WiLabV2Xsim

https://github.com/V2Xgithub/WiLabV2Xsim

Description of the main aspects

Updated to WiLabV2Xsim version 6.1

Slides updated on August 2022

WiLabV2Xsim (was LTEV2Vsim)

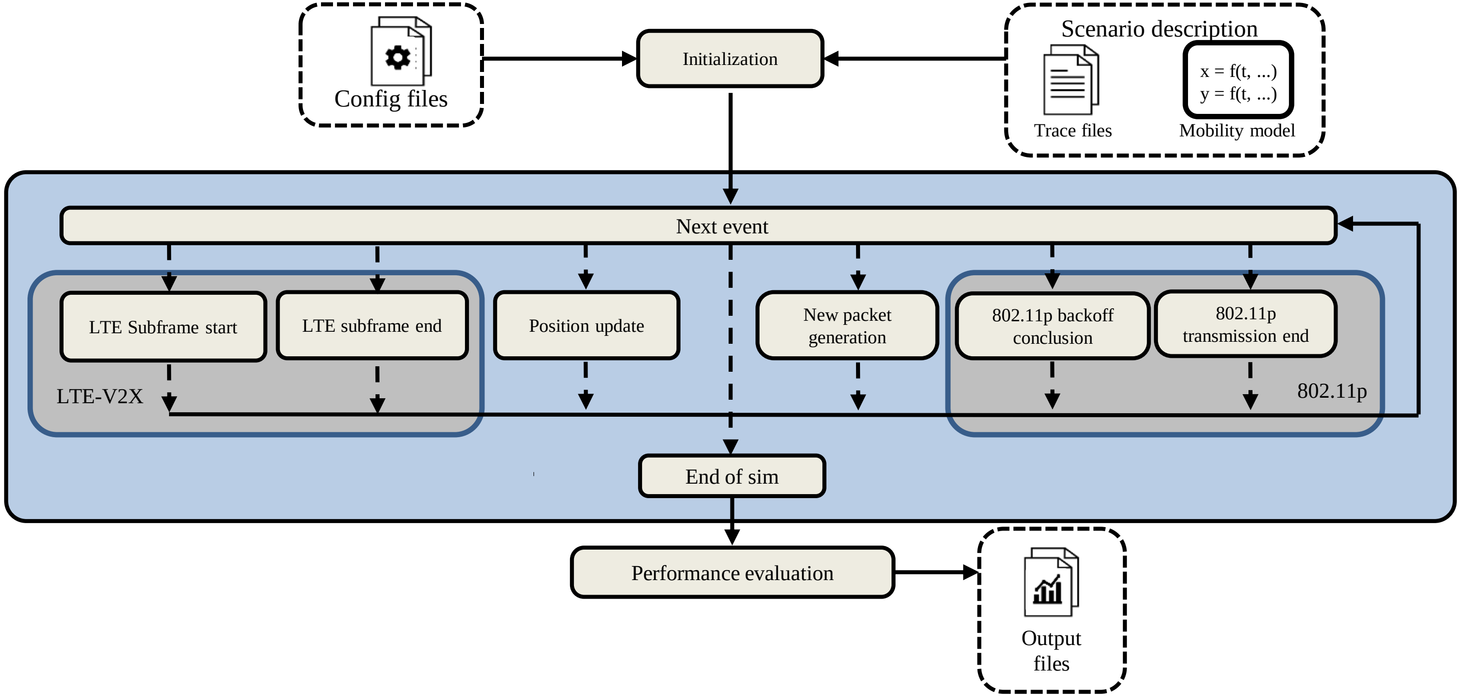
Event driven dynamic simulator written in MATLAB

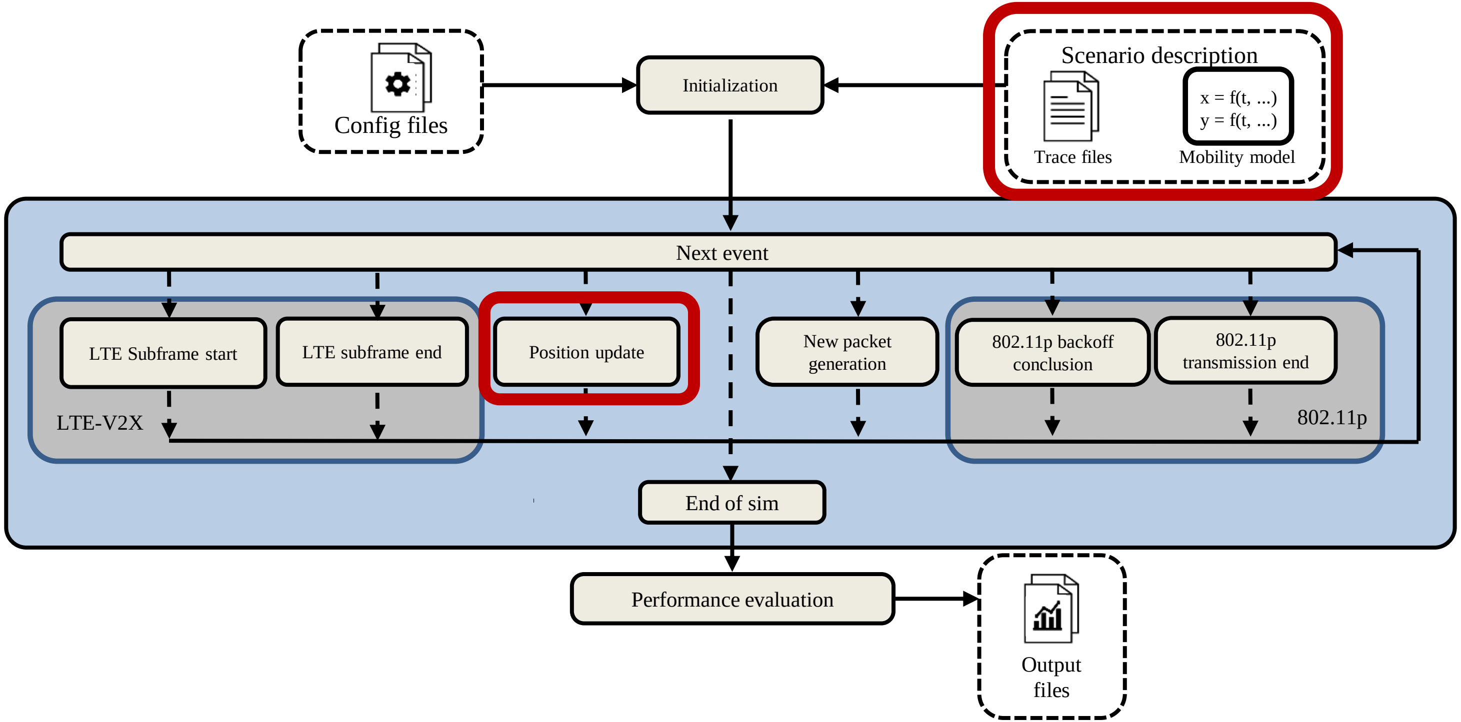
Simulates sidelink LTE-V2X/5G-V2X and IEEE 802.11p, currently focusing on cooperative awareness

Open source at https://github.com/V2Xgithub/WiLabV2Xsim

- *V. Todisco, S. Bartoletti, C. Campolo, A. Molinaro, A. O. Berthet, A. Bazzi, "Performance Analysis of Sidelink 5G-V2X Mode 2 through an Open-Source Simulator", IEEE Access, October 2021*
- *A. Bazzi, G. Cecchini, M. Menarini, B. M. Masini, A. Zanella, "Survey and Perspectives of Vehicular Wi-Fi Versus Sidelink Cellular-V2X in the 5G Era," invited paper in Future Internet, 29 May 2019, 11(6), 122. DOI: 10.3390/fi11060122*
- *G. Cecchini, A. Bazzi, B. M. Masini, and A. Zanella, "LTEV2Vsim: An LTE-V2V simulator for the investigation of resource allocation for cooperative awareness," MT-ITS 2017, Naples (Italy), June 2017.*

Block scheme of the WiLabV2Xsim

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802.11p
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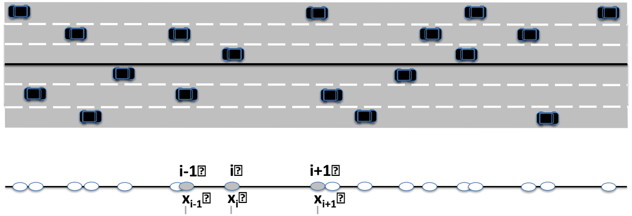
The **positions of the vehicles** can be taken either from



- **Theoretical model**: Poisson distribution (random on parallel lines), modeling a highway
  Main parameters: linear density, road length, road width, number of lanes per direction, mean and variance of the speed

- **Realistic traffic traces**: highway or urban areas; for example
  - *Congested highway*: metropolitan area of Bologna, 16 km length, 3 lanes per direction, 125 vehicles/km, average of 2000 vehicles, moving at 50 ± 3 km/h
  - *Bologna*: portion of 2.88 km^2 of the center of Bologna
    - Two different times of the day:
      - A (less congested): average of 452 vehicles, 156 vehicles/km^2
      - B (heavily congested): average of 667 vehicles, 231 vehicles/km^2

Interpolation:

Since traces are normally provided with a granularity that is much larger than the packet generation period (often 1 or 2 s versus 100 ms inter-packet generation), a proper interpolation module allows to infer the positions with the specified time interval.

- *From v3.3* interpolation is performed during the simulation; it exploits native MATLAB function "*interp1*" and starts together with the simulation, providing significant performance improvements, as well as a smoother trajectory (more realistic).

Example of trace interpolation

+ : coarse
o : from v3.3

Path loss

- **Useful received power:**

$$P_r = \frac{P_t \cdot G_t \cdot G_r \cdot S}{PL}$$

P_t: transmitted power
G_t: transmitter antenna gain
G_r: receiver antenna gain
S: shadowing coefficient
PL: path loss

WiLabV2Xsim implements different channel models

<u>Default is WINNER+, B1:</u>

The PL is computed following the recommendations of 3GPP for vehicular communications [C], hence considering an antenna height of 1.5 m and calculating <u>correlated shadowing</u> as a log-normal distribution with standard deviation σ of 3 dB in LOS and 4 dB in NLOS.

Scenario	Path loss [dB]	Shadowing std [dB]	Applicability range, antenna height default values
LOS	$PL = 22.7\log_{10}(d) + 27.0 + 20.0\log_{10}(f_c)$	σ=3	$d < d'_{BP}$
	$PL = 40.0\log_{10}(d) + 7.56 - 17.3\log_{10}(h'_{MS}) - 17.3\log_{10}(h'_{MS}) + 2.7\log_{10}(f_c)$	σ=3	$d'_{BP} < d < 5\text{km}$ $h_{MS} = 1.5\text{m}$
NLOS	$PL = (44.9 - 6.55\log_{10}(h_{MS}))\log_{10}(d) + 5.83\log_{10}(h_{MS}) + 18.38 + 23\log_{10}(f_c)$	σ=4	$d < 2\ 000$ m $h_{MS} = 1.5\text{m}$

"D5.3: WINNER+ final channel models," Wireless World Initiative New Radio WINNER+, June 2010.

where the effective breakpoint distance d'_{BP} is calculated as $d'_{BP} = 4\ h'_{MS}\ h'_{MS}\ f_c/c$; f_c is the central frequency in Hz, in this case equal to 5.9 GHz (ITS band), $c = 3 \times 10^8$ m/s is the propagation velocity in free space, and h'_{MS} is the effective antenna height at the MS.

The effective antenna height h'_{MS} is computed as follows: $h'_{MS} = h'_{MS} - 1.0$ m, where h'_{MS} is the actual antenna height, and the effective environment height in urban environments is assumed to be equal to 1.0 m.

The value of **shadowing** S_i is updated to its new value S_{i+1} as follows:

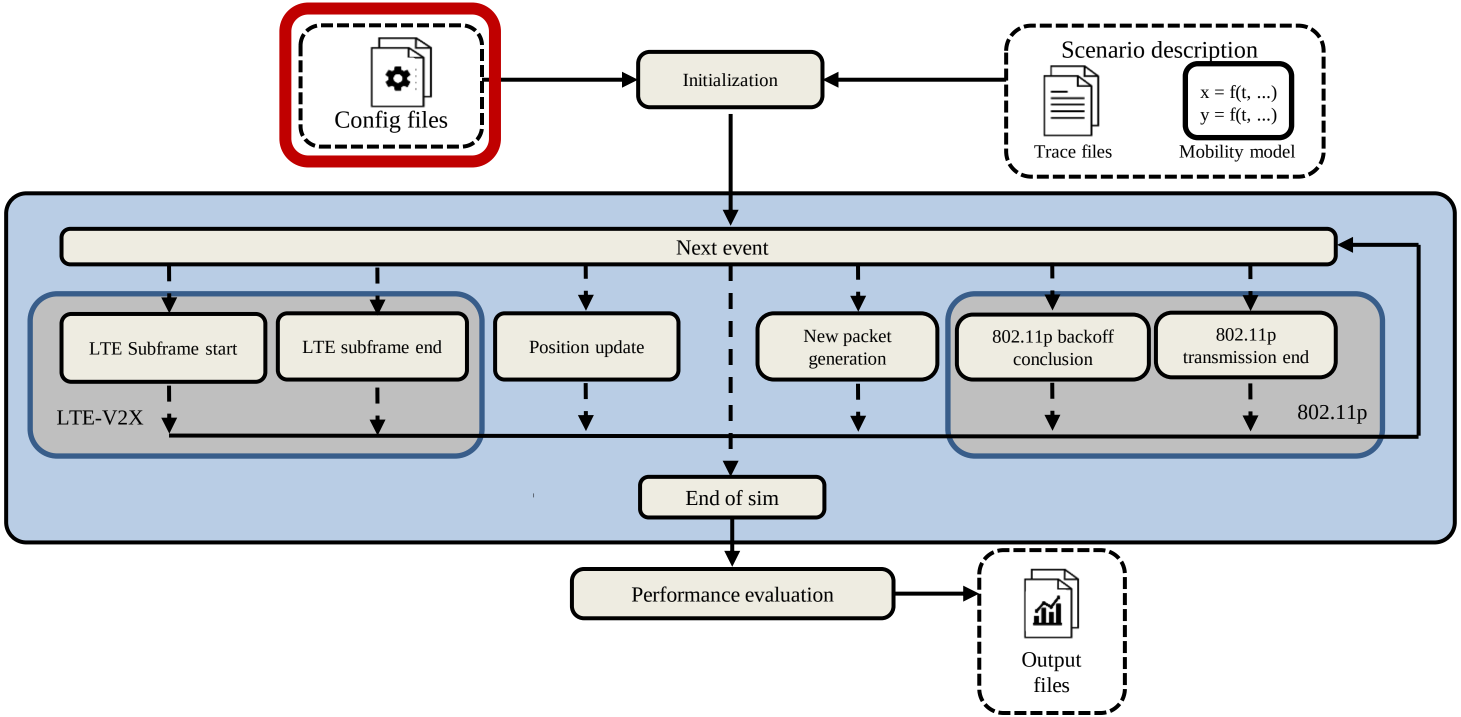
$$S_{i+1} = \exp\{-D/D_{corr}\}S_i + \sqrt{(1-\exp\{-2*D/D_{corr}\})}N_{i+1}$$

where D is the change in distance between the transmitter and the receiver, D_{corr} is the de-correlation distance (equal to 10m for the urban scenario and to 25m for the freeway case), N_{i+1} is a log-normal independent random variable with standard deviation σ.

[C] Table A.1.4-1 of 3GPP TR 36.885 V2.0.0 (2016-06)

MORE?

WILAB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WILAB

Input parameters

(all parameters are detailed in the document “WiLabV2Xsim Table of input parameters.pdf”)

To facilitate the initialization, each setting has a default value.

At the beginning of the simulation, a configuration file (*WiLabV2Xsim.cfg* or a *custom fileConfig*) is read and the values of the parameters contained in the file overwrite the default values.

Settings can also be passed through the command line, which has the priority over the first two methods, thus these values are overwritten.

Default → fileConfig → Command line

Hierarchy of input parameters (the right side has the highest priority)

Help

WiLabV2Xsim(‘help’) in the command window allows to get a list of the parameters and their default values.

NOTE: all the settings are listed in the command line once the simulation is started.

Example of default values

```
Physical layer settings for 5G-V2X
5G SCS: [SCS_NR] = 15 (default)
Number of DMRS per slot:    [nDMRS_NR] = 24 (default)
MCS for NR: [MCS_NR] = 7 (default)
Subchannel size:    [sizeSubchannel] = 10 (default)
Number of SCI symbols per slot: [SCIsymbols] = 3 (default)
Number of RBs dedicated to the SCI-1:    [nRB_SCI] = 10 (default)
Duplexing type: [duplexCV2X] = HD (default)
```

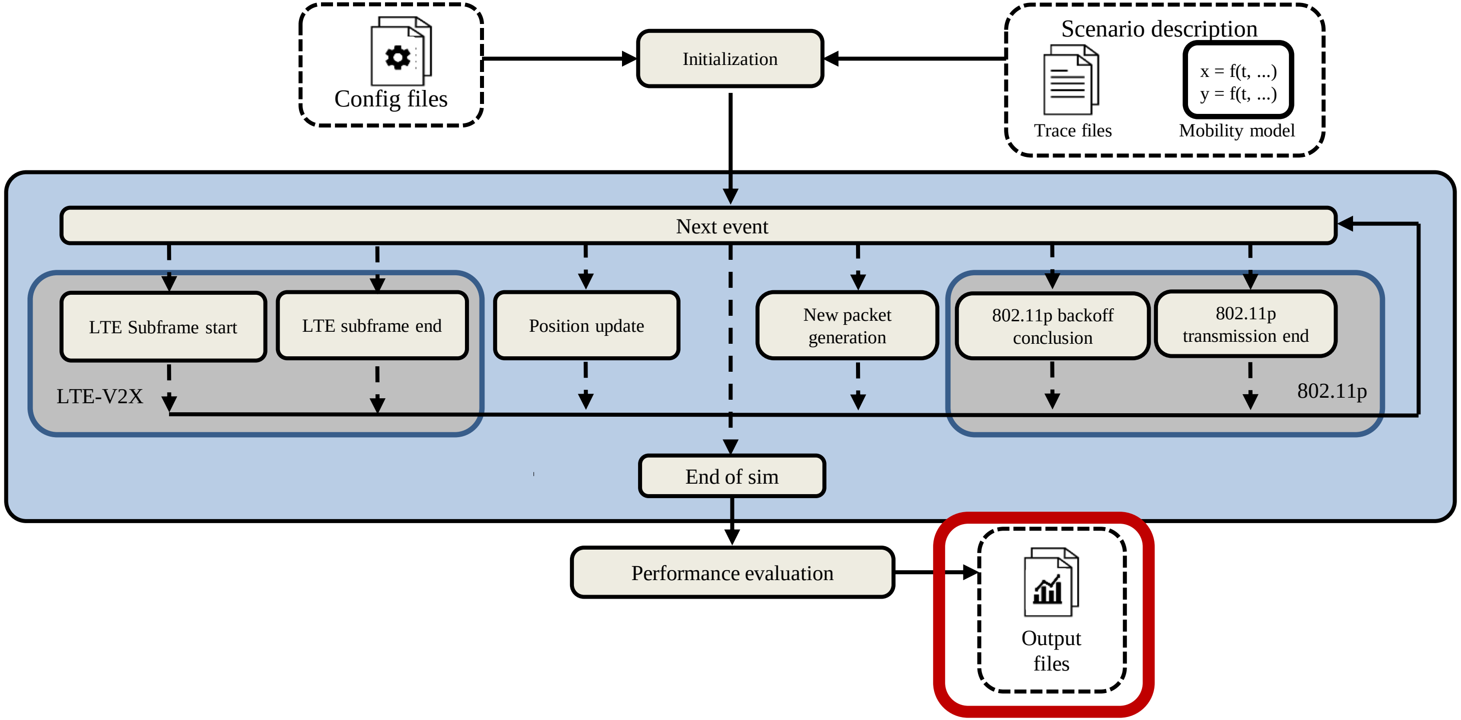
Example of fileConfig

WiLabV2Xsim.cfg

```
[beaconSizeBytes]        190
[TypeOfScenario]         ETSI-Highway
[Nlanes]                 3
[roadWidth]              4
[roadLength]             2000
[vStDev]                 0
```

Example of command line

```
WiLabV2Xsim('default','Technology','NR-V2X','simulationTime',T,'BRAlgorithm',18,...
    'Raw',150,    'beaconSizeBytes',B);
```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<u>Main output file: “*MainOut.xls*”</u> (always generated)

Each row of the file contains the main information about the performed simulation:

- ID of the simulation, simulator version, date, seed, simulation duration [s] and computation duration [s]
- The most relevant settings

The following KPIs for the selected <u>awareness range</u> (input parameter) are also reported:

- <u>Average number of neighbors</u> and variance of neighbors (a vehicle is considered as neighbor when its distance is within the awareness range)
- <u>Average PRR</u>
- <u>Average channel busy ratio</u>

SimID	Sim version	When	Seed	Simulated duration	Computation duration	Vehicles position	Sim (Mborder,Pos
1	v2.0.2	01-Jun-	10	90	1277.355564	File: HighwayPositions_interpolated2D90sec.txt	500,0.0,0.100000
2	v2.0.2	01-Jun-	10	90	1397.989193	File: HighwayPositions_interpolated2D90sec.txt	500,0.0,0.100000
3	v2.0.2	01-Jun-	10	90	1509.010732	File: HighwayPositions_interpolated2D90sec.txt	500,0.0,0.100000
4	v2.0.2	01-Jun-	10	90	1616.627575	File: HighwayPositions_interpolated2D90sec.txt	500,0.0,0.100000
5	v2.0.2	01-Jun-	10	90	1733.384213	File: HighwayPositions_interpolated2D90sec.txt	500,0.0,0.100000
6	v2.0.2	01-Jun-	10	90	1877.541933	File: HighwayPositions_interpolated2D90sec.txt	500,0.0,0.100000
7	v2.0.2	01-Jun-	10	90	2148.003761	File: HighwayPositions_interpolated2D90sec.txt	500,0.0,0.100000
8	v2.0.2	01-Jun-	10	90	2587.131696	File: HighwayPositions_interpolated2D90sec.txt	500,0.0,0.100000

Example of mainOut.xls

Main key performance indicator (KPI): PRR

The packet reception ratio (PRR) is computed as the average ratio between the number of vehicles correctly decoding a packet and the overall number of vehicles, given those receivers that are at a certain distance from the transmitter

Output file: "*packet_reception_ratio_$simID$_$tech$.xls*" (if *printPacketReceptionRatio* = true)
where $simID$ is a progressive integer and $tech$ is either 11p or LTE

This file provides detailed information on the fate of transmissions.

- Goal: to compute various metrics for distances up to the maximum range
- Following the order of the file, columns contain the following data:
  - Distance [m]
  - Number of correctly received packets
  - Number of errors
  - Number of discarded packets
  - Total number of packets
  - PRR

packet_reception_ratio_1_5G.xls - Blocco note di Windows

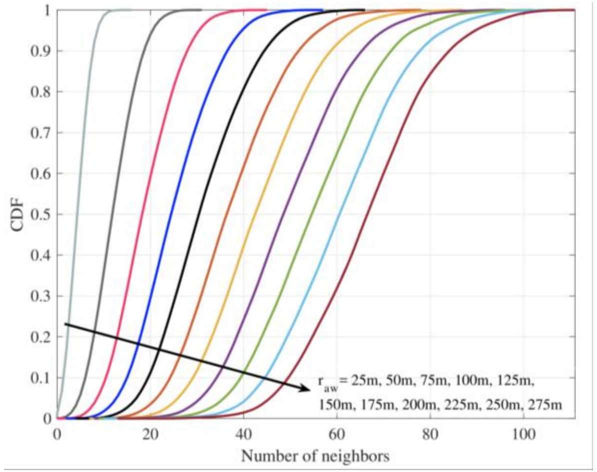
10	264077	338	0	264415	0.998722
20	541856	1364	0	543220	0.997489
30	541103	2207	0	543310	0.995938
40	489958	2259	0	492217	0.995411
50	478362	2908	0	481270	0.993958
60	476564	3209	0	479773	0.993311
70	472197	3876	0	476073	0.991858
80	481116	4344	0	485460	0.991052
90	466208	5281	0	471489	0.988799
100	468568	5910	0	474478	0.987544

Example PRR

Output file: "*neighbors_simID.xls*" (when *printNeighbors* = true)

This file contains only one column with the number of neighbors of each vehicle within the selected awareness range. It is useful to analyze the traffic trace.

Example:



Cumulative distribution function (CDF) of the number of neighbors at the variation of the awareness range in the highway scenario (traffic trace)

Outputs: delay

<u>Output file: “*update_delay_simID.xls*”</u> (when *printUpdateDelay* = true)

The <u>update delay</u> (a.k.a. inter-packet gap) is defined as the time interval between two consecutive successfully received beacons from the same node within the selected <u>awareness range</u>.

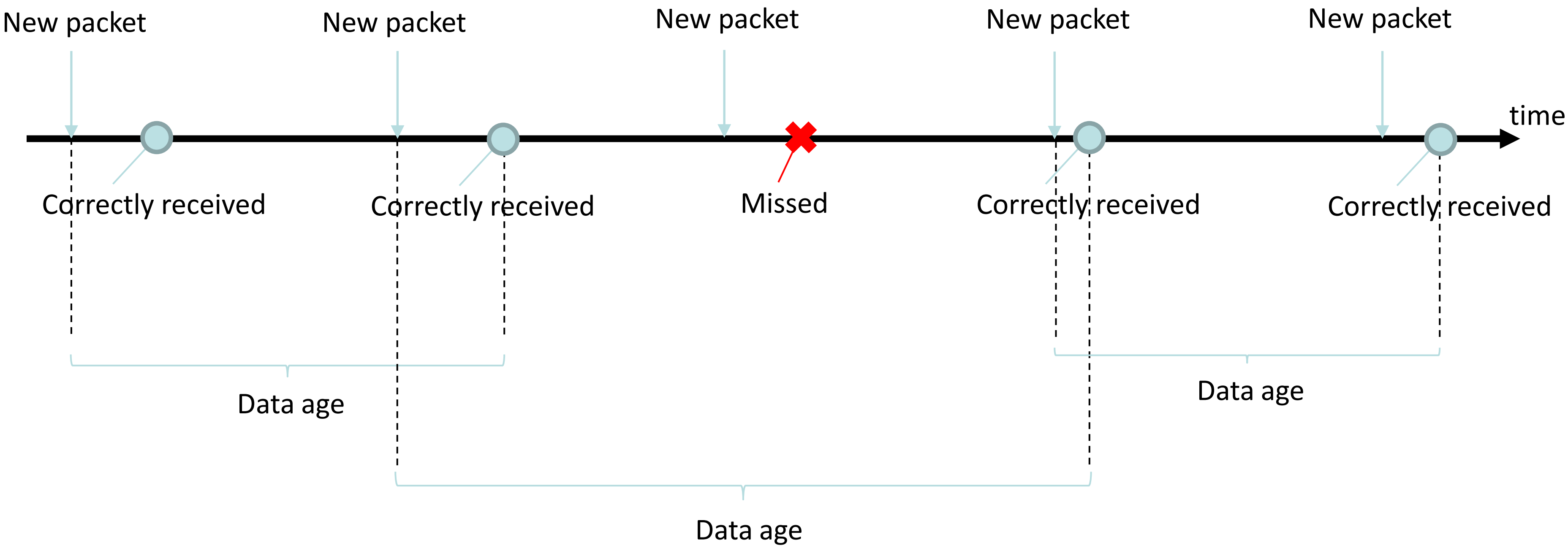
The file contains the following 3 columns in order:
- update delay time (according to the set *delayResolution* → default = 1 ms)
- number of events
- CDF

<u>Output file: “*packet_delay_simID.xls*”</u> (when *printPacketDelay* = true)

The <u>packet delay</u> is defined as the time interval between the generation of the packet and its effective transmission. The metric is computed for each successful reception within the selected <u>awareness range</u>.

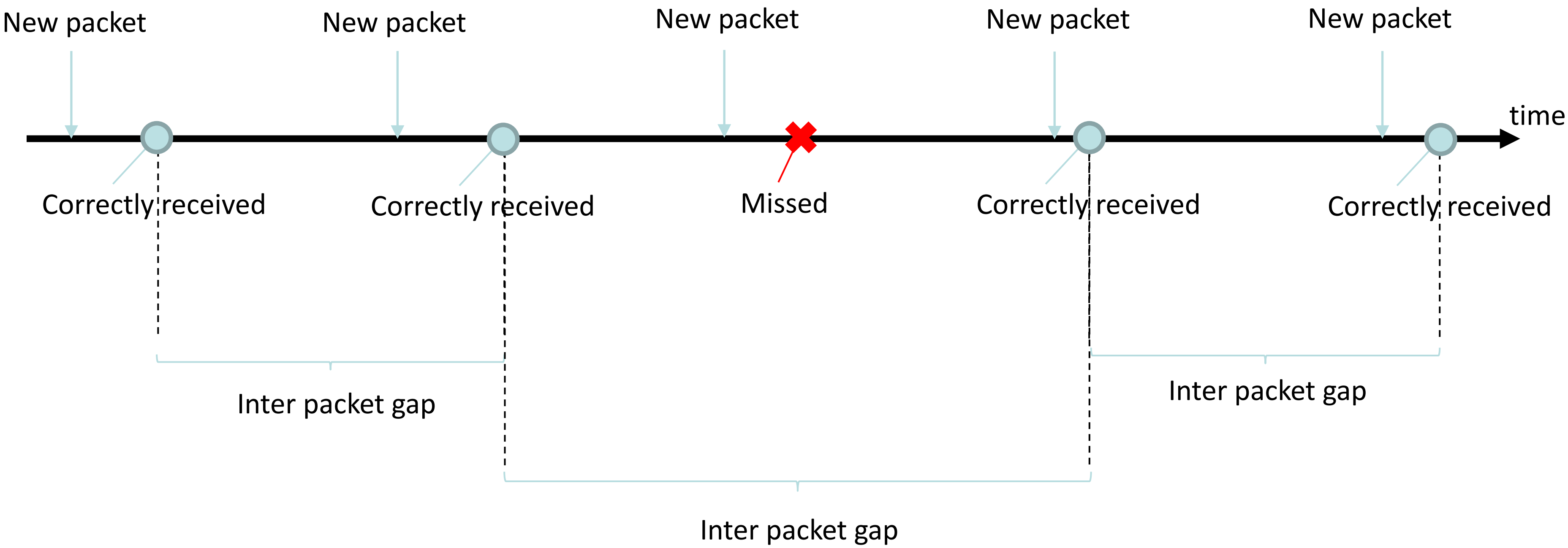
The file contains the following 3 columns in order:
- packet delay time (according to the set *delayResolution* → default = 1 ms)
- number of events
- CDF

DATA AGE

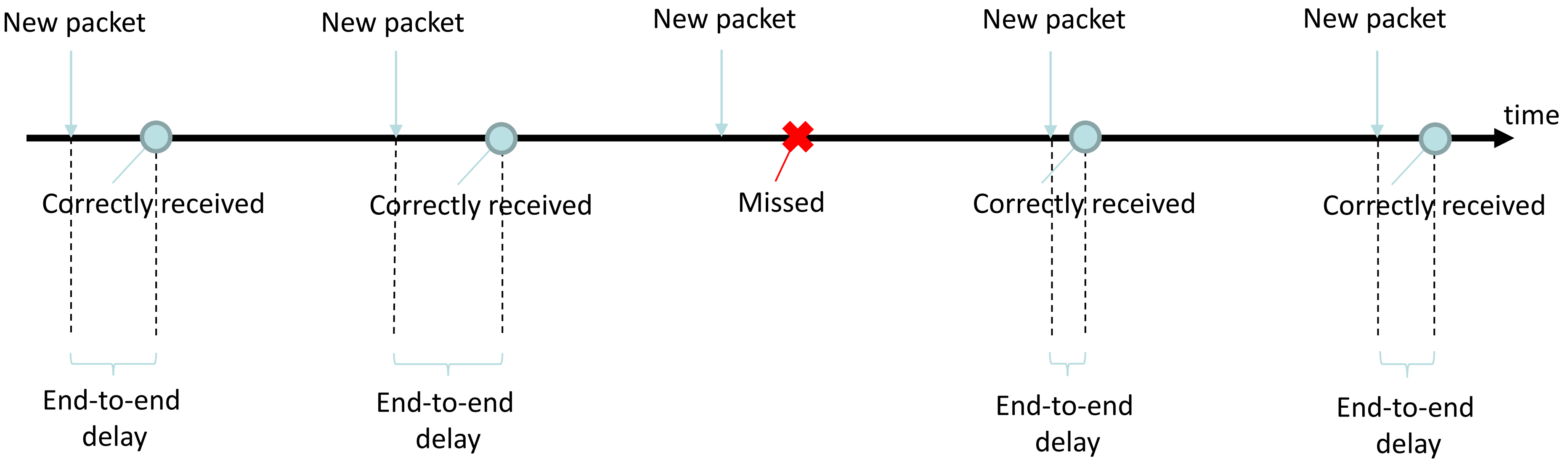


New packet
New packet
New packet
New packet
New packet
time
Correctly received
Correctly received
Missed
Correctly received
Correctly received
Data age
Data age
Data age

INTER PACKET GAP (update delay)



END-TO-END DELAY



MORE?

Resource allocation in C-V2X

Resource allocation algorithms

3GPP standard only defines one mode 4 algorithm based on power sensing, while mode 3 is left to network operators for LTE. In 5G-NR the network-controlled mode is labelled as mode 1 and the autonomous as mode 2

LTEV2Vsim v3.3 features 9 resource allocation algorithms for LTE-V2V.
In WiLabV2Xsim v6.1 mode 2 or mode 4 are fully supported, together with the random allocation.

- Simulation parameter: *BRAlgorithm*

1 → Network-controlled with reuse range (Mode 3)
2 → Network-controlled with reuse range and scheduled reassignments (Mode 3)
3 → Autonomous with sensing range (Mode 4)
4 → Autonomous with BR Map (Mode 4)
5 → Autonomous with sensing by Qualcomm (pre-standard proposal) (Mode 4)
6 → Autonomous with sensing by Intel (pre-standard proposal) (Mode 4)
8 → Autonomous with sensing (3GPP standard) (Mode 4)
102 → X-coordinate ordered allocation (Benchmark)

TO BE REVISED INDICATING THE STABLE ONES

101 → Random allocation (Benchmark)
18 → Autonomous with sensing (Mode 4 and Mode 2 depending on technology selection)

supported

MORE?

WiLabV2Xsim v6.1

TODO

In version 6.1, compared to LTEV2Vsim version 5.4:

- Introduced support for 5G-V2X
  - Numerology: 15,30,60 kHz
  - Calculates the Transport Block size according to various parameters
  - Support for 3GPP aperiodic packet generation
  - Packet generation interval and Resource reservation interval have two different variables
  - Support for Mode 2

Previous versions 1

In LTEV2Vsim version 5.4, compared to LTEV2Vsim version 5.0:

- Several parameters were added (e.g., it is now possible to fix the power density in LTE instead of the transmitted power, to change the congestion parameters of ITS-G5, etc.)
- The outputs were revised
- The highway and urban scenarios often used in ETSI and 3GPP documents were added
- The average SINR calculation was revised (details in following slides)
- Packet generation is not anymore necessarily periodic and an optional function calculates automatically the packet generation interval given the vehicle speed following the CAM triggering rules from ETSI
- The LTE allocation process was improved with the new packet generation (details in following slides)
- Revised packet acquisition phase in ITS-G5 (the stronger signal within 4us is used)
- CBR and DCC implemented for both technologies following ETSI rules (details in following slides)

Previous versions 2

In LTEV2Vsim version 5.0, compared to previous versions

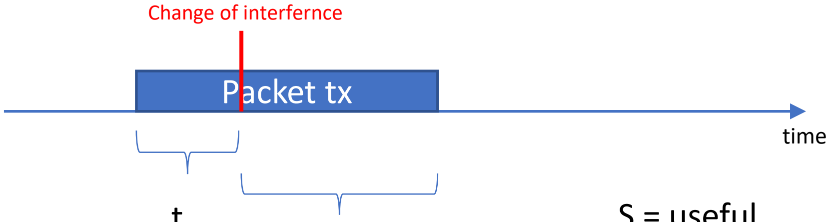
Before version 5.0, the simulator was based on a "beacon period" timing, which was a trade-off between accuracy and speed. Starting from version 5.0, the time granularity for LTE-V2X was reduced to 1 ms in order to allow simulating more cases, including traffic generation with non-uniform-periodic characteristics.
Additionaly, whereas before version 5.0 there were two separate main files for LTE-V2X and IEEE 802.11p, since verison 5.0 there is a single main, allowing simulating both technologies at the same time.

About SINR calculation

SINR CALCULATION

Approach before versions 5.4

The SINR was obtained as the average of instantaneous SINR



t_1

$I_1 \rightarrow SINR_1$

t_2

$I_2 \rightarrow SINR_2$

S = useful
N = noise
I = interference

$$SINR_i = \frac{S}{N + I_i}$$

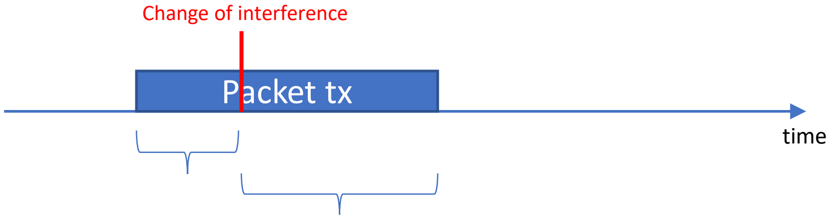
$$SINR_{av} = \frac{\sum(SINR_i \cdot t_i)}{\sum t_i}$$

This way, if we have 2 intervals, t_1=t_2, I_1=0 and I_2→inf we have

$$SINR \approx \frac{{}^{S}/_{N} + 0}{2} = \frac{1}{2}\frac{S}{N}$$

Approach starting from version 5.4

The SINR is obtained as the ratio between the received power (assumed constant on the short duration of a packet transmission) and the sum of noise power and the average interference, which is teh average of the instantaneous interference



t_1

$I_1 \rightarrow SINR_1$

t_2

$I_2 \rightarrow SINR_2$

$$I_{av} = \frac{\sum(I_i \cdot t_i)}{\sum t_i}$$

$$SINR_{av} = \frac{S}{N + I_{av}}$$

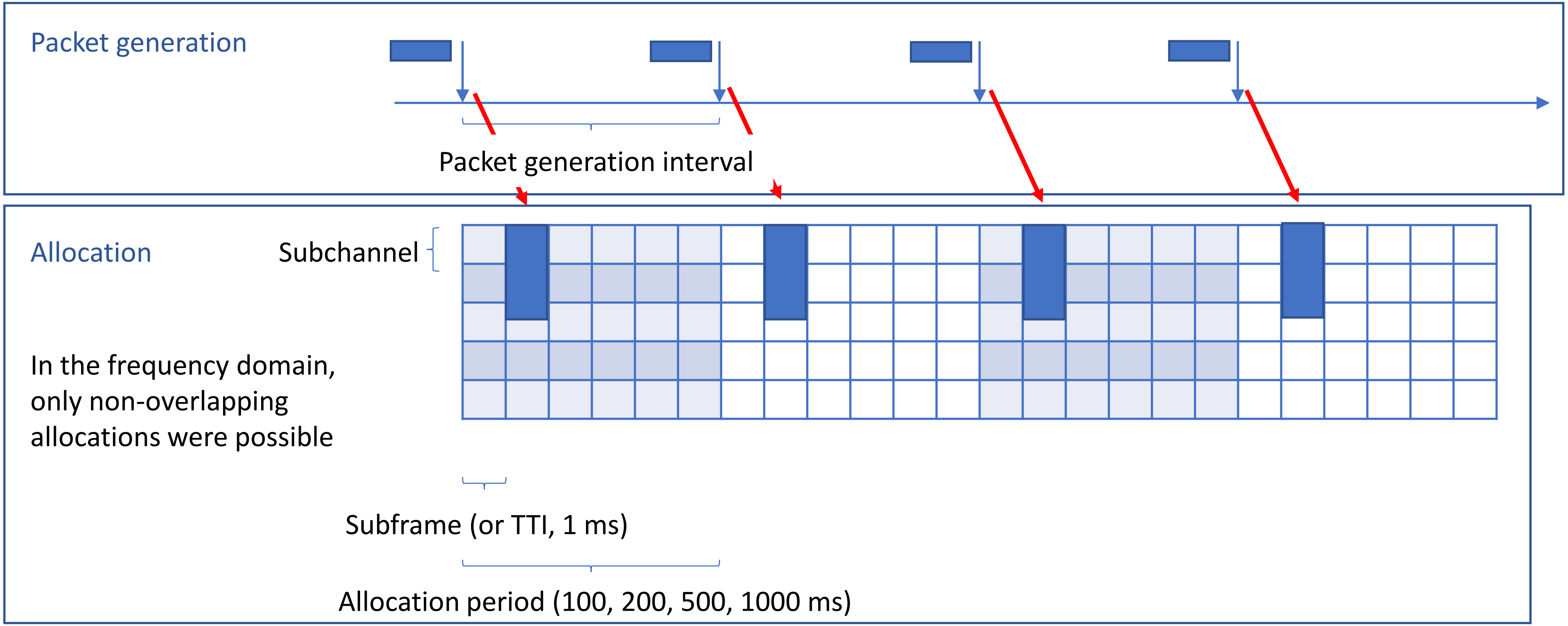
This way, if we have 2 intervals, t_1=t_2, I_1=0 and I_2→inf we have

$$SINR \approx \frac{S}{N + {}^{inf}/_{2}} \rightarrow 0$$

About LTE allocation process

About LTE allocation – Before version 5.0

Time granularity was the allocation period
Overlapping in the frequency domain was not allowed
The packet generation was periodic, with the same period as the allocation periodicity

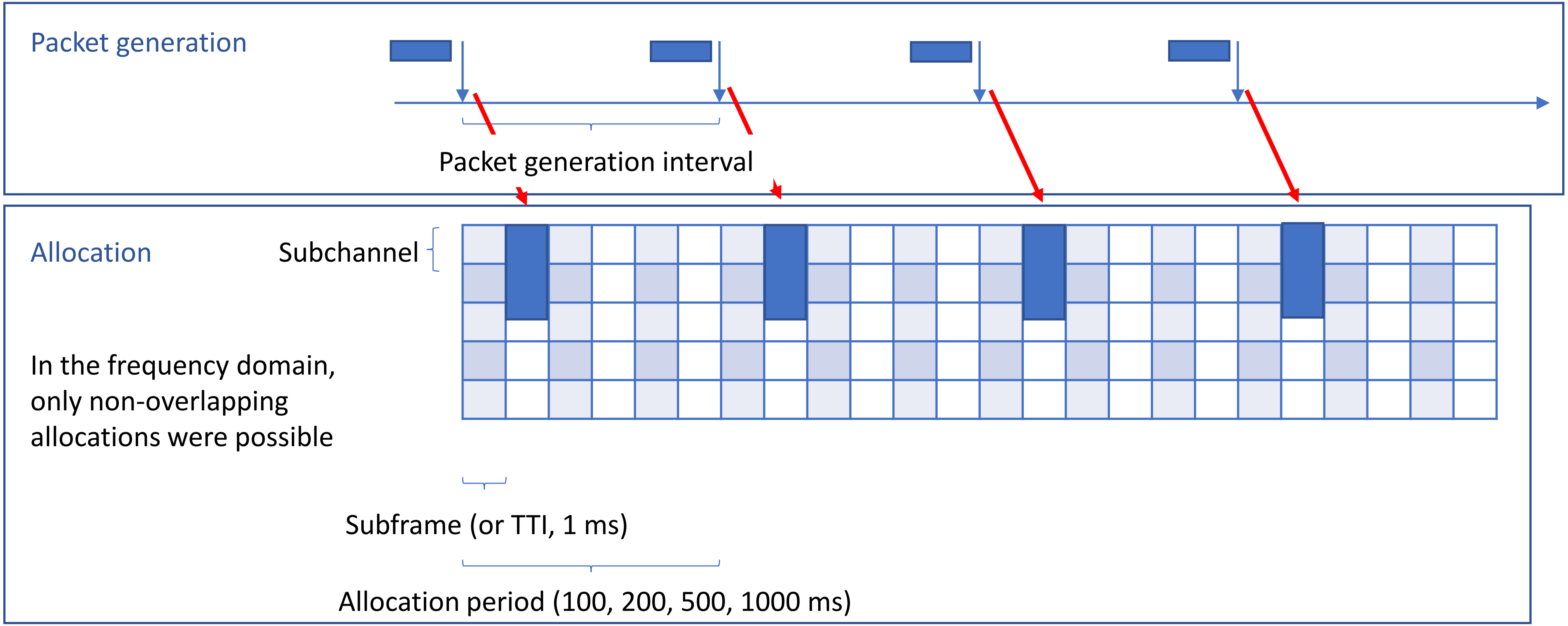


About LTE allocation – From 5.0

Time granularity is now the subframe

Overlapping in the frequency domain was not allowed

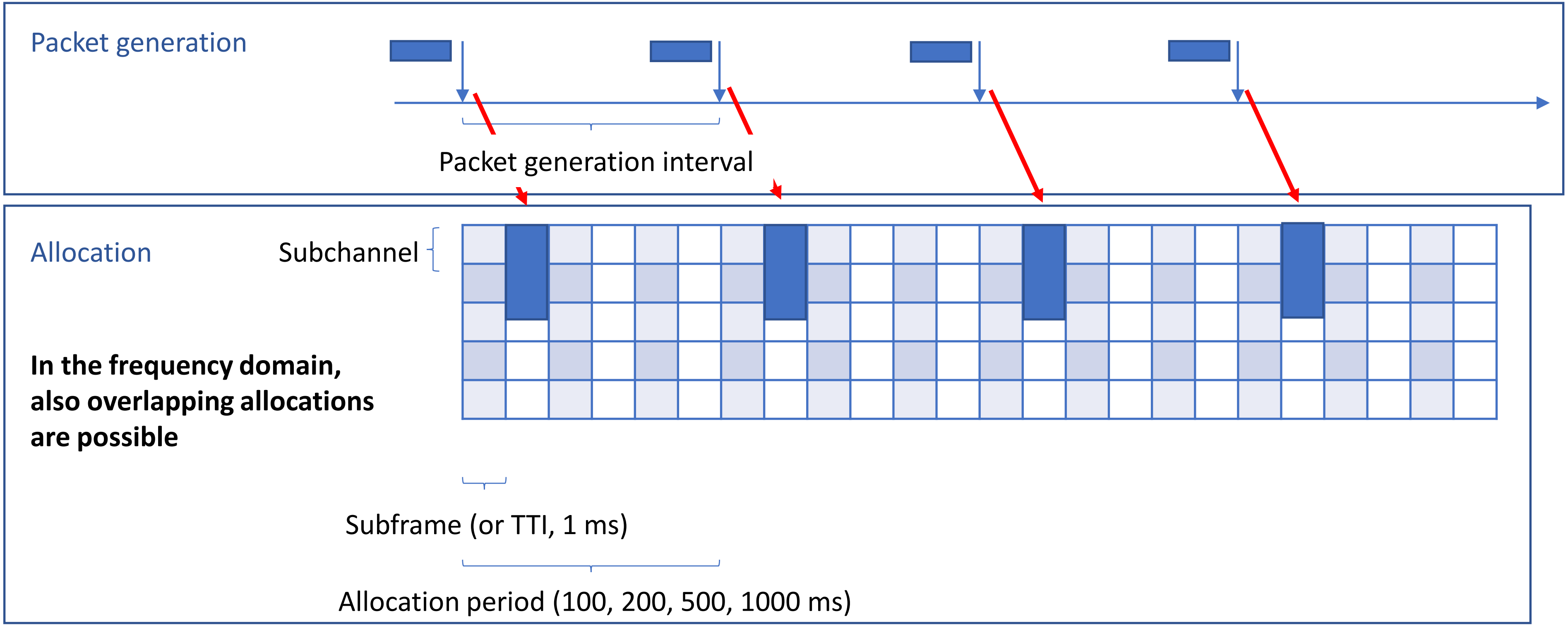
The packet generation was periodic, with the same period as the allocation periodicity



About LTE allocation – First step after v5.0

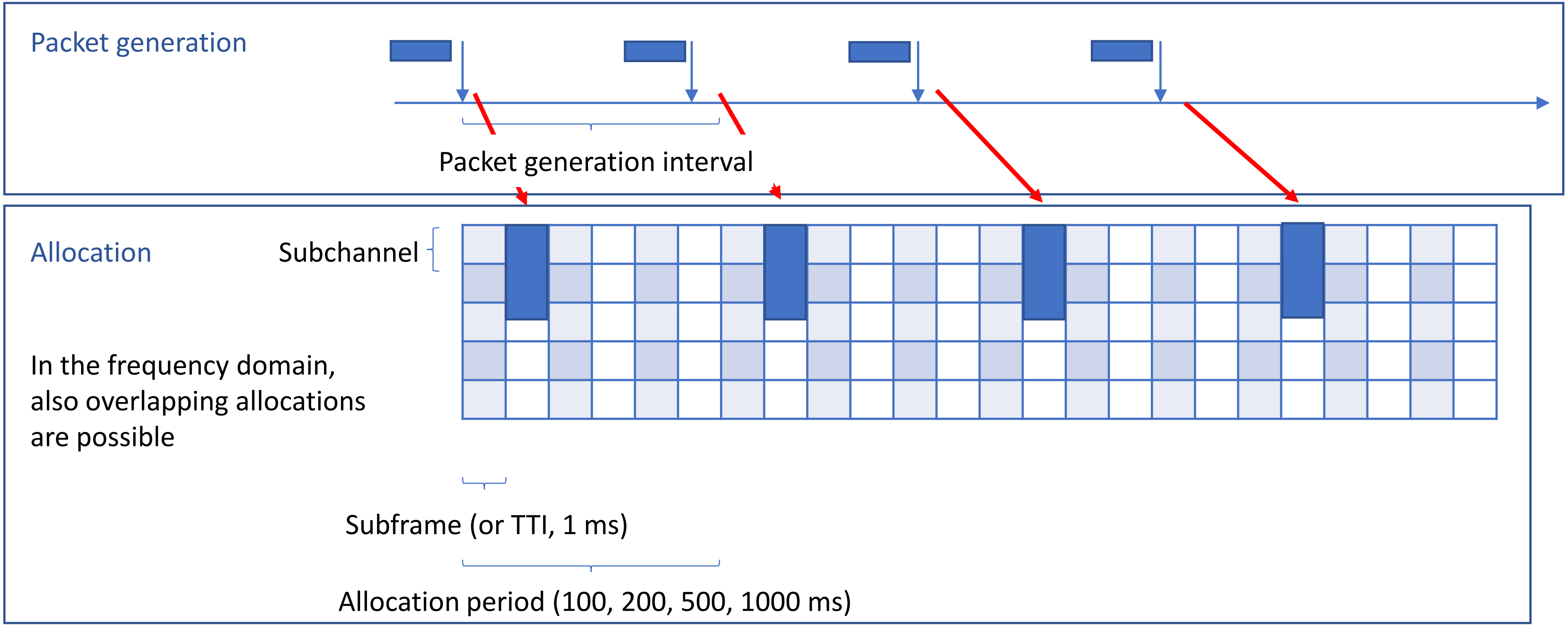
Overlapping in the frequency domain is allowed

The packet generation was periodic, with the same period as the allocation periodicity



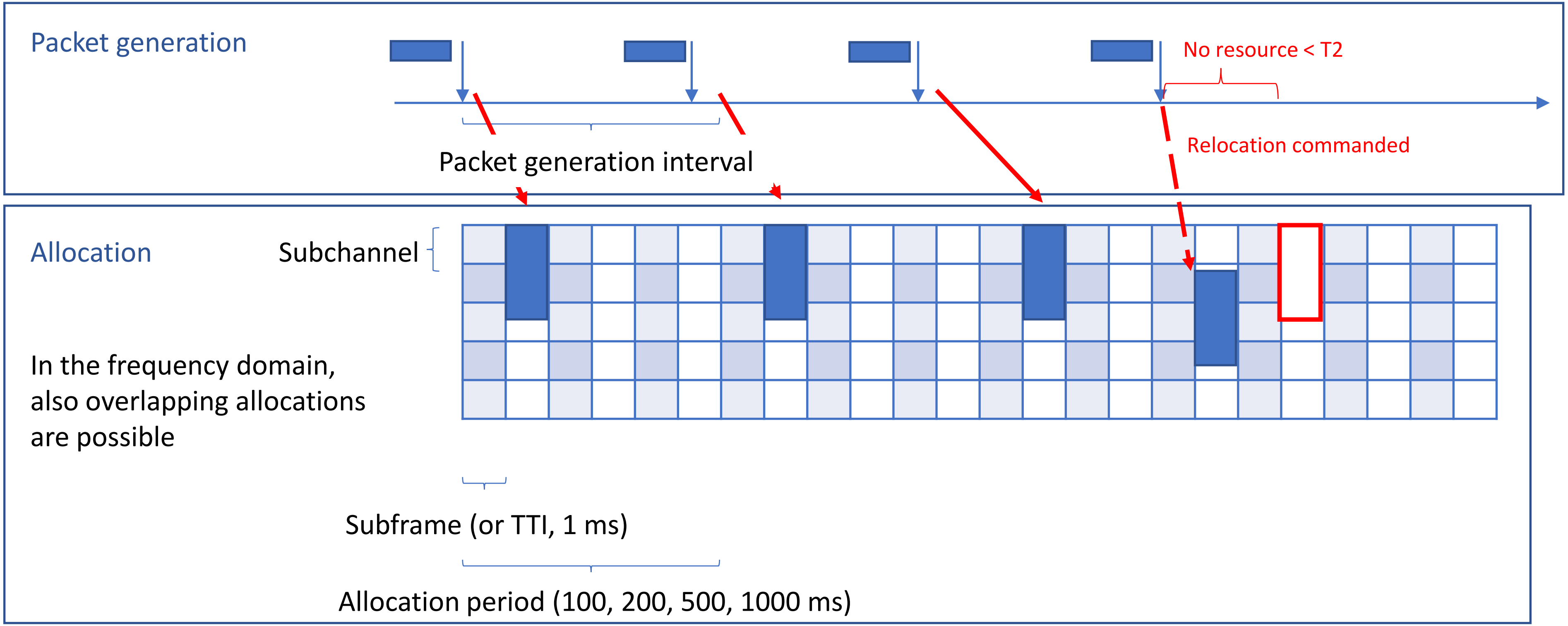
About LTE allocation – Second step after v5.0

The packet generation is periodic, possibly with a different period than the allocation periodicity



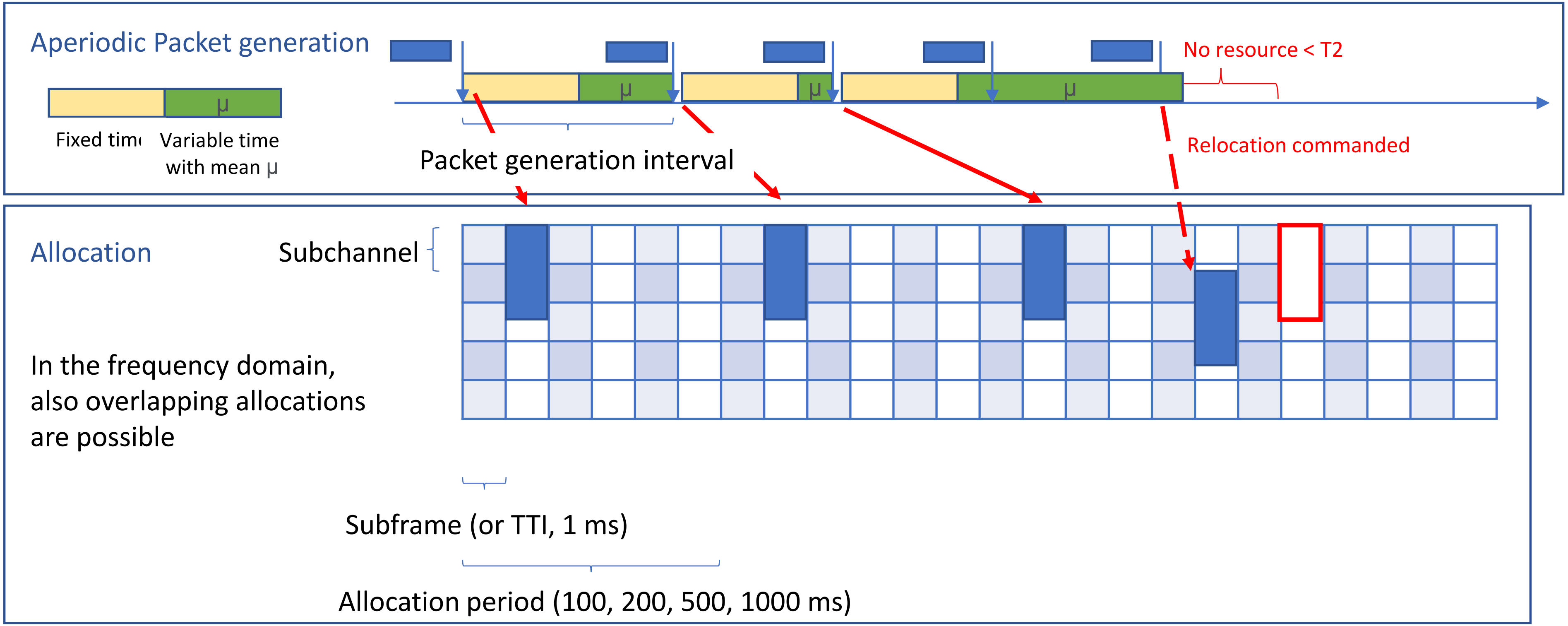
About LTE allocation – Third step after v5.0

A relocation is commanded if a resource in not available in the interval set by T1-T2



About LTE/NR allocation – WiLab v6.1

Packet generation can be aperiodic obtained by the sum of a fixed time interval and a variable one with a given mean.
Reservation can be Periodic or Dynamic scheduling, where a new resource is selected at each packet generation.



WILAB

About the Channel Busy Ratio (CBR) and Congestion Control in IEEE 802.11p

Channel sensing in ITS-G5/11p

At the instant t_0
A transmission starts (vehicle X)

Per each other vehicle Y:
- if Y is not transmitting or already receiving --- AND
    - if the SINR received from X is above the threshold corresponding to PER=0.9 --- OR
    - If the received power is above -65 dB

    THEN Y starts receiving from X (might conclude with an error)

NOTE: noise is well below -85 dBm, thus the threshold for assessing the channel as busy when the message is decodable is not used

Channel sensing in ITS-G5/11p

At the instant t_1
A transmission ends (vehicle X)

Per each vehicle Y that was receiving from X or was in wrongly receiving state
- If the received power is below -65 dB
  THEN Y stops receiving
  OTHERWISE moves/remains in wrongly receiving state

NOTE: the node cannot decode a new signal at this time, thus only the -65 dBm threshold is used

Calculation of CBR

At the instant t_0
A transmission starts (vehicle X)

Per each other vehicle Y:
- if Y is transmitting or the received power is above -85 dB
  THEN Y is in CBR busy state
  OTHERWISE in CBR free state

Calculation of CBR

At the instant t_1
A transmission ends (vehicle X)

Per each other vehicle Y:

- if Y is transmitting or the received power is above -85 dB
  THEN Y is in CBR busy state
  OTHERWISE in CBR free state

ITS-G5: Channel Busy Ratio (CBR)

REF: ETSI EN 302 663

- The occupancy of the channel T_{busy} is updated per each vehicle at each transmission start or end; the calculation of T_{busy} is based on the evaluation:

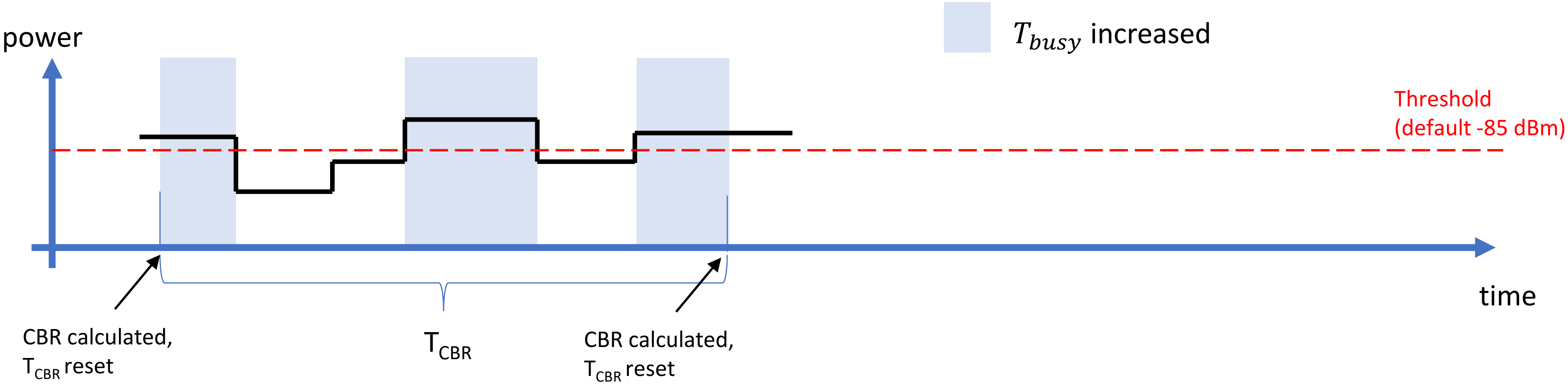
  sensed busy if $\sum P_{r_i} > S_{busy}$, not busy otherwise

  where $\sum P_{r_i}$ is the overall received power and S_{busy} is a threshold named phyParams.PrxSensWhenSynch, by default set to -85 dBm;

- The CBR is then calculated every T_{CBR} =100 ms as

  $CBR = T_{busy}/\, T_{CBR}$

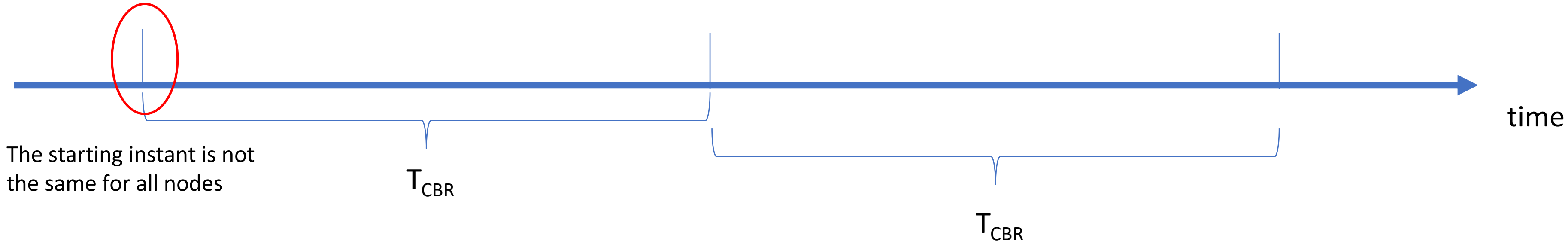
  (T_{busy} is reset everytime a new CBR is calculated)



ITS-G5: Channel Busy Ratio (CBR)

REF: ETSI EN 302 663

- In order to avoid synchronization among nodes and preserve simulation speed, each vehicle performs the CBR calculation every T_{CBR}, starting from a different instant randomly selected within one of T_{CBR}/N instants, where N is a parameter called simParams.cbrSensingIntervalDesynchN and set by default to 100



ITS-G5: DCC

REF: ETSI EN 302 663

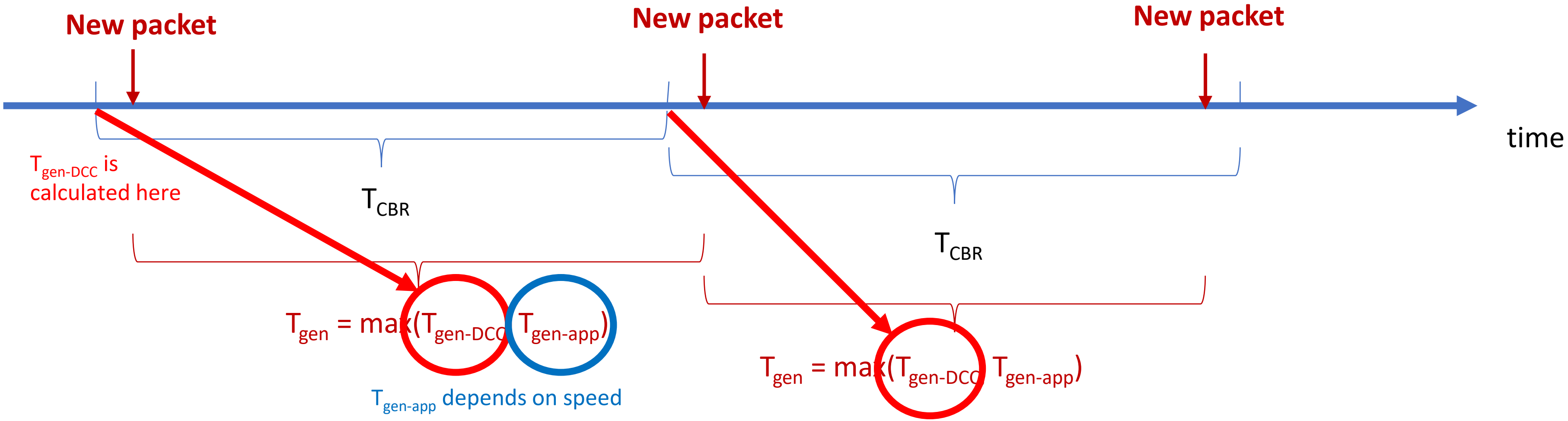
- Based on CBR, the minimum generation interval is calculated as

$$T_{gen-DCC} = \min(\,1, t_{pack}[ms] \cdot 4 \cdot \frac{CBR-0.62}{CBR}) \text{ [seconds]}$$

(note: there is no need to check CBR>0.62)

- Once a new packet is generated, the next one is planned based on

$$T_{gen} = \max(T_{gen-DCC}, T_{gen-app}) \text{ [seconds]}$$



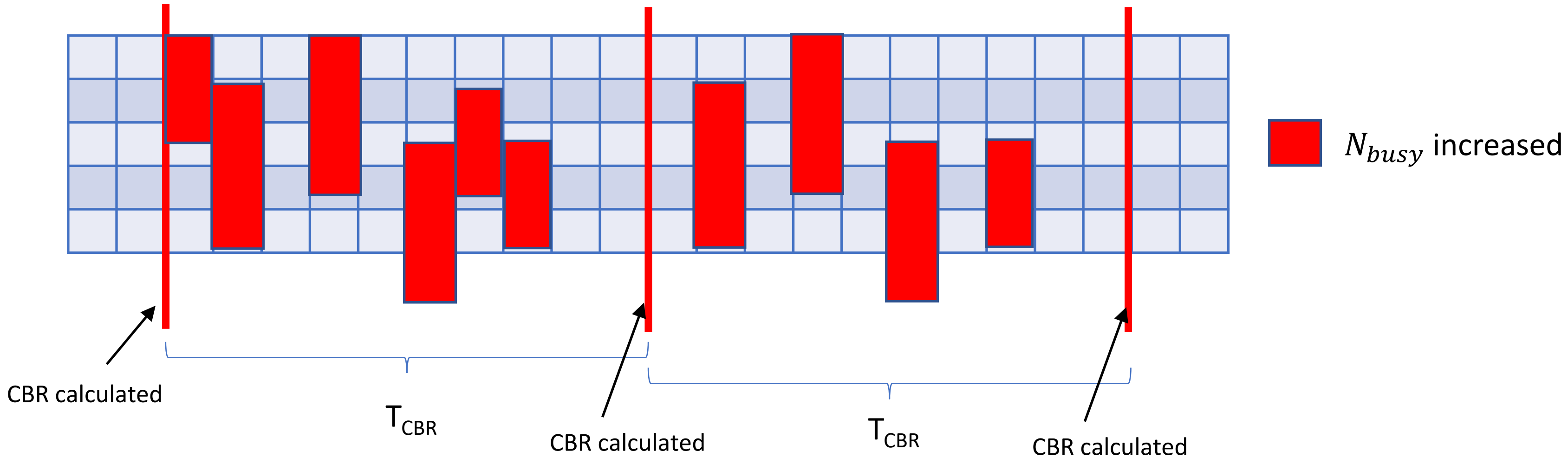
About the Channel Busy Ratio (CBR) and Congestion Control in C-V2X

LTE-V2X: Channel Busy Ratio (CBR)

REF: ETSI TS 103 574
ETSI TS 136 214

- The occupancy of one subchannel is measured based on the evaluation:
  sensed busy if $P_{r_s} > S_{busy}$, not busy otherwise
  where P_{r_s} is the power received in suchannel s and S_{busy} is a threshold fixed to -94 dBm;

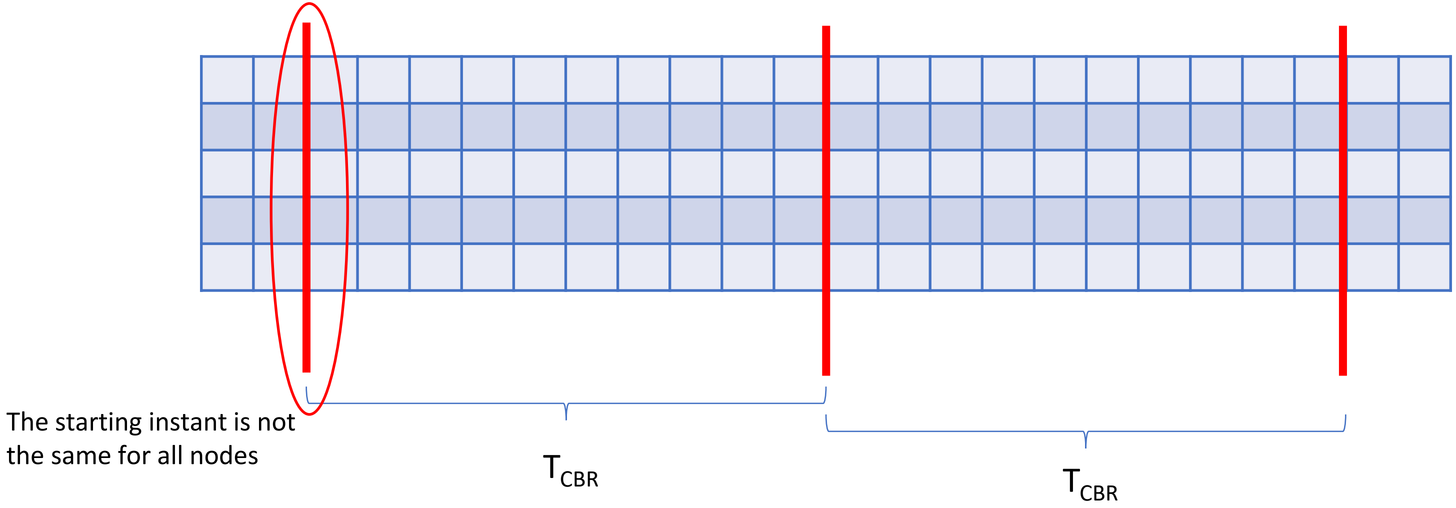
- The CBR is then calculated every T_{CBR} =100 ms as
  $CBR = N_{busy} / N_{CBR}$
  where N_{busy} is the number of suchannels sensed as busy in T_{CBR} and N_{CBR} is the overall number of suchannels in T_{CBR}



LTE-V2X: Channel Busy Ratio (CBR)

REF: ETSI TS 103 574
ETSI TS 136 214

- In order to avoid synchronization among nodes and preserve simulation speed, each vehicle performs the CBR calculation every T_{CBR}, starting from a different instant randomly selected within one of T_{CBR}/N instants, where N is a parameter called simParams.cbrSensingIntervalDesynchN and set by default to 100



LTE-V2X: DCC

REF: ETSI TS 103 574
ETSI TS 136 214

- Based on CBR, the variable CR_{limit} is calculated as (PPPP=5 for CAMs is assumed)

  $CR_{limit-PPPP5} = 1$ if CBR<=0.3,
  $CR_{limit-PPPP5} = 0.03$ if 0.3<CBR<=0.65,
  $CR_{limit-PPPP5} = 0.006$ if 0.65<CBR<=0.8,
  $CR_{limit-PPPP5} = 0.003$ if CBR>0.8

  and the minimum generation interval is derived as

  $$T_{gen-DCC} = \frac{n_{subch-packet}}{n_{subch}} \frac{T_{subframe}}{CR_{limit}}$$

- Once a new packet is generated, the next one is planned based on

  $T_{gen} = \max(T_{gen-DCC}, T_{gen-app})$ [seconds]

  (same as in ITS-G5)

- Note: it is assumed that the resources allocated at the access layer are at a constant periodicity, which is not in general synchronized with the generation interval