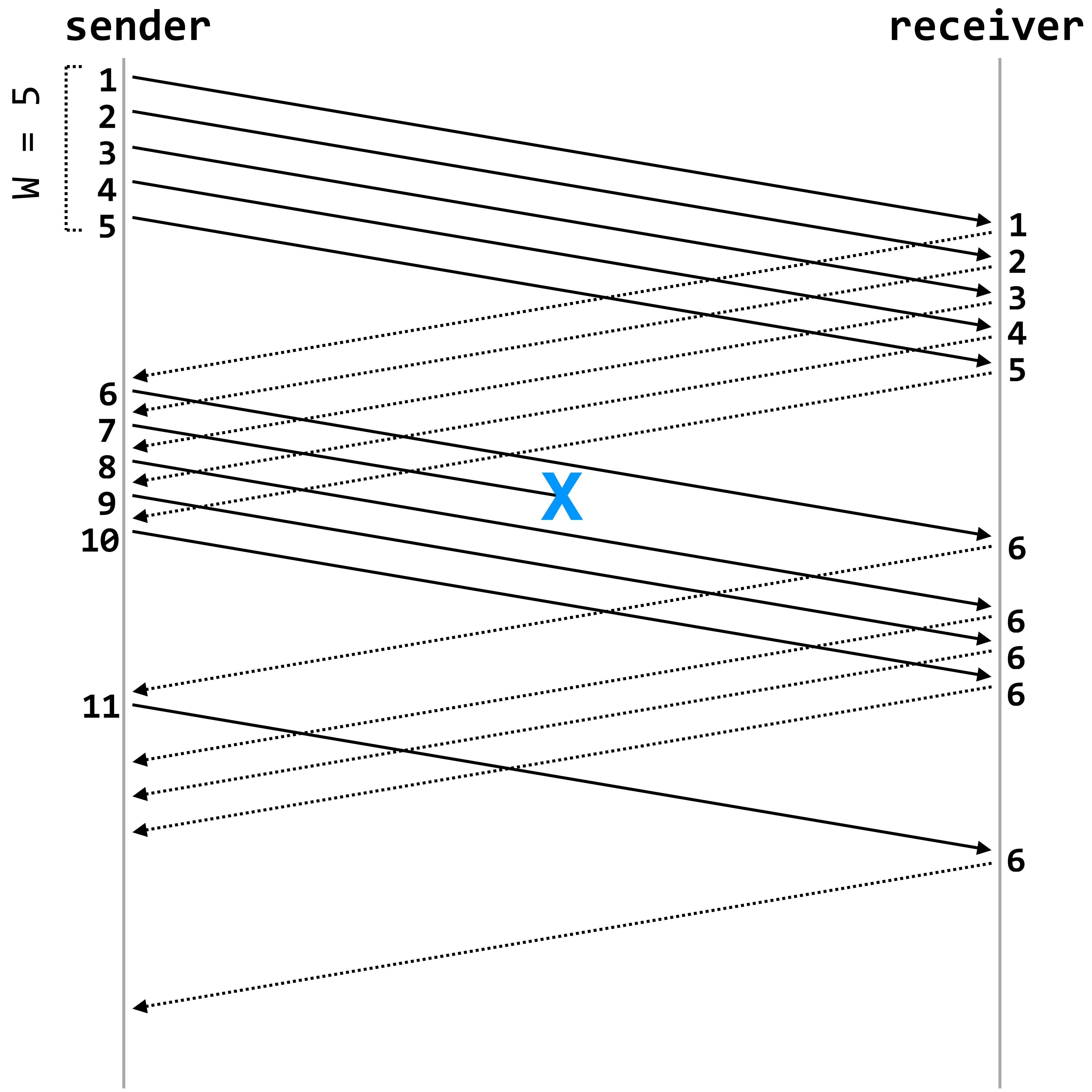

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question: can the sender infer that packet 7 has been lost?

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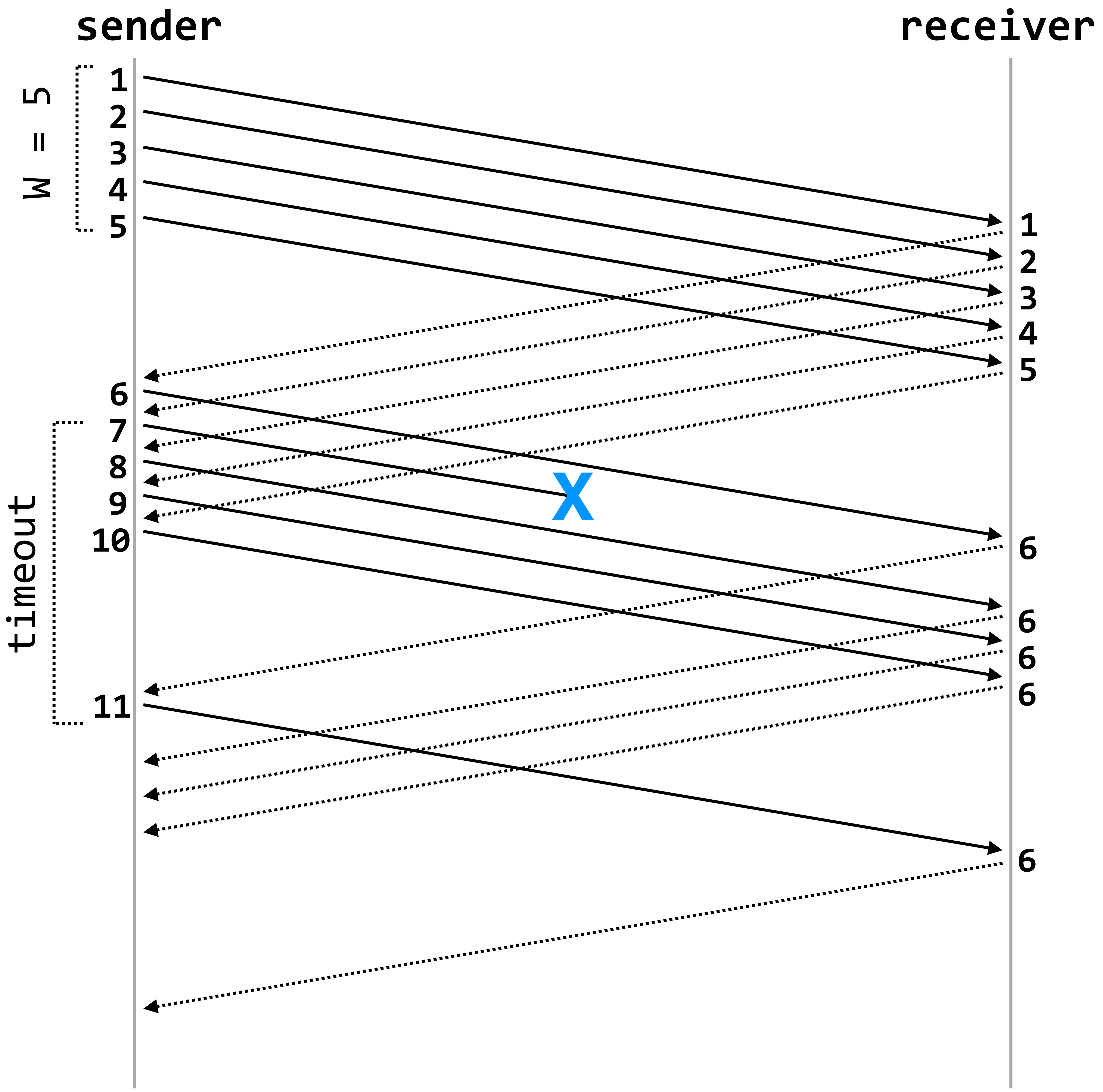

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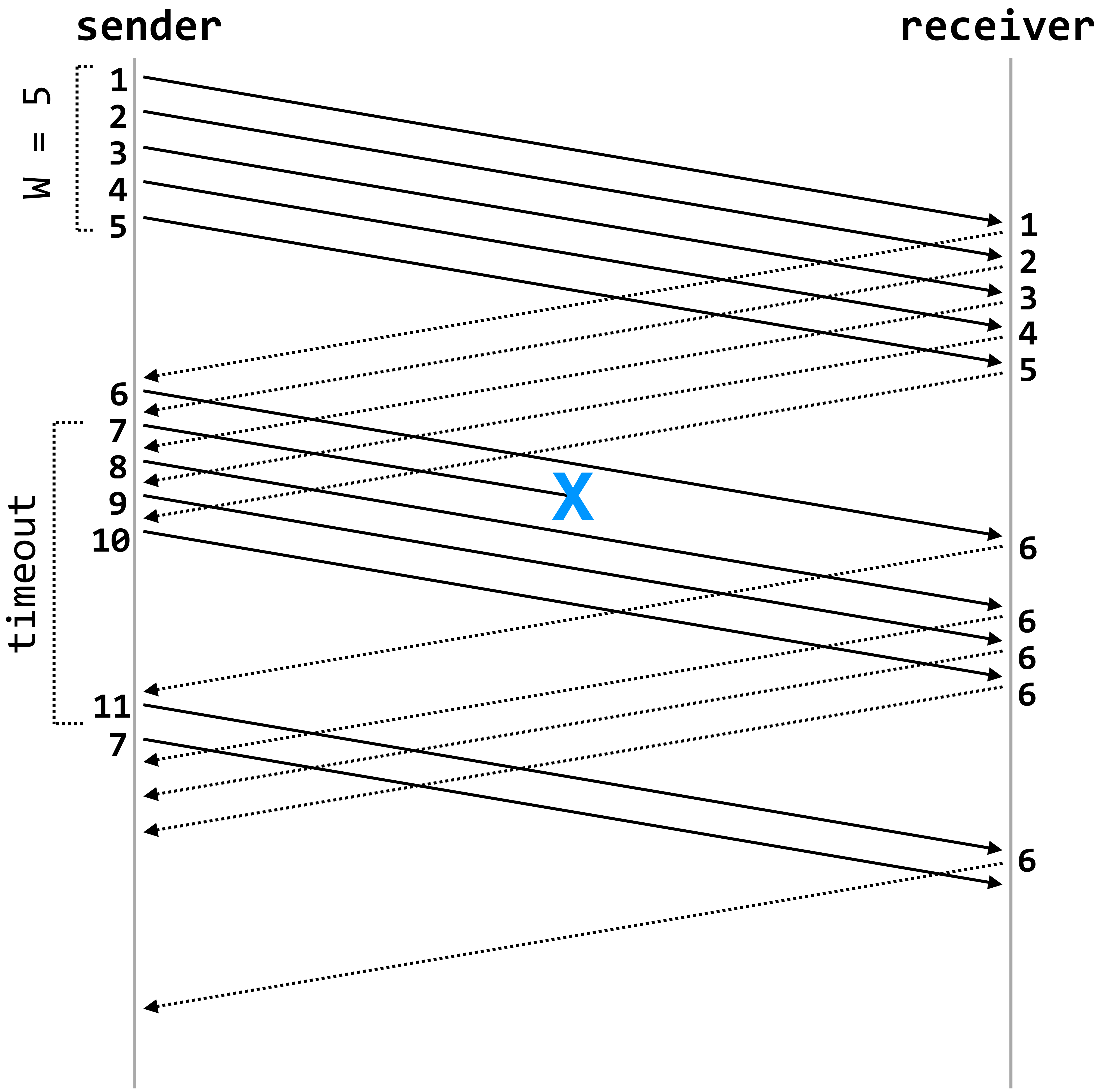

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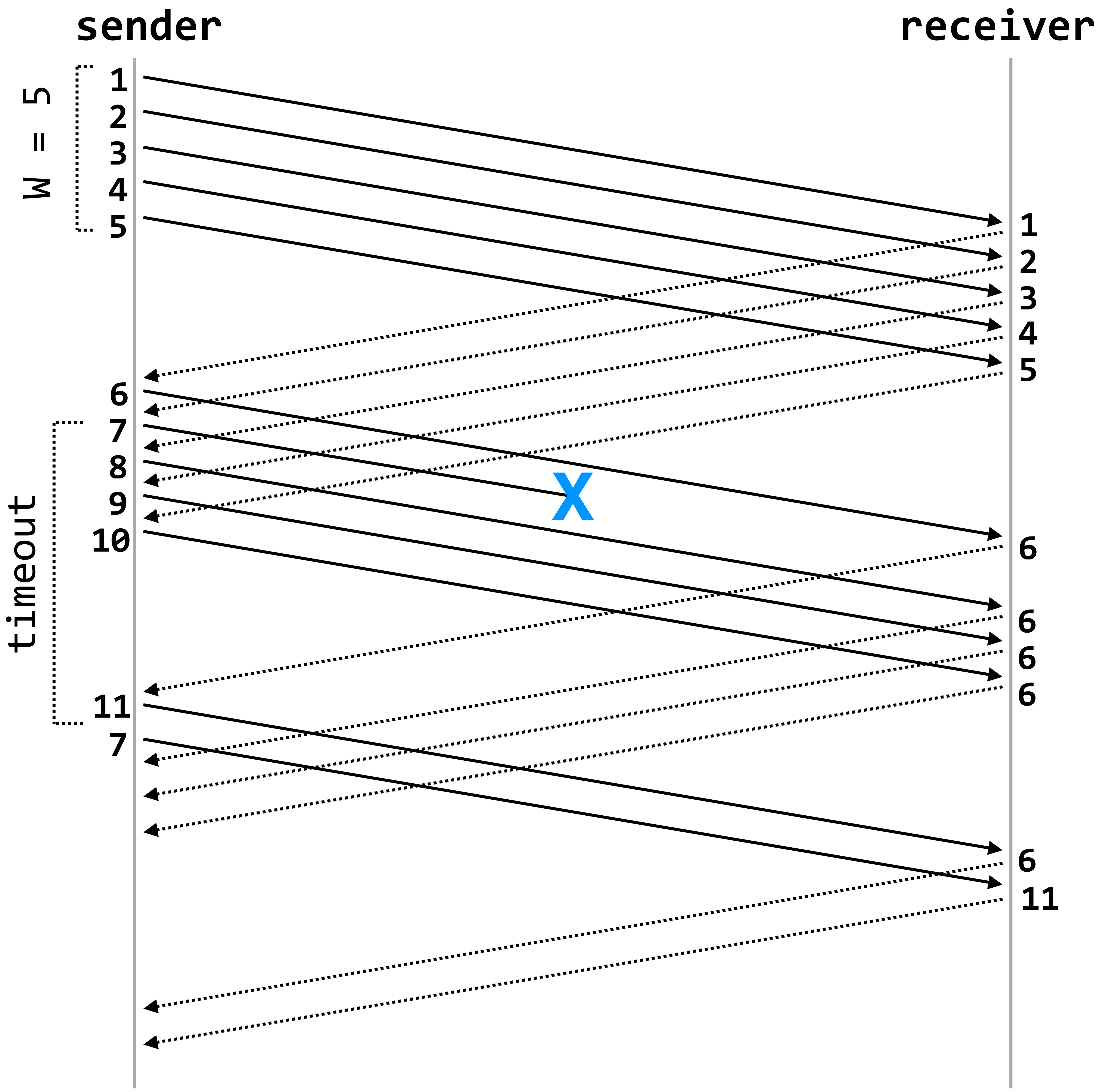

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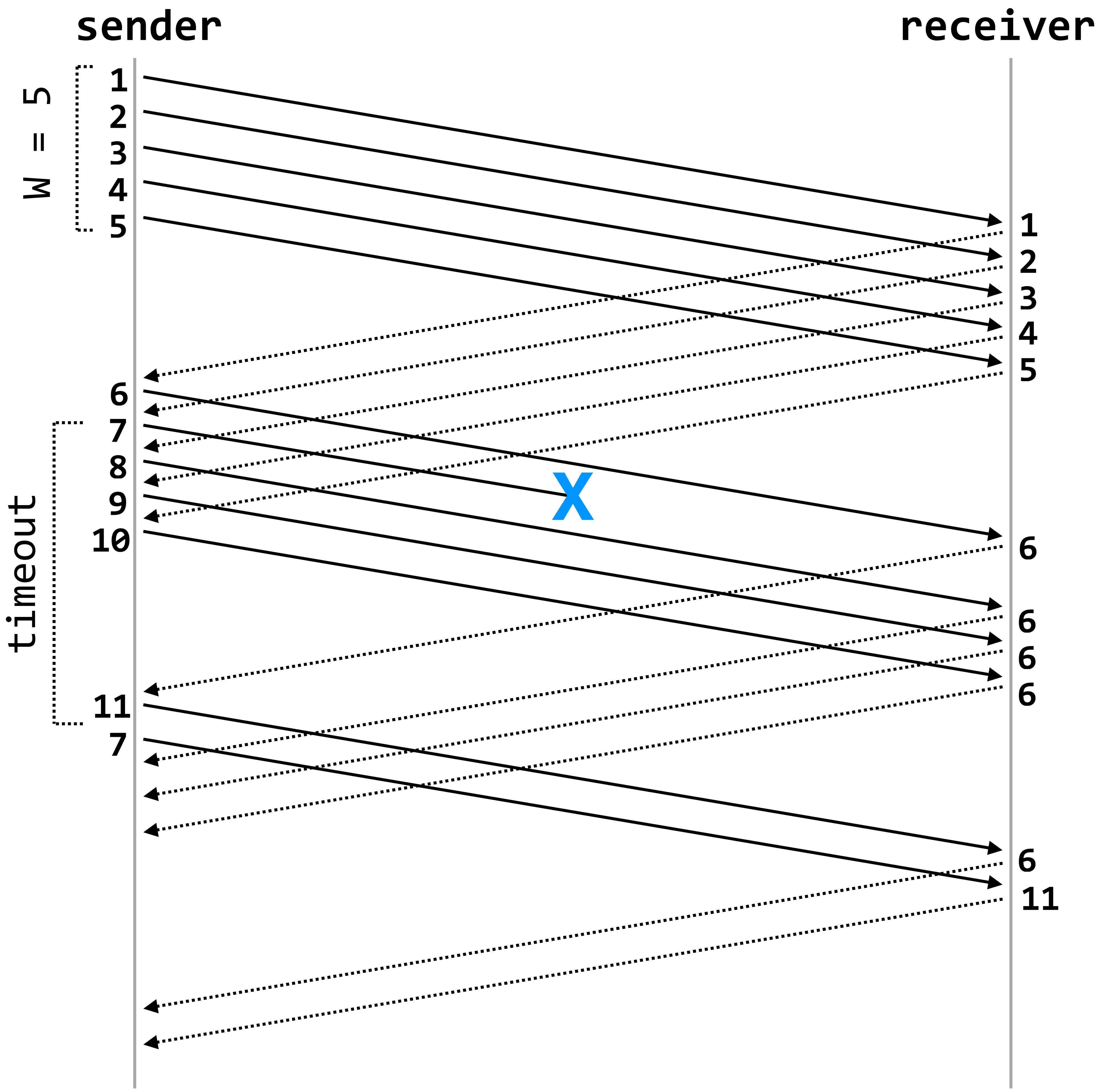

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note that the sender could also infer loss because it has received multiple ACKs with sequence number 6, but none with sequence number > 7; we'll come back to that

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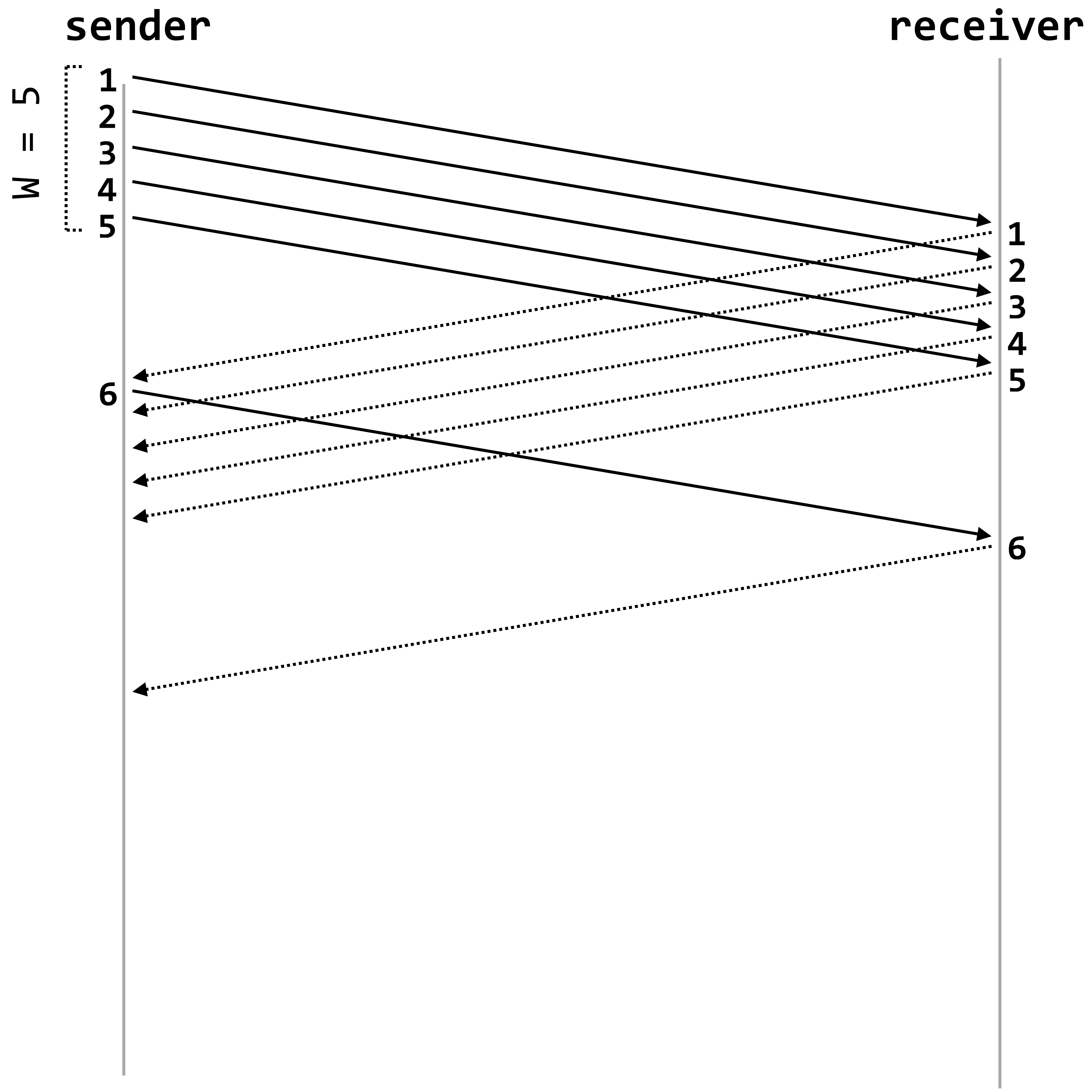

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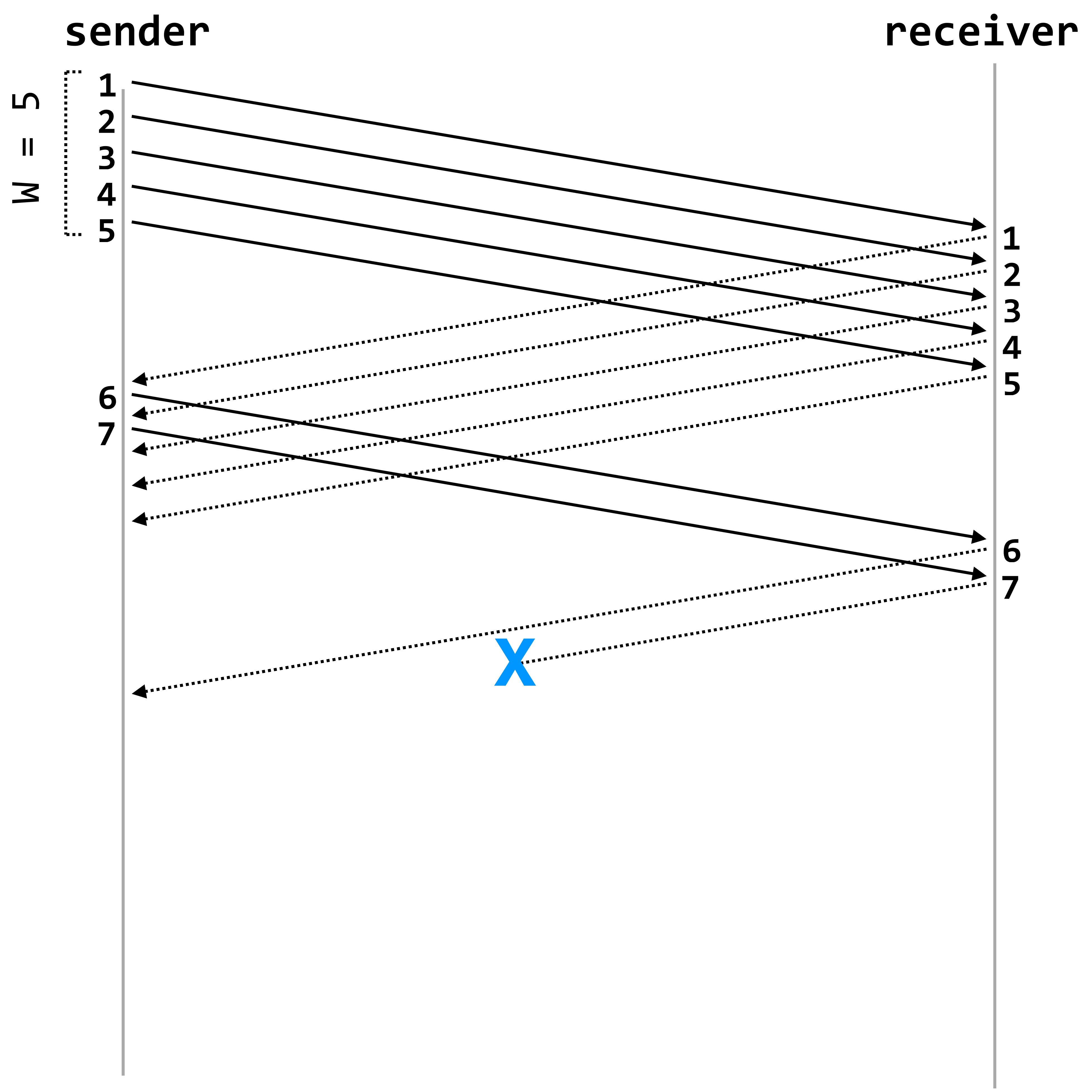

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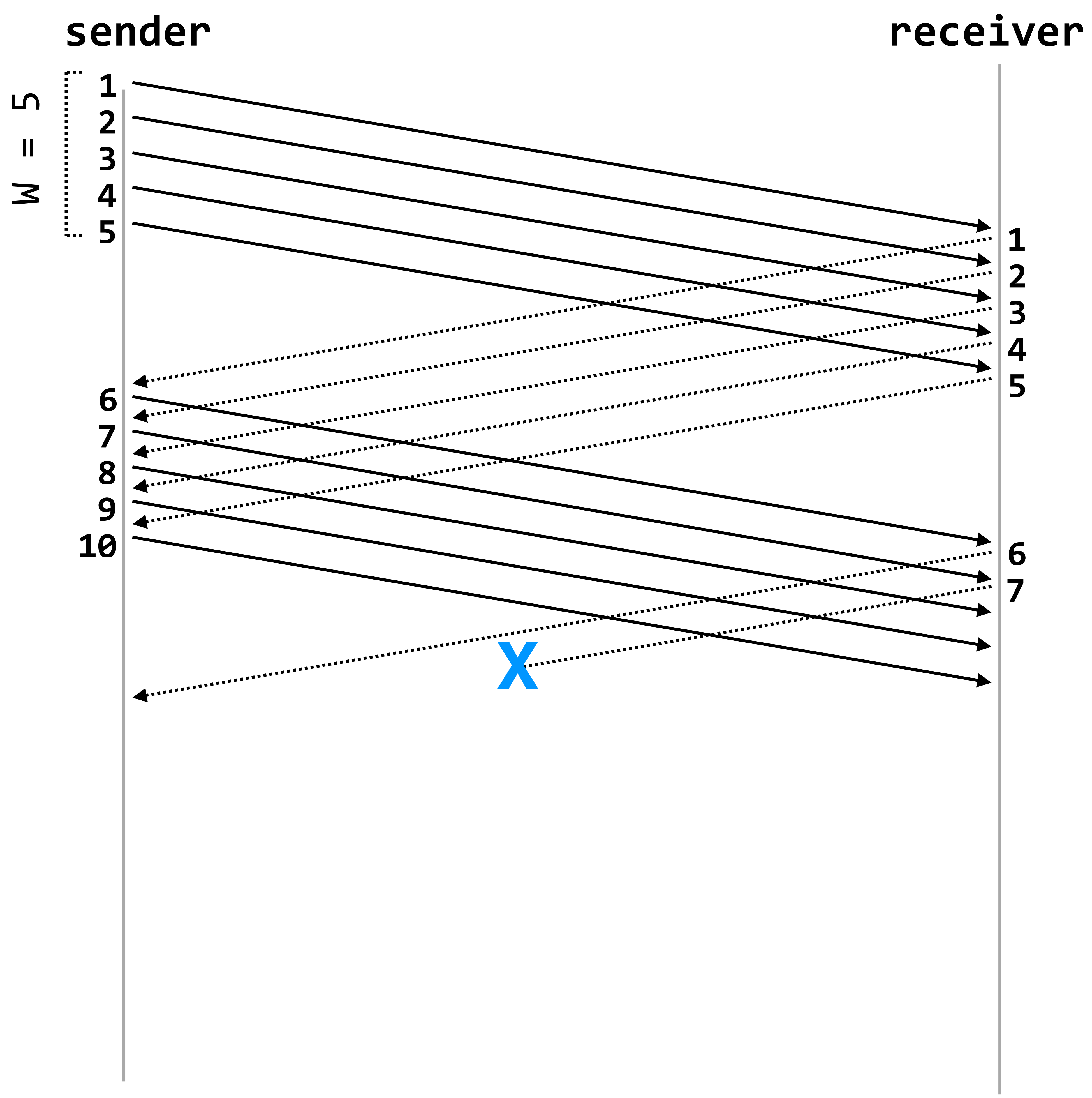

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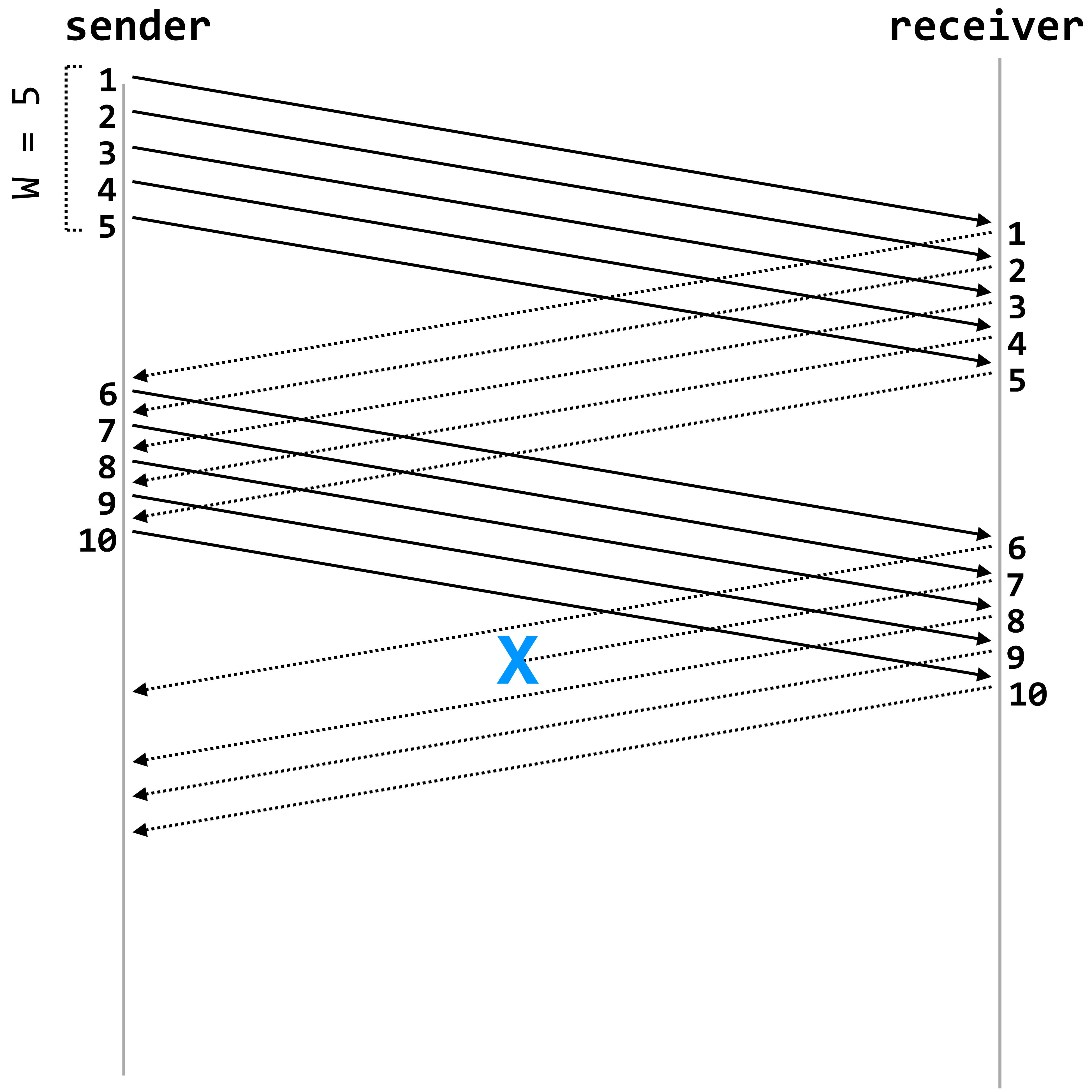

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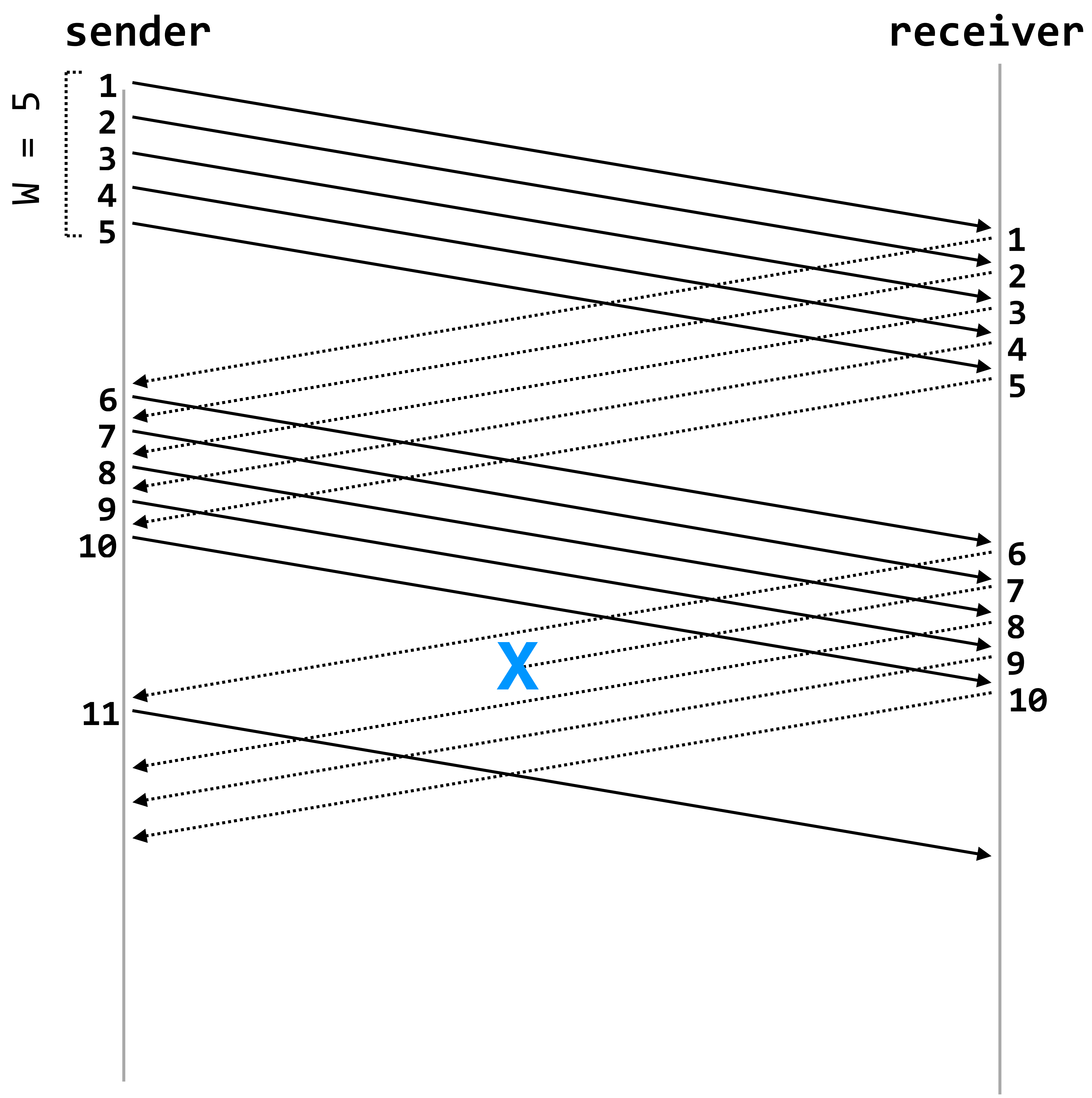

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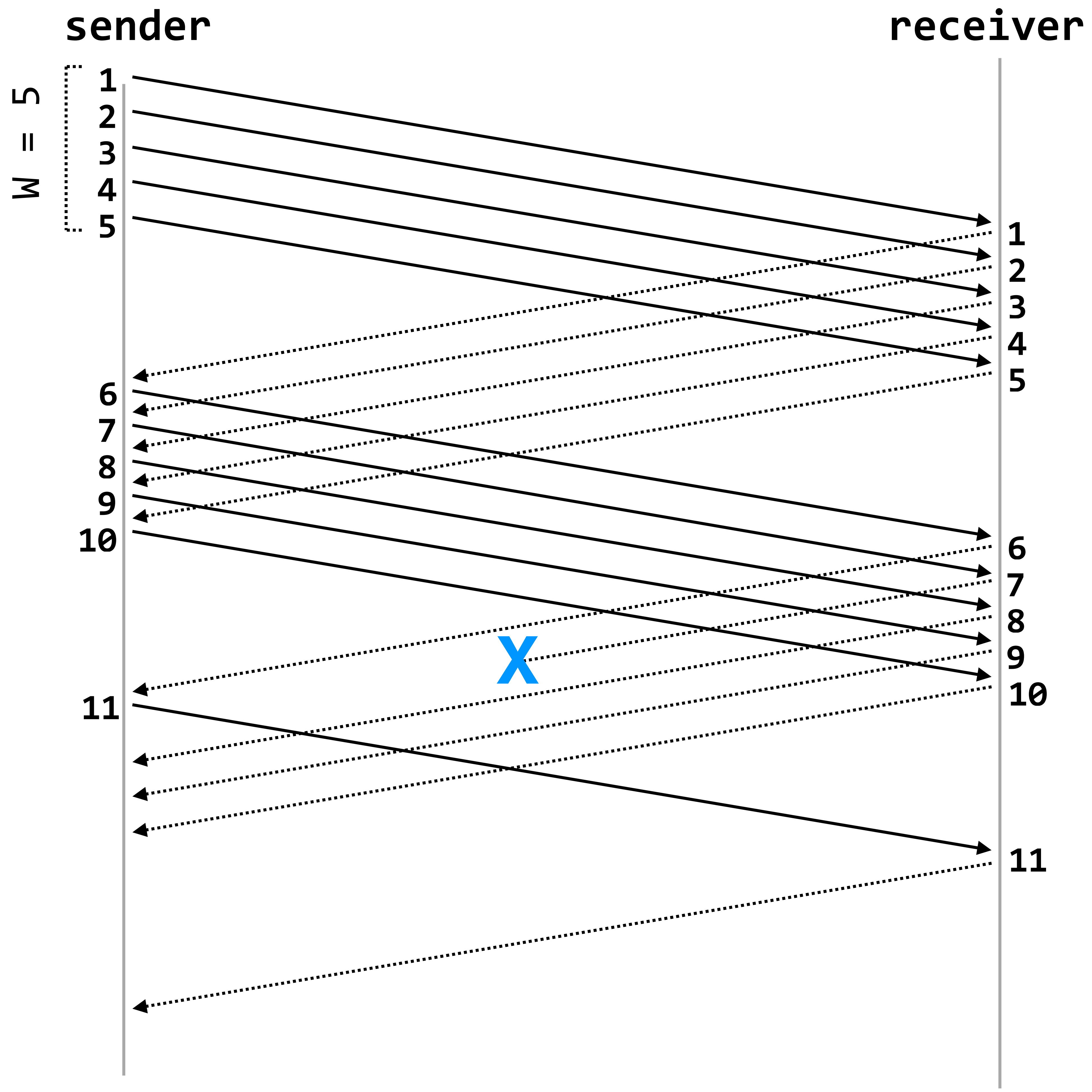

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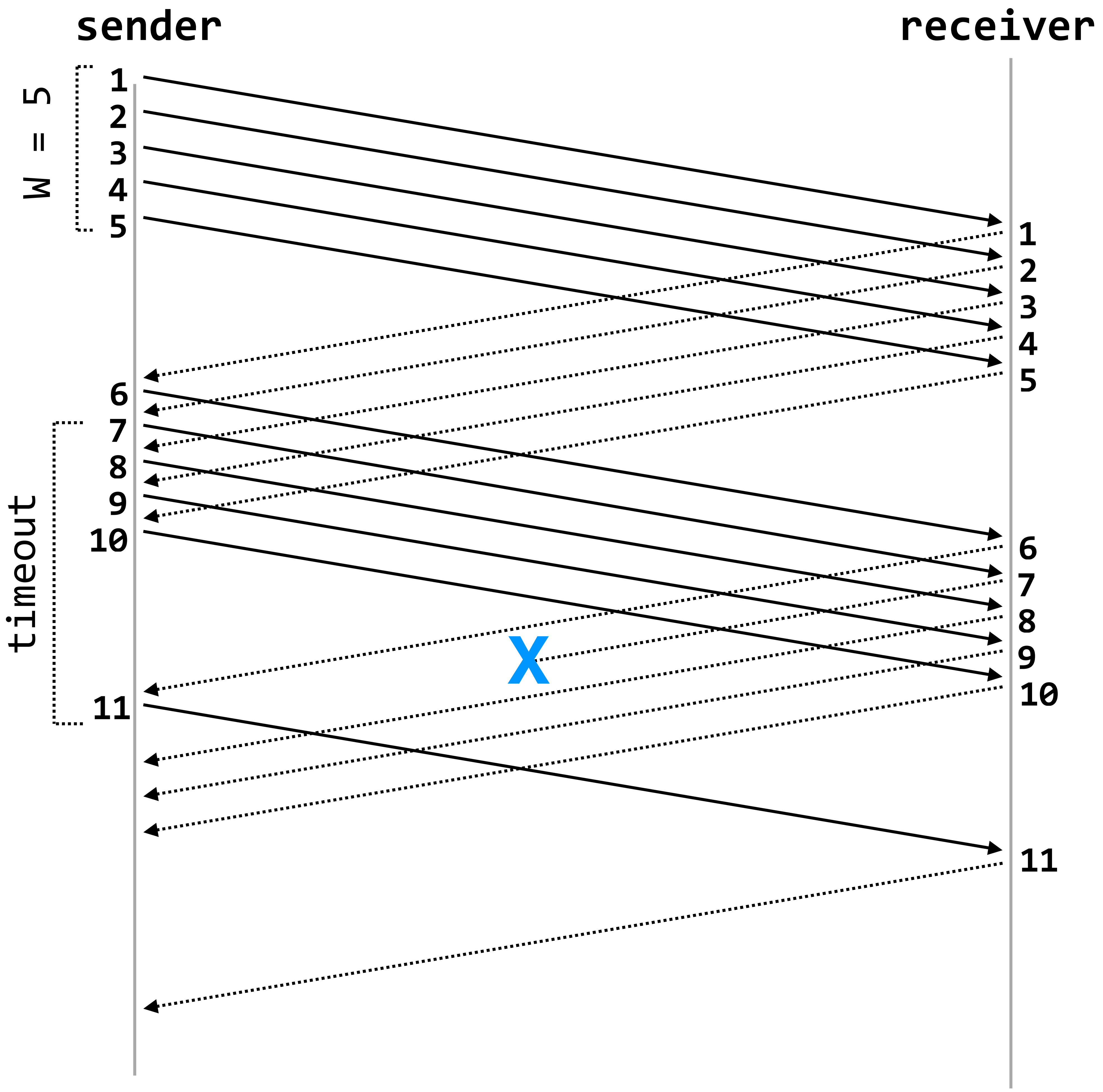

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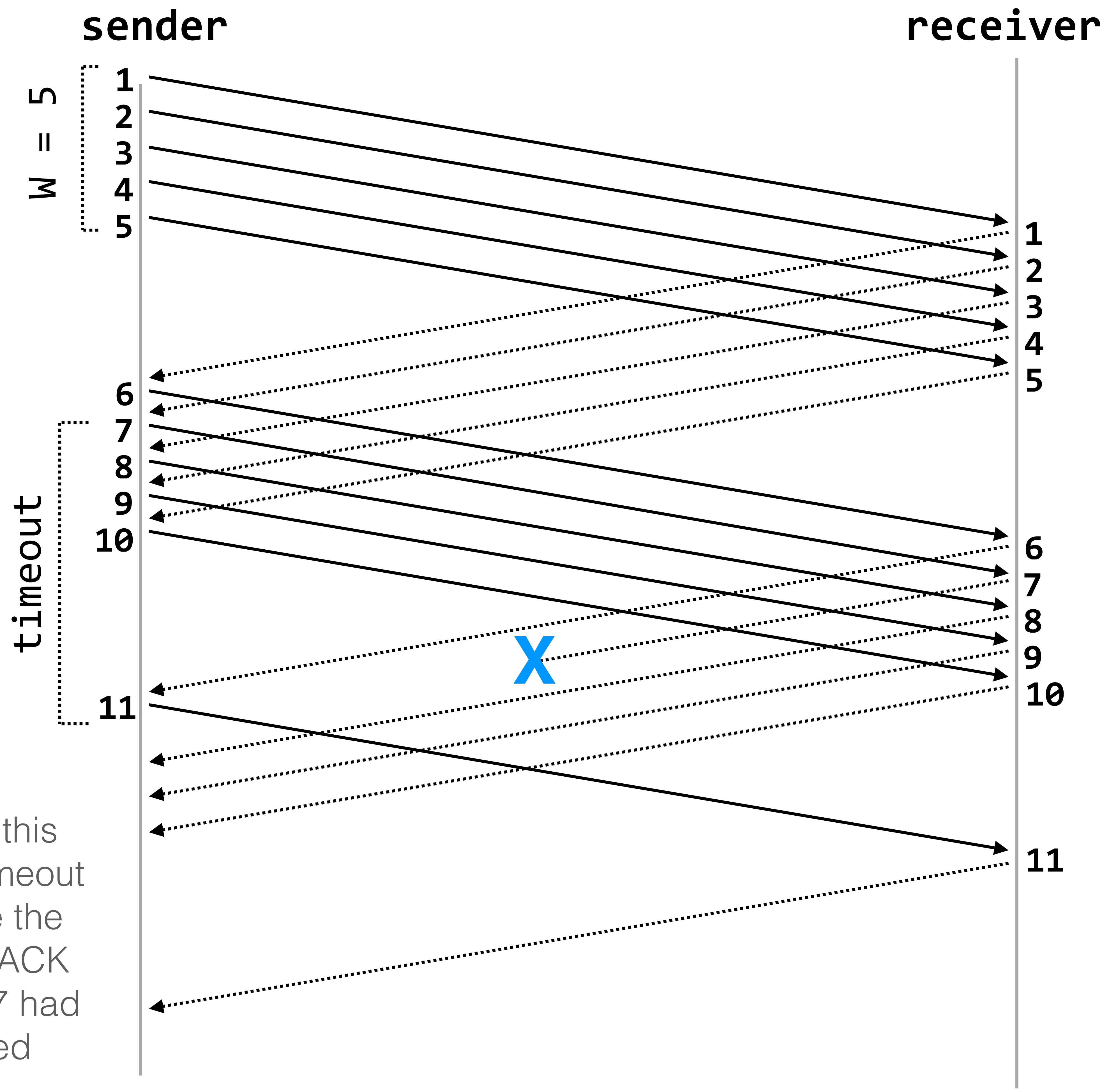

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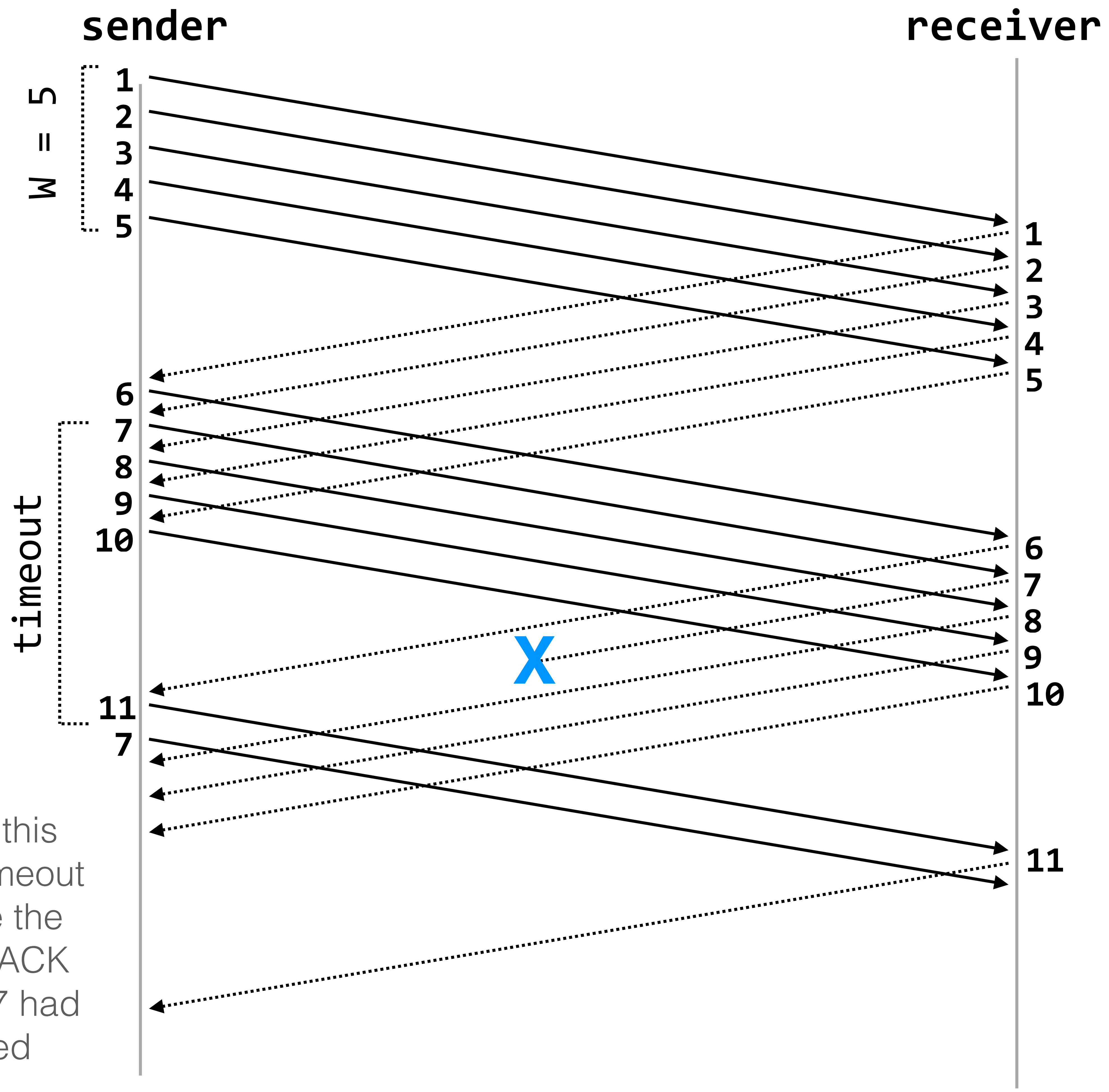

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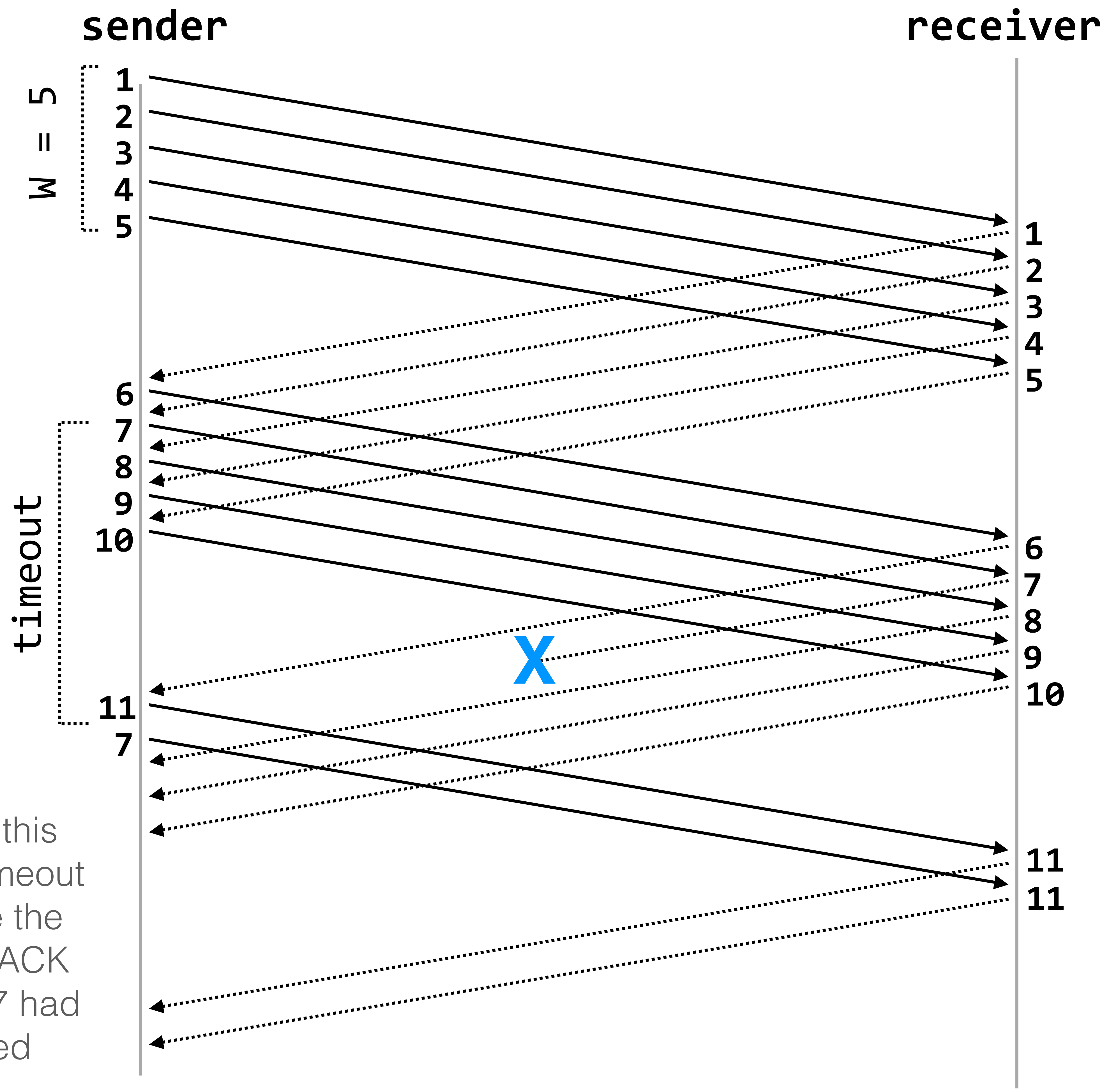

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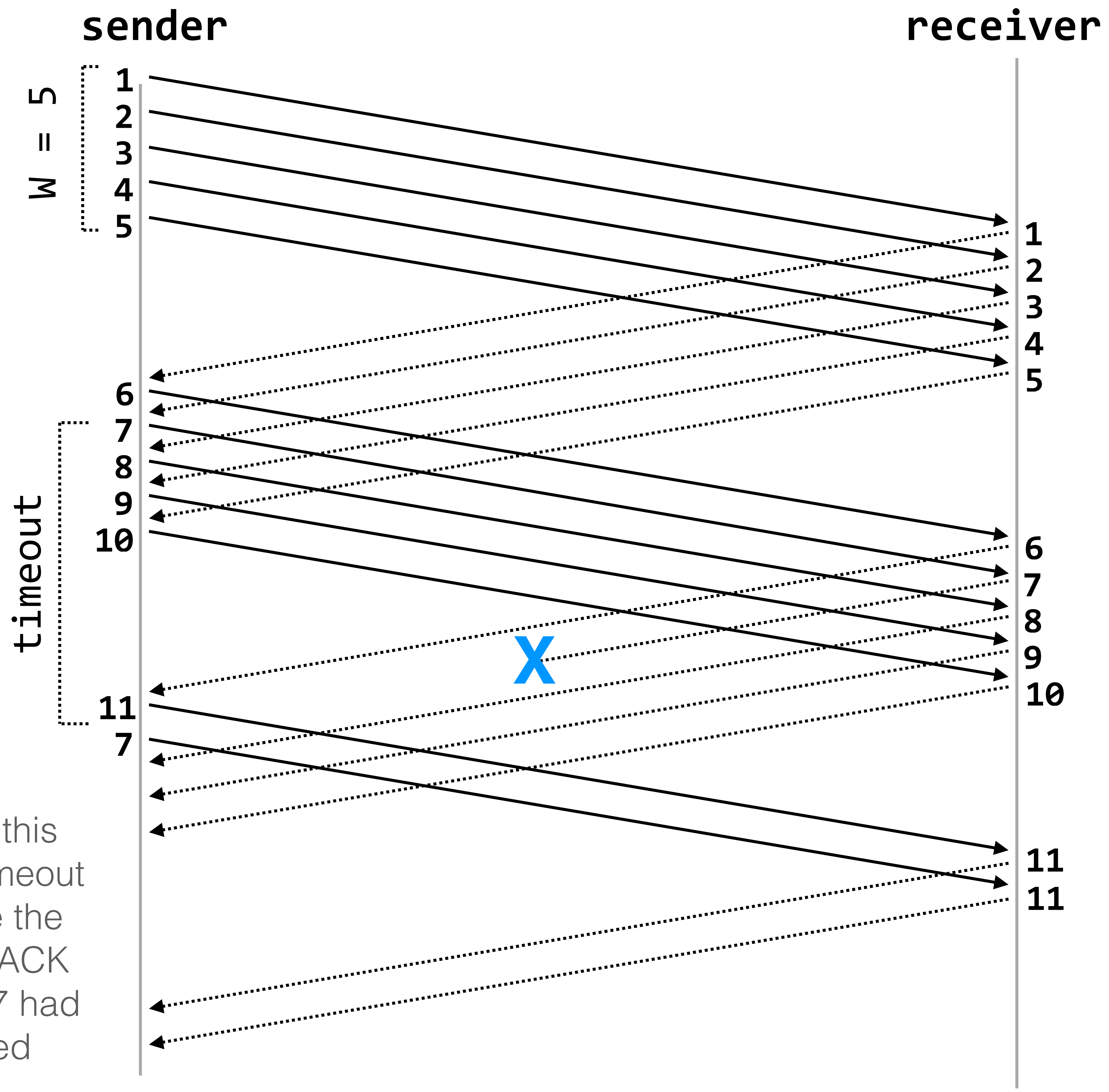

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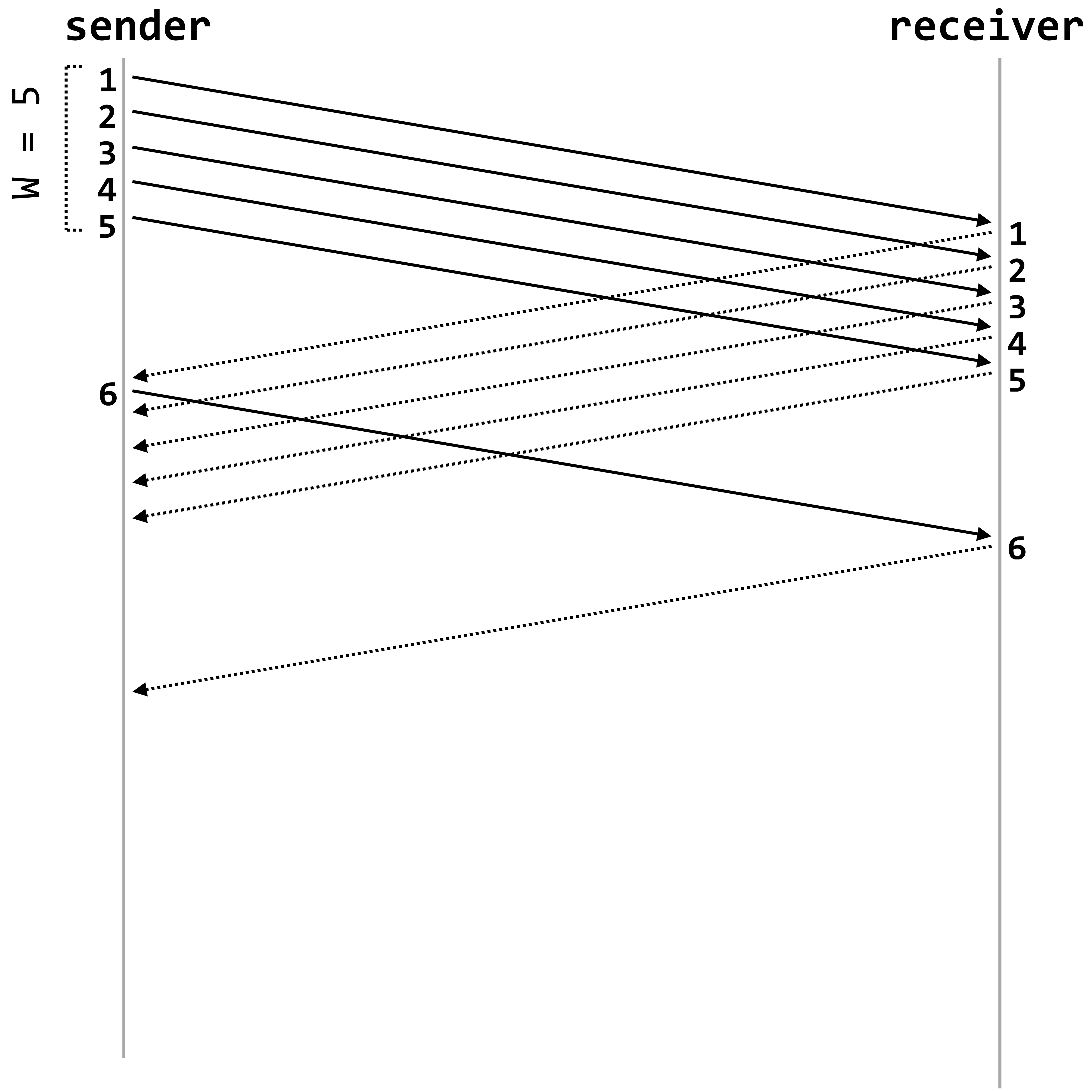

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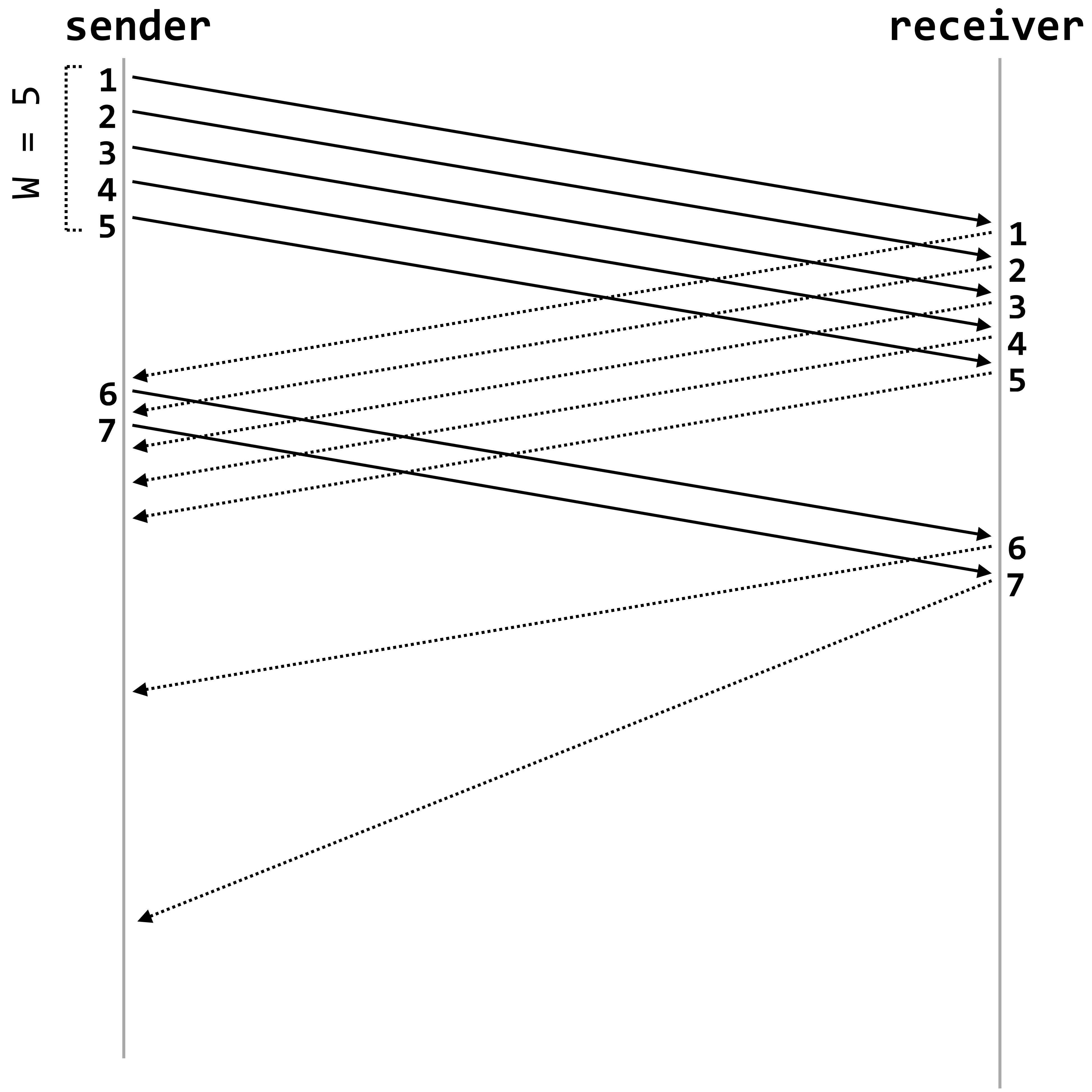

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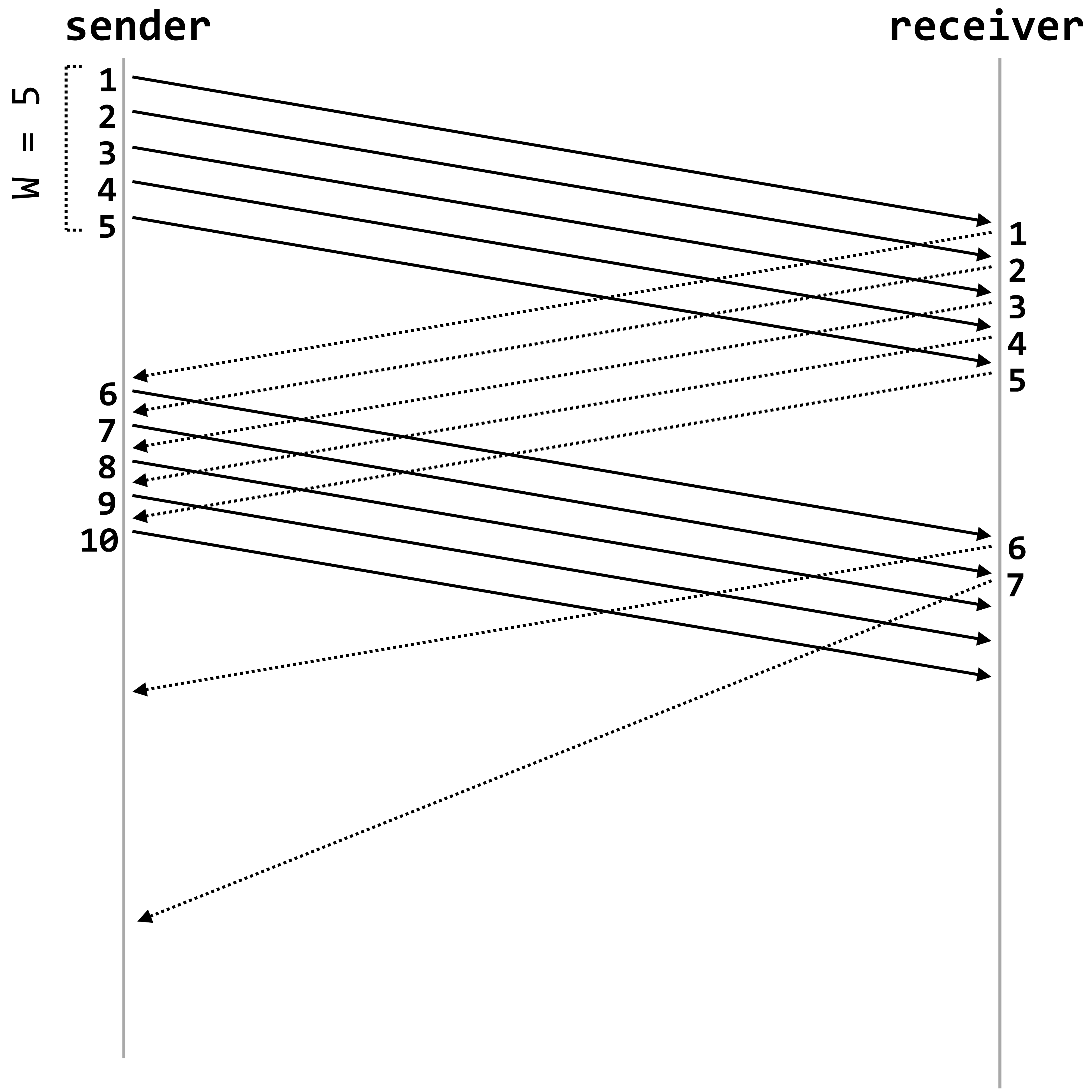

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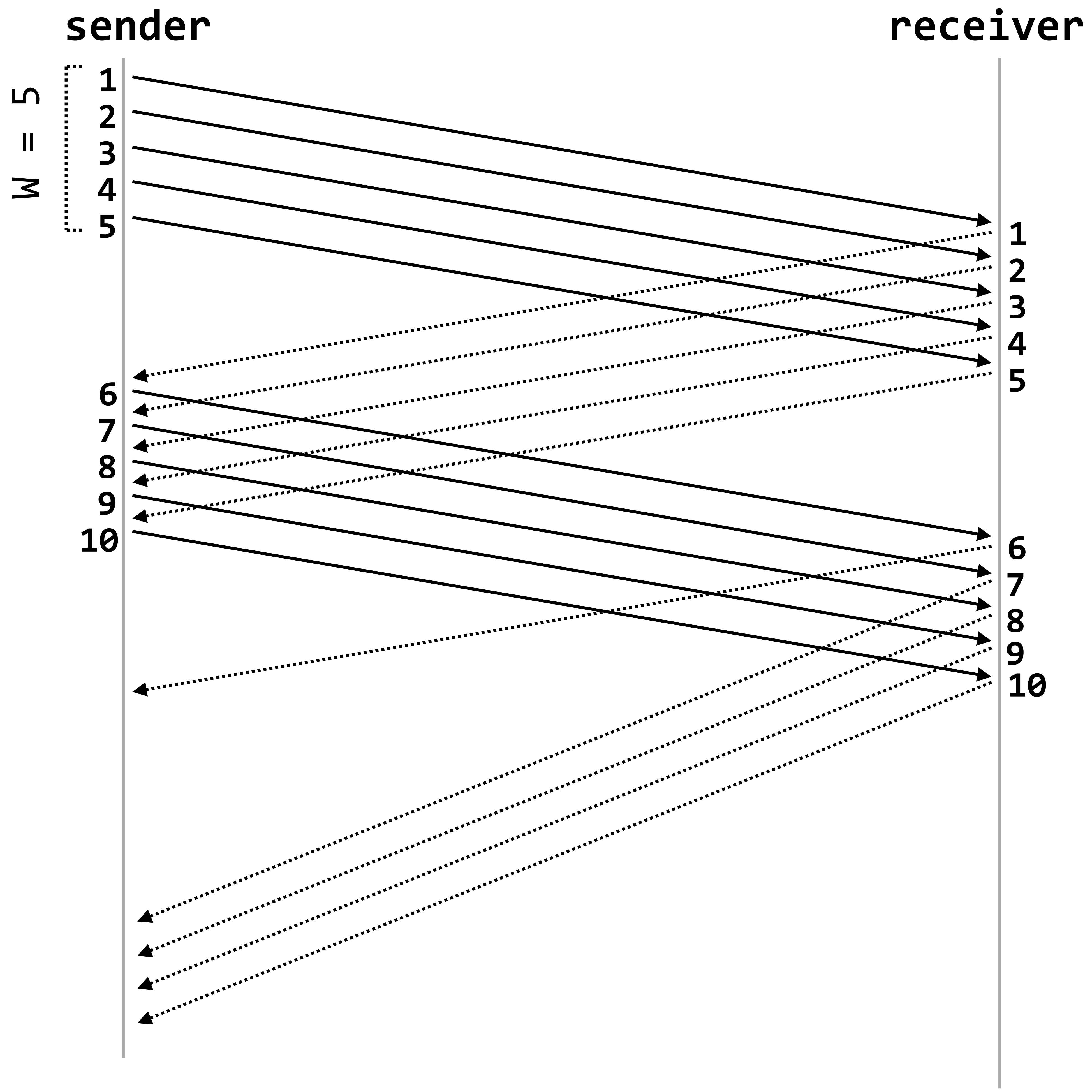

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Katrina LaCurts | lacurts@mit.edu | 6.1800 2024

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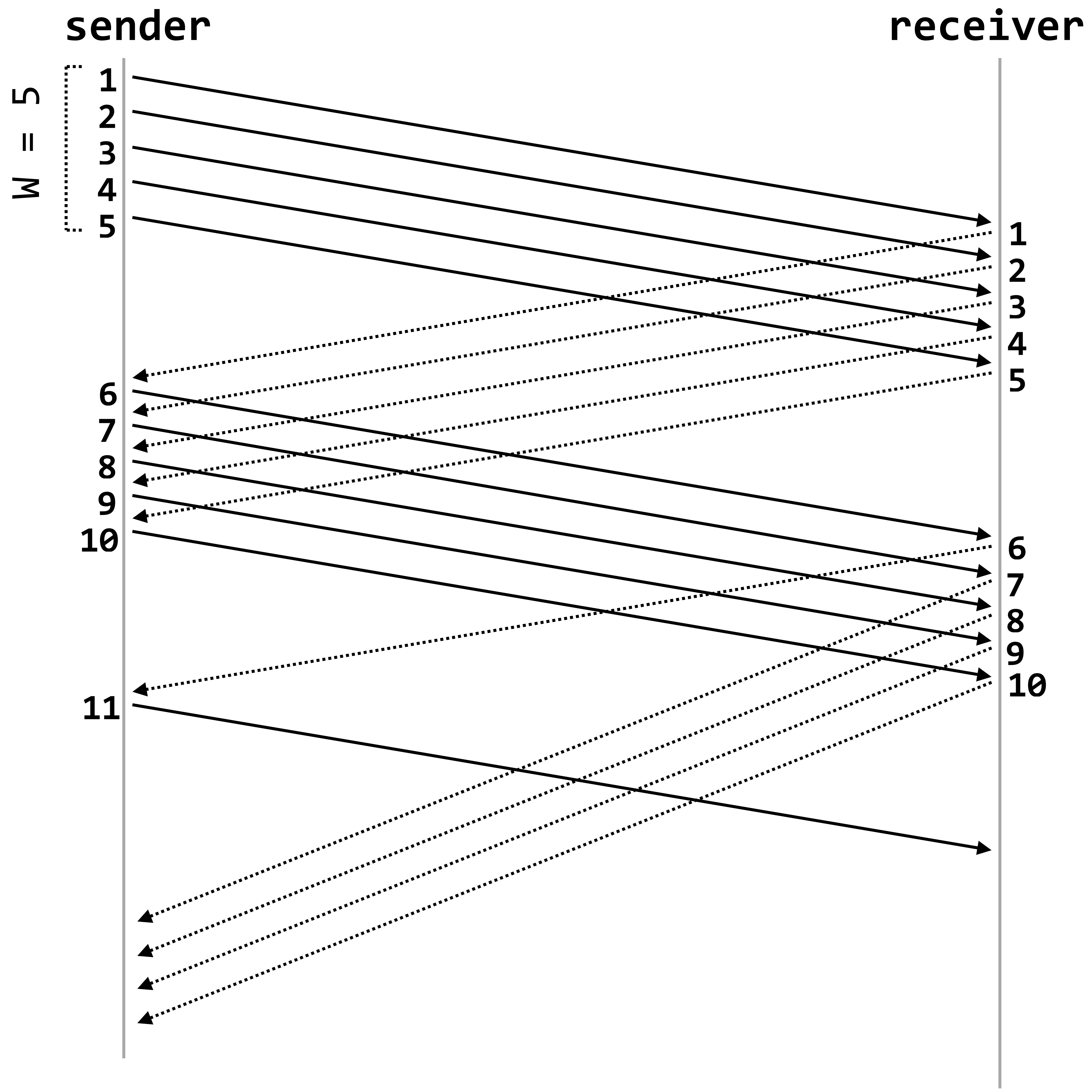

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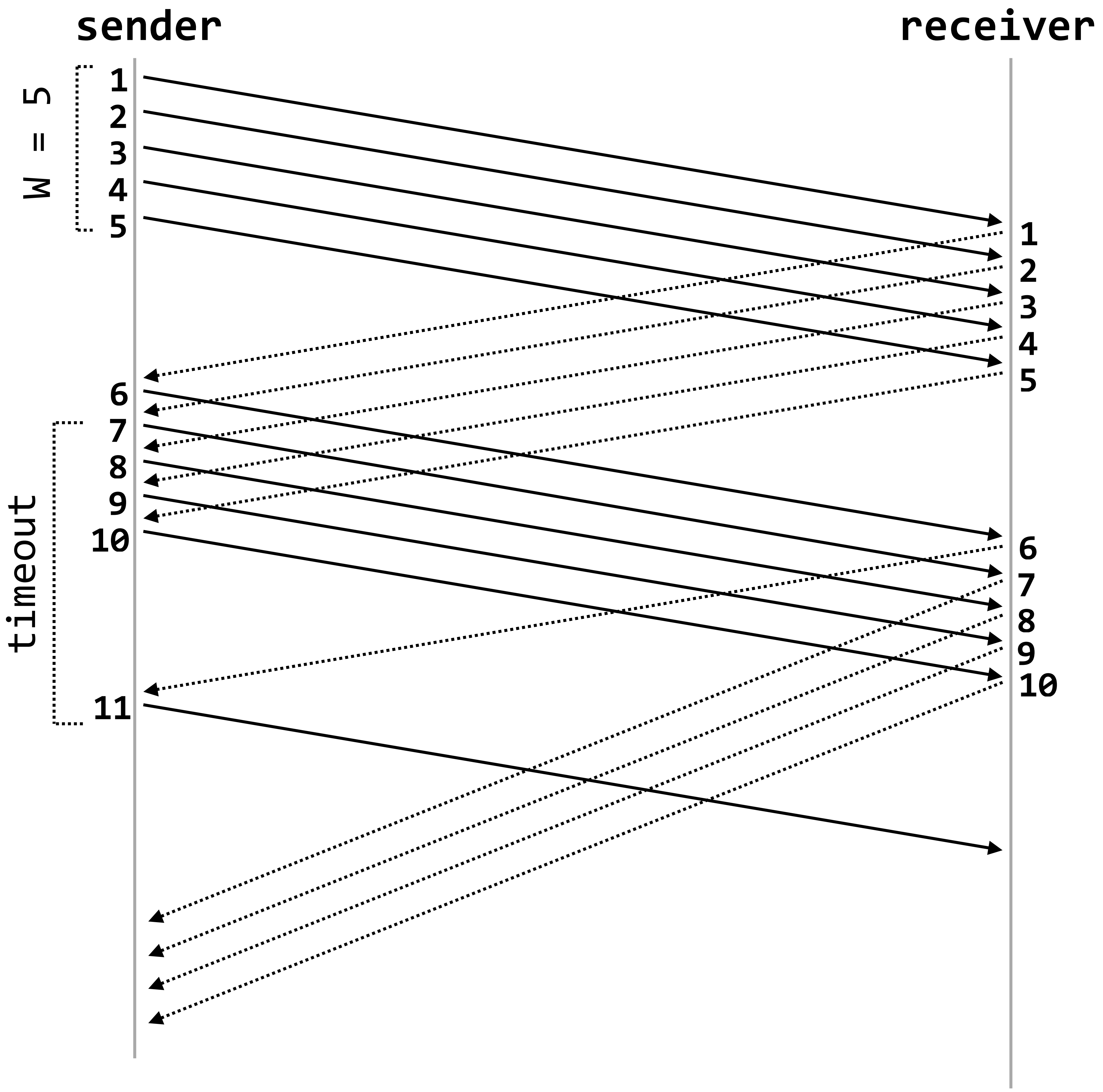

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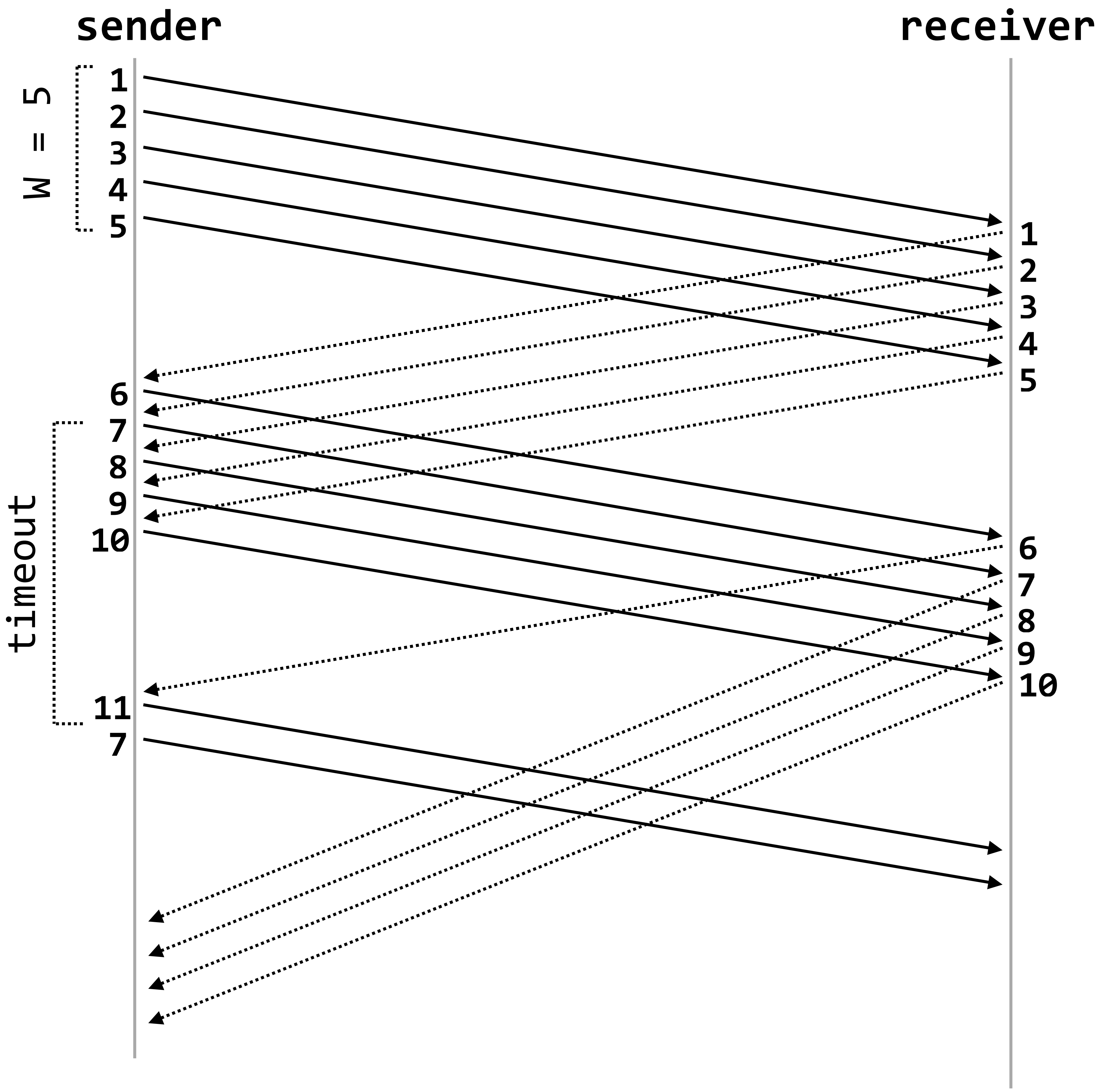

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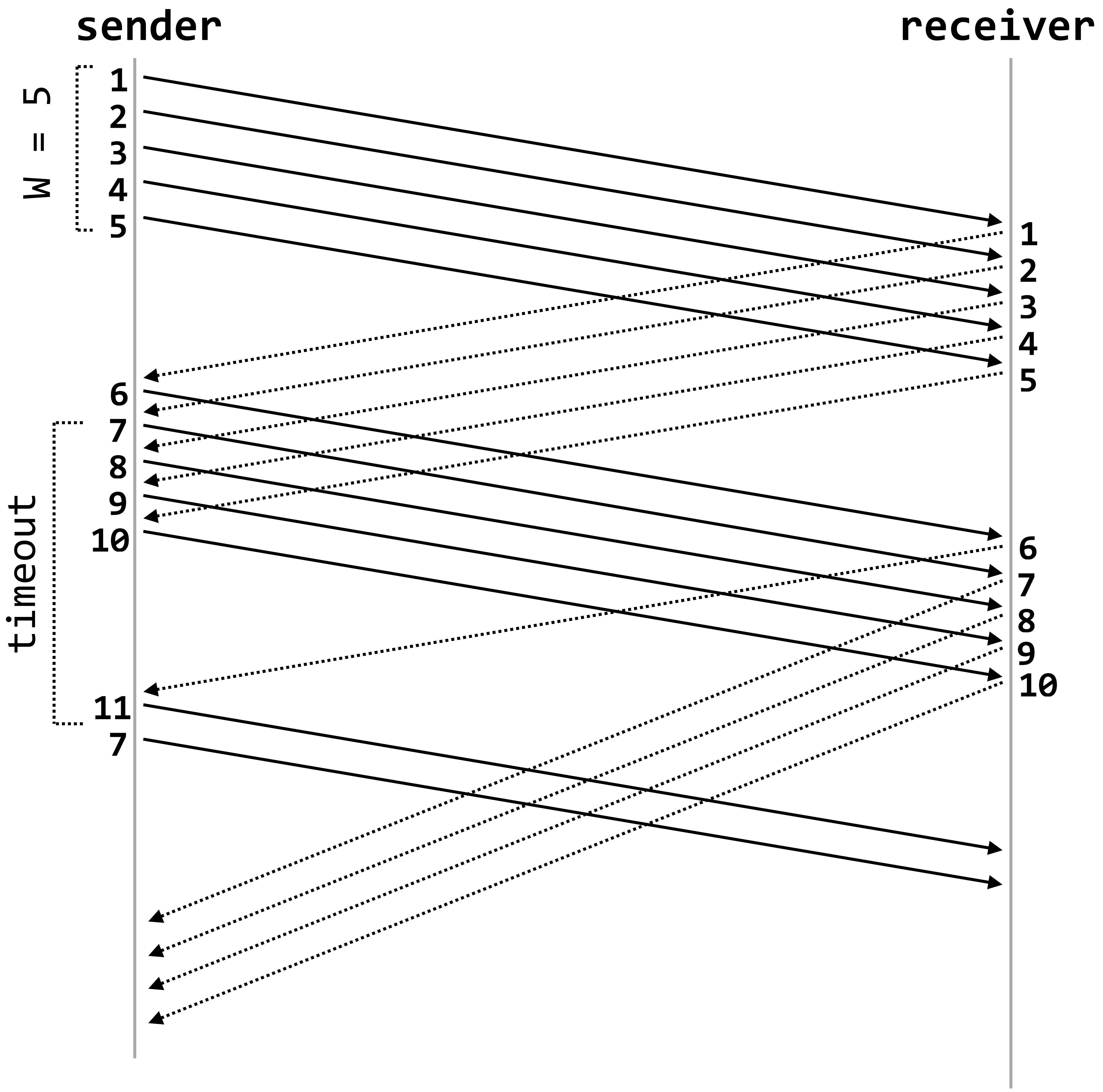

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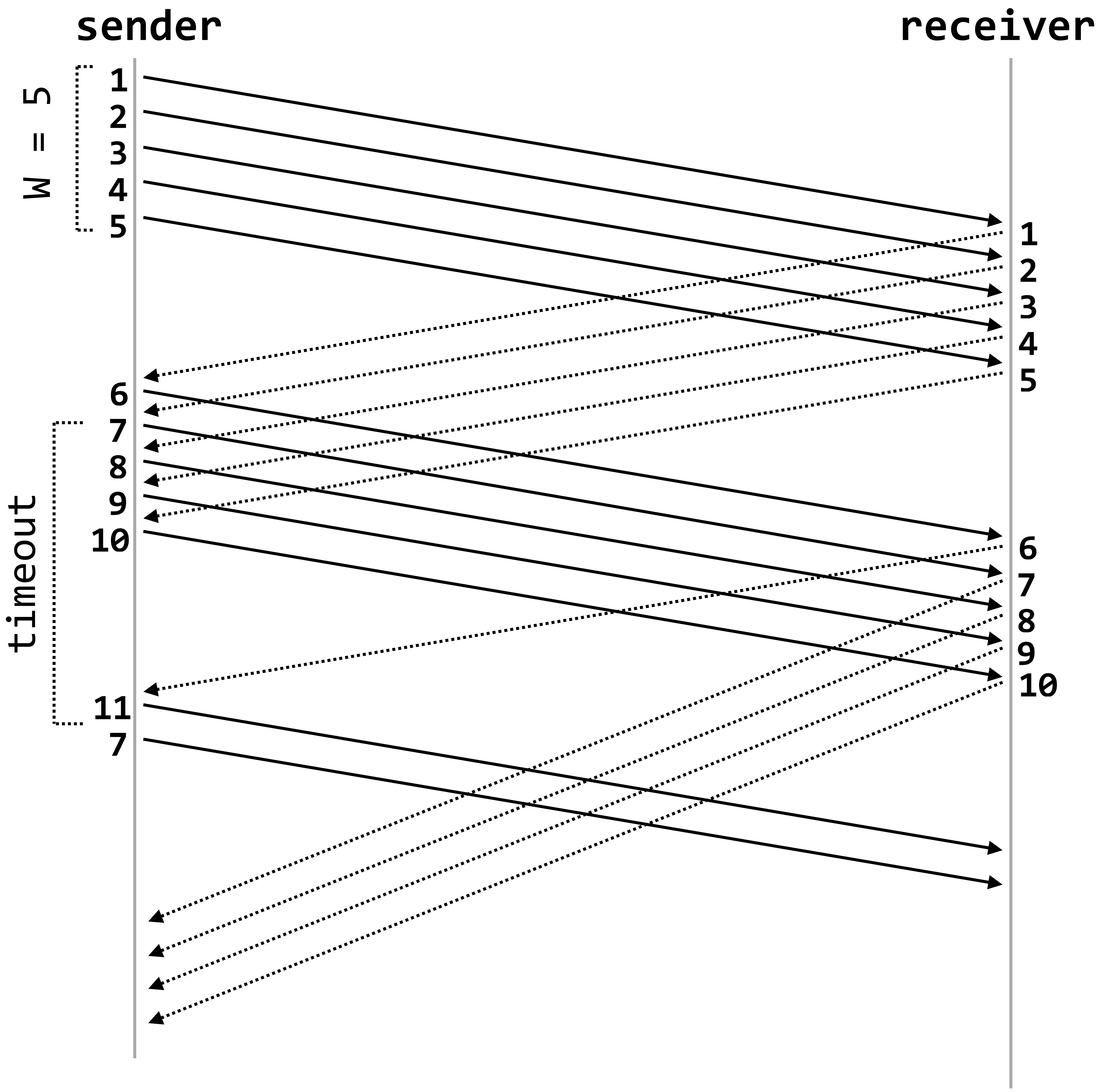

question: what should `W` be?

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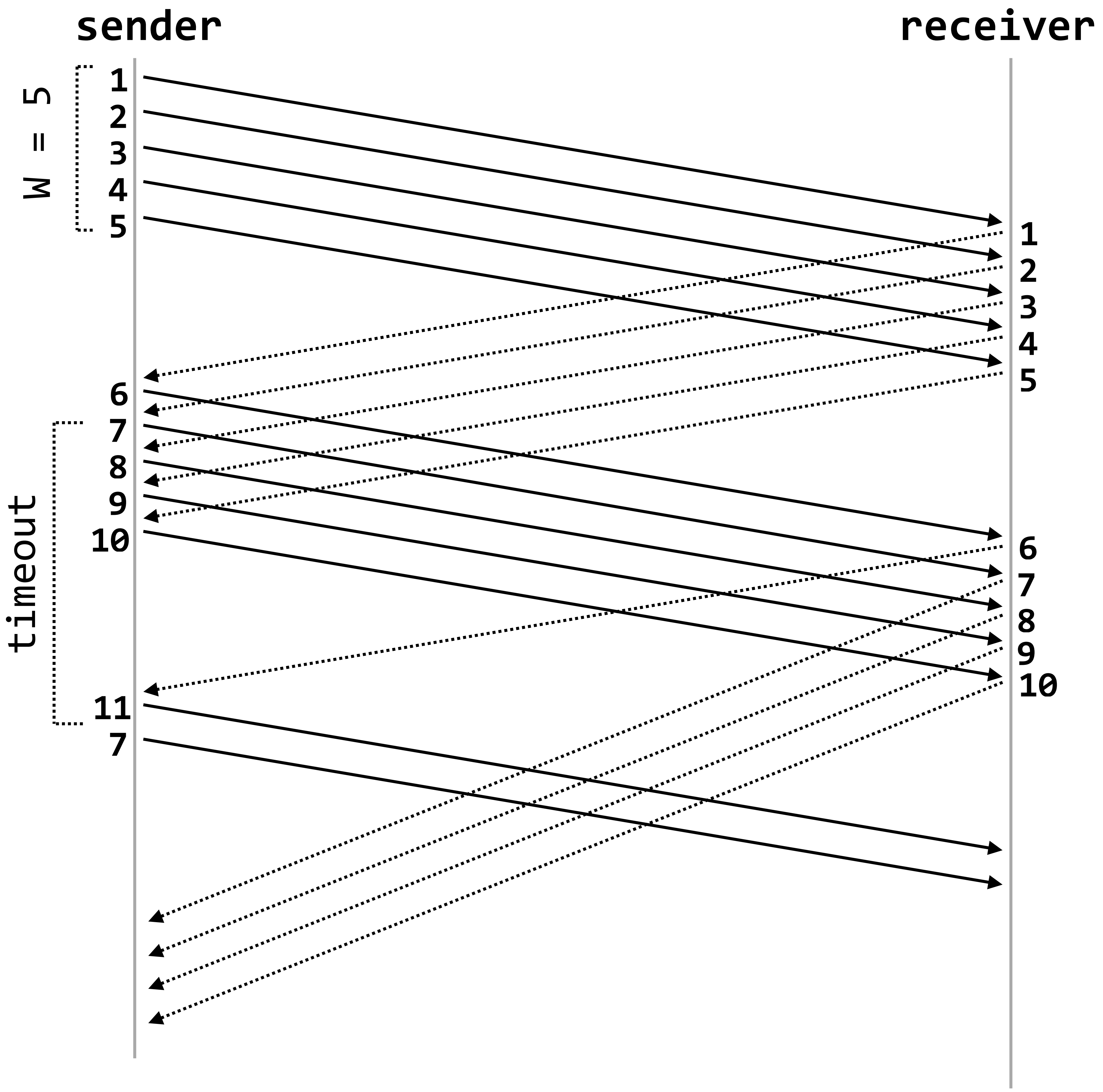

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how can a single reliable sender, using a sliding-window protocol, set its window size to **maximize utilization — but prevent congestion and unfairness** — given that there are many other end points using the network, all with different, changing demands?

congestion control: controlling the source rates to achieve **efficiency** and **fairness**

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efficiency: minimize drops, minimize delay, maximize bottleneck utilization

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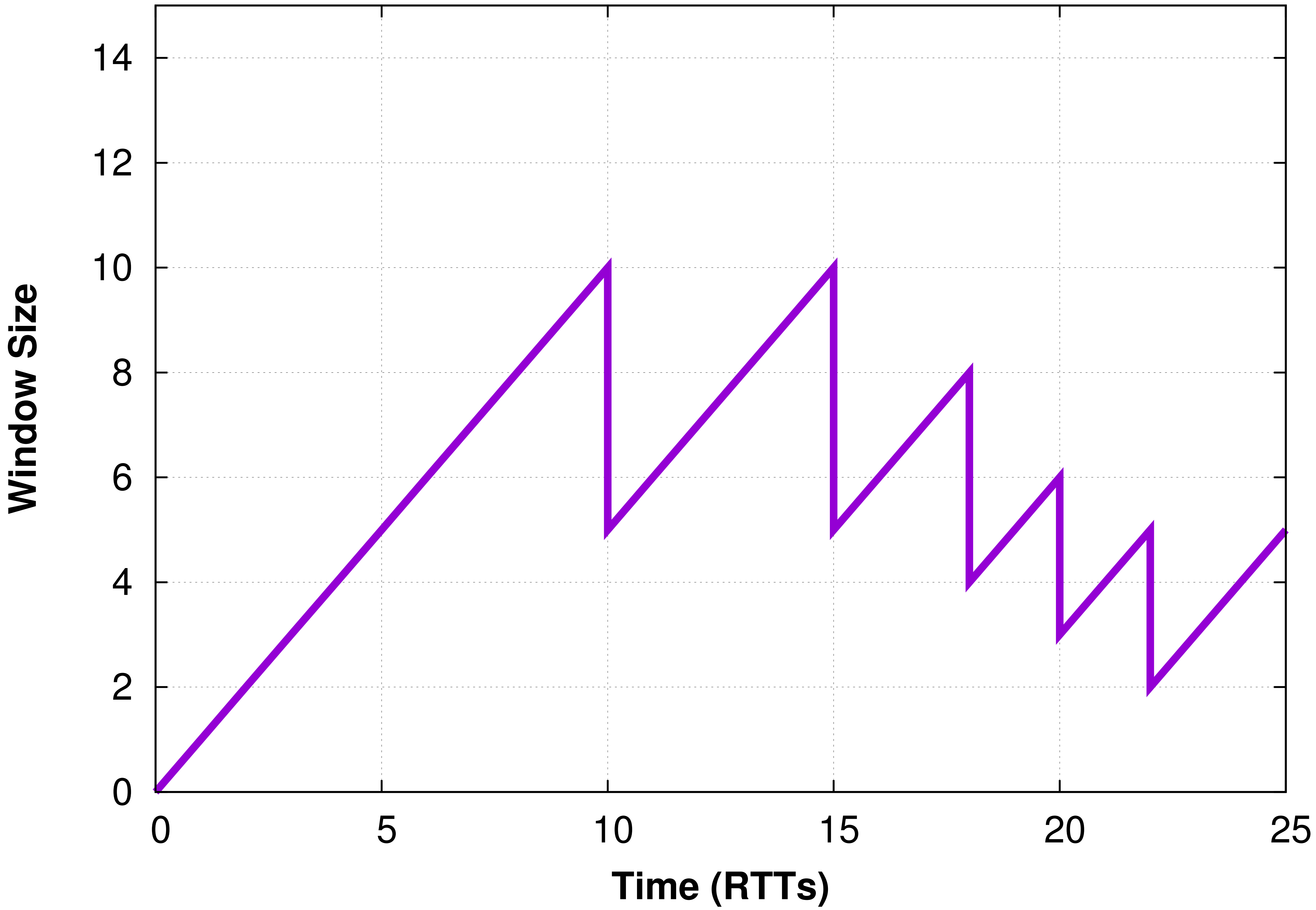

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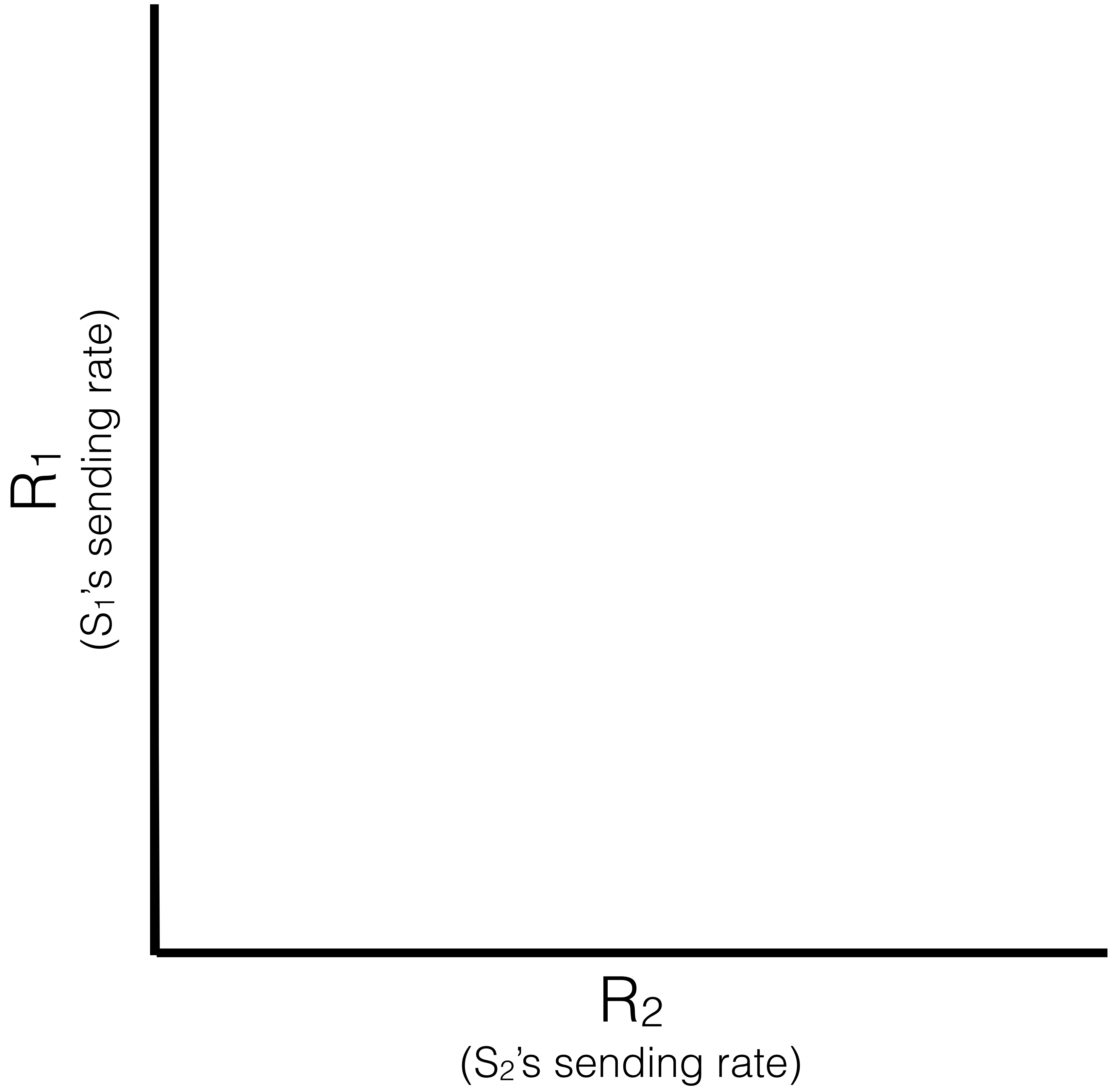

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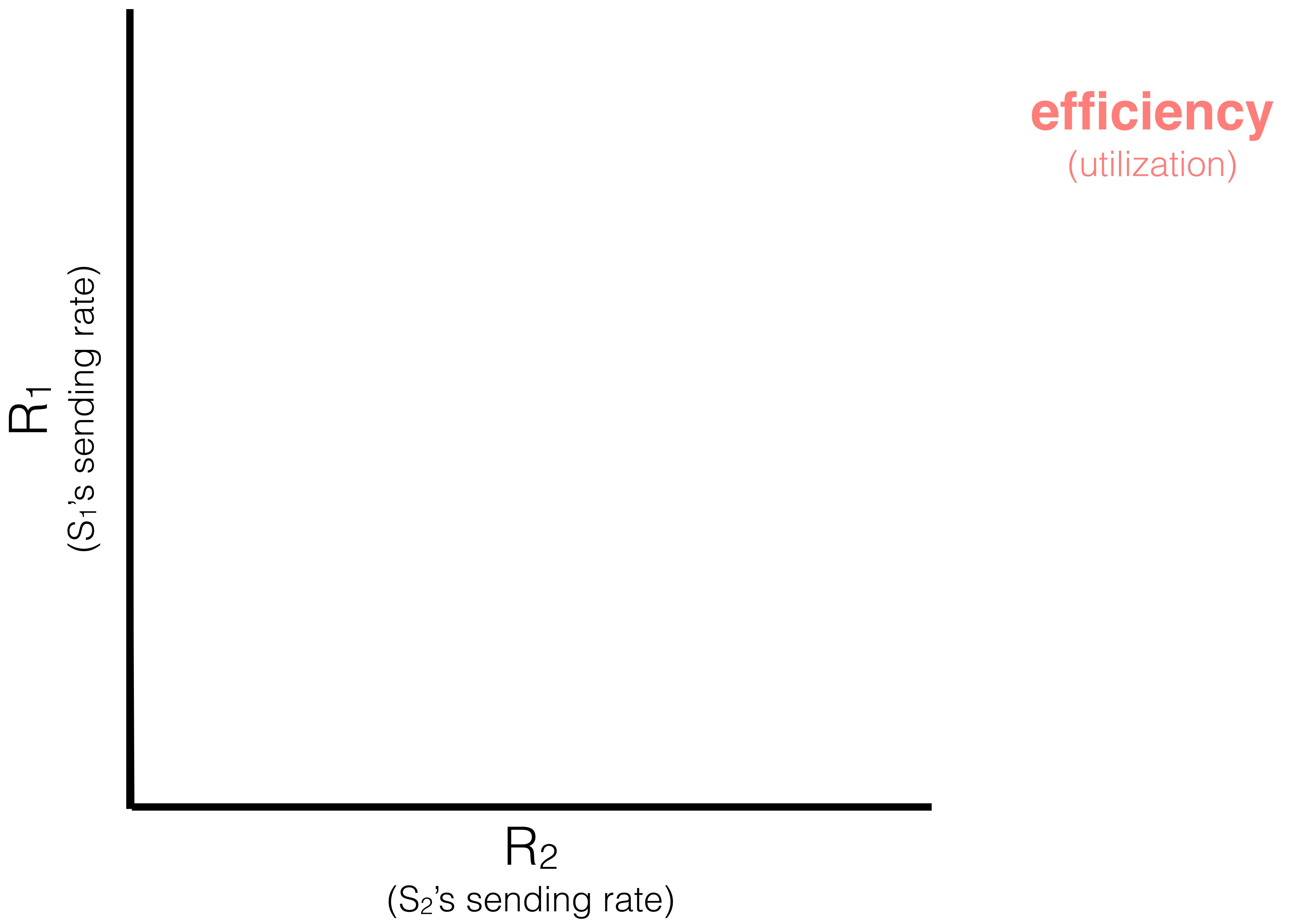

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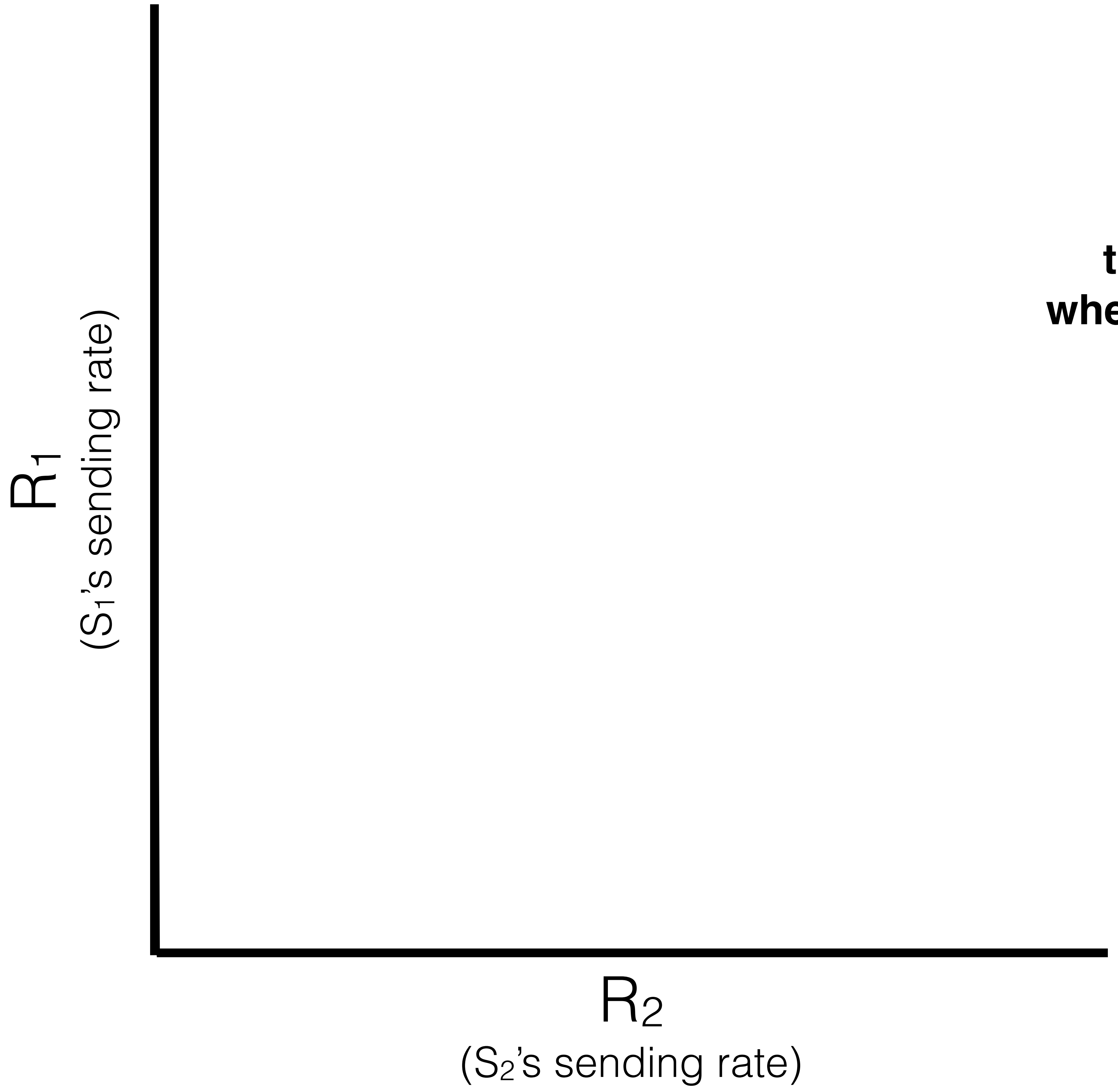

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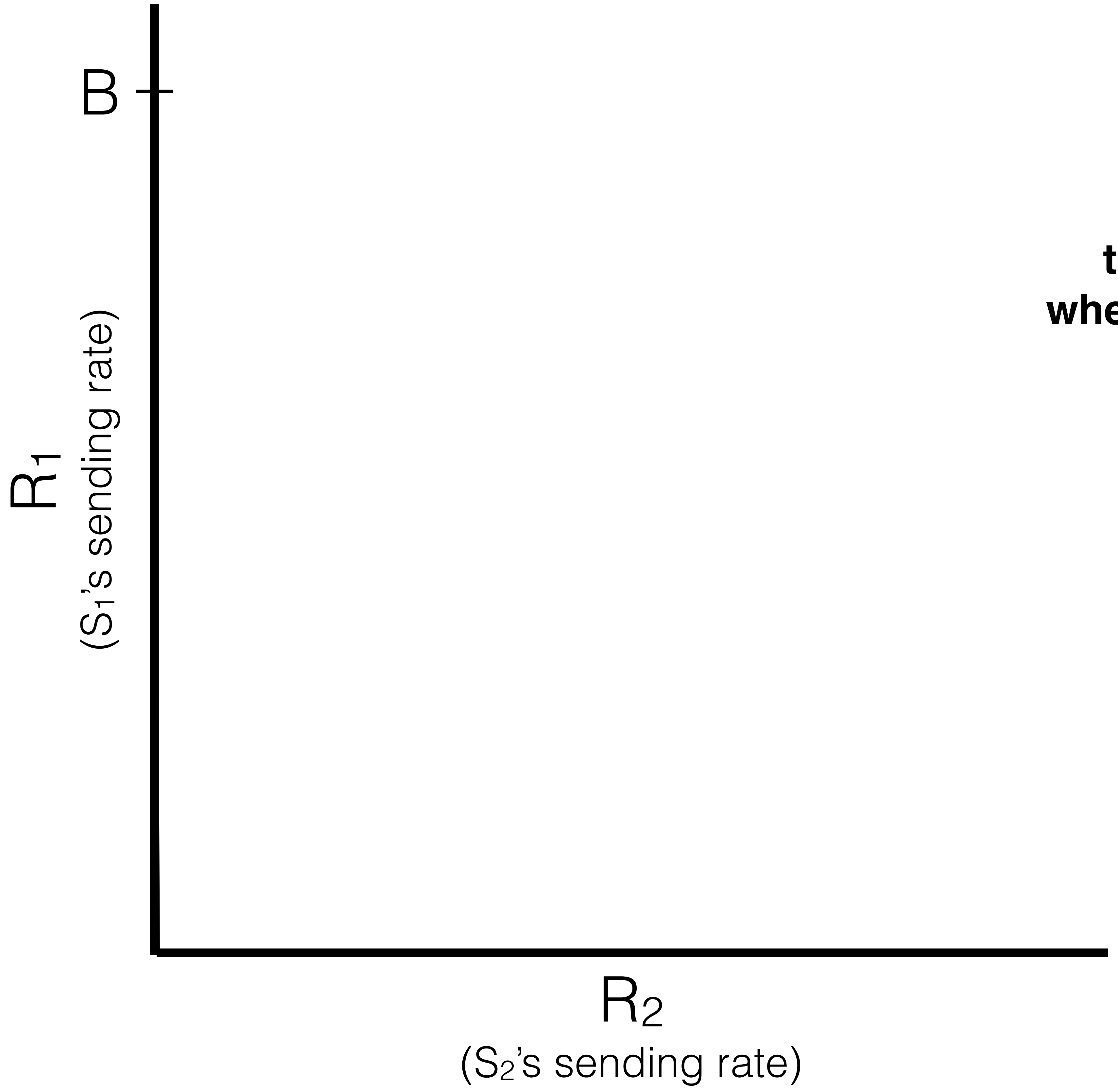

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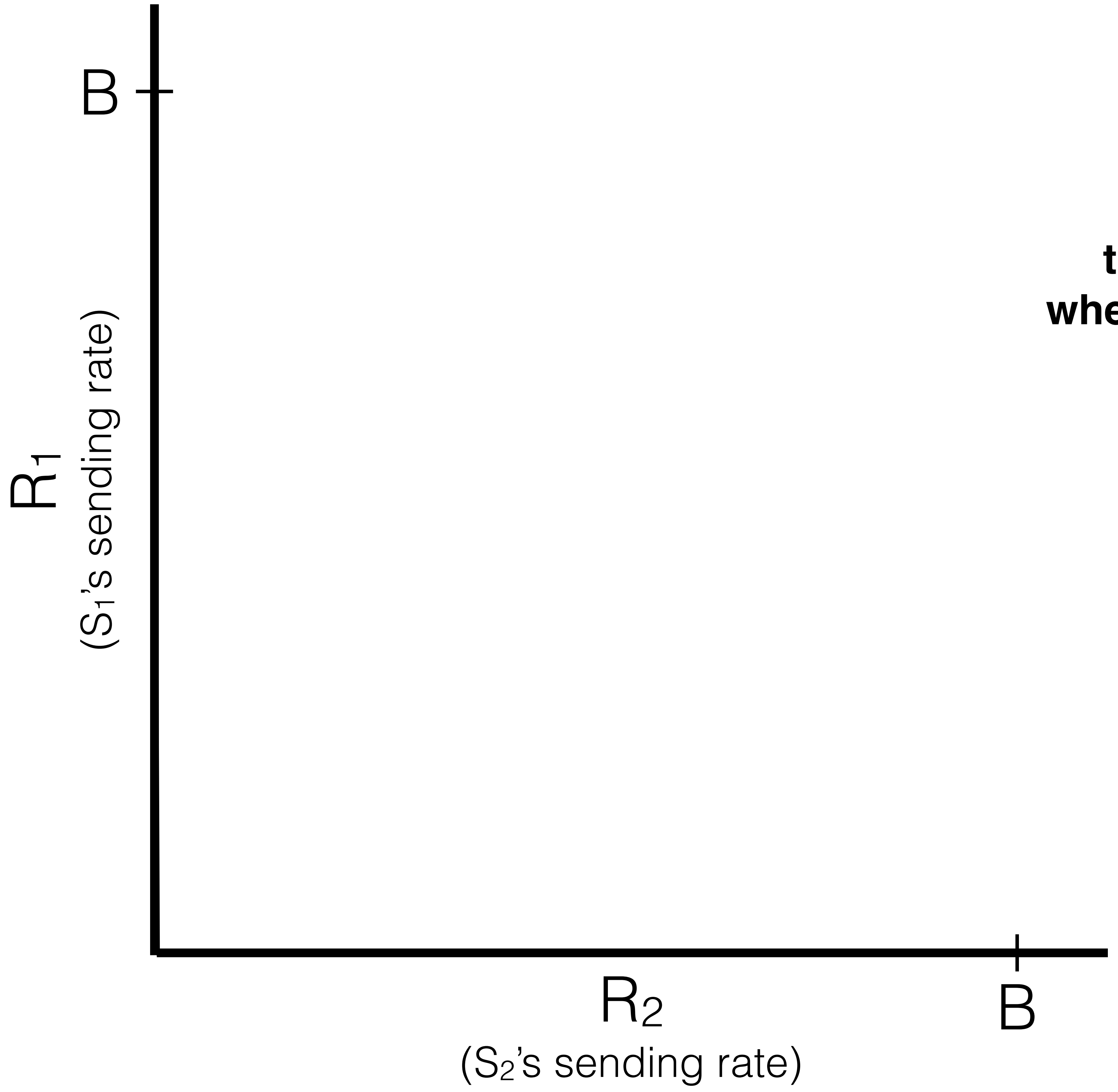

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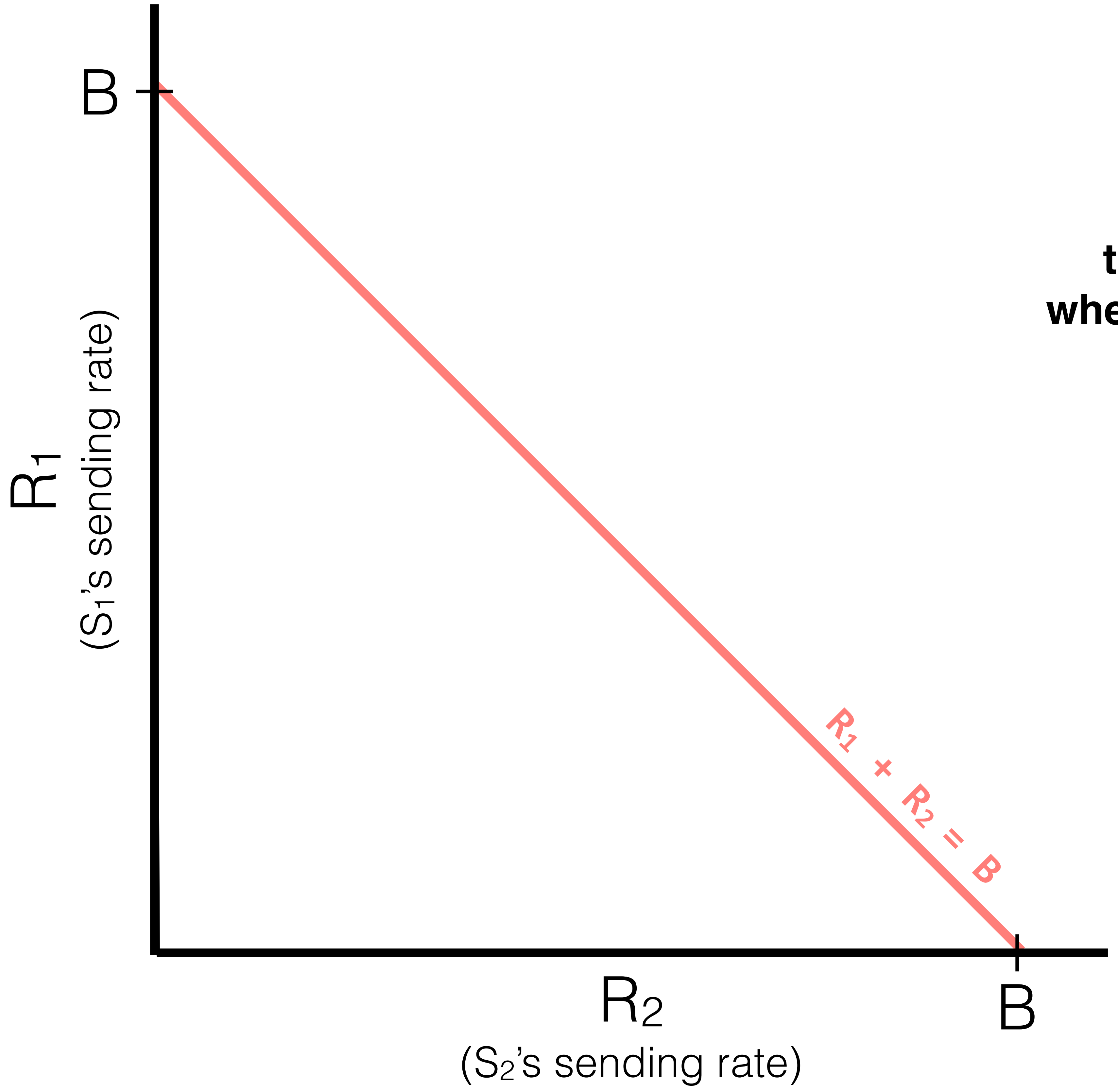

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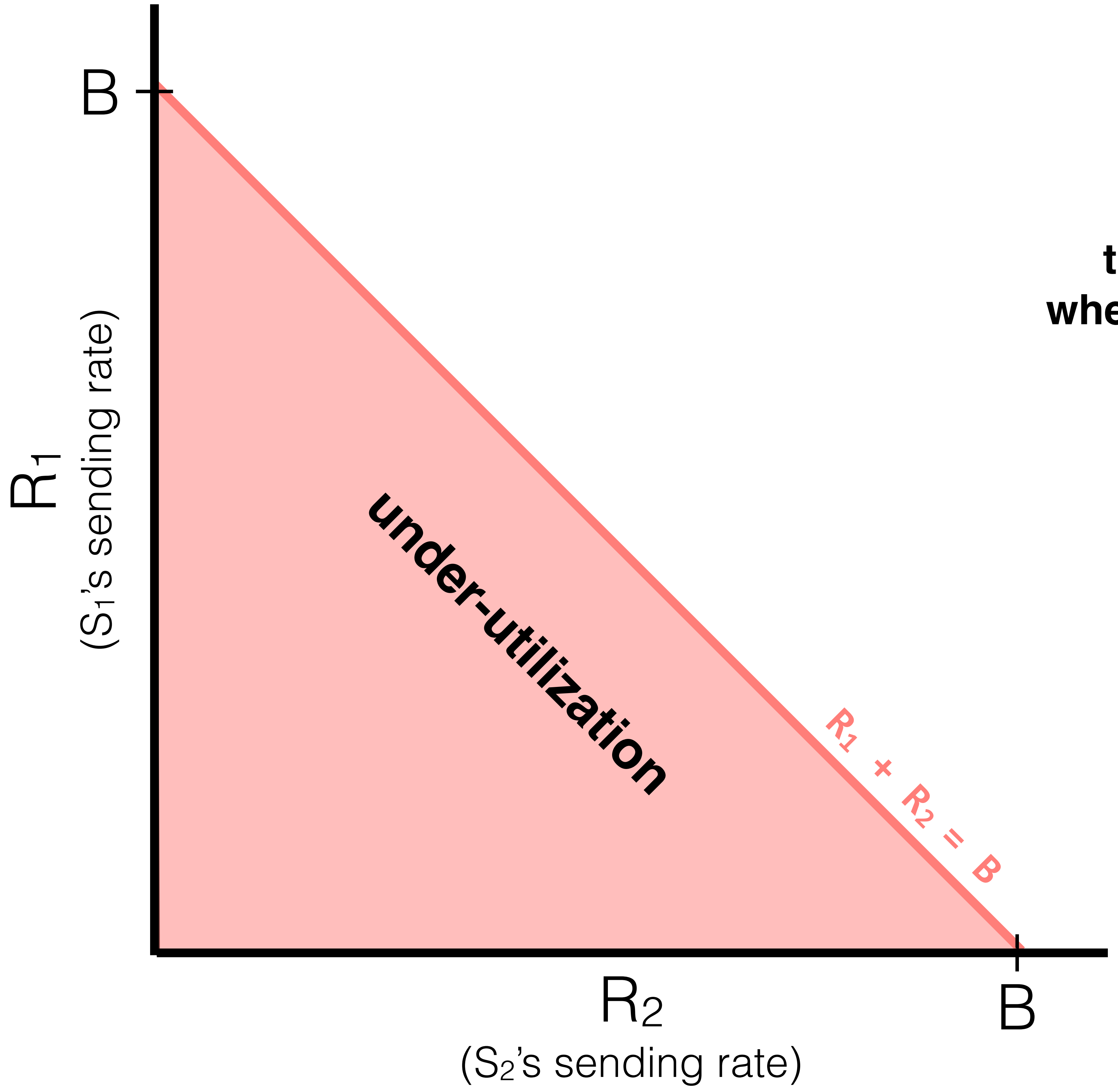

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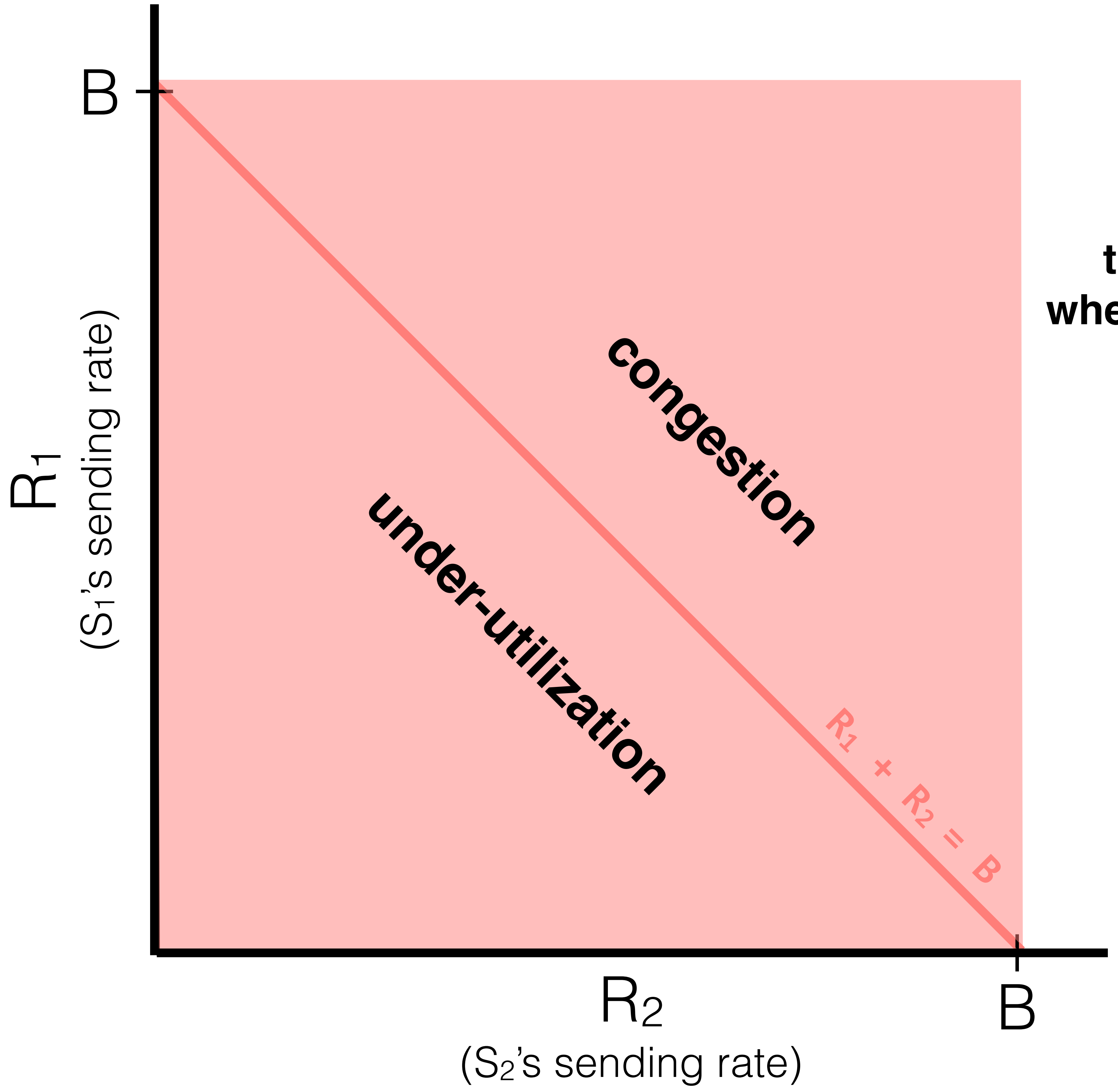

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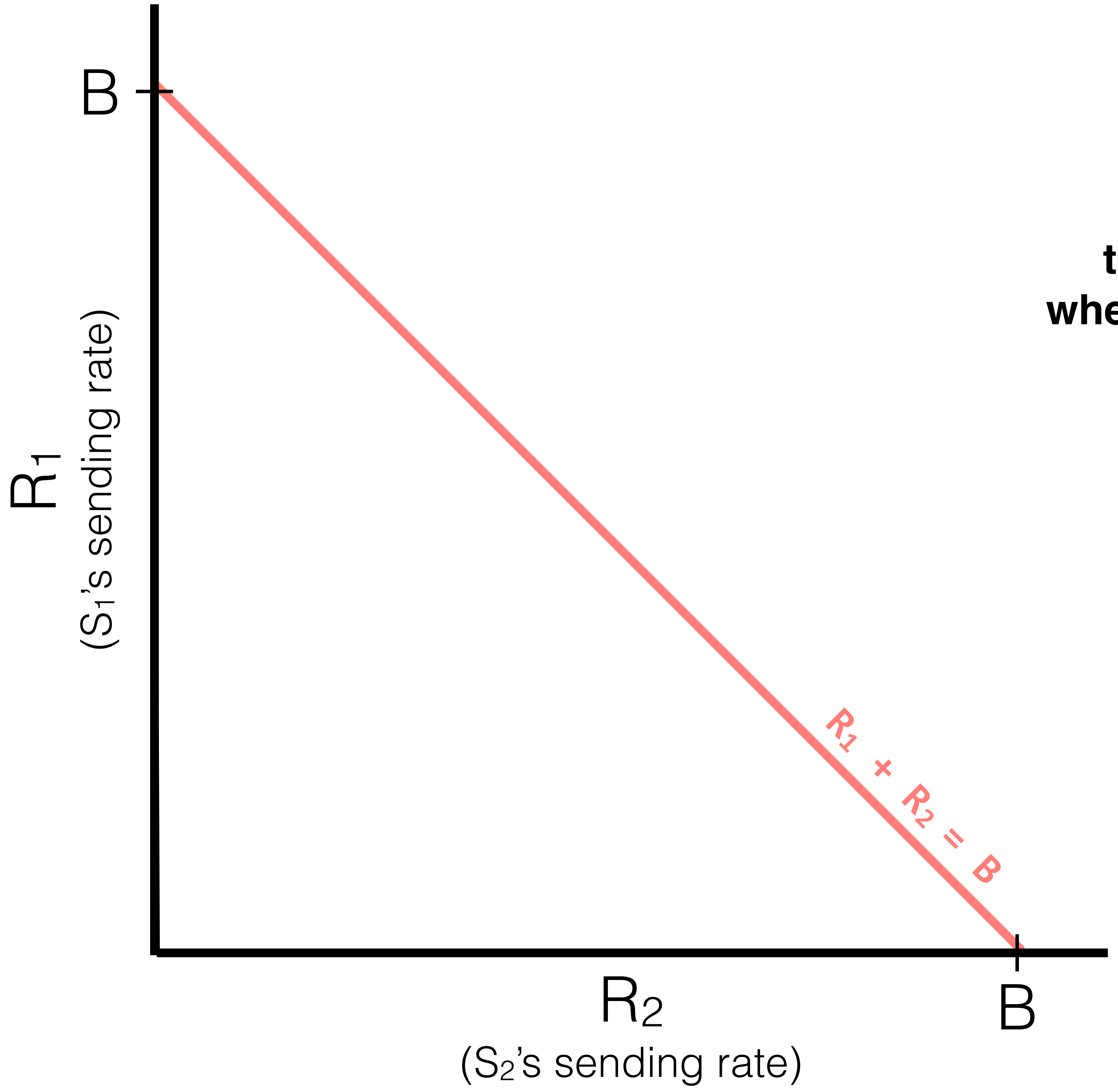

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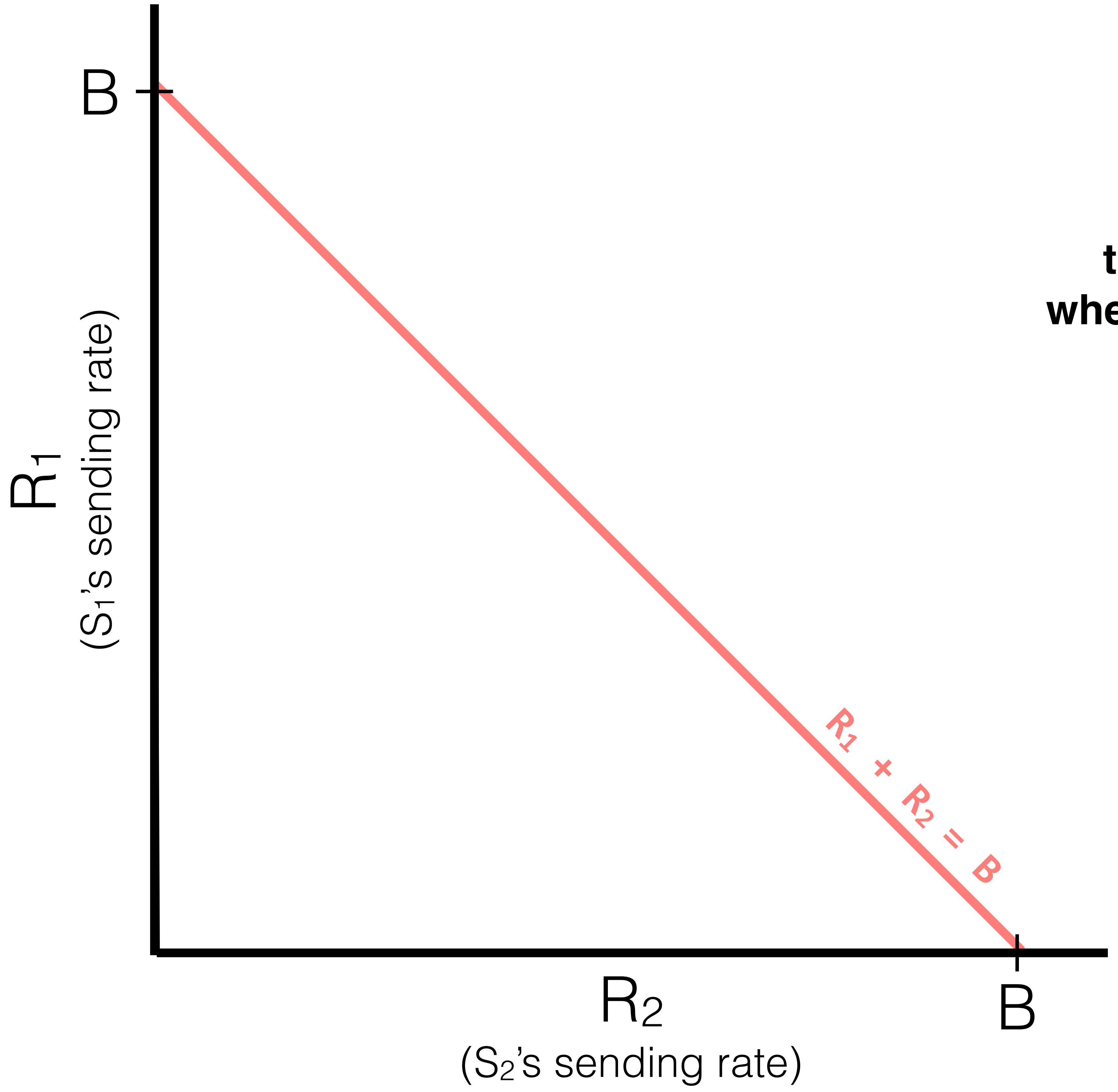

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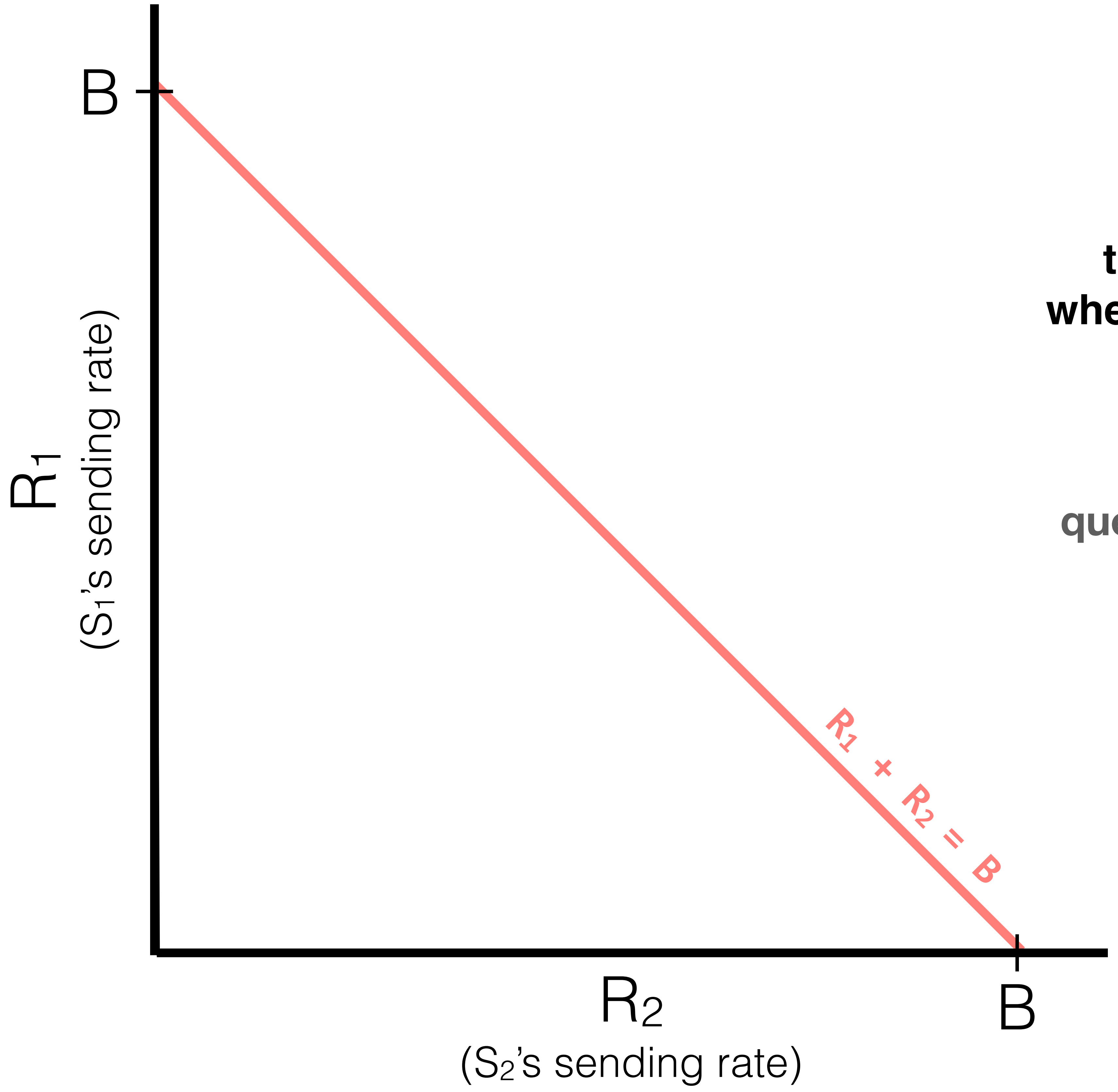

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question: what line on this graph would represent fairness?

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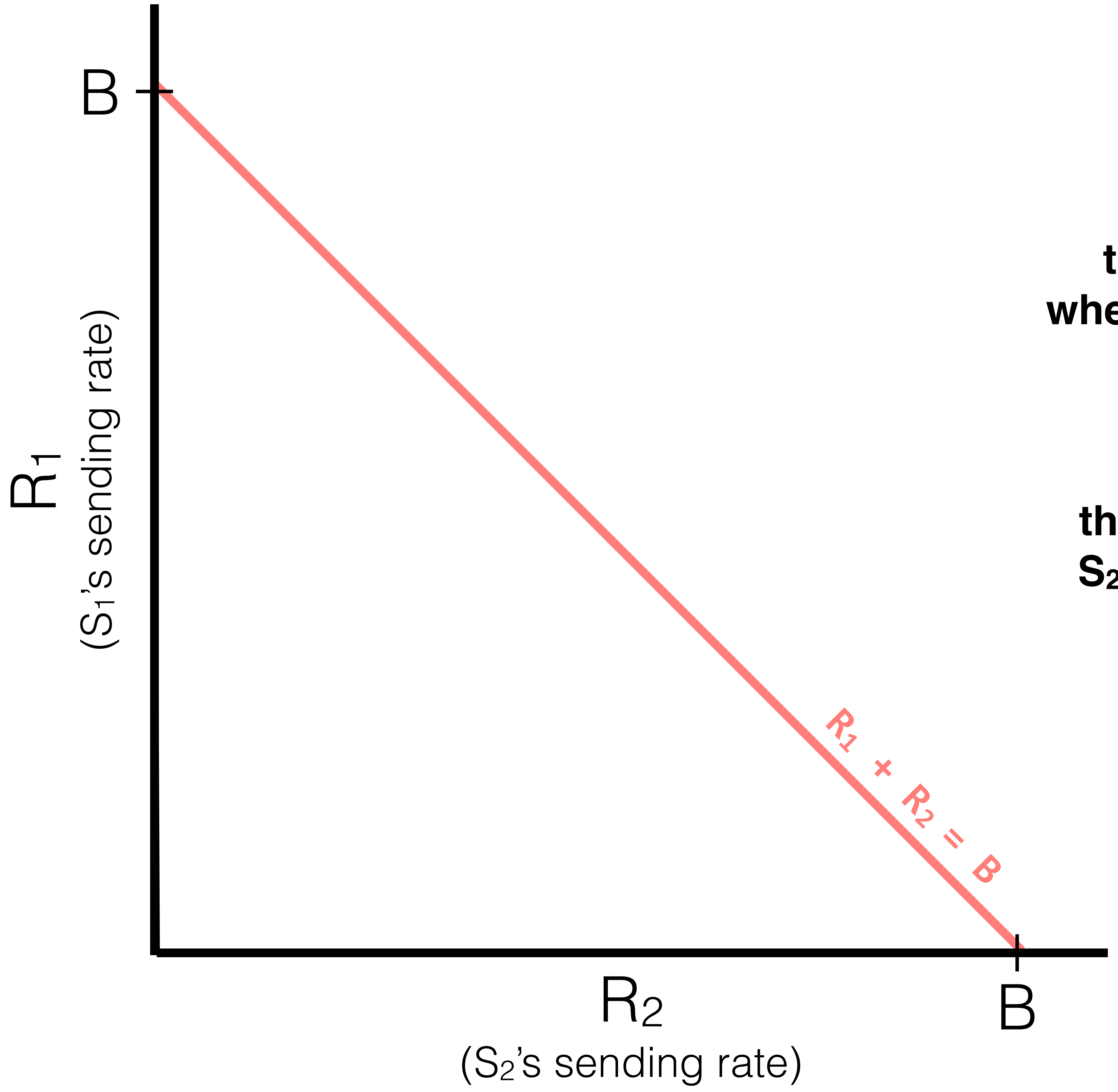

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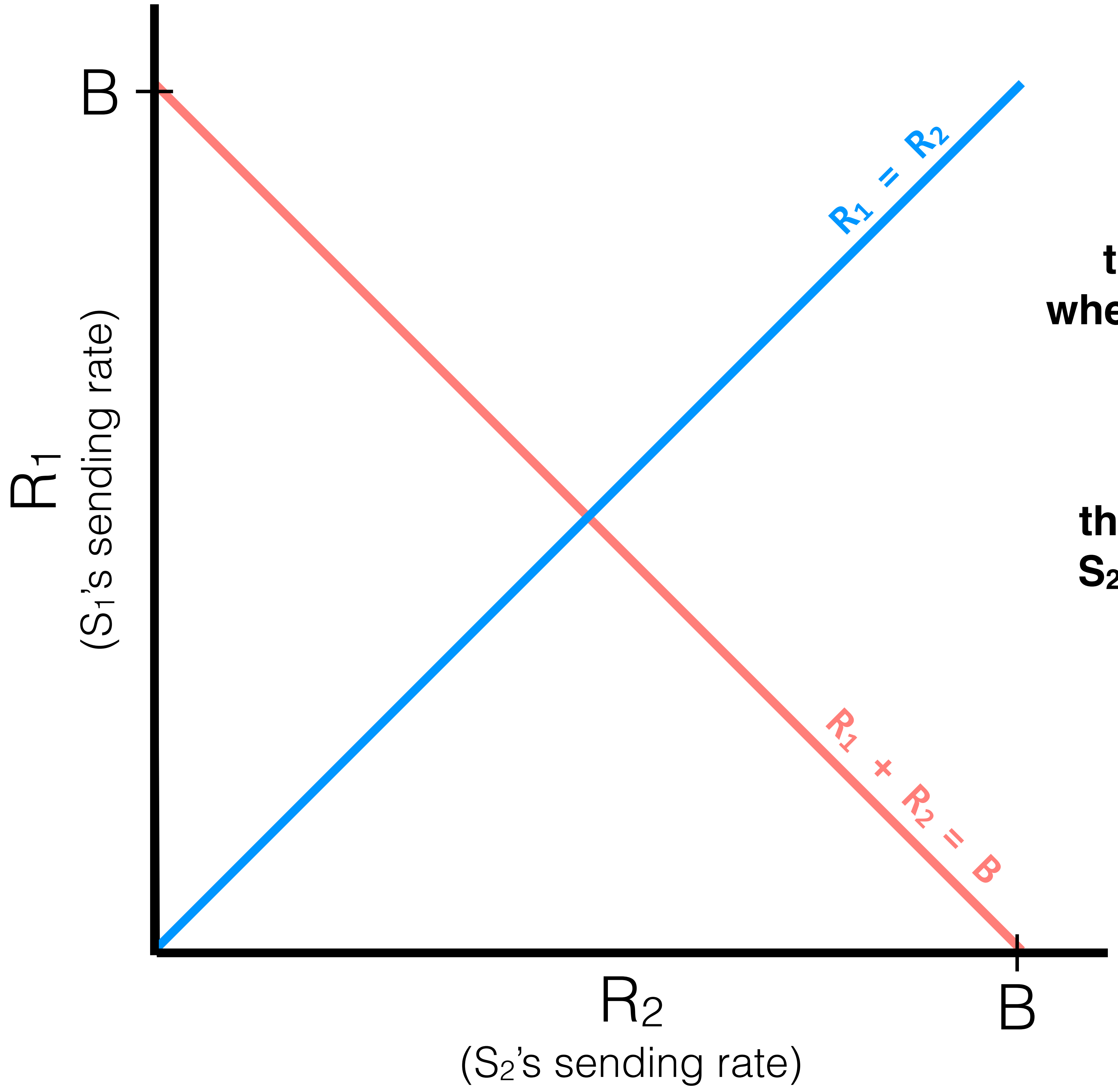

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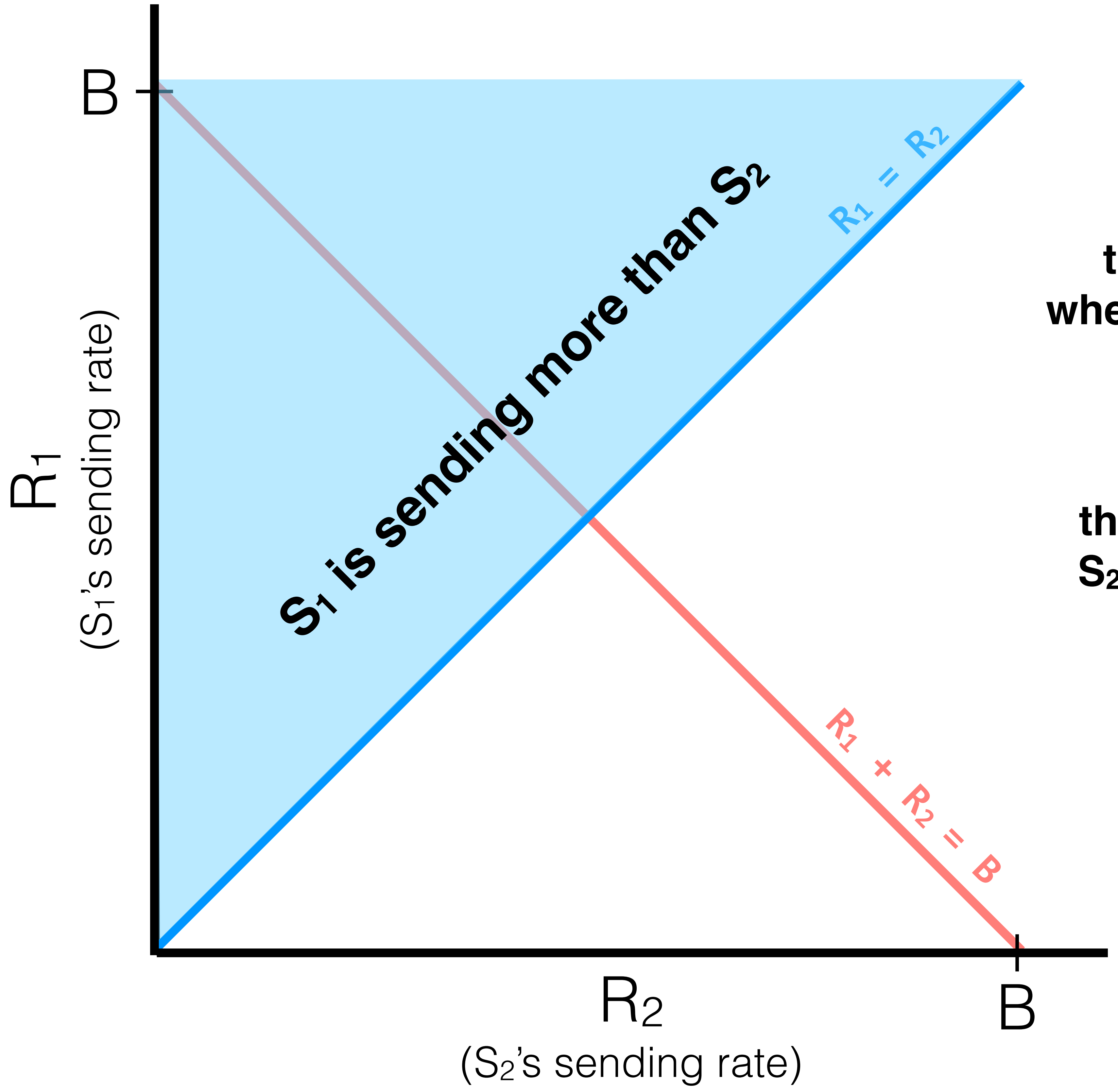

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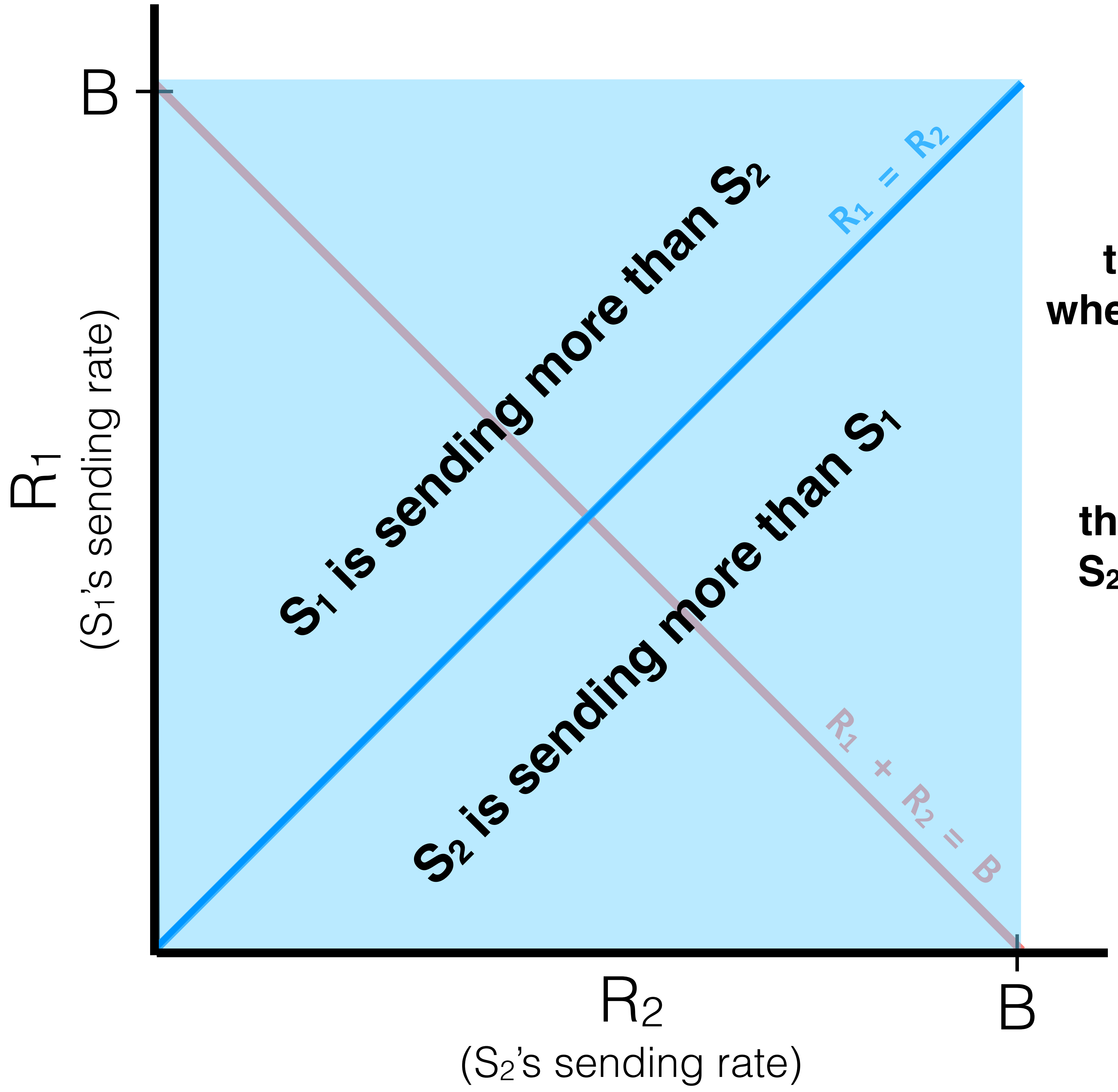

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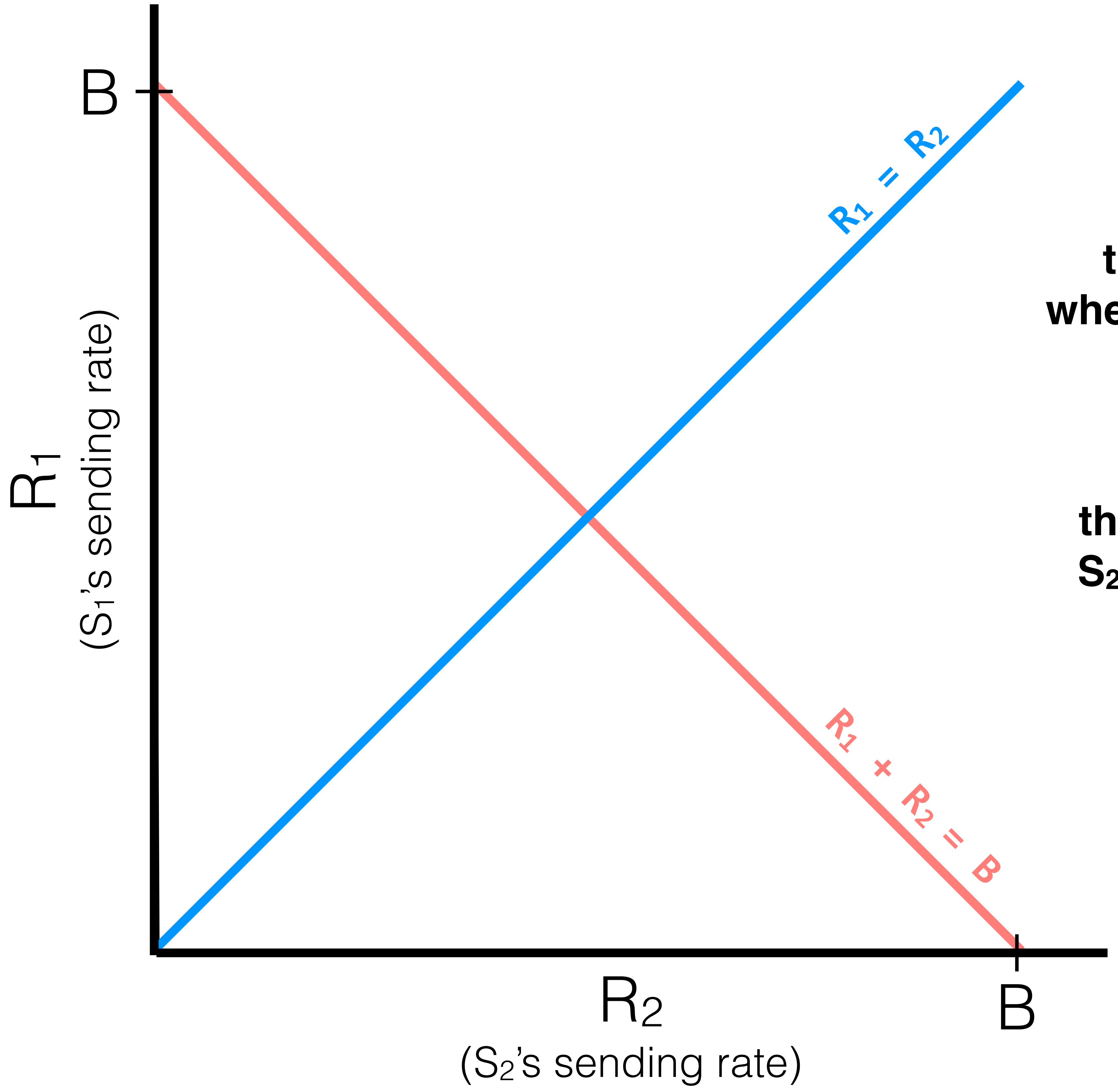

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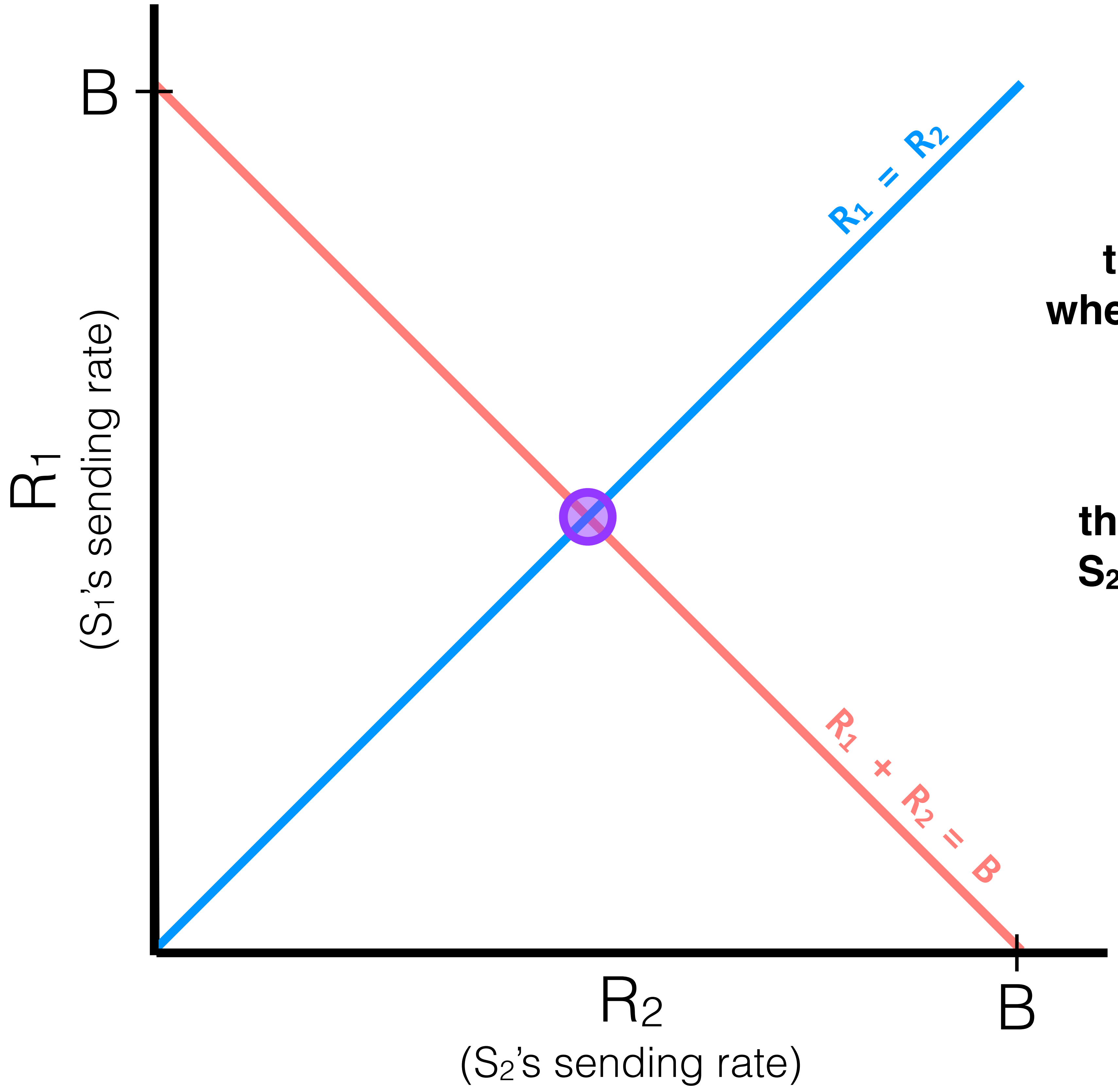

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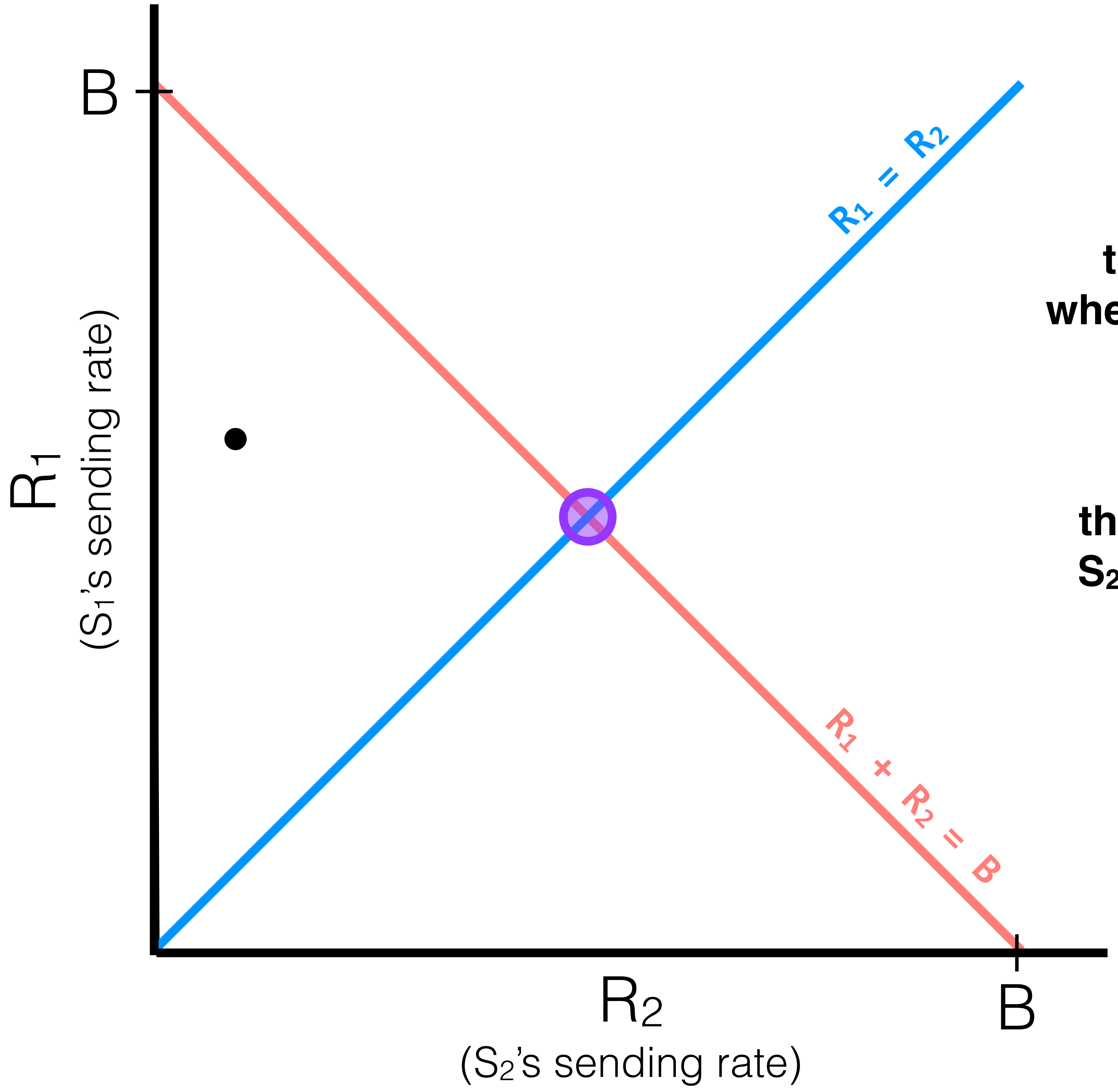

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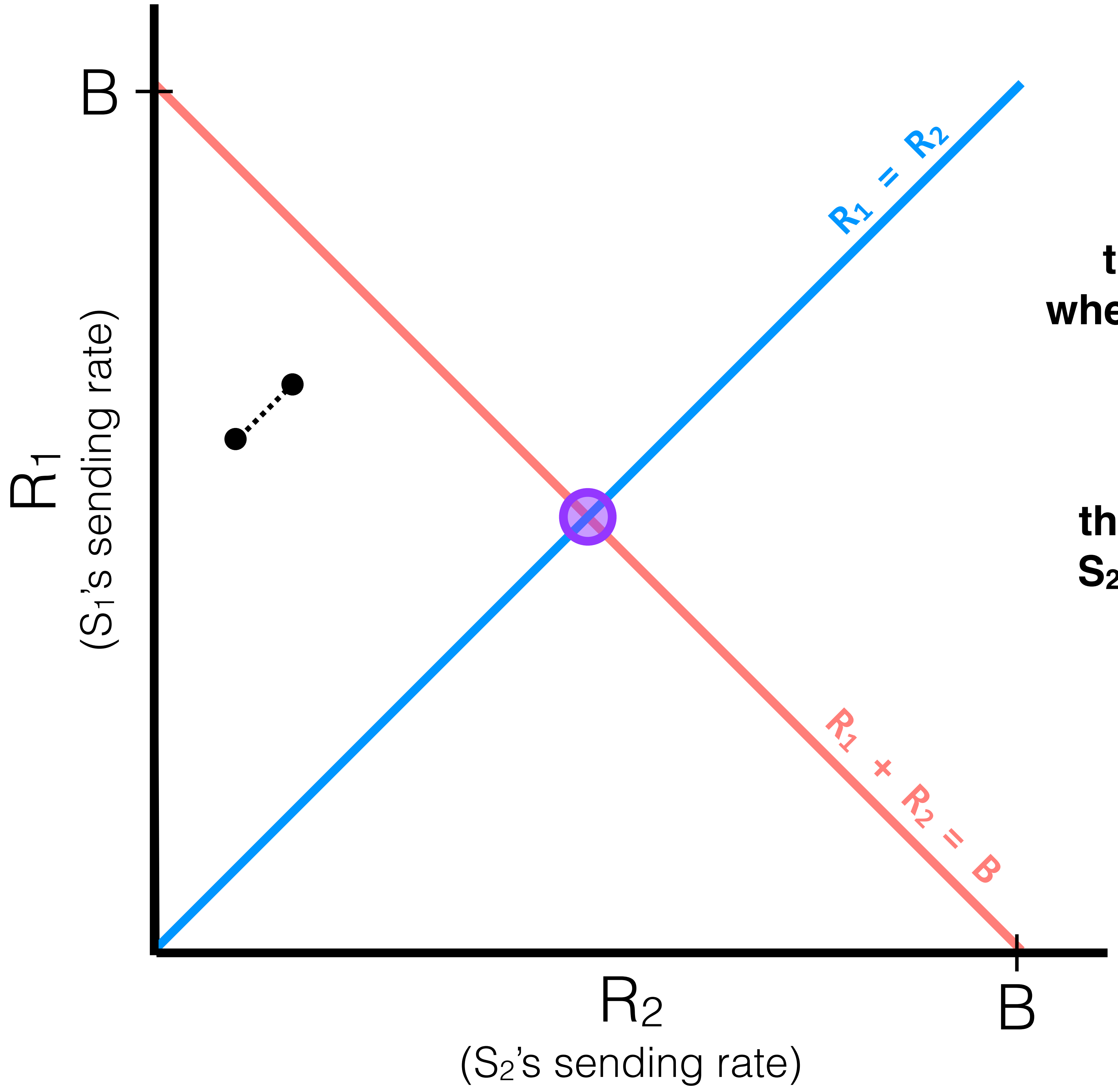

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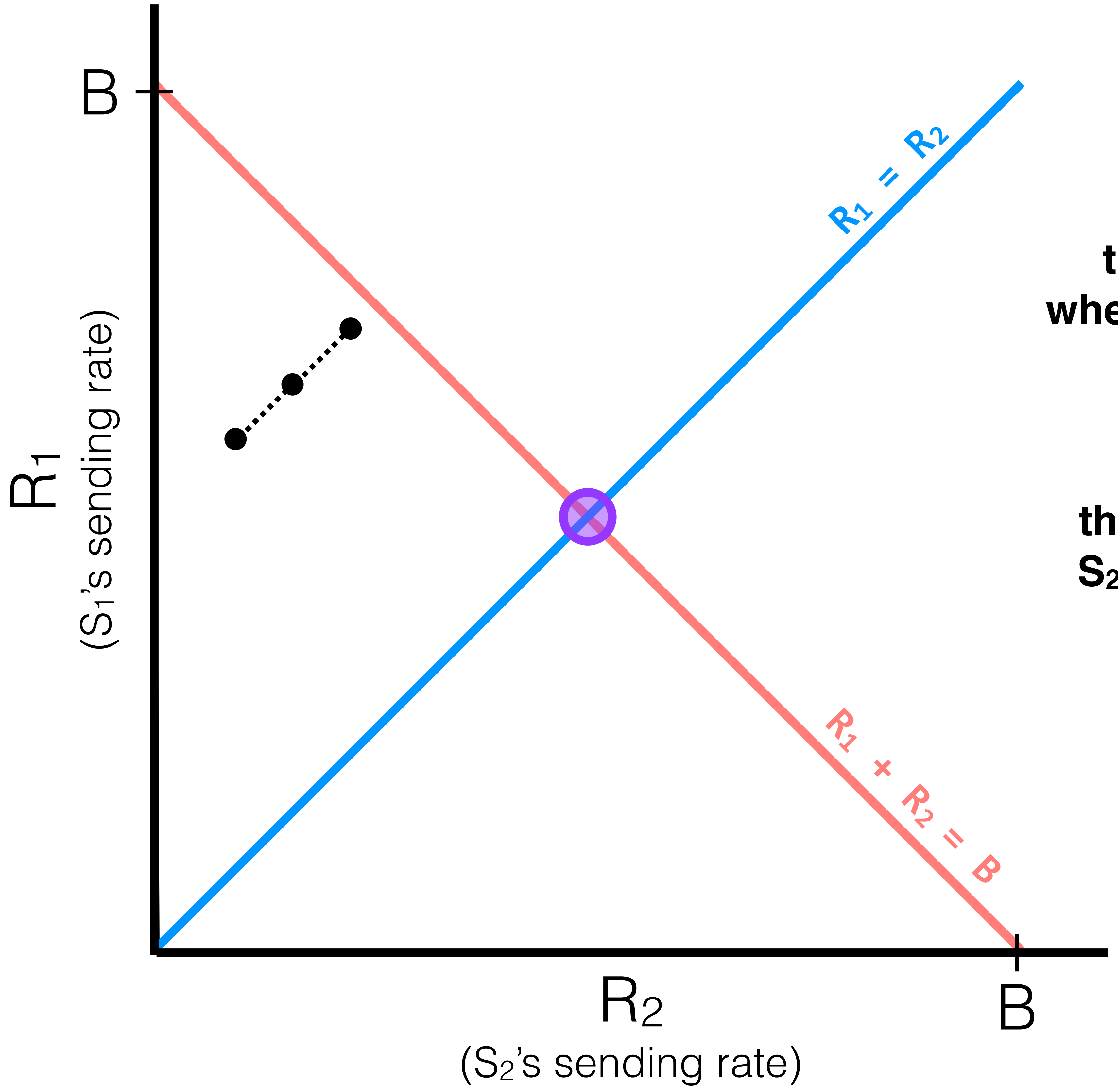

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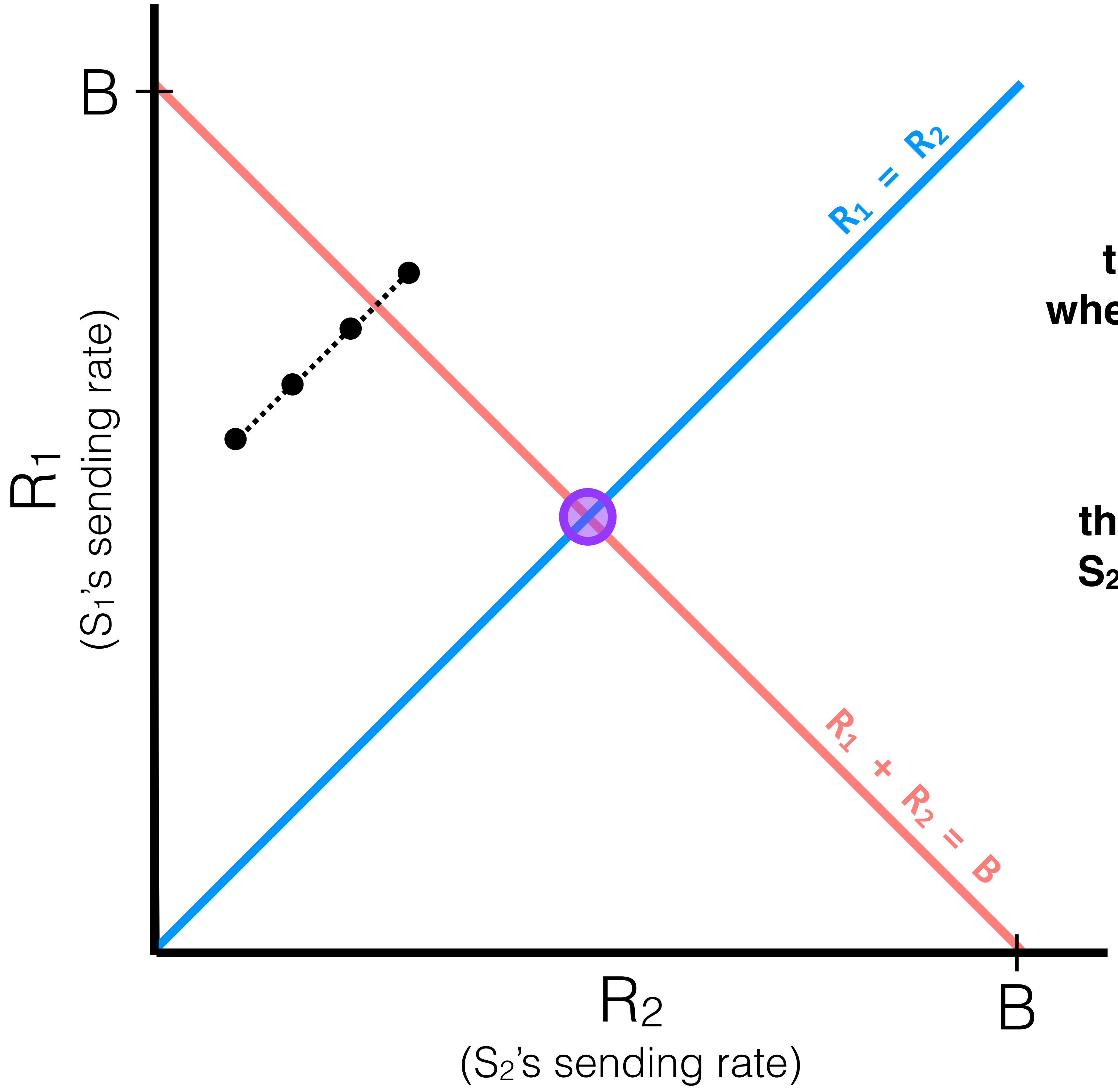

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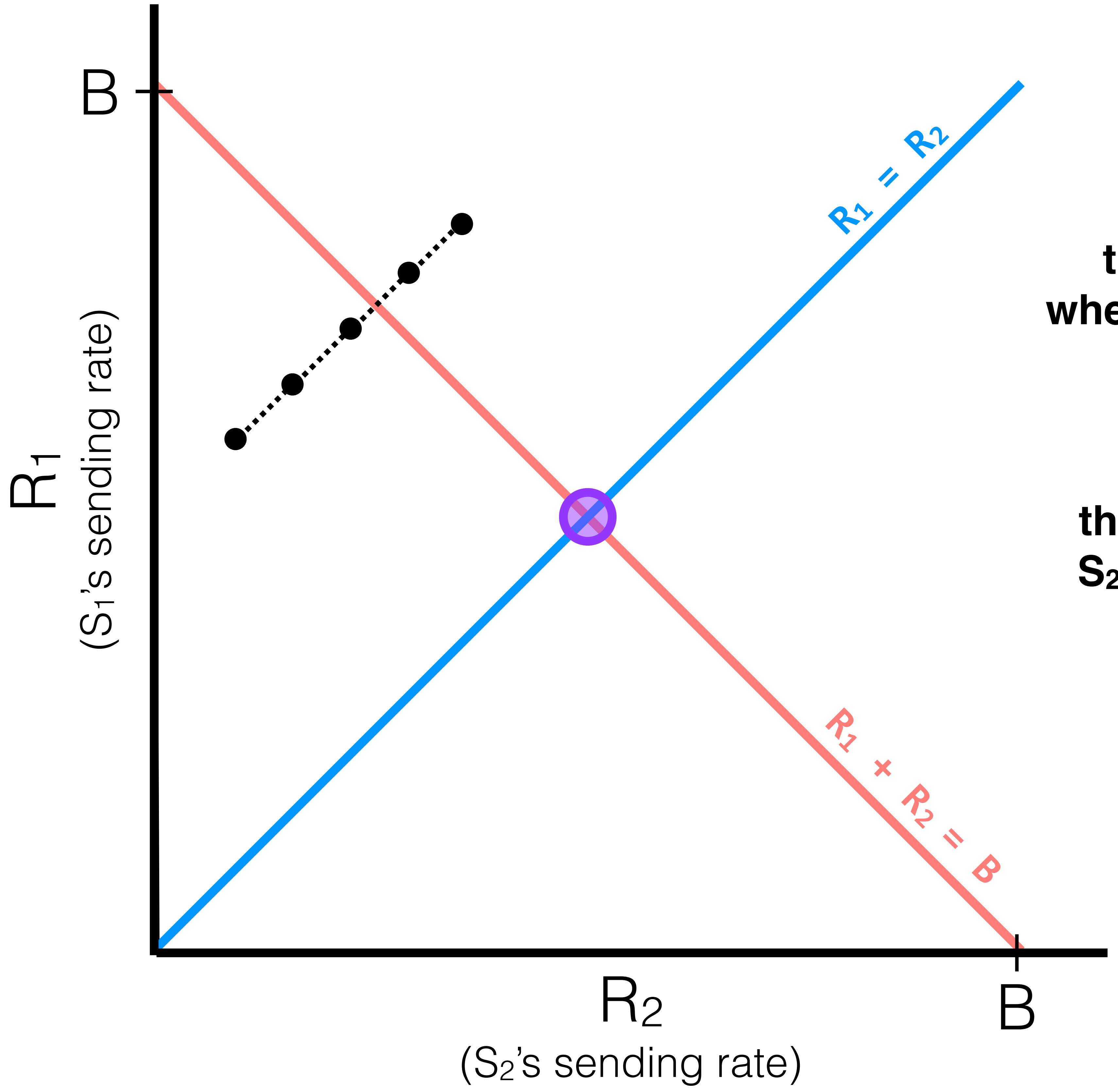

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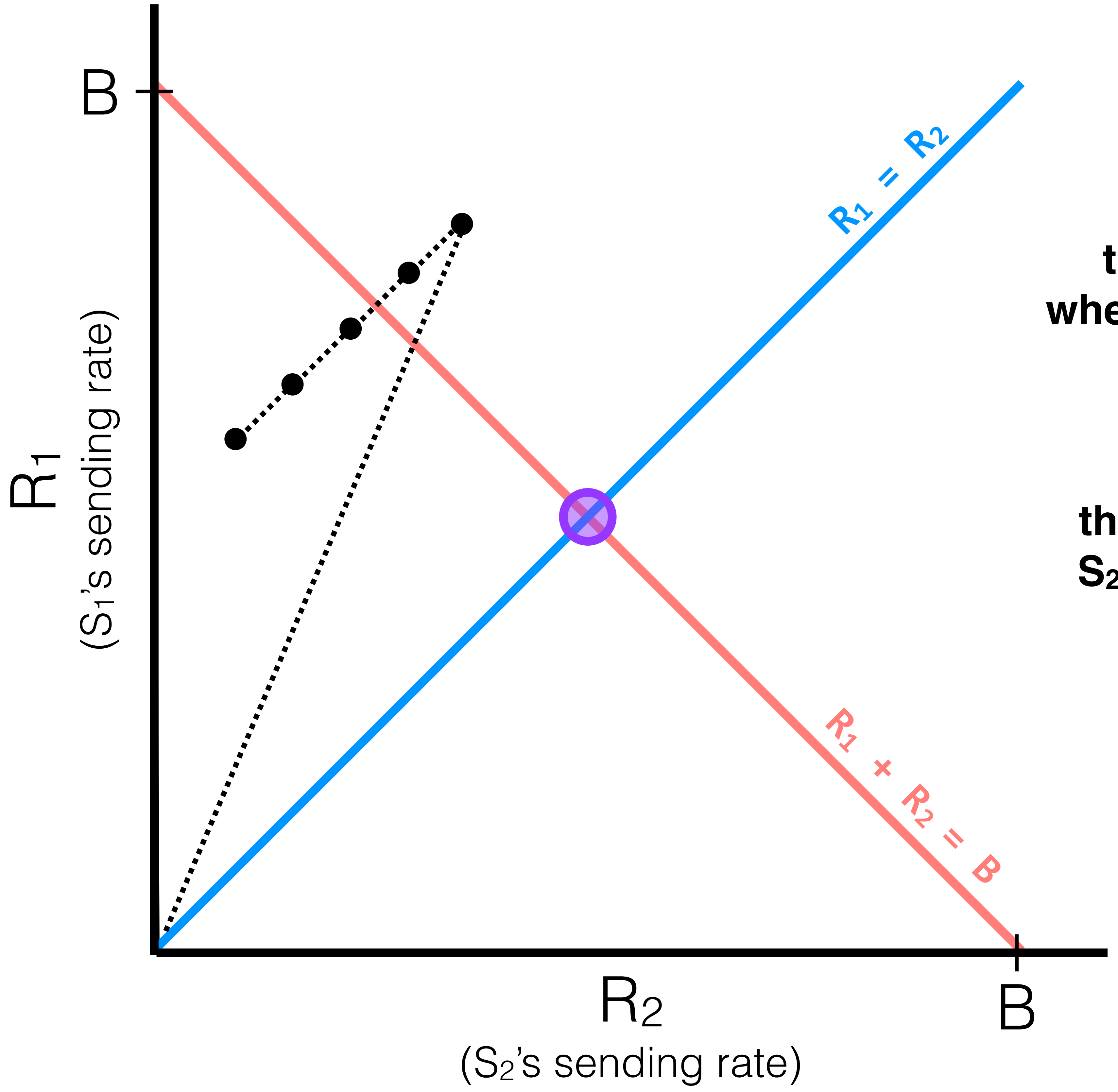

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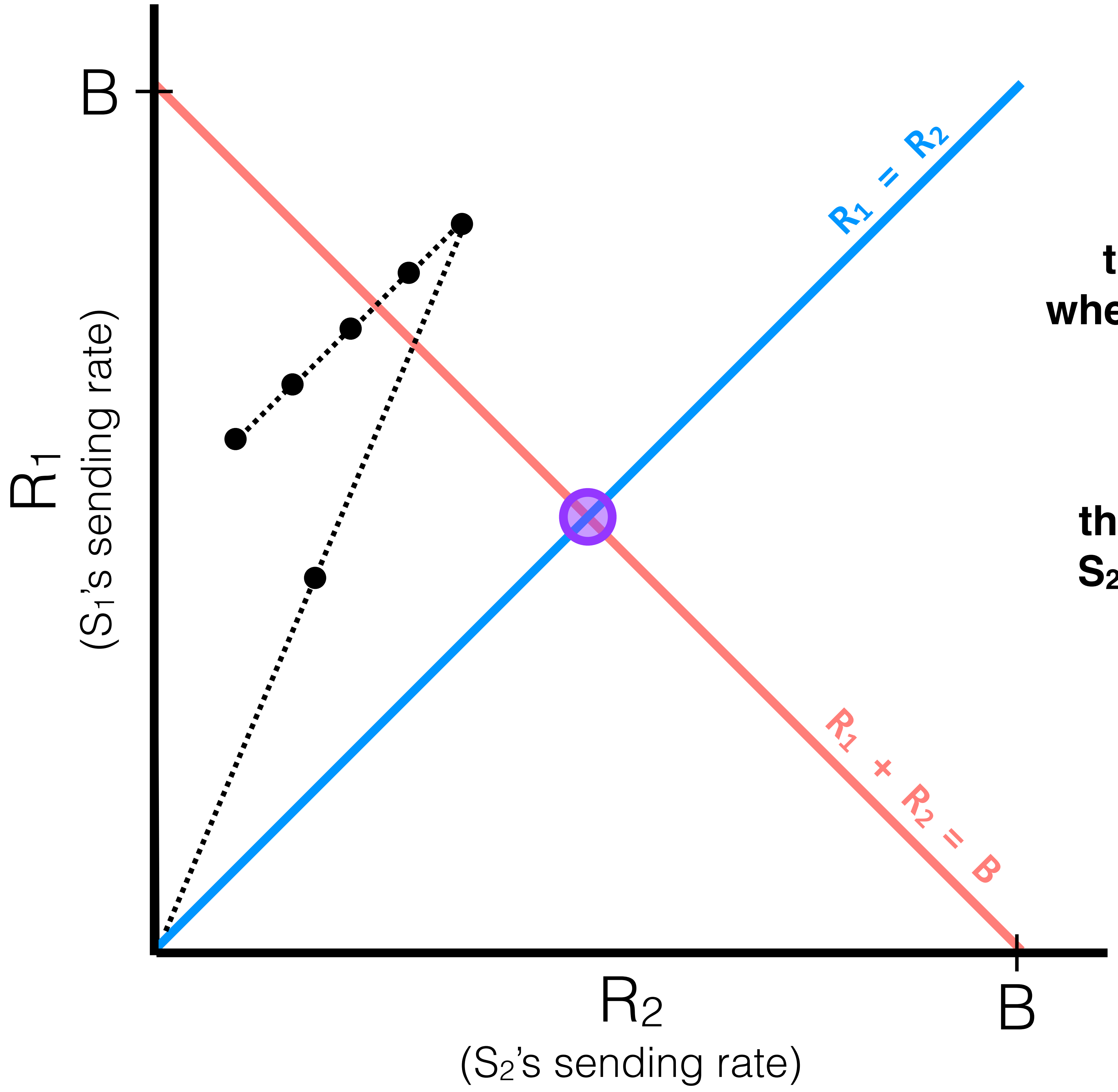

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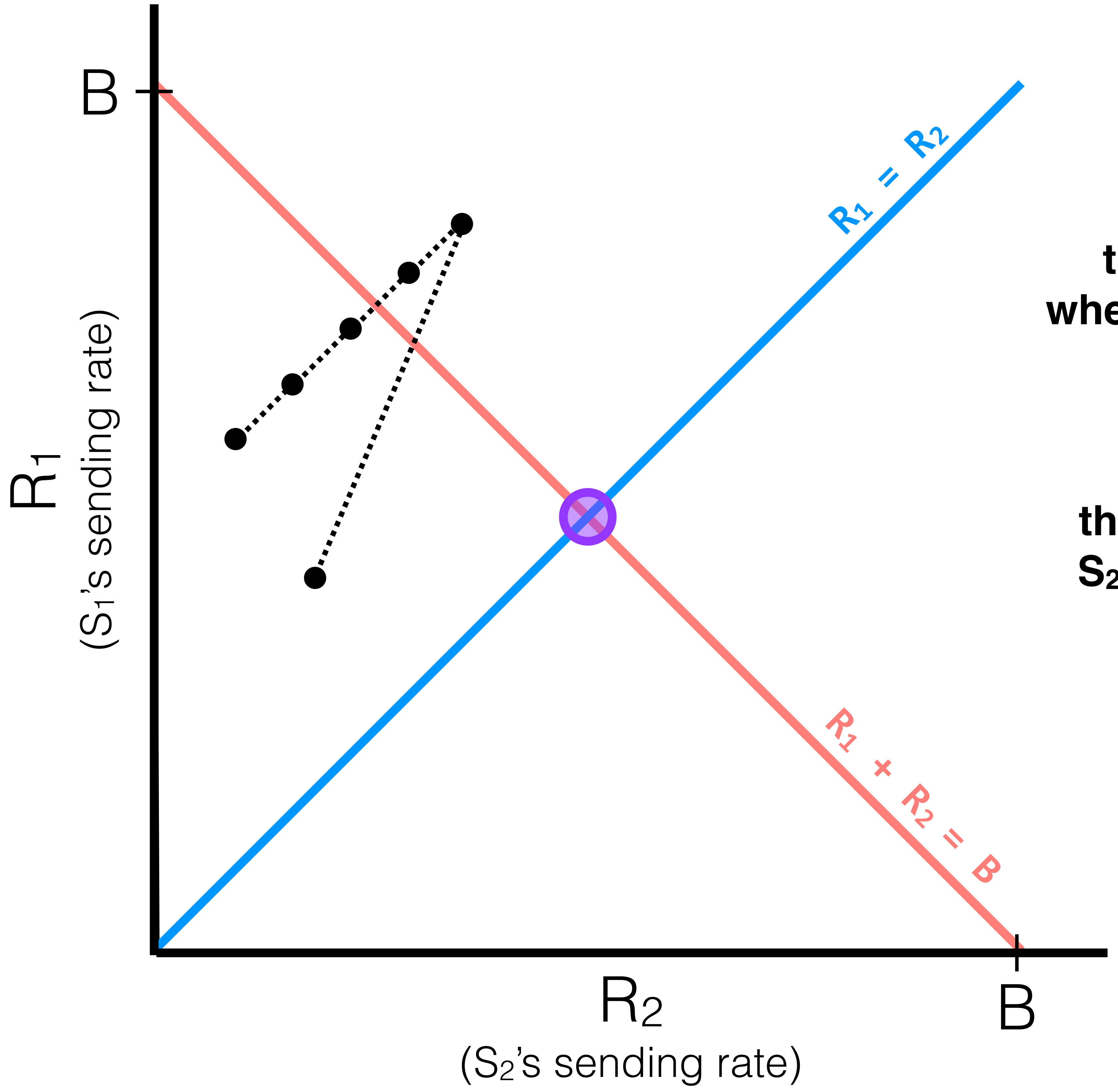

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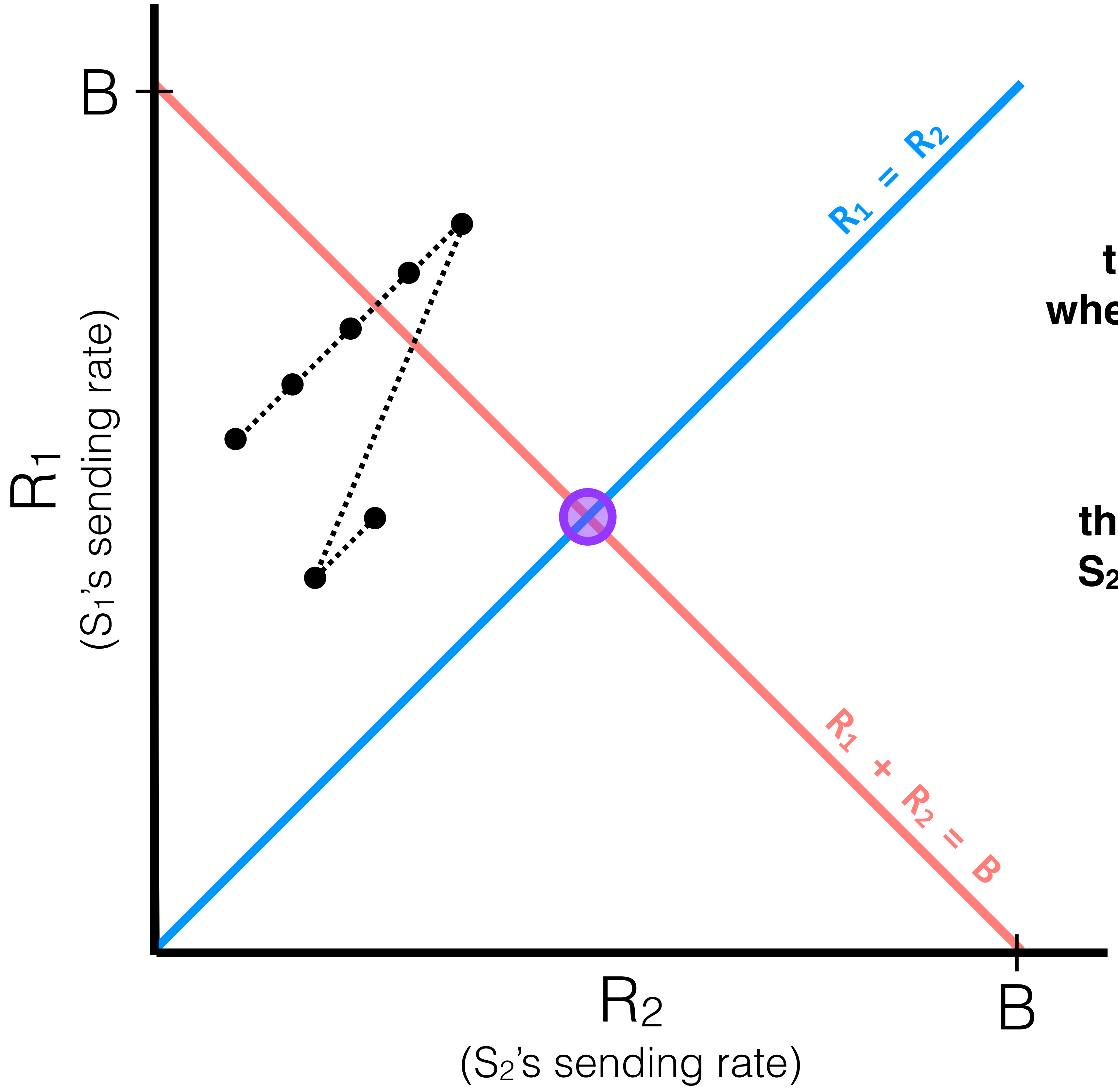

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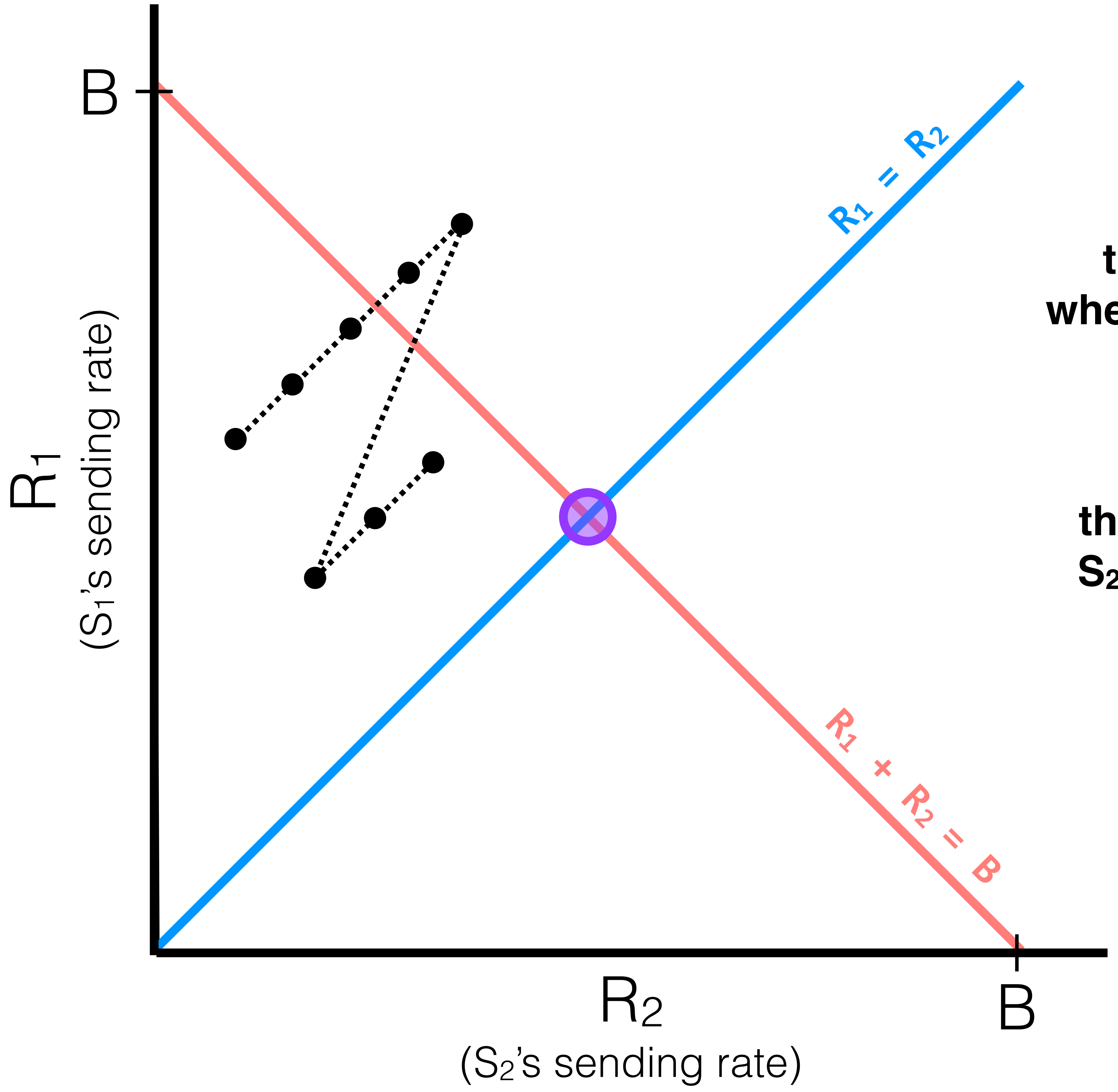

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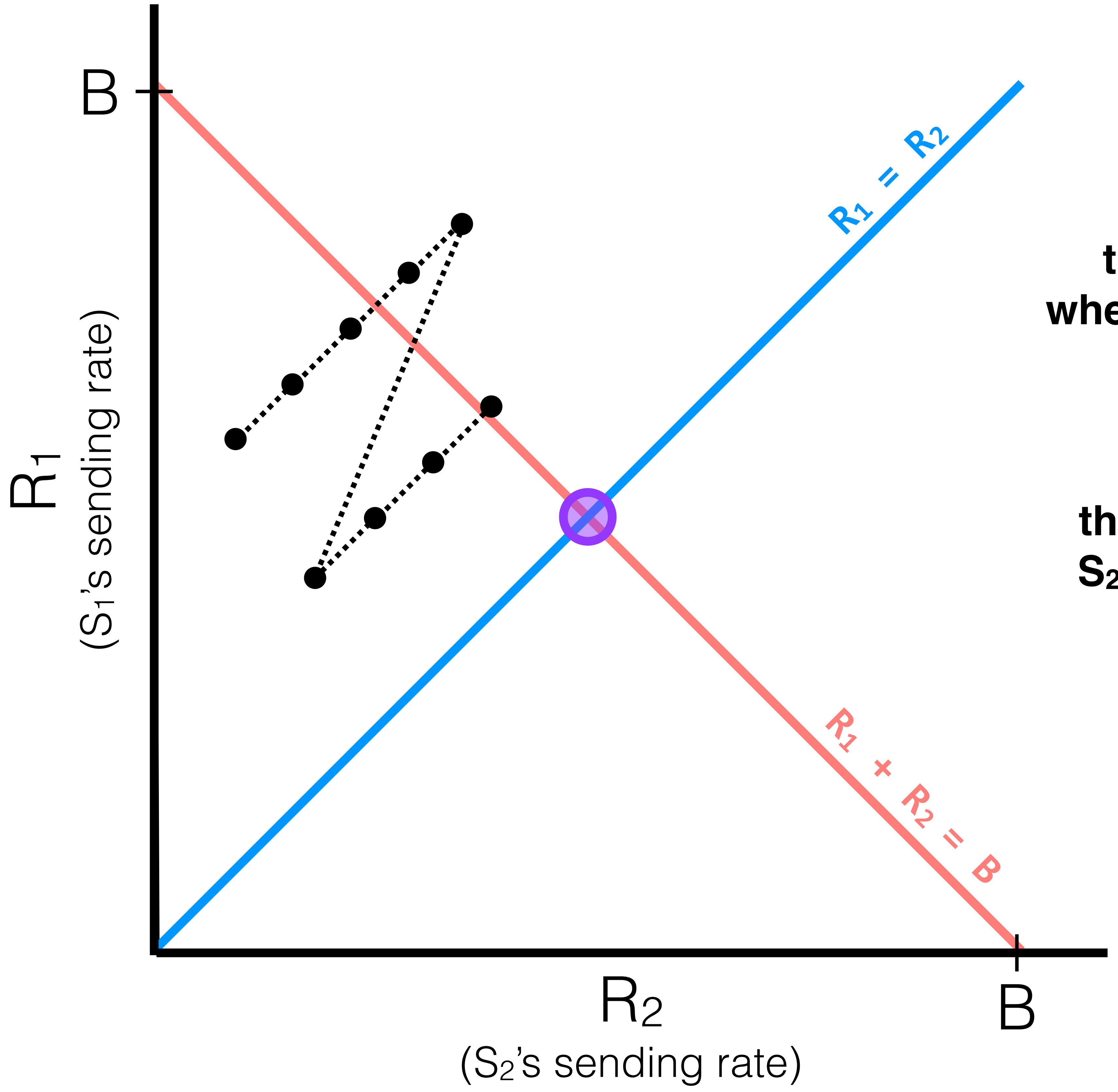

efficiency
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the network is fully utilized when the bottleneck link is "full"

fairness

the network is fair when S_1 and S_2 are sending at the same rate

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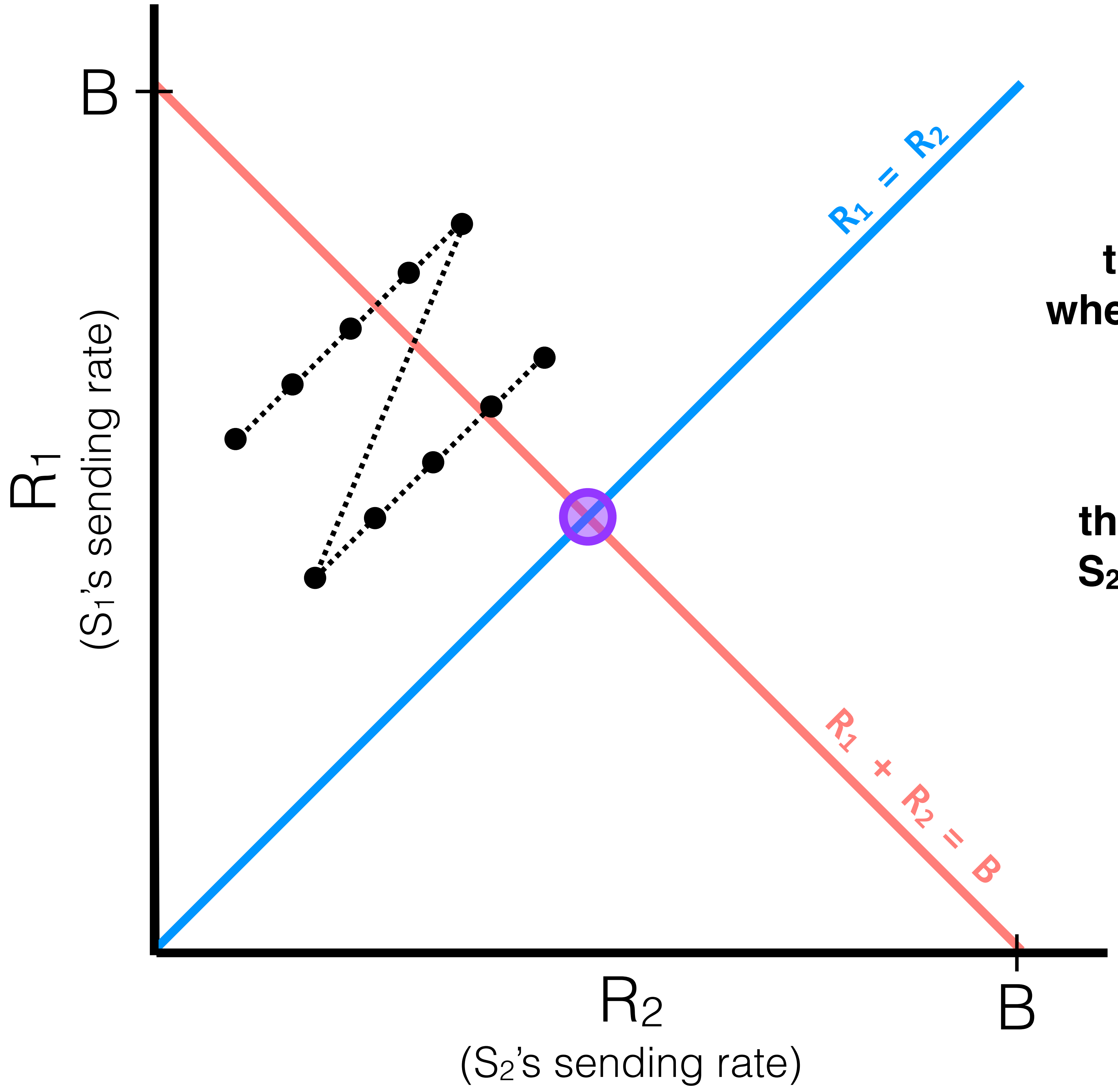

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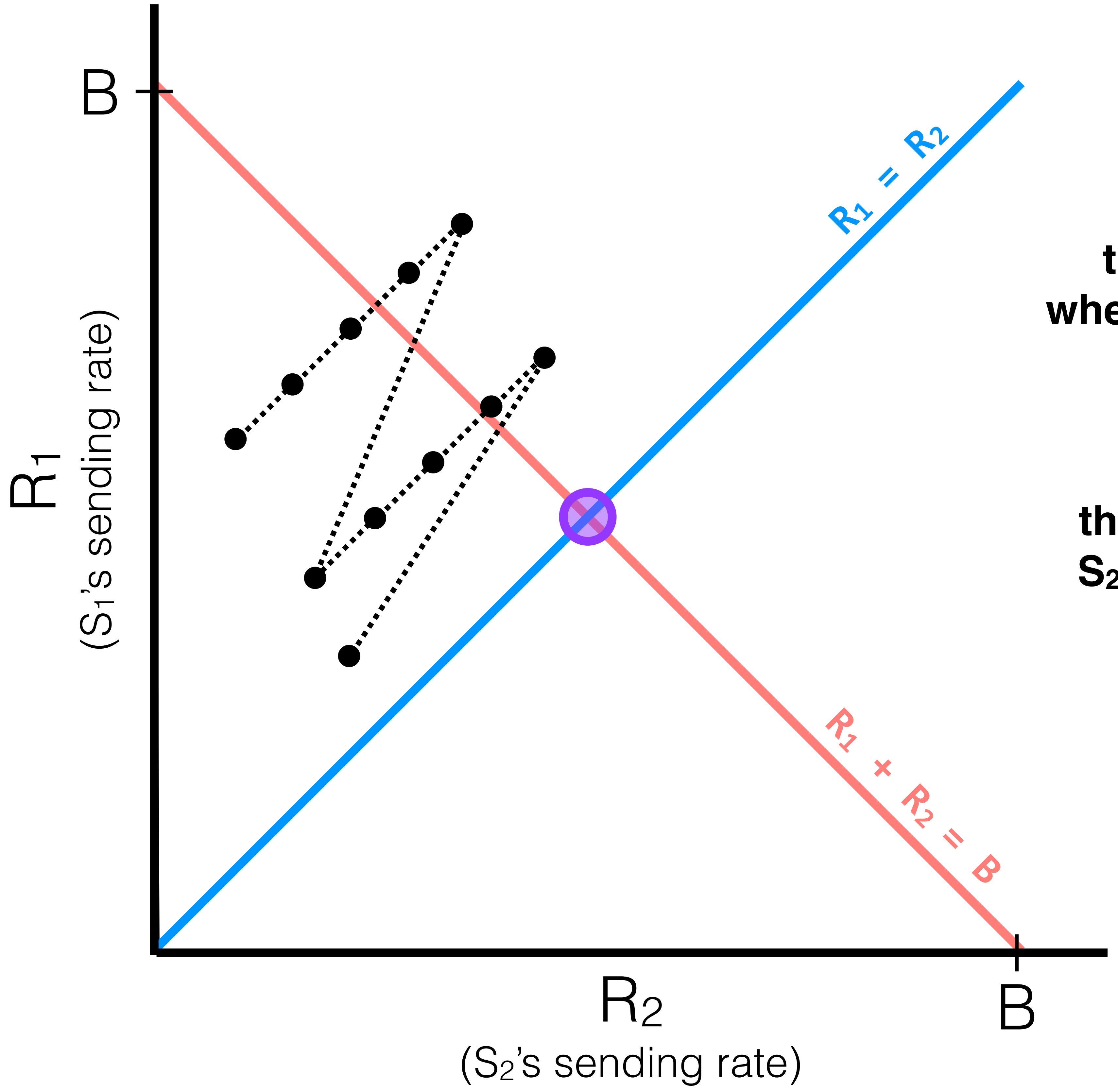

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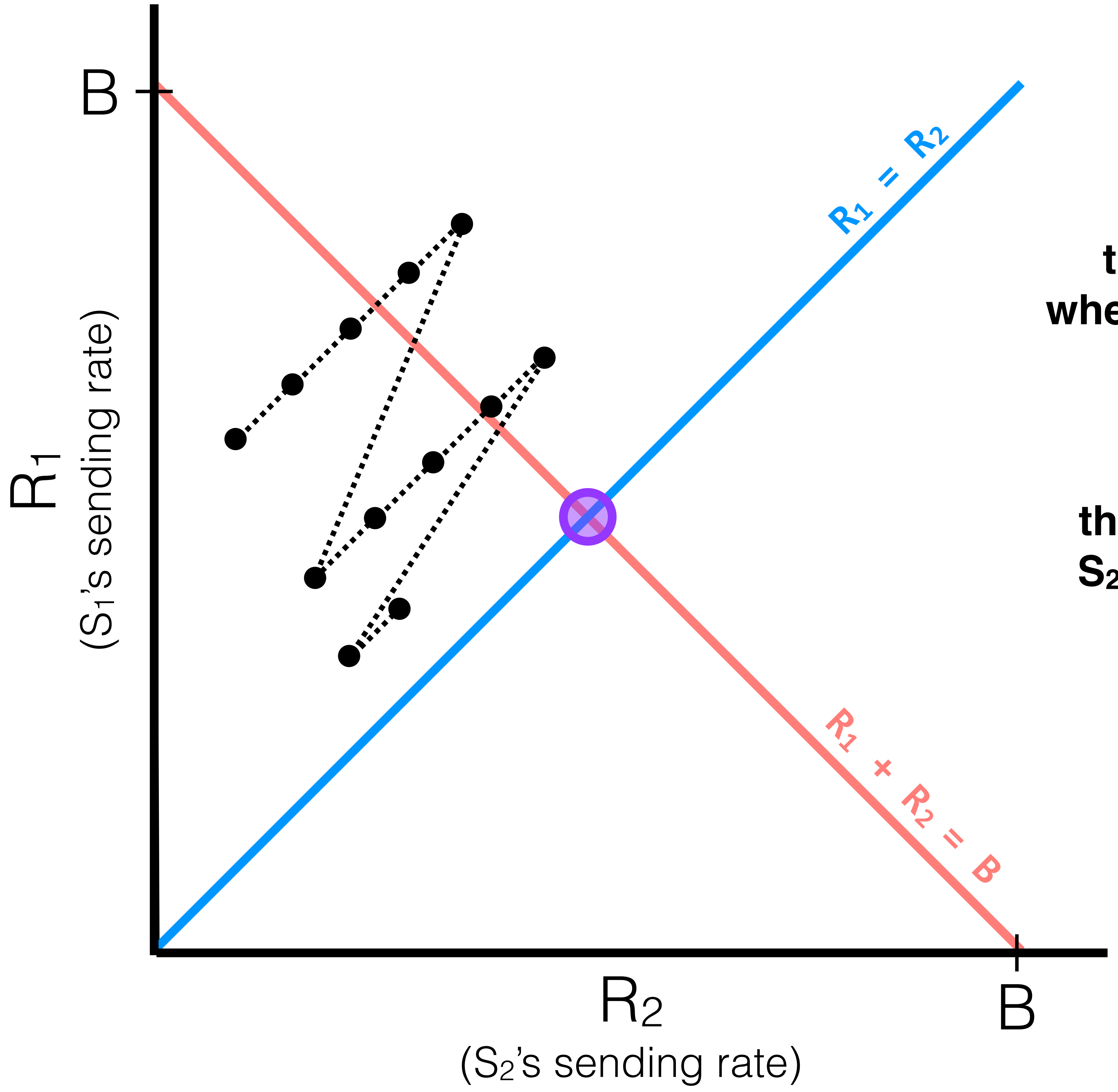

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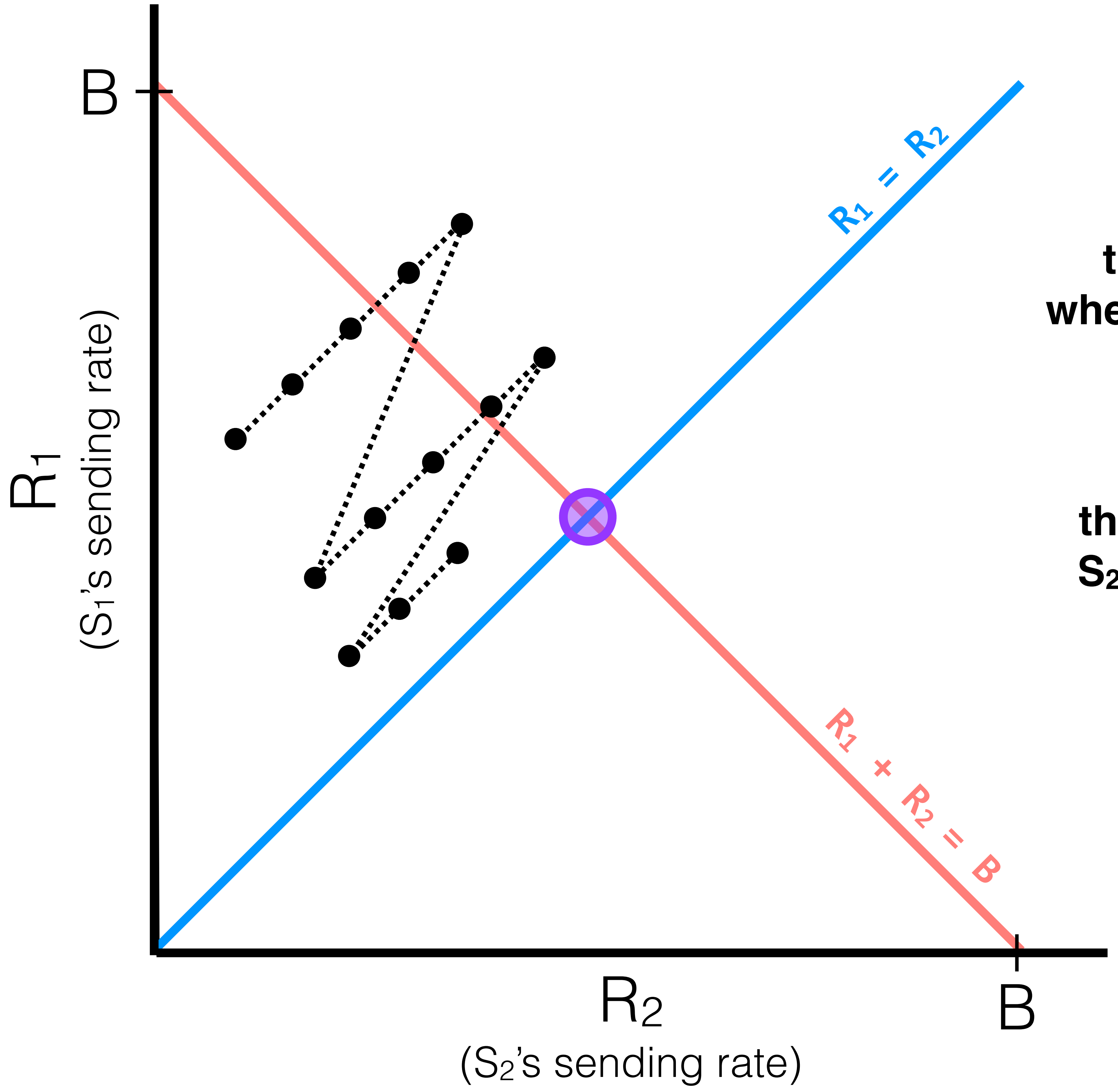

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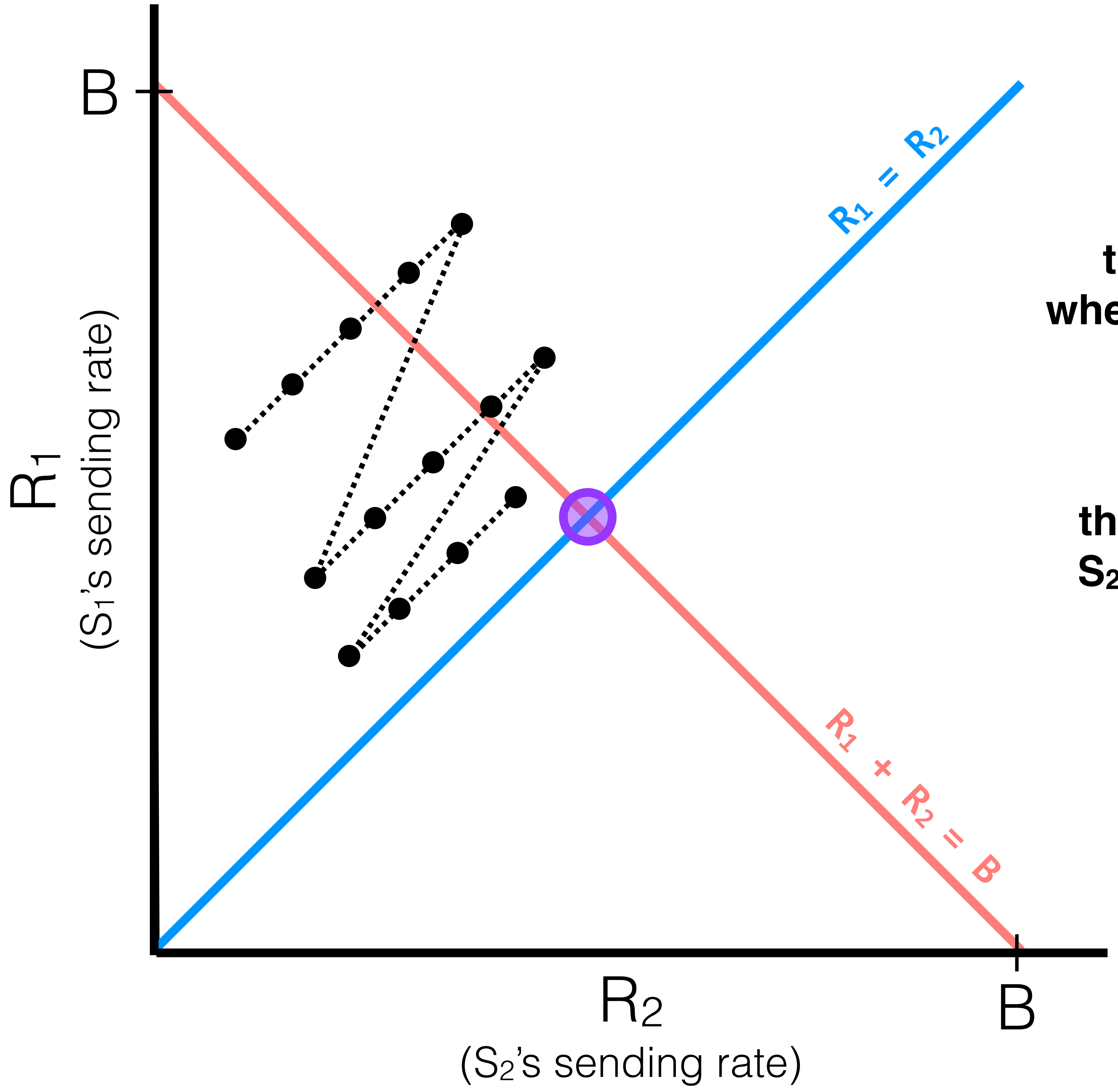

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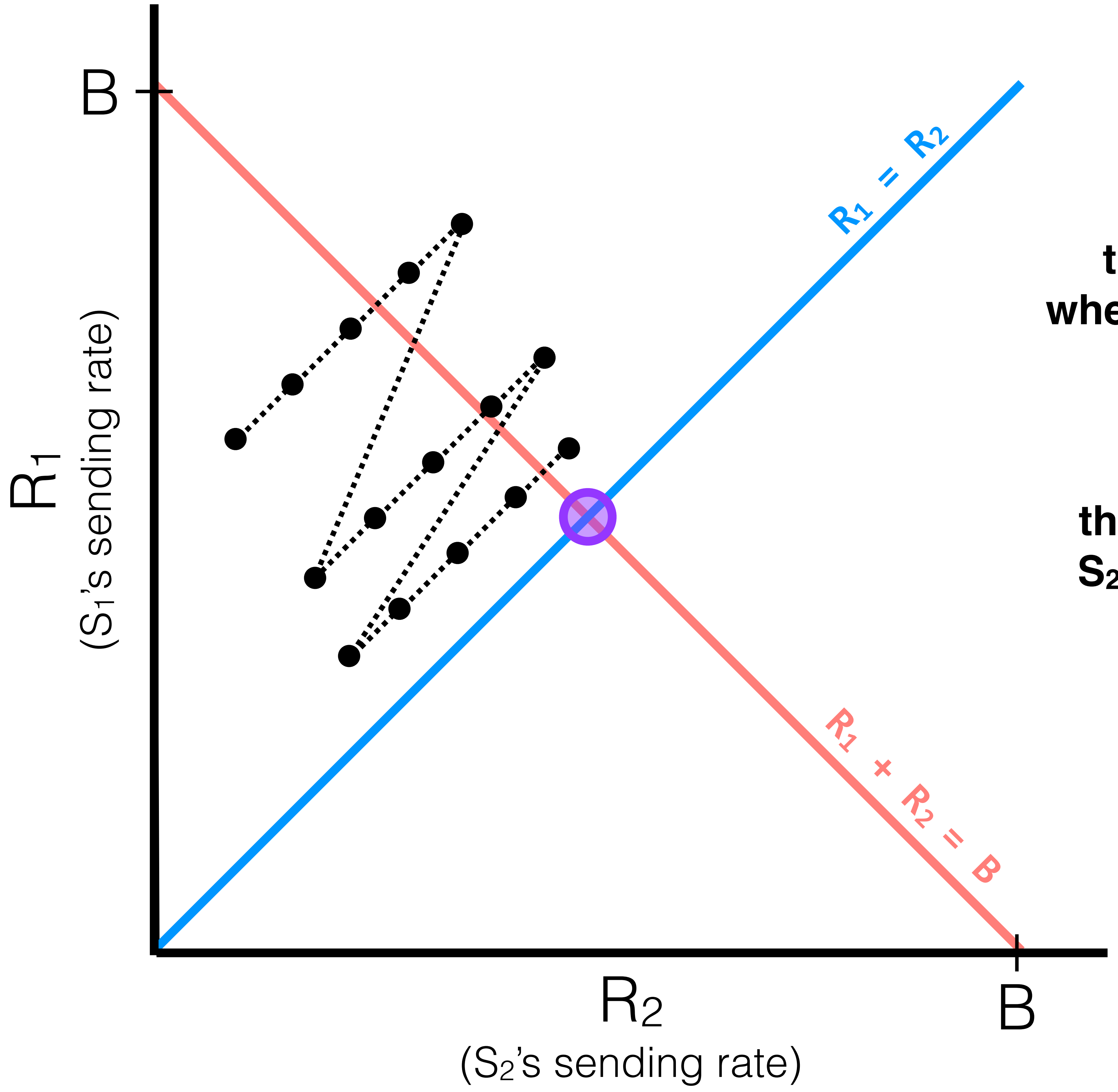

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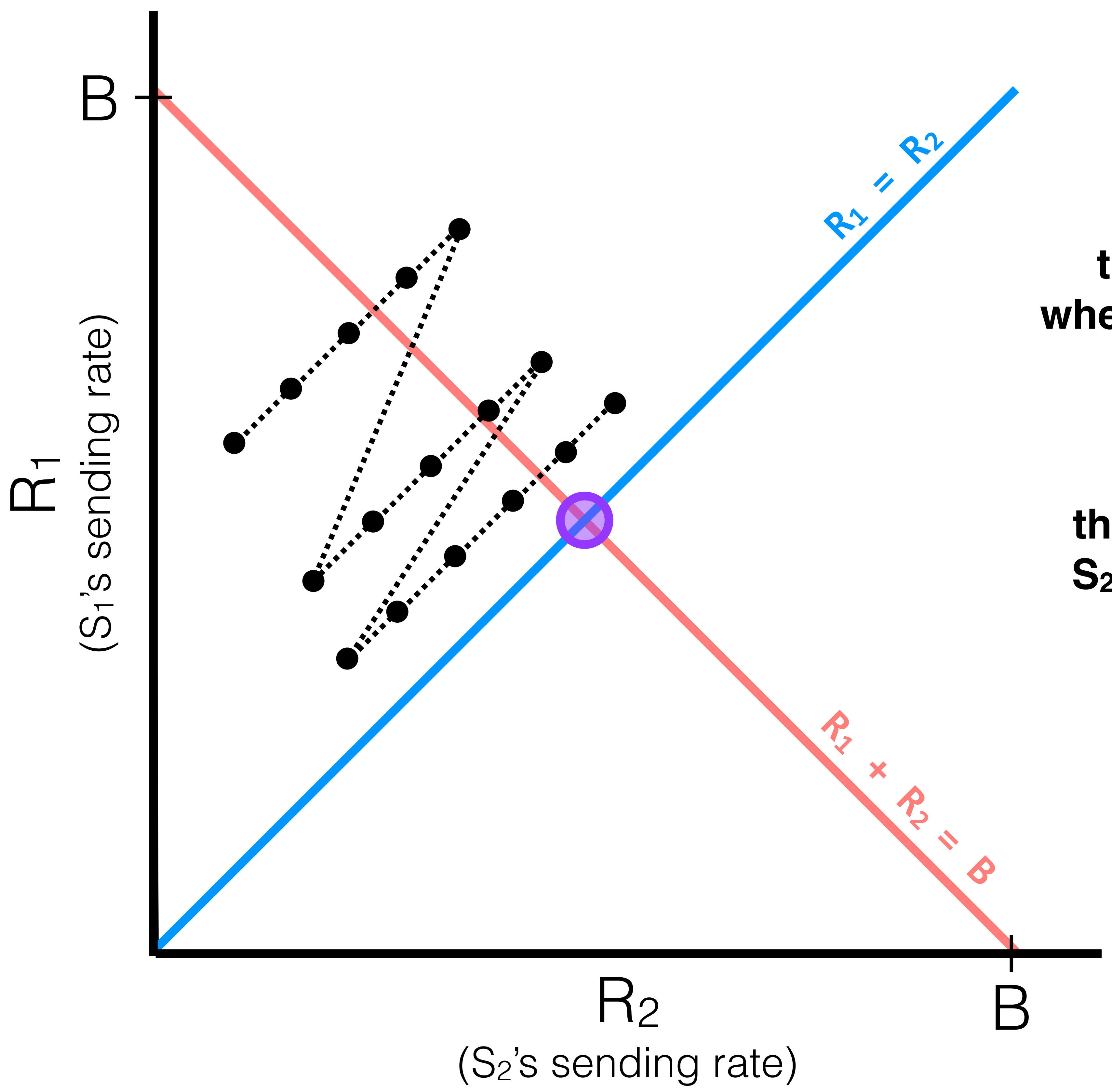

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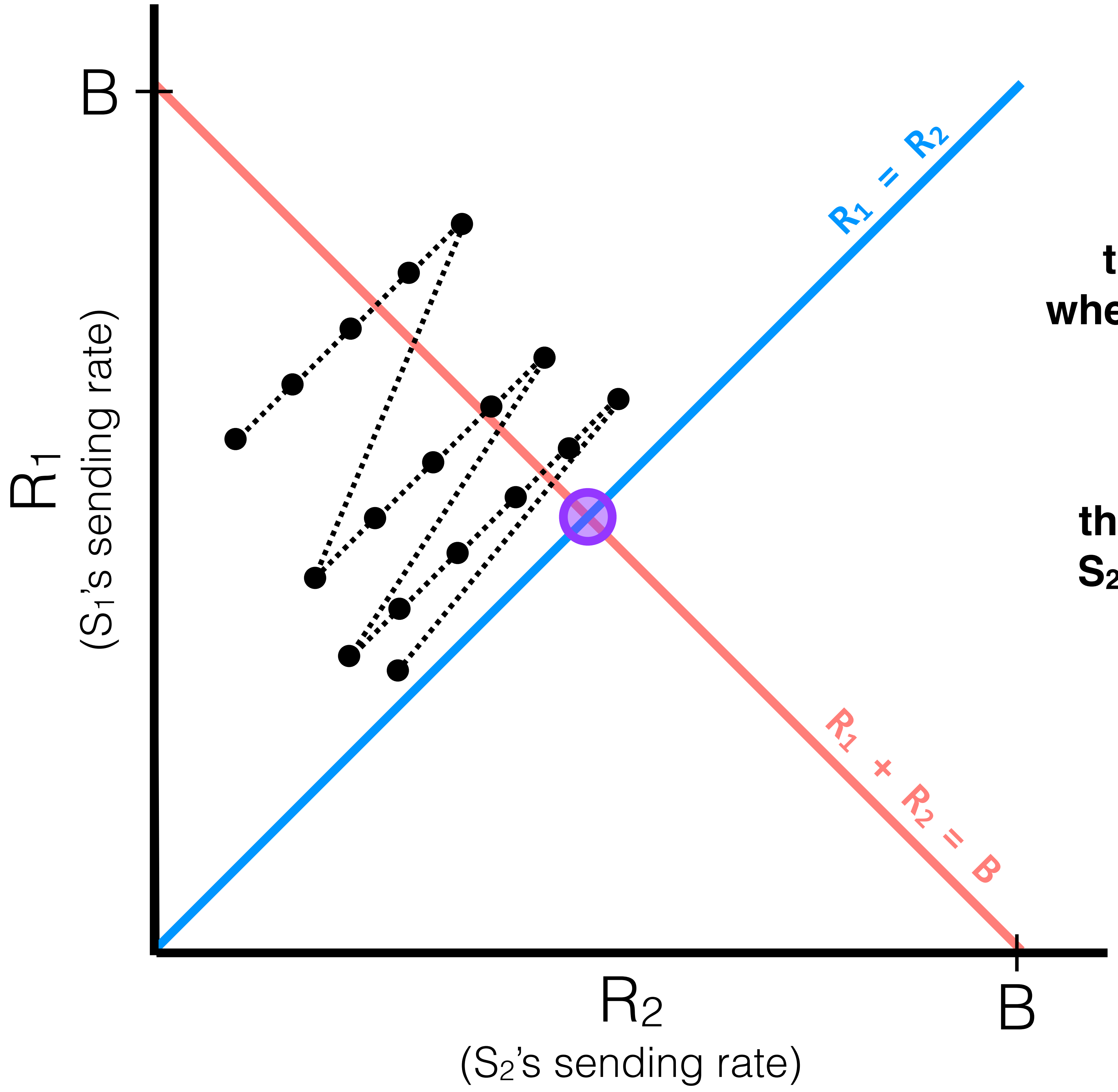

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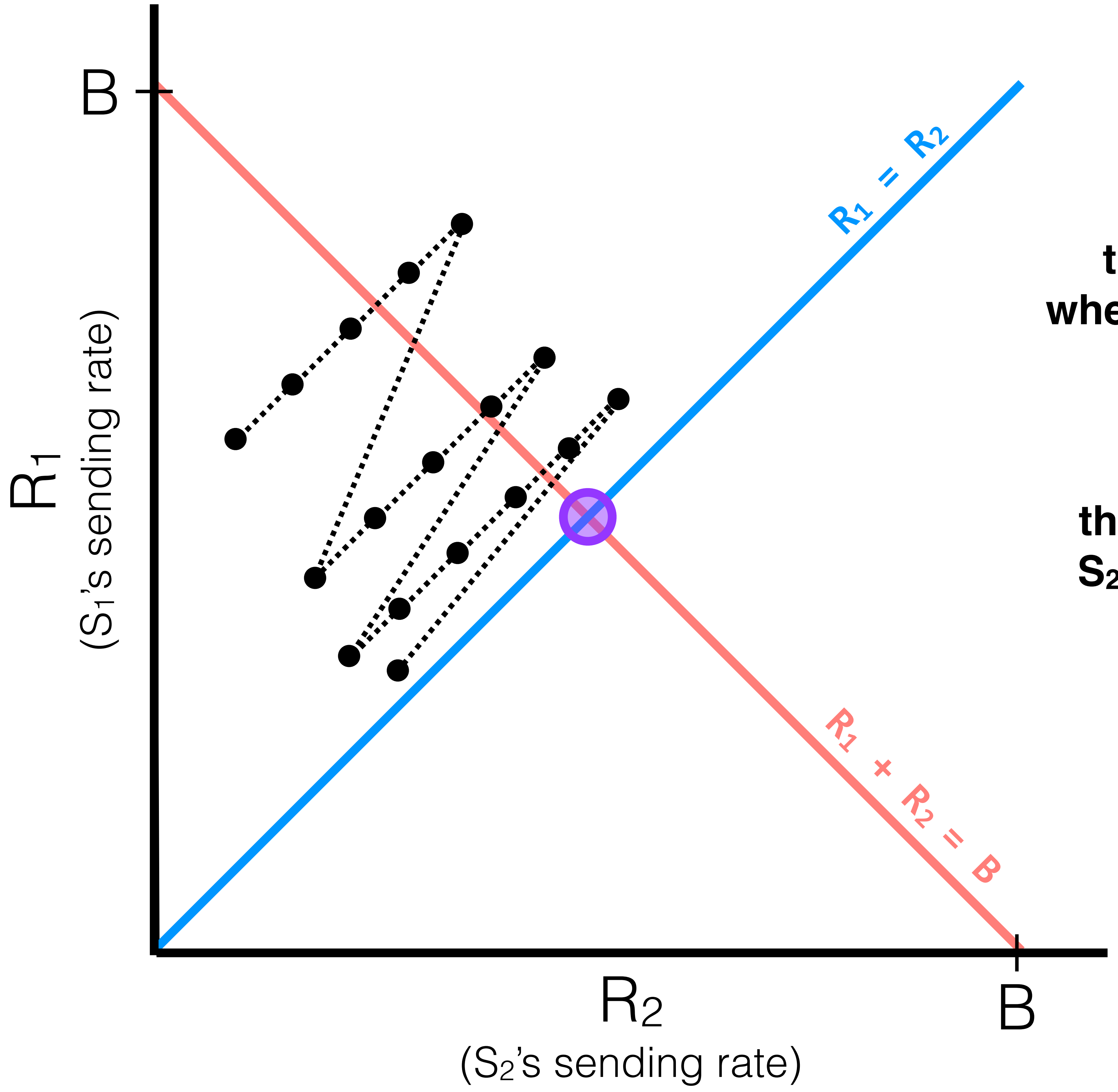

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eventually, R1 and R2 will come to oscillate around the fixed point

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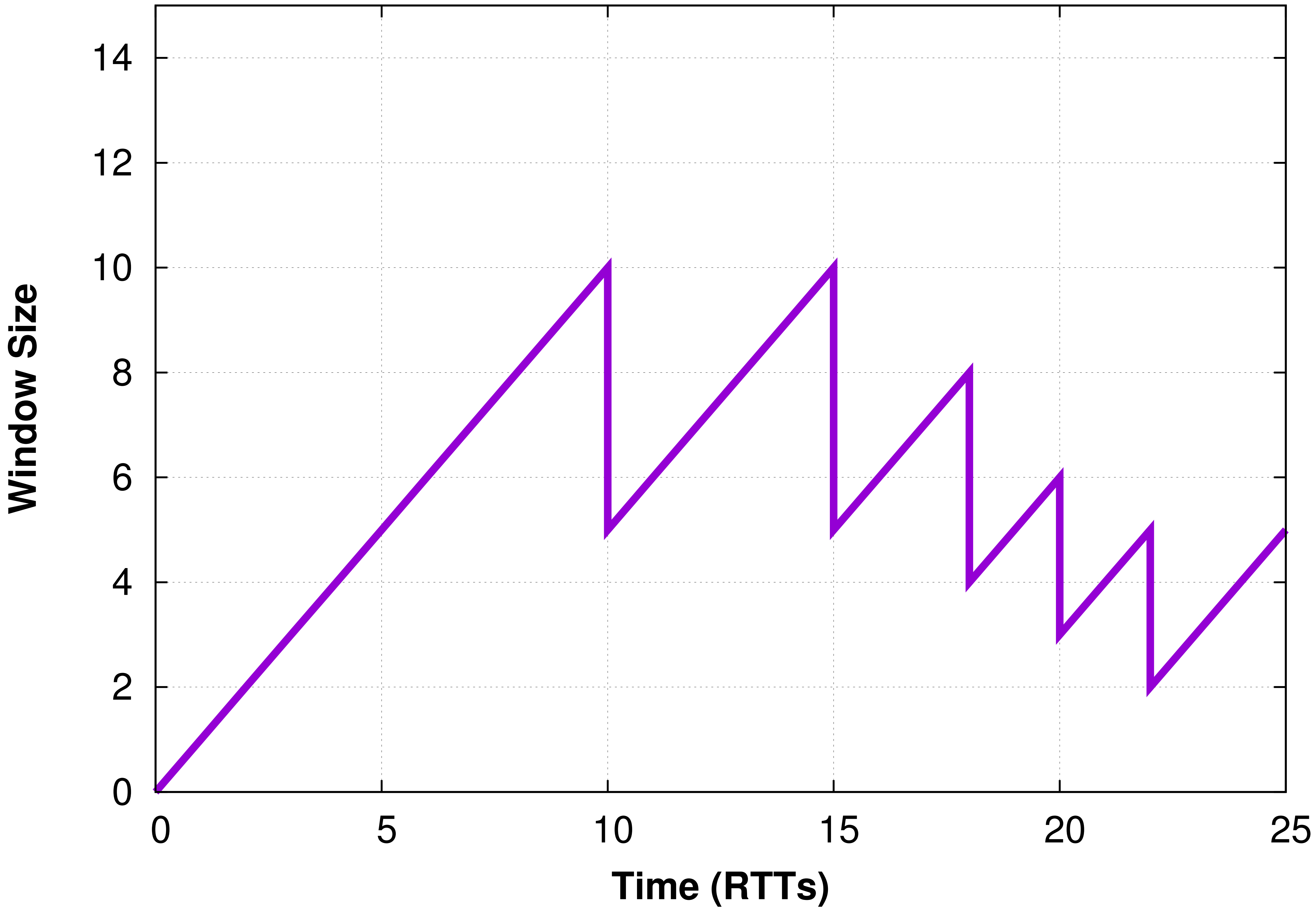

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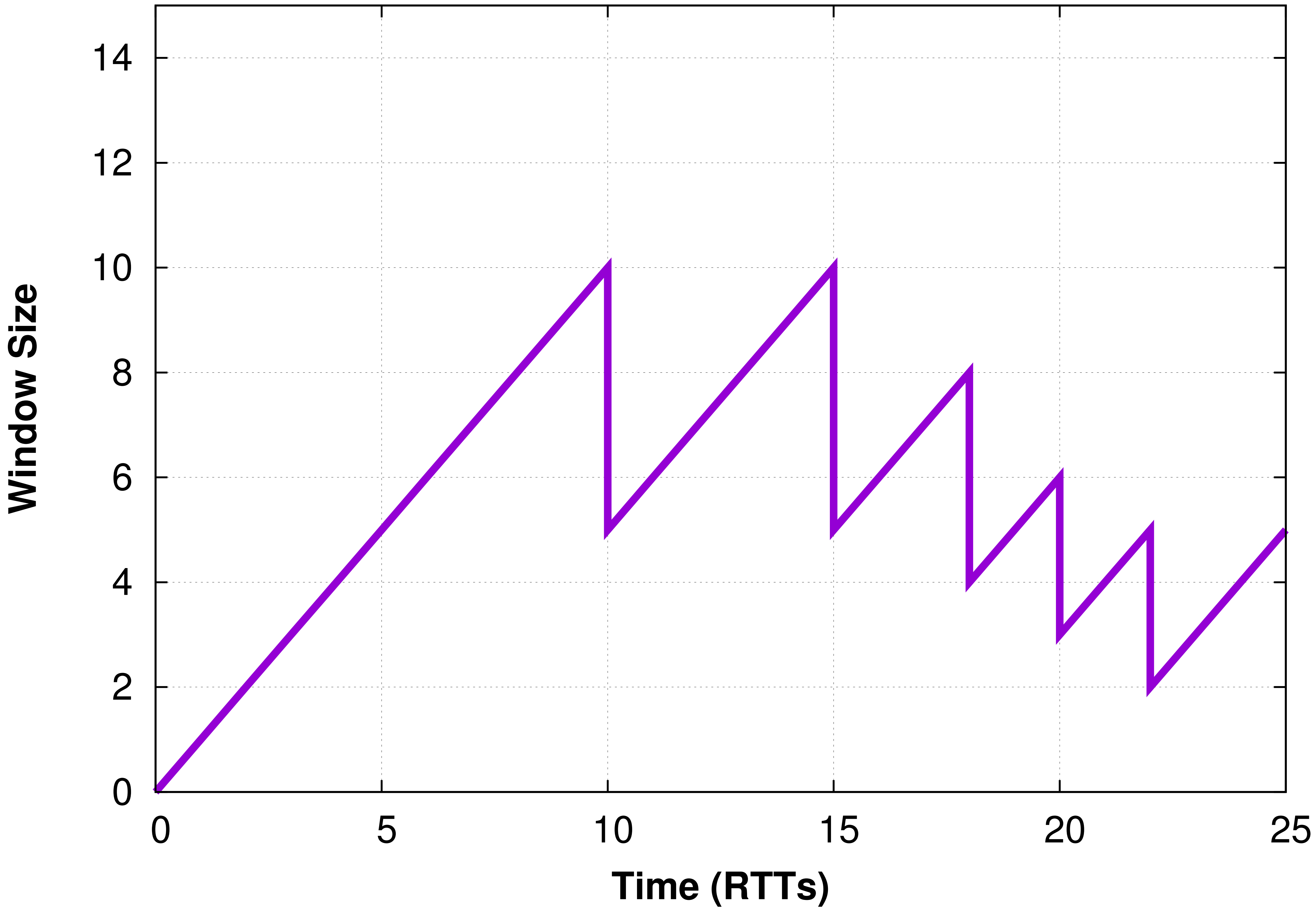

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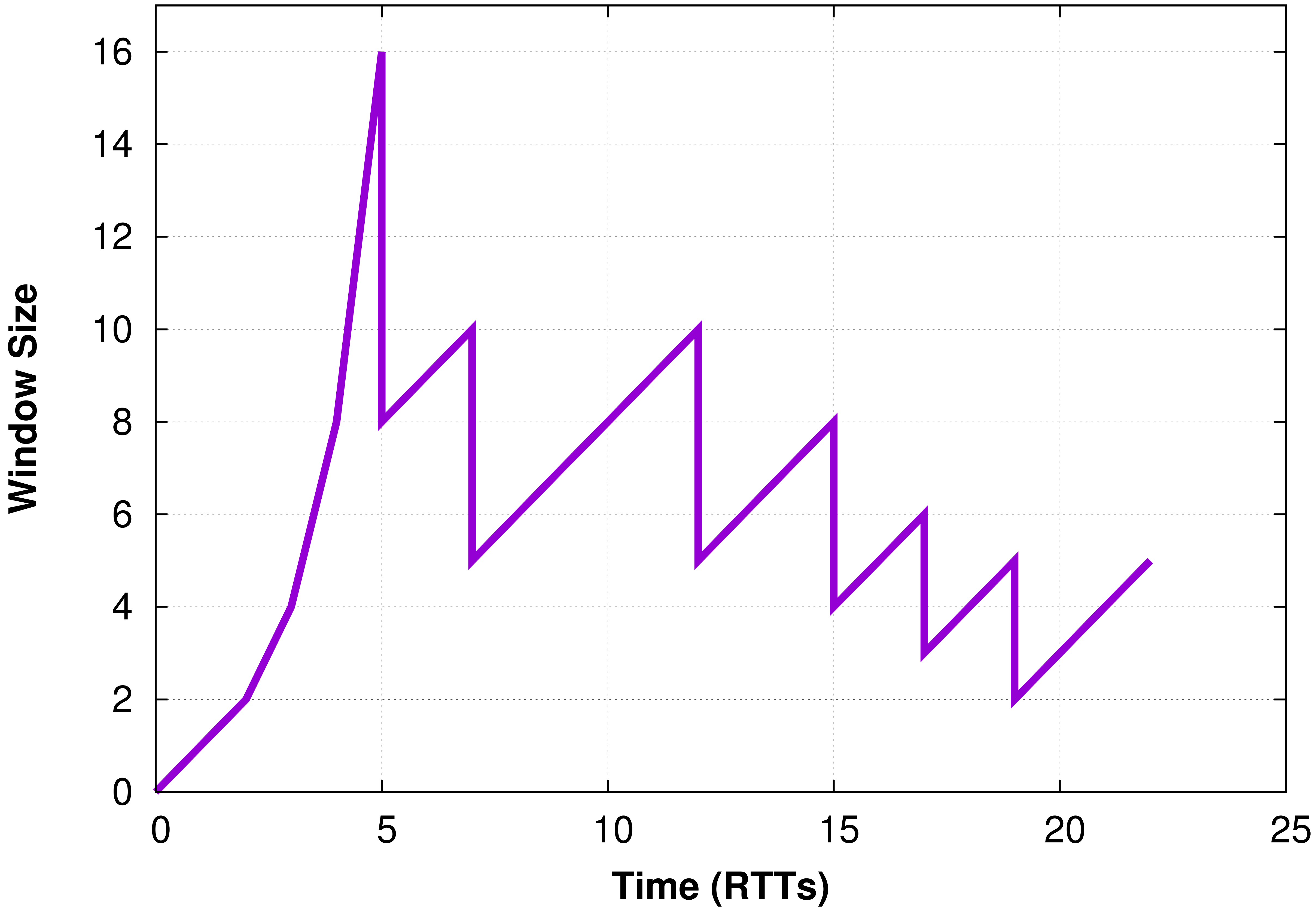

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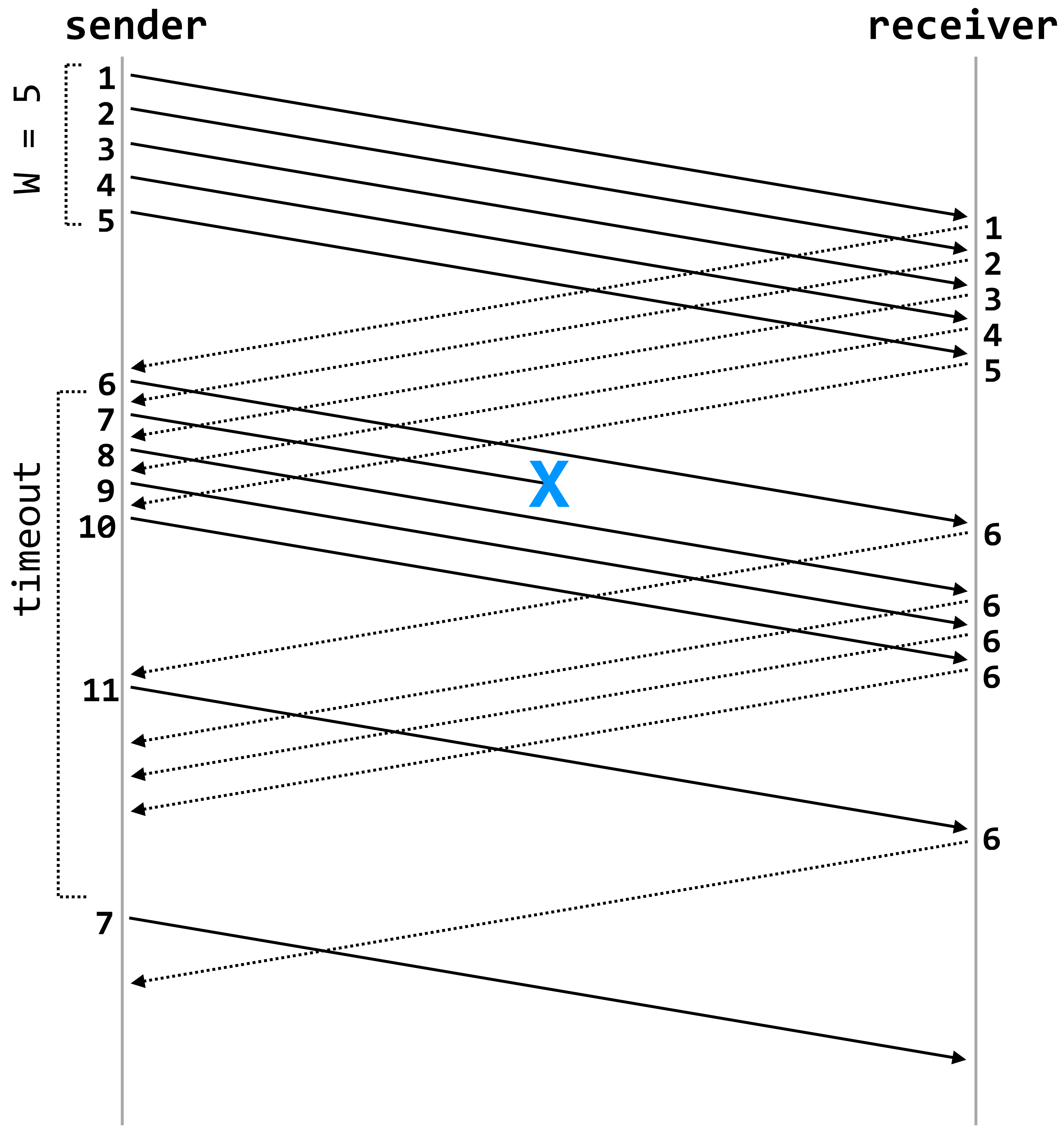

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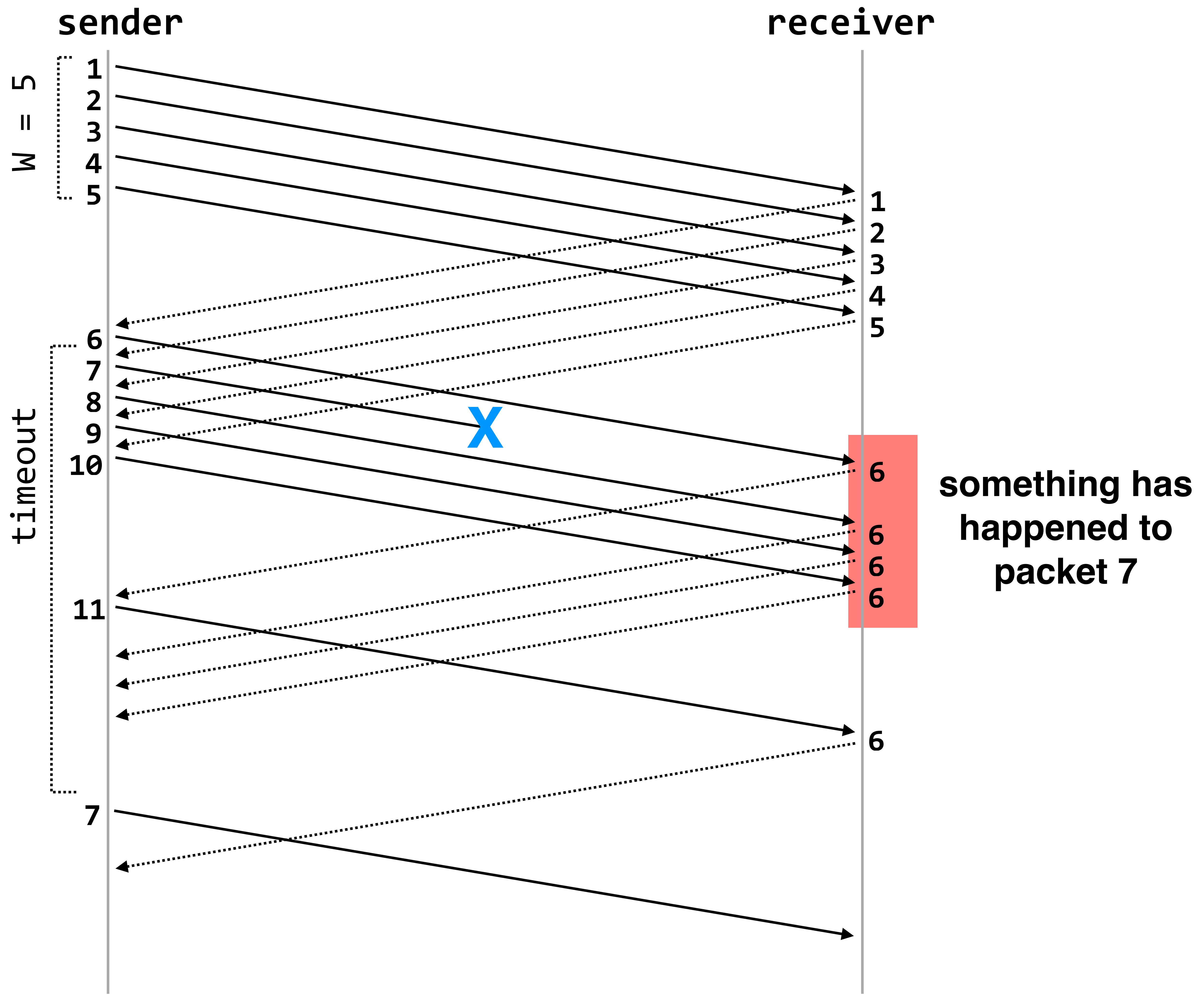

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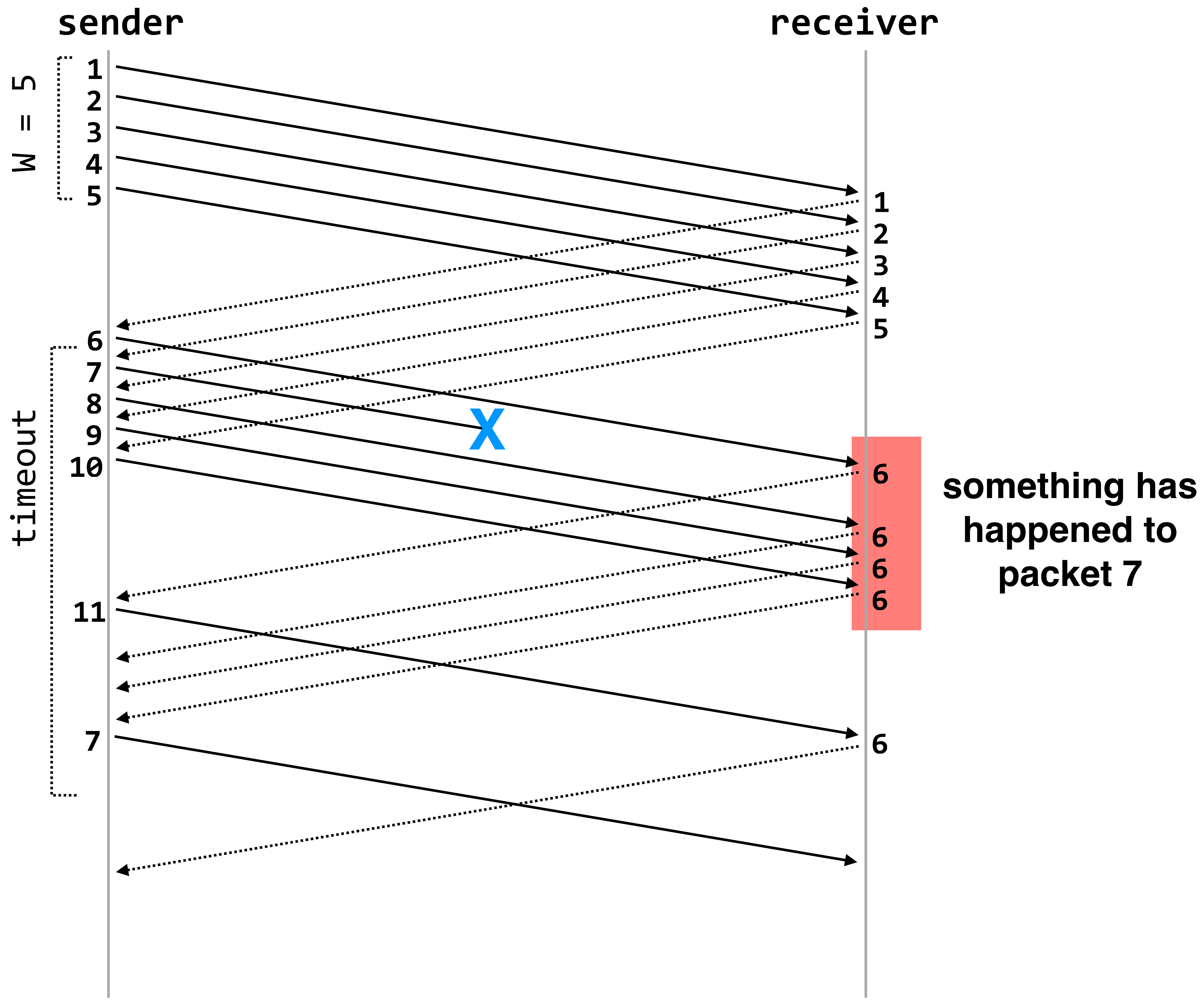

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(four = original ACK + 3 "dup" ACKs)

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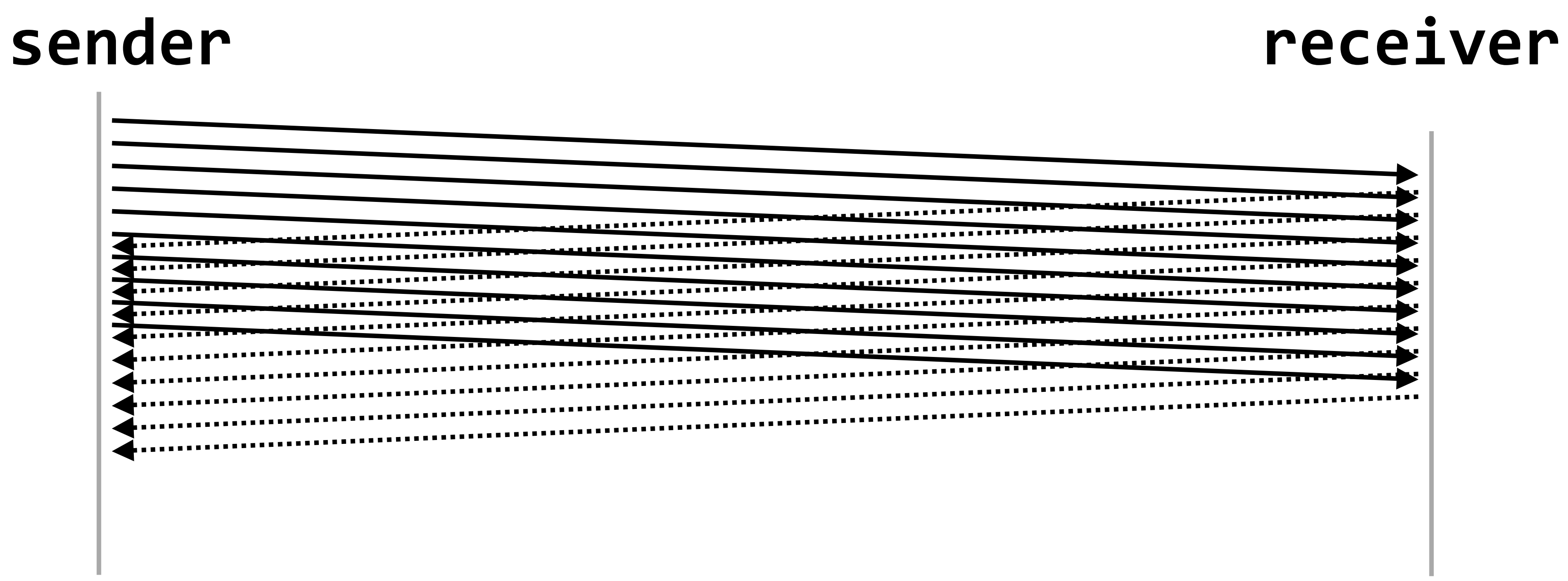

in practice, if a single packet is lost, the three "dup" ACKs will be received before the timeout for that packet expires

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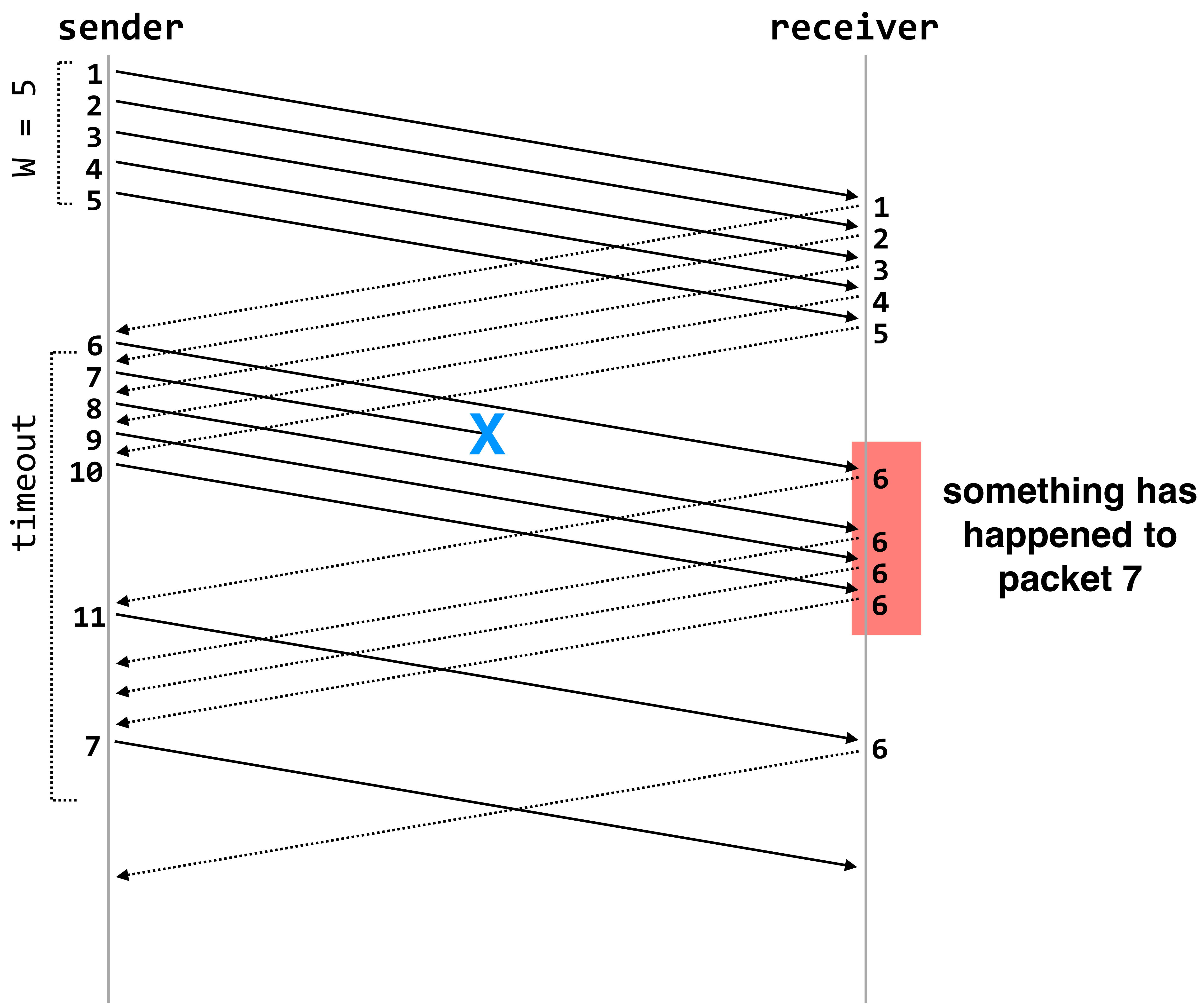

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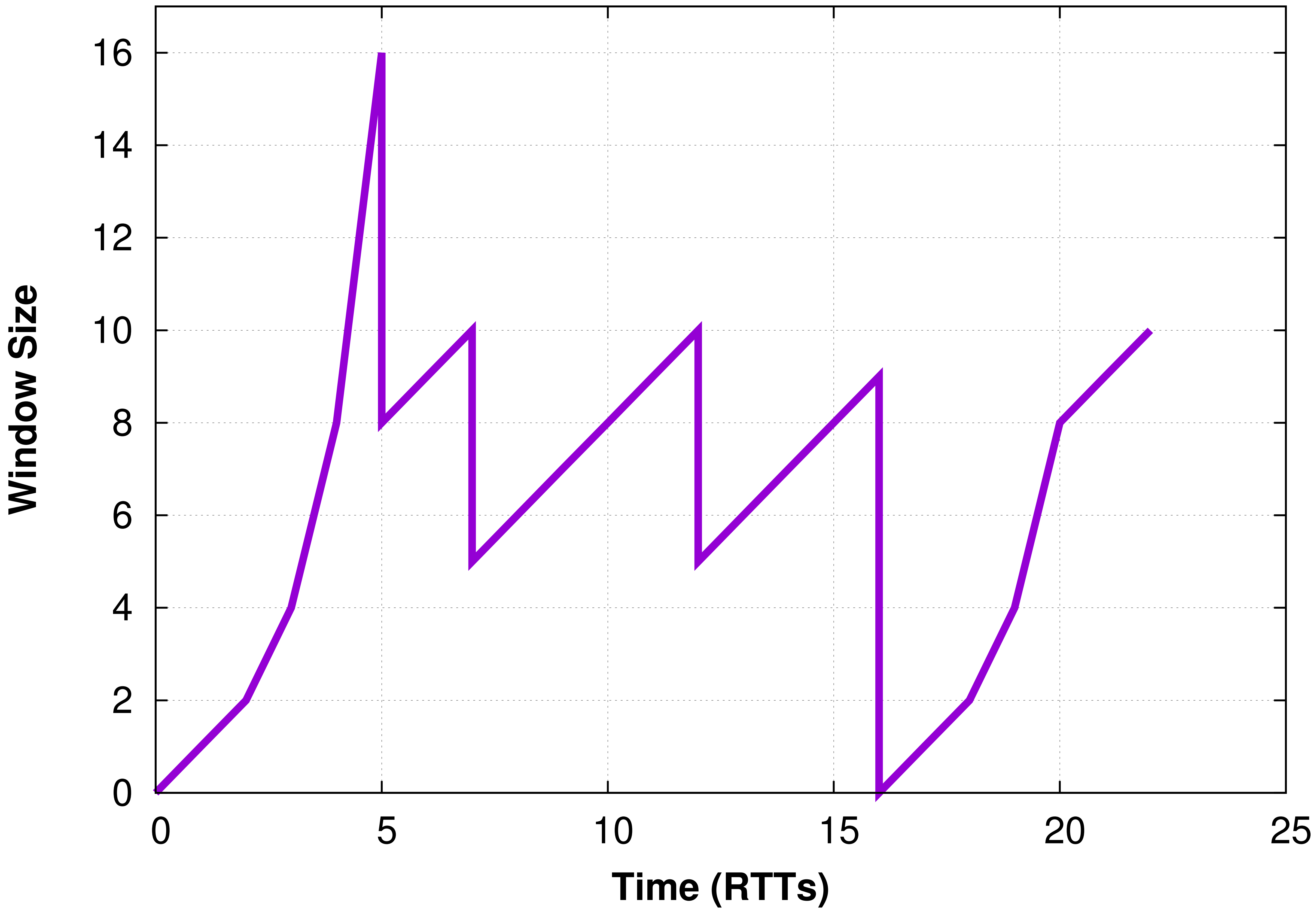

in practice, a retransmission due to a timeout happens when there is *significant* loss. senders are even more conservative, dropping their window back down to 1

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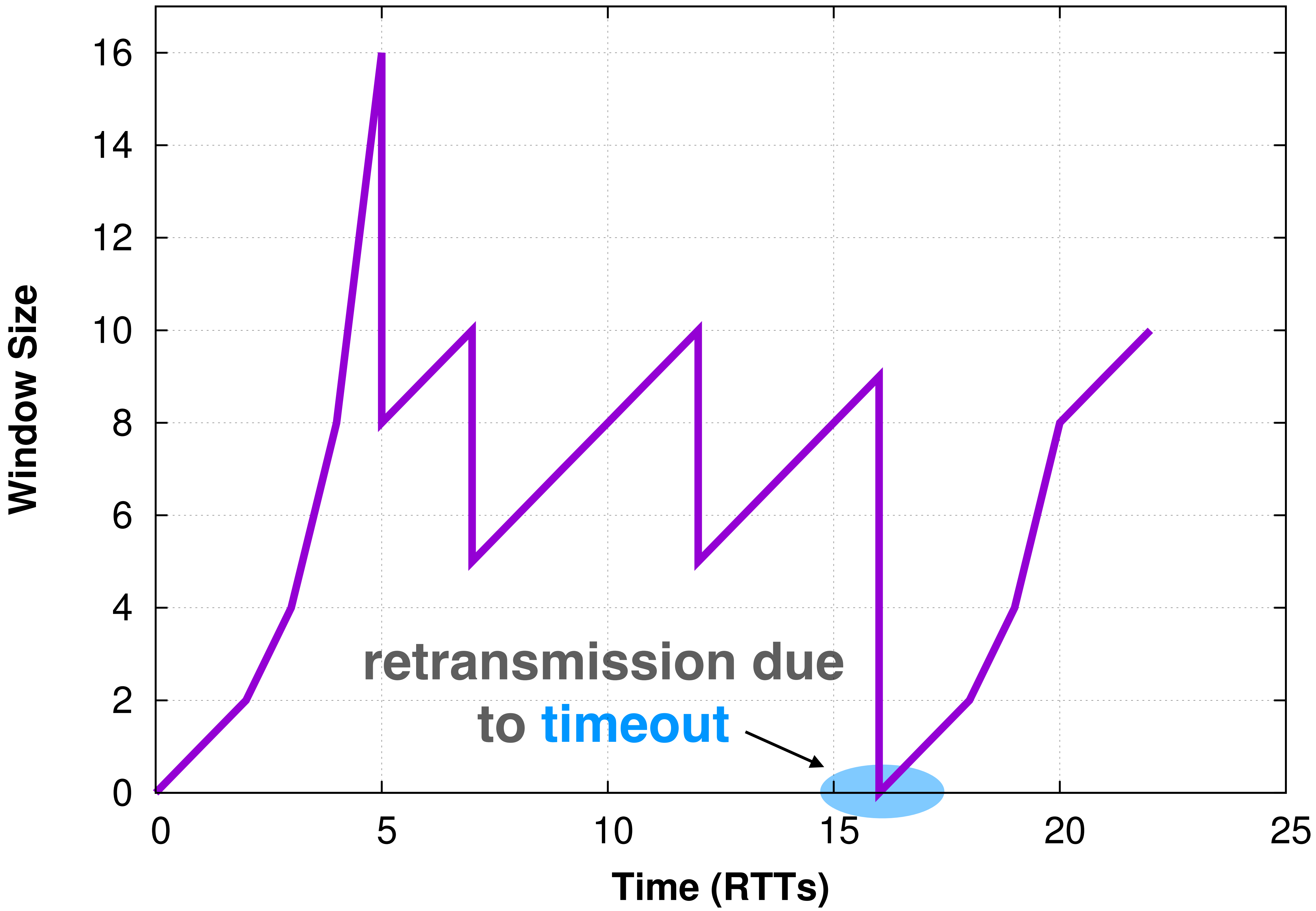

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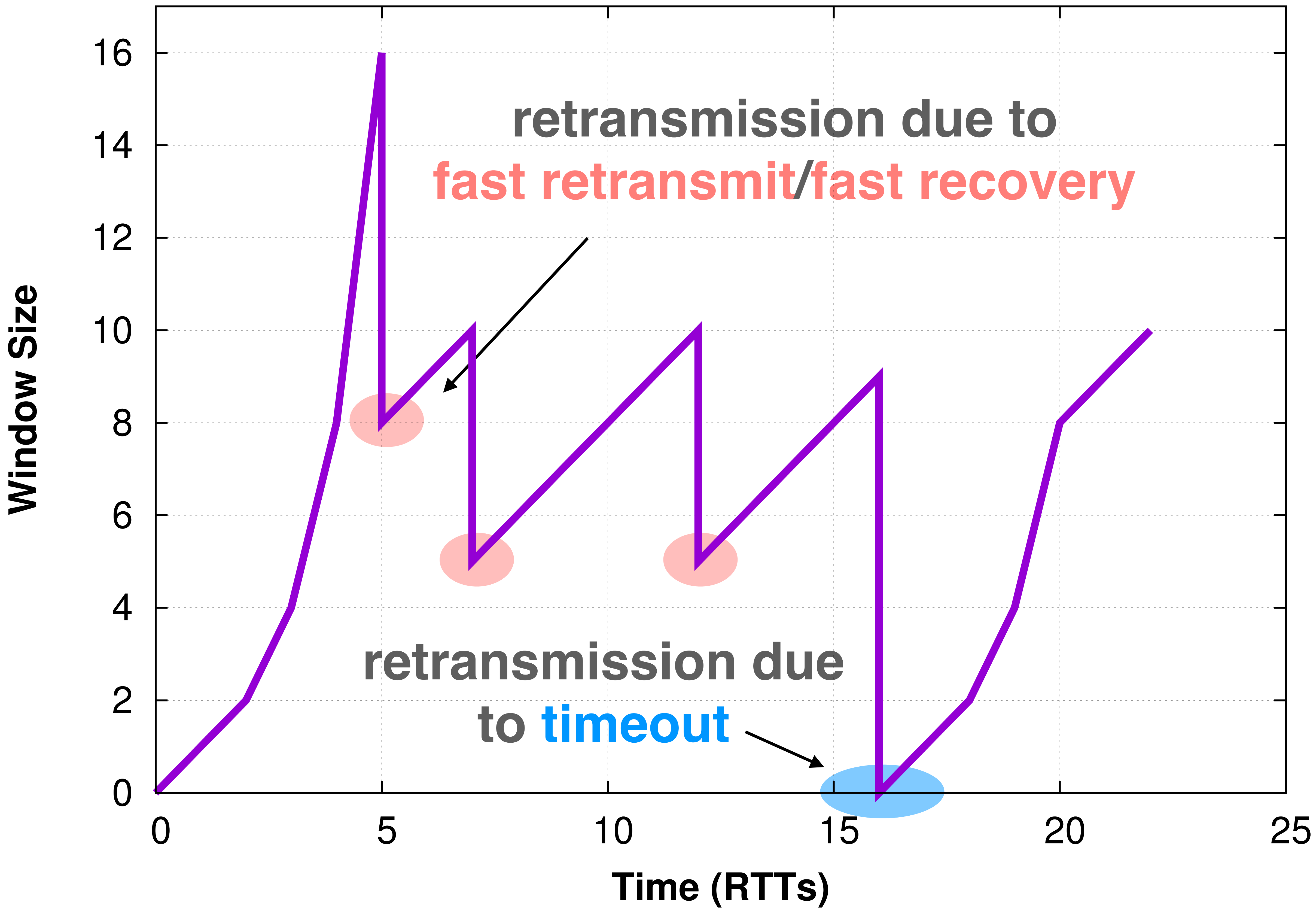

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in certain types of networks, this style of congestion control can make these problems *worse*

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AIMD is not the final word in congestion avoidance; modern versions (e.g. CUBIC TCP) use different rules to set the window size

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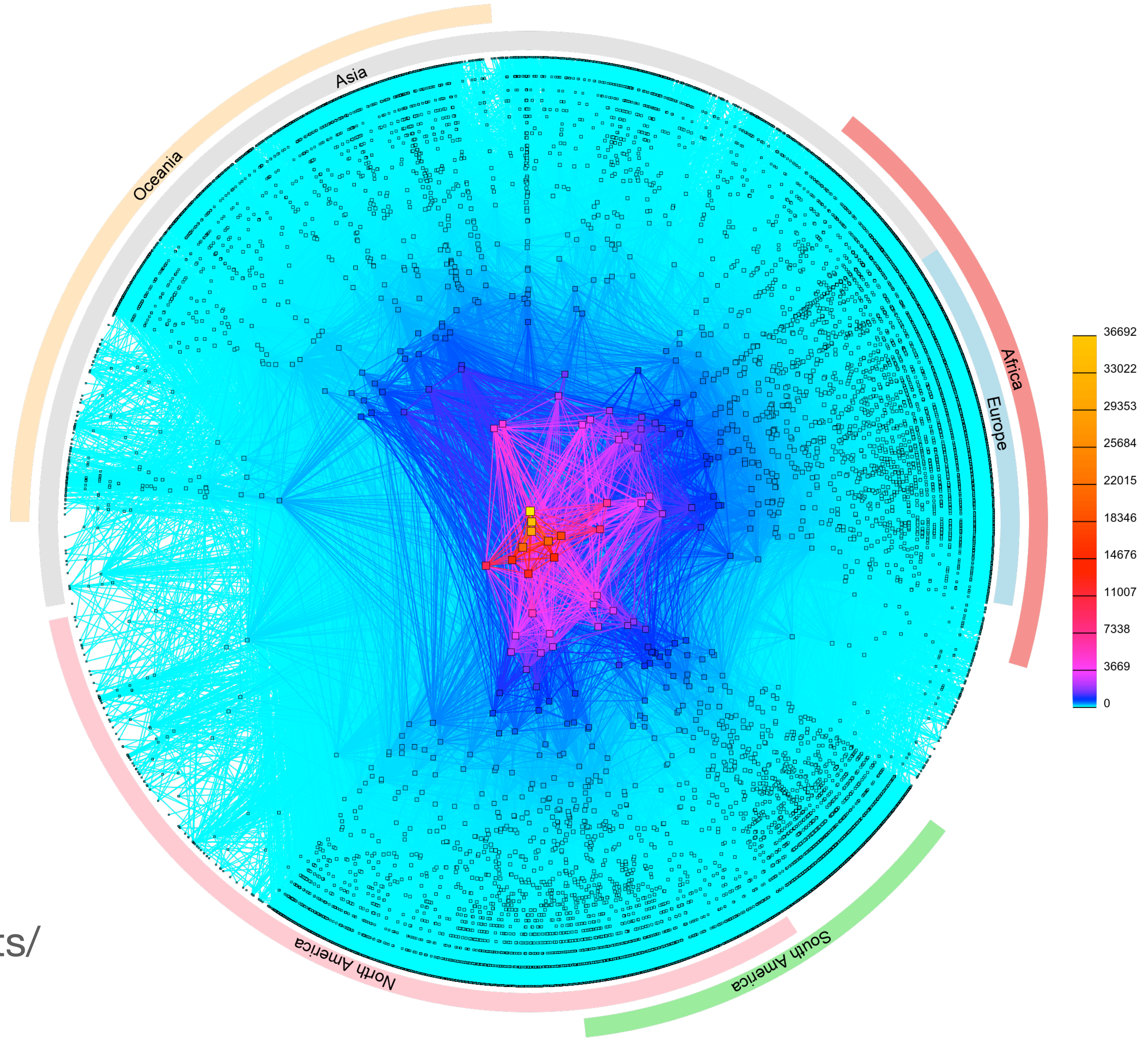
1970s: ARPAnet — 1978: flexibility and layering — early 80s: growth → change — late 80s: growth → problems — 1993: commercialization

hosts.txt | distance-vector | **TCP**, UDP | OSPF, EGP, DNS | congestion collapse (which led to **congestion control**) | policy routing | CIDR



CAIDA's IPv4 AS Core, January 2020 (https://www.caida.org/projects/cartography/as-core/2020/)

application	the things that actually generate traffic
transport	sharing the network, reliability (or not) *examples: TCP, UDP*
network	naming, addressing, routing *examples: IP*
link	communication between two directly-connected nodes *examples: ethernet, bluetooth, 802.11 (wifi)*

next time: TCP congestion control doesn't react to congestion until after it's a problem; could we get senders to react before queues are full?