Tutorial on Short-Range C-ITS Communication Technologies

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Revised version of presentation from ITG FG 5.2.4 workshop on "Vehicular Communication", 15.03.2018 in Aachen

Acknowledgment: I would like to thank my colleagues Guido Hiertz, Ricardo Blasco, and Marco Belleschi for supporting this presentation with their technical expertise.

Outline

- Introduction
- Brief intro to Medium Access Control (MAC) and Physical (PHY) Layer
- Protocol description
  - IEEE 802.11p
  - LTE-V2X Sidelink
- Summary

Introduction

IEEE 802.11p:

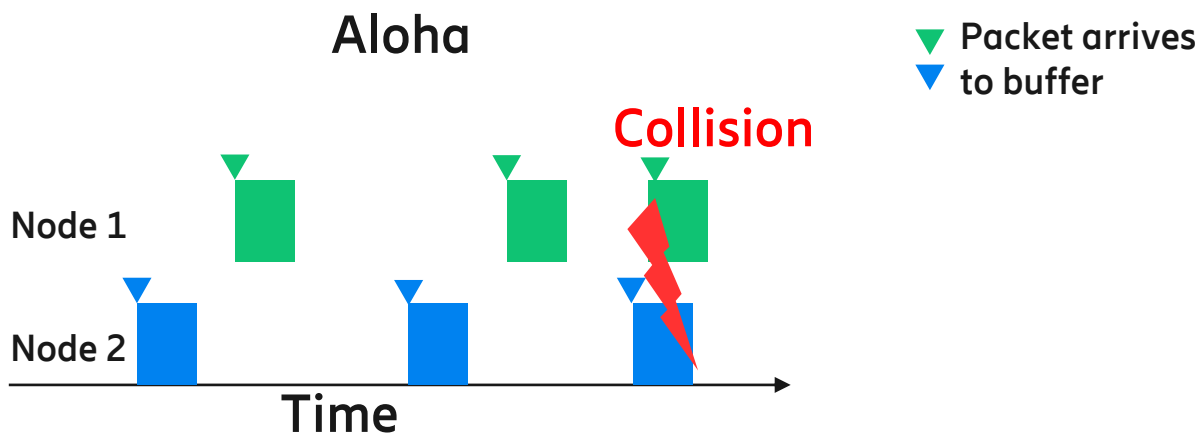
- IEEE 802.11p is based on the WLAN standard IEEE 802.11
- Often "ITS-G5" is used as synonym, since the ETSI ITS-G5 standard, specifying technology for 5.9 GHz spectrum access in Europe, currently only refers to IEEE 802.11p as Access Technology

LTE-V2X Sidelink:

- "Sidelink" communication was introduced for Mission Critical Push-to-Talk in 3GPP LTE Release 12
- Sidelink evolved to a "V2X-Sidelink" in LTE Release 14
- Often called "LTE-V2X" or "C(ellular)-V2X" because technology, originally developed for cellular communication, is used
- Also known as "PC5" to clearly distinguish from "Uu" interface used for cellular communication

Brief intro: MAC Layer

- A radio resource (time / frequency) can only be "used" by one transmitter simultaneously
- If more than one transmission simultaneously reaches the receiver, a "collision" occurs ➔ packet (segment) loss
- A wireless sender cannot directly detect a "collision", it can only detect it through a missing acknowledgement (ACK) from the receiver
- IEEE 802.11p and LTE-V2X Sidelink do broadcast ➔ no ACK possible; losses remain undetected



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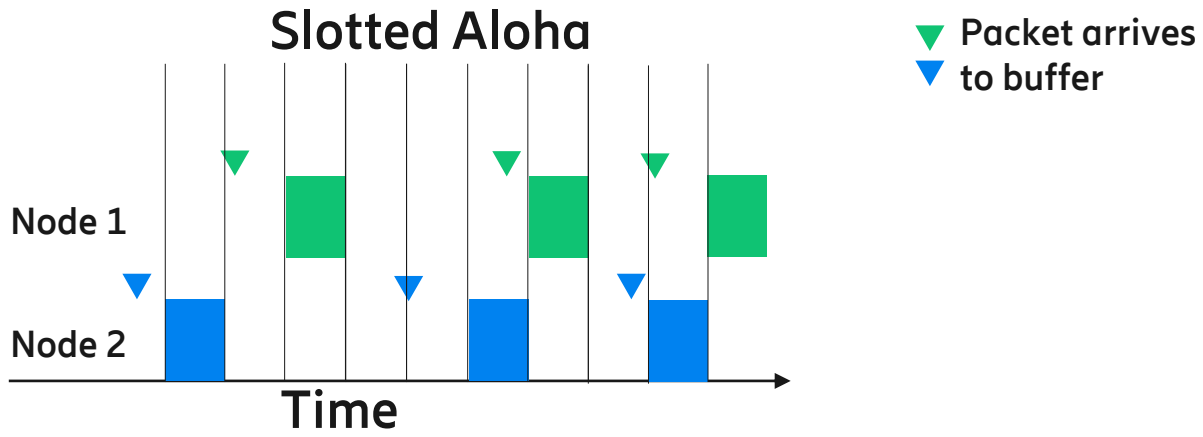
- MAC protocols often have loss vs. delay tradeoff



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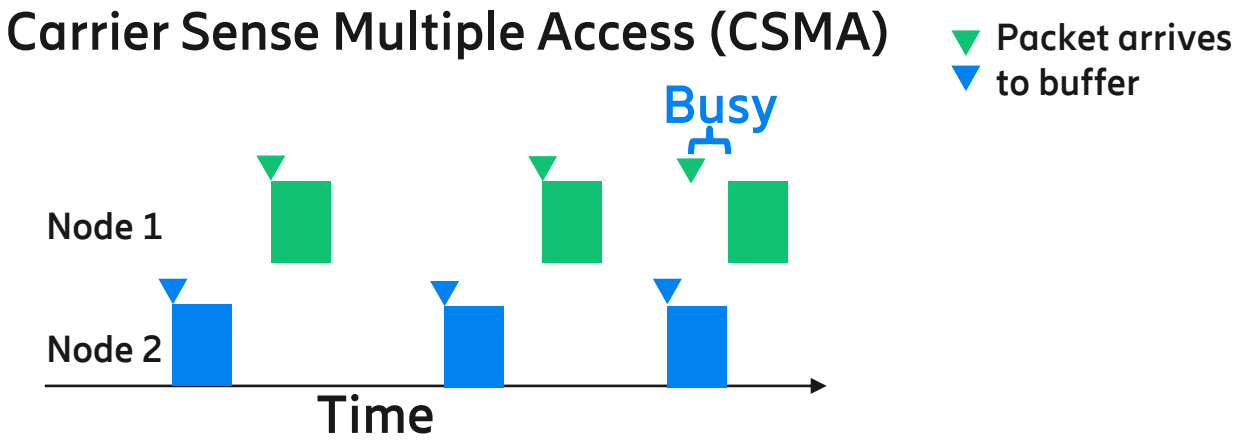

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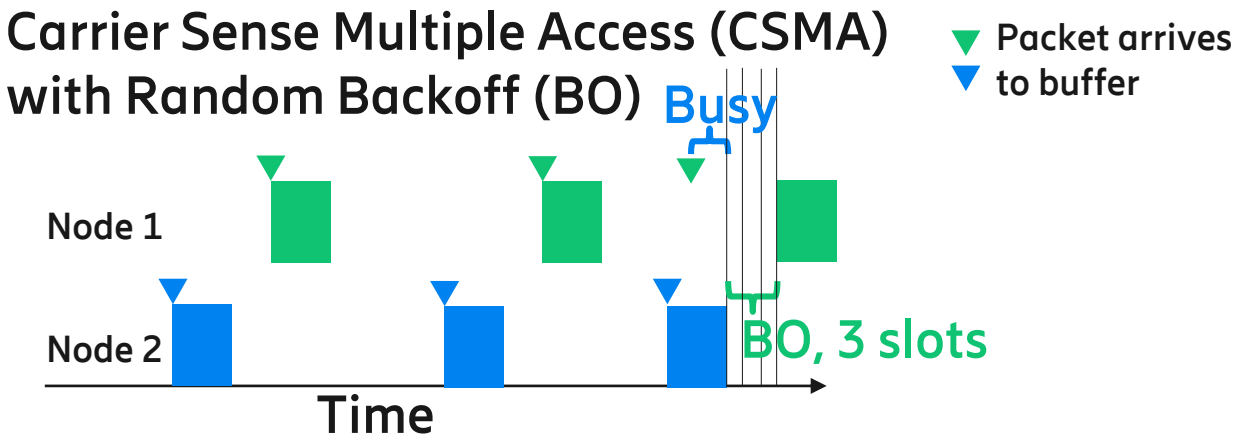

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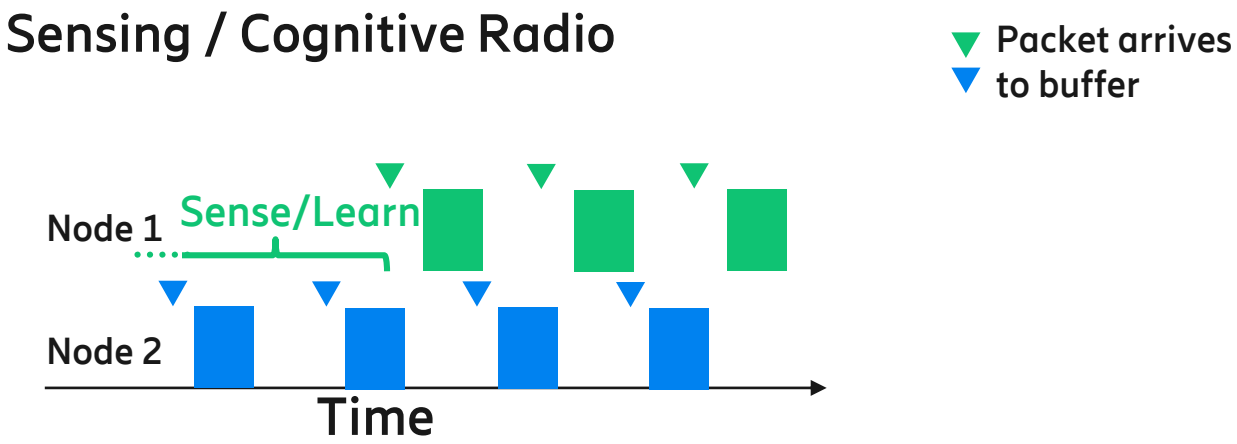
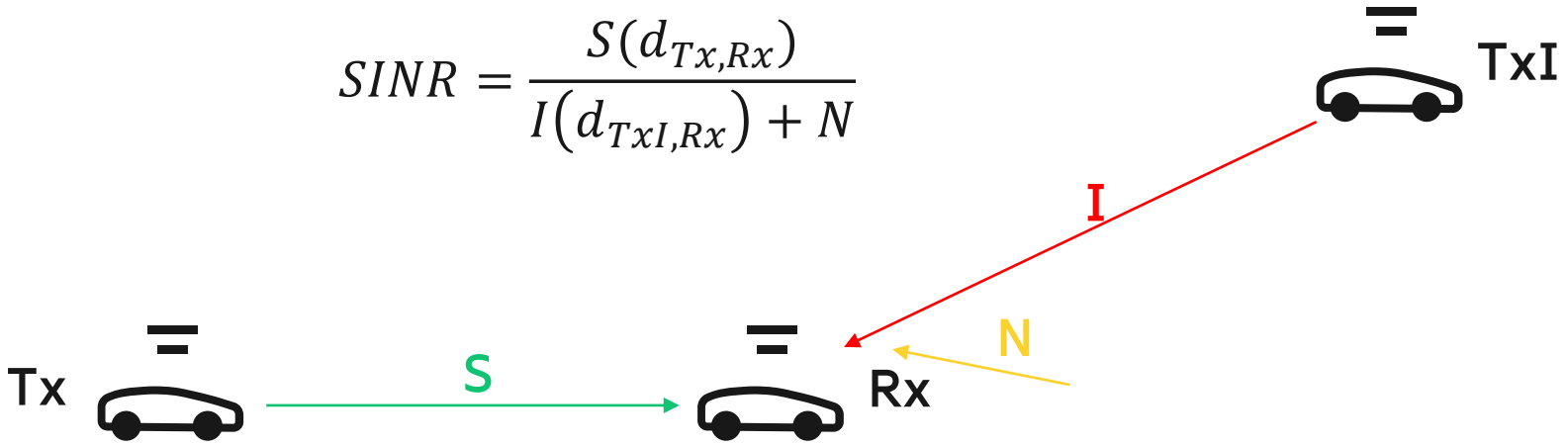


Brief intro: PHY Layer

- Packet can be decoded (with very high probability) if Signal to Interference and Noise Ratio (SINR) is high at the receiver
- Collision: SINR is very low due to very high interference (I) compared to received signal strength (S)

$$SINR = \frac{S(d_{Tx,Rx})}{I(d_{TxI,Rx}) + N}$$



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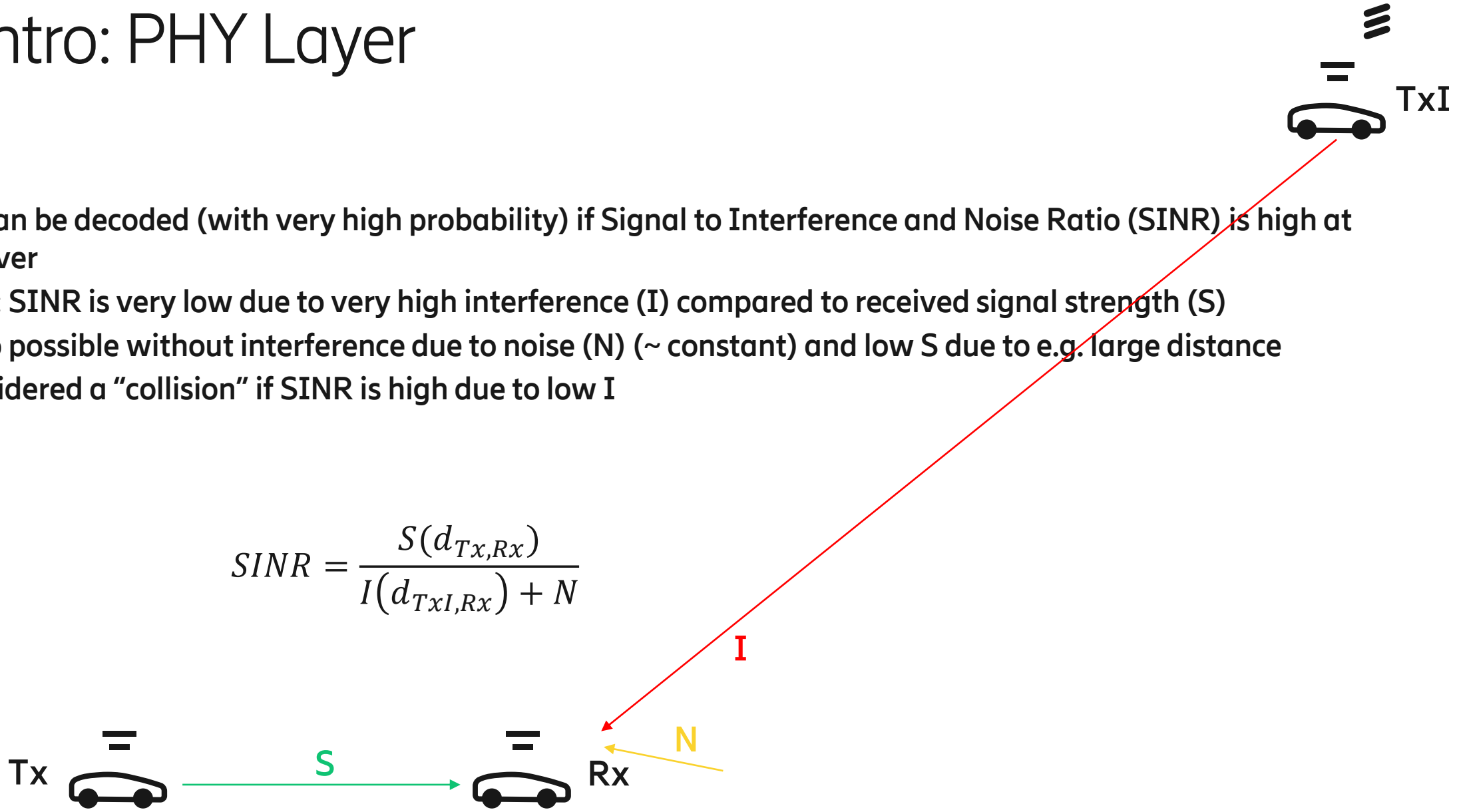

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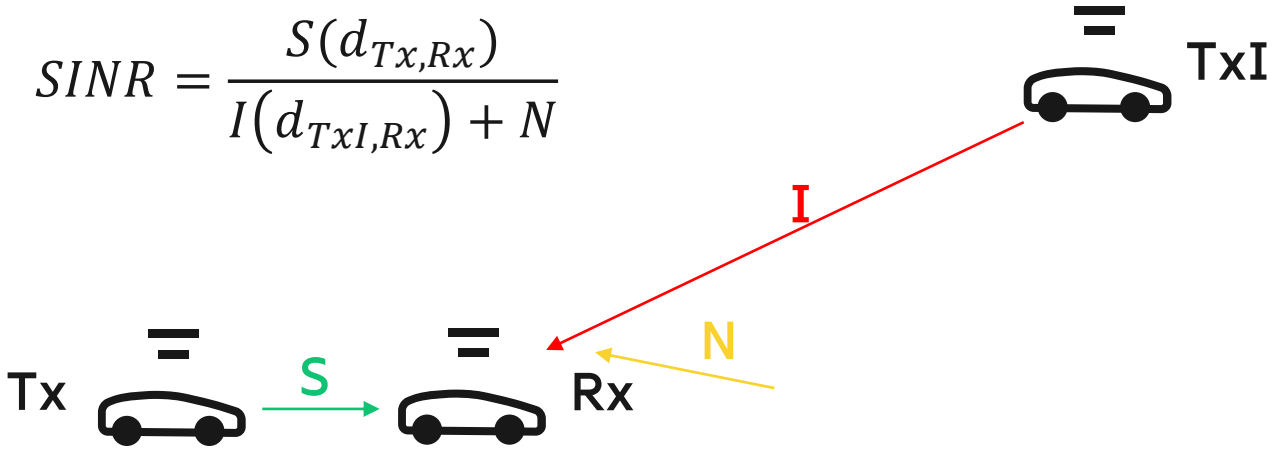

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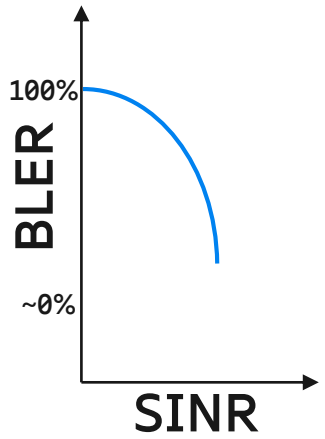
- SINR required for successful decoding depends on modulation and coding scheme (MCS) (called PHY-Mode in IEEE 802.11) and block size
- It especially depends on block error rate (BLER) to SINR characteristic (PHY Layer design)



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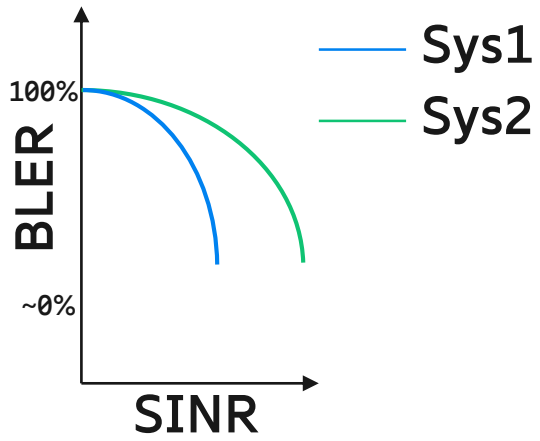

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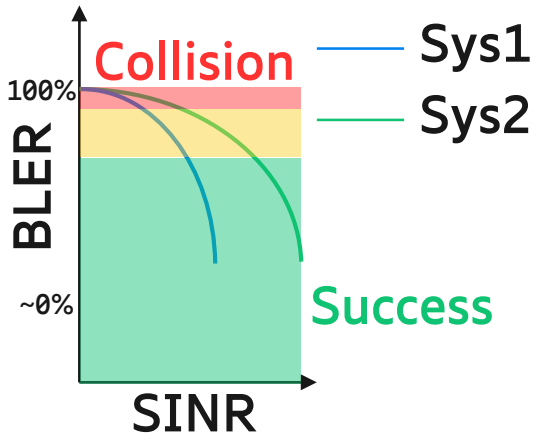
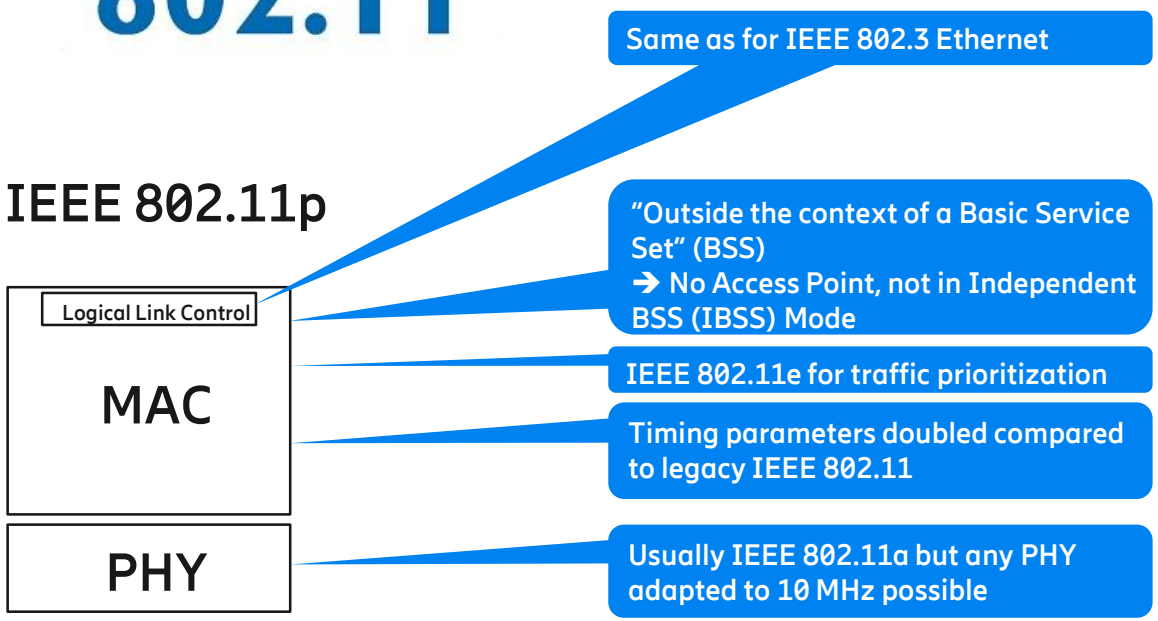


Protocol description

IEEE 802.11



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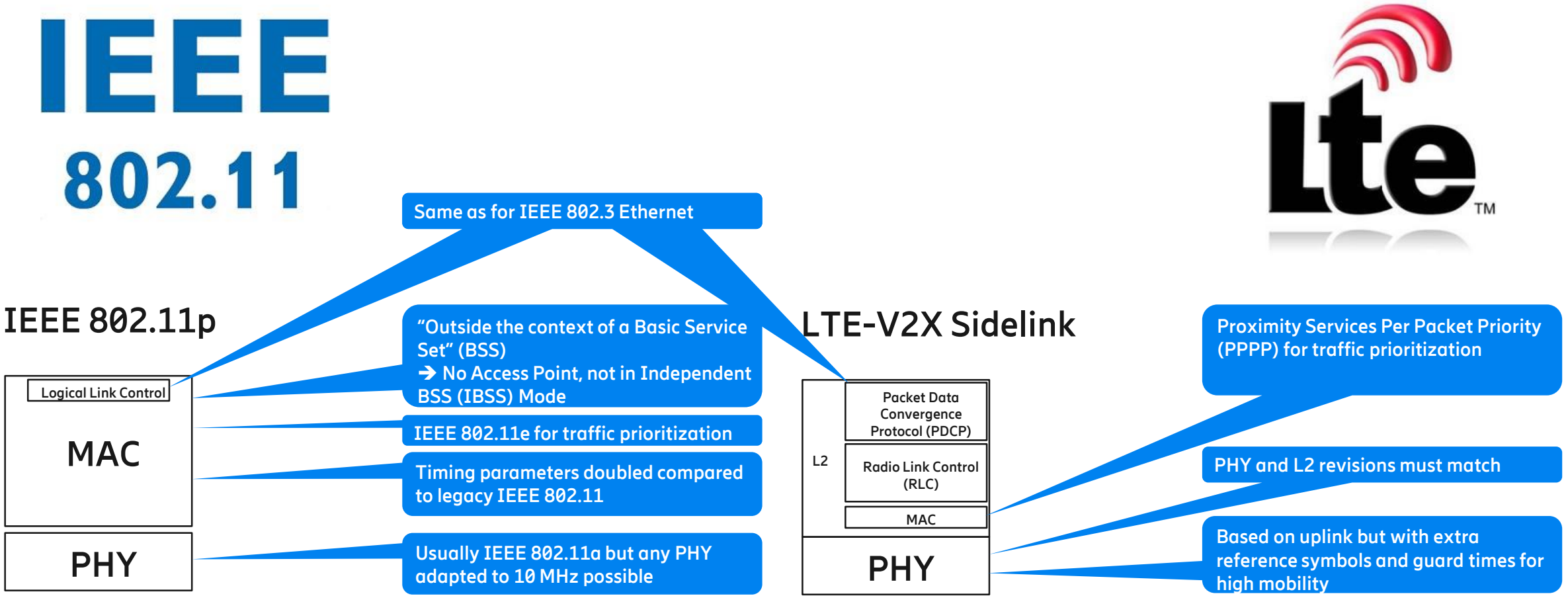
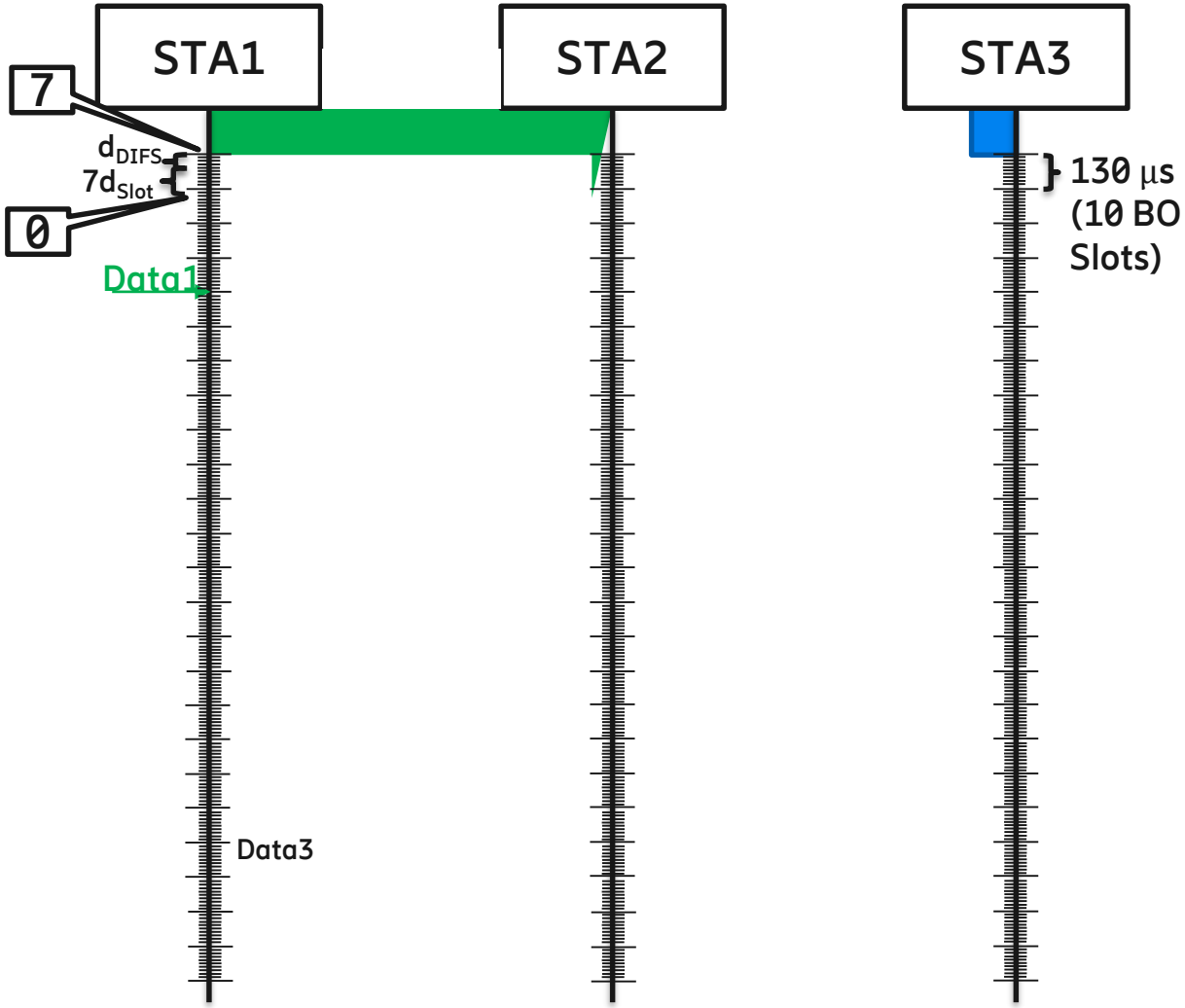


Protocol description: IEEE 802.11p

300 byte at 6 Mbit/s



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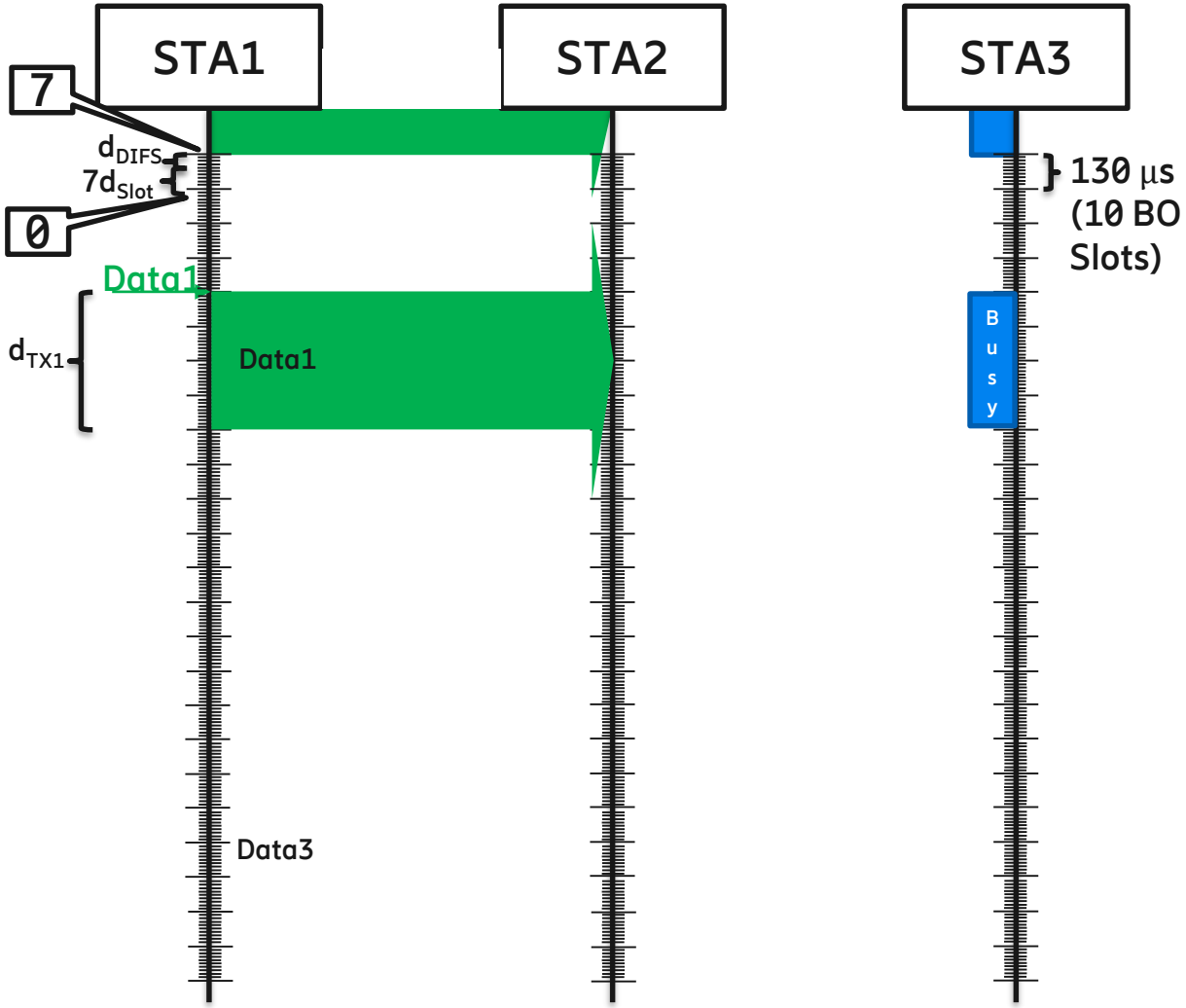

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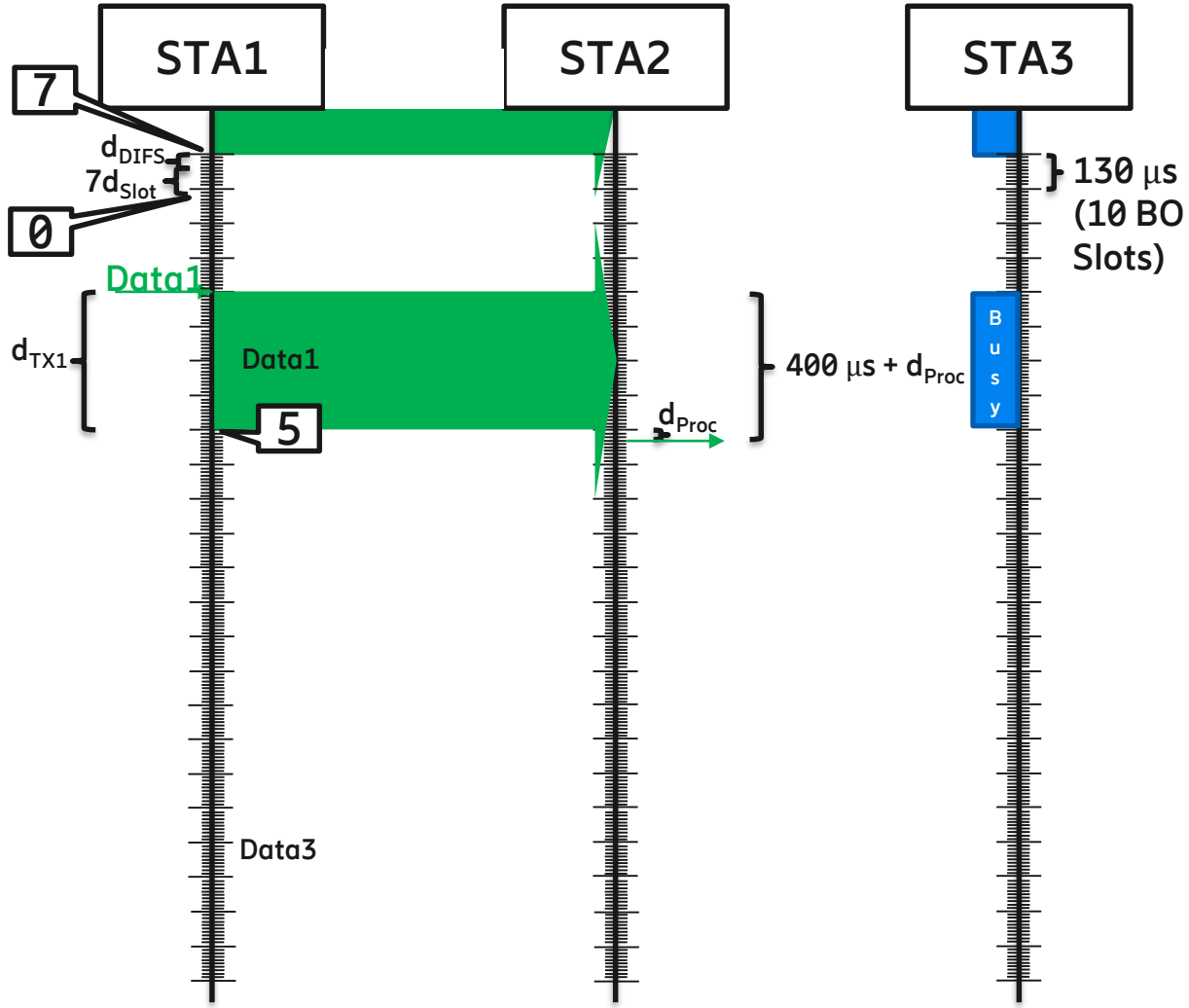

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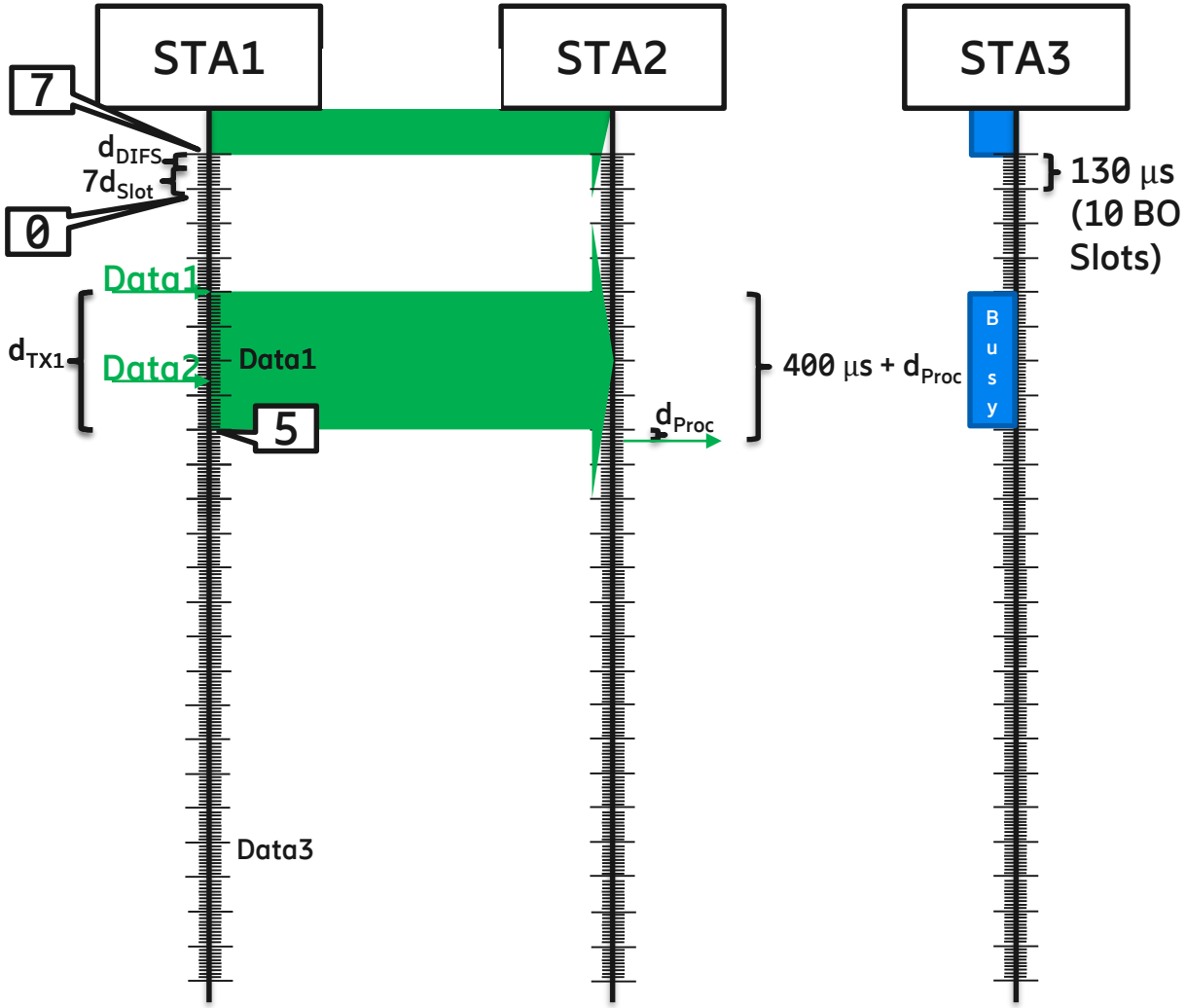

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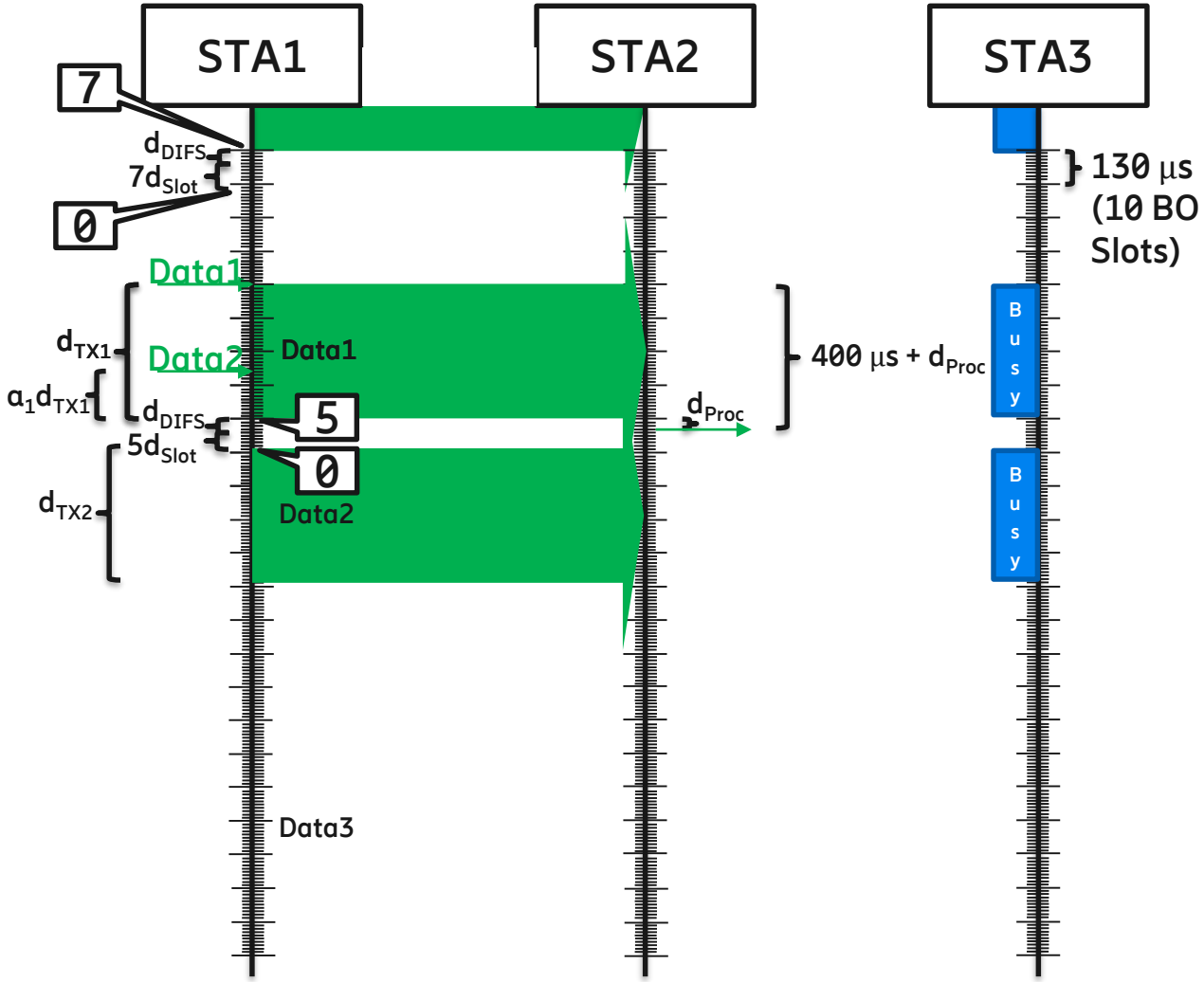

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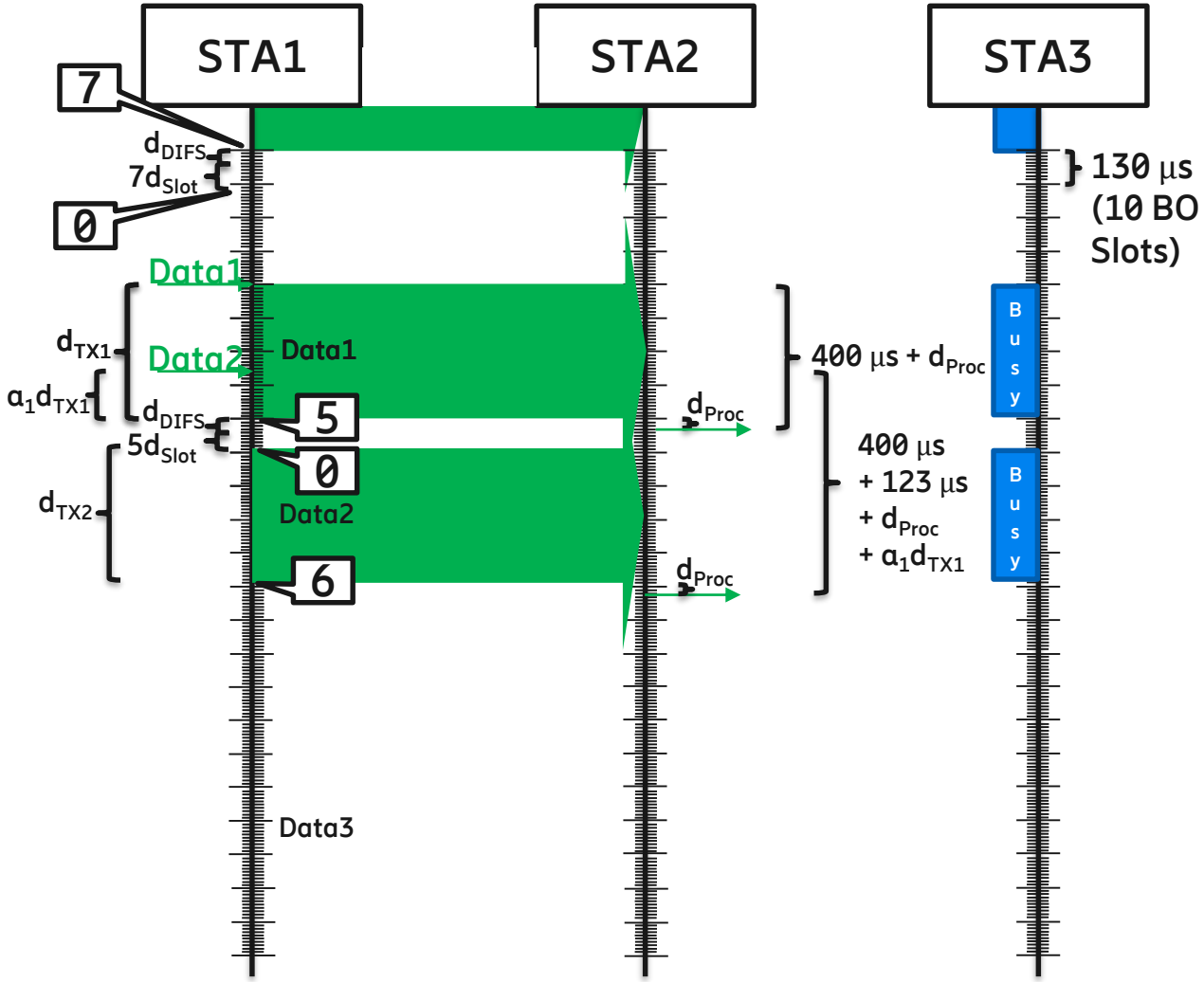

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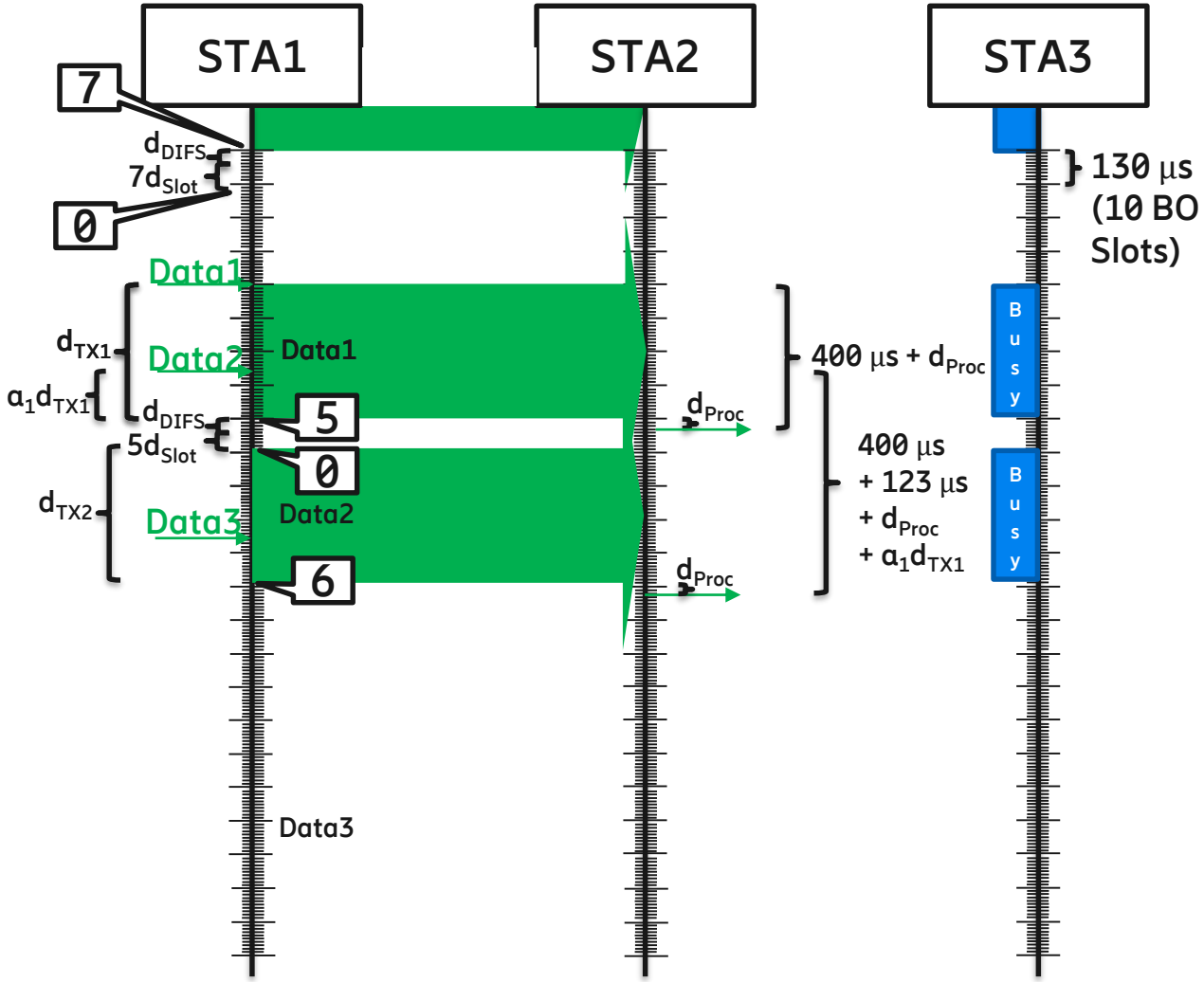

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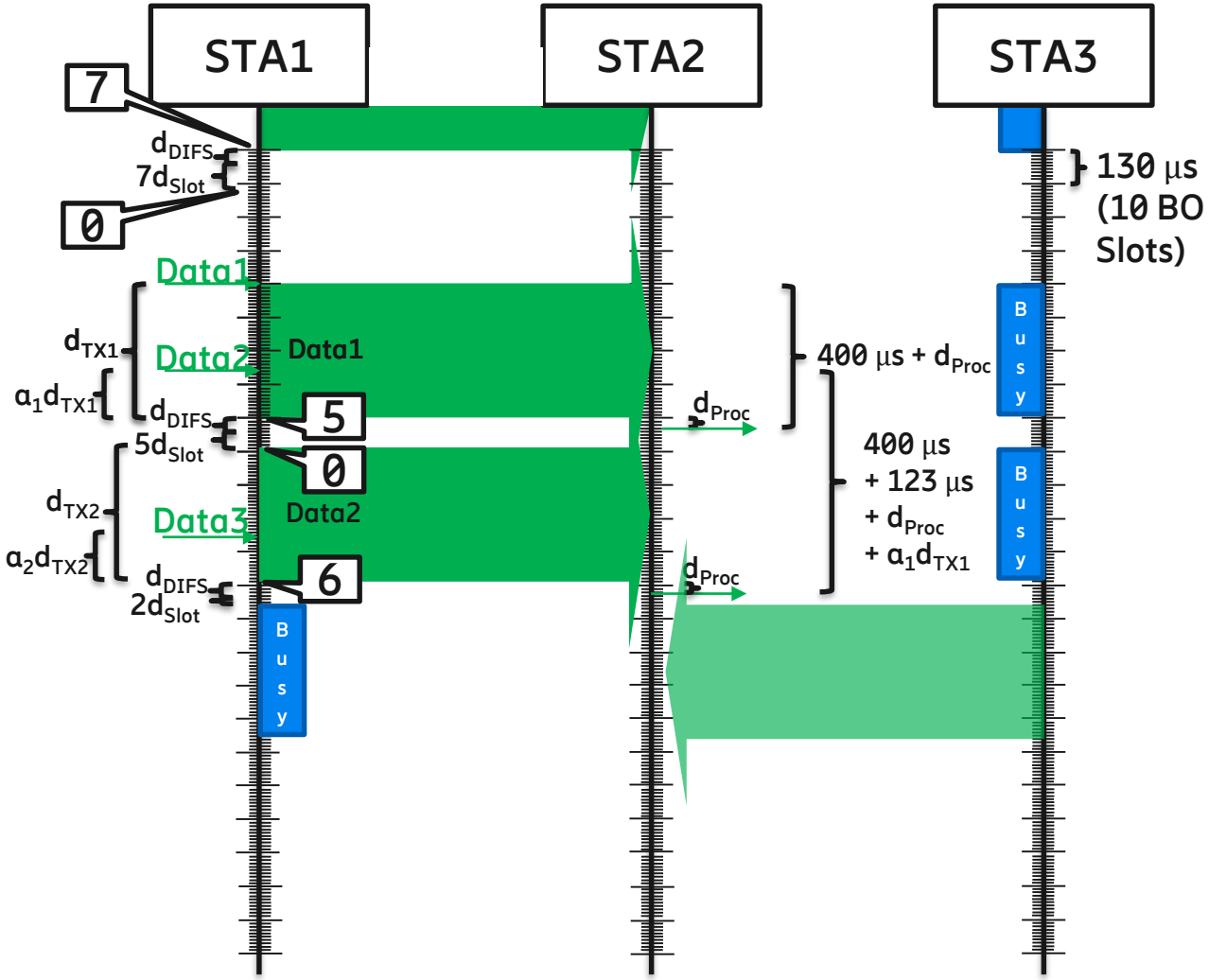

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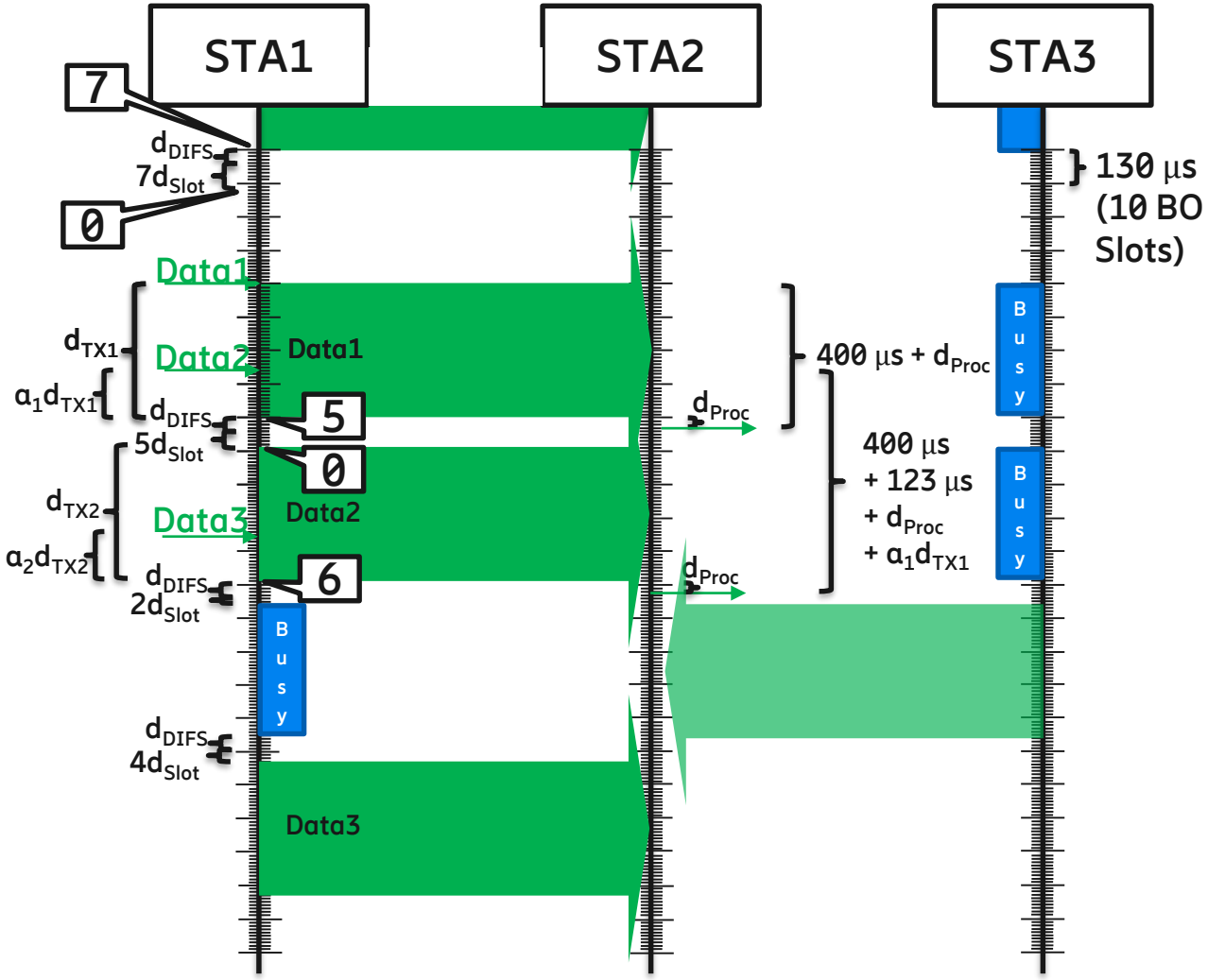

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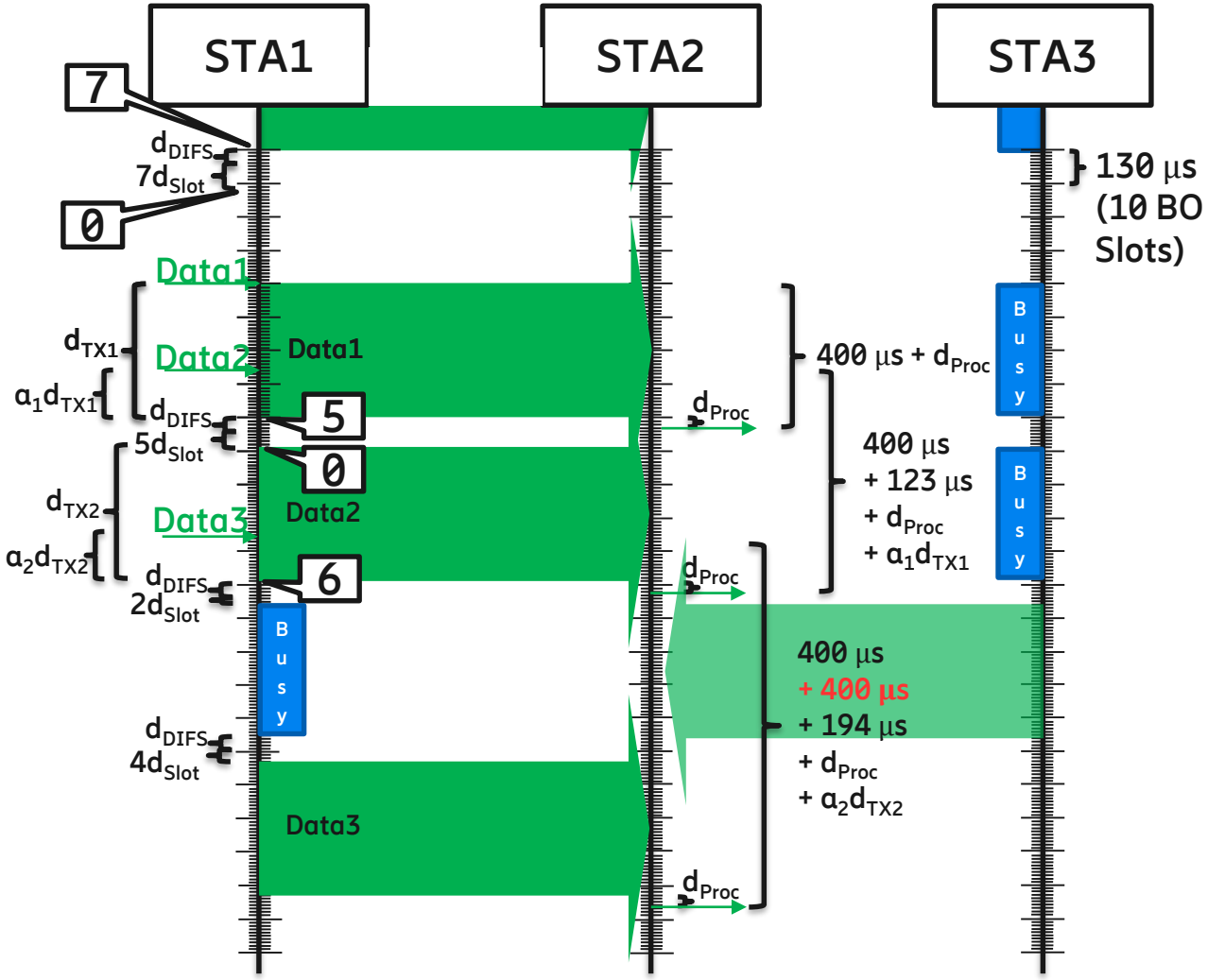

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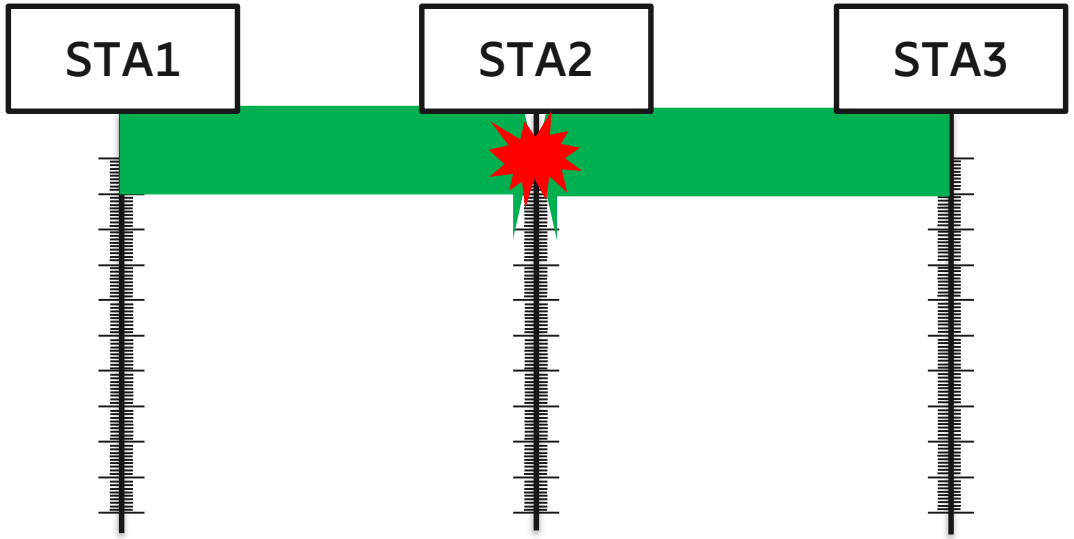
300 byte at 6 Mbit/s

Same random slot
➔ collision



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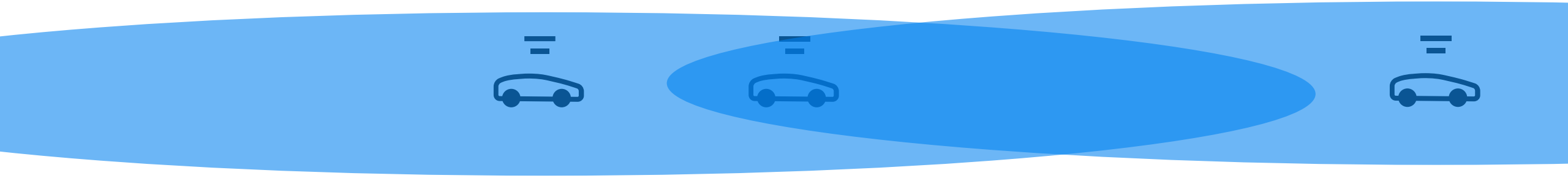
Large distances
➔ hidden node problem



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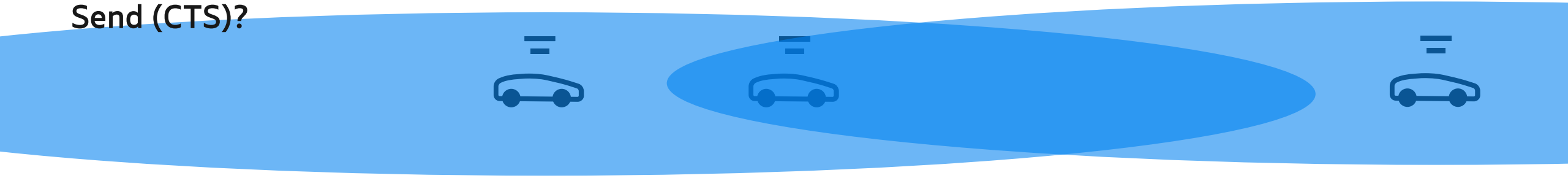
What about Ready to Send (RTS) / Clear to Send (CTS)?



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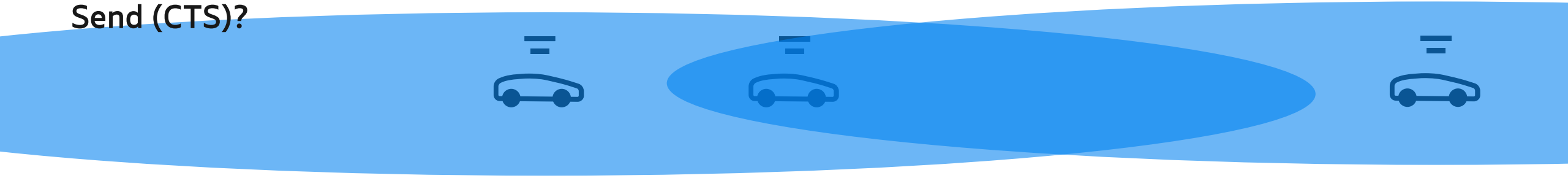
What about Ready to Send (RTS) / Clear to Send (CTS)?

Not possible for broadcast communication



Protocol description: IEEE 802.11p/e

Legacy IEEE 802.11

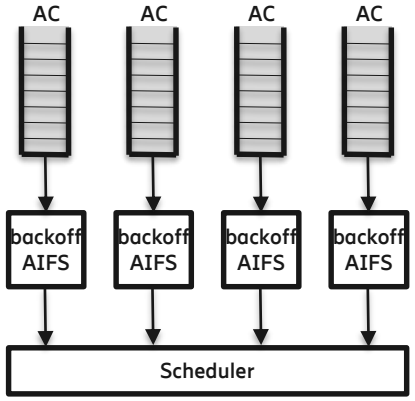
- Random slot is drawn between zero and CW_{Min}
- Always wait DIFS time before starting count down

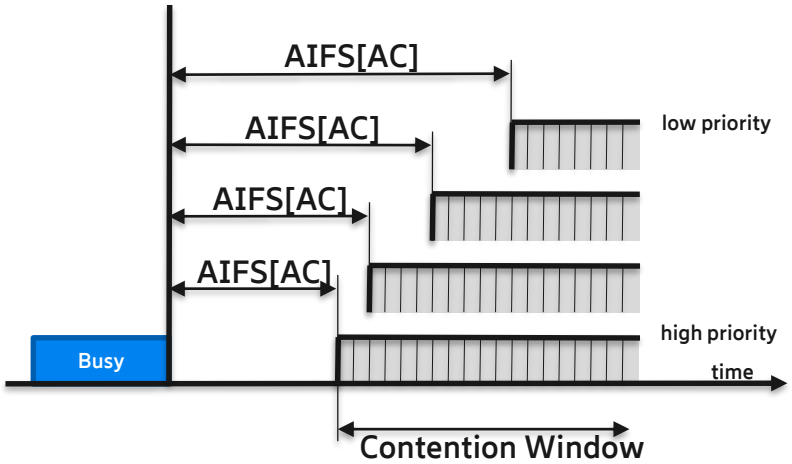
IEEE 802.11e

- Lower CW_{Min} for higher priority
- Arbitration Inter Frame Space (AIFS) before count down; shorter for higher priority

Priorities:

- Voice (VO)
- Video (VI)
- Best Effort (BE)
- Background (BK)





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Why is it called CW_{Min}?

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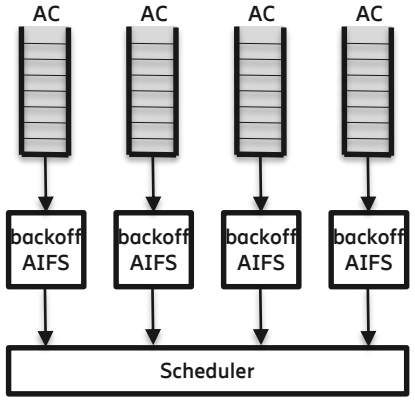

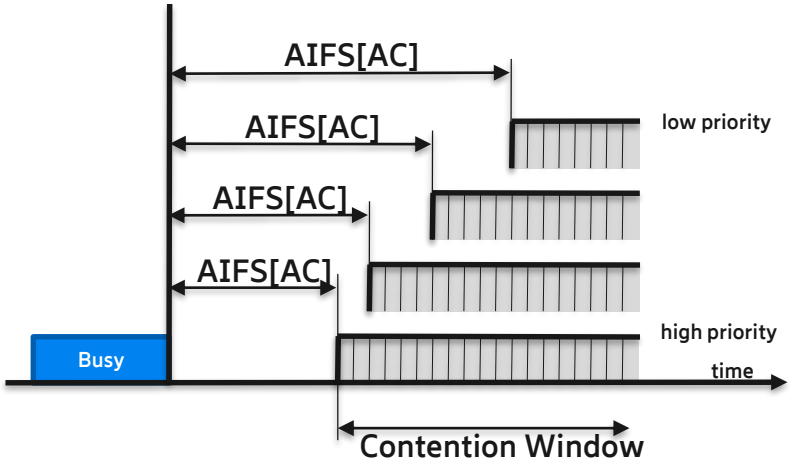

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Legacy IEEE 802.11

- Random slot is drawn between zero and CW_{Min}
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Why is it called CW_{Min}?

It's the maximum backoff value at the first (minimal) backoff stage.
But: No other backoff stage will be entered.

Priorities:

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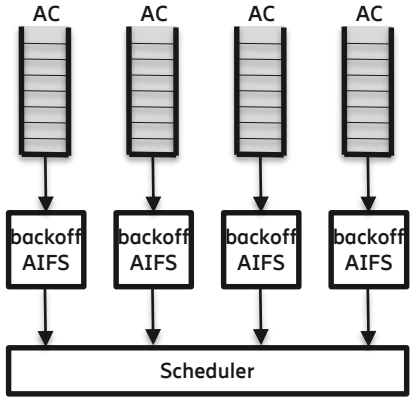
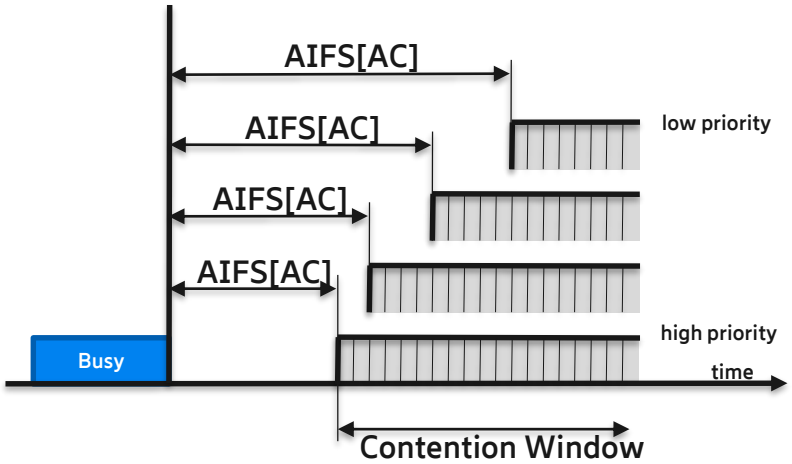
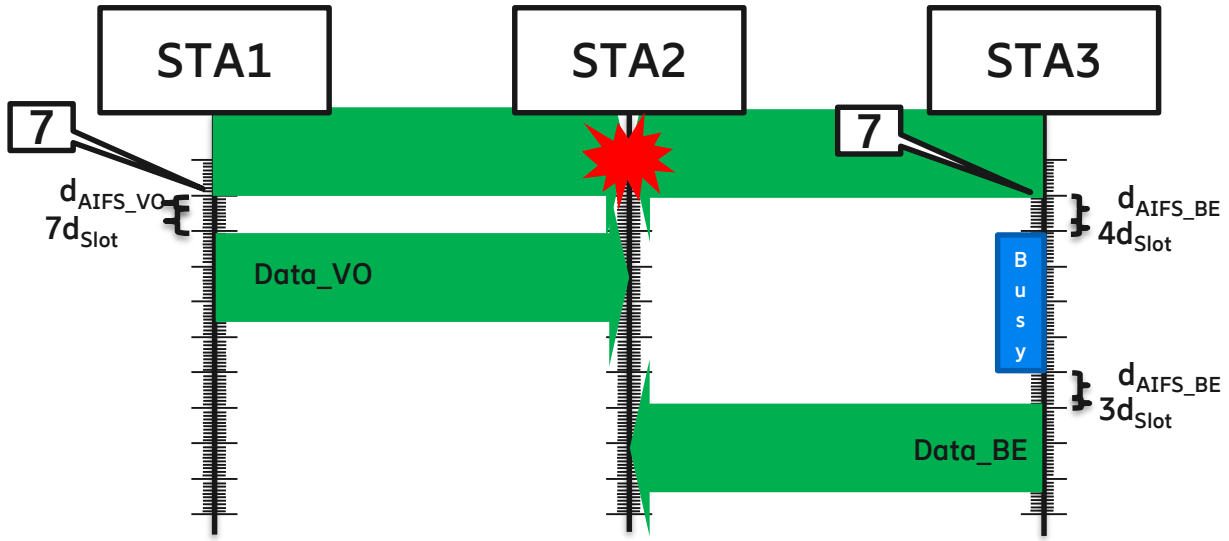




Protocol description: IEEE 802.11p/e

300 byte Voice (VO) class and 300 byte Best Effort (BE) class at 6 Mbit/s



AC	CW_{Min}	AIFS
Voice (VO)	3	58 μs
Video (VI)	7	71 μs
Best Effort (BE)	15	110 μs
Background (BK)	15	149 μs

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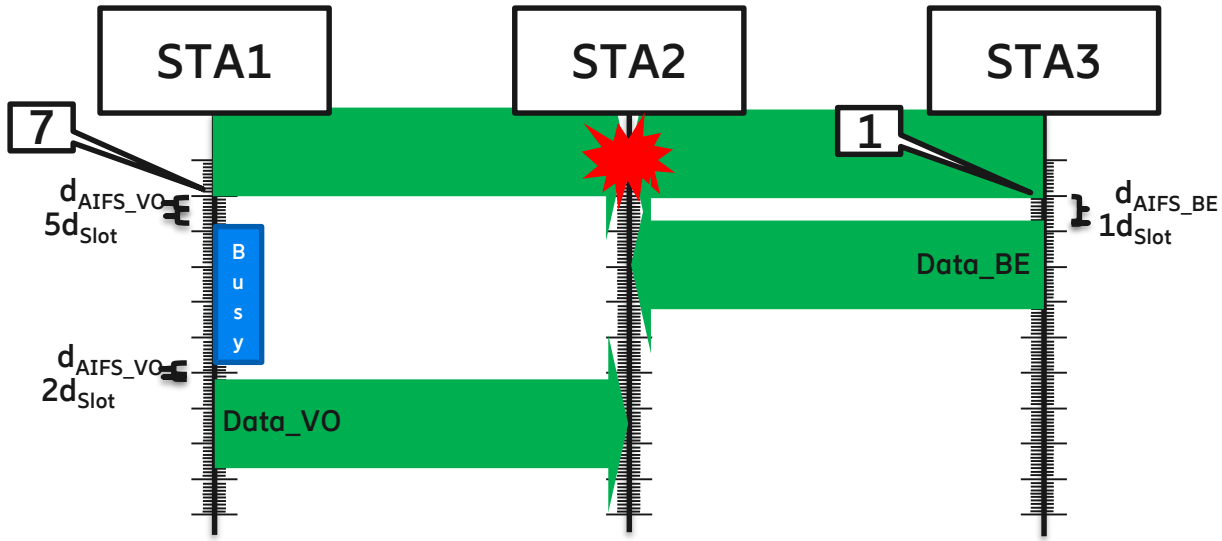

There is a probability BE gets priority over VO if transmitted by different nodes

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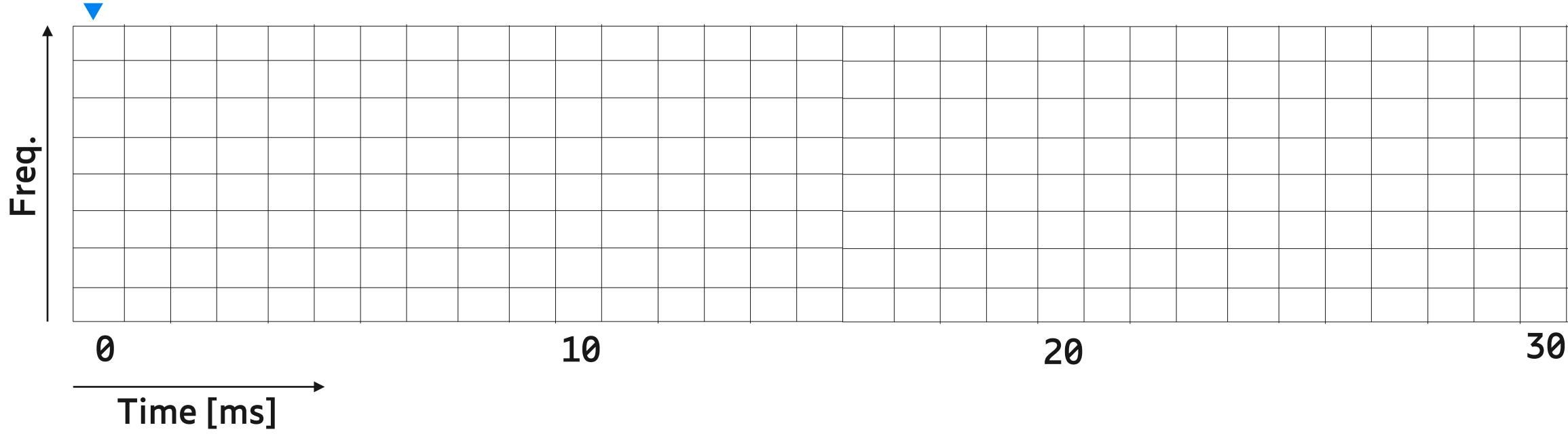
Protocol description: LTE-V2X Sidelink

Protocol description: LTE-V2X Sidelink Mode 4

Random scheduling



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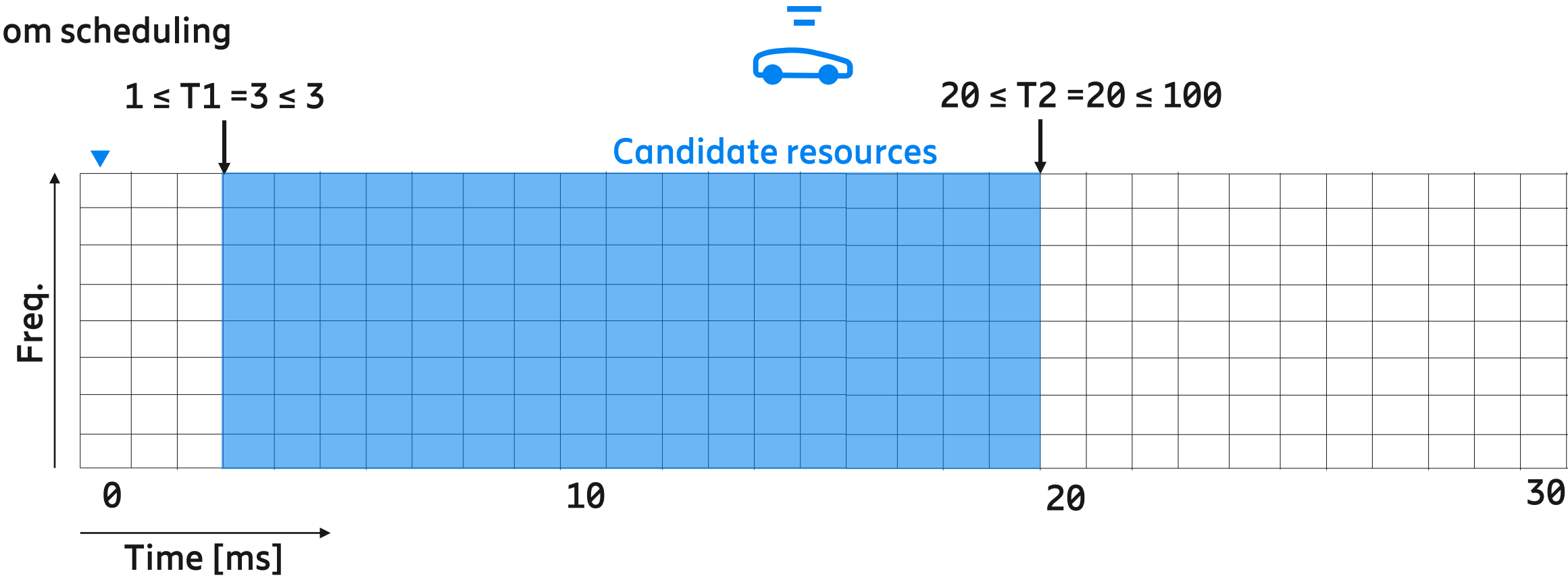

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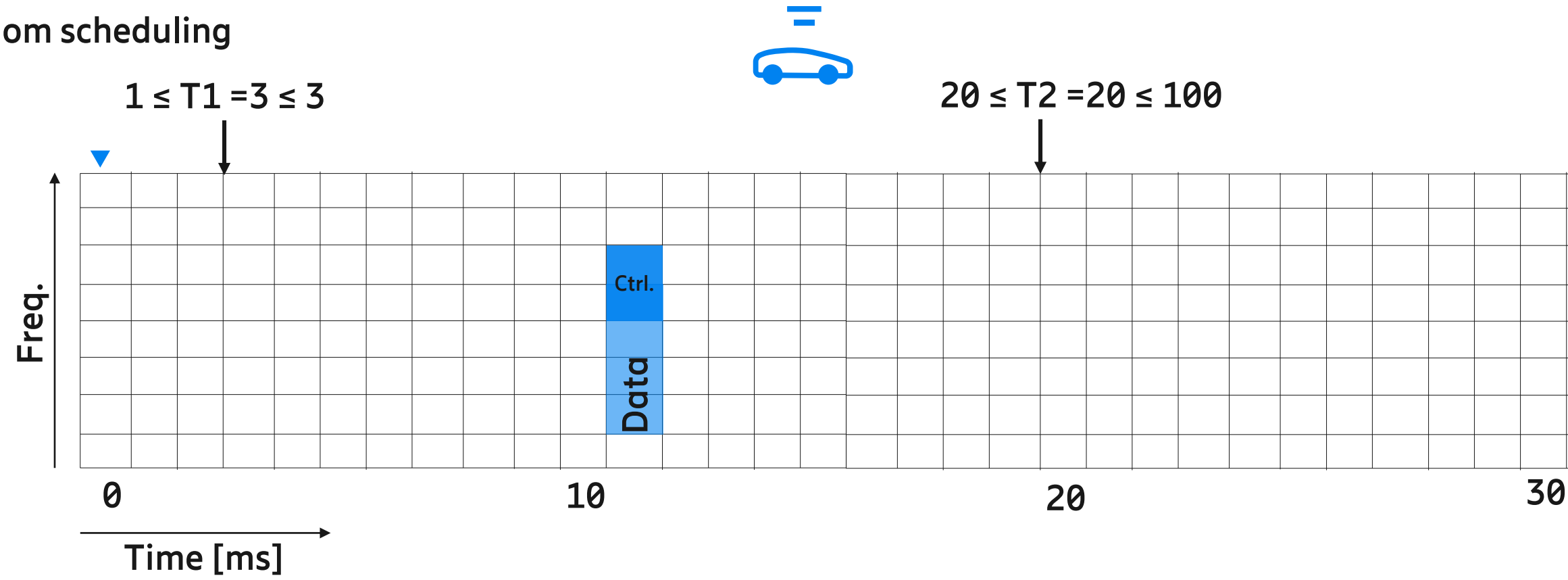
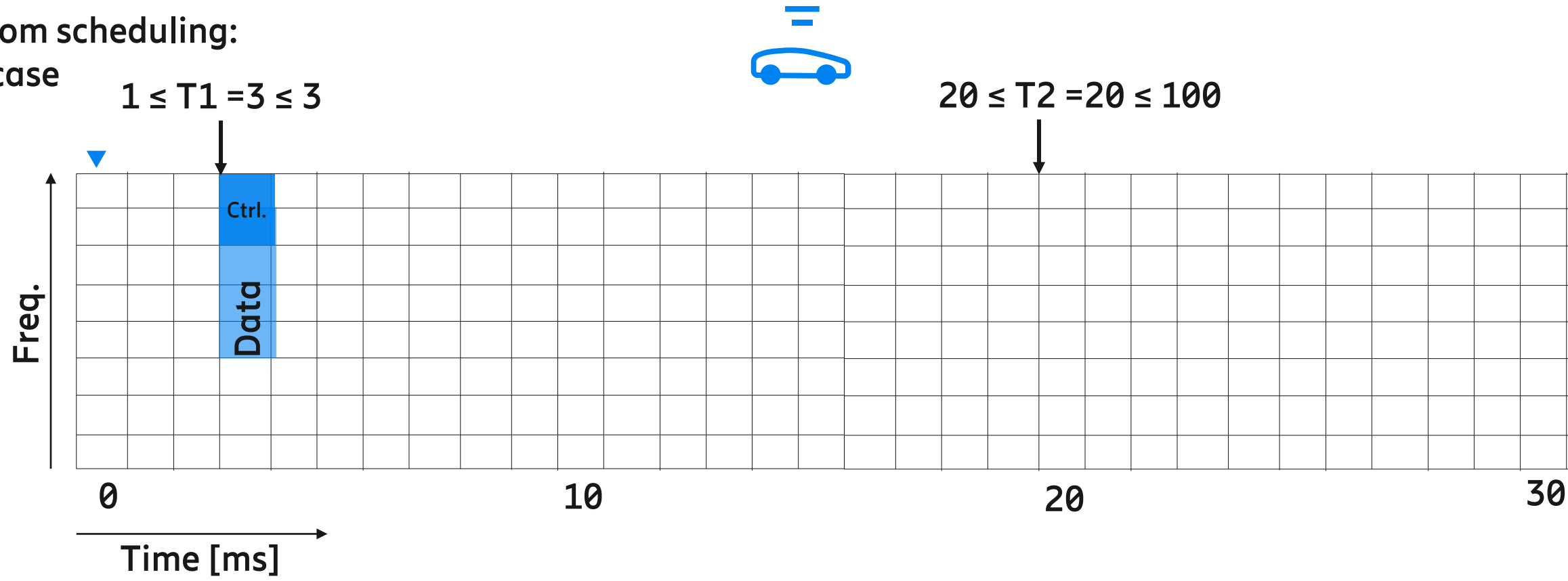


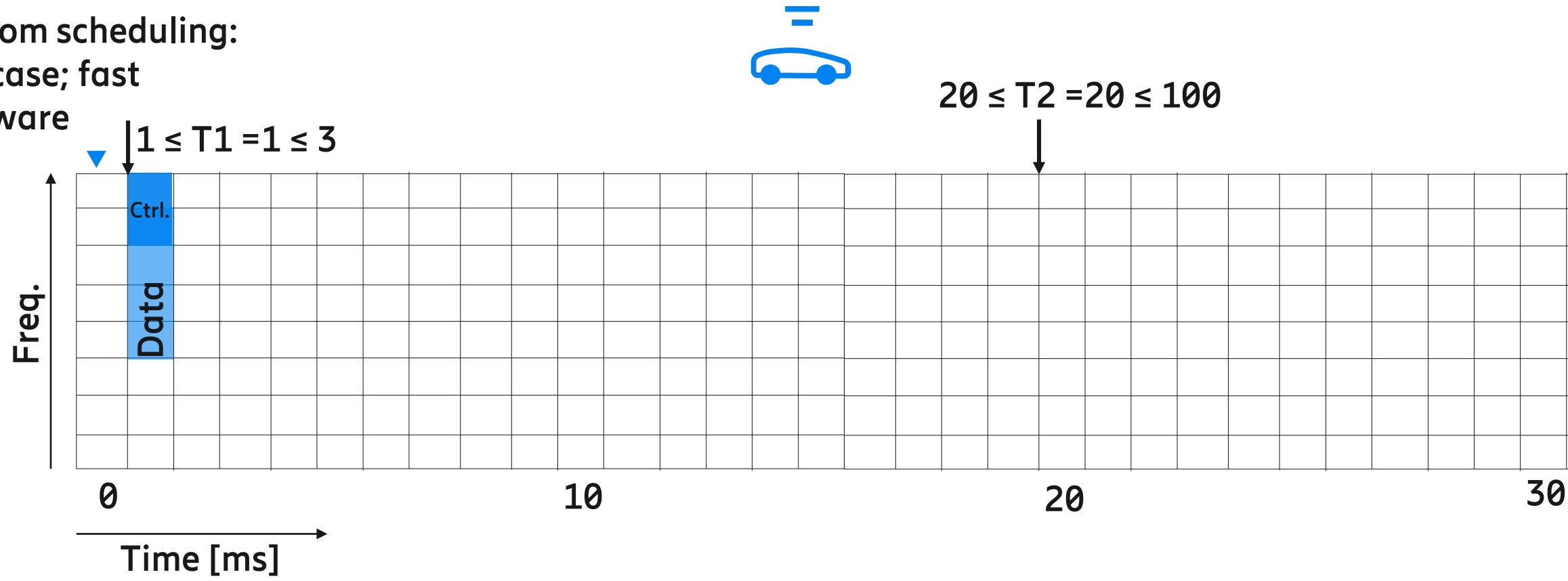
Protocol description: LTE-V2X Sidelink Mode 4

Random scheduling: best case



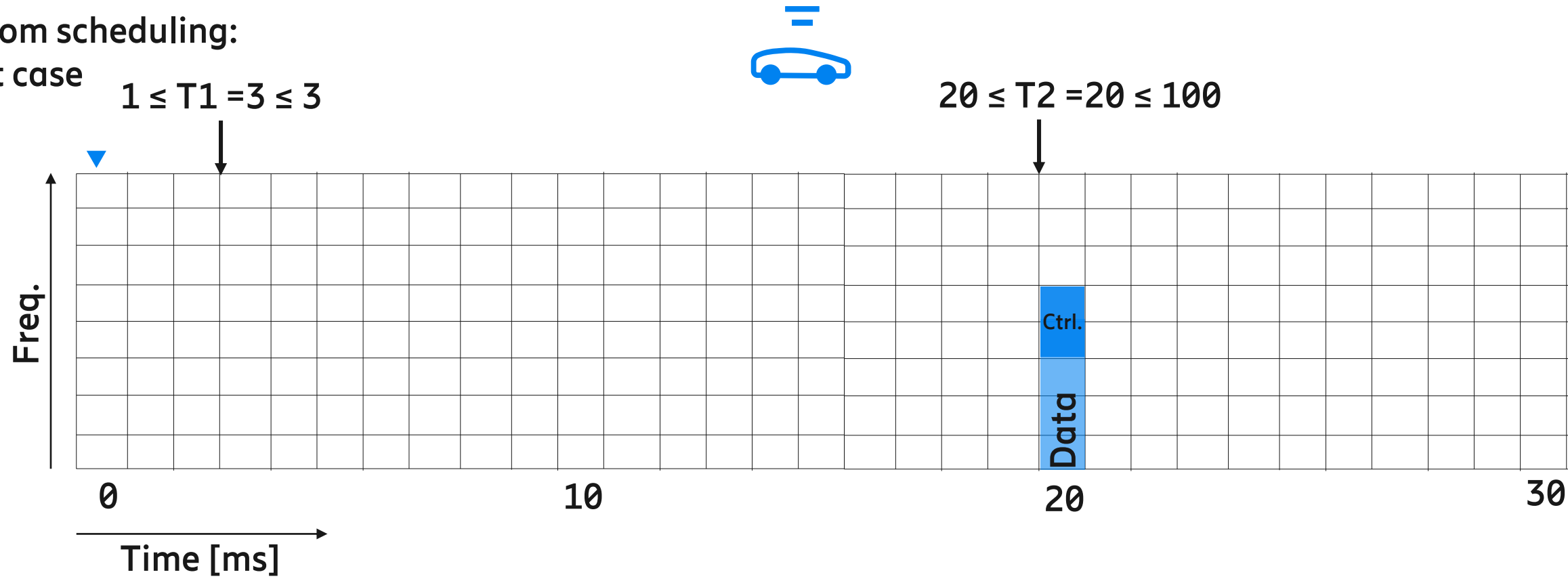
Protocol description: LTE-V2X Sidelink Mode 4

Random scheduling: best case; fast hardware



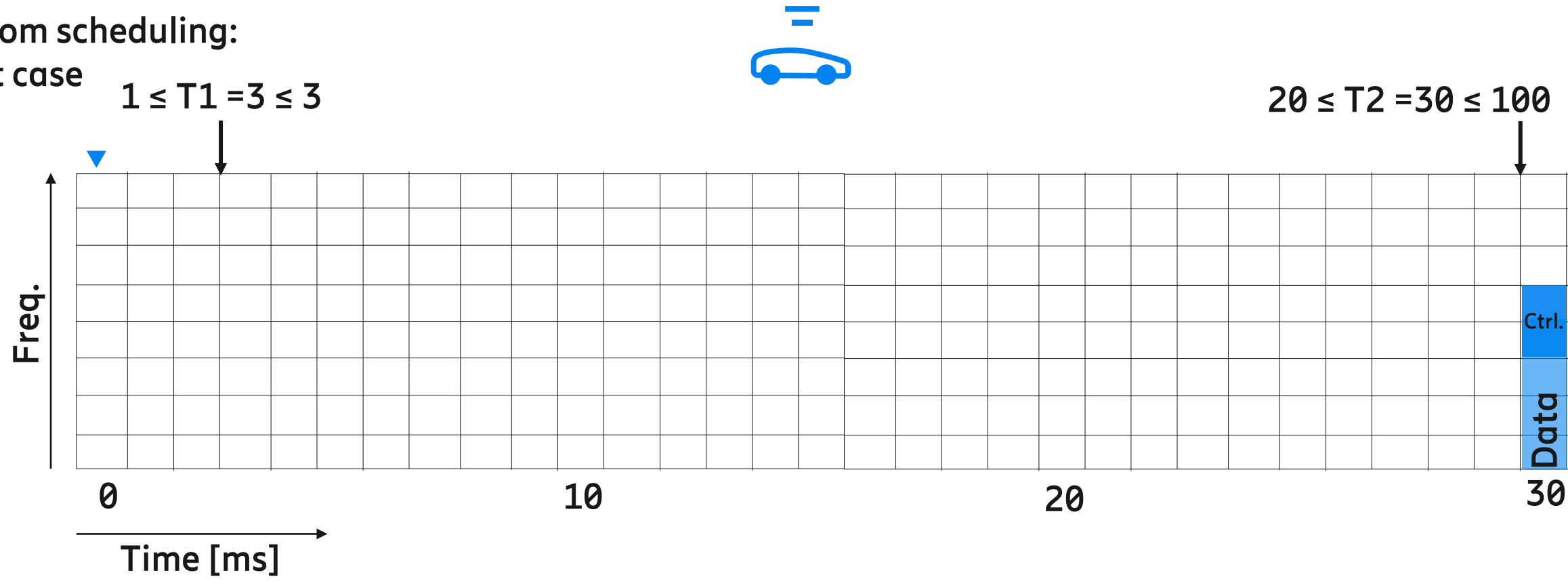
Protocol description: LTE-V2X Sidelink Mode 4

Random scheduling: worst case



Protocol description: LTE-V2X Sidelink Mode 4

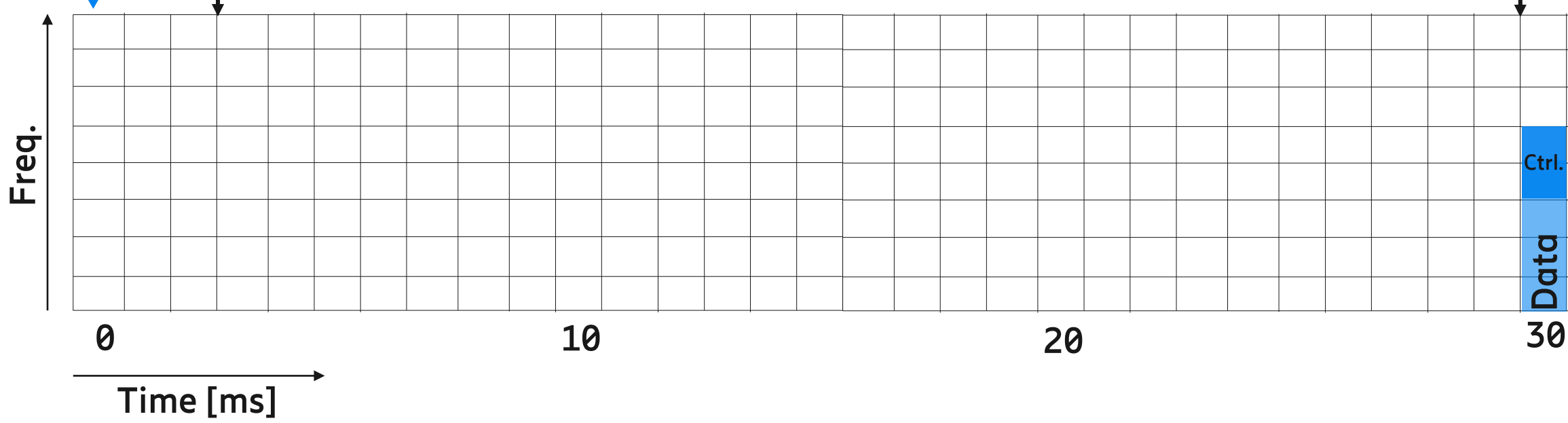
Random scheduling: worst case



Protocol description: LTE-V2X Sidelink Mode 4

Random scheduling: worst case

Why would you increase T2?



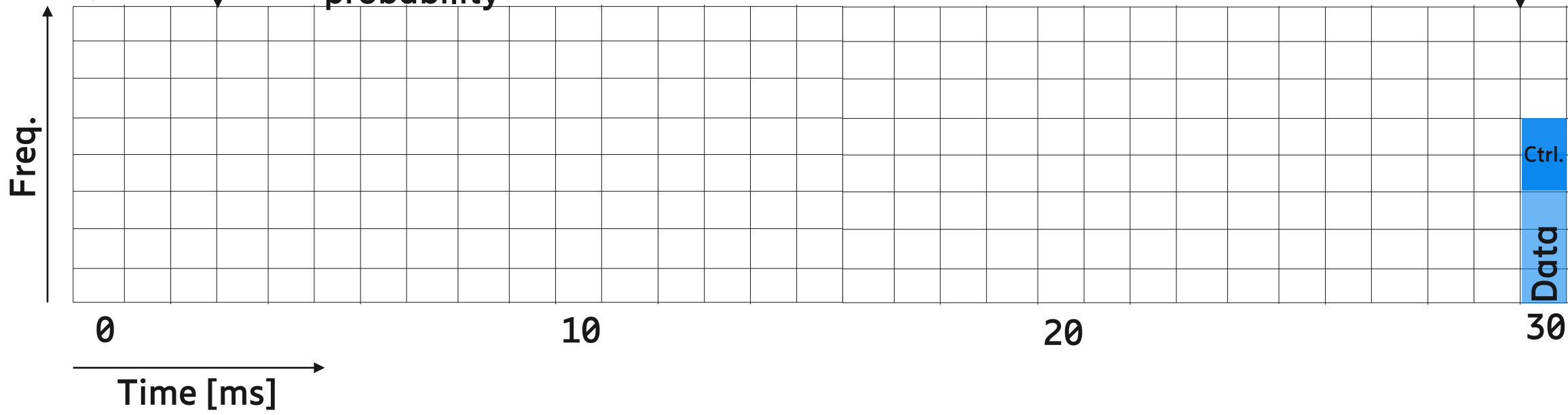
Protocol description: LTE-V2X Sidelink Mode 4

Random scheduling: worst case

1 ≤ T1 =3 ≤ 3

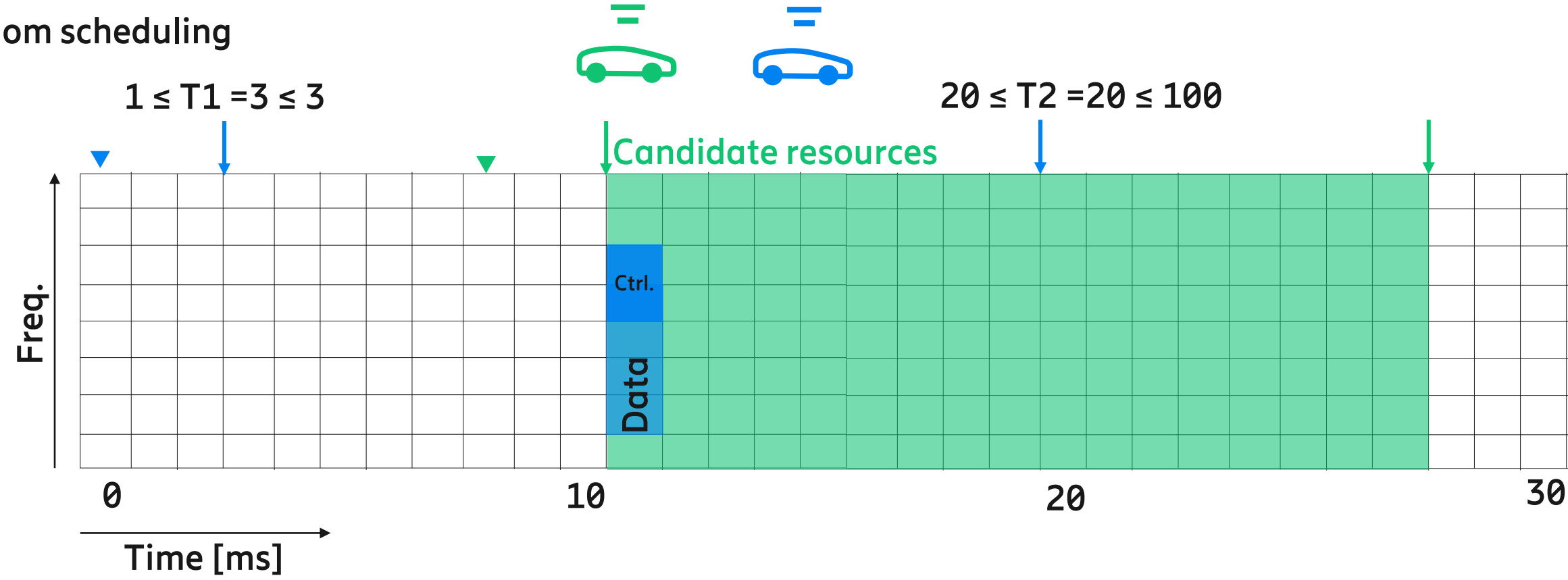
Why would you increase T2? To decrease collision probability

20 ≤ T2 =30 ≤ 100



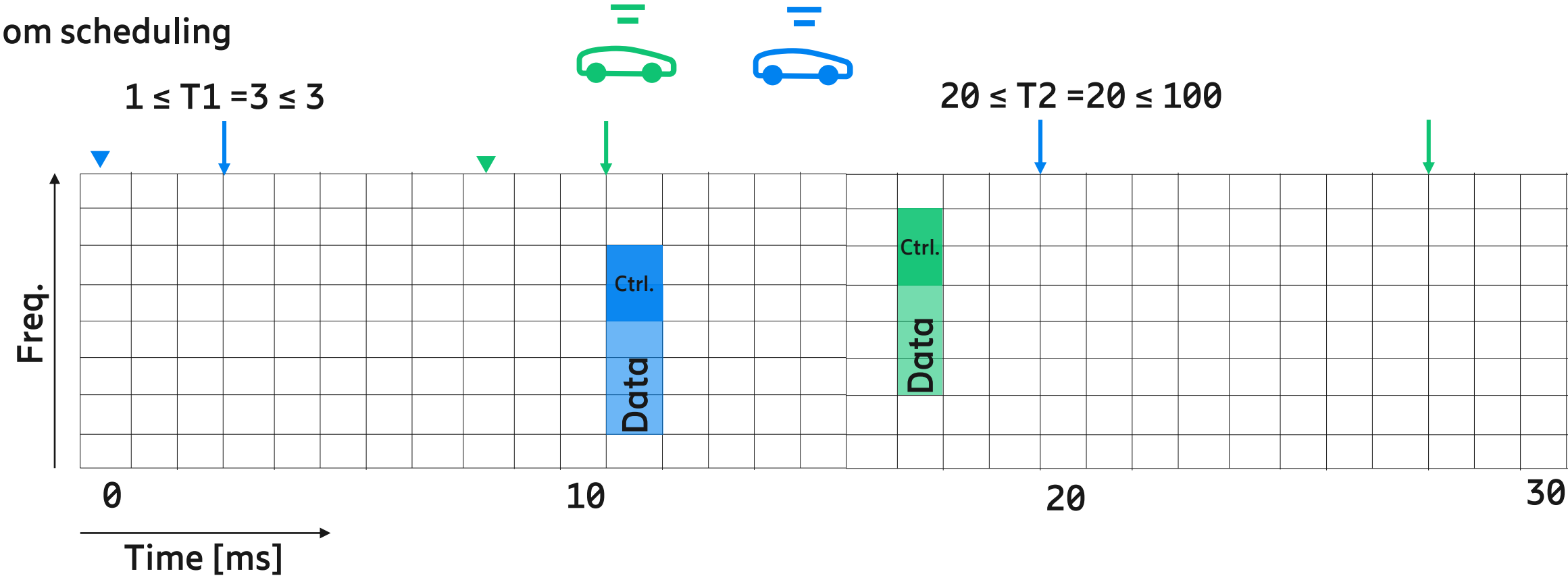
Protocol description: LTE-V2X Sidelink Mode 4

Random scheduling



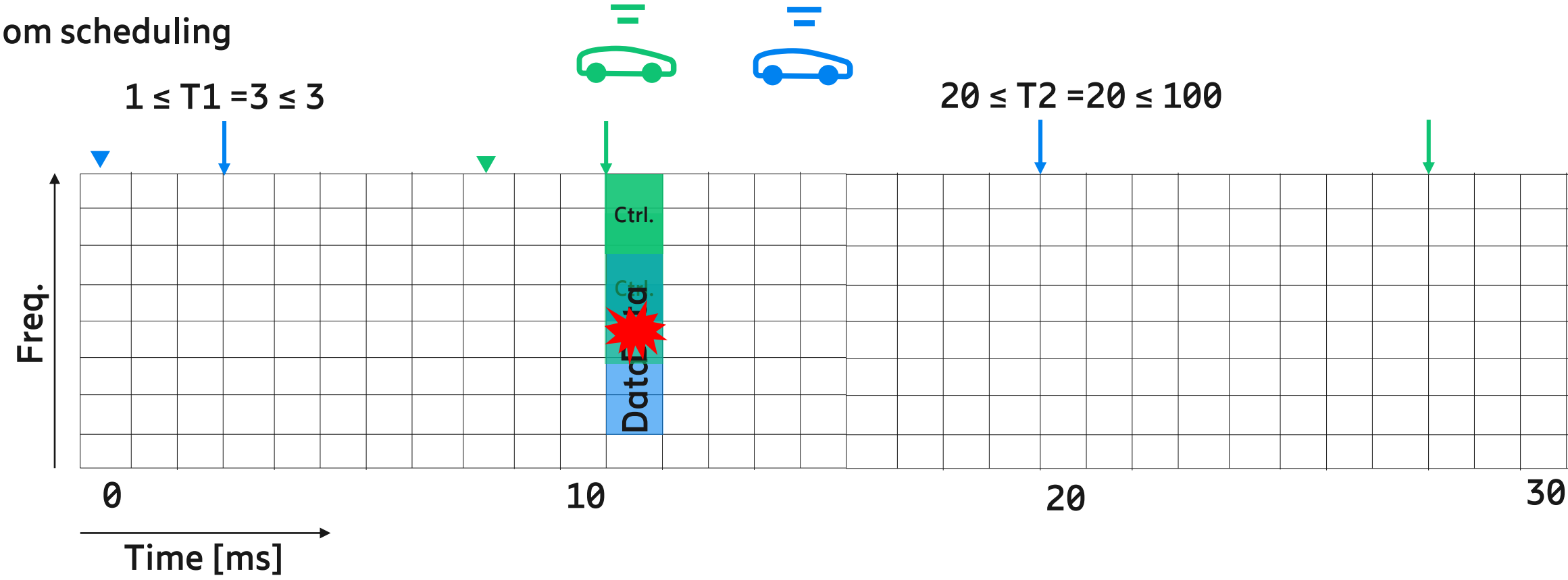
Protocol description: LTE-V2X Sidelink Mode 4

Random scheduling



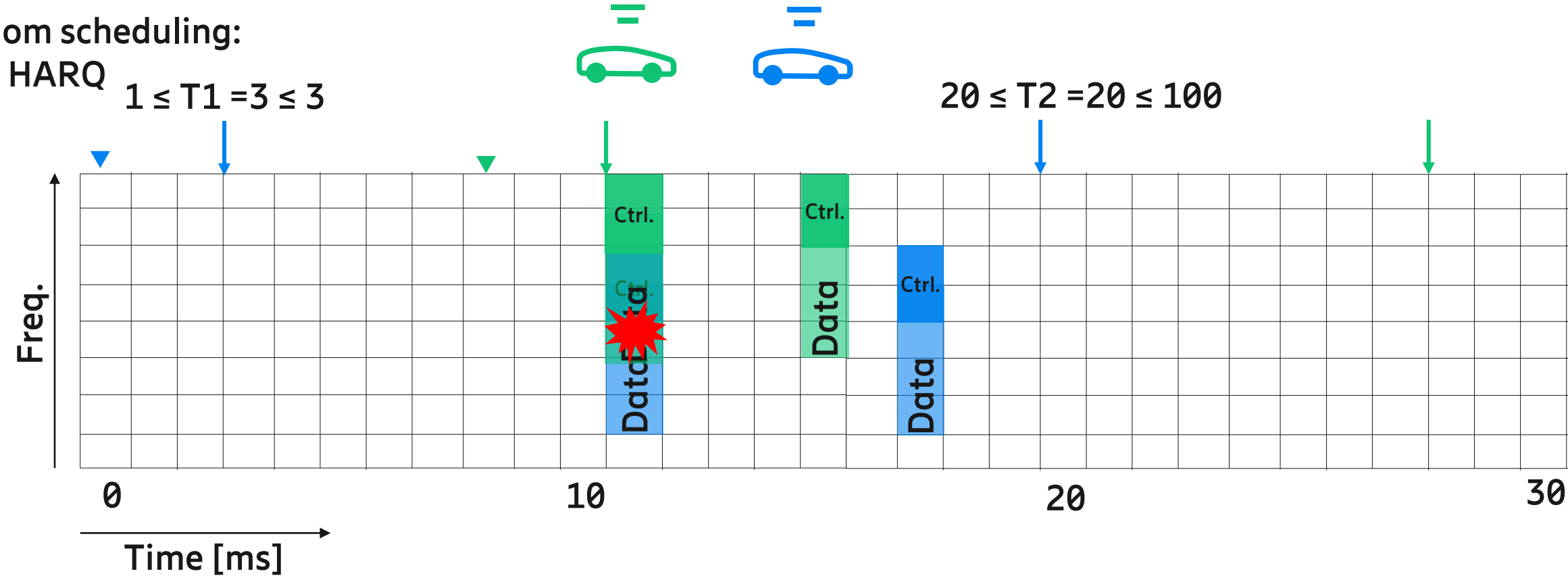
Protocol description: LTE-V2X Sidelink Mode 4

Random scheduling



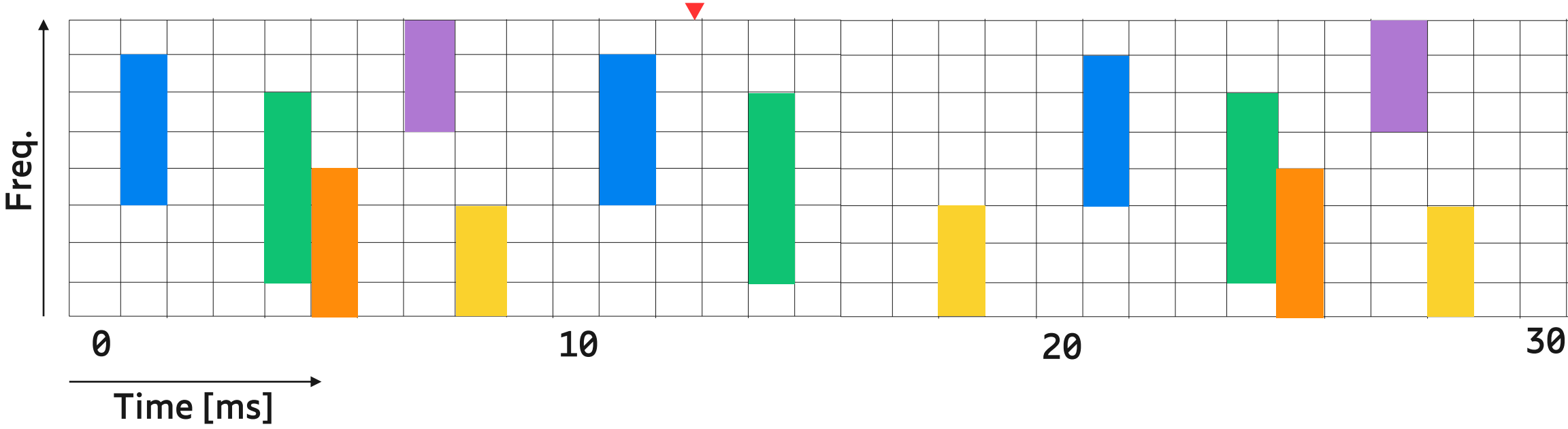
Protocol description: LTE-V2X Sidelink Mode 4

Random scheduling:
Blind HARQ



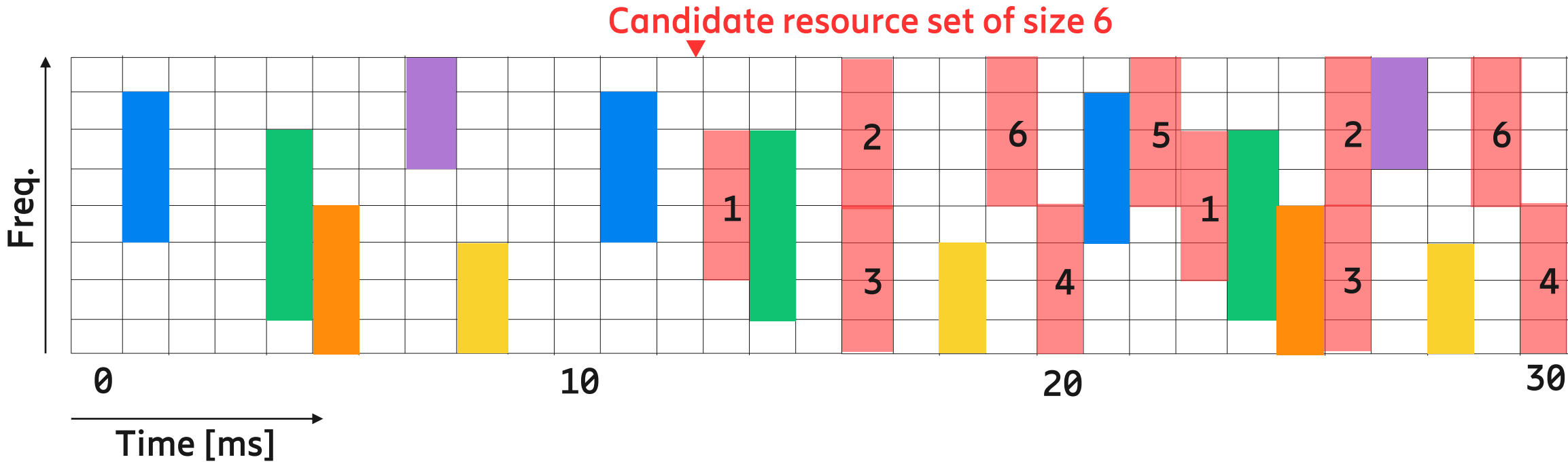
Protocol description: LTE-V2X Sidelink Mode 4

Sensing based scheduling



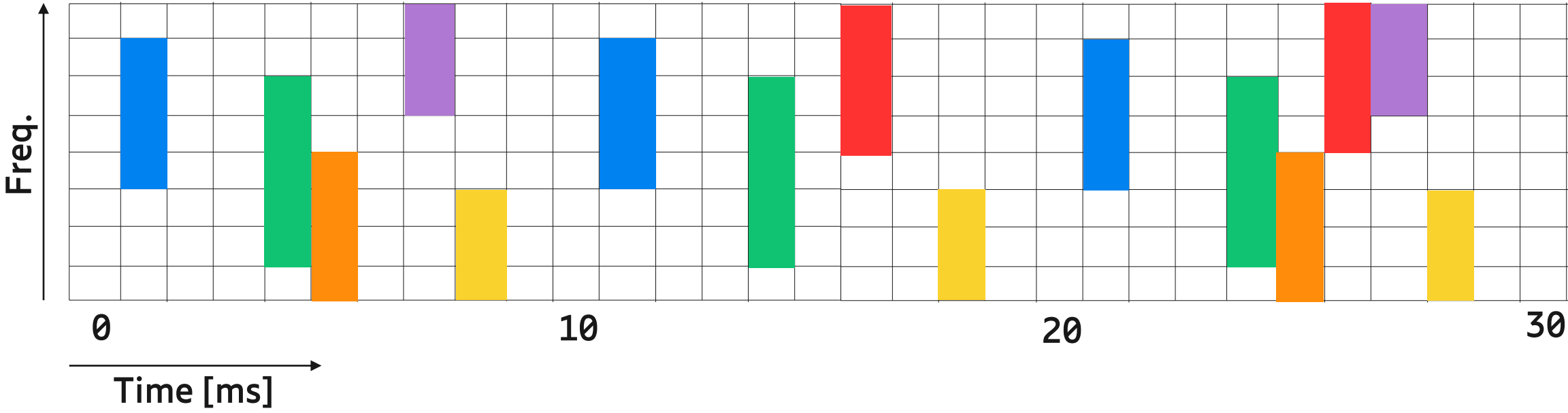
Protocol description: LTE-V2X Sidelink Mode 4

Sensing based scheduling



Protocol description: LTE-V2X Sidelink Mode 4

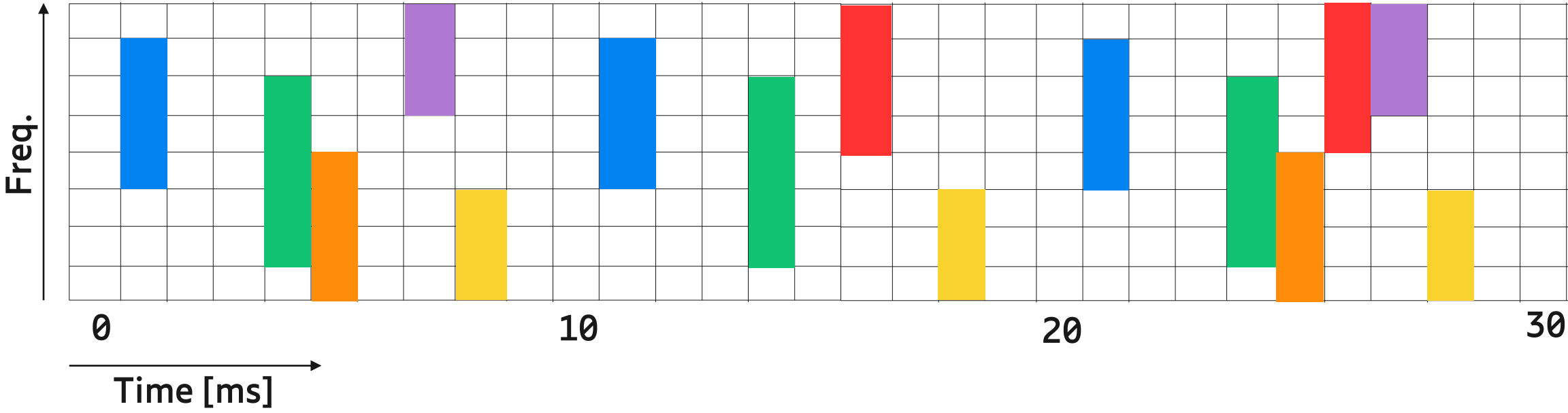
Sensing based scheduling



Protocol description: LTE-V2X Sidelink Mode 4

Sensing based scheduling

Why not candidate set size 1?

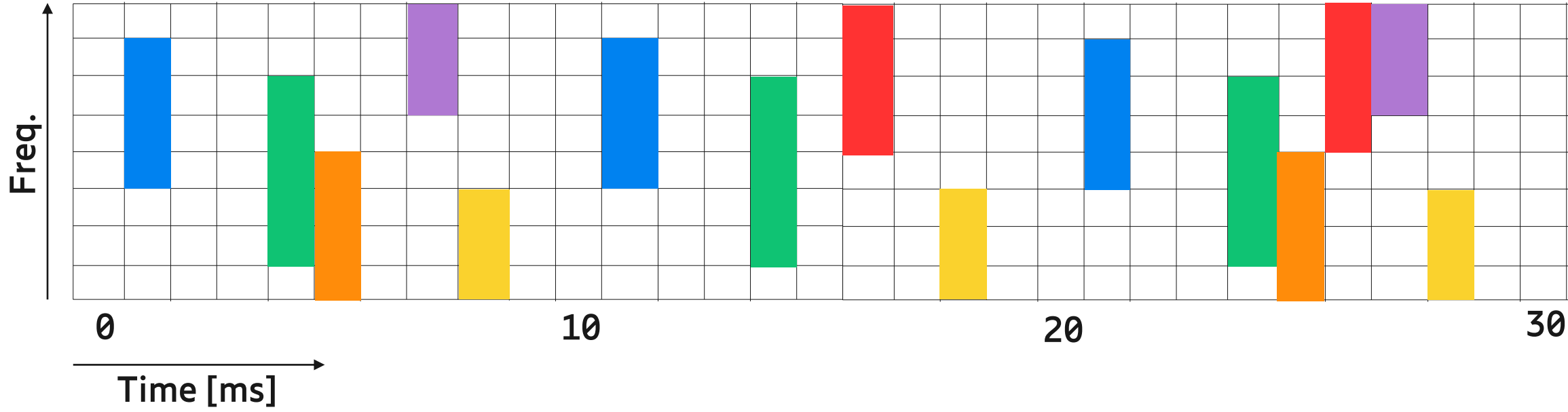


Protocol description: LTE-V2X Sidelink Mode 4

Sensing based scheduling

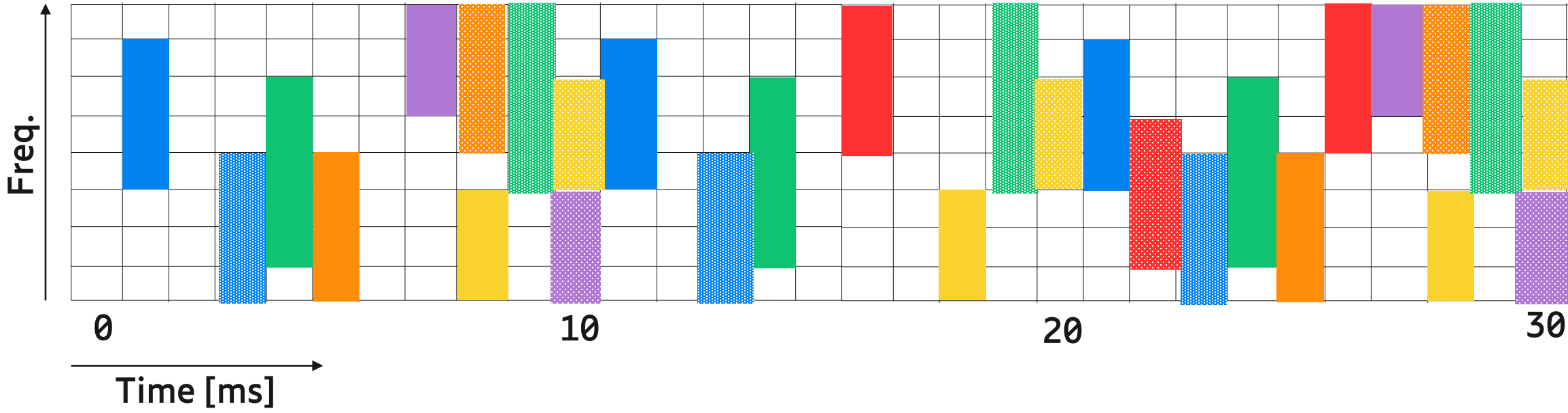
Why not candidate set size 1?

Reduce probability of collision if more than one vehicle scans for resources



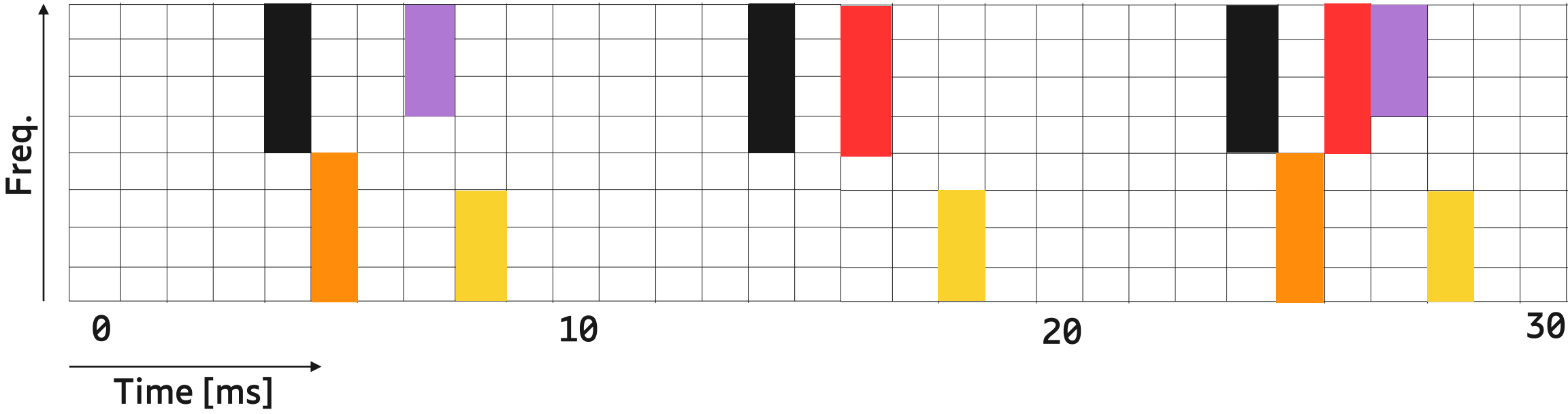
Protocol description: LTE-V2X Sidelink Mode 4

Sensing based scheduling with bling HARQ retransmissions



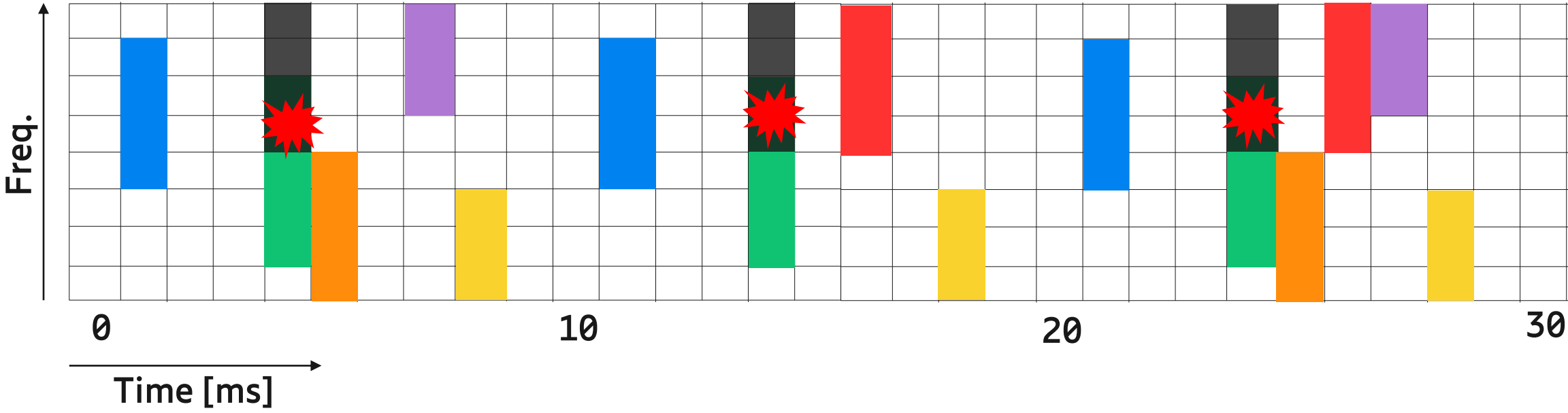
Protocol description: LTE-V2X Sidelink Mode 4

Sensing based scheduling & mobility



Protocol description: LTE-V2X Sidelink Mode 4

Sensing based scheduling & mobility

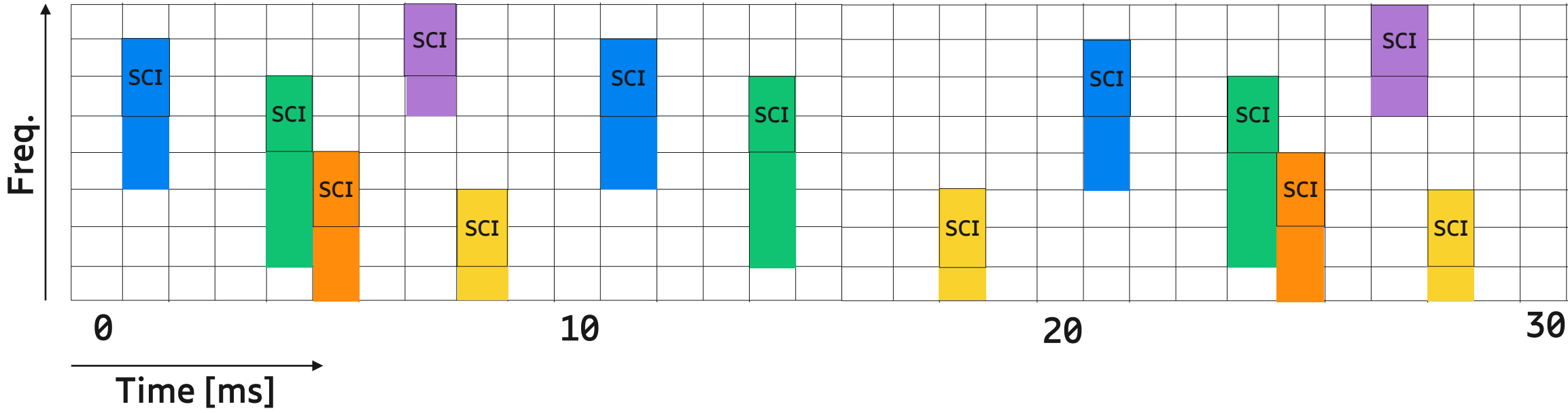


Protocol description: LTE-V2X Sidelink Mode 4

Sensing based scheduling & mobility

Protocol description: LTE-V2X Sidelink Mode 4

Sensing based scheduling: Sidelink Control Information (SCI)



Protocol description: LTE-V2X Sidelink Mode 4

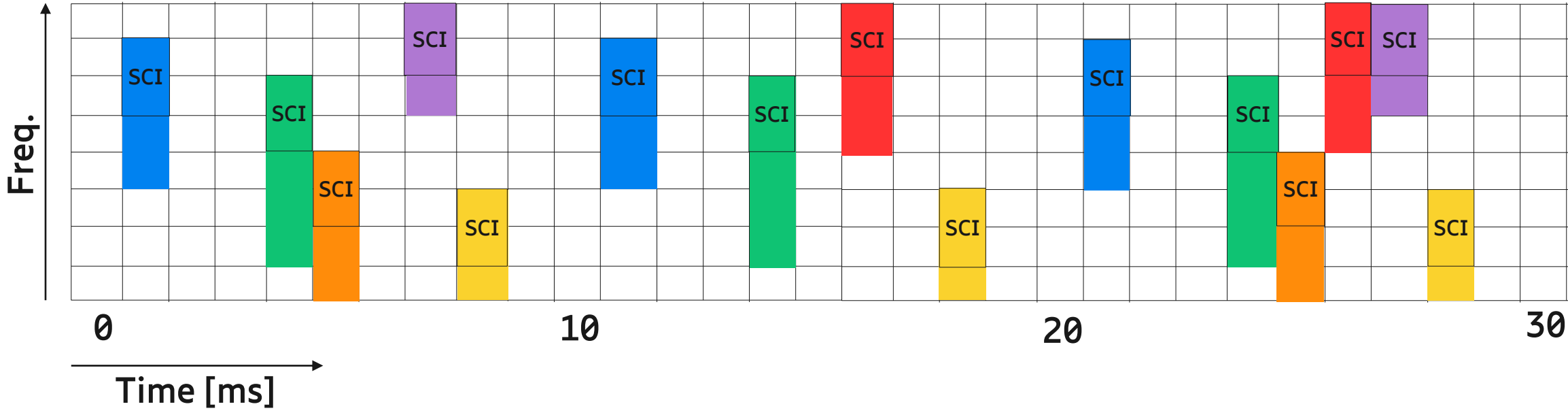
Sensing based scheduling: Sidelink Control Information (SCI)

Read SCIs to learn periods instead of/additionally to scanning

Protocol description: LTE-V2X Sidelink Mode 4

Sensing based scheduling: Sidelink Control Information (SCI)

Read SCIs to learn periods instead of/additionally to scanning



Protocol description: Degrees of freedom

IEEE 802.11

- Modulation and Coding Scheme (PHY Mode)
- Transmit power
- Maximum backoff slot CW_{Min} per Access Class

LTE

- Modulation and Coding Scheme
- Transmit power
- Scheduling algorithm
  - Random (dynamic or semi-persistent)
  - Sensing based (semi-persistent)
- Earliest (T1) and latest scheduling (T2)
- Candidate set size (for sensing based scheduling)
- Reservation duration time (for semi-persistent scheduling)
- Blind retransmissions (zero or one)
- Subset of resources (resource pool)

Summary

- Both, IEEE 802.11p and LTE-V2X Sidelink currently only support unacknowledged broadcast communication and cannot fully eliminate collisions causing packet loss
- Acknowledged cellular unicast communication is an alternative for applications requiring lower packet loss ratios

➔ Hybrid solutions exploiting advantages of both technologies

- Both, IEEE 802.11p and LTE-V2X Sidelink, are complex protocol standards and I just showed you some essentials
- Understand the key mechanisms contributing to delay and packet loss before judging a protocol
- Understand how the "environment" (communication behavior of application, mobility of vehicles, …) influences protocol performance