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A Novel Radio-Aware and Adaptive Numerology Configuration in V2X 5G NR Communications

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Abstract—As the main goal of connected autonomous vehicles' communications is to improve the traffic safety and save lives, any design of a resource allocation scheme must consider the stringent requirements of these applications in terms of latency and reliability for a dynamic environment. For this, 5G cellular networks suitably address these challenges. This paper proposes a new mechanism for the telco operator to adapt the physical (PHY) layer configuration for efficient radio resource management in 5G New Radio (NR) based system. To tackle this issue, we propose to adjust the PHY layer numerology configuration by fine-tuning it with a Radio-Aware Adaptive PHY Layer Configuration (RA-APC) algorithm in order to maximize the efficiency of radio resource management by using the Effectively Transmitted Packet (ETP) value. Extensive simulations show that our proposal RA-APC achieves strong improvements in terms of ETP, reliability and latency while considering safety and non-safety traffic scenarios.

Keywords—5G, NR-V2X, V2V, QoS, Numerology, Resource management, CQI.

I. INTRODUCTION

As Connected Autonomous Vehicles (CAV) help to improve traffic safety and save lives, efficient resource allocation management must handle the stringent requirements of CAV's communication regarding latency and reliability. 5G cellular networks can address these challenges because it enables very high throughput interconnections with low latency and high reliability, also called URLLC (Ultra-Reliable and Low Latency Communications). We focus on the URLLC service for Vehicle-to-Everything (V2X) communications. Unfortunately, in 4G LTE-V2X, numerology is static with a fixed Subcarrier Spacing (SCS) to 15 kHz, which deeply impacts the URLLC QoS. The 5G standard overcomes this limitation. In Release 15, 3GPP specified a new 5G air interface, known as New Radio (NR) which features low-latency support and spectrum flexibility with variable numerology. Many SCS are allowed (15, 30, 60, ... kHz) in aim to satisfy the QoS of flows thanks to the 5G's dynamic and scalable numerology. However, such agility requires efficient Resource Allocation (RA).

The proposal in [1] consists in allowing the telco operator to adapt the PHY layer configuration for efficient radio resource management in a 5G NR-based system. It proposed the Adaptive PHY Layer Configuration (APC) algorithm to maximize the number of packets effectively transmitted (ETP).

To extend this algorithm, we propose to adjust the PHY layer configuration by fine-tuning it using the Radio-Aware

Adaptive PHY Layer Configuration (RA-APC) algorithm, interact RA management for a dynamically environment.

The originality of our contribution is threefold: i) consider the radio channel state when searching for the best configuration, ii) study unicast communication in addition to broadcast communications, and iii) use of multiple subchannels in the same Transport Block (TB).

The simulation results showed significant improvements of the number of packets transmitted, reliability, and latency for both traffic scenarios: safety and non-safety.

This paper is organized as follows. Section II investigates the related work. Section III explains the system description and formulates the problem. Then, relying on 3GPP Release 16 (R16) NR-V2X compliant design, a robust RA scheme using a dynamic numerology is proposed in Section IV. Next, Section V presents our methodology and the obtained simulations results. Finally, Section VI concludes this paper.

II. RELATED WORK

A. 5G 3GPP NR-V2X: Communication and Protocol stack

In 3GPP R16 NR-V2X, three mode communications for SideLink (SL) are supported at the PHY layer: broadcast, unicast, and groupcast. Broadcast is only supported in LTE-V2X, while unicast and groupcast are added in NR-V2X for an extra flexibility in communication and QoS.

The 3GPP R16 5G NR-V2X is described in [2]. It defines control and user planes responsible for the transmission of user data and signaling, respectively. Three layers are defined as shown in Figure 1. When the PC5 User Plane traffic arrives from V2X application to V2X layer, each V2X packet is classified and marked. The association of PC5 traffic to QoS Flows is performed. At SDAP layer, the QoS flow is mapped to Sidelink Radio Bearer. Next, the RLC maps the Radio bearer to the Logical Channel (LC) in MAC layer. Finally, we associate this channel to TB in PHY layer. We handle both PHY and MAC layers.

B. 5G NR SL frame structure and numerology

Numerology is the value of SCS that affects the radio frame structure and varies from 0 to 4 depending on the SCS (15 KHz-240 KHz). In NR-V2X SL, four numerologies are supported: SCS 15 kHz, 30 kHz, 60 kHz for FR1 (410

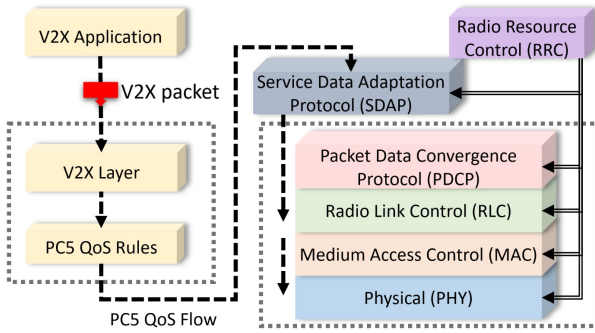


Figure 1: Protocol Stack of NR-V2X.

MHz–7125 MHz), and SCS 60 kHz, 120 kHz for FR2 (24250 MHz–52600 MHz).

In the time domain, a NR-V2X SL frame is fixed to 10 ms and divided into 10 subframes of 1 ms each. A subframe has one or many slots depending on the SCS value. A slot with 15 kHz SCS is 1 ms duration and contains one subframe. The slot length varies with the numerology and gets shorter as the SCS gets wider. A slot is bigger than an OFDM symbol and contains 14 symbols for Normal Cyclic Prefix (CP). We only use Normal CP in this article. The minimum unit for SL resource scheduling in the time domain is thus a slot.

In the frequency domain, Bandwidth Part (BWP), defined in 5G and used in NR-V2X, is a set of contiguous Resource Blocks (RB) in the bandwidth with the same numerology. In NR, a RB has 12 consecutive subcarriers. The SL-BWP is divided to subchannels, each is a set of 10, 12, 15, 20, 25, 50, 75, or 100 contiguous RBs. All subchannels in SL BWP must have the same number of RBs. A subchannel is the minimum unit for SL resource scheduling in the frequency domain.

Resource Element (RE) [3] is the smallest Resource Unit (RU) in NR-V2X, defined by a subcarrier over an OFDM symbol. A TB is bigger than RE. TB is a RU with one slot in the time domain and one or multiple subchannels in frequency domain. TB contains the entire data packet.

C. Link Adaptation: Channel-State Information (CSI)

The CSI Reference Signal (CSI-RS) combined with Adaptive Modulation and Coding (AMC) enables link adaptation in both 3GPP 5G NR and Unicast communication NR-V2X SL to increase efficiency and reliability. First, a transmitter sends the SL CSI-RS in the PSSCH to a receiver. The latter measures the SL channel and extracts the Channel Quality Indicator (CQI) specifying the highest modulation and coding scheme the receiver can support. To do that, a mapping is necessary of the radio quality to CQI index, from a CQI table associated to the configured MCS table for a PSSCH [4]. Then, the receiver sends the estimated channel state back to the transmitter. In mode 1, the transmitter then forwards it to gNB, thus allowing the base station to track the quality of the radio for link adaptation.

D. Literature overview

The impact of the flexible 5G numerology is tackled in [5] but assuming autonomous mode 4, which was then improved

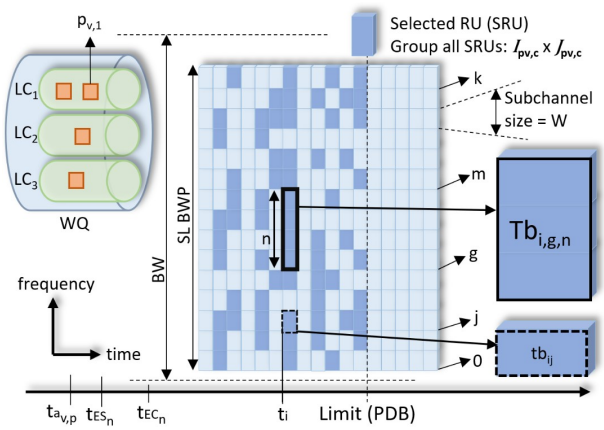


Figure 2: Supported BWP Frequency

to autonomous mode 2 in [6]. Few related papers addressed NR V2X resource allocation. [7] proposed a geographic-location RA algorithm. [8] focused on the interference-aware scheme. [9] developed a cluster-based resource selection scheme. Unfortunately, these above related work considered only mode 2 in NR-V2X or 4 in LTE-V2X.

[1] is the first considering the flexibility of numerology and subchannel size of 5G NR-V2X in mode 1. It proposed an APC algorithm, interact with RA management to find the best PHY configuration in terms of SCS and subchannel size. It profits the flexibility of 3GPP NR-V2X standard for a dynamic traffic environment. However, its proposals were based on only Broadcast communication, lack of considering the radio channel state, limited the size of the TB.

III. PROBLEM STATEMENT

A. System description

Let v be a transmitter (TX) vehicle operating using 3GPP R16 NR-V2X mode 1 DG, scheduled by gNB within one macrocell.

1) *V2X application and traffic model*: Let A_1, A_2, A_3 be three V2X applications supported by the system and communicating with unicast mode at the PHY layer. A_1 provides the Emergency Trajectory Alignment (EmerTA) service working under time-critical constraint. A_2 provides the Cooperative Collision Avoidance (CoCA) service that is less critical than A_1 but is still under delay constraint. A_3 provides the Sensor Information Sharing (SensIS) service with the lowest priority.

The arrival packet time $t_{a,v,p}$ is periodic for A_2 and A_3 and is aperiodic for A_1 . Besides, as described in Section II-A, these applications are mapped to three Logical Channels (LC), each one is associated with a packet queue. These packets are denoted by $p_c^{(v,rx)}$ where c is the service class, v the TX sending the packets, and rx the receiver (RX) vehicle that receiving in unicast mode.

2) *PHY layer*: We set the system parameters according to the 3GPP R16 standard for NR-V2X SL (Table I). The frequency domain supports one **SLBWP** = $(k+1)W$ where $k \in \mathbb{N}$, $W \in \{10, 12, 15, 20, 25, 50, 75, 100\}$ is the subchannel size as a number of contiguous RBs.

Table I: 3GPP 5G NR-V2X SL parameters

Symbol(s)	Meaning
v	The ID of the transmitter vehicle
rx	The ID of the receiver vehicle
T	The slot duration
i	The slot index in the time domain
j	The subchannel's index in SL BWP
W	Subchannel's size in {10, 12, 15, 20, 25, 50, 75, 100} RBs
Z	Number of subcarriers in one subchannel
k	Last subchannel's index in SL BWP
$p_c^{(v,rx)}$	The MPDU packet with service c from v to V_{rx}
x_{ij}^{pv}	0-1 variable deciding whether tb_{ij} is allocated to $p_c^{(v,rx)}$
$I_{p_c^{(v,rx)}}$	Set of the slot's indexes selected for the packet $p_c^{(v,rx)}$
$J_{p_c^{(v,rx)}}$	Set of subchannel's indexes selected for the packet $p_c^{(v,rx)}$
$tb_{ij}^{(v,rx)}$	A RU defined by slot i and one subchannel from index j
$TB_{i,j,n}^{p_c^{(v,rx)}}$	Transport block, at slot i from subchannel $j \dots j + n$ for $p_c^{(v,rx)}$
b_{ij}	The number of bits carried by tb_{ij}
$B_{p_c^{(v,rx)}}$	The number of bits allocated $p_c^{(v,rx)}$
$S_{i,s,v}$	Signal power over SCS s in time slot i for vehicle v
$\bar{S}_{i,v}$	Average Signal power
N	Noise power
$SINR_{i,j}^{(v,rx)}$	SINR over RU j in time slot i by v to V_{rx}
μ	Bandwidth of a SCS
$t_{a,vp}$	Time packet p of vehicle v arrived
t_{ES_n}	Time scheduler n is activated
t_{EC_n}	Time scheduler n finishes the calculating

Let us index the frequency with a **subcarrier index** s . This is later defined by a subchannel with index j . We deduce that $s=12jW=Zj$, where 12 is the number of subcarriers of each RB, $Z=12W$ the number of subcarriers in one subchannel.

Let tb_{ij} be the **RU** in the PHY layer to transmit MAC Protocol Data Unit (MPDU) $p_c^{(v,rx)}$ from TX v to rx , such that i and j , respectively, are the slot index in the time domain and the subchannel index in the frequency domain, tb_{ij} is therefore equal to 1 slot \times 1 subchannel, such that $tb_{ij} \in I_{p_{v,c}} \times J_{p_{v,c}}$ is the group of RUs selected for the packet $p_c^{(v,rx)}$.

The **Transport Block** $TB_{i,j,n}^{p_c^{(v,rx)}}$ assigned to a packet $p_c^{(v,rx)}$ is a set of $n=m-g$ contiguous tb_{ij} such that $(i,j) \in I_{p_{v,c}} \times J_{p_{v,c}}$ and $g \leq j \leq m-1$. Thus, the maximum size of the TB, $TB_{i,g,n}^{p_c^{(v,rx)}}$ in time and frequency domain is 1 slot \times $(k+1)$ subchannels which corresponds setting $g=j=0$ and $m=k+1$, k the highest subchannel index and $k+1$ the number of subchannels assigned to the $p_c^{(v,rx)}$.

3) *Mobility environment*: With wireless vehicular network operating inside a radio environment, the channel conditions (interference, vehicle position, etc.) dictate the system capacity variation and affect the total number of bits b_{ij} of each TB. The channel state sensed by each vehicle corresponds to the Signal to Interference plus Noise Ratio (SINR) and is reported to the base station gNB. We denote $SINR_{i,j}^{(v,rx)}$ the channel state of the transmission between v and rx for subchannel j in a slot i .

B. Problem formulation

We develop a scheduling algorithm to identify which MPDUs to be transmitted and a PHY resource assignment strategy to select the best TB satisfying the requested QoS constraints of the MPDU in the LC. We focus solely on SL communication in mode 1 DG. Configuring the PHY layer involves choosing the coupling SCS and subchannel

Table II: CQI/SINR mapping

CQI	1	2	3	4	5	6	7	8
SINR	-1.889	-0.817	0.954	2.948	4.899	7.39	8.898	11.02
CQI	9	10	11	12	13	14	15	-
SINR	13.32	14.68	16.62	18.91	21.58	24.88	29.32	-

size (μ, W) according to the system conditions. Hereafter, we describe the system specification and the QoS performance parameters impacting the choice of the optimal PHY layer configuration and TB allocation.

Following Shannon theorem, for a subcarrier index s in a time slot t_i , the capacity of a subchannel from s is given by (1) where $S_{i,s,v}$ is the signal power over subcarrier index s at time slot t_i of vehicle v .

$$C_{i,s}^v = \sum_s^{s+Z-1} \mu \times \log_2 \left(1 + \frac{S_{i,s,v}}{N} \right) \quad (1)$$

Thus, the number of bits $b_{i,s}^v$ carried by one RU $tb_{i,s}$ is defined in (2) where T is the constant duration of a slot.

$$b_{i,s}^v = T \times C_{i,s}^v = T \times \sum_s^{s+Z-1} \mu \times \log_2 \left(1 + \frac{S_{i,s,v}}{N} \right) \quad (2)$$

Then, we compute the total bit that $TB_{i,g,n}^{p_c^{(v,rx)}}$ can transport to adapt the requested payload of $p_c^{(v,rx)}$ (3).

$$TB_{i,g,n}^{p_c^{(v,rx)}} = \sum_{j=Z \times g}^{Z(m-1)} b_{i,j}^v = T \cdot Z \cdot n \cdot \mu \times \log_2 \left(1 + \frac{\bar{S}_{i,v}}{N} \right) \quad (3)$$

where

$$\bar{S}_{i,v} = \sum_{s=Z \times g}^{Z(m-1)} (S_{i,s,v} / (Z \times n)) \quad (4)$$

$$n = m - g \quad (5)$$

Besides, we have the data rate calculation from 3GPP [10] for SL that also adapts the requested payload $p_c^{(v,rx)}$ (6), setting $N_{RB} = W \times n$. Therefore, we obtain (7).

$$A = L_{\text{layer}} \times f \times Q_m \times R \times \frac{12N_{RB}}{T/14} \times (1 - OH) \quad (6)$$

$$Q_m \times R = \frac{T \times \mu \times \log_2 \left(1 + \frac{\bar{S}_{i,v}}{N} \right)}{L_{\text{layer}} \times f \times (1 - OH) \times 14} \quad (7)$$

Q_m and R are mapped to MCS_{tx} index value [4].

On the receiver, let $\min SINR_{i,g,n,v,rx}$ be the minimum SINR with j from g to $g+n-1$. SL-CSI maps $SINR_{i,j,v,rx}$ to CQI value, we obtain MCS_{rx} , therefore (8) holds.

$$MCS_{tx} \leq MCS_{rx} \quad (8)$$

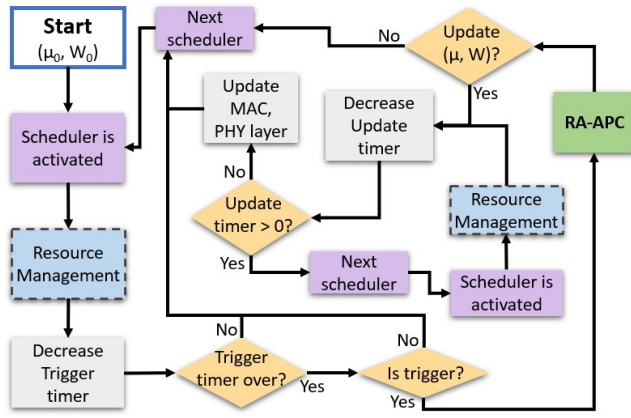


Figure 3: Interaction between RM and RA-APC.

C. Performance evaluation parameters

For a vehicle v , the **throughput** of the service c is the total bit transported by all TB allocated for c within v (9), where x_{ij}^{pv} is a 0-1 variable deciding whether tb_{ij} is allocated to the vehicle transmitting $p_c^{(v,rx)}$.

$$th_{v,c} = \frac{1}{T} \sum_{(i,j) \in I_{pv,c} \times J_{pv,c}} x_{ij}^{pv,c} b_{ij} \quad (9)$$

The **latency** is the sum of four components: i) transmission time, ii) the signal propagation delay from TX to RX, iii) the time required to perform encoding, decoding and channel estimation in the initial transmission, and iv) the preprocessing delay for the signal exchange such as connection request, scheduling, and queuing delay.

Reliability is the probability that a data of size D is successfully delivered within a time period T from source to destination. For broadcast, unicast or groupcast transmission, a TX vehicle sends packet to neighbor RX vehicles around. Among the received packets N_r , the receiver may fail to decode some packets. The reliability parameter R is ratio between the number of packets decoded successfully N_s and the number of packets received by RX vehicles: $R = N_s/N_r$.

We define a new performance parameter computing the **number of packets effectively transmitted** among N packets that has received the TB to send: $ETP = N \times R$.

IV. PROPOSAL

To adapt the vehicle's QoS requirements to the dynamic environment, we update the PHY layer configuration of SCS μ and subchannel size W with respect to the QoS triggers (Section III-C). Our solution is based on two main stages (Figure 3). First, the Radio-Aware Adaptive PHY layer Configuration (RA-APC) selects the best pair (μ, W) to maximize the ETP. Then, the Radio Resource Management (RM), handled by our scheduler, identifies the suitable TB for the packet.

A. RA-APC

Using the flexible numerology at the PHY layer of 5G NR, RA-APC adapts μ and W when the performance of the RA algorithm is not as expected in terms of latency, reliability,

 Table III: Physical SCS μ - Subchannel size W

$\mu \setminus W$	10	12	15	20	25	50	75	100
15	1-21	2-18	3-14	4-10	5-8	6-4	7-2	8-2
30	9-10	10-8	11-7	12-5	13-4	14-2	15-1	16-1
60	17-5	18-4	19-3	20-2	21-2	22-1	-	-

and data rate (Section III). Violating any of these constraints triggers the system with RA-APC mechanism to update the configuration, which consists of selecting the pair $(\mu, W) \in \{15, 30, 60\} \times \{10, 12, 15, 20, 25, 50, 75, 100\}$ (Table III). For example, the pair 5 – 8 shows the PHY configuration State 5 with 8 subchannels (or 8 RUs, one slot and one subchannel for each) for scheduling and matches the configuration pair of $\mu = 15$ kHz and $W = 25$ contiguous RBs.

The trigger updates the configuration (μ, W) . Table III shows that increasing μ raises the throughput, decreasing W increases the number of RUs and more vehicles can be served, in the case of high density. However, this increases the MCS value and decreases the reliability, if assuming a fixed payload. The objective is to find the best trade-off between the reliability and the number of RUs. Thus, despite good performance of the scheduler, variations in the radio environment, density, or data traffic may degrade the latency and/or reliability and/or throughput. In this case, the triggers are activated and the configuration is updated at the PHY layer to consider the new radio state. First, the RA-APC picks another SCS index μ achieving the minimum throughput but bigger than the throughput constraint of the highest priority LC. Then, W is calibrated to maximize ETP, and that State, we call it Balance State (BS).

B. Resource Management Algorithm

The RA scheduler distributes the TBs for packets in the Waiting Queue (WQ), serves the packets of the LC from the highest to lowest priority on the first-in-first-out basis. The scheduler processes each packet in the time domain that does not exceed the Packet Delay Budget (PDB) and in the frequency domain from the lowest to highest subchannel index for each slot. A vehicle in one slot can send only one TB. The first TB satisfying these constraints is chosen by the scheduler to transmit the packet: i) no other TB in this slot has been assigned to the transmitter and receiver vehicle before, and ii) the TB adapts the CQI feedback from the receiver. After a packet receives TB, it is moved to the Transmission Queue (TQ). Otherwise, it waits in the WQ or is dropped if it reaches PDB. Algorithm 1 summarizes our proposal.

1) *Preemption method*: The scheduler is preemptive if it allocates a TB already assigned to another packet. As we cannot predict the aperiodic packet arrival in high priority LC to make an ‘‘early’’ reservation, these packets will seize the TB that ought to serve other packets in the lower priority LC. To tackle this issue, we impose an interest window t_{interest} on the scheduler such that it forces the scheduler to select only the TB present in t_{interest} to serve the packets in the WQ, while other packets remain in the WQ and wait until the next scheduling period. Those whose PDB has been reached are discarded. The interest window must be smaller than the smallest PDB.

Algorithm 1: Resource Management Algorithm

Data:
 $t_{a_{vp}}$ arrival time of a packet p of vehicle v
 t_{ES_n} starting time of the execution scheduler n
 t_{Ec_n} finish time of the execution scheduler n
 t_i time slot i
 $t_{interest}$ interest window time
 j index of the subchannel j
 k index of the last subchannel in BWP

WQ \leftarrow AESPR;
for all $p_c^{(v,rx)}$ in the WQ **do**
 $a \leftarrow$ whether the entire BWP can contain $p_c^{(v,rx)}$ payload ;
 if a is false **then**
 Drop $p_c^{(v,rx)}$;
 Check next $p_c^{(v,rx)}$ in WQ;
 while $\begin{cases} t_i - t_{a_{vp}} < PDB \\ t_i < t_{Ec_n} + t_{interest} \\ t_i > t_{Ec_n} > t_{ES_n} > t_{a_{vp}} \end{cases}$ **do**
 $a \leftarrow$ Check slot i violated half-duplex constraint ;
 if a is true **then** Check next slot i ;
 $minSub \leftarrow$ min #subchannel can contain $p_c^{(v,rx)}$;
 for n from $minSub$ to $(k+1)$ subchannel **do**
 for j from 0 to $(k-1)$ subchannel index **do**
 $MCS_{tx} \leftarrow$ minimum MSC such that $TB_{ij,n}$
 can contain $p_c^{(v,rx)}$;
 $MCS_{rx} \leftarrow$ maximum MSC such that V_{rx} can
 decode $TB_{ij,n}$;
 if $MCS_{tx} \leq MCS_{rx}$ **then**
 Select $TB_{ij,n}$;
 Check next $p_c^{(v,rx)}$ in WQ;
 if $t_i \geq PDB$ **then** Drop $p_c^{(v,rx)}$;
 else Keep $p_c^{(v,rx)}$ in WQ;

2) *Adaptive Expected Serving Packet Rate (AESPR)*: Starvation of low priority packets happens when these packets wait in the WQ too long due to their low priority and are dropped once their PDB is exceeded. To avoid starvation, we define a rate value $Rate_{Exp_c}$ that is the expectation that the scheduler serves the a minimum ratio of packets depending on the priority of LC_c . A bigger $Rate_{Exp_c}$ means more packets have a chance to be assigned a TB.

Let us define an observation window w_o equal to a number of time slot. First, we can predict N_{tot}^p the number of packets to be assigned RUs within the current time slot by averaging over the past observation window (10). Then, we compute the expected number of packets in each LC_c (11) and deduce the total number of expected packets (12). The expected processing rate $Rate_{LC_c}$ for each LC_c is shown in (13). Finally, we determine $N_{ser}^{LC_c}$ the number of packets the scheduler must process first in each LC_c . We expect that a majority of these packets will be assigned a TB for transmission (14). Then, the scheduler processes the remaining packets in the WQ to maximize the sending capacity, even if the probability that these packets received TB for transmission can be low.

$$N_{tot}^p = \left(\sum_{t=1}^{w_o} N_t \right) / w_o \quad (10)$$

$$N_{Exp}^{LC_c} = Rate_{Exp_c} \times N_c \quad (11)$$

$$N_{tot}^{Exp} = \sum_{c=1}^3 N_{Exp}^{LC_c} \quad (12)$$

Table IV: Simulation network parameters

Name	Value	Name	Value
Band	n47	Noise figure	9 dB
Bandwidth	40 MHz	Tx, Rx antenna gain	3 dB
HARQ	No	Mode scheduling	Mode 1 DG
CSI	Yes	Channel Model	3GPP 3-D mm-Wave
MIMO	No	Duplex Mode	Half-duplex
Tx power	23 dBm	Mode communication	Unicast

Table V: V2X QoS requirement of studied application

Communication scenario	MAC layer	Priority	Payload (Bytes)	Tx rate	Latency (ms)	Reliability(%)	Mbps
EmerTA	LC 1	1	2000	-	3	99.999	30
CoCA	LC 2	2	2000	100	10	99.99	10
SensIS	LC 3	3	1600	10	100	99	-

$$Rate_{LC_c} = N_{Exp}^{LC_c} / N_{tot}^{Exp} \quad (13)$$

$$N_{ser}^{LC_c} = Rate_{LC_c} \times N_{tot}^p \quad (14)$$

V. PERFORMANCE EVALUATION

We assess the performance of our proposal using a self-developed simulator implementing 3GPP R16 NR-V2X standard, built upon the LTEV2Vsim v3.5 simulator¹. Table IV summarizes the main network parameters.

We simulate the vehicles' movements in a 4000-meter urban road, composed of three lanes of 3.5 meters width in each direction, one microcell and control by a gNB. The average speed is set to 57 km/h with a standard deviation of 12.65 km/h. Simulations are conducted for 1000 vehicles in the road, which means 250 vehicles/km density. We simulate three NR-V2X services A_c of three user cases [11], described in Table V, mapped to three logical channels LC_c , $c \in \{1, 2, 3\}$. Assuming a constant packet size for these applications, we set $R_1 = R_2 = 2000$ bytes for A_1 and A_2 , $R_3 = 1600$ bytes for A_3 . The arrival time is $t_{a-vp_2} = 10$ ms and $t_{a-vp_3} = 100$ ms. Since A_1 is non periodic traffic, we simulate a uniform random arrival time distribution. A_2 started with the simulation, after 800 ms A_3 appears in LC_3 . Finally, A_1 is executed from 1100 ms to 1300 ms. Table V lists the requirements for these NR-V2X services. We ran 1100 simulations for 22 states.

First, we compare our proposal RA-APC with the baseline non-aware radio APC algorithm fixing the TB's size to one subchannel in [1]. Figure 4 shows the trade-off between Packet Sent and Reliability of APC and our proposal RA-APC (upper and lower row, respectively). For APC, the density is set to 100 vehicles/km. In Figure 4a, we see that RA-APC manages the resources much better even if the density is 2.5 times higher. When the density increases, the performance parameters degrade. Consequently, RA-APC adapts the PHY layer configuration to obtain more PHY resources, while also considering the variations in the radio environment. We also achieved a better reliability $\approx 99.75\%$ (Figure 4b). This can be explained thanks to RA-APC which can detect the variations in the radio state, and hence successfully decodes more packets than APC. In Figure 4c, RA-APC always achieved

¹<https://github.com/alessandrobazzi/LTEV2Vsim>

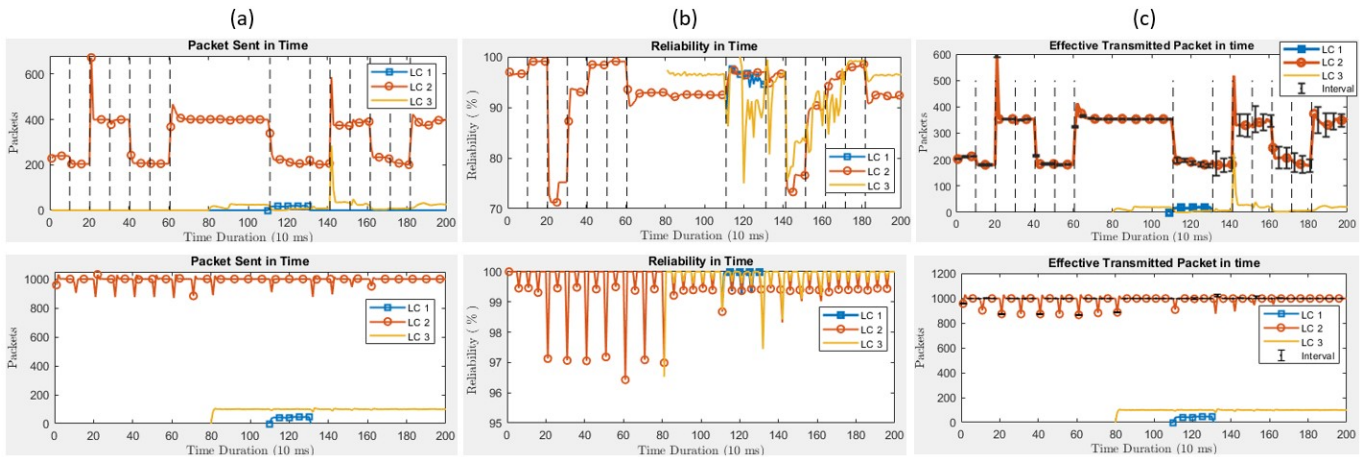


Figure 4: (a) Packet sent +/- Radio awareness, (b) Reliability +/- Radio awareness, (c) ETP +/- Radio awareness

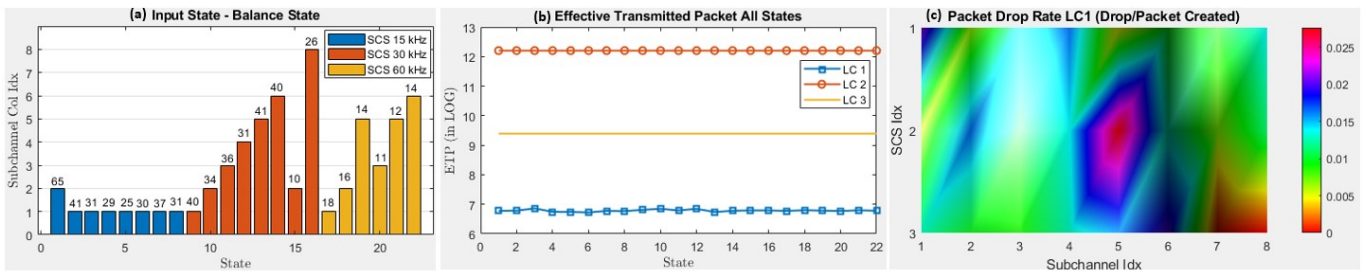


Figure 5: Balance state, ETP, and Packet Drop of all States

the maximum ETP, whereas APC only reached it after 600 ms within a 98% confidence interval.

Figure 5a presents the balance point corresponding to the best configuration for each starting state and for every SCS. Figure 5b demonstrates a good performance in terms of ETP for each state and each application A_c . Finally, Figure 5c visualizes the Packet Drop Rate (PDR) of LC1 while varying (μ, W) . The worst case is when $PDR = 0.025$ that is very lowland and matches with the constraints of a contingent application like A_1 .

VI. CONCLUSION

To achieve efficient resource allocation for 5G NR, our contribution is threefold: first, we used the a RA-APC to maximize ETP, then, a resource management algorithm with pre-emption method, and finally, we proposed AESPR scheme to regulate the serving rate to address the starvation phenomenon of packets in low-priority LCs. The RA-APC and RA management consider the radio channel state, study unicast communication and use multiple subchannels for the same TB. Our contribution does not aim to propose a new RA algorithm but a new mechanism allowing the telco operator to adapt the configuration of the PHY layer, thanks to the 5G NR flexibility, for an efficient management of radio resources.

The simulations show that the PHY layer can find the BS such that the ETP is maximized and the RA-APC algorithm has proven better than APC.

In the future, we can improve the convergence time to find the BS by Machine Learning. We will tackle to all RA modes, that means mode 1 and mode 2 in 5G 3GPP NR-V2X.

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