

# NR V2X TUTORIAL: MODELS, IMPLEMENTATION, AND EXAMPLES

21/06/2022, WNS3 TUTORIAL

Zoraze Ali

Former CTTC Researcher

# ORGANIZATION

---

- **15:20 – 16:00 UTC**
  - **Part I: The theoretical part**
    - Motivation
    - Sidelink standard overview
    - NR V2X standard vs *ns-3*
    - NR V2X key aspect and their implementation in *ns-3*
    - Key aspects of *ns-3* NR V2X model design
    - Potential Contributions/extensions
    - How to contribute?
- **16:00 – 16:15 UTC**
  - **15 min break**
- **16:15 – 16:45 UTC**
  - **Part II: The practical part**
    - A walk through the *ns-3* NR-V2X examples



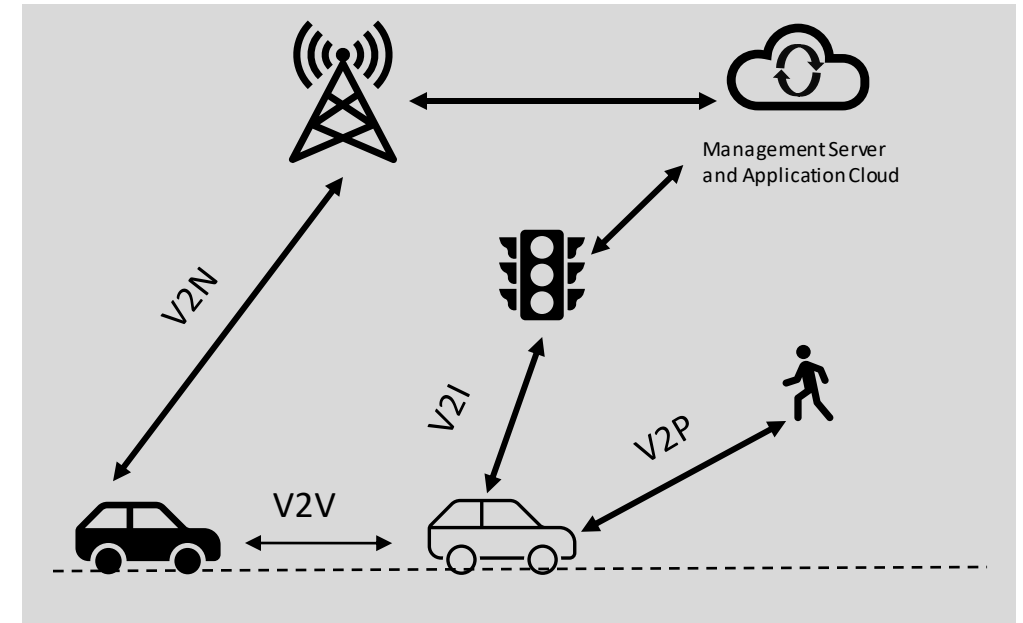
# ACKNOWLEDGEMENTS

---

- Sandra Lagén (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Spain)
- Lorenza Giupponi (Former CTTC )
- Richard Rouil (National Institute of Standards and Technology (NIST), US)
  
- This work was funded by NIST grant 2019-NIST-MSE-1: "Modeling, Simulation and Performance Evaluation of NR V2X"

# MOTIVATION

- Automotive industry's vision of building a V2X ecosystem to:
  - Increase traffic safety
  - Save time
  - Save money
  - Save environment
  - Increase convenience
- Synergies between the efforts of two previous and separate activities carried out within the OpenSim department at CTTC.
  - NIST grant 2017-NIST-PSIAP-01 NOFO: “Modelling, Simulation and Performance Evaluation for Public Safety Networks”, which resulted in the release of the 3GPP Release-12 D2D (Device to Device) feature for ns-3 LTE [[Public Safety Communications](#)].
  - A collaboration with InterDigital, which resulted in the first release of a new NR model for ns-3, compliant with 3GPP Release-15 NR [[5G-LENA](#)].



# SIDELINK STANDARD OVERVIEW

2014

## LTE D2D (Release 12 -13)

- Proximity Services (ProSe)
- Sidelink/PC5
- FDD, TDD
- Sidelink in uplink bands
- Groupcast and Broadcast
- Mode 1 and Mode 2
- Frequency and Time multiplexed PHY channels
- Blind HARQ ReTx(s)
- UE-to-Network relays

2015

## LTE V2X (Release 14)

- Basic safety applications
- Event-Triggered messages
- FDD, TDD
- Sidelink in ITS bands
- Broadcast
- Mode 3 and Mode 4
- Frequency multiplexed PHY channels
- Blind HARQ ReTx(s)

2017

## LTE eV2X (Release 15)

- Enhancement to Rel-14 LTE V2X
- Safety and non-safety applications.

2018

## NRV2X (Release 16)

- Advance safety and non-safety applications
- FDD, TDD
- Sidelink in ITS and licensed FR1 and FR2 bands
- Mode 1 and Mode 2
- Unicast, Groupcast, Broadcast
- Frequency and time multiplexed PHY channels
- Feedback-based HARQ ReTx(s) for groupcast and unicast
- Channel State Information (CSI) for unicast

2019

2020

## NRV2X (Release 17)

- Advance safety and non-safety applications targeting more KPIs than REL.16
- FDD, TDD
- Power Savings Resource Allocation
- UE relay
- UE power savings (DRX)
- Sidelink positioning and ranging beamforming

2021

# NR V2X STANDARD VS NS-3

	NR V2X standard	NR V2X ns-3
Communication types	Broadcast, Groupcast, Unicast	Broadcast
MCS	QPSK, 16QAM, 64QAM, 256QAM	QPSK, 16QAM, 64QAM, 256QAM
Waveform	OFDMA	OFDMA
Frequency range	sub-6 GHz, mmWave	sub-6 GHz, mmWave
Subcarrier spacing	sub-6 GHz: 30, 60 kHz mmWave: 60, 120 kHz	sub-6 GHz: 30, 60 kHz mmWave: 60, 120 kHz
Duplexing mode	FDD, TDD	TDD
Retransmissions	Broadcast: blind, Groupcast: blind, feedback-based Unicast: blind, feedback-based	Broadcast: blind
PHY channels	PSCCH, PSSCH, PSBCH, PSFCH	PSCCH, PSSCH
Control and data multiplexing	Frequency, Time	Time
Scheduling interval	1 slot	1 slot
Sidelink mode	MODE 1, MODE 2	MODE 2
Channel models	V2V highway, V2V Urban	V2V highway, V2V Urban

# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3

---

## SIDELINK PHYSICAL CHANNELS

1. Physical Sidelink Control Channel (PSCCH)
  - Sidelink Control Information (1st- stage-SCI)
2. Physical Sidelink Shared Channel (PSSCH)
  - 2nd-Stage-SCI, User plane data

Code reference:

- [NrSpectrumPhy::StartTxSICtrlFrames](#)
- [NrSpectrumPhy::StartTxSIDataFrames](#)
- [NrSpectrumPhy::RxSIPscch](#)
- [NrSpectrumPhy::RxSIPssch](#)

# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3

---

## RESOURCE ALLOCATION MODE 2

- The UE autonomously determines sidelink transmission resources within sidelink resources configured by the gNB or pre-configured in UE.
- Resource reservation for NR V2X Mode 2 under periodic traffic mostly reuses the LTE C-V2X sidelink Mode 4 long-term sensing-based semi-persistent scheduling.
- In addition, NR V2X Mode 2 also supports a random resource selection.

Code reference:

- [EnableSensing attribute of UE MAC](#)
- [NrUeMac::DoNrSISlotIndication](#)



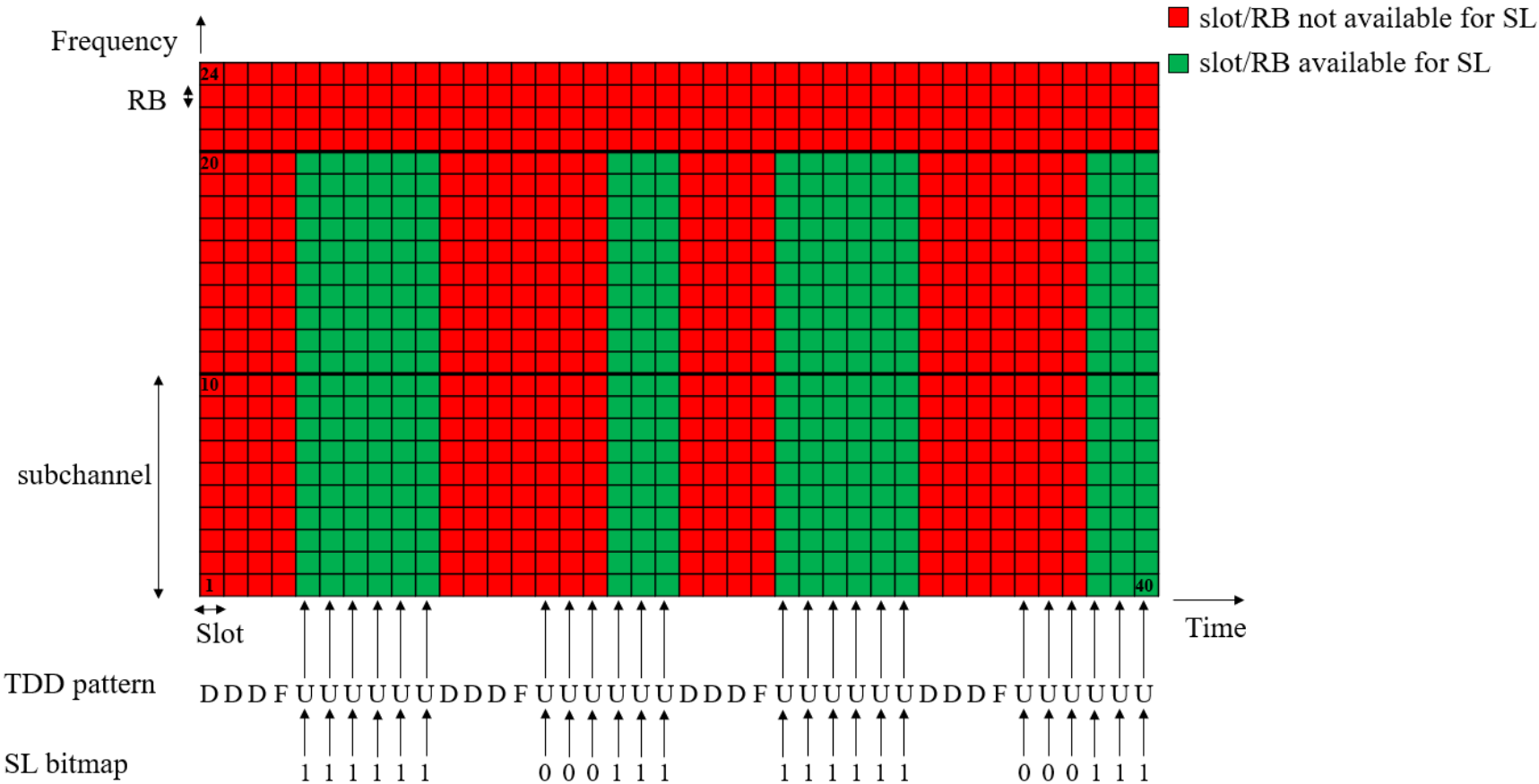
# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3

## SIDELINK RESOURCE POOL

A sidelink resource pool can be used for transmission and reception of PSCCH/PSSCH.

- Frequency domain:
  - Sidelink resource pool consists of a number of contiguous subchannels.
  - The size of each subchannel is fixed and it is composed of N contiguous RBs.
  - Both the number of subchannels and the subchannel size are higher layer pre-configured, by RRC.
  - NR V2X supports  $N = 10, 15, 20, 25, 50, 75,$  and 100 RBs for possible sub-channel sizes.
- Time domain:
  - The resources (i.e., slots) available for sidelink are determined by repeating sidelink bitmaps.
  - The bitmap is pre-configured and characterized by a certain size.
  - The resource pool parameter from RRC, *sl-TimeResource*, defines the bitmap size and takes values 10, 11, 12, ..., 160.
  - In particular, in the case of Time Division Duplex (TDD), the time resources available sidelink are given by the combination of the TDD pattern and the sidelink bitmap.

# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3



TDD pattern : [D D D F U U U U U U U]  
 Sidelink bitmap: [1 1 1 1 1 1 0 0 0 1 1 1]  
 Final/Physical sidelink bitmap: [0 0 0 0 1 1 1 1 1 1 0 0 0 0 0 0 0 1 1 1]

# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3

## ASSUMPTIONS

Assumptions for the configuration of a TDD pattern, sidelink bitmap and the resource reservation period in the simulator.

1. The size of a sidelink bitmap should always be a multiple of the number of UL slots in a TDD pattern.

**Reason:** If the bitmap size is not multiple of the number of UL slots, we can not construct the physical bitmap which could be applied repeatedly throughout a simulation.

1. The resource reservation period used in the simulation should always be a multiple of the resultant physical bitmap size.

**Reason:** This is adopted to guarantee that once a slot is selected for sidelink communications, it is available for sidelink after the resource reservation period in *ms* and the sensing-based resource selection mechanism of neighboring UEs can operate adequately, which receive the resource reservation period of other UEs in SCI stage 1.

Code reference:

- [NrSIUeRrc::DoGetPhysicalSIPool](#), [NrUeMac::DoAddNrSICommTxPool](#),
- [NrSICommResourcePool::IsRsvpMultipOfPoolLen](#)

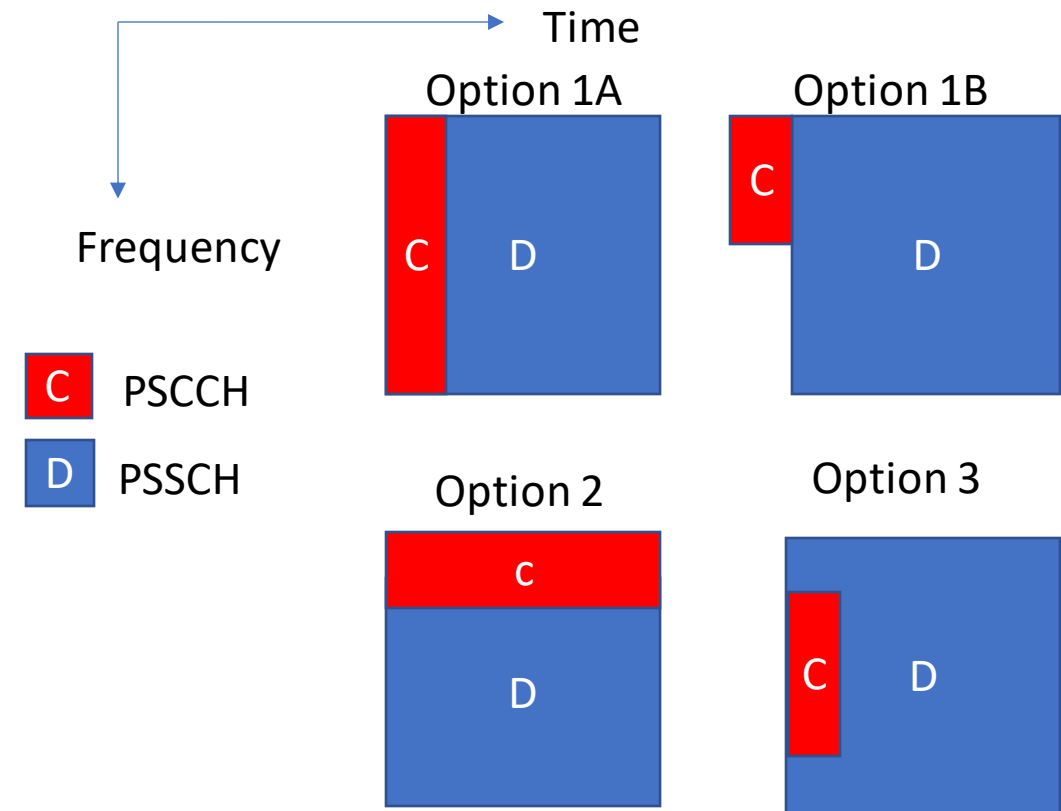
# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3

## MULTIPLEXING OF PSCCH, PSSCH

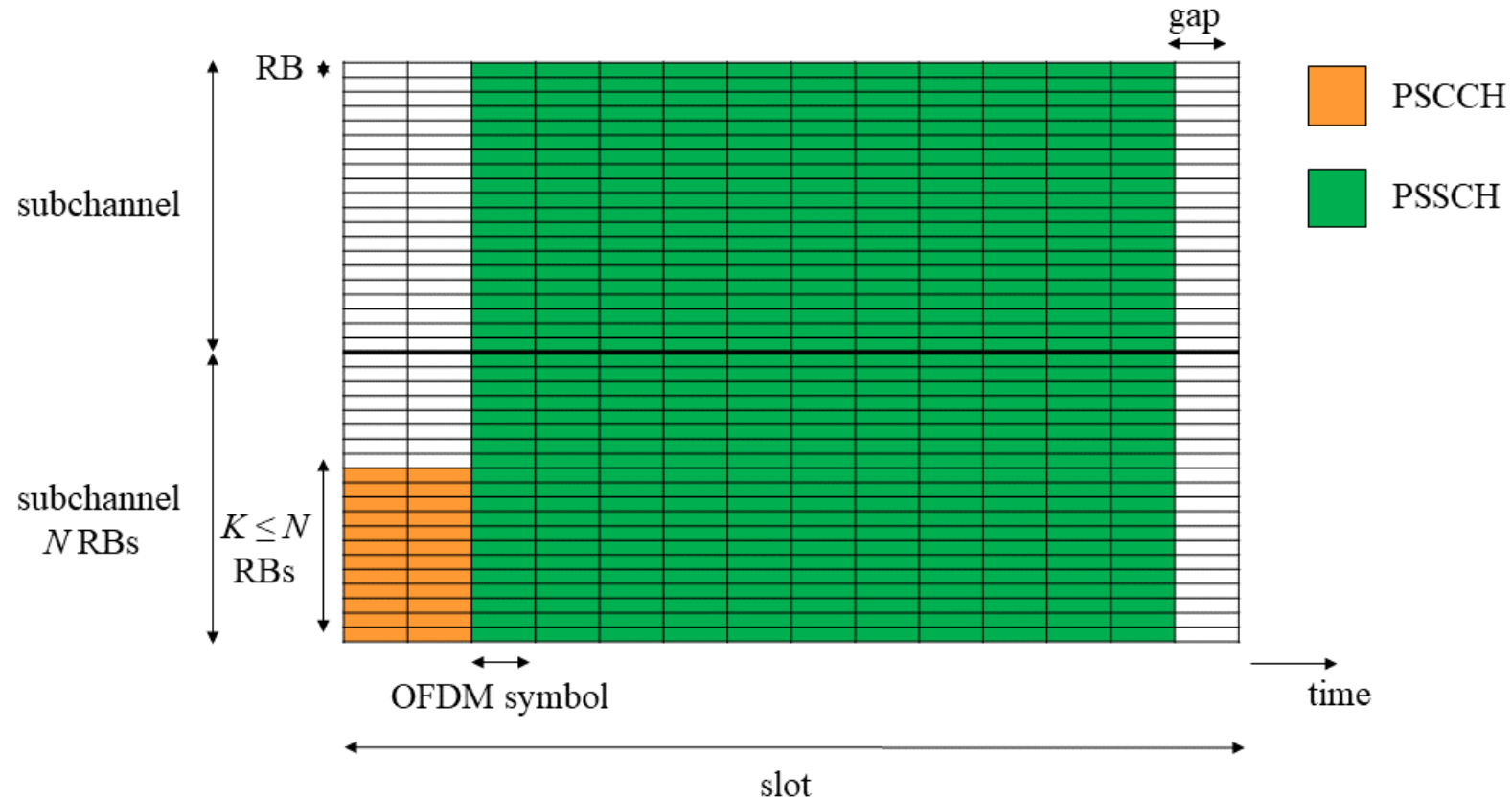
- In LTE C-V2X, PSCCH and PSSCH channels are multiplexed in the frequency domain.
- In NR V2X four options are proposed in the standard for PSCCH and PSSCH.
- Two consider time multiplexing, i.e., the PSCCH will be transmitted first, followed by the transmission of PSSCH.
- *ns-3* NR V2X module supports option 1A.

Code reference:

- [NrSICommResourcePool::GetNrSICommOpportunities](#)



# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3



- In the above example, PSCCH is pre-configured to 2 symbols, PSSCH starts at the 3rd symbol with a duration of 11 symbols, and the 14th symbol is left empty as a guard period.
- $N = 20$  RBs is the subchannel size, and  $K = 12$  RBs are used for the PSCCH.

# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3

## RETRANSMISSIONS

- NR V2X only supports blind retransmissions for broadcast communications.
- $N_{PSSCH,maxTx}$  parameter specifies the total number of PSSCH transmissions (i.e., first transmission + retransmissions).
- $N_{PSSCH,maxTx}$  is pre-configured and can be equal to 32.
- However, the final total number of transmissions depends on the number of available slots.
- If  $K$  is the total number of available slots, then:

$$N_{selected} = \begin{cases} N_{PSSCH,maxTx}, & \text{if } K \geq N_{PSSCH,maxTx} \\ K, & \text{otherwise} \end{cases}$$

Code reference:

- [sIPsschTxParameters](#)
- [NrSIUeMacSchedulerSimple::RandomlySelectSlots](#)

# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3

## SIDELINK CONTROL INFORMATION

Two SCI formats have been defined in the NR V2X standard:

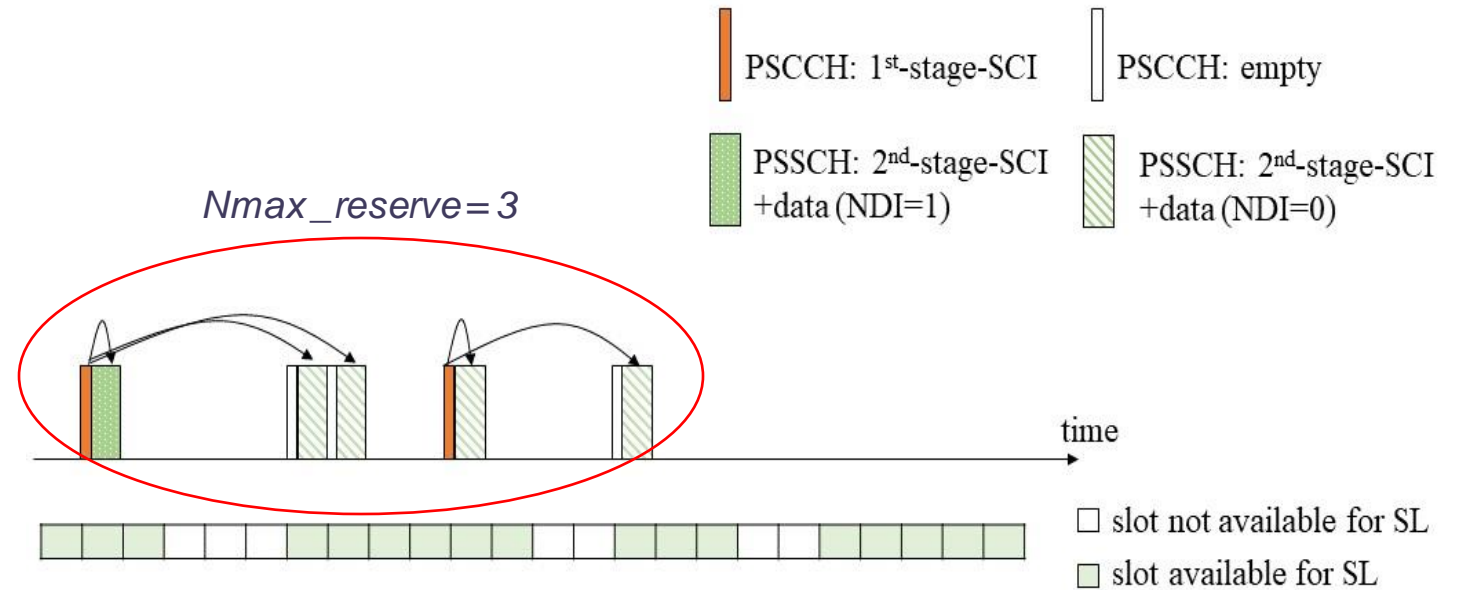
- SCI Format 0-1 (1st- stage-SCI)
  - Carried by PSCCH
  - Includes scheduling information: The priority of transmission, time/frequency resource assignment, 2nd-stage-SCI format (2-A, 2-B), MCS, and resource reservation period.
- SCI Format 0-2 (2nd- stage-SCI)
  - Carried by PSSCH
  - Transports information used for the decoding of PSSCH. This includes the HARQ process ID, new data indicator (NDI), Redundancy Version (RV), source ID, and destination ID.

Code reference:

- [1st-stage-SCI](#)
- [2nd-stage-SCI](#)
- [2nd-stage-sci-format-2a](#)

# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3

- 1st-stage-SCI indicates the reservation of  $N_{max\_reserve}$  (pre-configured) number of sidelink slots.  $N_{max\_reserve}$  can be 2 or 3.
- The resource reservation is indicated in the *time and frequency resource assignment* field of the 1st-stage-SCI.
- This means some slots may have empty PSCCH and only carry information in the PSSCH.



Code reference:

- [Indication of slots carrying SCI-stage-1](#)
- [SCI-stage-1 initialization](#)



# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3

## SENSING BASED RESOURCE SELECTION PROCEDURE

The sensing-based resource selection procedure is composed of two procedures:

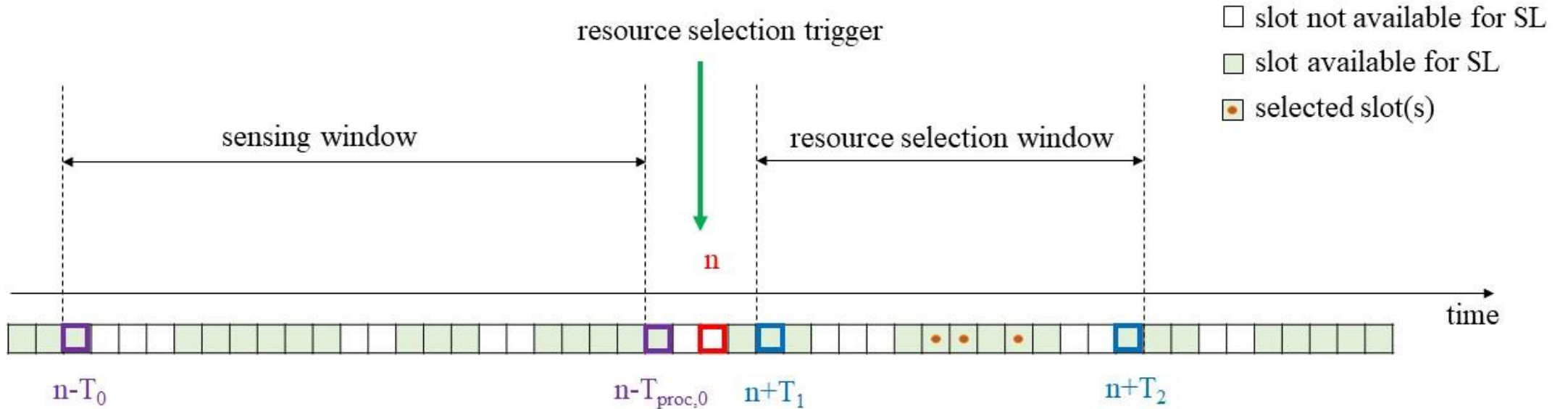
1. A sensing procedure
  2. A resource selection procedure
- Sensing procedure
    - The sensing procedure is in charge of identifying the resources which are candidate for resource selection.
    - It is based on the decoding of the 1st-stage-SCI received from the surrounding UEs and on sidelink power measurements in terms of Reference Signal Received Power (RSRP).

Code reference

- [Reception of PSCCH at UE PHY](#)
- [RSRP computation](#)

# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3

- Example with  $T_0 = 20$  slots,  $T_{proc,0} = 2$  slots,  $T_1 = 2$  slots, and  $T_2 = 16$  slots.



- The sensing procedure is performed during the so-called sensing window, defined by the pre-configured parameter  $T_0$  and a UE-specific parameter  $T_{proc,0}$ .
- Once the resource selection is triggered, e.g., at time  $n$ , the UE will consider the sidelink measurements performed during the interval  $[n - T_0; n - T_{proc,0}]$ .

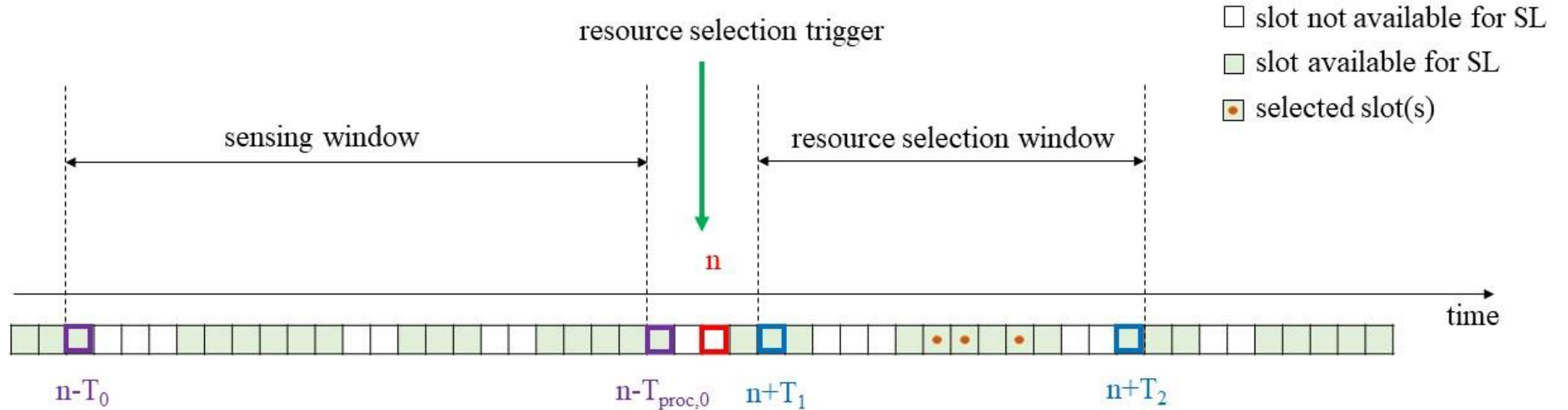
Code reference:

[T0](#), [Tproc,0](#), [NrUeMac::UpdateSensingWindow](#), [ApplyTproc,0](#)

# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3

- Resource selection procedure

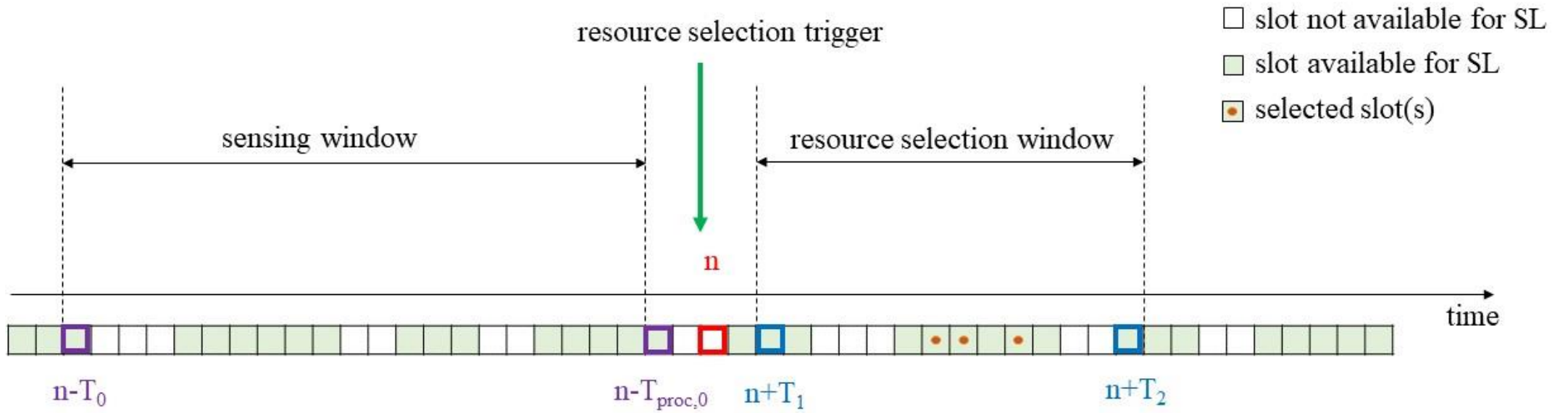
- Example with  $T_0 = 20$  slots,  $T_{proc,0} = 2$  slots,  $T_1 = 2$  slots, and  $T_2 = 16$  slots.



- $T_2$  depends on the packet delay budget (PDB) and on an RRC pre-configured parameter called  $T_{2,min}$ .
- In case  $PDB > T_{2,min}$ ,  $T_2$  is determined by the UE implementation and must meet the following condition:
  - $T_{2,min} \leq T_2 \leq PDB$ .

# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3

- Example with  $T_0 = 20$  slots,  $T_{proc,0} = 2$  slots,  $T_1 = 2$  slots, and  $T_2 = 16$  slots.



- In case  $PDB \leq T_{2,min}$  then  $T_2 = PDB$ .
- $T_1$  is selected so that  $T_{proc,1} \leq T_1$ , where  $T_{proc,1}$  is the time required to identify the candidate resources and select a subset of resources for sidelink transmission.

Code reference

- [T1, T2, T2,min, NrSlCommResourcePool::GetNrSlCommOpportunities](#)

# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3

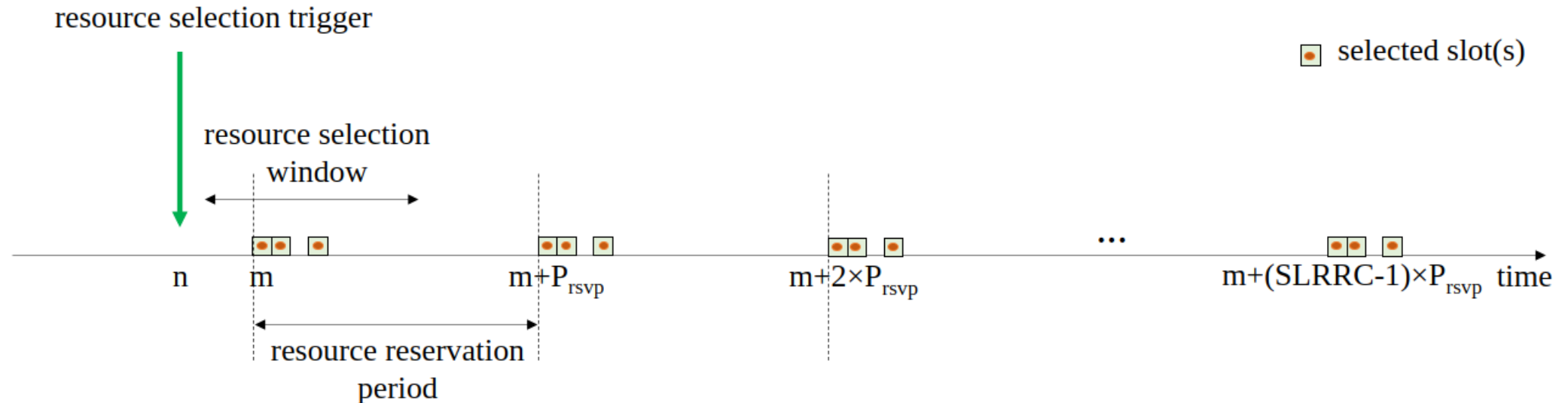
- First, the candidate resources within the resource selection window are identified.
  - A resource (in time and frequency) is indicated as non-candidate:
    1. If an SCI is received on that slot or the corresponding slot is reserved by a previous SCI
    2. And the associated sidelink RSRP measurement is above a sidelink RSRP threshold.
  - The resulting set of candidate resources within the resource selection window should be at least a **X** % of the total resources within the resource selection window to proceed with the second step of the resource selection.
  - The value of **X** is configured by RRC and can be 20 %, 35 % or 50 %.
  - If the above condition is not met, the RSRP threshold is increased by 3 dB and the procedure is repeated.
- Second, the transmitting UE/Sidelink scheduler performs the resource selection from the identified candidate resources. For that, a randomized resource selection is supported.

Code reference:

- [NrUeMac::GetNrSITxOpportunities](#), [Call to the scheduler from UE MAC](#), [NrSIUeMacSchedulerSimple](#)

# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3

## SEMI-PERSISTENT SCHEDULING



- Once one or multiple resources are selected, the UE will consider periodic transmissions, using SPS.
- The transmission interval is defined by the Resource Reservation Period ( $P_{rsvp}$ ), which is pre-configured by RRC between 1 ms and 1000 ms.
- $P_{rsvp}$  value is included in the 1st-stage-SCI, to allow other UEs to estimate which resources are reserved in the future.

# NR V2X KEY ASPECTS AND THEIR IMPLEMENTATION IN NS-3

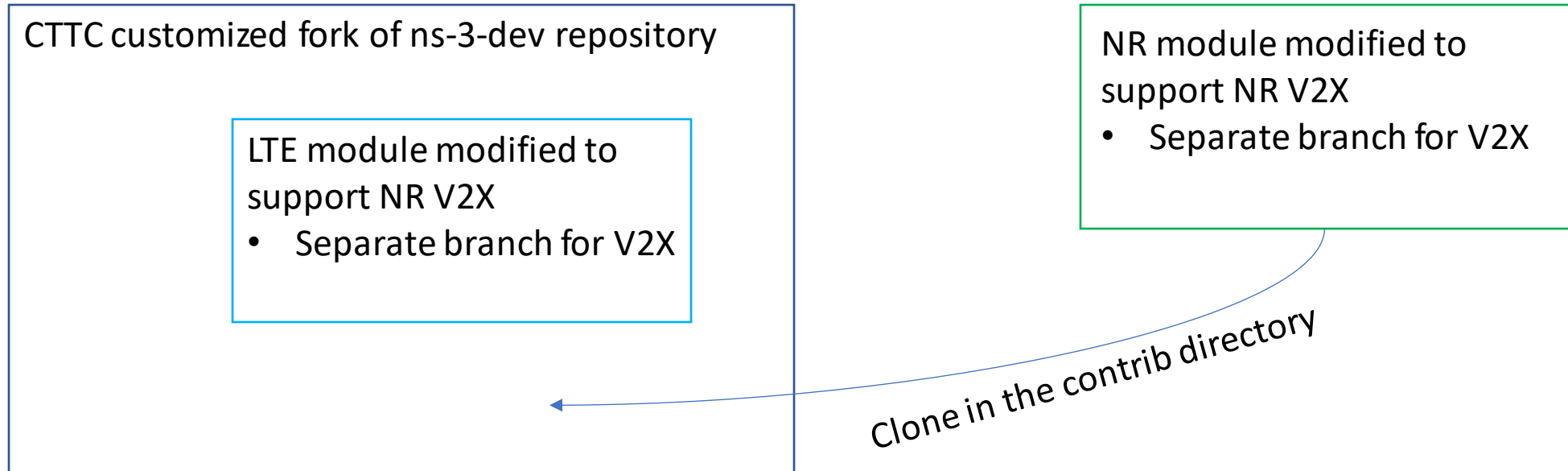
- After using the resource for the number of transmissions equal to the Sidelink Resource Reselection Counter (SLRRC), the UE either keeps the previous selection or selects new resources based on the pre-configured probability value, called, “probability of resource keep”.
- The value of SLRRC is randomly selected from the interval [5, 15] for  $P_{\text{rsvp}} \geq 100$  ms.
- For  $P_{\text{rsvp}} < 100$  ms, the value of SLRRC is randomly selected from the interval:

$$\left[ 5 \times \frac{100}{\max(20, P_{\text{rsvp}})}, 15 \times \frac{100}{\max(20, P_{\text{rsvp}})} \right]$$

- The maximum number of times that the same resource can be used for SPS is defined by:
  - $\text{Cresel} = 10 \times \text{SLRRC}$
  - After which the resource reselection has to be triggered, independently of the probability of resource keep.

Code reference: [SLRRC and Cresel assignment](#), [NrUeMac::GetRndmReselectionCounter](#)

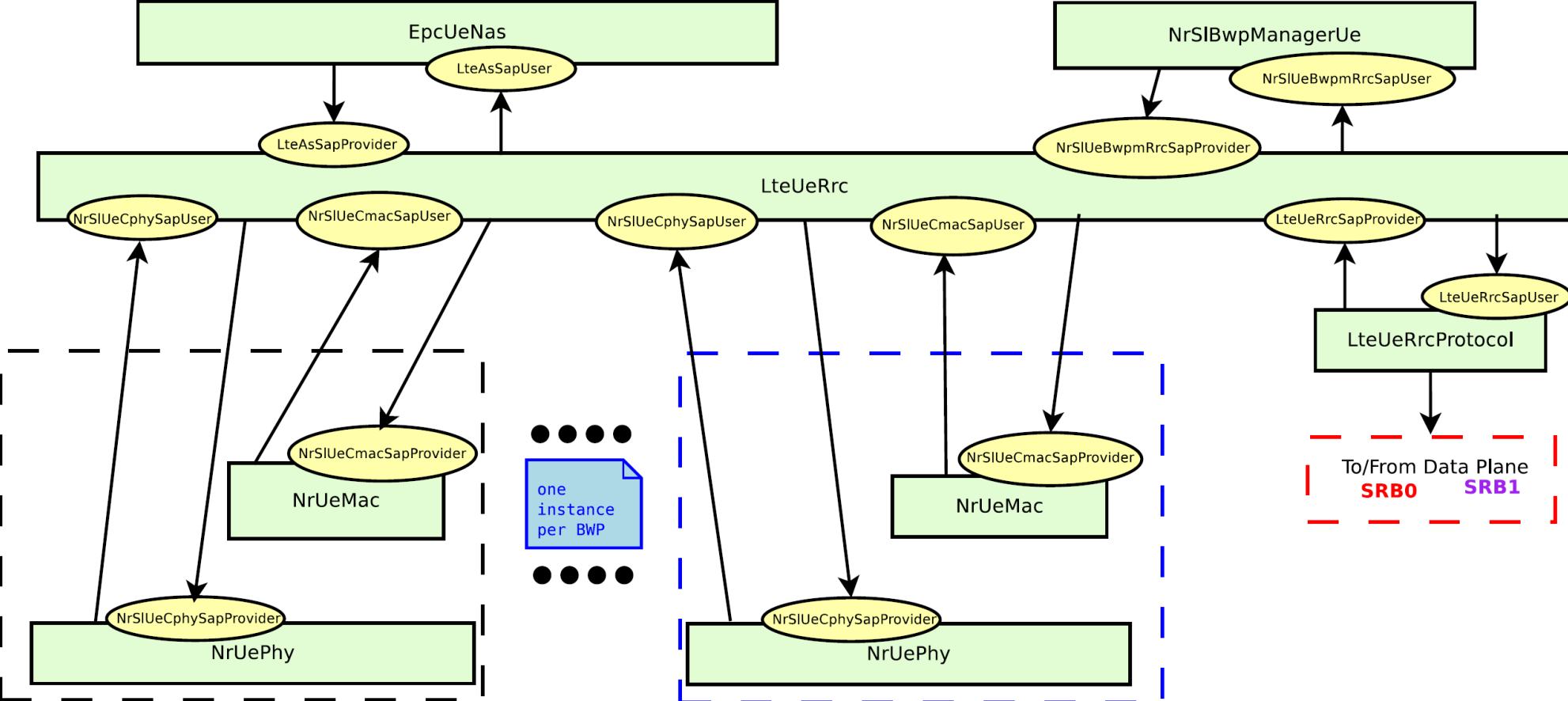
# KEY ASPECTS OF NS-3 NR V2X MODEL DESIGN: REPOSITORY STRUCTURE



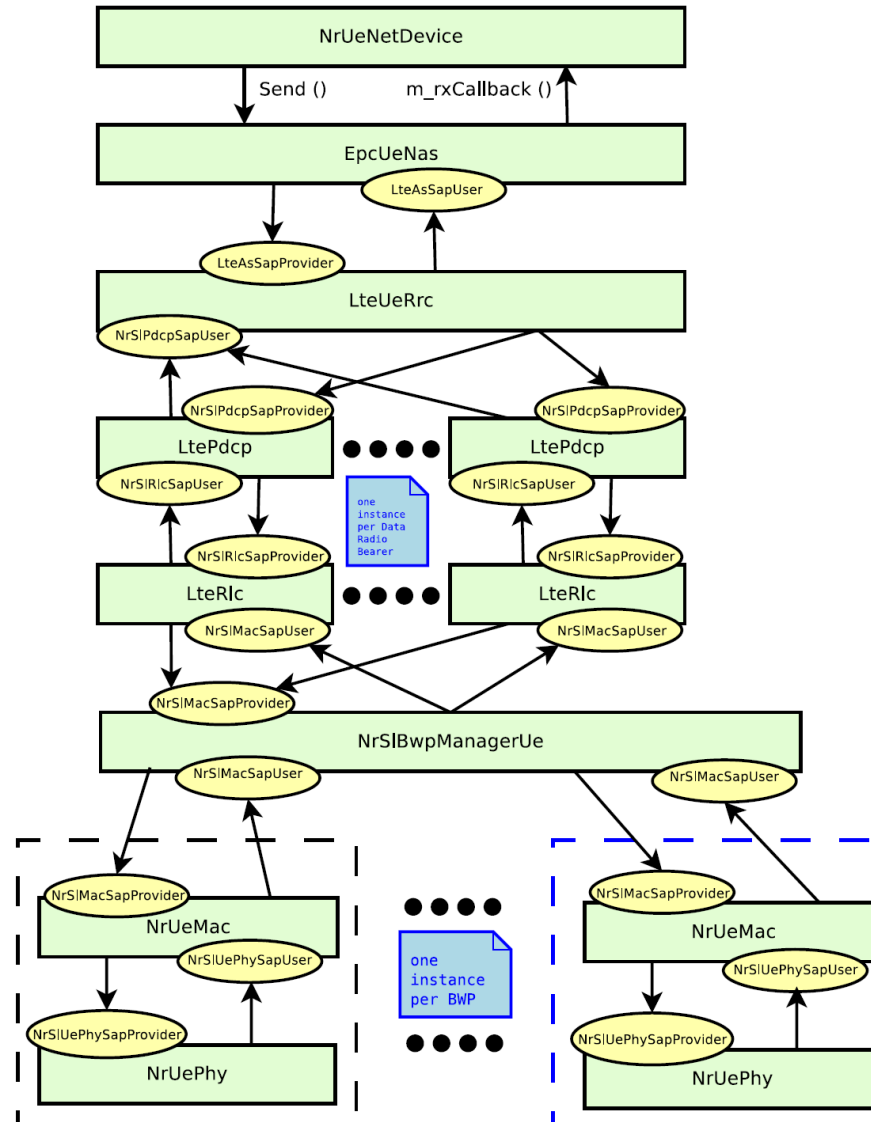
- Repositories and the development branches for NR V2X:
  - [CTTC customized fork of ns-3](#)
  - [NR module](#)



# KEY ASPECTS OF NS-3 NR V2X MODEL DESIGN: UE CONTROL PLANE ENHANCEMENTS



# KEY ASPECTS OF NS-3 NR V2X MODEL DESIGN: UE DATA PLANE ENHANCEMENTS



# KEY ASPECTS OF NS-3 NR V2X MODEL DESIGN: SIDELINK HELPER CLASS

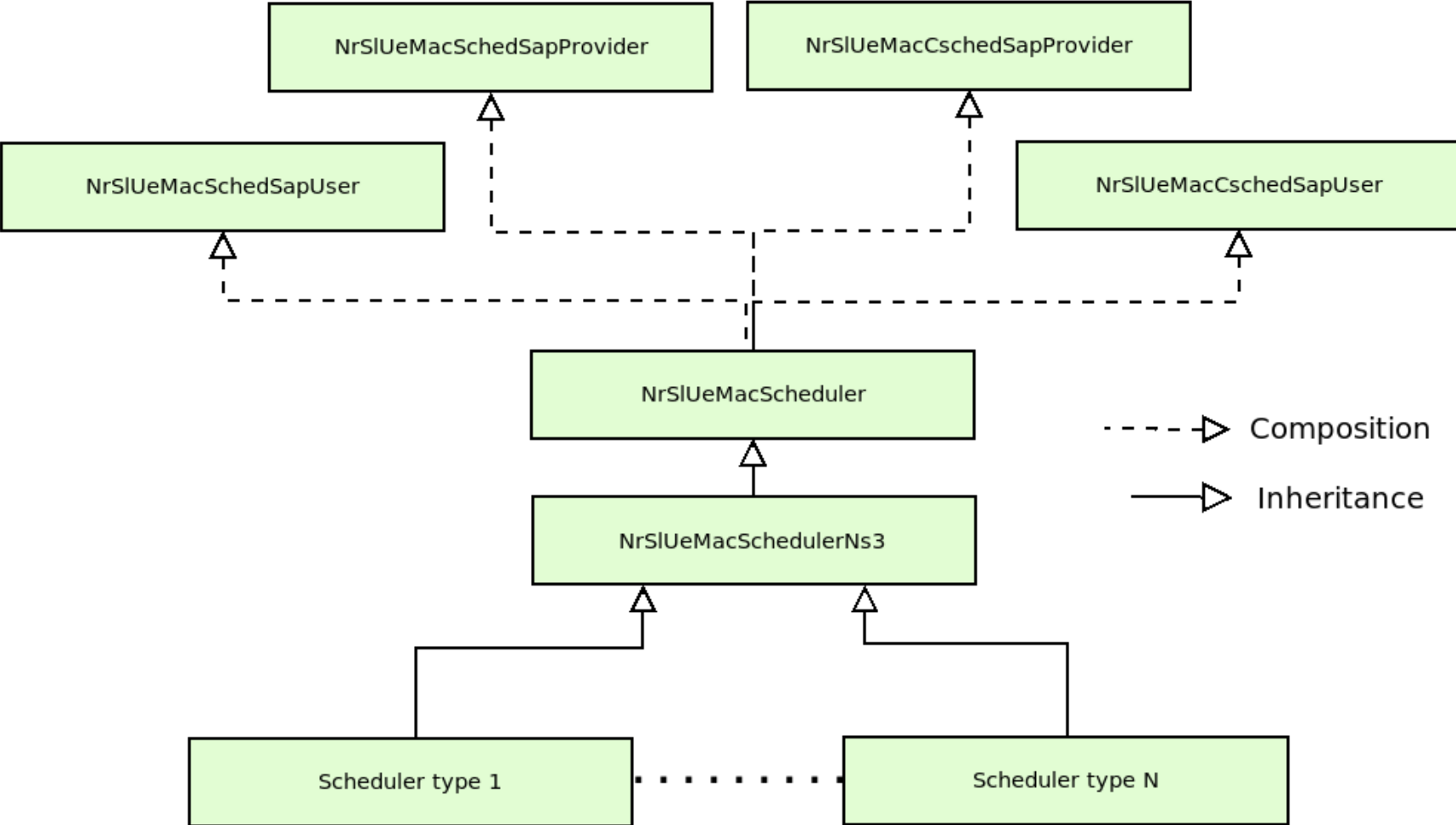
---

- *NrSIHelper* class is responsible to glue everything. For example,
  - To configure all the SAPs
  - To configure the error model
  - To configure sidelink UE scheduler
  - To install sidelink preconfiguration in UE RRC
  - To configure sidelink physical layer parameters, e.g., sidelink BWP id, numerology, symbols per slot, BW, and TDD pattern.

# KEY ASPECTS OF NS-3 NR V2X MODEL DESIGN: SIDELINK UE MAC SCHEDULER INTERFACE

- The NR module MAC scheduler API design is different from the LTE module.
- For the sake of consistency, NR sidelink UE MAC scheduler API should follow the NR module MAC scheduler API design.
  - New classes:
    - SAP interfaces following FemtoForum/Small Cell Forum API
      - NrSIUeMacCschedSapProvider
      - NrSIUeMacCschedSapUser[ primitives, which deal with scheduler configuration
    - NrSIUeMacSchedSapProvider
    - NrSIUeMacSchedSapUser[ primitives, which deal with the execution of the scheduler
  - **NrSIUeMacScheduler**: A pure interface for all the schedulers
  - **NrSIUeMacSchedulerNs3**: An interface, which implements all the SAP methods and introduces some pure virtual methods, which must be implemented by the child classes, e.g., a method for allocating Sidelink resources for active destinations.

# KEY ASPECTS OF NS-3 NR V2X MODEL DESIGN: SIDELINK UE MAC SCHEDULER INTERFACE





---

## **PART II: THE PRACTICAL PART**

# A WALK THROUGH THE NS-3 NR-V2X EXAMPLES

NS-3 V2X model supports the extraction of 3GPP standardised range-based KPIs:

- PIR (Packet Inter-reception Delay)
  - Interval of time elapsed between two successful packet receptions of packets transmitted by a specific neighbouring UE.
- PRR (Packet Reception Ratio)
  - For each packet transmitted by a UE, a ratio of the number of neighboring UEs that successfully receive that packet over the total number of neighboring UEs.
- All the KPIs are dumped in a Sqlite database.
  - <https://sqlitebrowser.org/>

Code reference:

- [V2xKpi::ComputeAvrgPir](#)
- [V2xKpi::ComputeAvrgPrr](#)

# A WALK THROUGH THE NS-3 NR-V2X EXAMPLES

---

Two example scripts to simulate out-of-coverage communication were developed.

- [cttc-nr-v2x-demo-simple.cc](http://cttc-nr-v2x-demo-simple.cc)
  - This example simulates a simple topology consisting of 2 static UEs, where UE-1 transmits, and UE-2 receives.
    - A good example to check PIR computation.
- [nr-v2x-west-to-east-highway.cc](http://nr-v2x-west-to-east-highway.cc)
  - This example simulates a configurable highway topology on which there could be an only odd number of type 2 vehicular UEs (see TR 37.885 sec 6.1.2) per lane, which travel from west to east.
  - It allows two configurations:
    - All the vehicular UEs transmit and receive during a simulation.
    - A middle vehicular UE per lane is the transmitter and the rest of the vehicular UEs are the receivers (default).



# A WALK THROUGH THE NS-3 NR-V2X EXAMPLES

Following are some commands to get familiar with [nr-v2x-west-to-east-highway.cc](https://github.com/ericniebler/ns-3-nr-v2x-examples) example.

- `./waf --run "nr-v2x-west-to-east-highway --help"`
- `./waf --run "nr-v2x-west-to-east-highway --generateGifGnuScript=1"`
  - `gnuplot -p gif-script-mobility-default-nr-v2x-west-to-east-highway.txt`
- `./waf --run "nr-v2x-west-to-east-highway --simTag=sensing --enableSensing=1 --RngRun=1"`
- `./waf --run "nr-v2x-west-to-east-highway --simTag=sensing --enableSensing=1 --RngRun=2"`



# POTENTIAL CONTRIBUTIONS/EXTENSIONS

---

- Mode 1 (gNB-scheduled resource allocation) for in-coverage scenario
- Unicast and groupcast communications
- Error model for sidelink
- HARQ feedback, PSFCH and HARQ-feedback-based retransmissions
- Synchronization and discovery procedures

# HOW TO CONTRIBUTE?

- Merge requests to the NR repo are allowed since June 2022: <https://gitlab.com/cttc-lena/nr>
- In the NR repo, we have created a development branch for the NR V2X:
  - <https://gitlab.com/cttc-lena/nr/-/tree/nr-v2x-dev>
- How to contribute?
  - Contributing process is basically the same as for the ns-3 simulator
  - Basic steps:
    - Create your own fork of the public nr repository: <https://gitlab.com/cttc-lena/nr>
    - Create a feature branch on your forked NR repo based on the **nr-v2x-dev**
    - Once the pipelines pass, and you consider that your feature branch is clean and ready for review create a MR towards **nr-v2x-dev** branch
- Currently, the NR V2X code uses the customized ns-3-dev: <https://gitlab.com/cttc-lena/ns-3-dev/-/tree/v2x-lte-dev>
- The ideal roadmap for the N2 V2X code if there are contributors/fundings would be:
  1. The official NR module to include its own RLC, PDCCP, and RRC implementations
  2. Move NR V2X changes from customized ns-3-dev to the NR module (RLC,PDCCP, RRC)
  3. NR-V2X module becomes a part of the official NR module in one of two ways:
    - NR-V2X branch gets merged into the NR master
    - NR-V2X refactored to be a sub-module of NR, e.g., such as the NR-U module
  4. At this point NR-V2X is compatible with the latest ns-3 release and the latest NR.