5G NR Sidelink, ProSe, and Public Safety Communications models

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Disclaimer

Certain software is identified in this presentation in order to visualize simulation outputs adequately. Such identification is not intended to imply recommendation or endorsement of any product or service by National Institute of Standards and Technology (NIST), nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

Acknowledgments

- This talk updates last year's tutorial on 5G New Radio (NR) Sidelink (SL), which derived from an earlier NR-V2X tutorial by **Zoraze Ali** (formerly of CTTC)
  - **Zoraze Ali** is the author of the initial ns-3 NR V2X/SL models

- Some of this work was performed at **University of Washington** and funded by NIST, led by **Richard Rouil** and **Wesley Garey**

- **Samantha Gamboa** and **Aziza Ben-Mosbah** developed the ns-3 ProSe models and contributed many of these slides
  - Samantha Gamboa authored slides 5-17, 21-22
  - Aziza Ben-Mosbah authored slides 18-20

- **Wesley Garey** is primarily responsible for the ns-3 MCPTT models

- Several NIST authors developed the public safety communications models

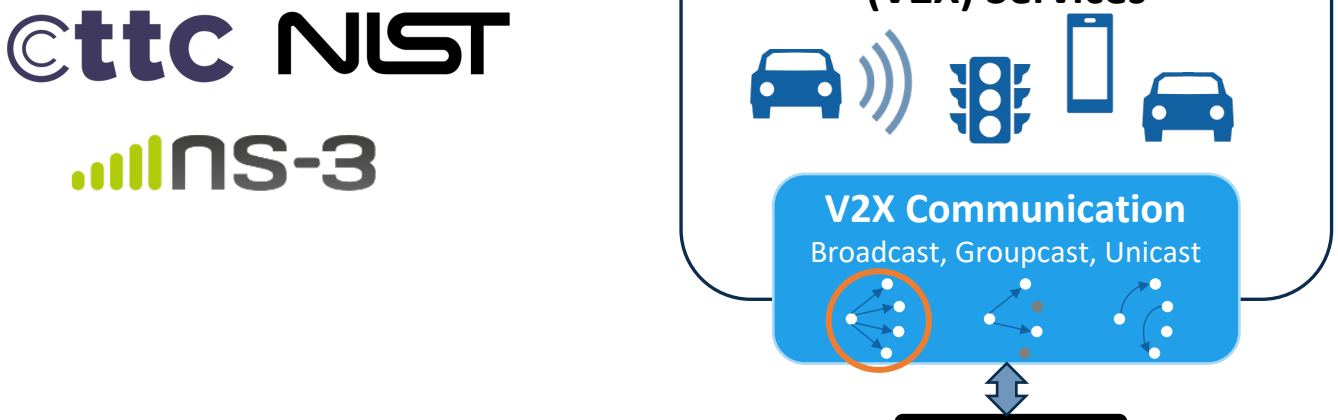
Outline

- Context and motivation
  - The baseline ns-3 NR SL model
  - Proximity Services (ProSe) and Public Safety applications
- Public safety use case: Mission Critical Push-to-Talk (MCPTT)
  - Overview
  - MCPTT over SL simulation needs
- Evolution of the ns-3 NR SL model
  - Overview
  - New functionalities
- ProSe models

Sidelink (SL)

- Cellular network functionality
- Enables a direct data link between UEs
- Specified to work:
  - In-coverage (with or without network control), or
  - Out-of-coverage (based on pre-configuration)
- Introduced in 3GPP cellular networks:
  - LTE in Release 12 (2014)
  - NR in Release 16 (2020)

The baseline ns-3 NR SL model



3GPP: Third Generation Partnership Project
Rel: Release
UE: User Equipment
PDU: Protocol Data Unit

Legend:
Baseline implementation

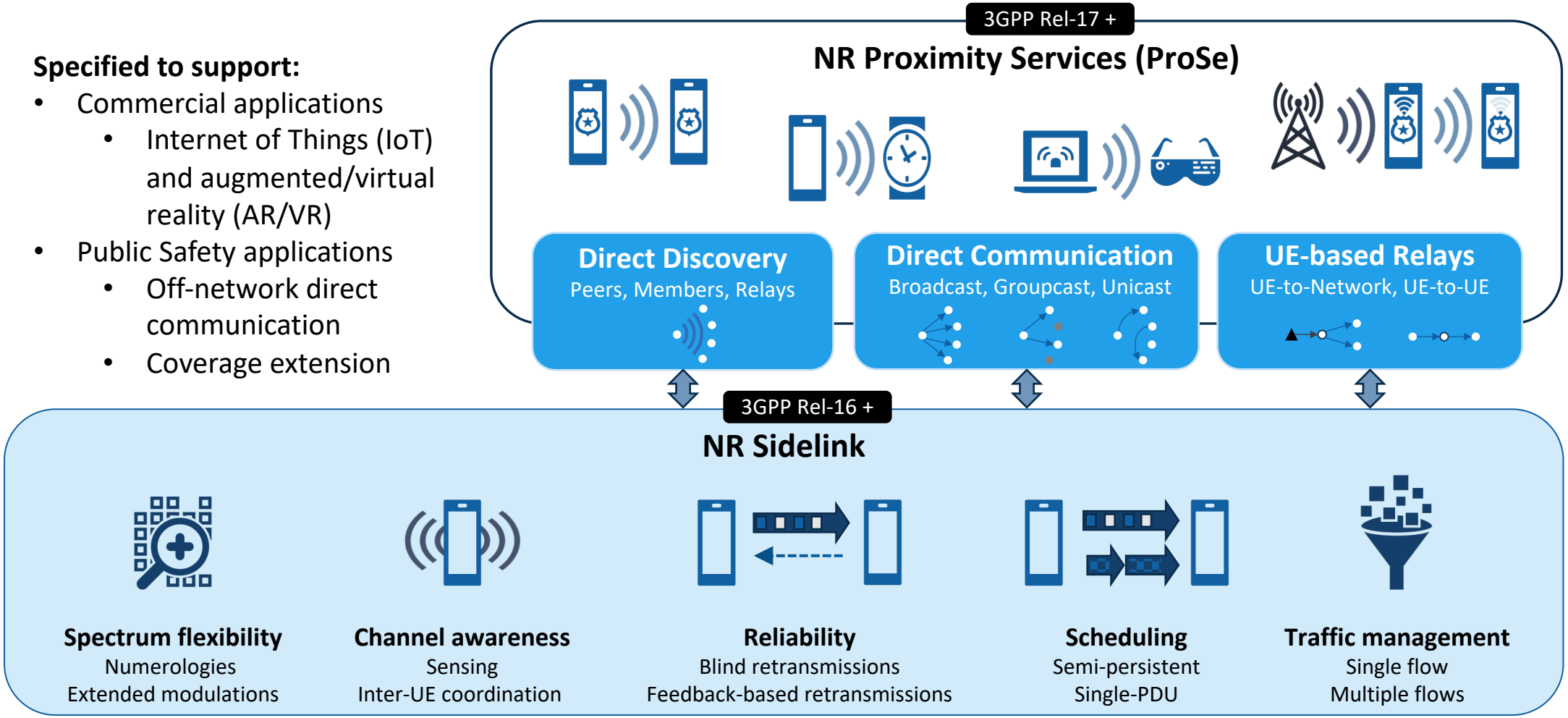
Baseline repository: https://5g-lena.cttc.es/download/

Reference article: Z. Ali, S. Lagén, L. Giupponi and R. Rouil, "3GPP NR V2X Mode 2: Overview, Models and System-Level Evaluation," in IEEE Access, vol. 9, 2021

Proximity services

Specified to support:

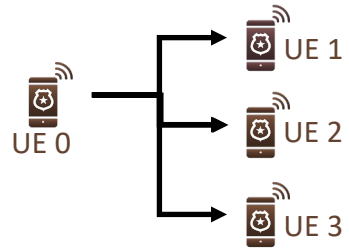
- Commercial applications
  - Internet of Things (IoT) and augmented/virtual reality (AR/VR)
- Public Safety applications
  - Off-network direct communication
  - Coverage extension



Can the baseline ns-3 NR SL model support the accurate simulation of public safety ProSe applications?

Mission Critical Push-to-Talk (MCPTT)

- Principle
  - Walkie-Talkie type of communication over cellular networks
- Different types of communication
  - Group call
  - Private calls



In this basic scenario, User Equpment (UE) 0
will use MCPTT to send a talk Spurt to UEs 1-3. This is an "on-network" group of UEs.

Mission Critical Push-to-Talk (MCPTT)

- Principle
  - Walkie-Talkie type of communication over cellular networks
- Different types of communication
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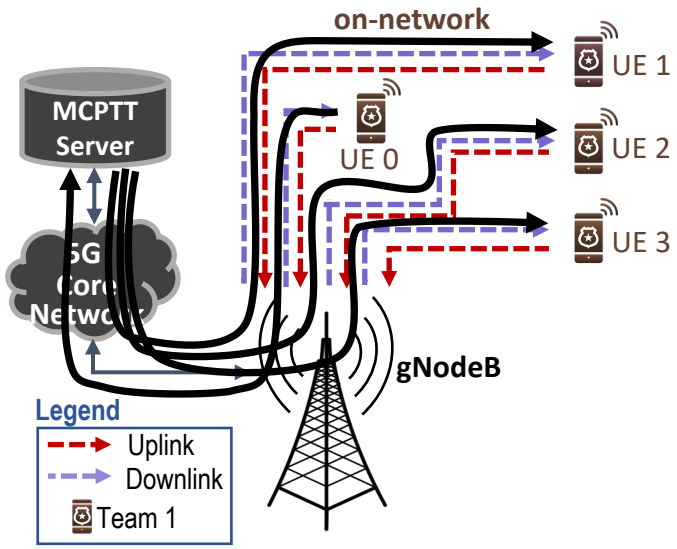
  - Private calls
- Three modes of operation
  - On-network MCPTT
    - Centralized control over network infrastructure



All UEs are connected to the network, so all flows are relayed by an MCPTT Server in the core (i.e., there is not direct UE-to-UE communication)

Mission Critical Push-to-Talk (MCPTT)

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- Three modes of operation
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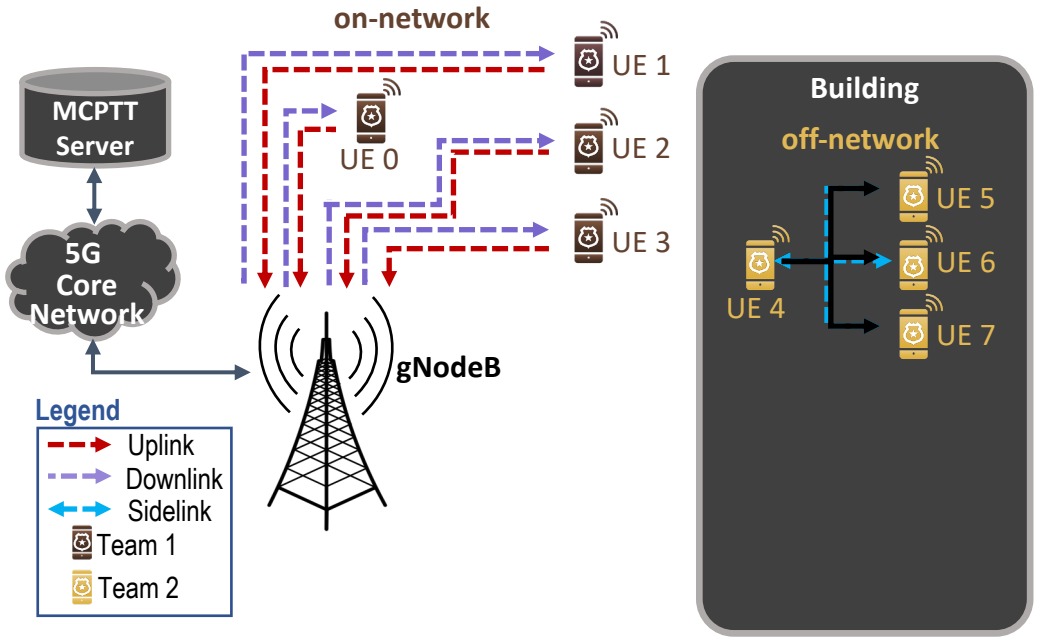
    - Centralized control over network infrastructure
  - Off-network MCPTT
    - Distributed control over SL



This scenario also shows that some groups of UEs may be out of network coverage, such as within a building. These UEs will use sidelink mode 2.

Mission Critical Push-to-Talk (MCPTT)

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  - Private calls
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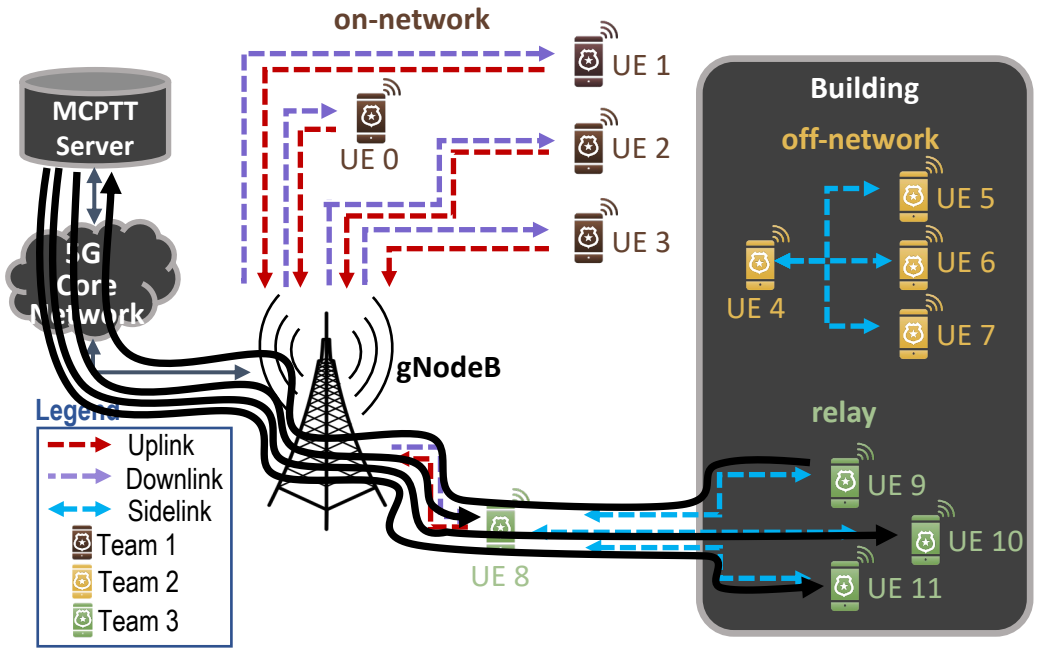
  - On-network MCPTT
    - Centralized control over network infrastructure
  - Off-network MCPTT
    - Distributed control over SL
  - On-network MCPTT over UE-to-Network relay
    - Centralized control over network infrastructure and SL



Finally, consider a third group of UEs participating in a call. One of the UEs can serve as a UE-to-Network Relay for the other three within the building. All flows are relayed through the MCPTT Server.

Mission Critical Push-to-Talk (MCPTT)

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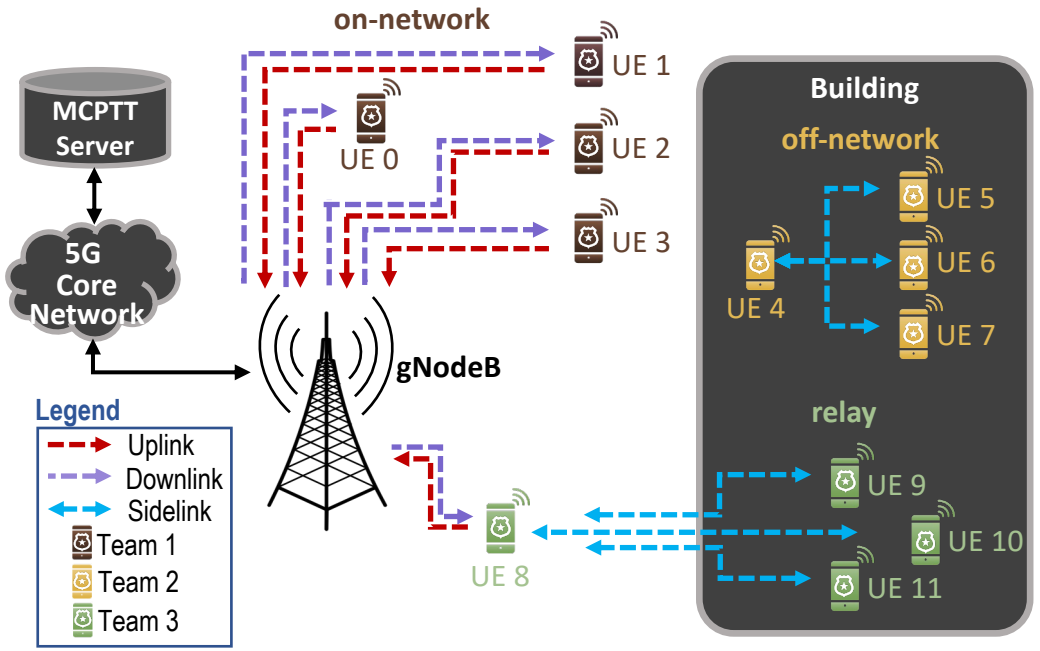
  - Off-network MCPTT
    - Distributed control over SL
  - On-network MCPTT over UE-to-Network relay
    - Centralized control over network infrastructure and SL
- MCPTT ns-3 model is publicly available
  - 3GPP compliant application implementation
  - User behavior model based on real-life application traces



Available in ns-3 app store: https://apps.nsnam.org/app/tag/publicsafety/
Hosted in NIST GitHub: https://github.com/usnistgov/psc-ns3

MCPTT over SL simulation needs

- For a single application we have mixed traffic
  - Signaling and media (voice)

→ Simulator needs to support multiple traffic flows with different patterns and quality-of-service (QoS) characteristics

- Media traffic is audio codec dependent and periodic within talk spurts
  - Codec dictates packet size, packet inter-arrival time, etc. Either a fixed or adaptive Codec could be modeled.

→ Can be supported with semi-persistent scheduling (SPS) already available in the baseline simulator

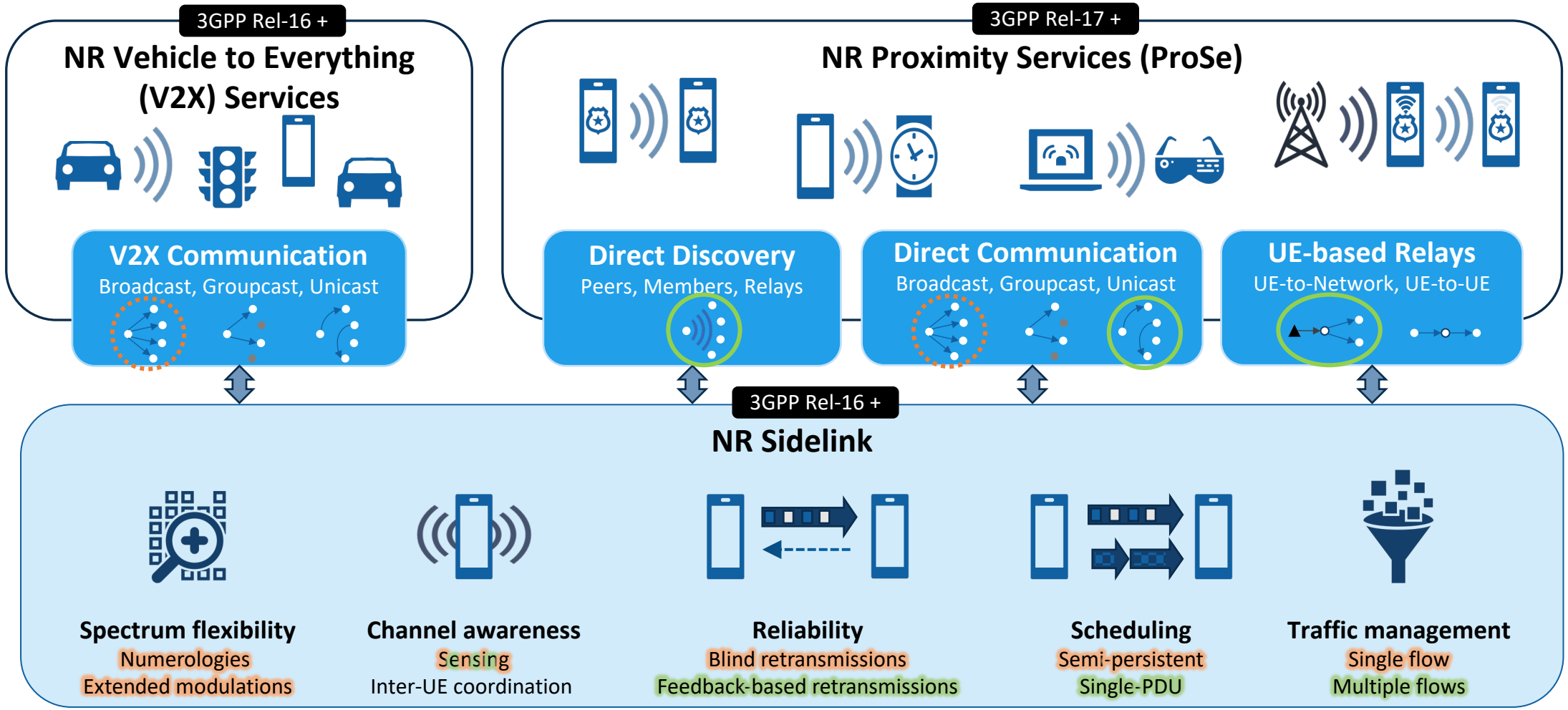
- Signaling traffic is aperiodic
  - Timing, packet size, etc. depends on user input and call conditions. Our ns-3 model uses a stochastic talk spurt generator with probabilities distilled from traces.

→ Simulator needs dynamic single-PDU scheduling

- Asymmetrical SL usage when using User-to-Network (U2N) relay
  - The relay UE SL usage in this scenario is high (serving three UEs) and it is further increased when using retransmissions for reliability

→ Simulator fidelity requires feedback-based retransmissions

Evolution of the ns-3 NR SL model



Legend:
Baseline implementation
Our extensions

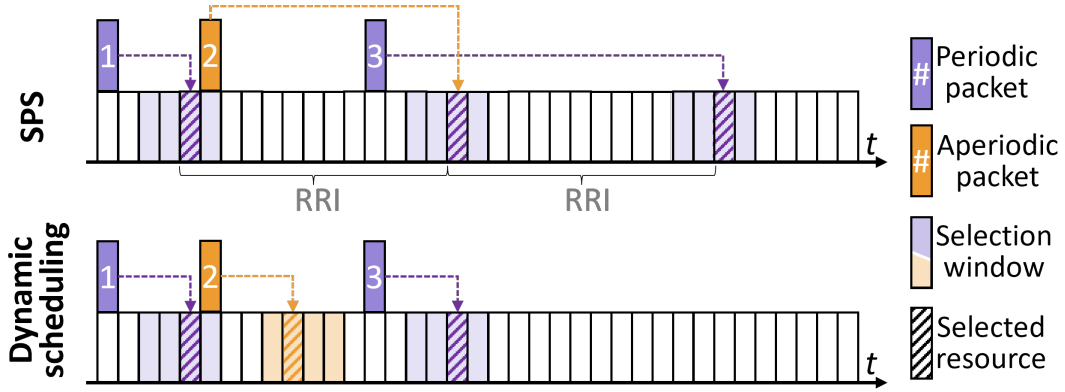
Code snapshot for this paper: https://github.com/usnistgov/psc-ns3/tree/wfpst-2024-nr-sl-mcptt
In progress:
- Integration of new NR SL capabilities to the baseline implementation
- Preparation of the release of the ProSe module

New functionalities: Support for mixed traffic

- The baseline ns-3 NR SL module supported broadcast type of transmissions with all traffic going to the same destination ID
  - Lower layers supported the scheduling of only one logical channel towards a given destination ID
- We extended the model to support the **transmission to multiple destinations and multiple logical channels** per destination
  - The objective was to support unicast type of communication (and relay) as well as applications with multiple traffic flows requiring different scheduling characteristics (such as MCPTT)
  - Implied a general refactoring of the MAC layer and SL scheduler
- We enabled the **mapping between applications traffic flows and logical channels** in the scenario
  - Allows to configure the logical channel scheduling characteristics adapted to the traffic it will carry
- We implemented a streamlined version of the standard **logical channel prioritization procedure**
  - Logical channels with data to transmit are selected for allocation based on priority and type of scheduling
  - Random selection is used in case of ties

New functionalities: Single-PDU dynamic scheduler

- Semi-persistent scheduling is not designed to efficiently handle **aperiodic traffic**



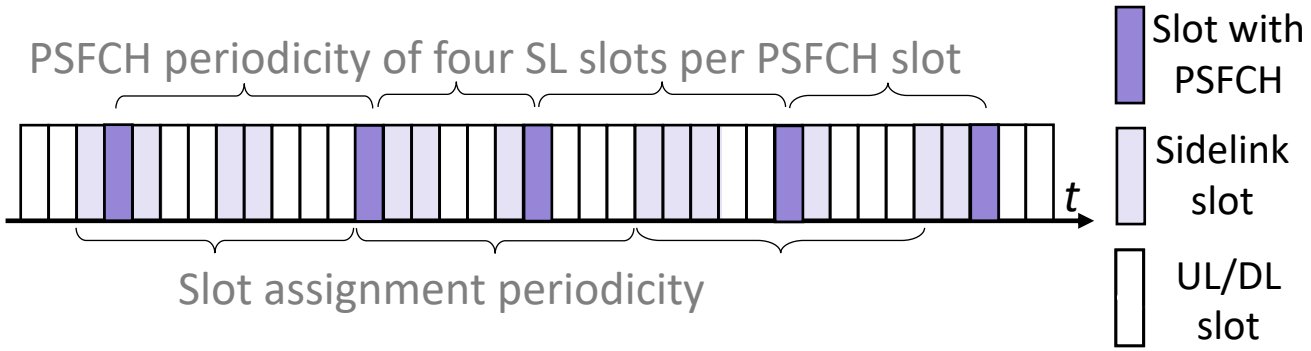
RRI: Resource Reservation Interval

- We added **single-PDU dynamic scheduling policy** to the SL scheduler in the baseline ns-3 NR SL module
  - Resource selection and grant allocation is triggered each time the logical channel is selected for scheduling
  - Dynamic grants consist of the resources allocated to serve one PDU and it associated retransmissions
  - Hybrid Automatic Repeat Request (HARQ) sidelink processes are assigned in a per-grant basis

- **Logical channel prioritization** procedure was extended to consider the **type of scheduling**
  - Configurable attribute used to break ties if multiple logical channels with different scheduling policies are competing

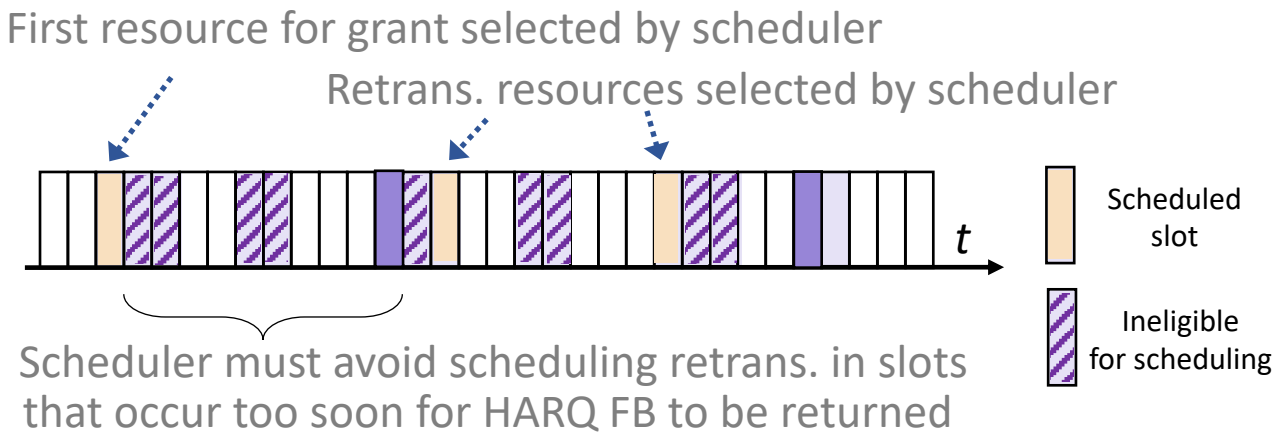
New functionalities: Feedback-based HARQ (1/2)

- Combines **forward error correction (FEC) coding** with **retransmissions** managed by the scheduler and MAC layer
- We added **feedback-based HARQ** to the existing forward error correction (**FEC) coding model** and **blind retransmission** strategy implemented in the baseline ns-3 NR SL module
  - Addition of a (perfect) **Physical Sidelink Feedback Channel (PSFCH)** with configurable periodicity
  - Support for **positive feedback acknowledgment** to cancel future TB retransmissions
  - **Physical Sidelink Shared Channel (PSSCH) to HARQ feedback timing support**, based on *MinTimeGapPsfch* parameter and PSFCH periodicity



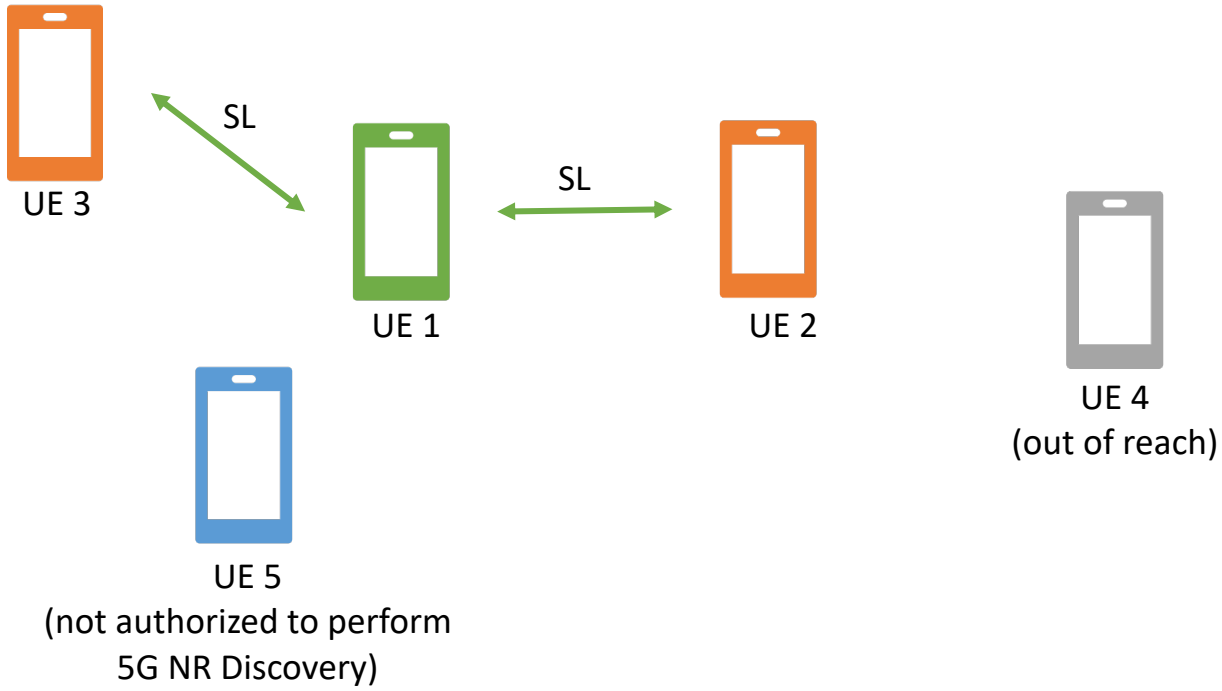
New functionalities: Feedback-based HARQ (2/2)

- New fixed modulation and coding scheme (MCS) scheduler is constrained to separate retransmission resources by a **minimum time gap** that allows for processing



- Positive acknowledgment by at least one recipient will **cancel future retransmissions** of the current transport block (but will not reclaim the resource for scheduling)
- PSFCH channels are configured on a **per-resource-pool basis**
  - If PSFCH is absent, retransmissions will be blind
- Retransmissions are configured on a **per-logical-channel basis**

NR ProSe direct discovery: Overview



- 5G ProSe direct discovery allows 5G ProSe-enabled UEs discover other 5G ProSe-enabled UEs within their reach using direct NR radio transmissions. It can be performed independently from 5G ProSe Direct Communication or can be used to initiate one-to-one unicast communication.
- Direct discovery can be either open or restricted depending on whether an explicit permission from the 5G ProSe-enabled UE being discovered is needed.

NR ProSe direct discovery: Models

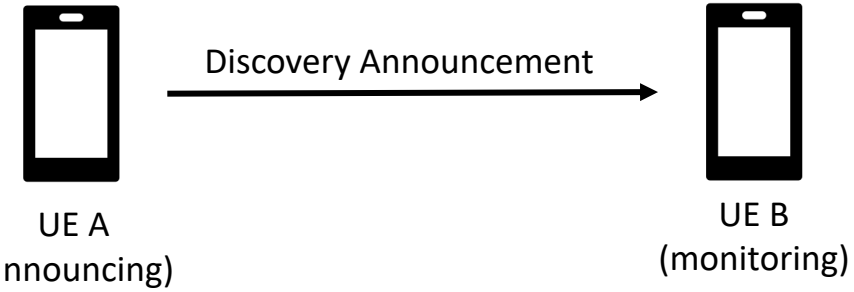
Model A

Model A is a discovery announcement using a **broadcast of a single discovery message** and can be either **open or restricted**.

The UE sending the ProSe PC5 discovery message is called the "**announcing** UE" and the "**monitoring** UE" is the UE that triggers the lower layer to start listening for such message.

ProSe: Proximity Services

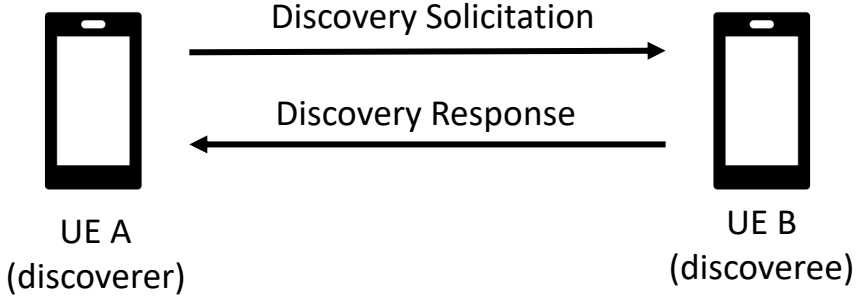
PC5: a reference to the UE-to-UE logical interface point



Model B

Model B employs a set of discovery messages based on a **Request/Response exchange** and can only be **restricted**.

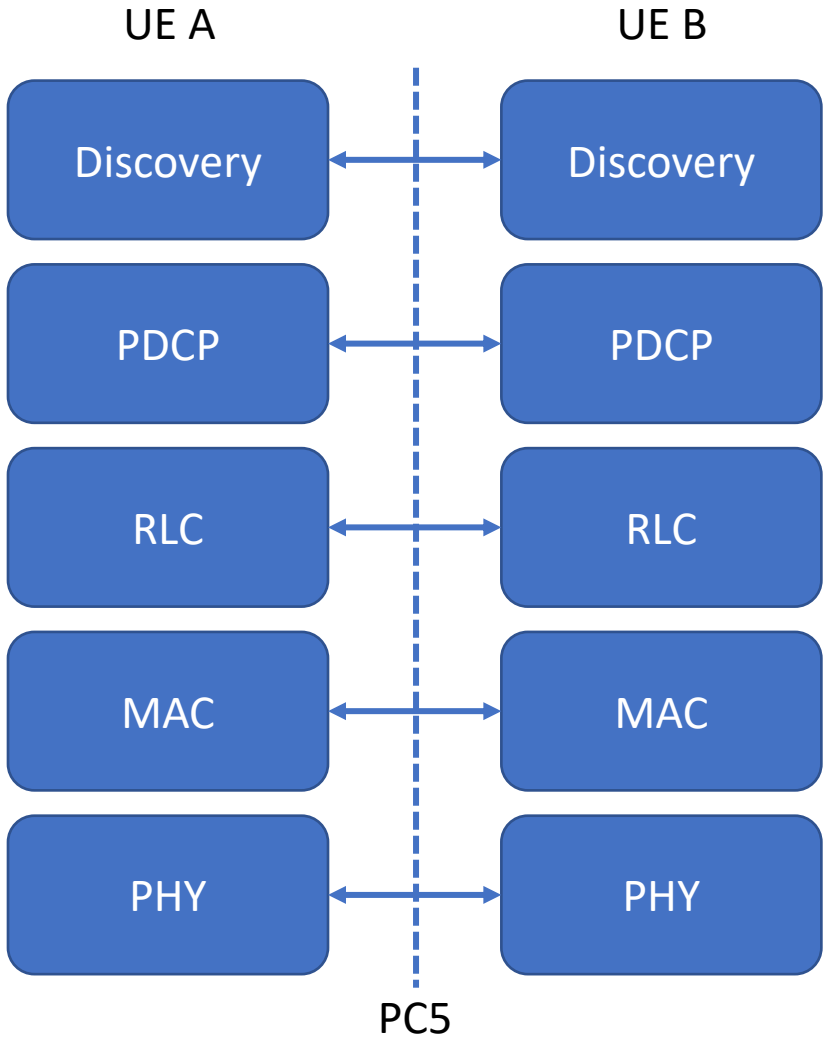
The UE sending the first discovery message is called the "**Discoverer** UE" and the UE receiving and responding to this message is called the "**Discoveree** UE".



NR ProSe direct discovery: PC5 Procedures

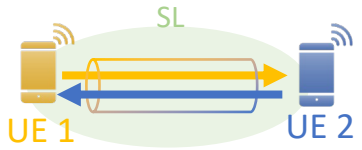
PC5 discovery supports the initiation and completion of the following PC5 procedures for both models A and B:

- **Direct or peer discovery** (for open and restricted modes)
  - to enable a ProSe-enabled UE to detect and identify another ProSe-enabled UE over PC5 interface.
- **Group member discovery** (only available for restricted mode) both public safety use and commercial services
  - to enable a ProSe-enabled UE to detect and identify another ProSe-enabled UE that belongs to the same application layer group (e.g. sharing the same application layer group ID) over PC5 interface.
- **UE-to-Network relay discovery** (only available for restricted mode)
  - to enable a ProSe-enabled UE to detect and identify another ProSe-enabled UE over PC5 interface for UE-to-Network relay communication between a UE and 5G Core (5GC).

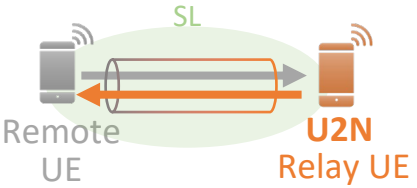


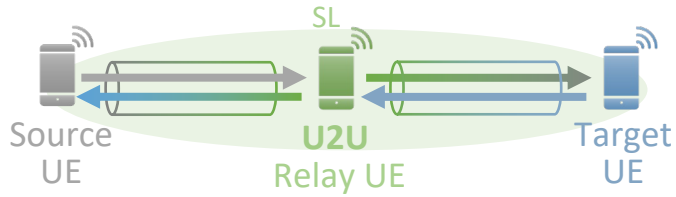
NR ProSe unicast communication - Overview

- Desired configurations
  - Manual unicast link association from scenario (pre-simulation)
    - Enables the evaluation of unicast communication protocols
      - Scheduling, HARQ, power control
      - Link control (PC5-S, PC5-RRC, RLF)



  - Dynamic unicast link association during simulation
    - Enables the use of unicast communication in other functionalities
      - E.g., U2N relay, U2U relay
        - Link establishment after relay discovery and selection

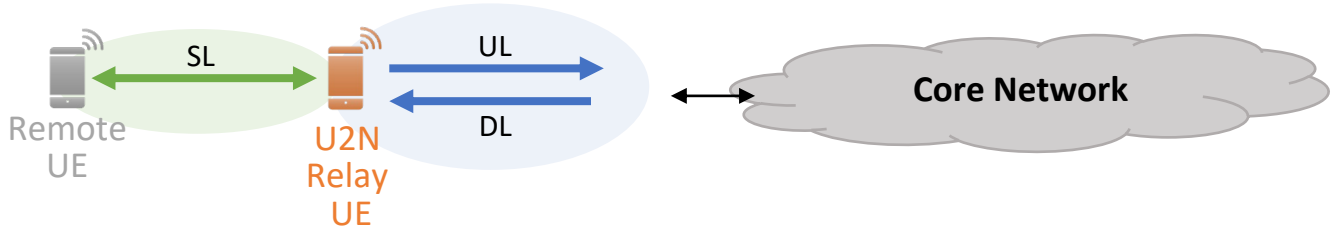


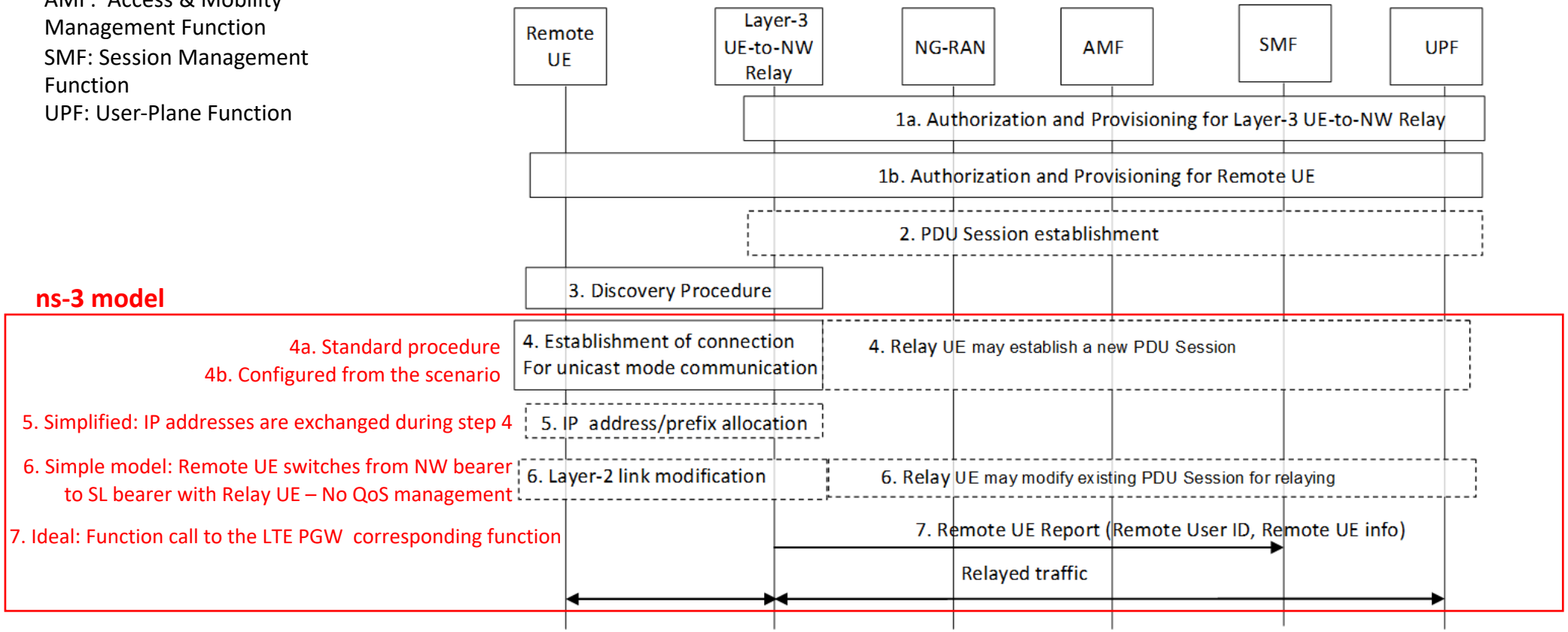


RRC: Radio Resource Control
RLF: Radio Link Failure
U2U: UE-to-UE

NR ProSe L3 UE-to-Network relay - Overview

UL: Uplink
DL: Downlink
NG-RAN: Next-Generation Radio Access Network
AMF: Access & Mobility Management Function
SMF: Session Management Function
UPF: User-Plane Function





ns-3 model

4a. Standard procedure
4b. Configured from the scenario

5. Simplified: IP addresses are exchanged during step 4

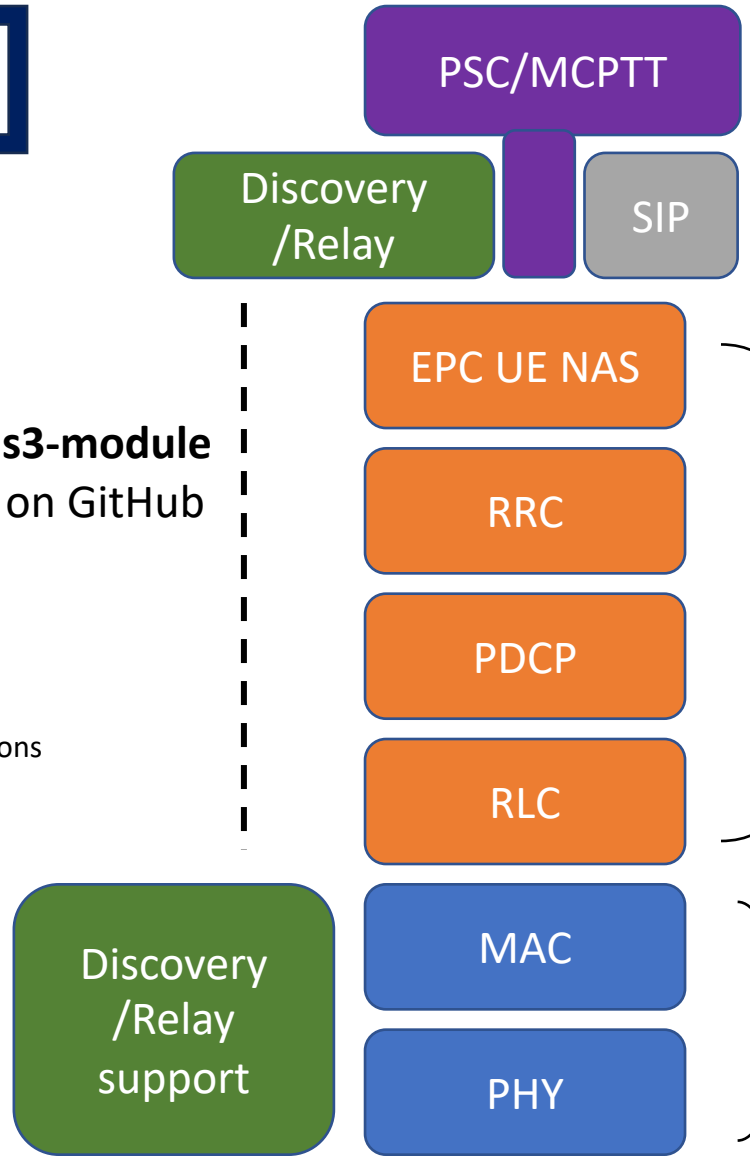
6. Simple model: Remote UE switches from NW bearer to SL bearer with Relay UE – No QoS management

7. Ideal: Function call to the LTE PGW corresponding function

TS 23.304 **Figure 6.5.1.1-1: 5G ProSe Communication via 5G ProSe Layer-3 UE-to-Network Relay without N3IWF**

Current software organization

All components are **ns-3.42** compatible



New NIST **psc-ns3-module** repository on GitHub

New **sip** module at GitLab.com (tomhend/modules)

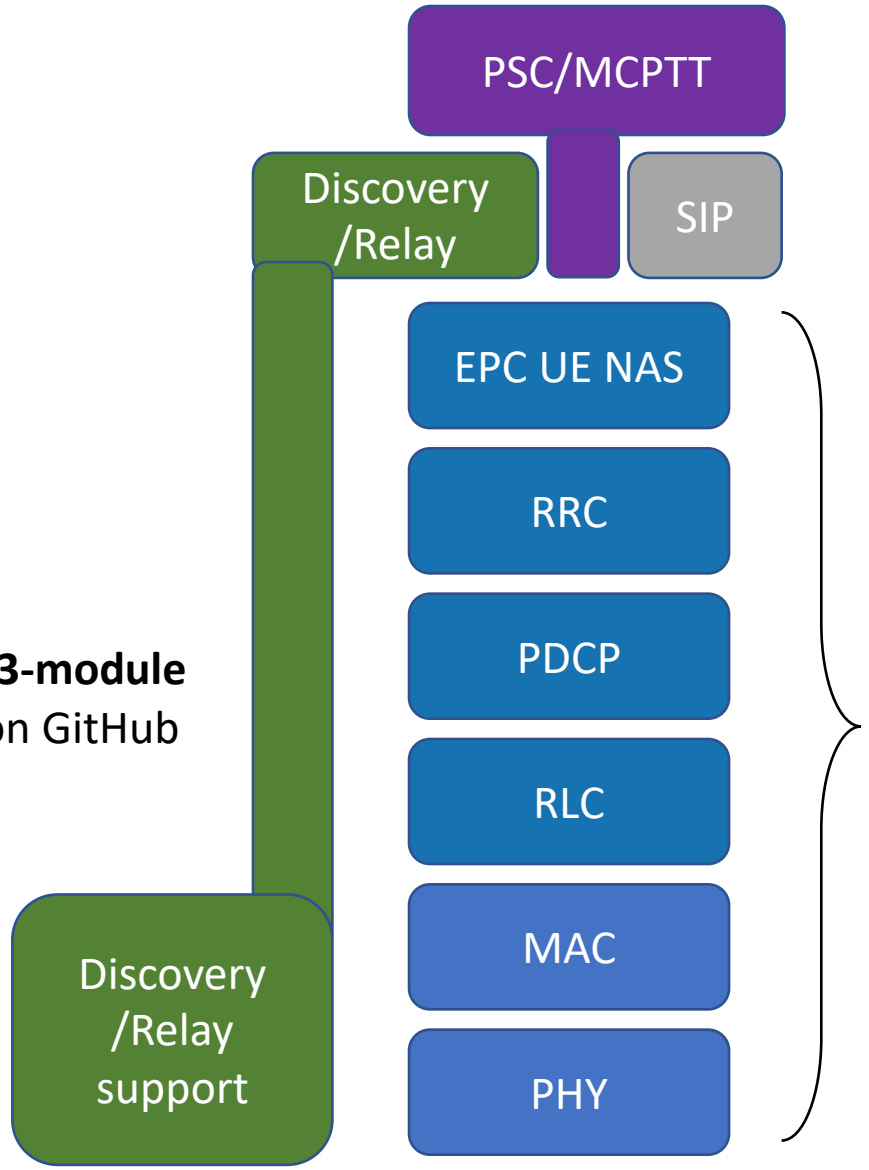
New NIST **nr-prose-ns3-module** repository on GitHub

NIST **v2x-lte-dev-prose branch** extending CTTC NR V2X 1.0 v2x-lte-dev (fork of ns-3) with some ProSe extensions, on NIST GitHub (usnistgov/psc-ns3)

CTTC **nr, branch nr-v2x-dev** (NR V2X 1.0 release)

PSC: Public Safety Communications
SIP: Session Initiation Protocol
EPC: Evolved Packet Core
NAS: Non-access Stratum
PDCP: Packet Data Convergence Protocol
RLC: Radio Link Control
MAC: Medium Access Control
PHY: Physical Layer

Future planned software organization



NIST **psc-ns3-module** repository hosted on GitHub

sip module at GitLab.com (tomhend/modules)

NIST
nr-prose-ns3-module
repository on GitHub

CTTC **nr** repository on GitLab
after the following two steps are made:

1) Decouple nr from lte module
2) Merge NR V2X branch to nr master branch

Summary and next steps

- We extended the ns-3 NR SL model to enable more accurate system-level simulations of PS applications
  - Enabled multiple traffic flow simulation per UE to cover applications with mixed traffic
  - Introduced the SL per-packet dynamic scheduling to efficiently handle aperiodic traffic
  - Implemented feedback-based HARQ retransmission scheme to increase simulation fidelity
  - Enhanced 3GPP standard fidelity across the model

- A recent paper illustrated the need of these enhancements in the context of the MCPTT application
  - ***Towards System Level Simulations of Public Safety Applications over 5G NR Sidelink***
    Samantha Gamboa), Thomas R Henderson, Wesley Garey, Chunmei Liu and Richard Rouil
- We are about to release a new NR-V2X version, two new ns-3 apps (nr-prose and psc), have released a SIP app, and have an extended v2x-lte-dev branch supporting the nr-prose at the higher layers
- We are following the current standardization process of the Rel-19 multi-hop UE-based relay functionalities (UE-to-Network and UE-to-UE) in 3GPP
  - The support of off-network MCPTT with extended coverage is one of the main drivers of this study item
  - Implementing these functionalities in the simulator can provide standardization support and research opportunities

Questions?

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https://www.nist.gov/ctl/wireless-networks-division/wireless-systems-innovation-and-performance-group