# Tutorial on Short-Range C-ITS Communication Technologies

**Maciej Muehleisen, Ericsson Research**

**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:

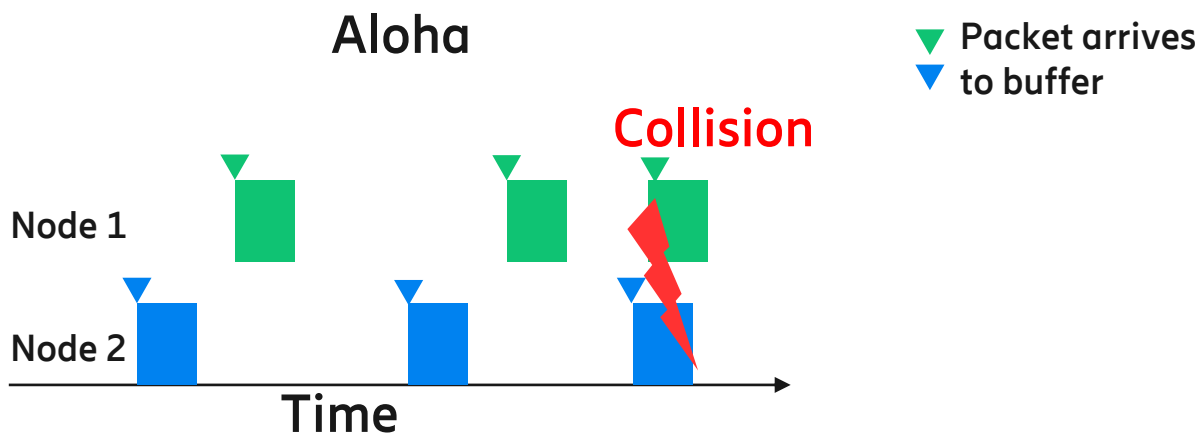
- IEEE 802.11p is based on the WLAN standard IEEE 802.11
- Often "ITS-G5" is used as synonym, since the ETSI ITS-G5 standard, specifying technology for 5.9 GHz spectrum access in Europe, currently only refers to IEEE 802.11p as Access Technology

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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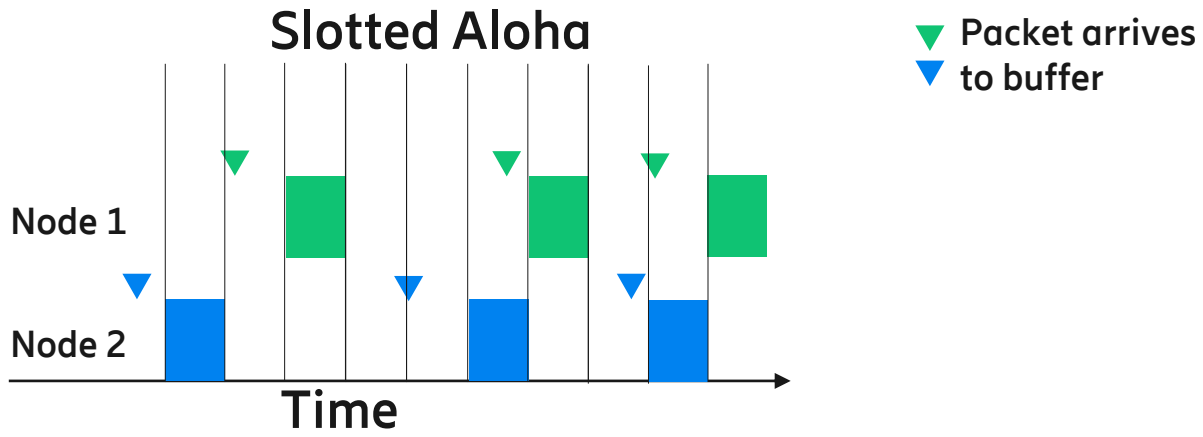
- MAC protocols often have loss vs. delay tradeoff



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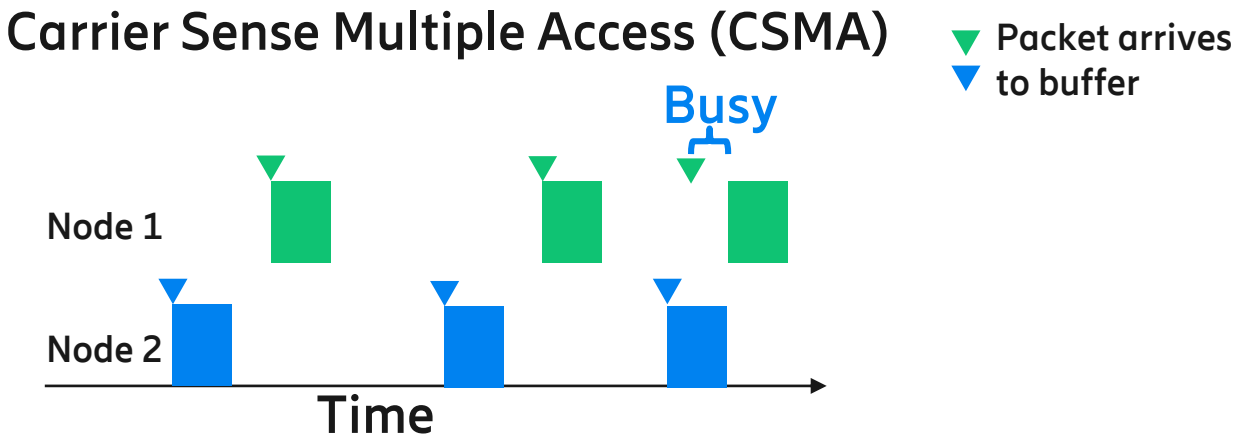

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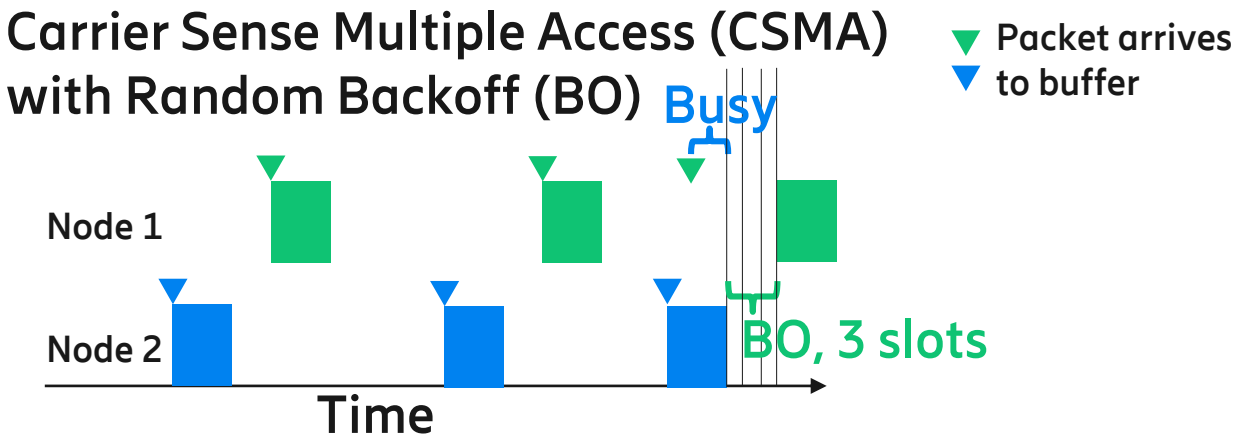

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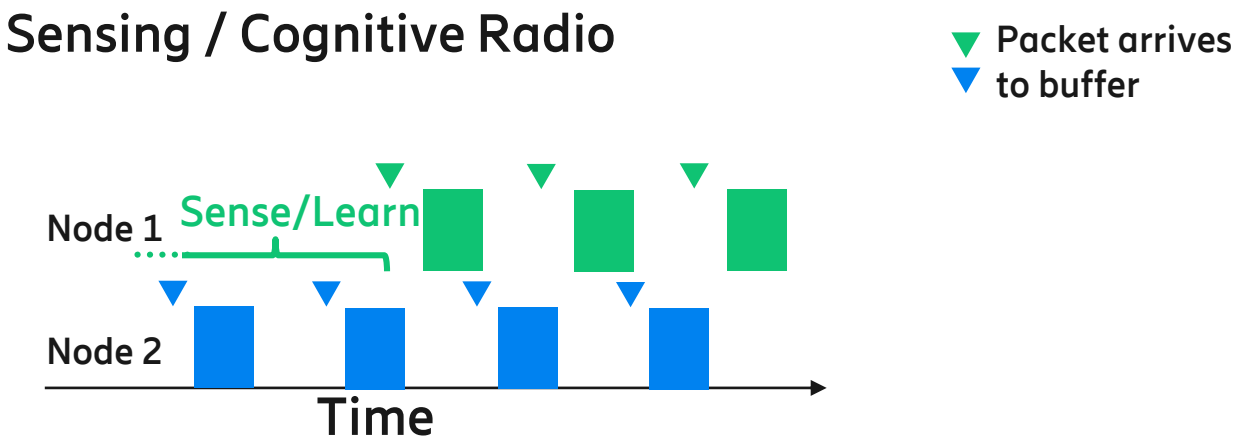
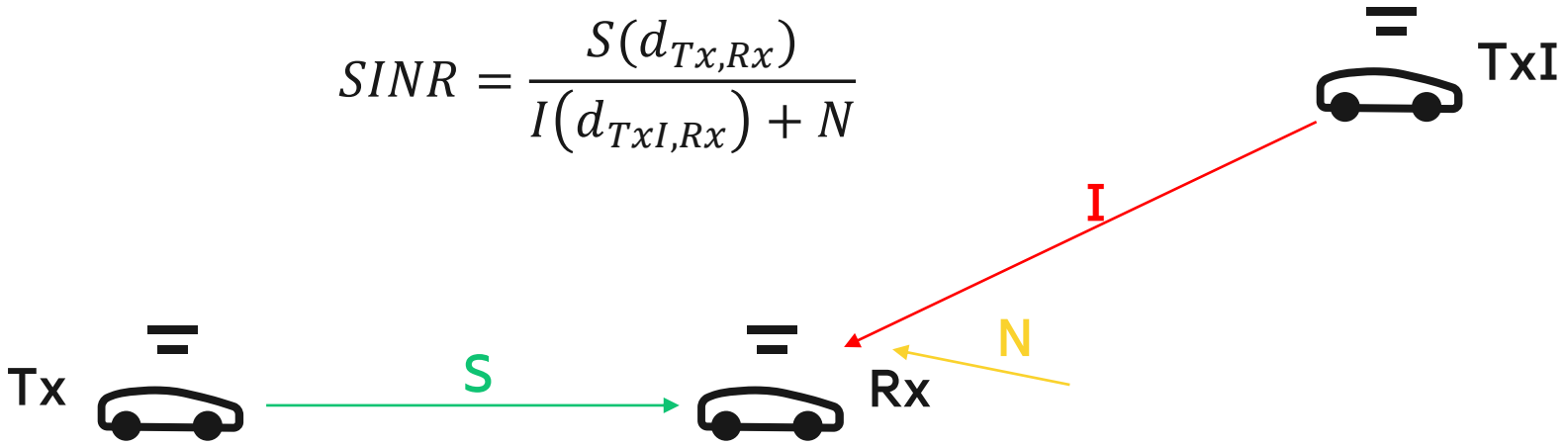


# Brief intro: PHY Layer

- 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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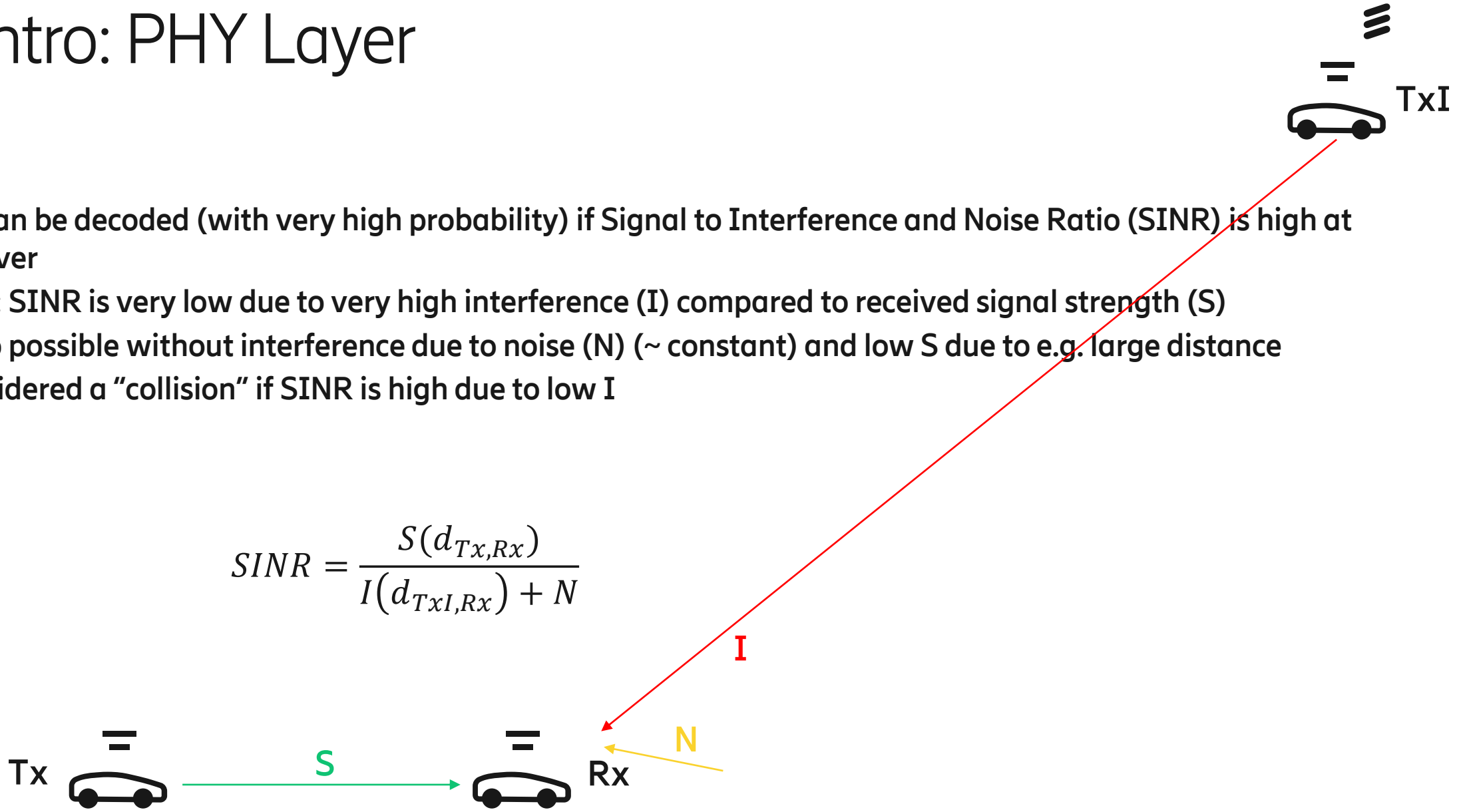

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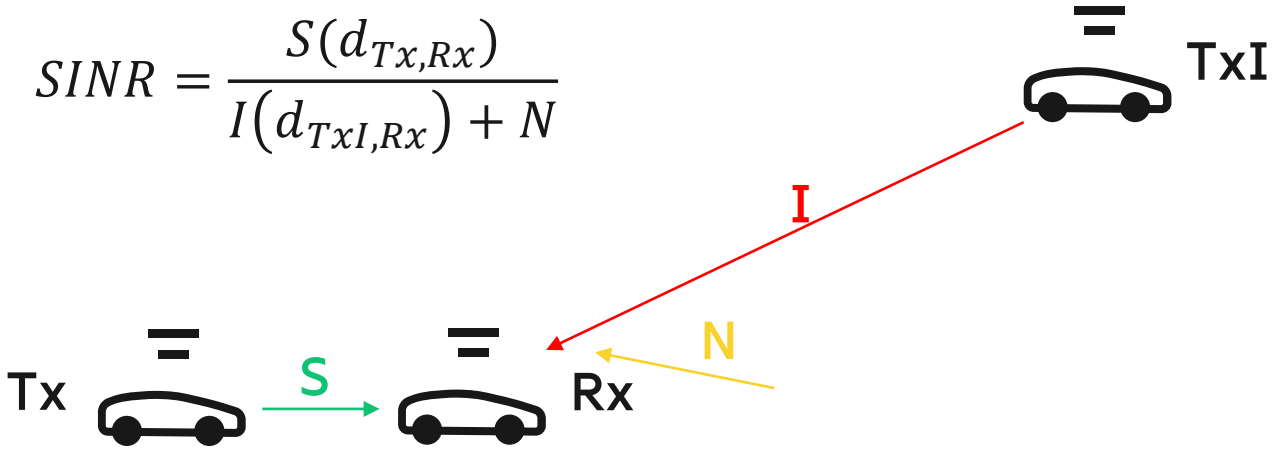
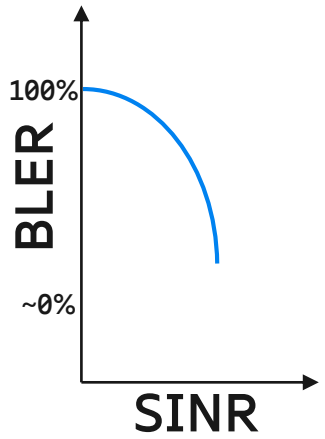


# Brief intro: PHY Layer

- 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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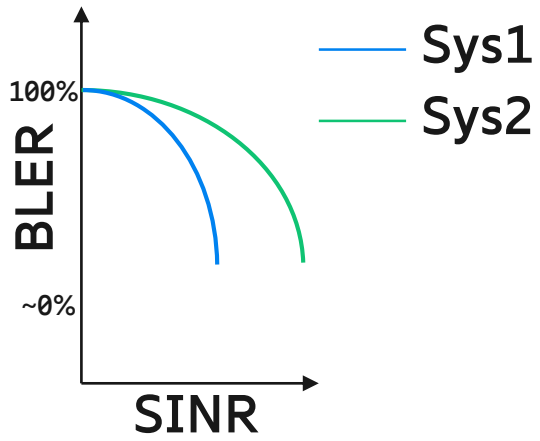

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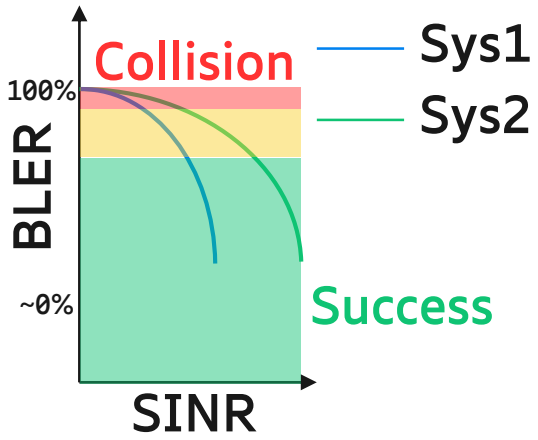
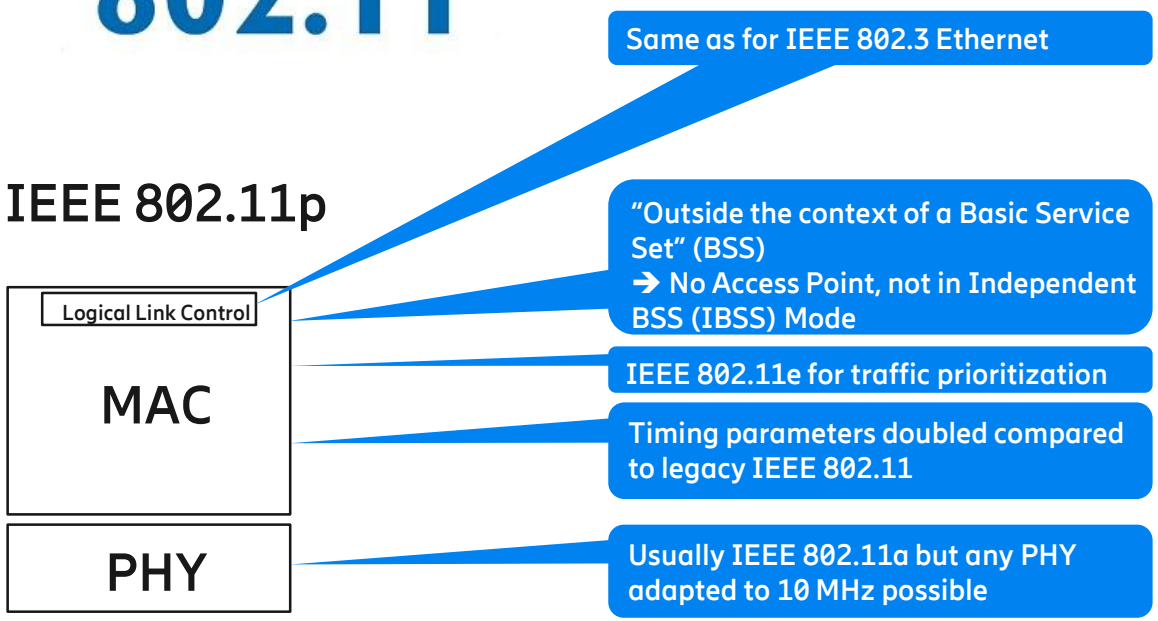


# Protocol description

IEEE 802.11



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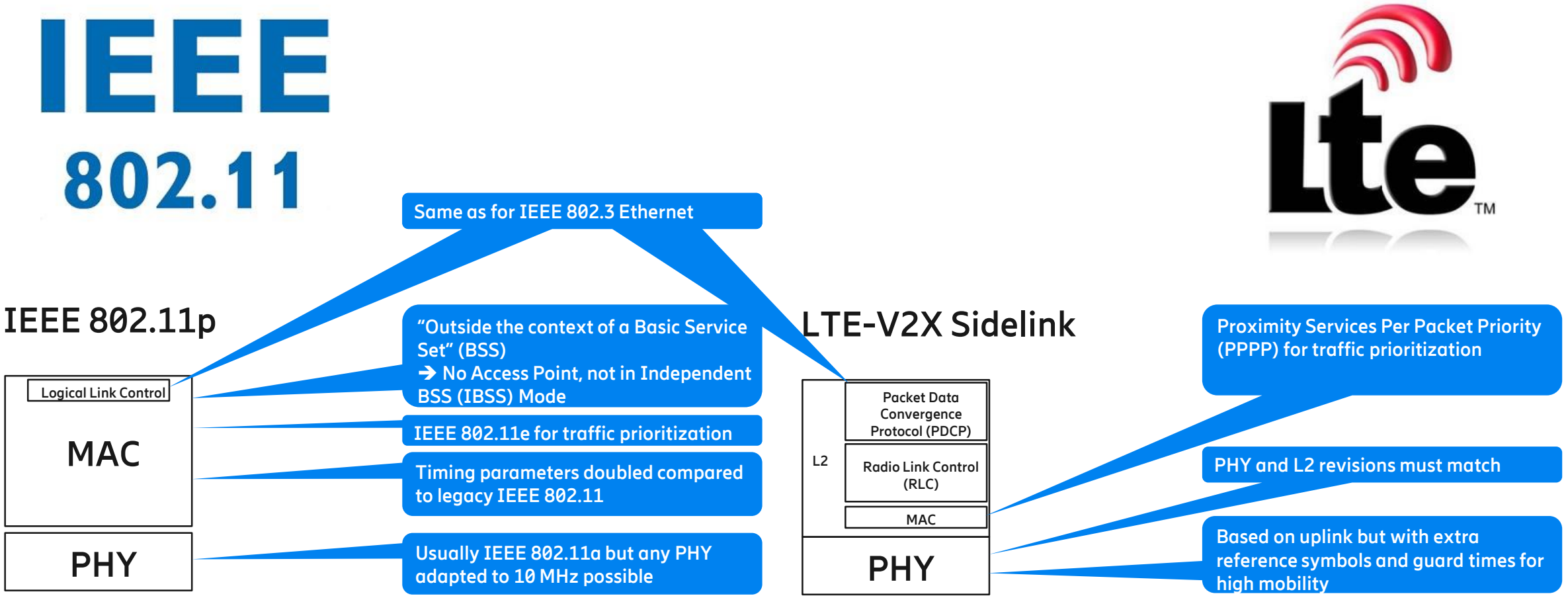

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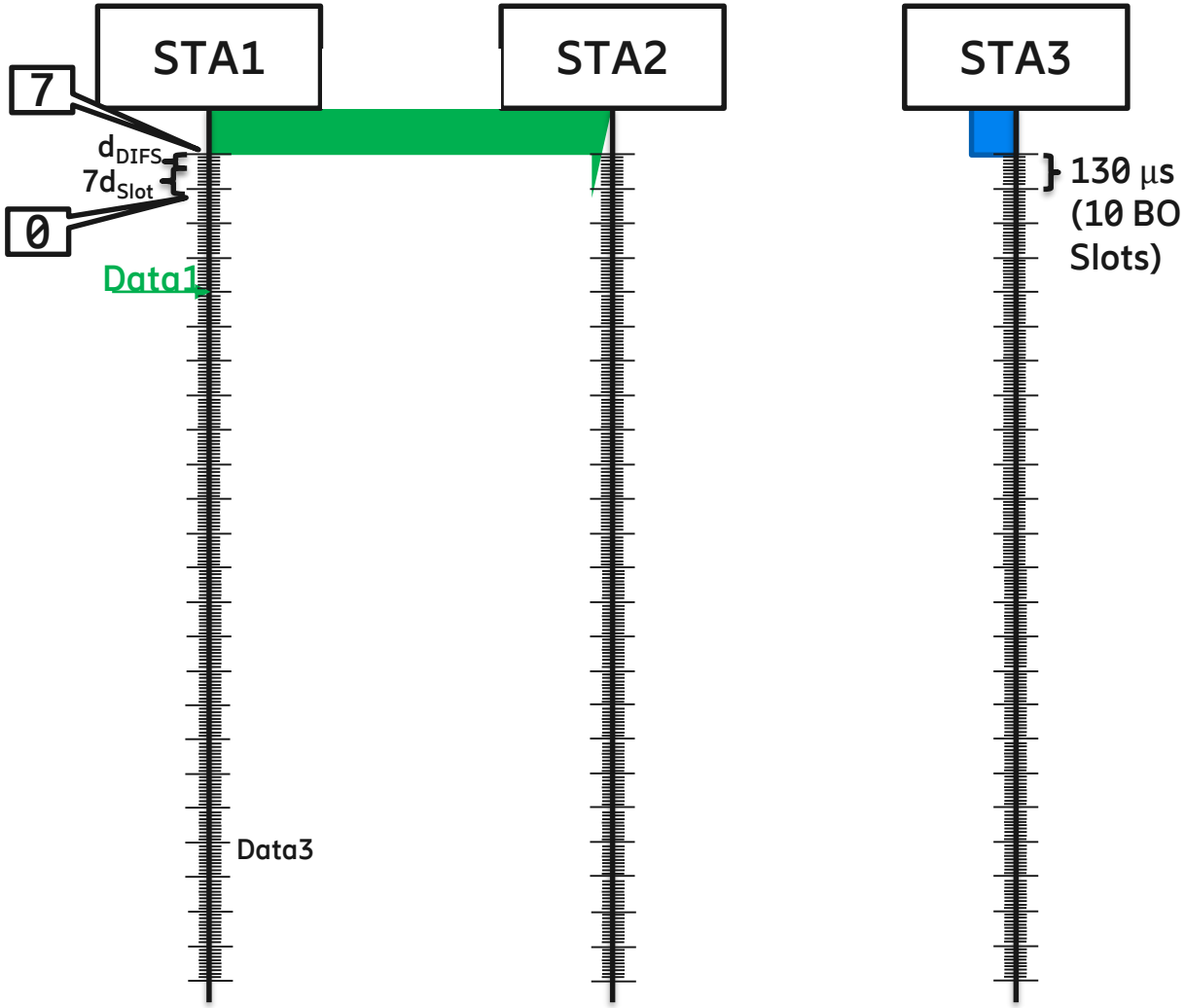
**300 byte at 6 Mbit/s**



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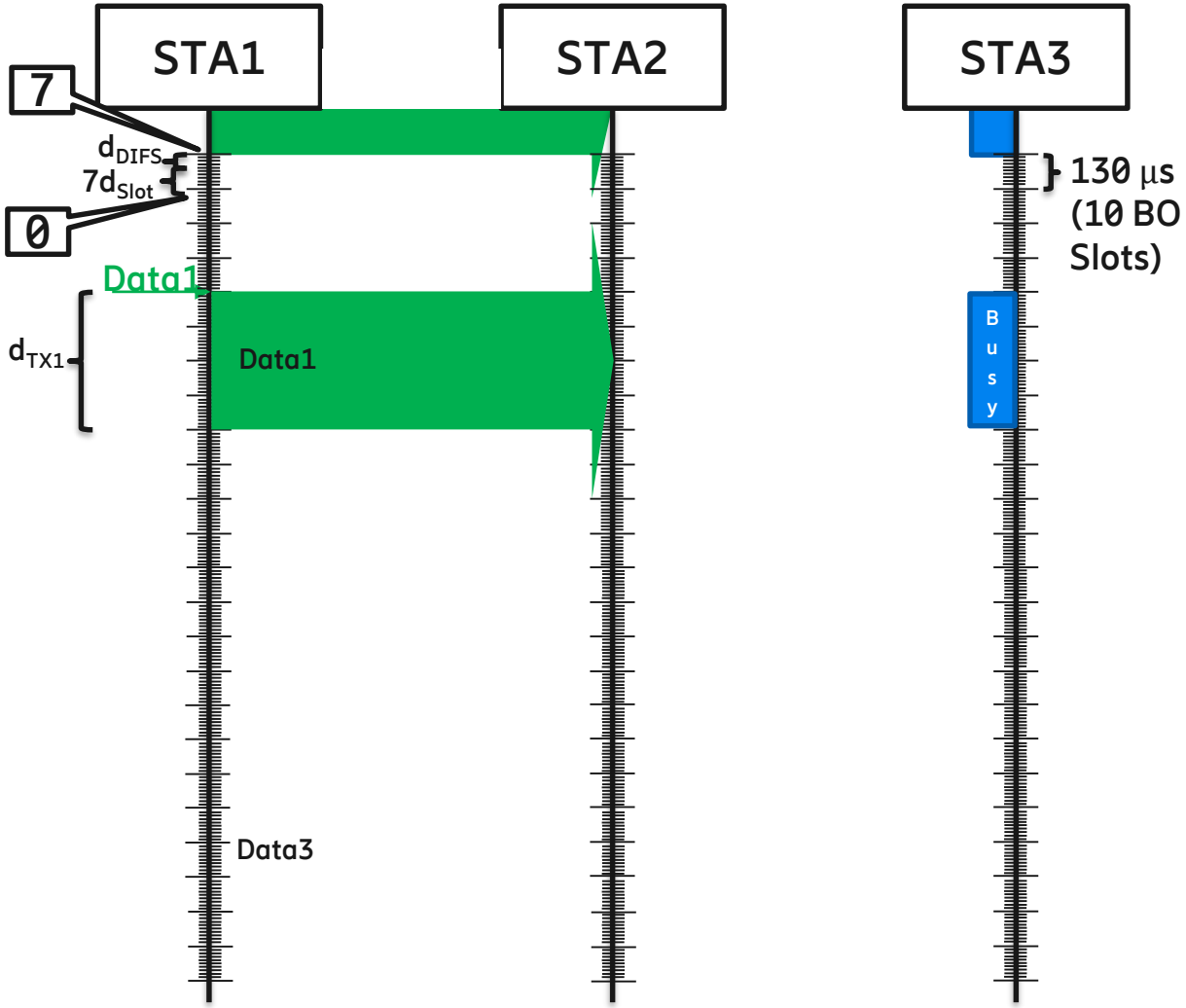

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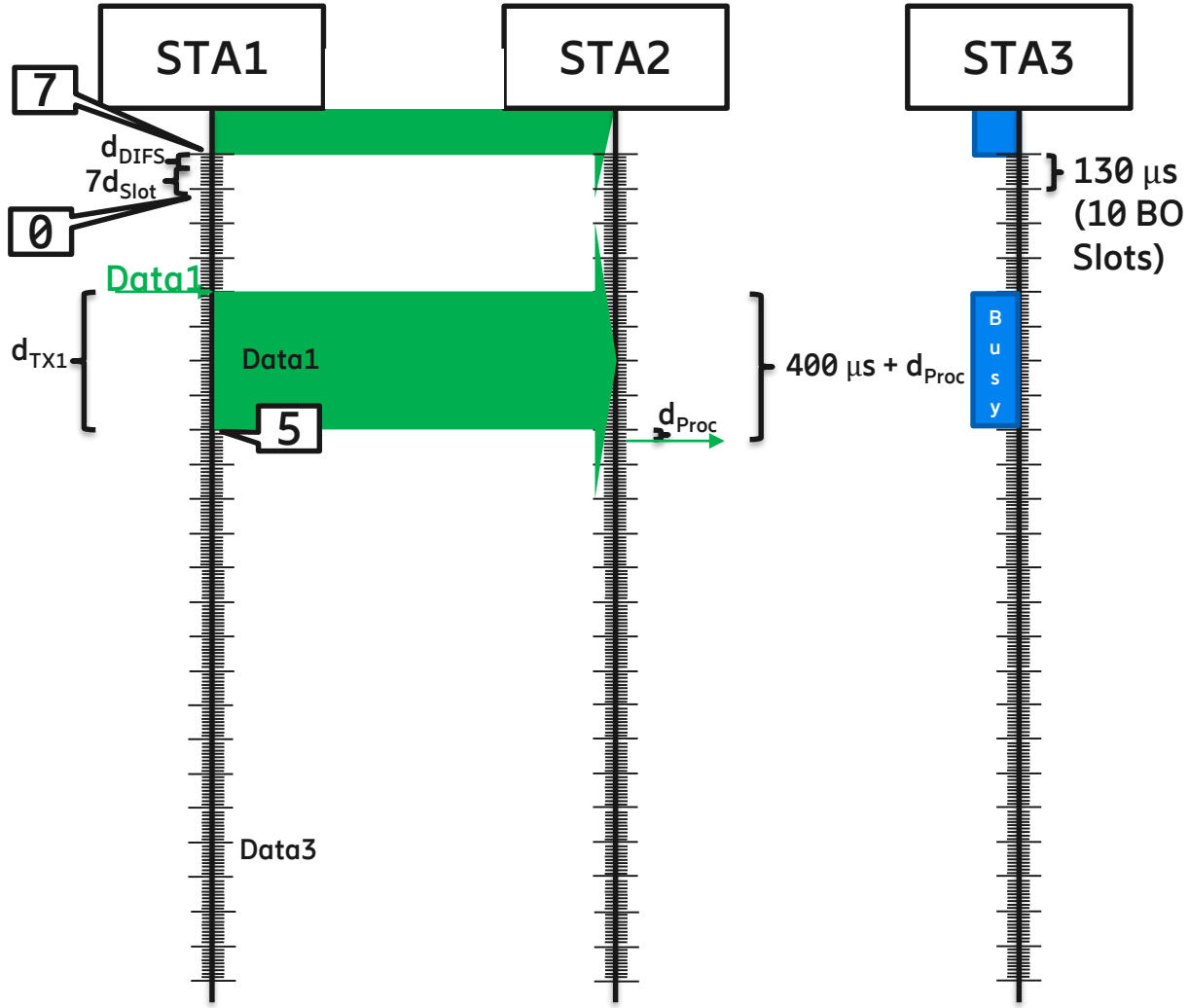

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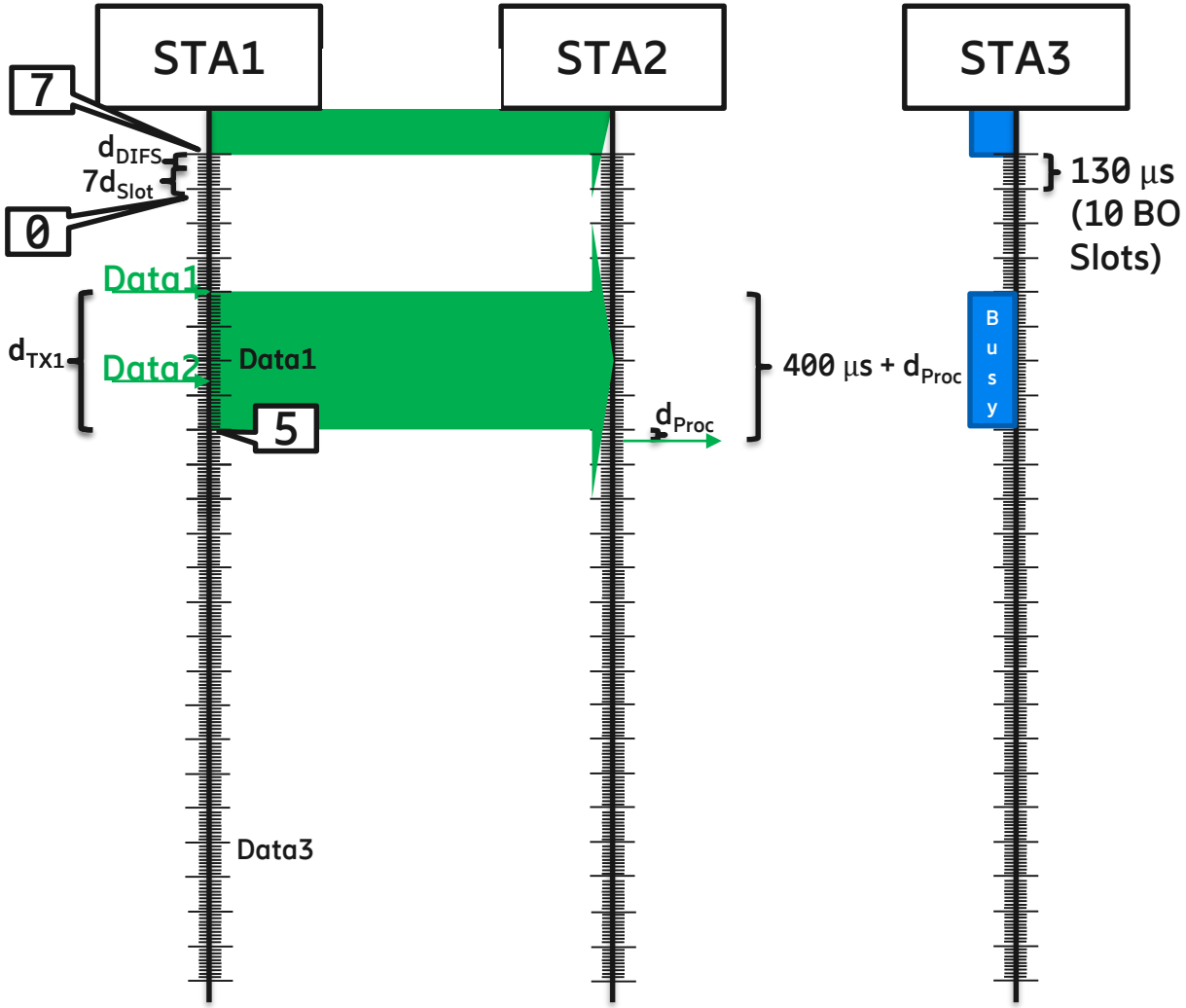

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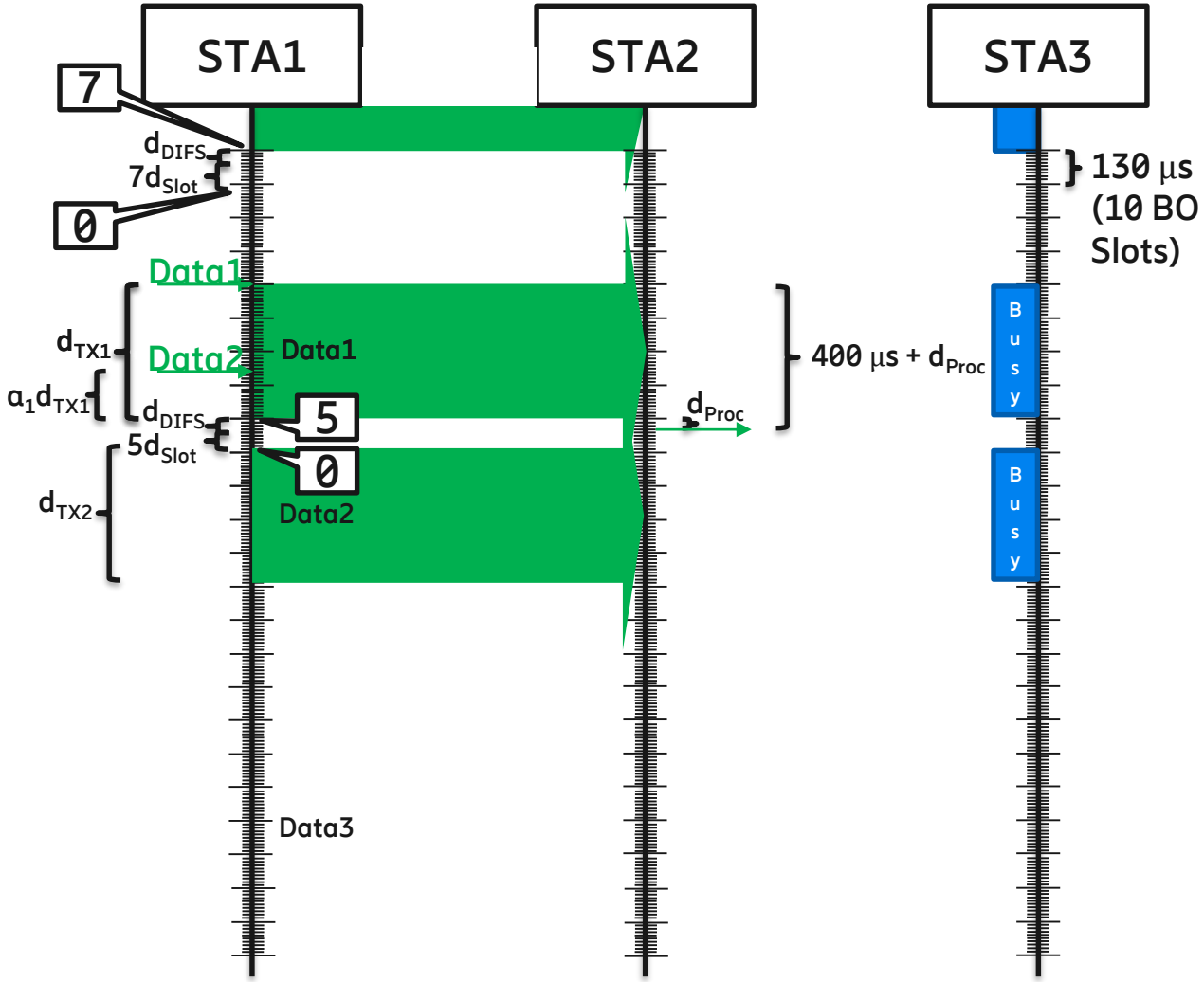

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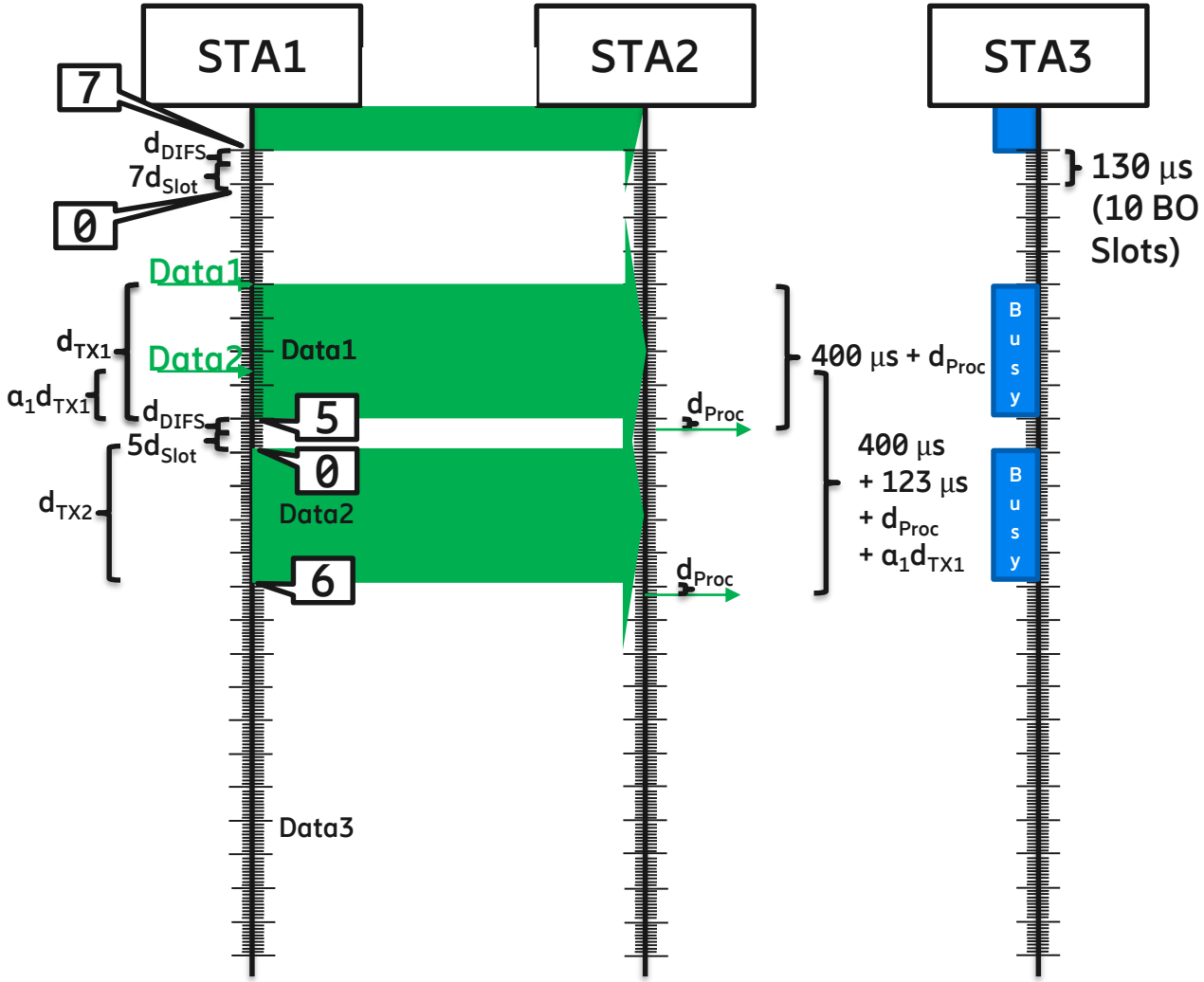

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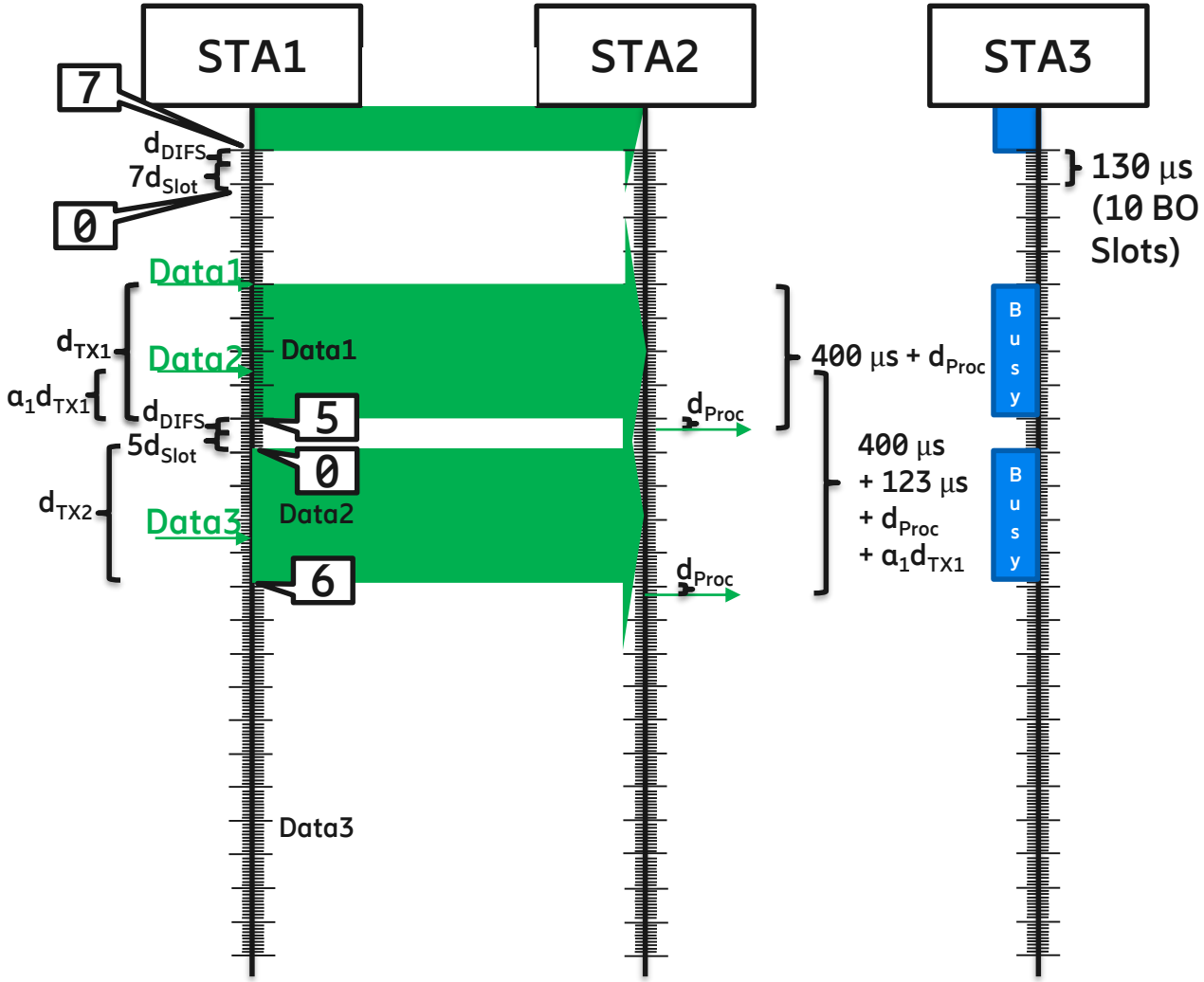

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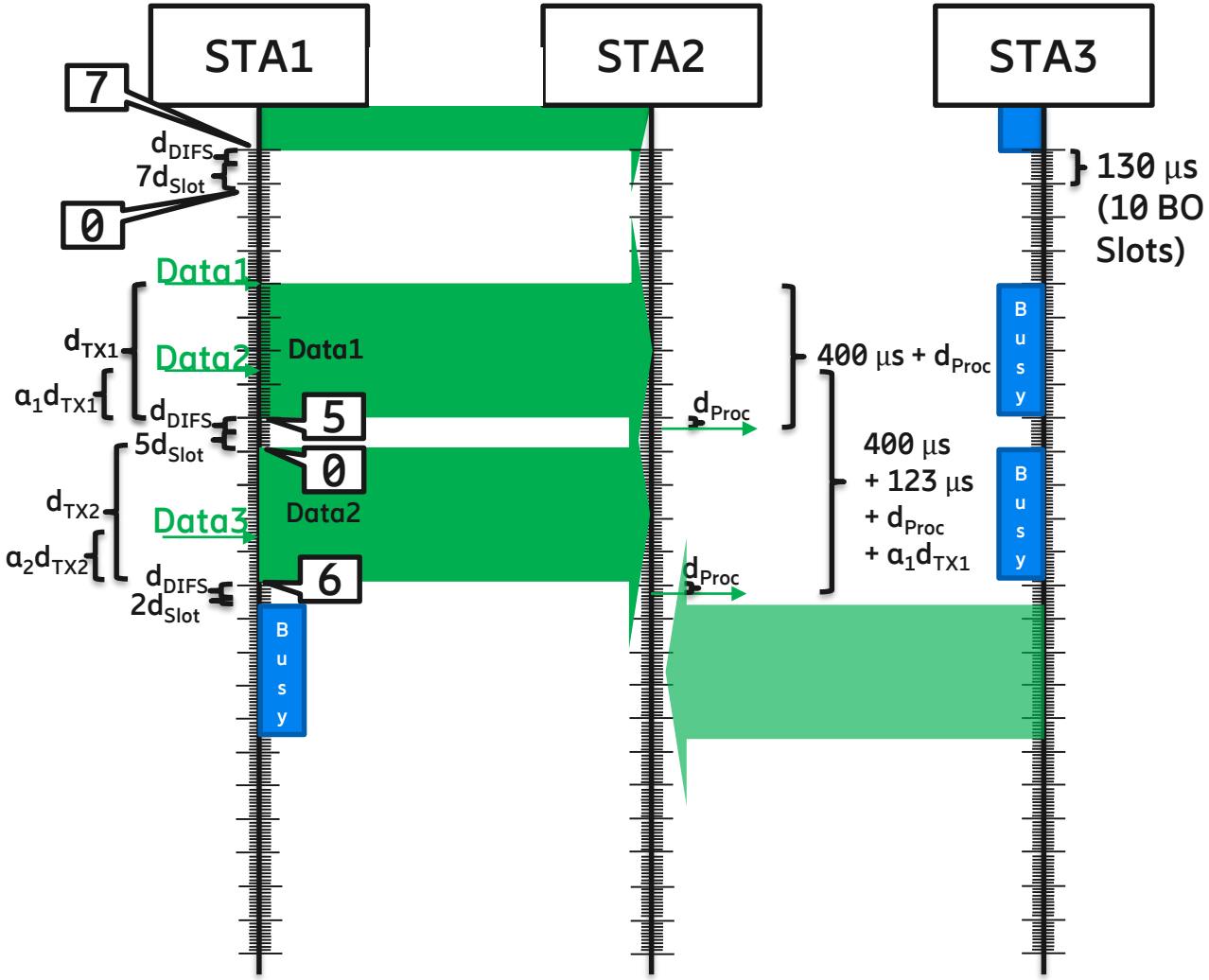

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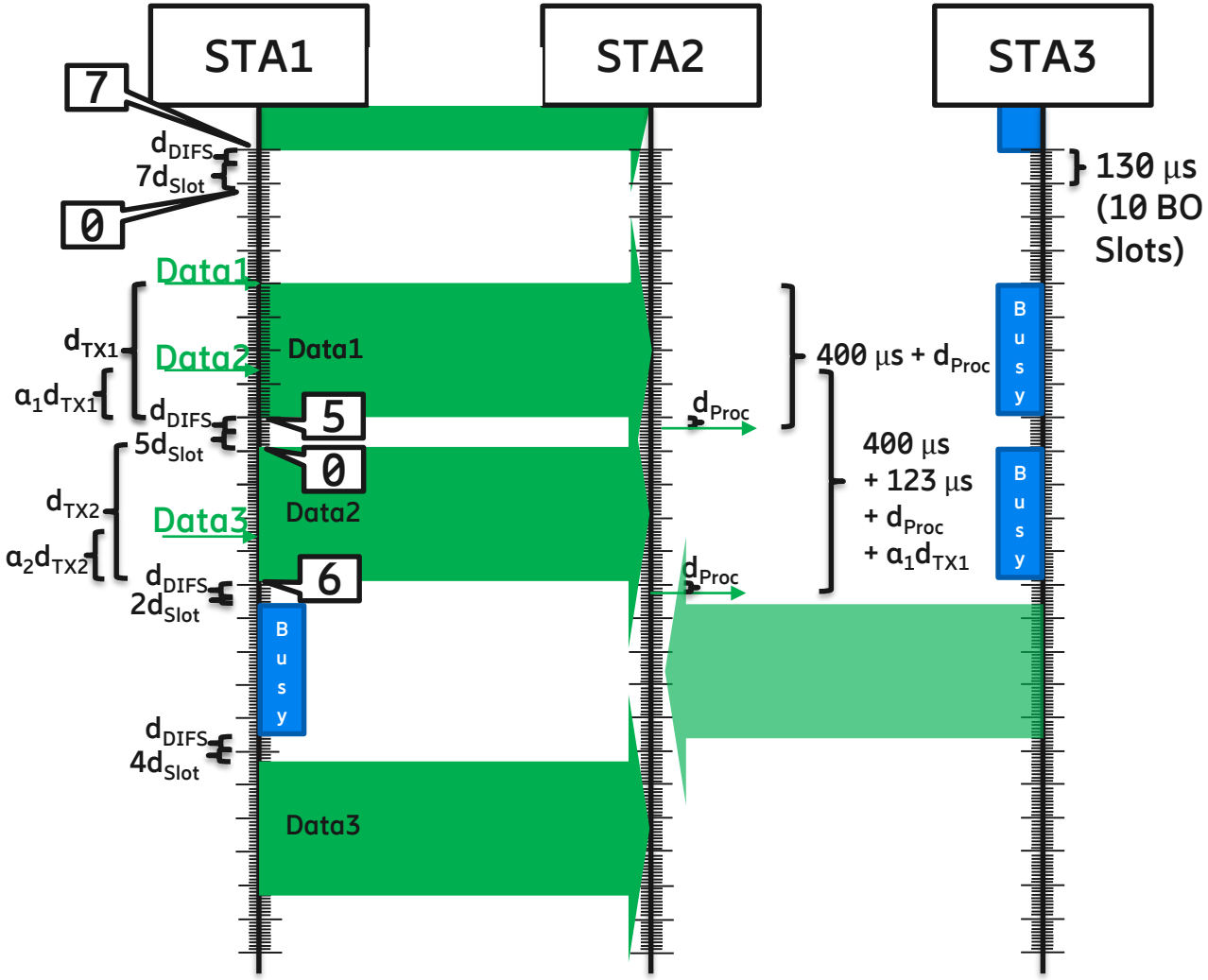

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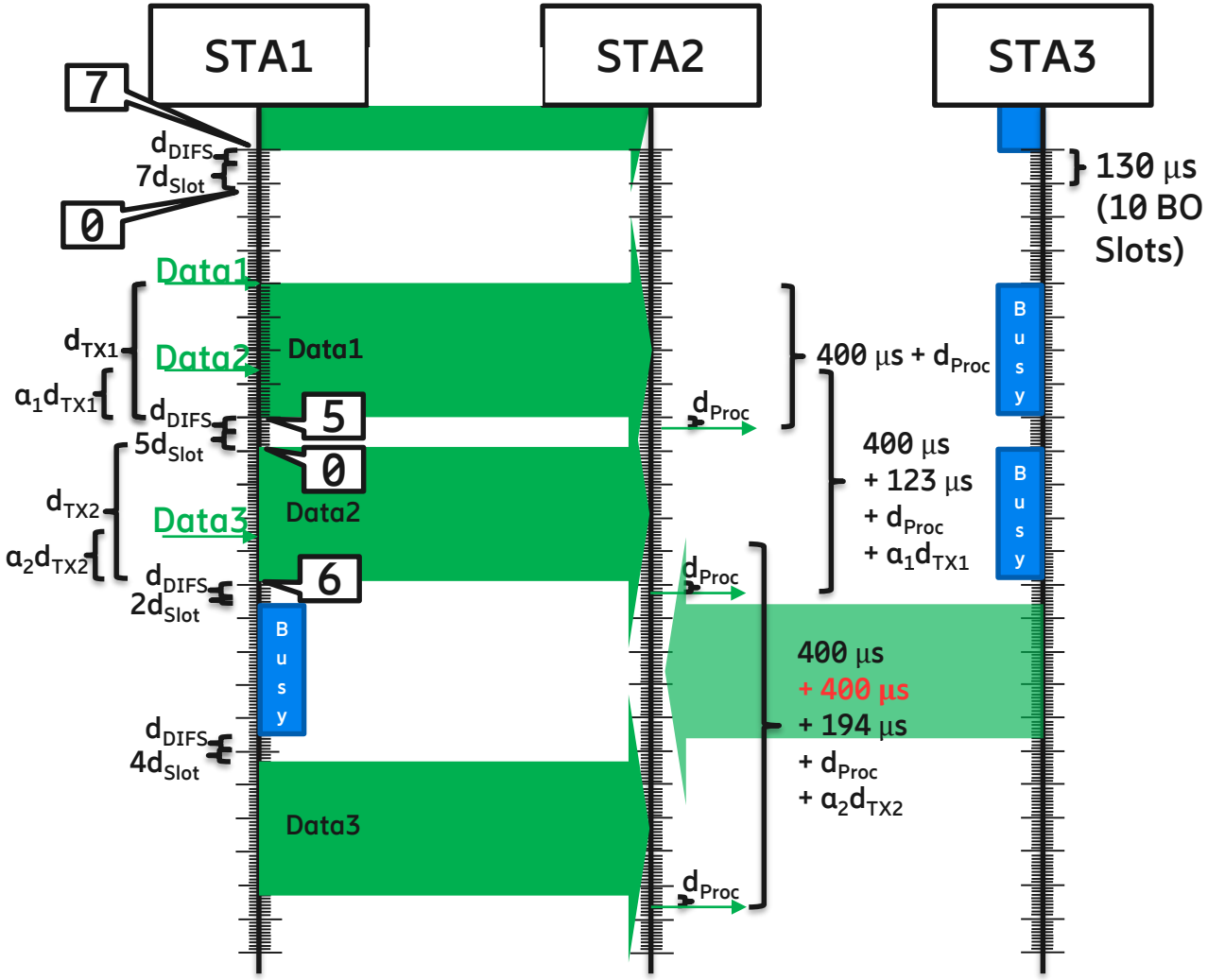

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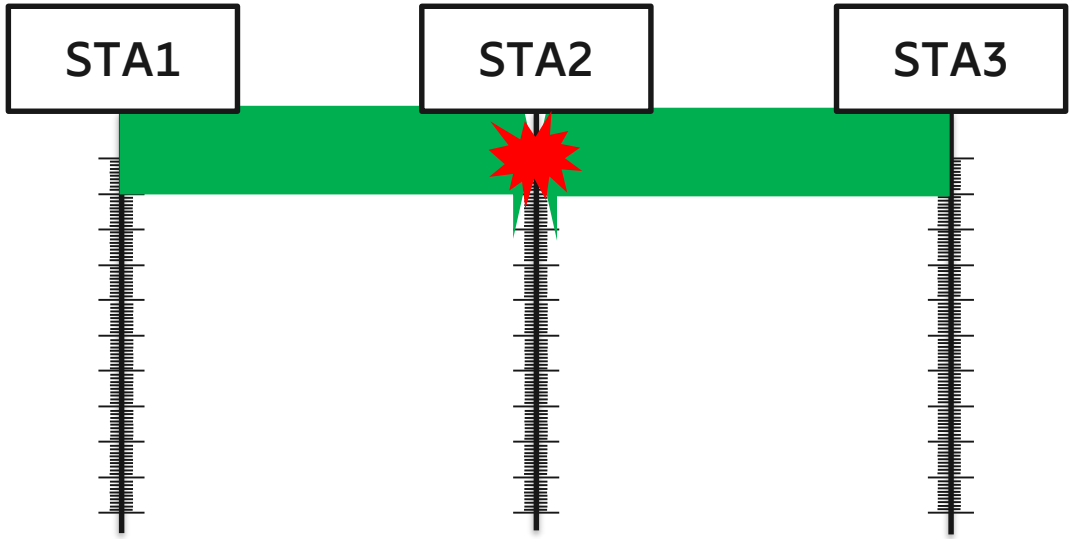
**300 byte at 6 Mbit/s**

**Same random slot**
**➔ collision**



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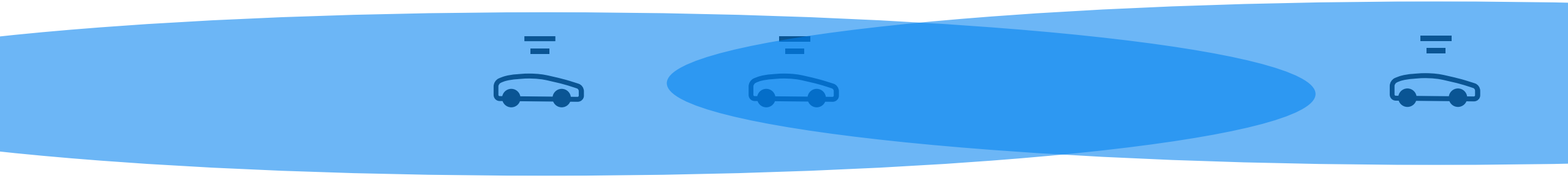
**300 byte at 6 Mbit/s**

**Large distances**
**➔ hidden node problem**

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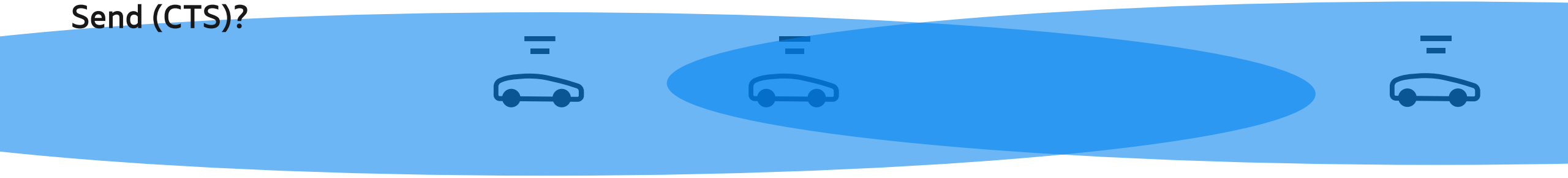
What about Ready to Send (RTS) / Clear to Send (CTS)?



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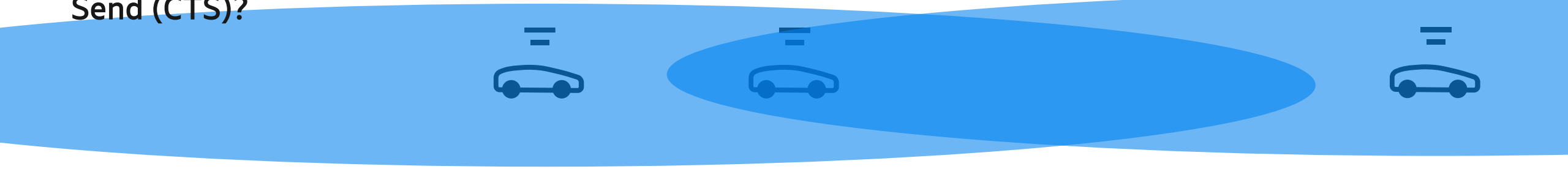
What about Ready to Send (RTS) / Clear to Send (CTS)?

Not possible for broadcast communication



# Protocol description: IEEE 802.11p/e

Legacy IEEE 802.11

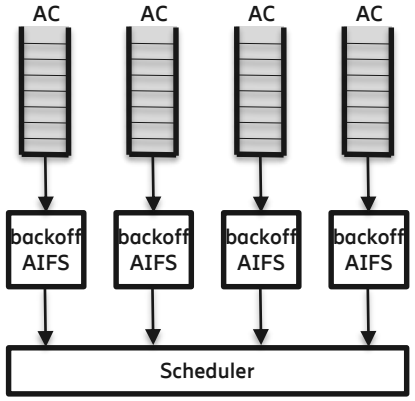
- Random slot is drawn between zero and $CW_{Min}$
- Always wait DIFS time before starting count down

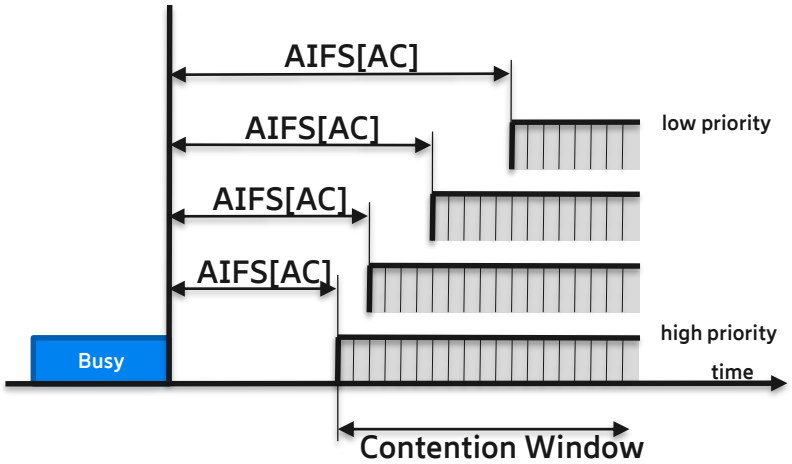
IEEE 802.11e

- 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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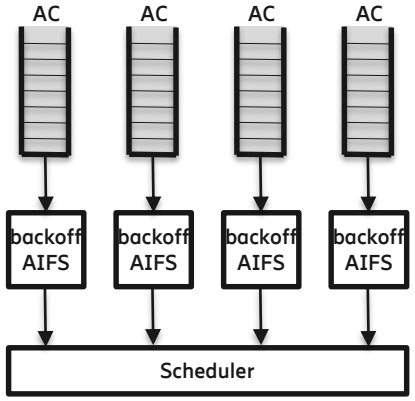


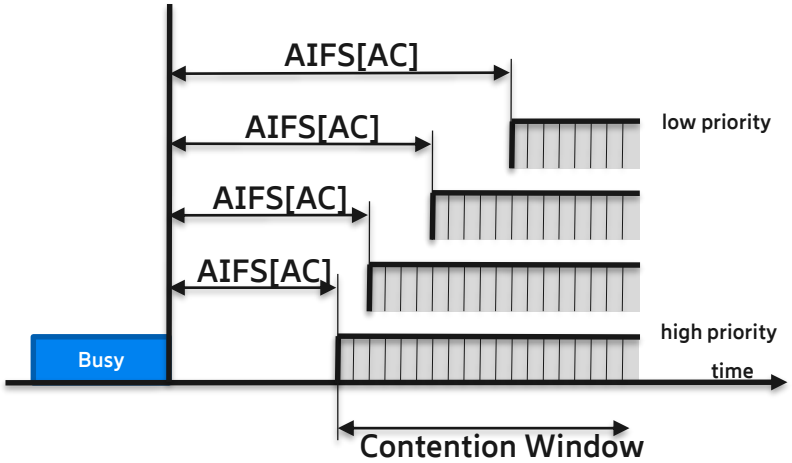

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- Random slot is drawn between zero and $CW_{Min}$
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Why is it called $CW_{Min}$?

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

Priorities:

- Voice (VO)
- Video (VI)
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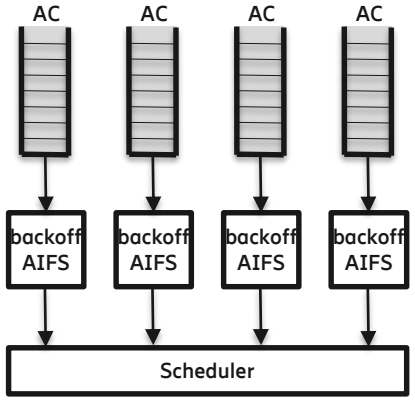
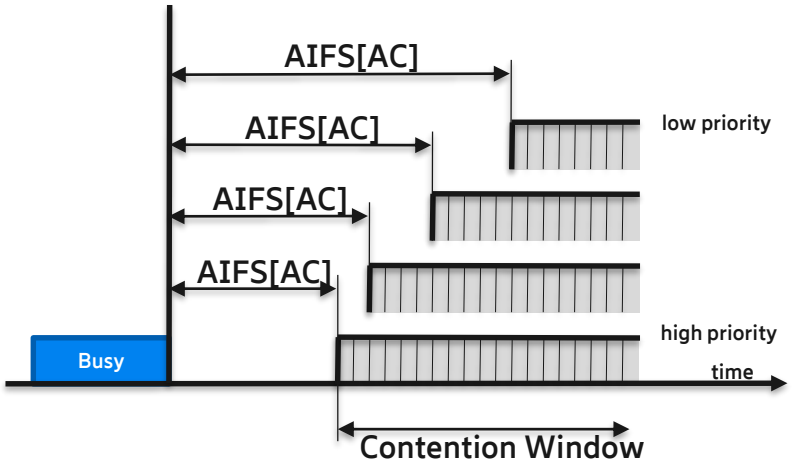
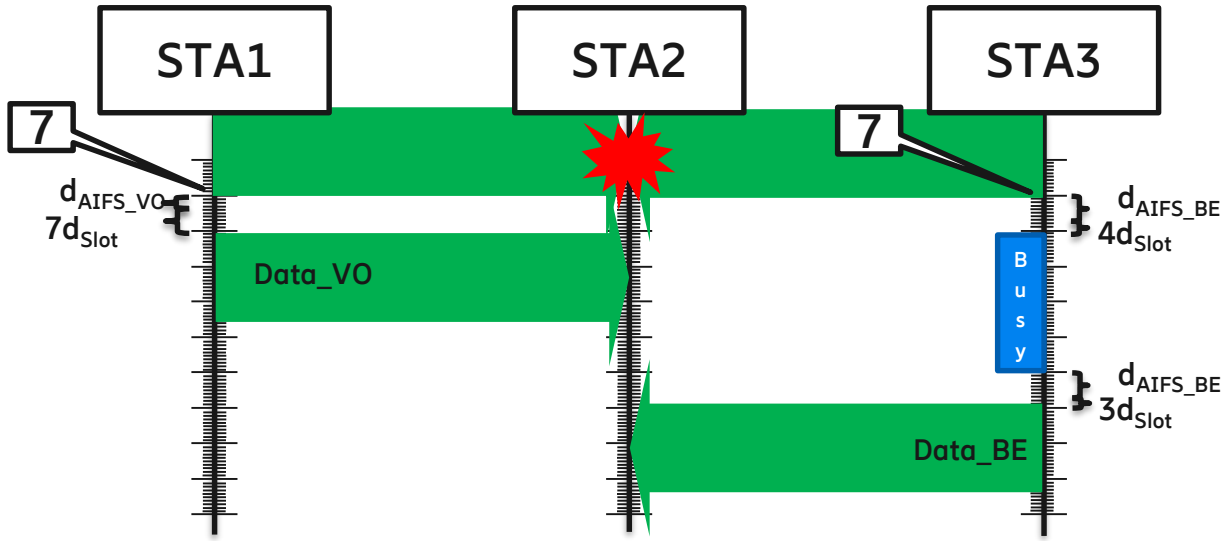


# Protocol description: IEEE 802.11p/e

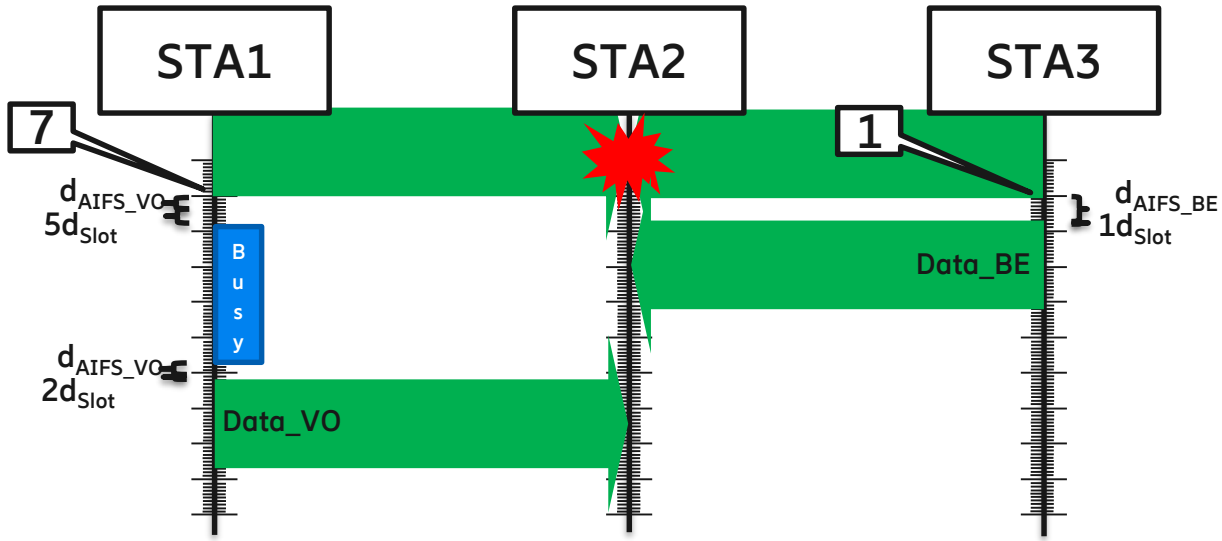
**300 byte Voice (VO) class and 300 byte Best Effort (BE) class at 6 Mbit/s**




| AC | $CW_{Min}$ | AIFS |
|---|---|---|
| Voice (VO) | 3 | 58 $\mu s$ |
| Video (VI) | 7 | 71 $\mu s$ |
| Best Effort (BE) | 15 | 110 $\mu s$ |
| Background (BK) | 15 | 149 $\mu s$ |

# Protocol description: IEEE 802.11p/e

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




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

| AC | $CW_{Min}$ | AIFS |
|---|---|---|
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# Protocol description: LTE-V2X Sidelink

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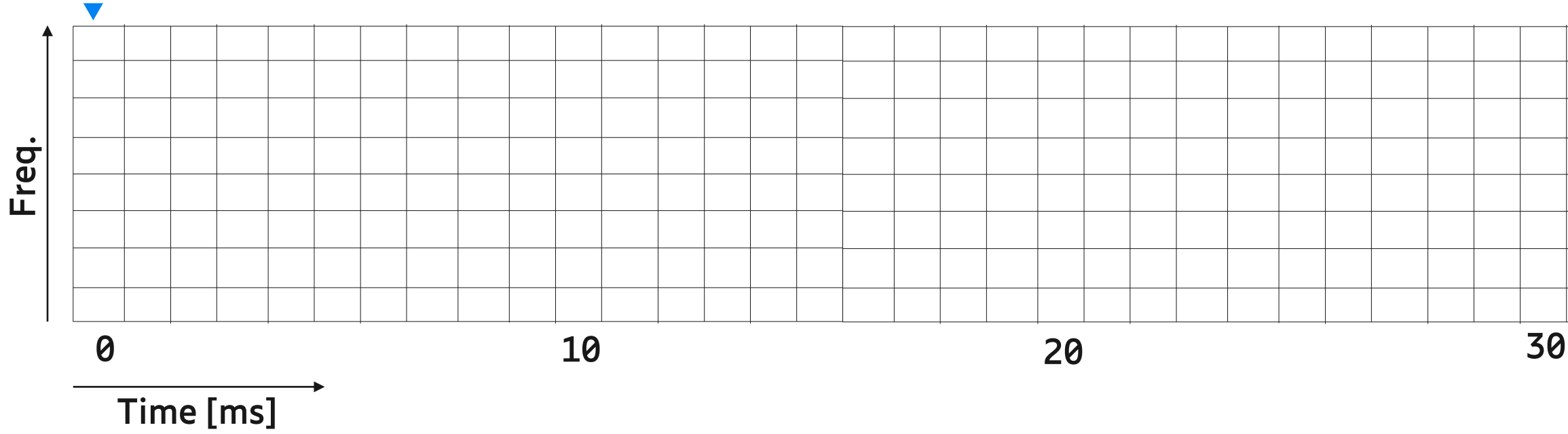
**Random scheduling**



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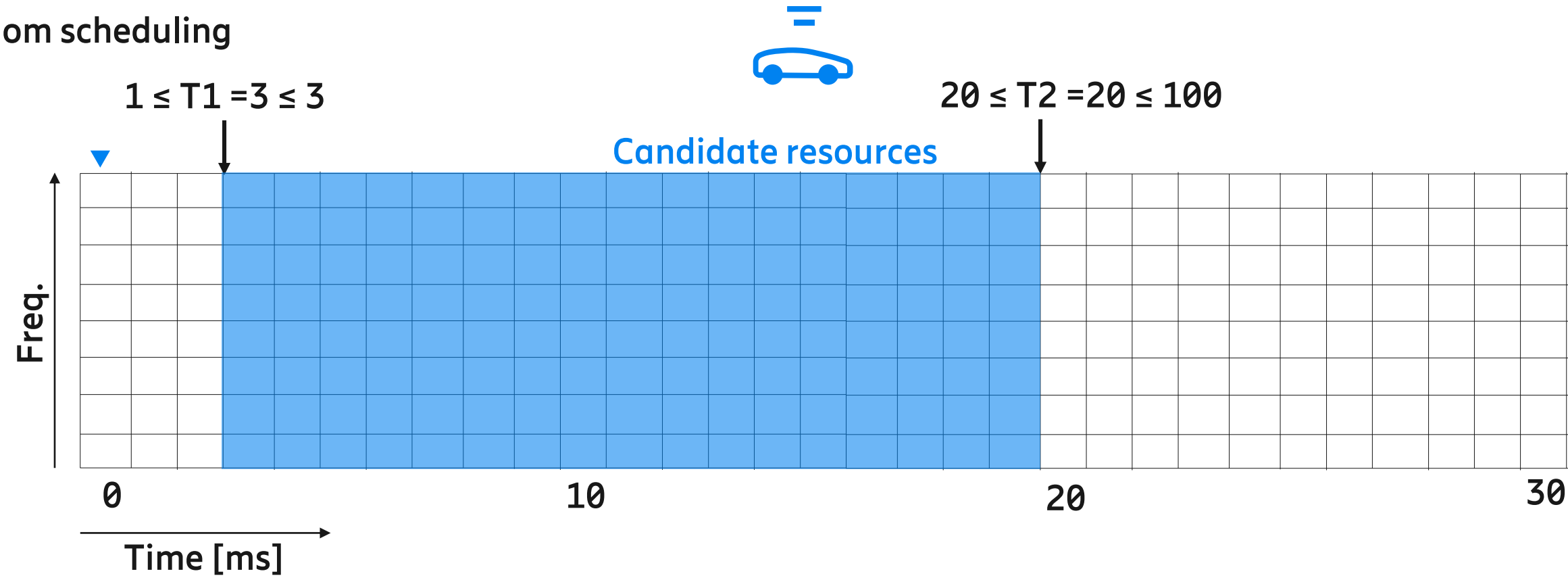

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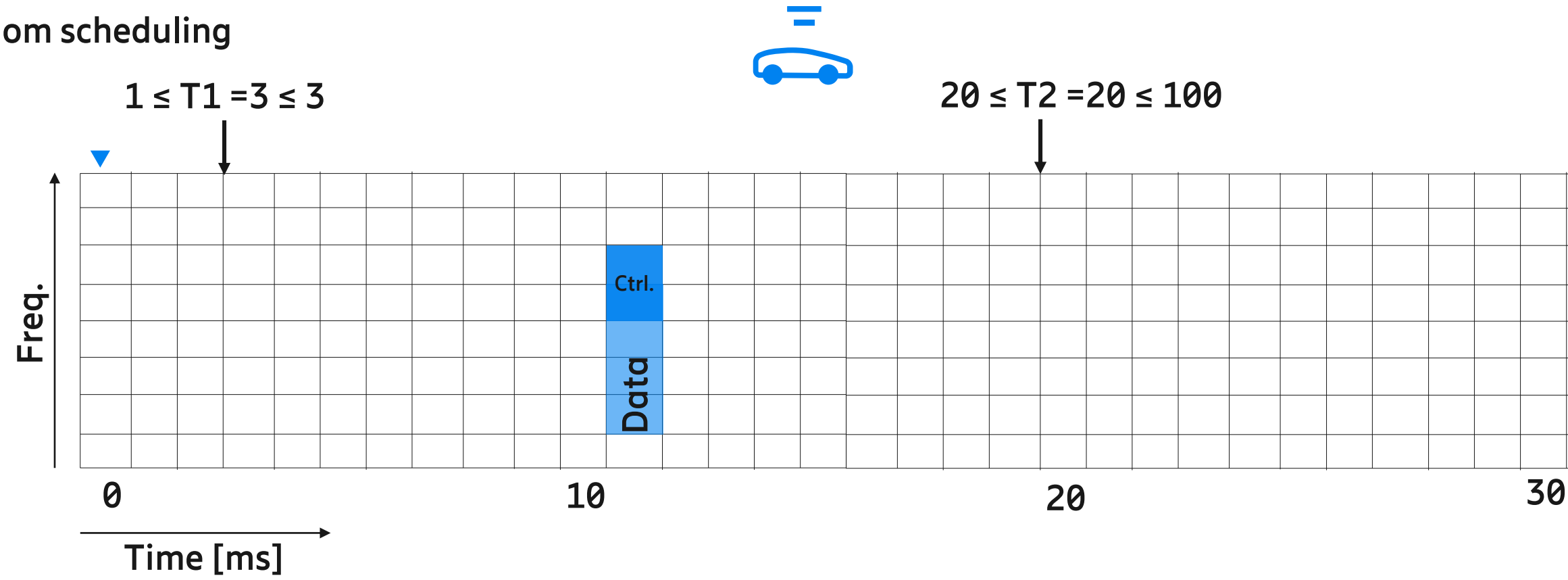

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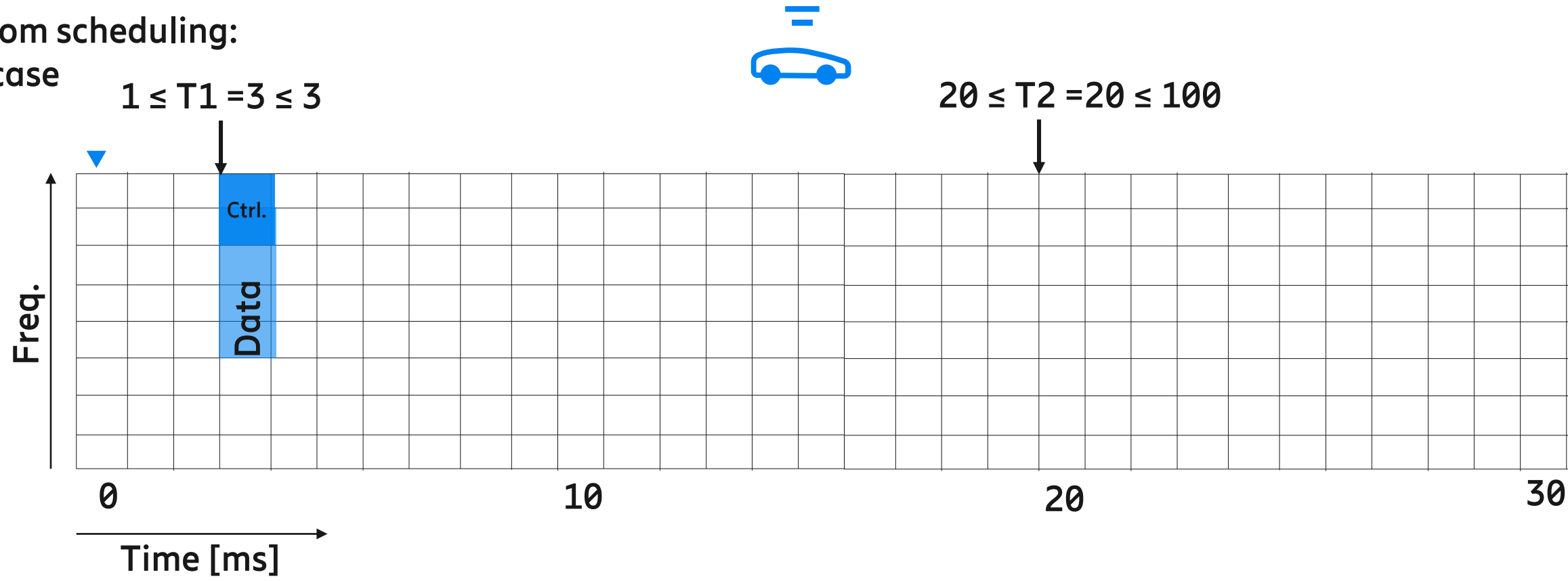
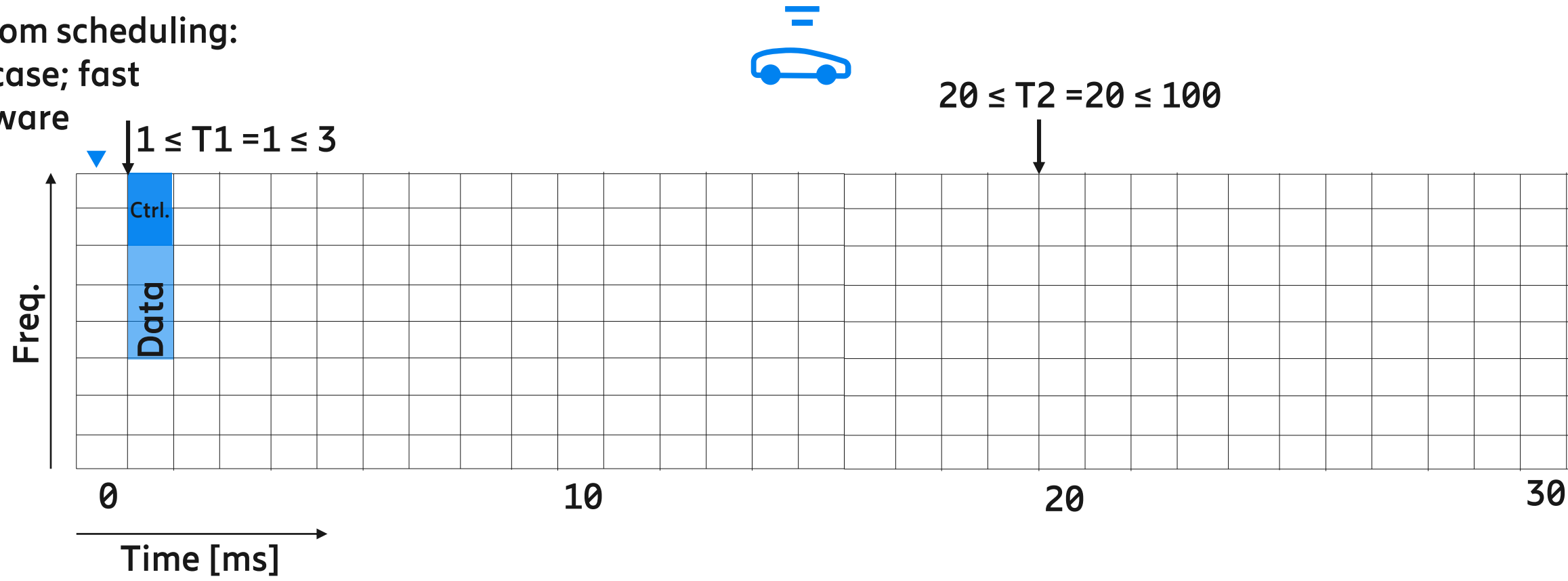
**Random scheduling: best case**



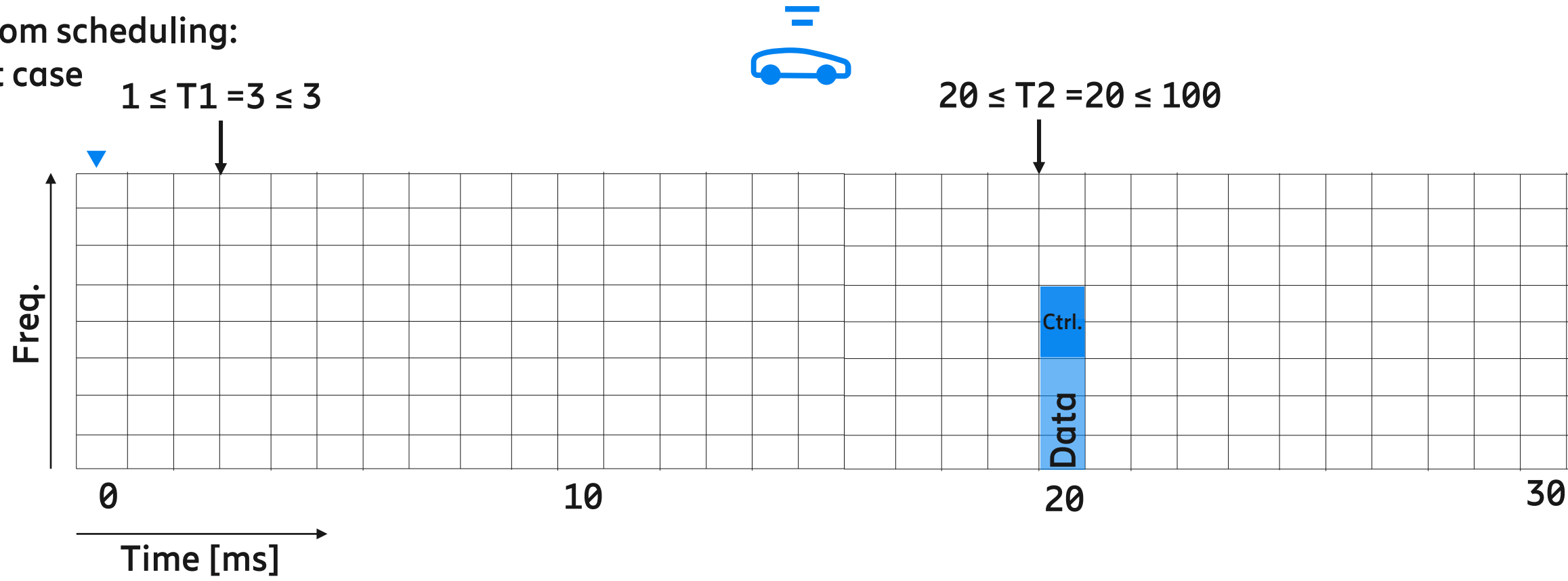
# Protocol description: LTE-V2X Sidelink Mode 4

**Random scheduling: best case; fast hardware**



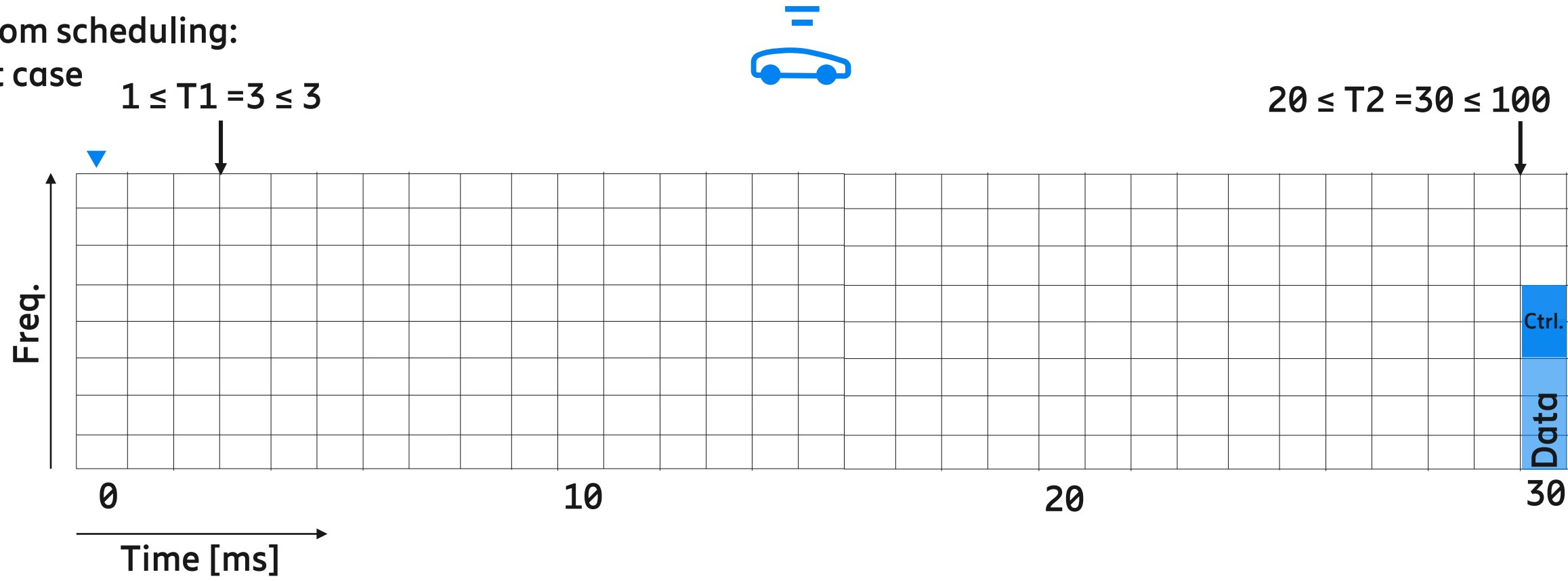
# Protocol description: LTE-V2X Sidelink Mode 4

**Random scheduling: worst case**



# Protocol description: LTE-V2X Sidelink Mode 4

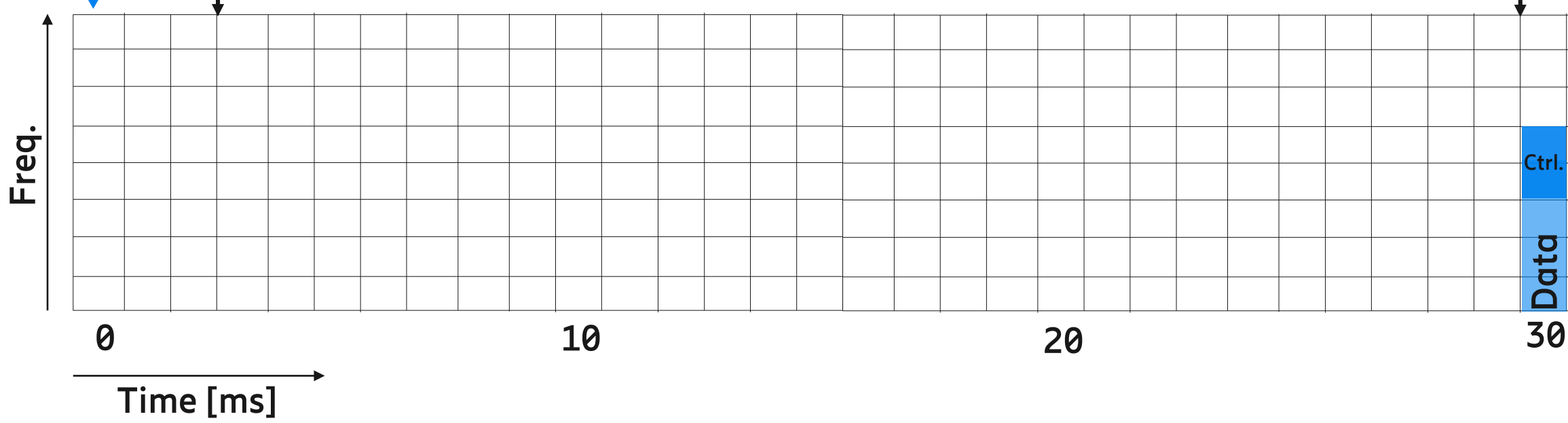
**Random scheduling: worst case**



# Protocol description: LTE-V2X Sidelink Mode 4

**Random scheduling: worst case**

**Why would you increase T2?**



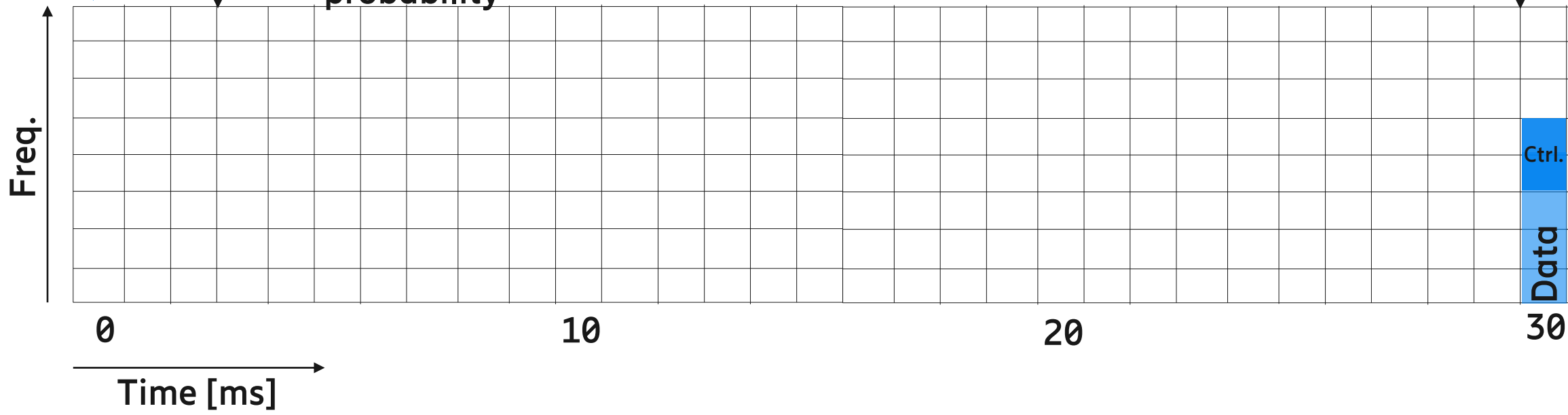
# Protocol description: LTE-V2X Sidelink Mode 4

**Random scheduling: worst case**

**1 ≤ T1 =3 ≤ 3**

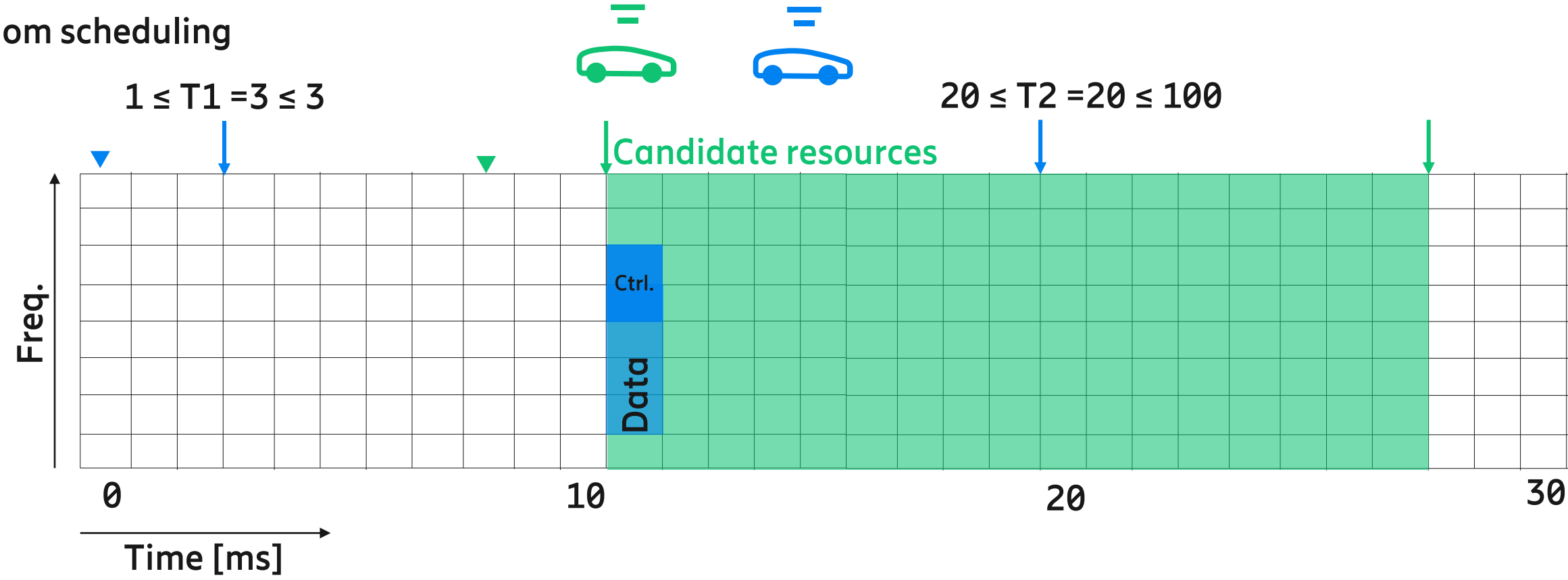
**Why would you increase T2? To decrease collision probability**

**20 ≤ T2 =30 ≤ 100**



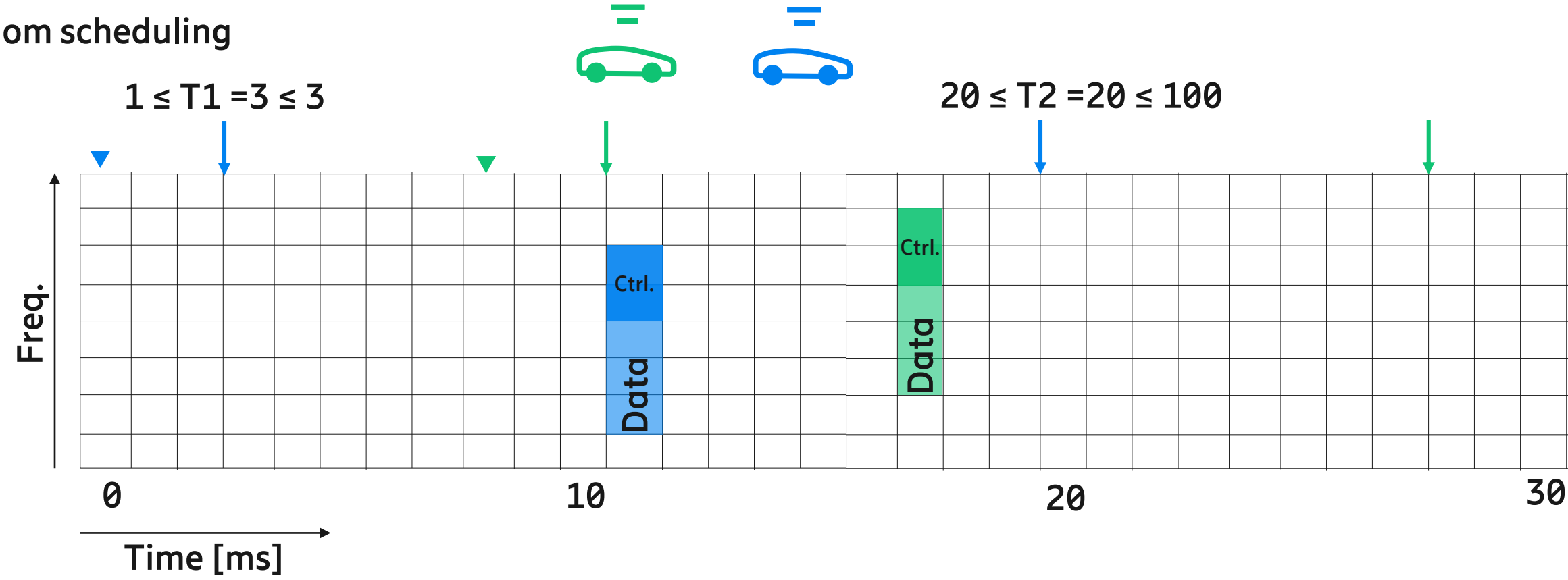
# Protocol description: LTE-V2X Sidelink Mode 4

**Random scheduling**



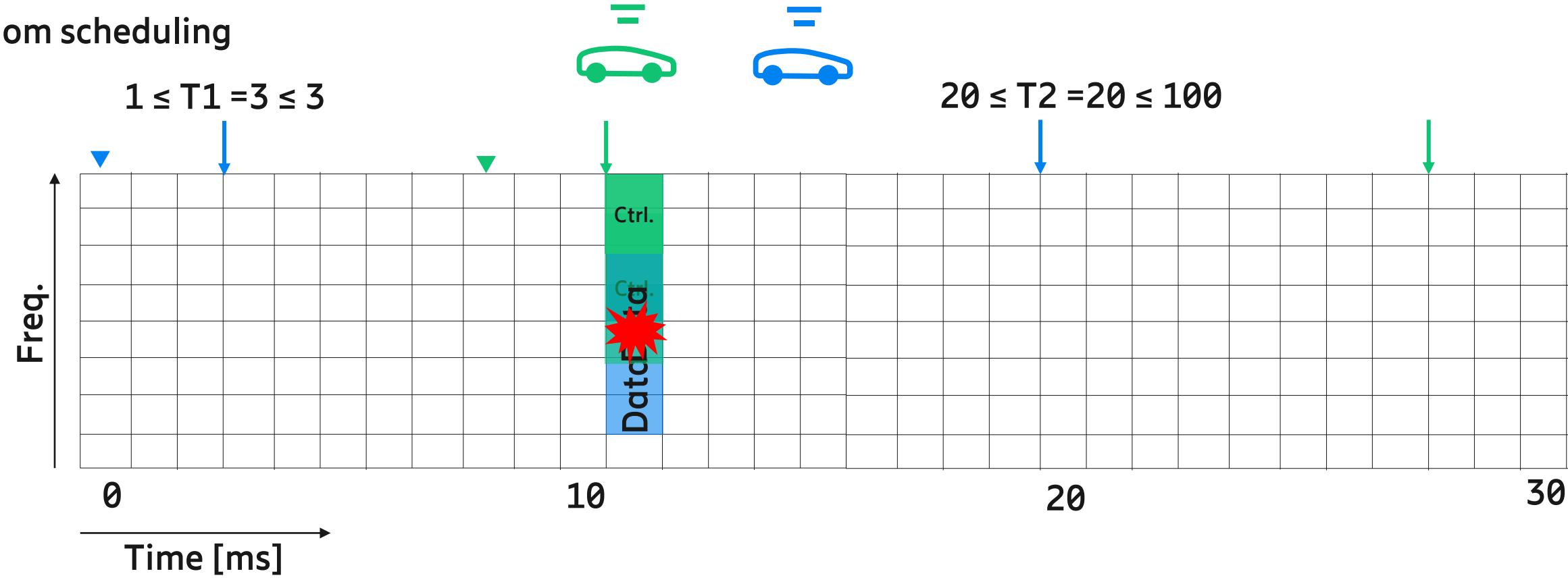
# Protocol description: LTE-V2X Sidelink Mode 4

**Random scheduling**



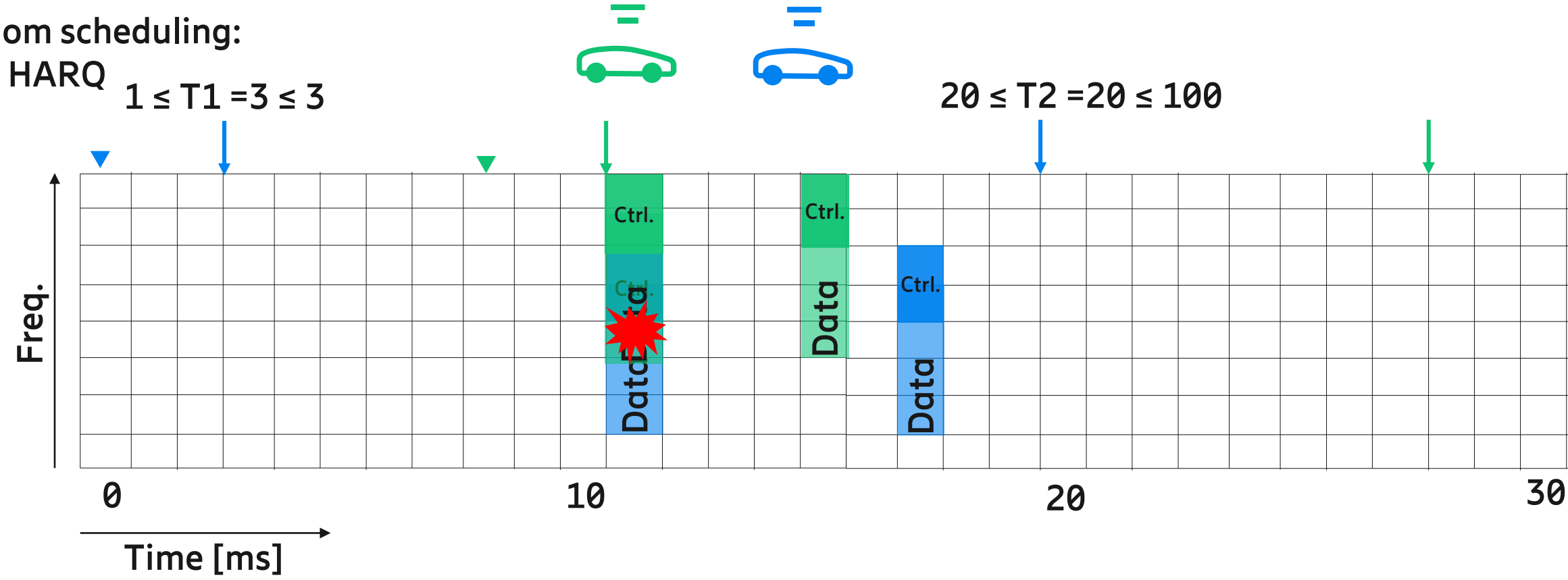
# Protocol description: LTE-V2X Sidelink Mode 4

**Random scheduling**



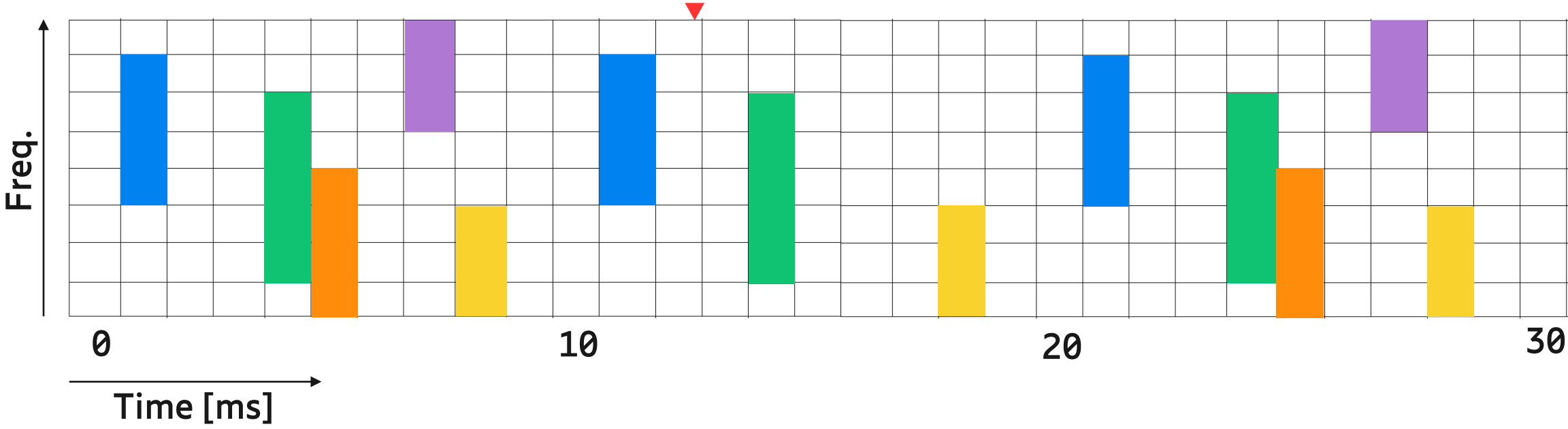
# Protocol description: LTE-V2X Sidelink Mode 4

**Random scheduling:**
**Blind HARQ**



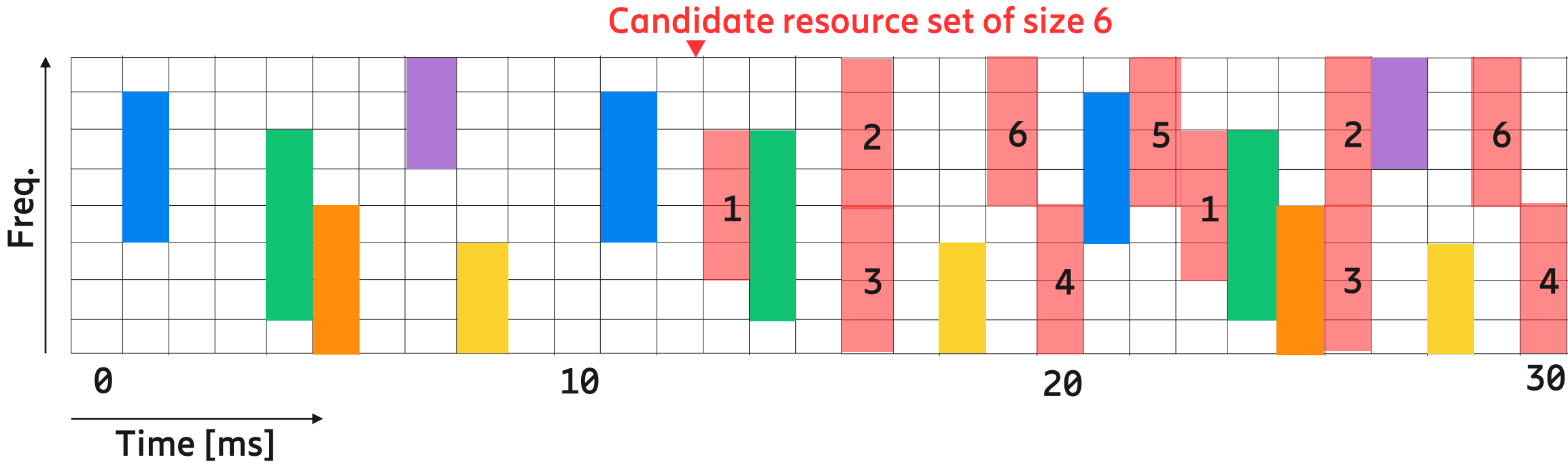
# Protocol description: LTE-V2X Sidelink Mode 4

**Sensing based scheduling**



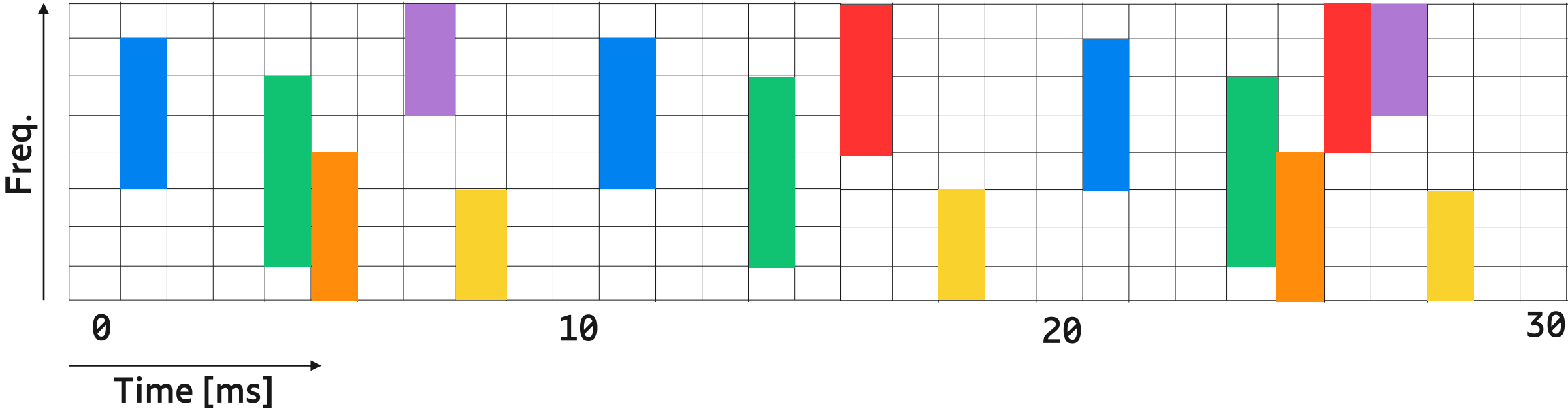
# Protocol description: LTE-V2X Sidelink Mode 4

**Sensing based scheduling**



# Protocol description: LTE-V2X Sidelink Mode 4

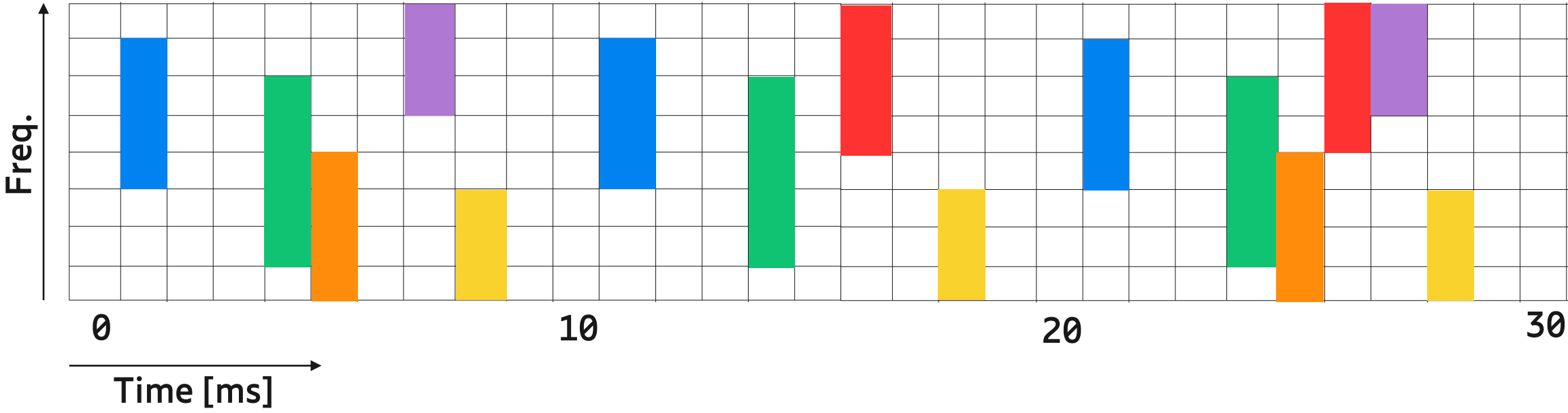
**Sensing based scheduling**



# Protocol description: LTE-V2X Sidelink Mode 4

**Sensing based scheduling**

**Why not candidate set size 1?**

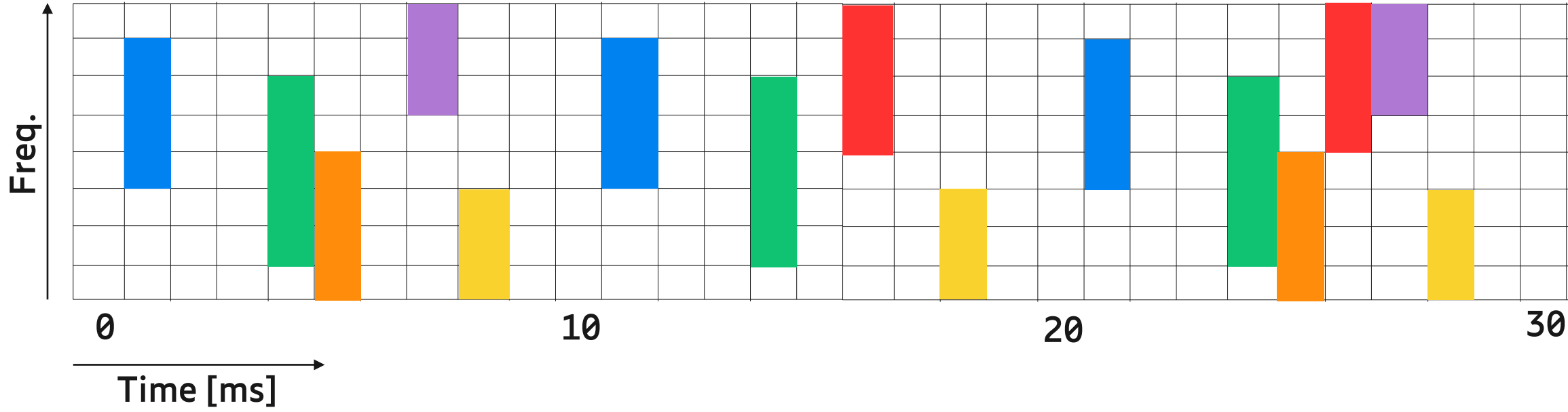


# Protocol description: LTE-V2X Sidelink Mode 4

**Sensing based scheduling**

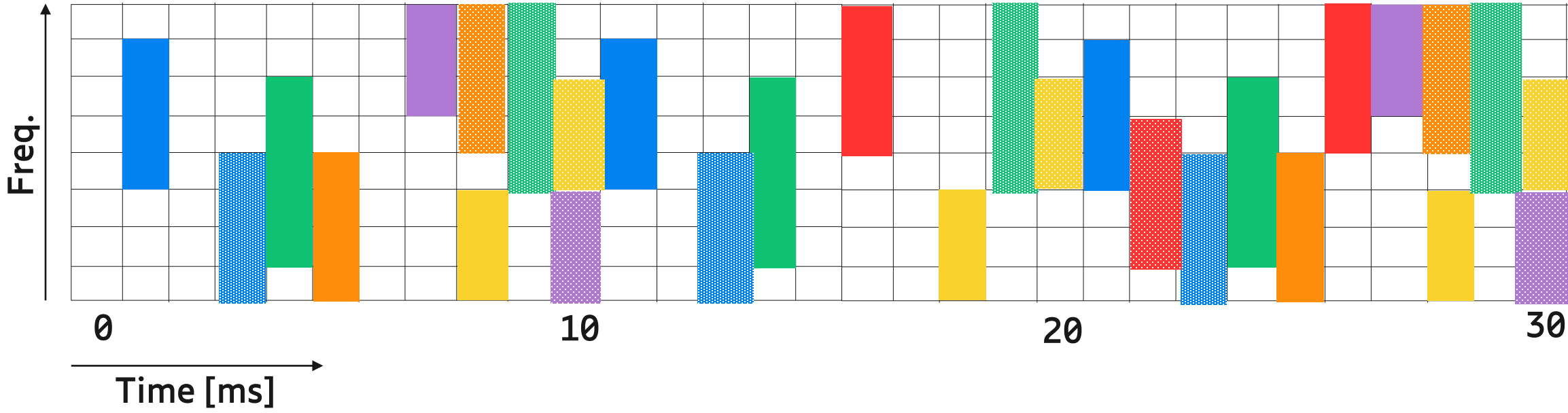
**Why not candidate set size 1?**

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



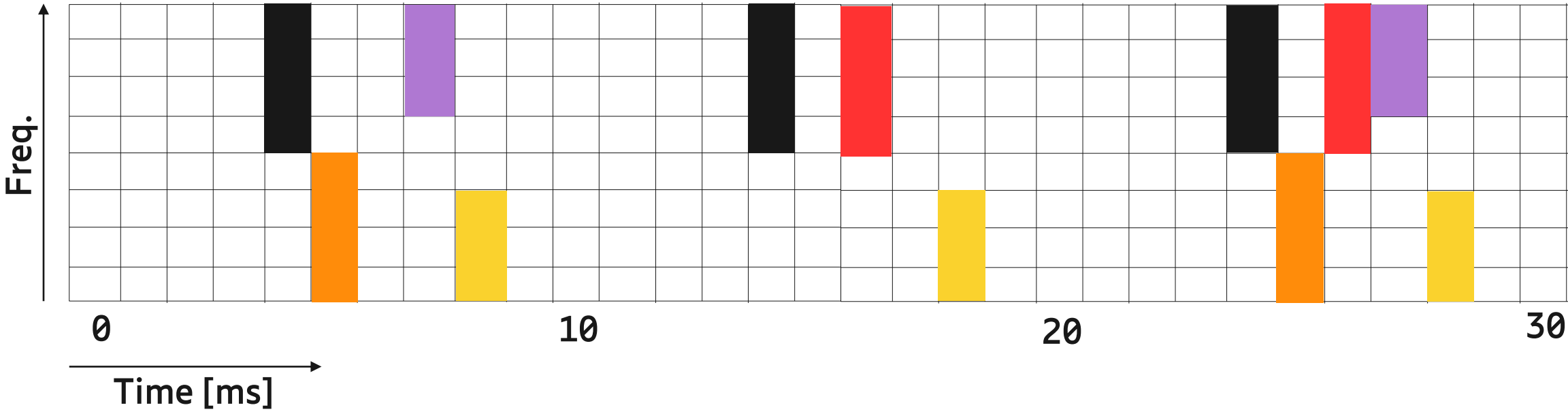
# Protocol description: LTE-V2X Sidelink Mode 4

**Sensing based scheduling with bling HARQ retransmissions**



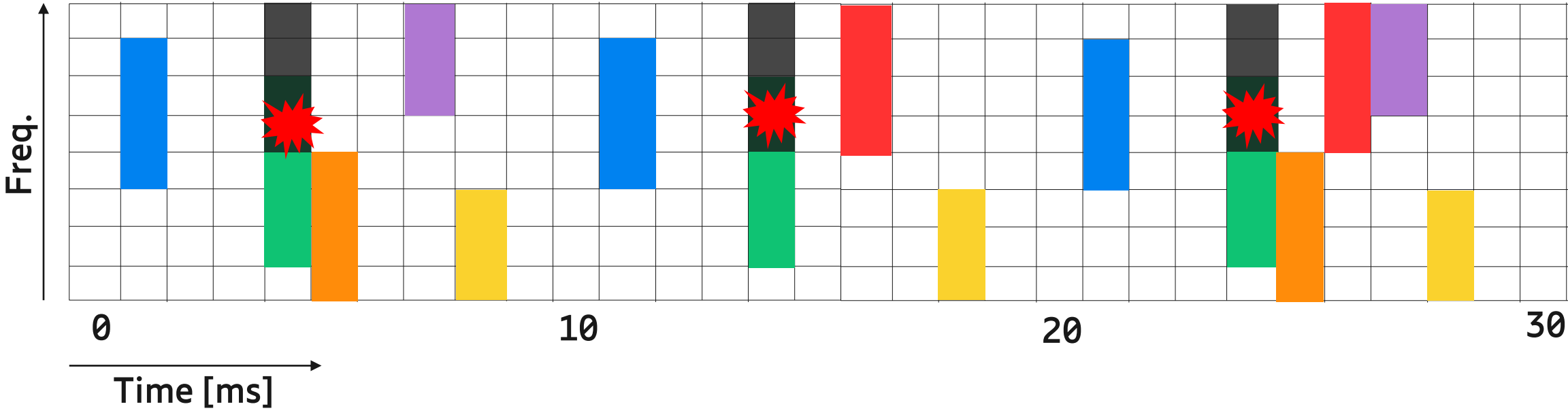
# Protocol description: LTE-V2X Sidelink Mode 4

**Sensing based scheduling & mobility**



# Protocol description: LTE-V2X Sidelink Mode 4

**Sensing based scheduling & mobility**

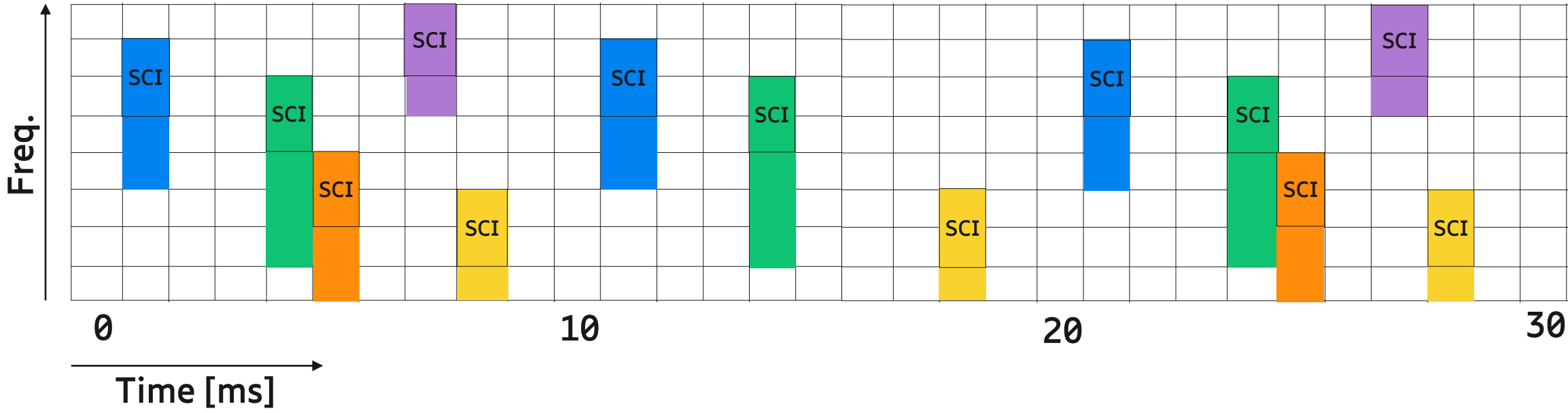


# Protocol description: LTE-V2X Sidelink Mode 4

**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

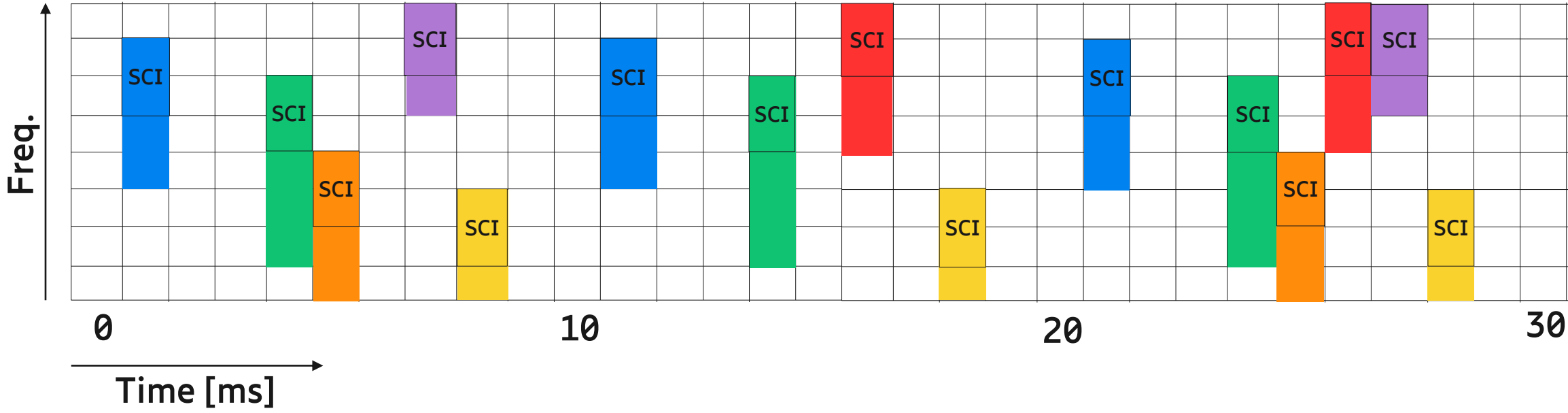
**Sensing based scheduling: Sidelink Control Information (SCI)**

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