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2–5 September 2024 // Valencia, Spain

Elevating 6G Beyond Connectivity

IEEE International
Symposium on

Personal, Indoor and Mobile Radio Communications

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Elevating 6G Beyond Connectivity

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“Novel Radio Frame Design for Efficient Integration of Wireless Links into Time-Sensitive Networks”

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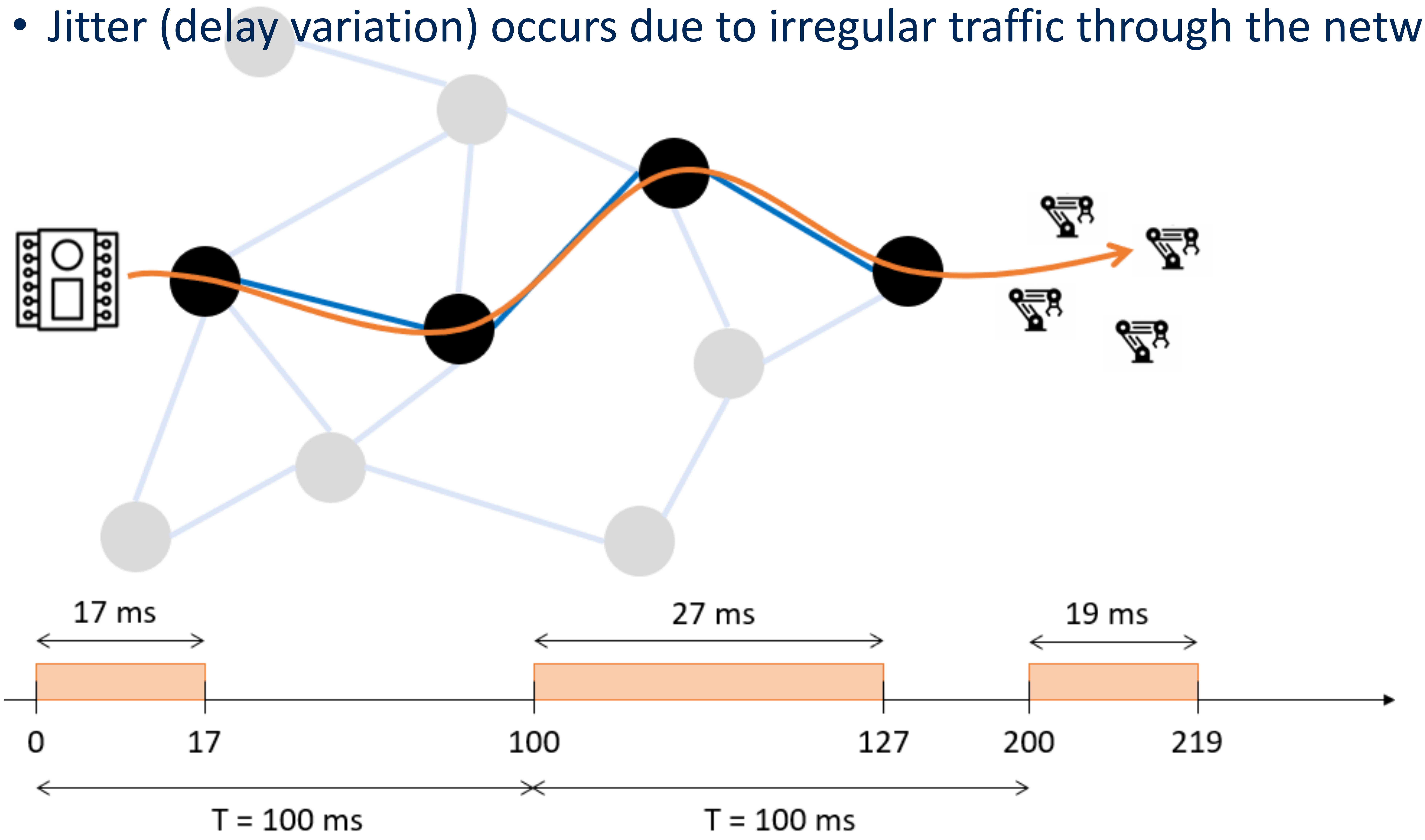
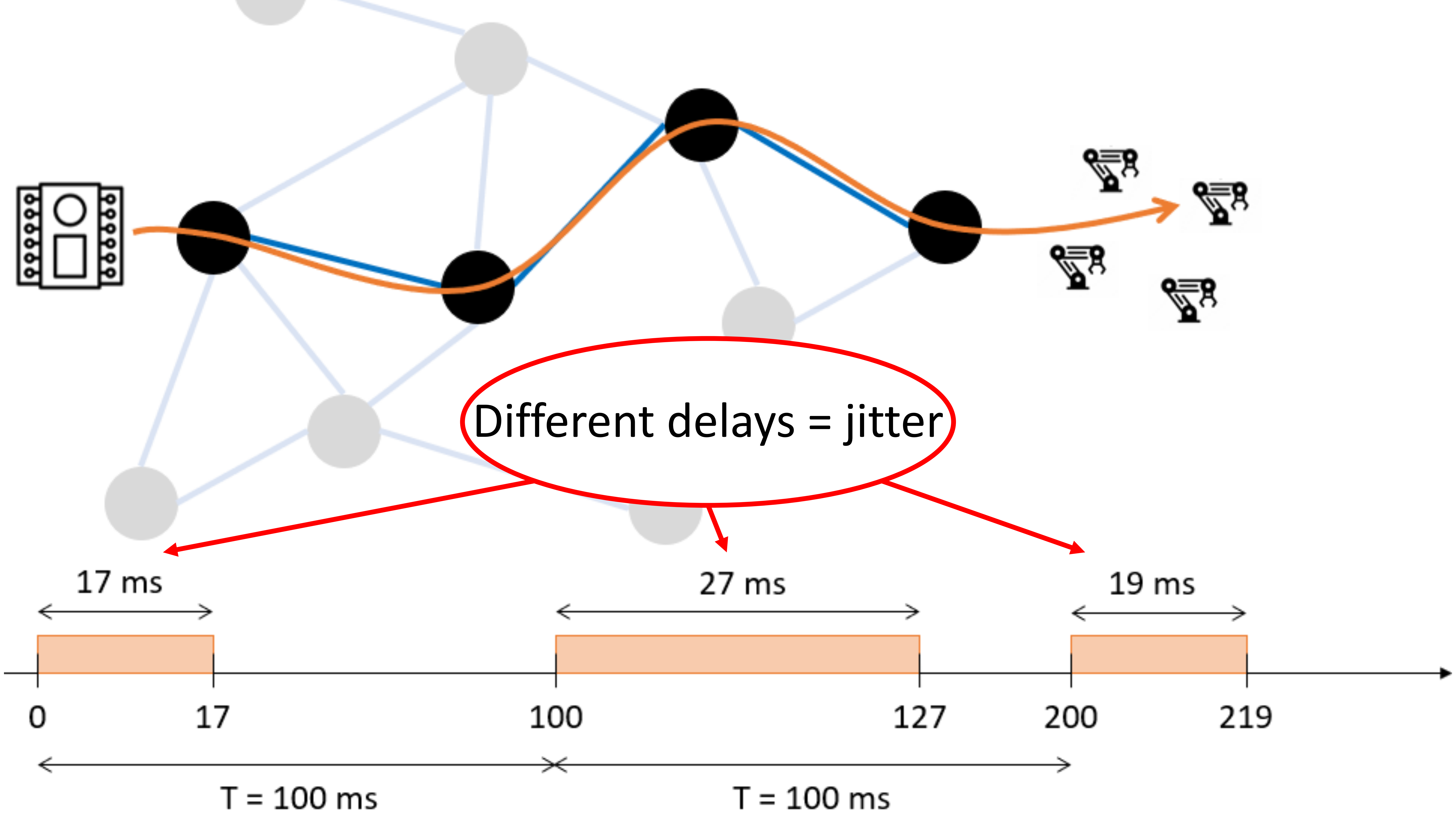
Introduction

- Jitter (delay variation) occurs due to irregular traffic through the network.


17 ms
27 ms
19 ms
0
17
100
127
200
219
T = 100 ms
T = 100 ms

Introduction

- Jitter (delay variation) occurs due to irregular traffic through the network.

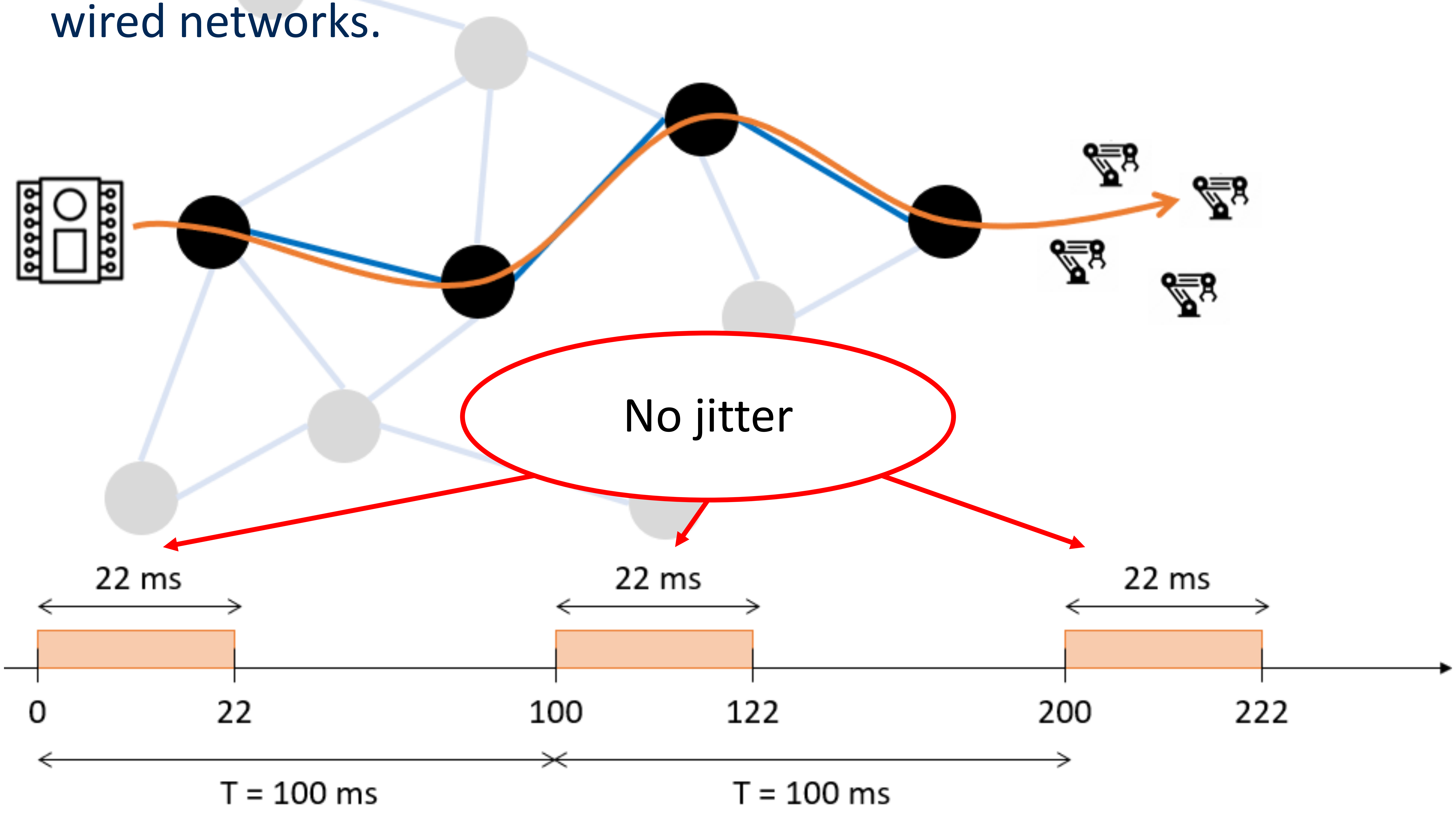


Different delays = jitter

17 ms
27 ms
19 ms
0
17
100
127
200
219
T = 100 ms
T = 100 ms

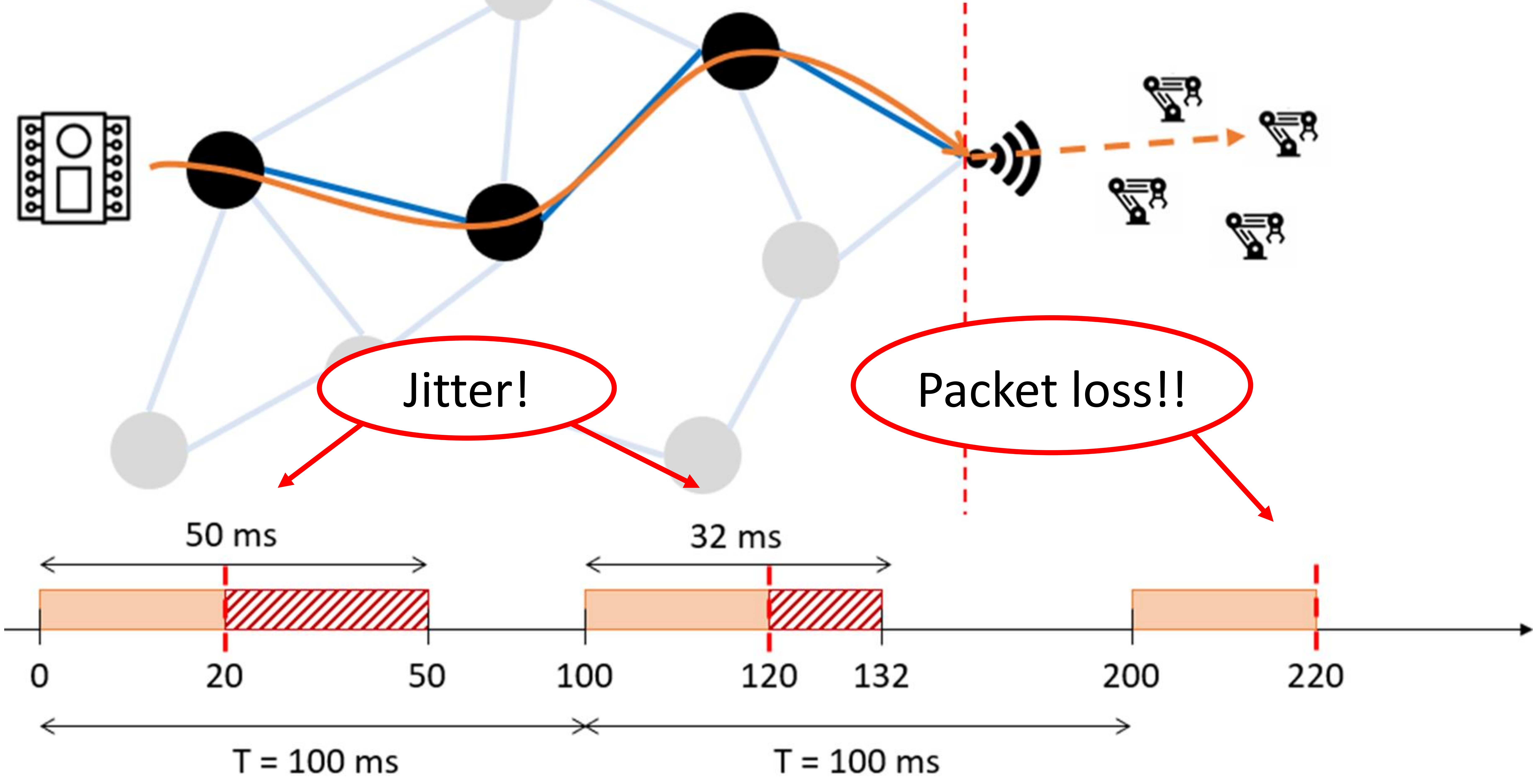
Introduction

- IEEE Time-Sensitive Networking standards can be implemented to eliminate jitter in wired networks.


No jitter
22 ms
22 ms
22 ms
0
22
100
122
200
222
T = 100 ms
T = 100 ms

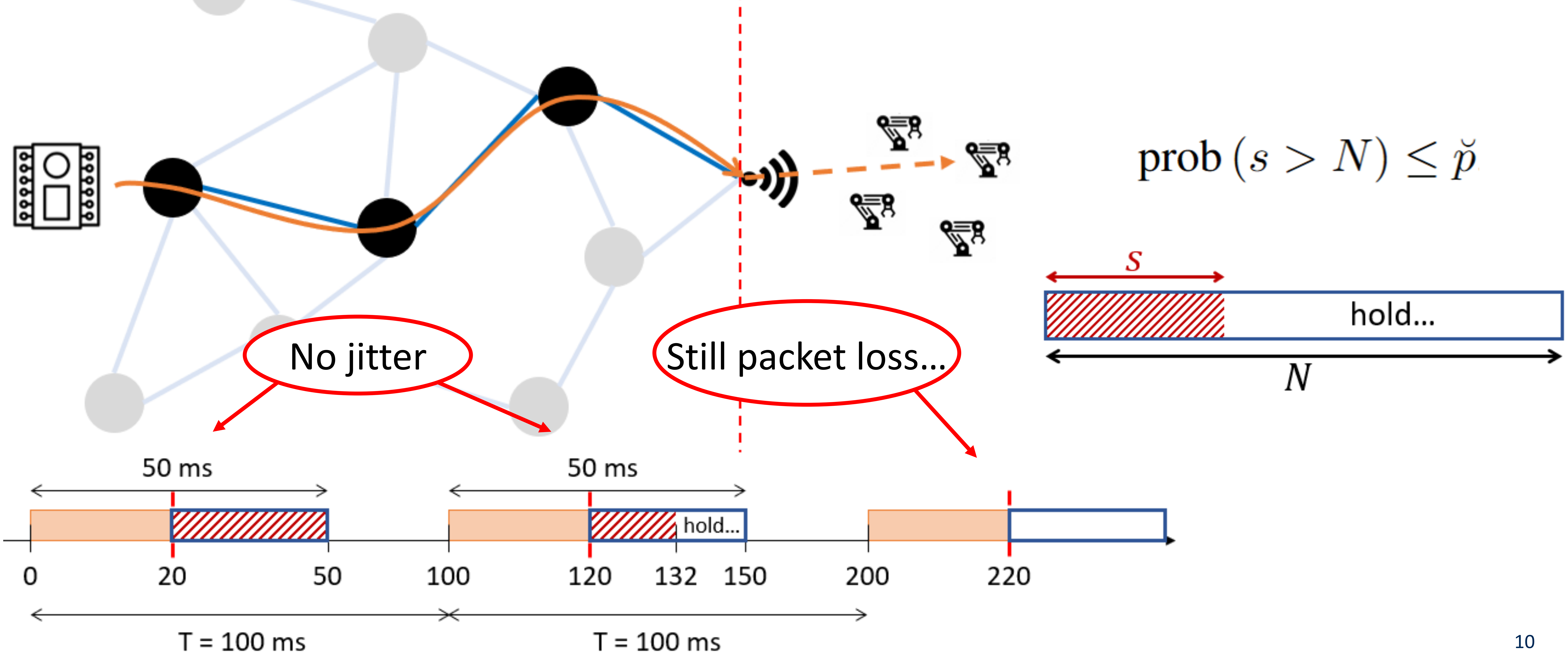
Introduction

- However, current TSN standards do not guarantee null jitter in wireless networks.
- The multipath effect in wireless links causes random delays and even packet loss.


Jitter!
Packet loss!!
50 ms
32 ms
0
20
50
100
120
132
200
220
T = 100 ms
T = 100 ms

Hold&Forward

- To avoid jitter, we implement the Hold&Forward technique.



$$\text{prob}\,(s > N) \le \breve{p}$$

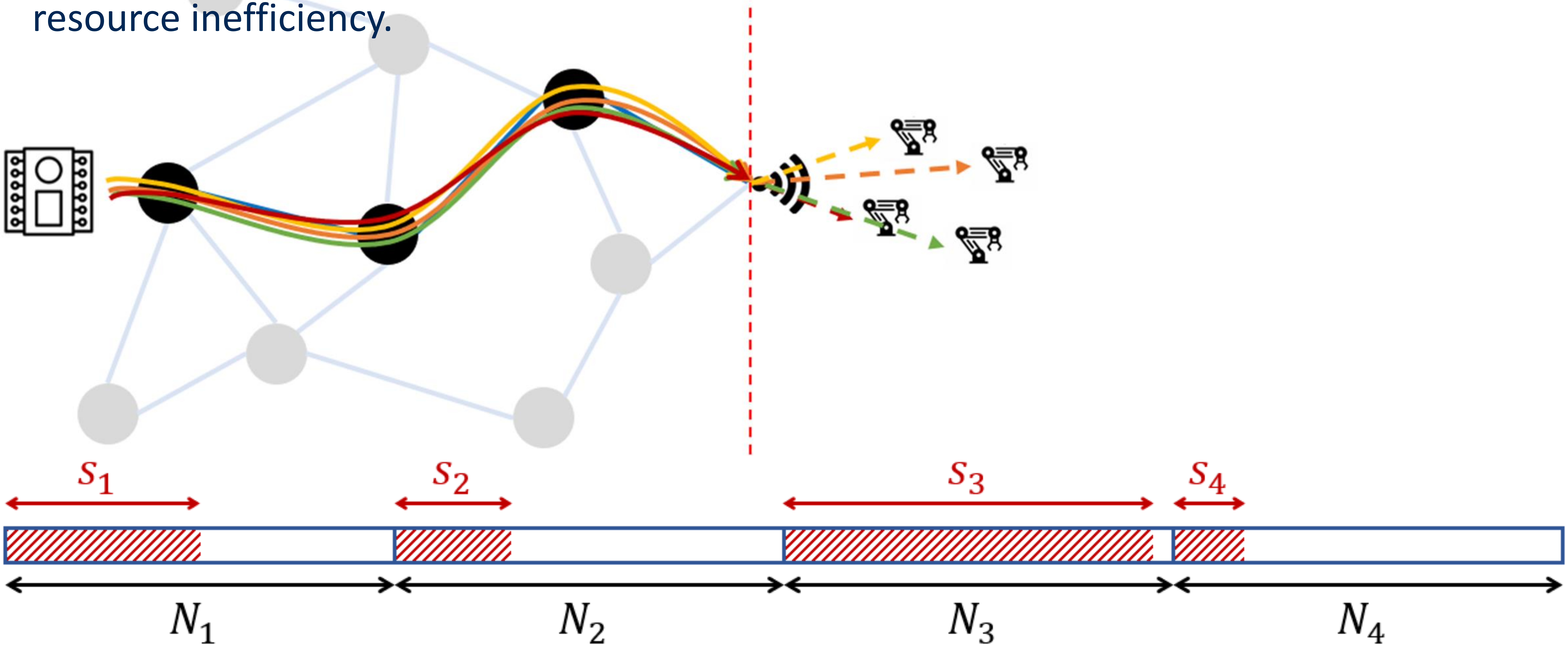
No jitter

Still packet loss…

s
hold…
N
50 ms
50 ms
hold…
0
20
50
100
120
132
150
200
220
T = 100 ms
T = 100 ms

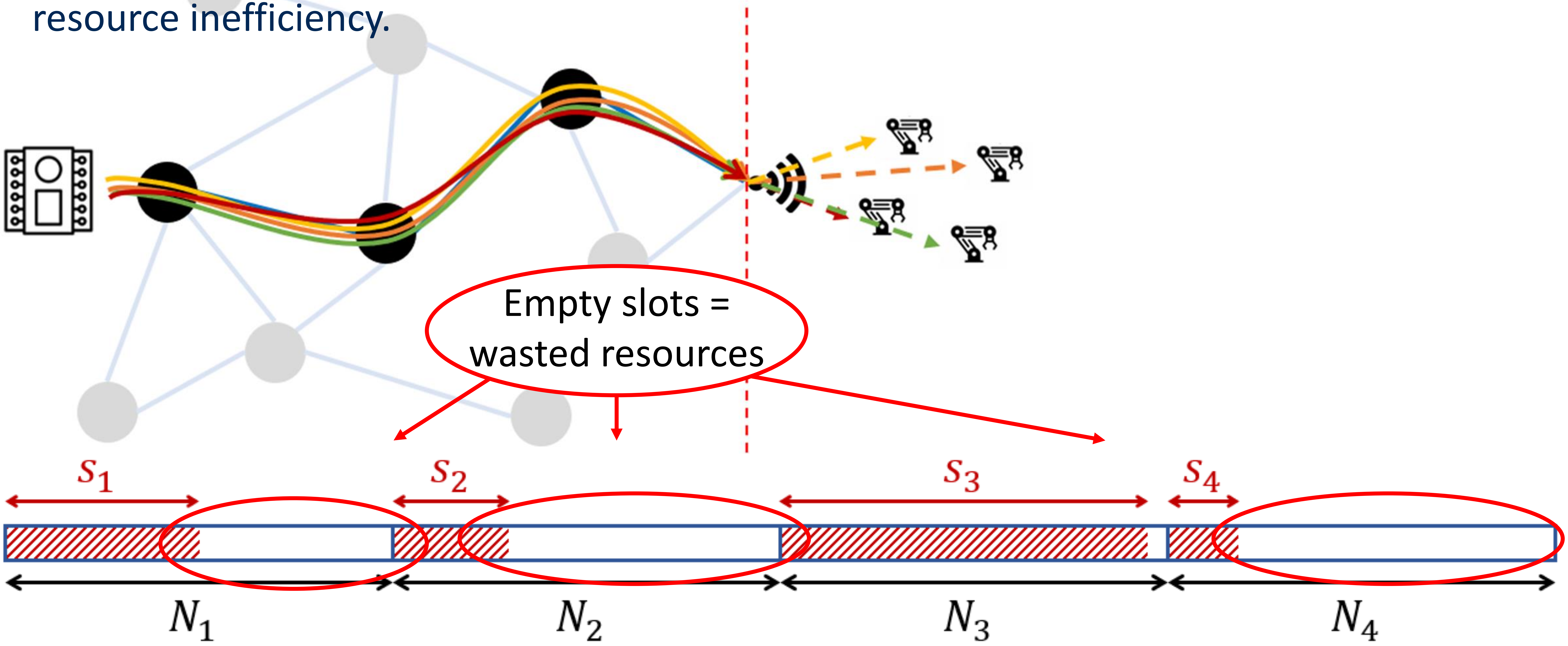
Multiple flows scenario

- Generalisation of the Hold&Forward design to multiple flows is simple, but leads to high resource inefficiency.


s_1
s_2
s_3
s_4
N_1
N_2
N_3
N_4

Non-overlapping windows design

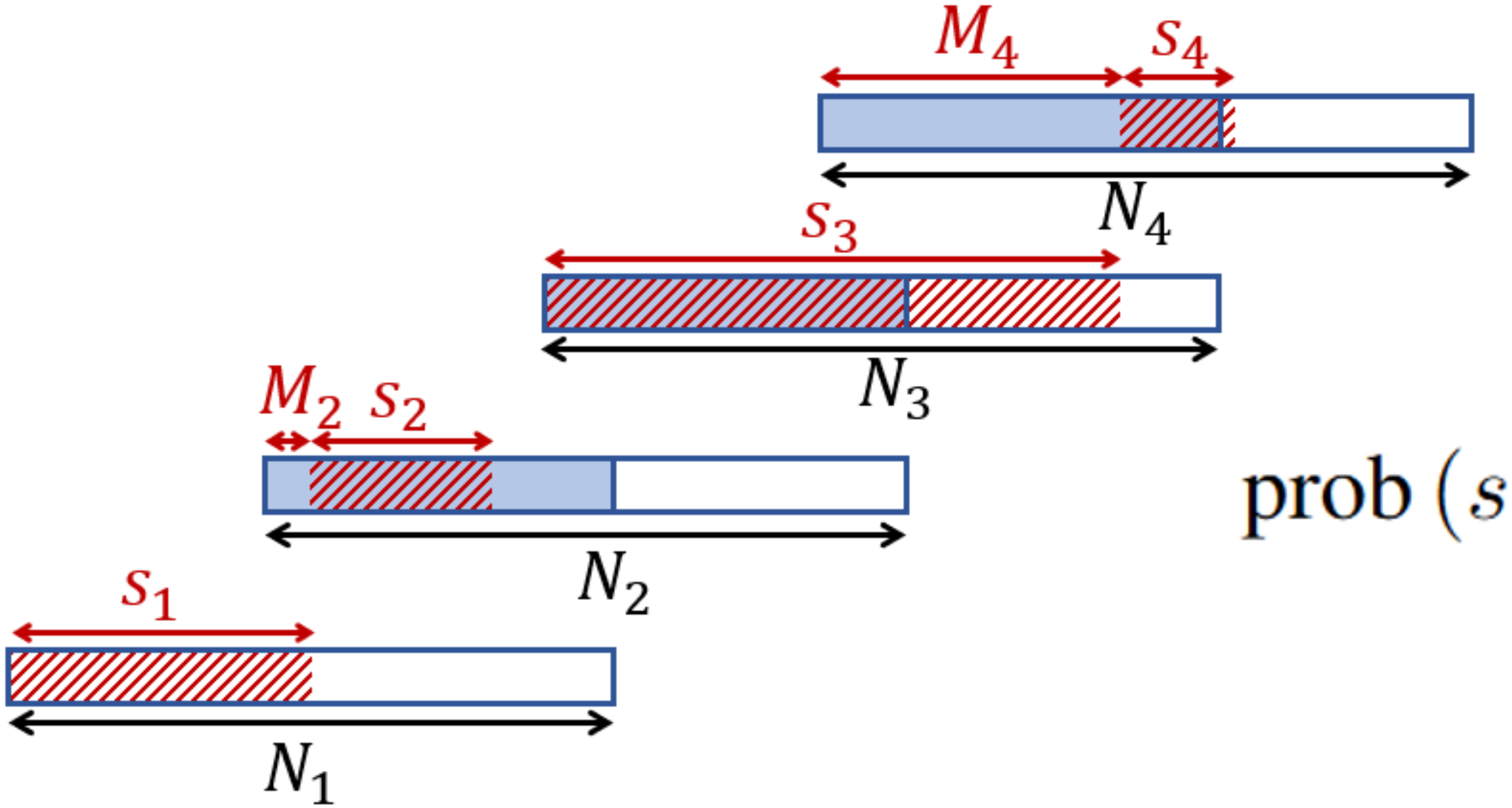
- Generalisation of the Hold&Forward design to multiple flows is simple, but leads to high resource inefficiency.



Empty slots = wasted resources

Overlapping windows design

- Overlapping windows increases resource efficiency
- Efficiency Vs Delay trade-off



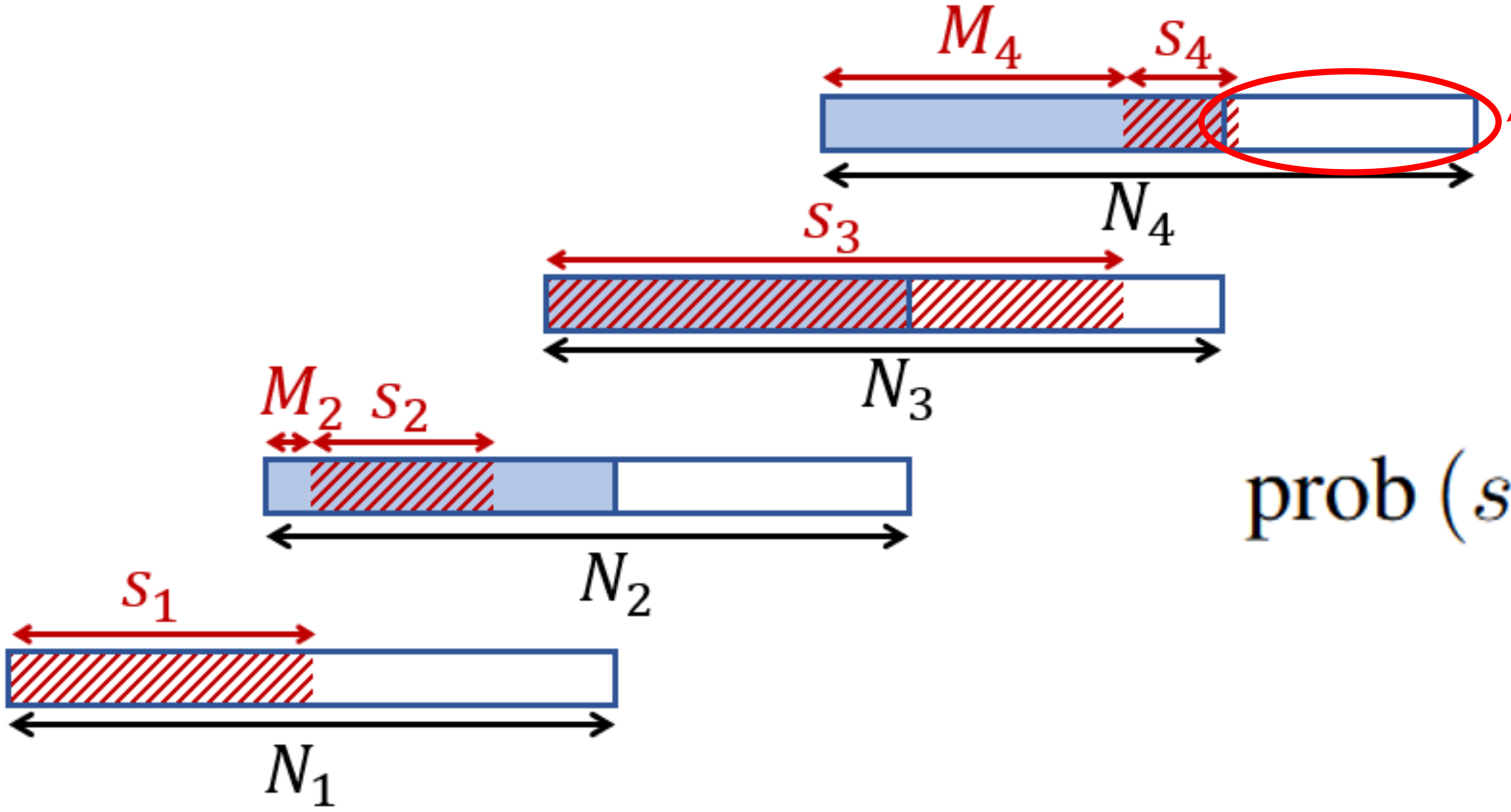
M_4
s_4
N_4
s_3
N_3
M_2
s_2
N_2
s_1
N_1

$$\mathrm{prob}\left(s_k + M_k > N_k\right) \leq \breve{p}_k$$

$$N_k \leq \breve{d}_k$$

Overlapping windows design

- Overlapping windows increases resource efficiency
- Efficiency Vs Delay trade-off


M_4
s_4
N_4
s_3
N_3
M_2
s_2
N_2
s_1
N_1

Few empty slots

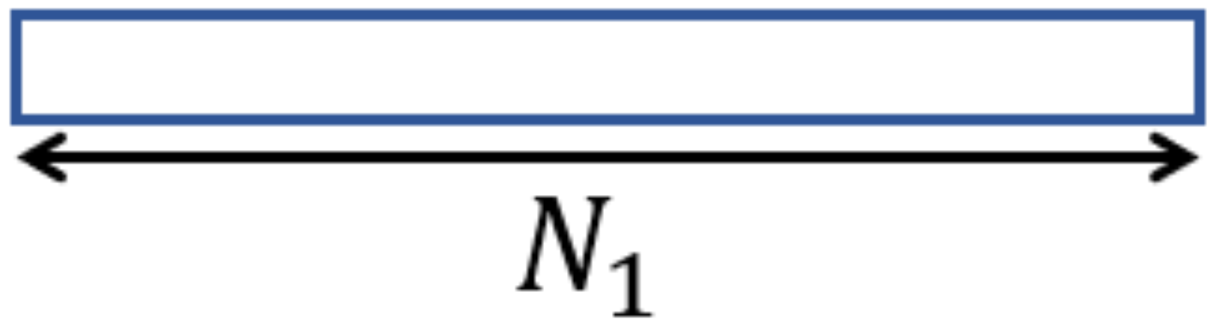
$$\mathrm{prob}\left(s_k + M_k > N_k\right) \leq \breve{p}_k$$

$$N_k \leq \breve{d}_k$$

Overlapping windows design

- Design 1st window

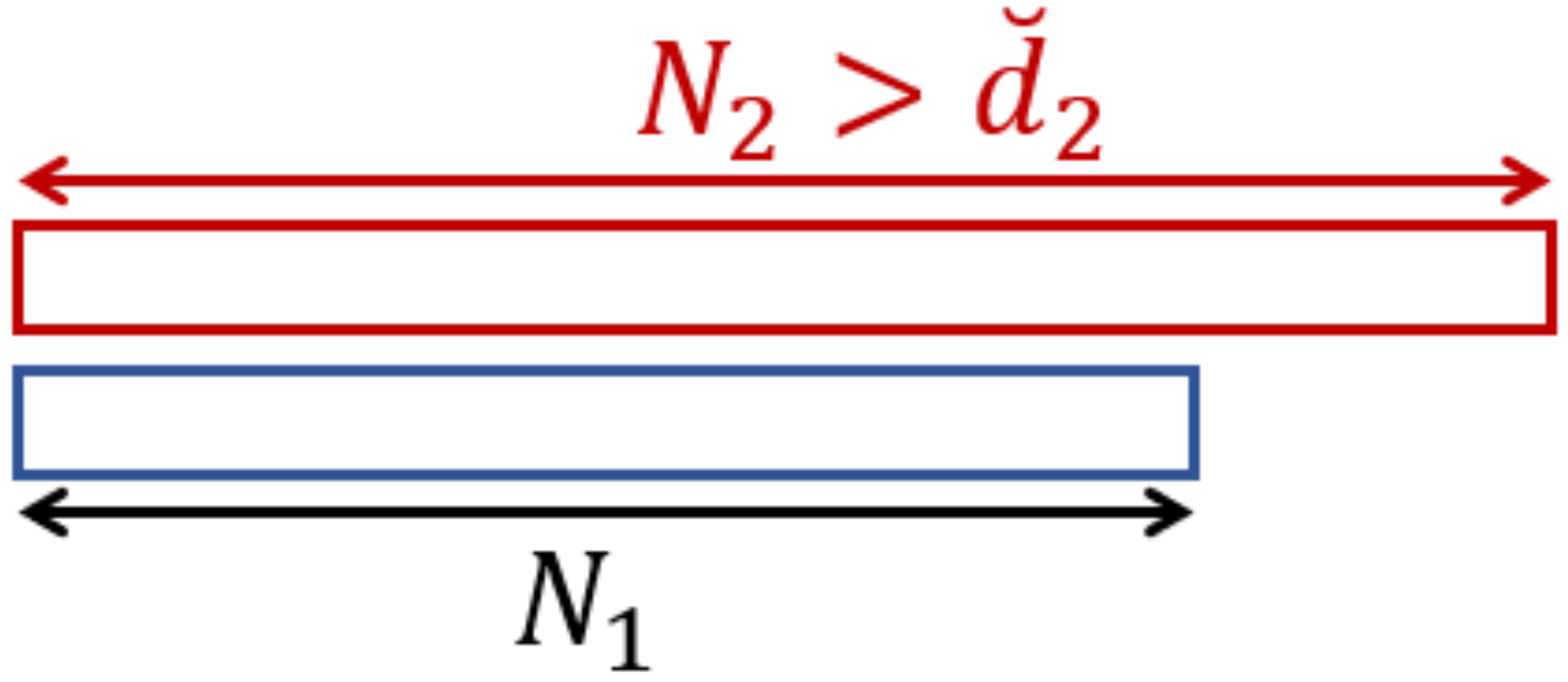
$$\text{prob}\left(s_1 > N_1\right) \leq \breve{p}_1$$



Overlapping windows design

- Design 2nd window

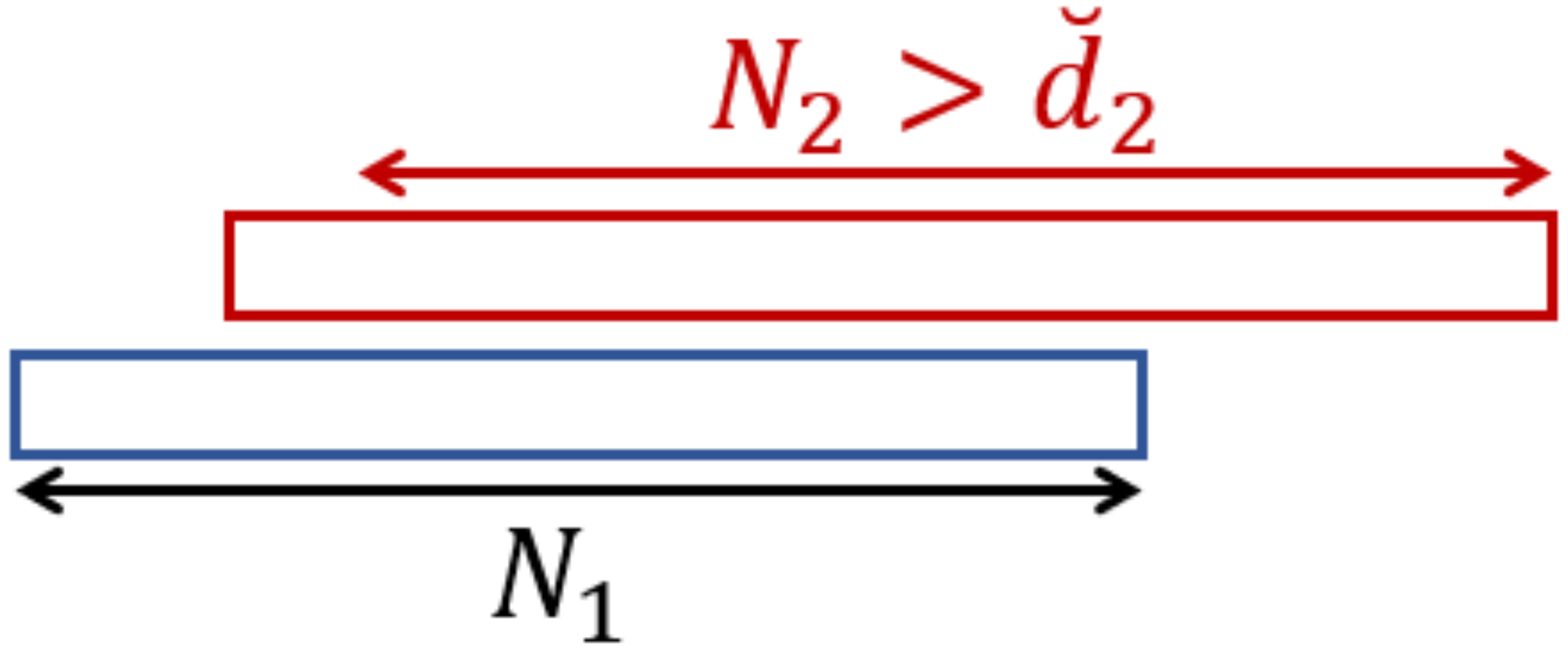
$$\text{prob}\left(s_2 + M_2 > N_2\right) \leq \breve{p}_2$$


$N_2 > \breve{d}_2$
N_1

Overlapping windows design

- Design 2nd window

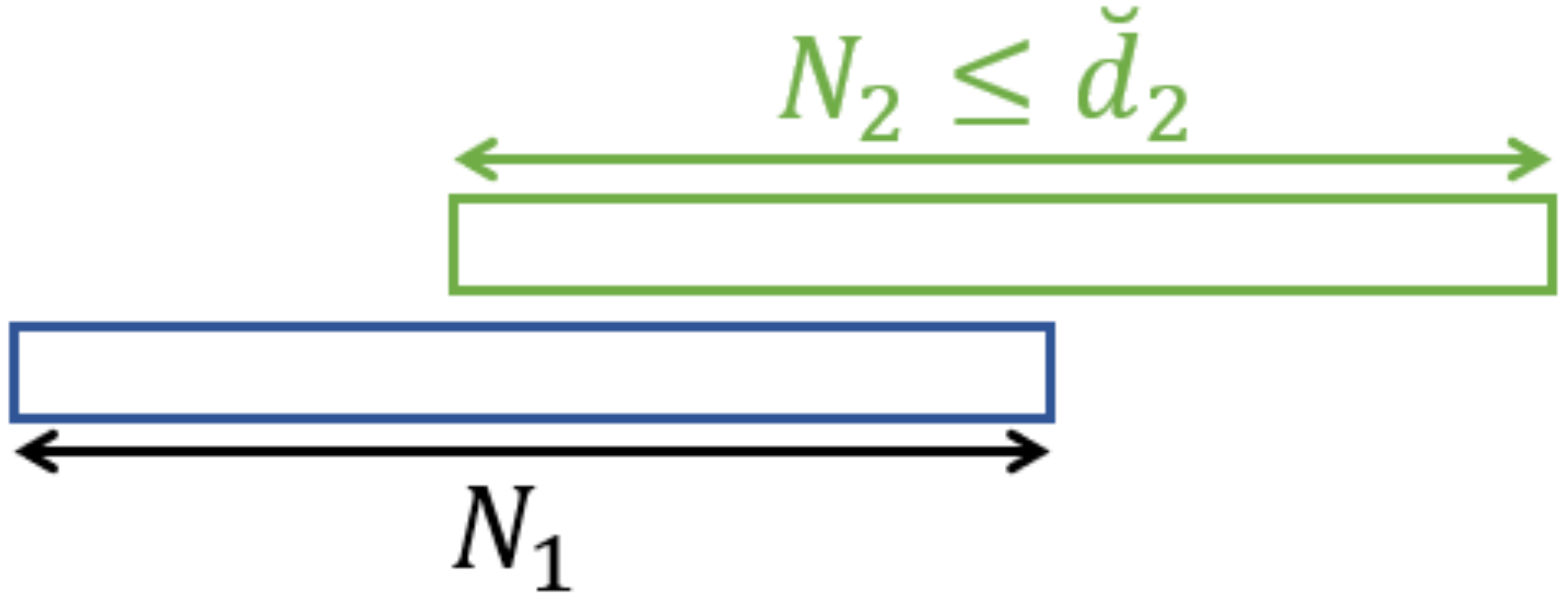
$$\text{prob}\left(s_2 + M_2 > N_2\right) \leq \breve{p}_2$$


$N_2 > \breve{d}_2$
N_1

Overlapping windows design

- Design 2nd window

$$\text{prob}\left(s_2 + M_2 > N_2\right) \leq \breve{p}_2$$

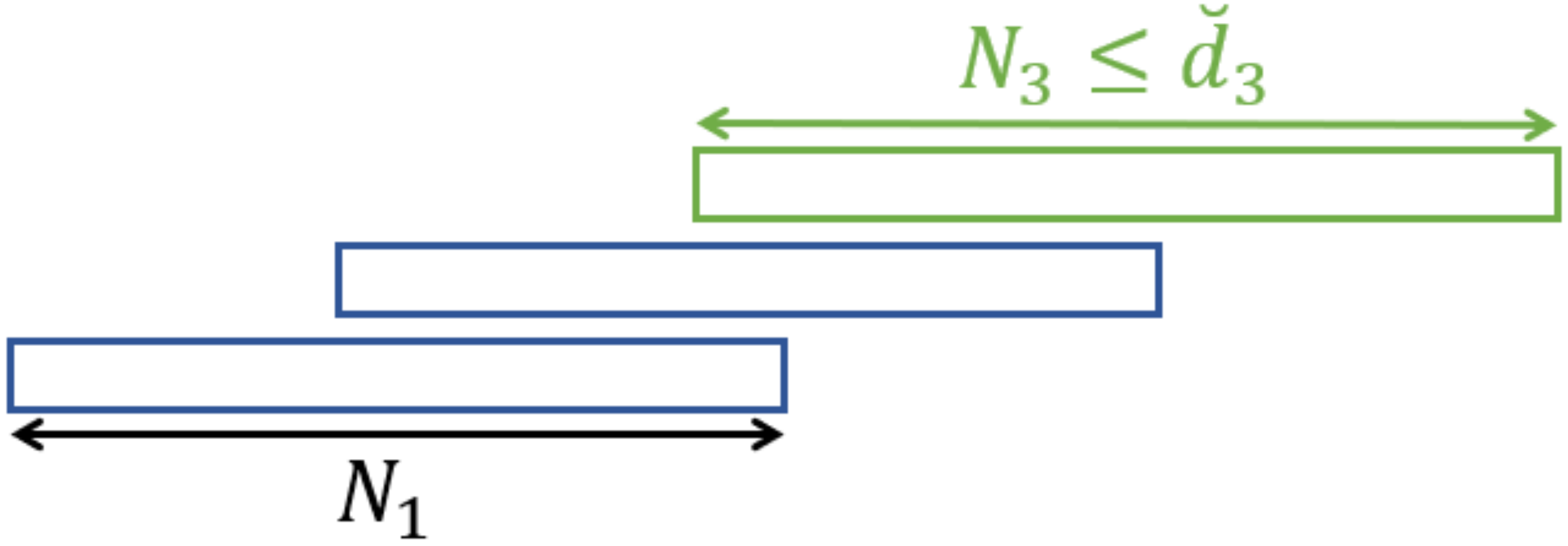


$N_2 \leq \breve{d}_2$
N_1

Overlapping windows design

- Design 3rd window

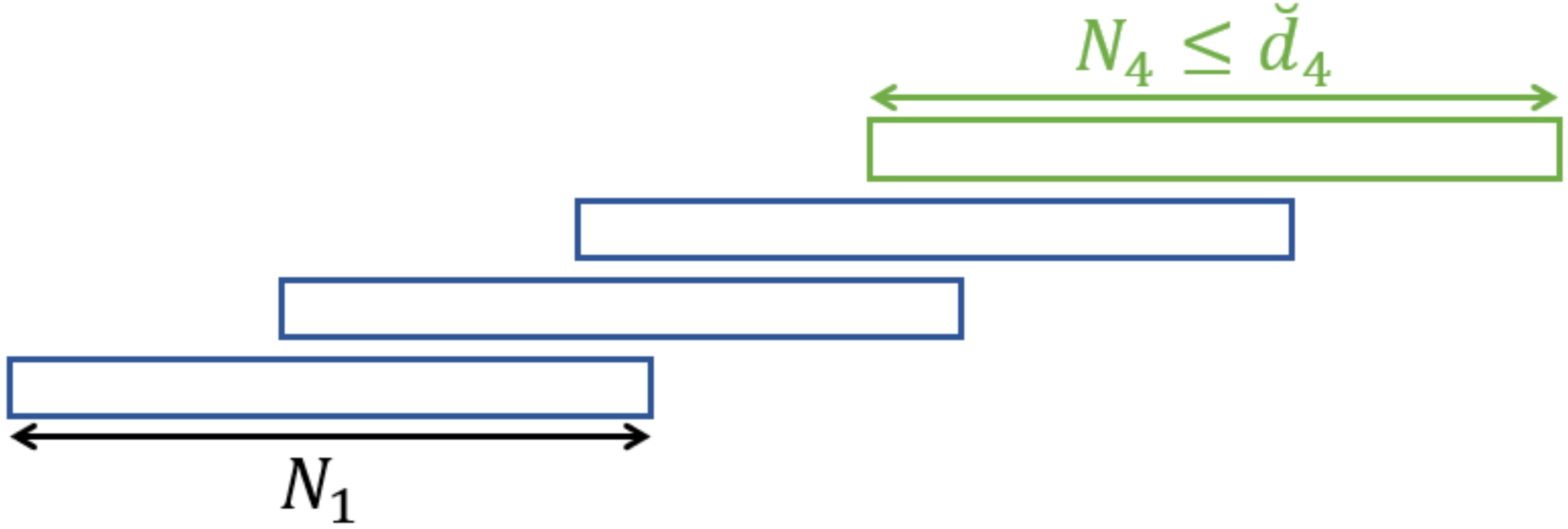
$$\mathrm{prob}\left(s_3 + M_3 > N_3\right) \leq \breve{p}_3$$


$N_3 \leq \breve{d}_3$
N_1

Overlapping windows design

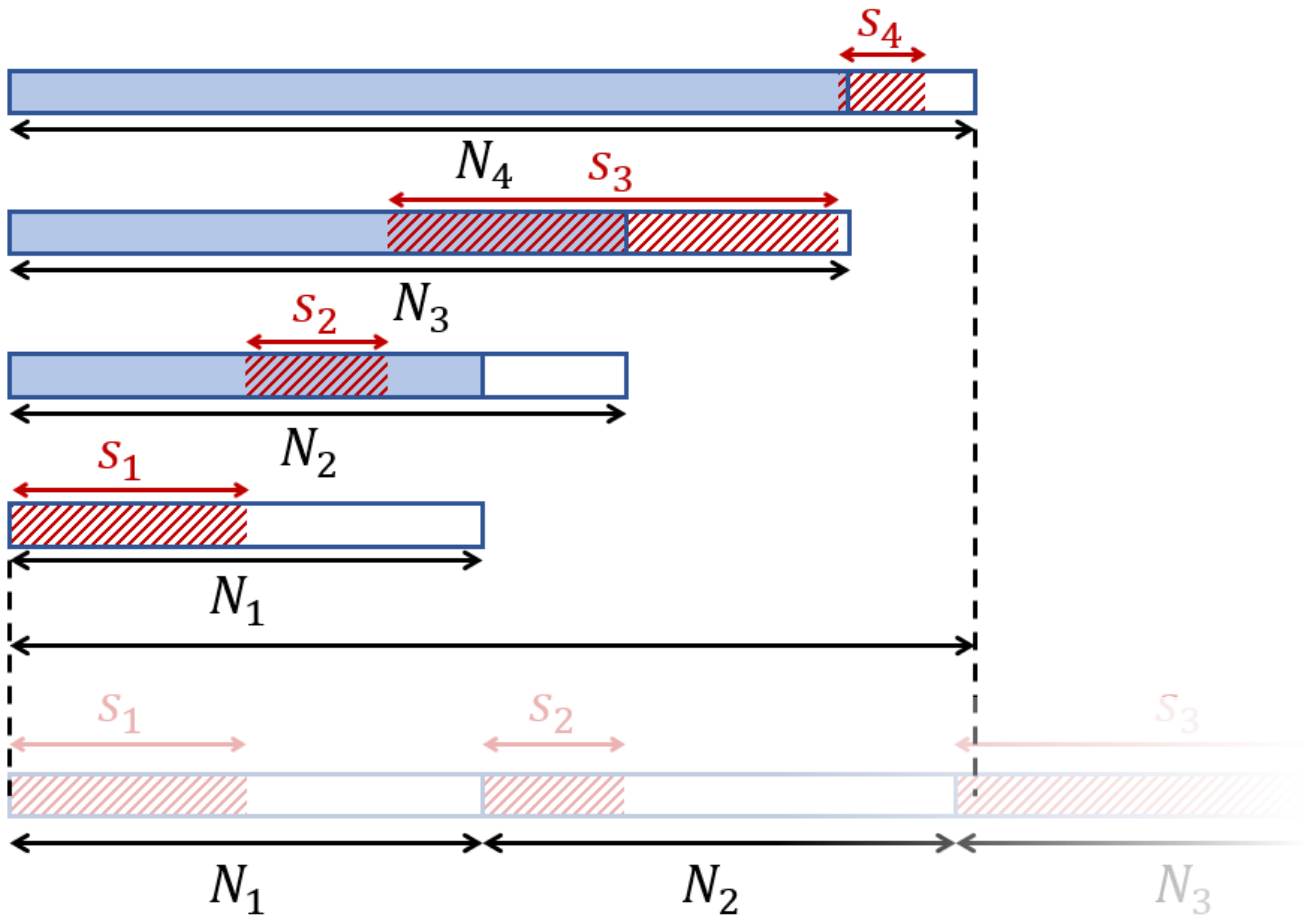
- Design 4th window and so on…

$$\mathrm{prob}\left(s_4 + M_4 > N_4\right) \leq \breve{p}_4$$

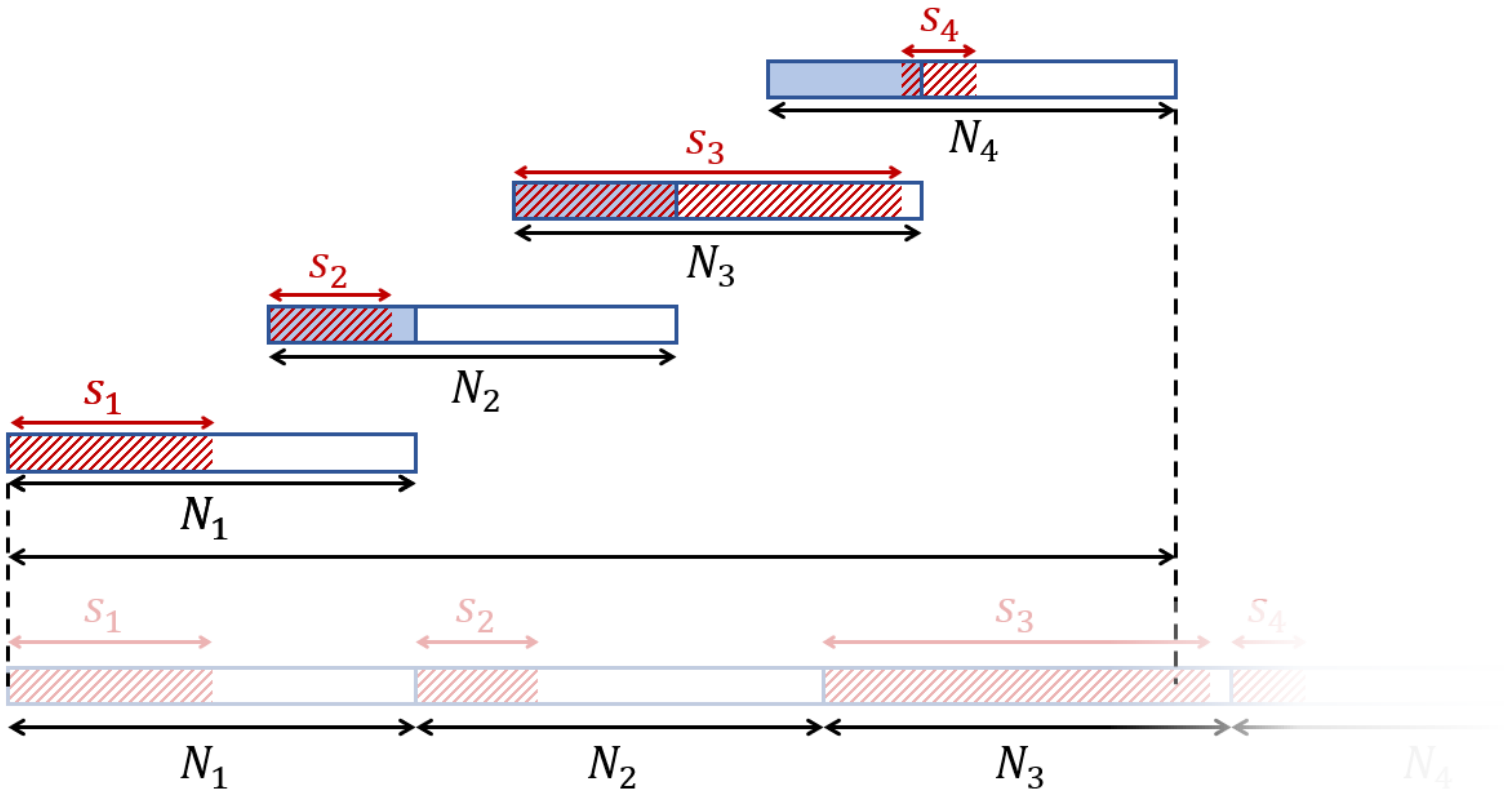

$N_4 \leq \breve{d}_4$
N_1

Overlapping windows design

Full overlap (no delay constraints)


s_4
N_4
s_3
N_3
s_2
N_2
s_1
N_1
s_1
s_2
s_3
N_1
N_2
N_3

Minimum delay (strictest delay constraints)


s_4
N_4
s_3
N_3
s_2
N_2
s_1
N_1
s_1
s_2
s_3
s_4
N_1
N_2
N_3
N_4

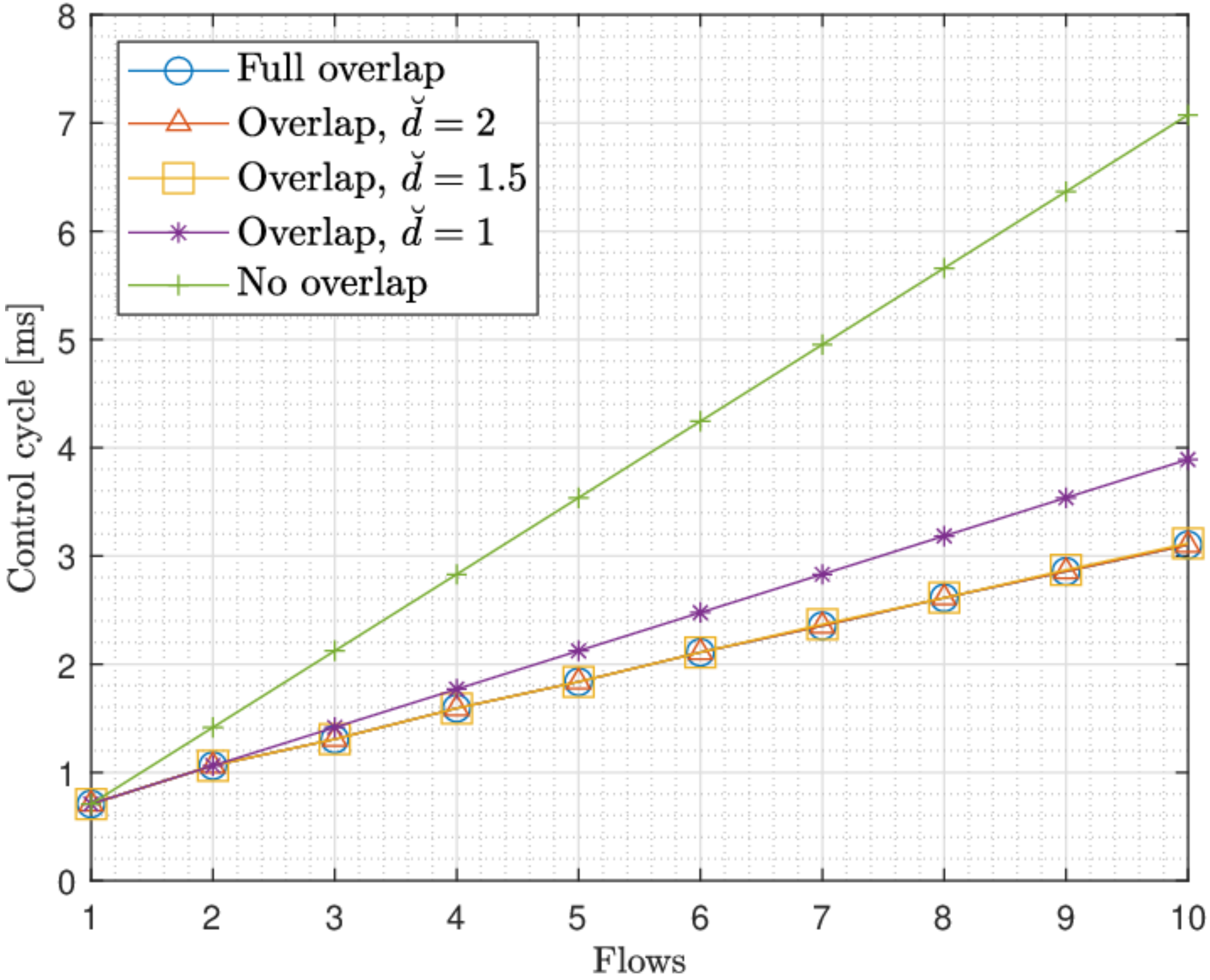
Simulation results

Simulated scenario

Downlink transmission from a wireless access point to multiple receiving terminals.

Simulation parameters

- WiFi 7 with 20 MHz bandwidth
- 1500-Bytes packets with constant control cycle
- Wireless channel is Rayleigh-distributed, with 50 ns delay spread and 20 dB average SNR
- 0.2% packet loss tolerance



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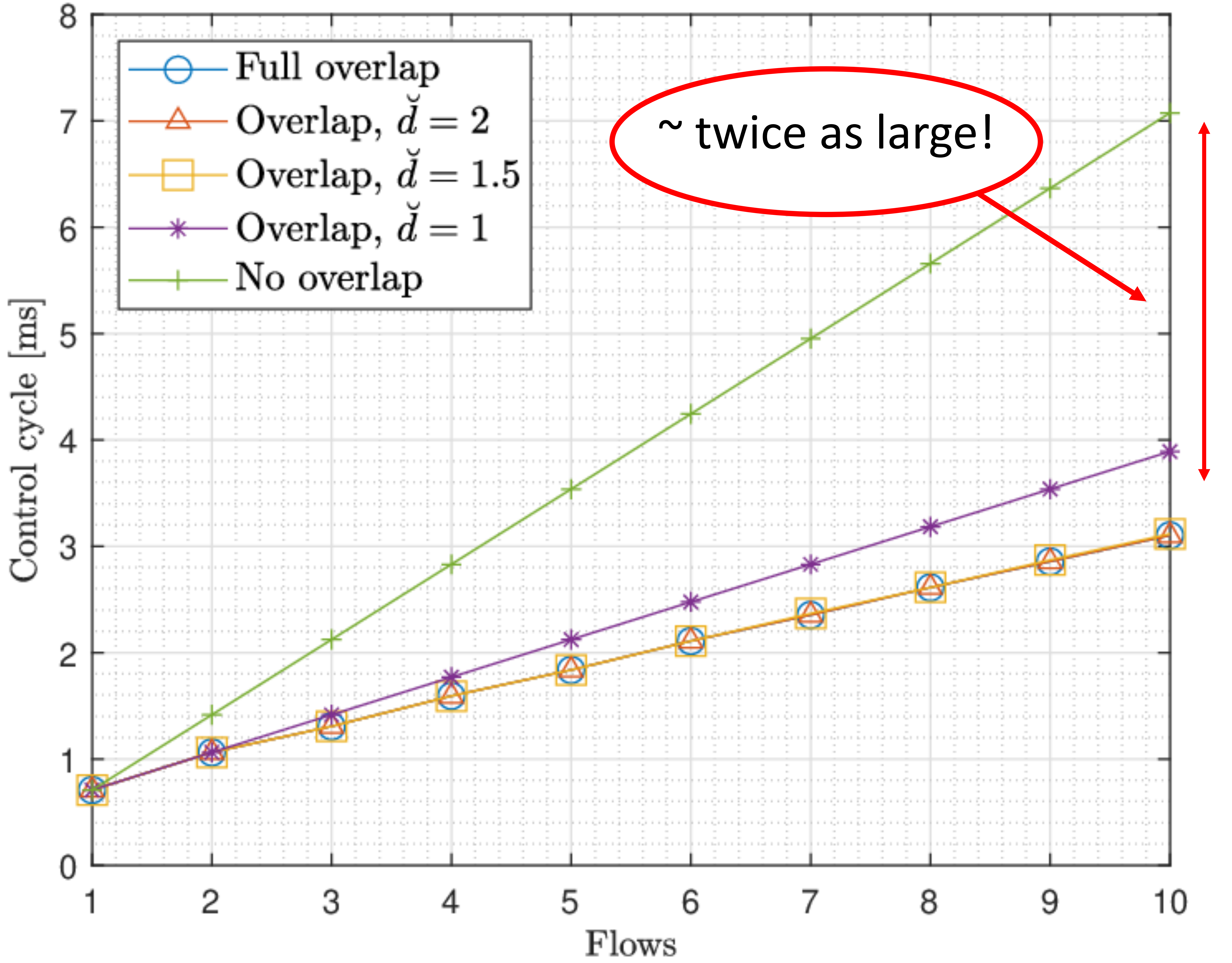

~ twice as large!

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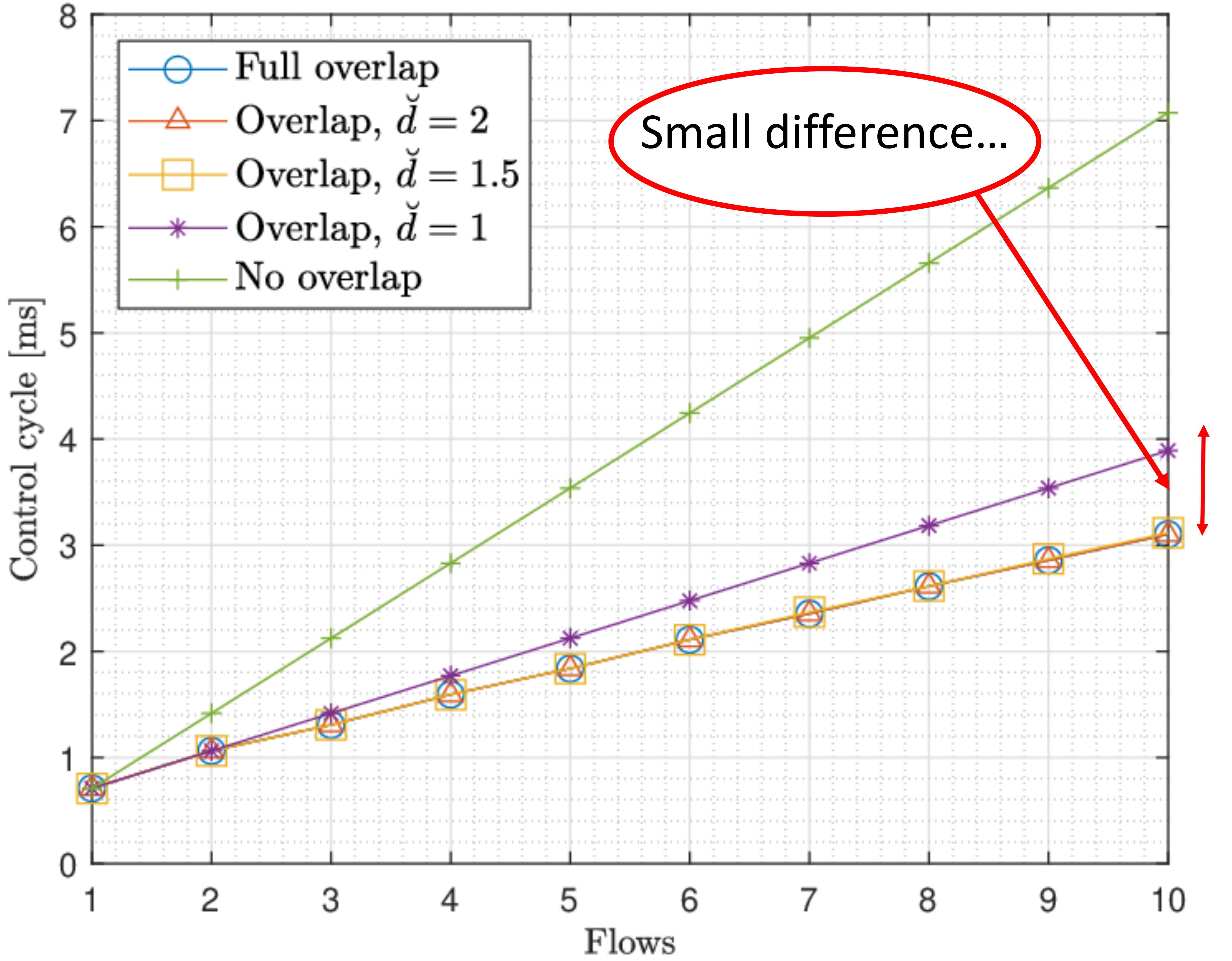

Small difference…

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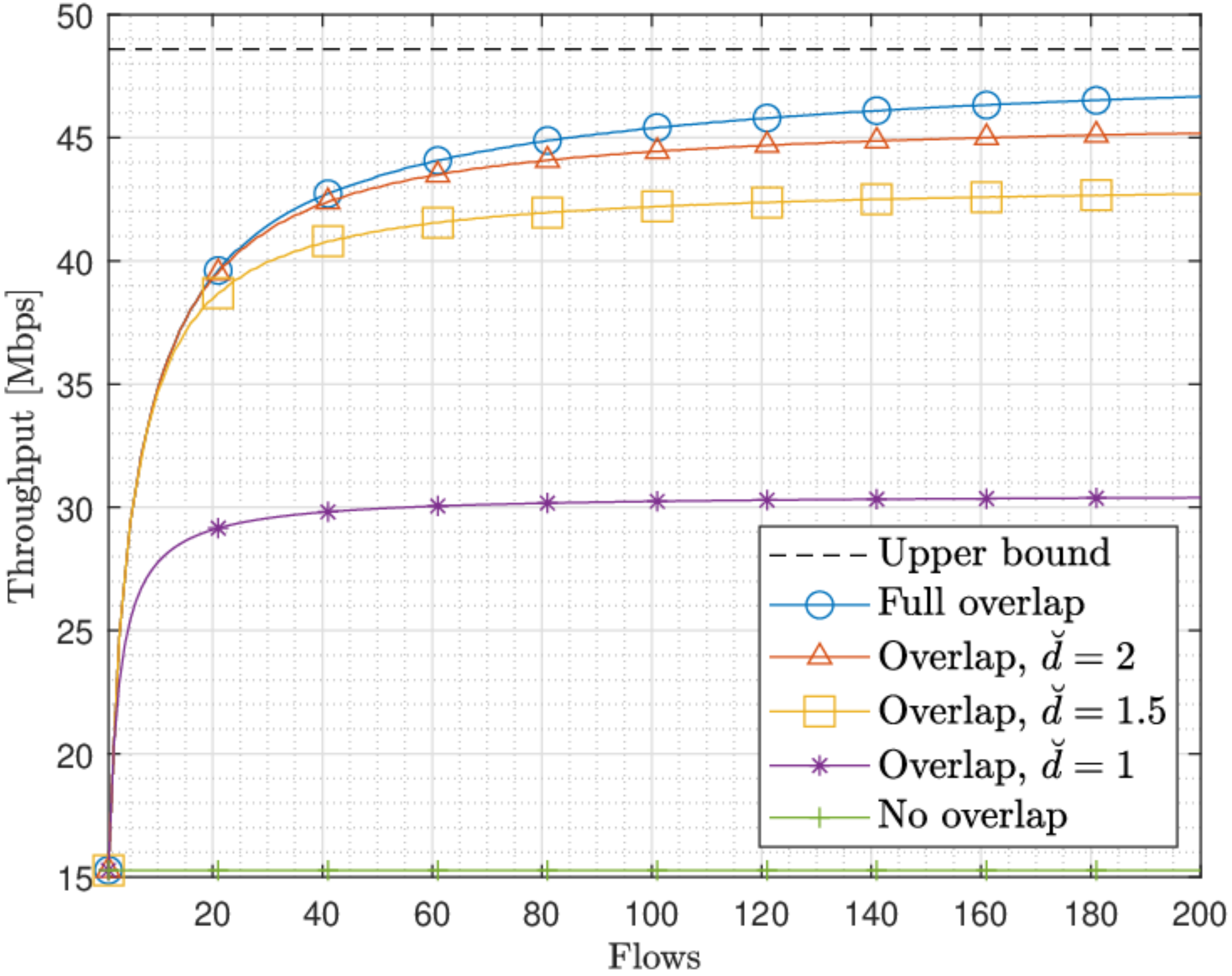

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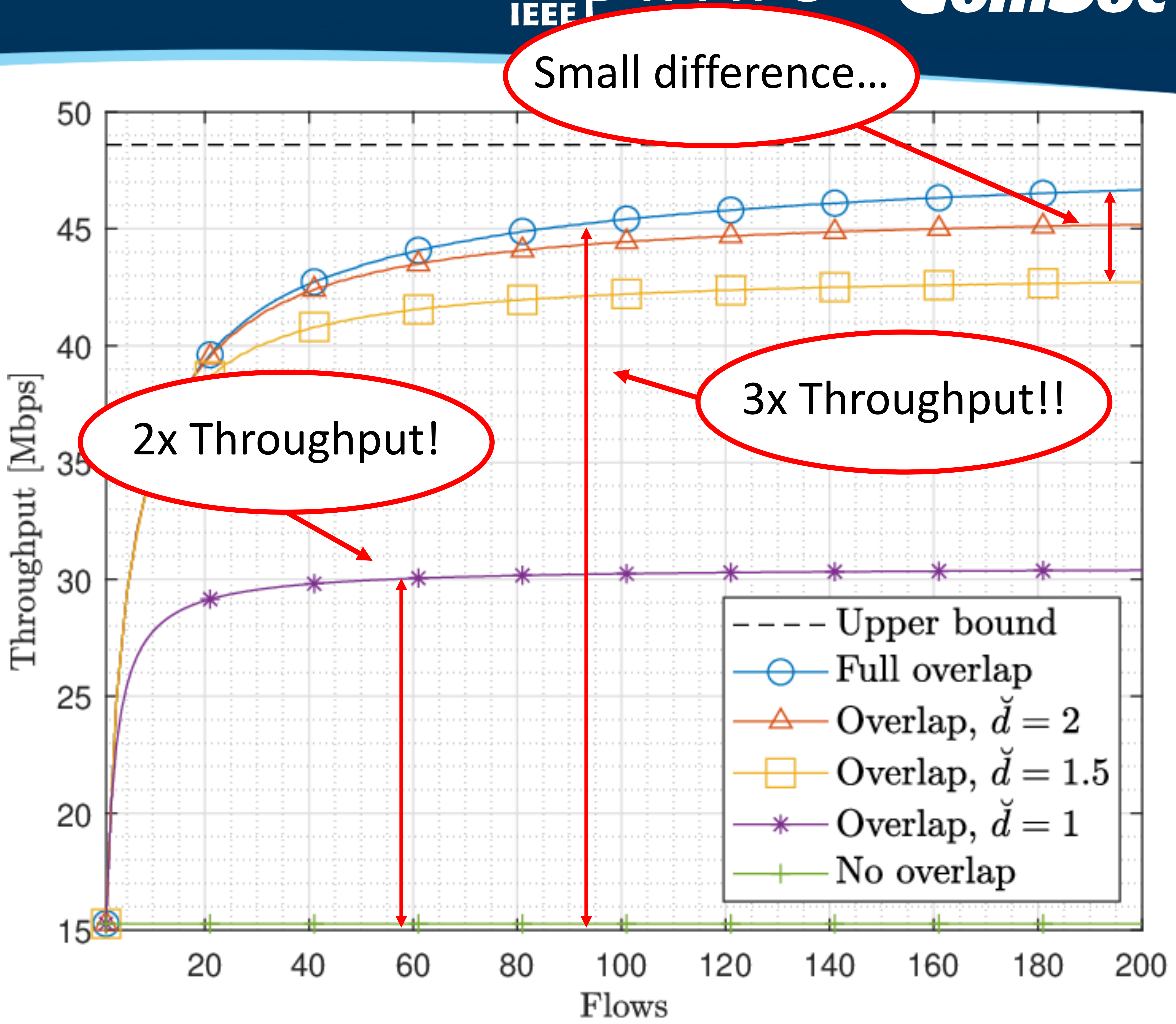

Small difference…

3x Throughput!!

2x Throughput!

Closing Remarks

- Two frame design proposals to eliminate jitter in wireless time-sensitive links
- Non-overlapping windows is simple but resource inefficient
- Overlapping windows increases efficency -> more throughput
- Trade-off Efficiency Vs. Delay, but small increases in delay reach nearly maximum efficiency

THANK YOU!

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