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## Applicability of 5G Technology for a Wireless Train Backbone

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### III. INFRASTRUCTURE-BASED 5G FOR WLTB

In this section a numerical analysis is presented for a WLTB based on 5G technology with an infrastructure (i.e. with gNodeB).

#### A. Network Topology and Traffic

The infrastructure-based WLTB operates as a star topology, where the gNodeB acts as gateway managing the traffic which flows through the network (see Fig. 2). In this configuration, one User Equipment (UE) is deployed per consist, and one gNodeB per train.

The requirements for the traffic of the train backbone are detailed in TABLE I [6]. This traffic is split between periodic and aperiodic traffic, and it can be unicast or multicast. Therefore, a worst-case scenario in terms of capacity will occur when all periodic (PD, SD) and aperiodic (MD) messages are sent in the same subframe of 1 msec. This worst-case calculation is summarized in TABLE II, where 10 extra bytes have also been added to each traffic to account for the payload of the upper layers of 5G.

#### B. Design of 5G-NR Resource Grid

In order to determine if 5G-NR is able to cover the maximum traffic requirements detailed in TABLE II, a custom resource-grid has been designed.

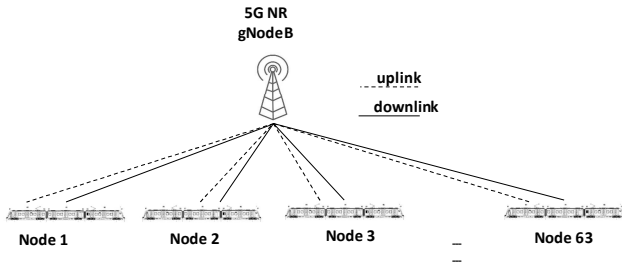


Fig. 2. Infrastructure-based 5G WLTB

TABLE I. TCMS TRAFFIC REQUIREMENTS [6]

	Process Data (PD)		Message Data (MD)	Supervisory Data (SD)
	Time Sensitive (TS)	Normal (N)		
Data Size (bytes)	1432	1432	65388	1500
Cycle time (ms)	1	10	N/A	50
Data Rate (Mbps)	100	100	10	10
Latency (ms)	4	8	250	8
	<i>Periodic</i>		<i>Aperiodic</i>	<i>Periodic</i>

TABLE II. TRAFFIC GENERATED PER NODE (BITS PER MILLISECOND)

PD		MD	SD	TOTAL
TS	N			
11536	1226	10080	320	<b>23162</b>

TABLE III. RESOURCE GRID: UPLINK (LEFT), DOWNLINK (RIGHT)

PRACH		SSB	
M (msg1-FSM)	8	Aggregation Level	16
SRS		Coreset symbols	3
Symbols per slot	4	CSI-RS	
Density per RB (kTC)	4	Density per RB	1
RB <sub>s</sub>	264	Slots density	4
CSI-RS		PDSCH	
Density per RB	1	PT-RS RB density	2
Slots density	4	PT-RS time density	1
PUSCH		DMRS time type	A
PT-RS RB density	2	DMRS length	1
PT-RS time density	1	Additional DMRS symbols	0
DMRS time type	A	DMRS freq type	2
DMRS length	1	DMRS freq density	4
Additional DMRS symbols	0		
DMRS freq type	2		
DMRS freq density	4		

PRACH: Physical Random Access Channel  
SRS: Sounding Reference Signal  
CSI-RS: Channel Status Information – Reference Signal  
SSB: Synchronization Signal Block  
CSI-RS in Downlink  
PUSCH: Physical Uplink Shared Channel in Uplink  
PDSCH: Physical Downlink Shared Channel  
DM-RS: Demodulation Reference Signals  
PT-RS: Phase Tracking Reference Signals  
RB: Resource Block  
SCS: Sub-Carrier Spacing

Due to the significant variability of the 5G parameters, several assumptions have been made for this design. For example, the most restrictive configuration has been adopted regarding the amount of resources occupied by reference channels and signals. The parameters involved in this configuration are specified in TABLE III. In order to obtain this restrictive scenario, it is assumed that the periodic information (PRACH, SRS, CSI-RS in Uplink, SSB and CSI-RS in Downlink) is transmitted in the same subframe as the data (PUSCH in Uplink, PDSCH in Downlink), and together with the reference signals DM-RS and PT-RS.

On the other hand, in 5G-NR two operating bands are available: Frequency Range 1 (FR1, below 7 GHz) and Frequency Range 2 (FR2 in millimeter waves, above 24 GHz). In FR1, the widest transmission bandwidth is 100 MHz with a full capacity of 273 RBs and a SCS of 30 kHz ( $\mu=1$ ), while FR2 presents a maximum bandwidth of 400 MHz, a SCS of 120 kHz ( $\mu=3$ ) and 264 RBs available ([7]). For this work it is assumed that the whole bandwidth is available, half for the uplink and half for the downlink transmissions (i.e. symmetric resource allocation). It is also considered that the streams from codeword codifications are directly mapped into RF ports and physical antennas, therefore allowing spatial multiplexing.

Based on the previous assumptions, full Resource Elements (RE) are obtained for both Uplink and Downlink: 91728 for FR1 (273 RBs x  $2^1$  x 14 symbols x 12 subcarriers) and 354816 for FR2 (264 RBs x  $2^3$  x 14 symbols x 12 subcarriers). Afterwards, REs which are reserved for channel control and signal references (see TABLE III) are subtracted

from the initial planning obtaining the REs actually used for data transmission: PUSCH for Uplink and PDSCH for Downlink. Taking this into consideration, and depending on the configuration used regarding spatial multiplexing (i.e. number of antennas) and frequency range (FR1 or FR2), the maximum capacity offered by the 5G resource grid is obtained for different frequency ranges, antenna configurations and Modulation Coding Scheme (MCS) values (see TABLE IV). Four MCS values have been taken as representative between 0 and 28 (MCS=0, 10, 20 and 28).

### C. WLTB Traffic and 5G Resource-Grid Match

Applying the WLTB traffic detailed in Section III.A to the resource-grid allocation described in Section III.B, required 5G bit rates have been obtained for different MCS configurations and for an increasing number of nodes, as shown in Fig. 3 and Fig. 4. These graphs indicate the required Uplink and Downlink 5G bit rates for different MCS values (only MCS 28 graphs are shown here for brevity). Up to 63 nodes have been considered, which is the maximum number of consists in a train.

Matching these graphs with the maximum capacity provided by each 5G configuration (see TABLE IV), the maximum number of nodes per configuration are obtained. These results are presented in Fig. 5 (Uplink) and Fig. 6 (Downlink) and show the maximum number of nodes that can be managed by a specific 5G configuration. From these results it can be concluded that a minimum configuration of 2 antennas in FR2 is needed in order to cover a full 63-consist train, while FR1 operation up to 22 consists is possible by using 4 antennas and MCS 28. However, it must be noted that this analysis has been made considering full bandwidth availability. This means that if the WLTB is to be operated with lower MCS values or lower number of antennas, the requirements for the WLTB should be scaled down.

TABLE IV. MAXIMUM CAPACITY (MEGABITS PER SECOND)

		Antennas	MCS Index			
			0	10	20	28
UP	FR1	1	6	33	83	138
		2	12	66	166	277
		3	18	99	248	415
		4	23	132	331	554
	FR2	1	36	205	512	856
		2	72	409	1024	1711
		3	108	614	1535	2567
		4	144	818	2047	3423
DOWN	FR1	1	9	49	112	205
		2	18	97	223	409
		3	27	146	335	614
		4	35	194	446	818
	FR2	1	38	207	474	869
		2	75	413	948	1738
		3	113	620	1422	2608
		4	150	826	1896	3477

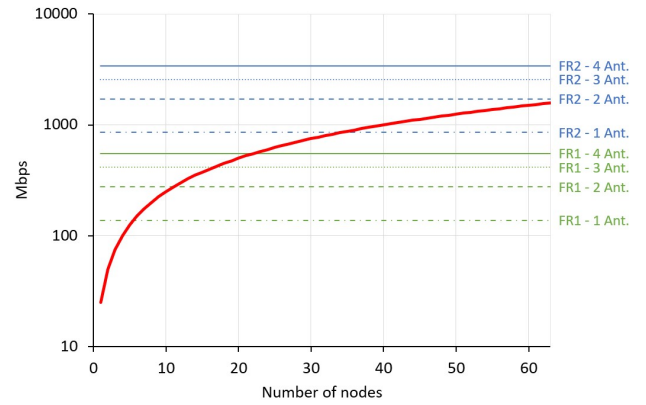


Fig. 3. Required Traffic vs 5G capacity (Uplink) - MCS 28

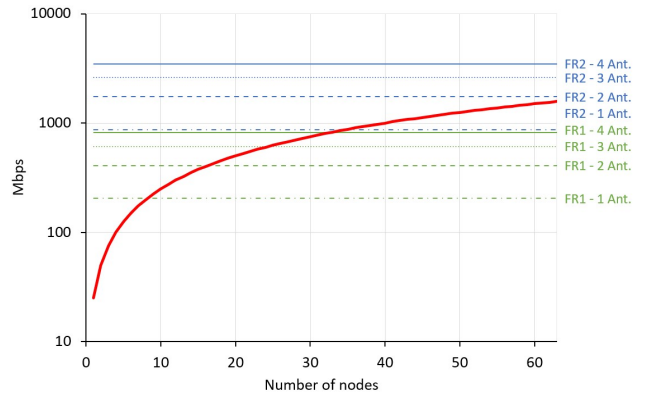


Fig. 4. Required Traffic vs 5G capacity (Downlink) - MCS 28

## IV. 5G-V2X FOR WLTB

3GPP 5G Rel. 16 provides the specification of NR-V2X, the 5G extension of the cellular V2X technology. It has been designed to support the critical data capacity, latency and reliability of advanced V2X use cases, such as platooning and highly automated driving, or massive sensor exchanges. Therefore, NR-V2X communications could bring connectivity for WLTB in railway corridors where infrastructure is not available. NR-V2X aims at complementing LTE-V2X and not replacing it. Compared to LTE-V2X, NR-V2X has several salient enhancements, such as a more robust NR physical layer, unicast and groupcast communication, dynamic resource reallocation, or a new physical sidelink *feedback* channel (PSFCH) for HARQ (Hybrid Automatic Repeat Request).

NR-V2X supports two modes of operation: infrastructure V2X (mode 1) and autonomous V2X (mode 2), the latter being subdivided in 4 different autonomous scheduling strategies (mode 2a to mode 2d), enabling enhanced control on how resources can be allocated in NR-V2X.

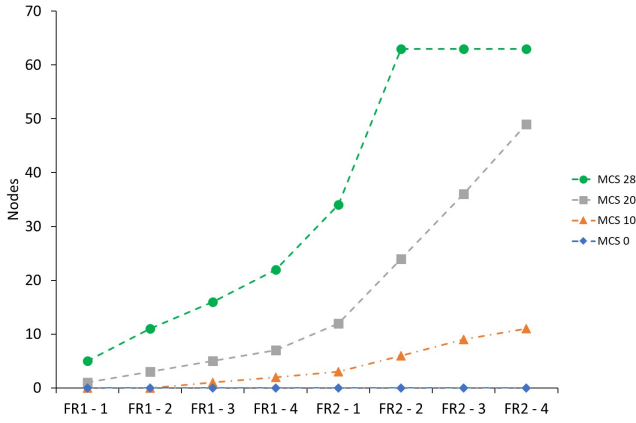


Fig. 5. Maximum network size (Uplink)

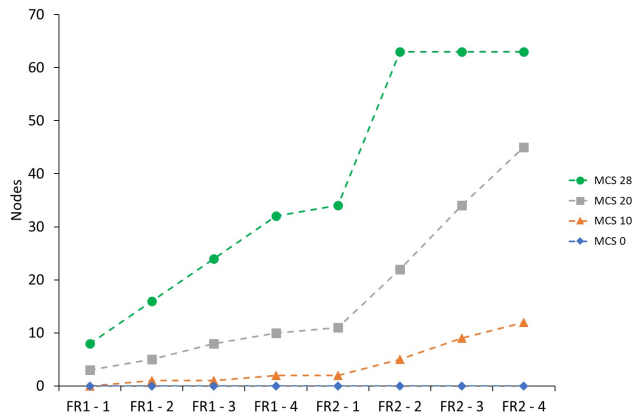


Fig. 6. Maximum network size (Downlink)

NR-V2X is expected to be beneficial for a WLTB by proposing enhanced support in the following domains:

1. *Dynamic HARQ*: supporting highly reliable HARQ communications between one or a group of consists.
2. *Long/Short term sensing & mini-slots*: supporting single-digit milliseconds resource allocations for low-latency WLTB communications.
3. *Resource preemption*: supporting the preemption of resources, and strict Quality of Service (QoS) for critical WLTB communications.
4. *Deterministic ad-hoc resource allocation*: allowing one UE to schedule resources for a group of UEs, even in the absence of 5G infrastructure.

NR-V2X is therefore expected to be a critical technology for WLTB communications. TABLE V shows the key differences between LTE-V2X and NR-V2X, together with the WLTB requirements.

## V. 5G-V2X RESOURCE MANAGEMENT FOR WLTB

NR-V2X introduces four sub-modes to the NR-V2X autonomous resource allocation mechanisms (mode 2), the two most promising ones being mode 2(a) and mode 2(d). In this section, we discuss two research lines for these two modes, which could be beneficial for the WLTB: improved NR-V2X mode 2(a) with Self-organizing Time-Division

Multiple Access (STDMA), as well as cluster-based scheduling NR-V2X mode 2(d).

The NR-V2X mode 2(a) corresponds to an autonomous resource allocation, and inherits from the SP-LBT (Semi-Persistent Listen-Before-Talk) scheduler available for LTE-V2X. Several studies [8] showed that such scheduler has critical limitations both in terms of reliability and resilience under heavy communication loads, but also suffers from half-duplex limitations (see Fig. 7). However, NR-V2X provides new smart mechanisms to reach reliable V2X communications, such as short-term sensing, resource pre-emption, resource reservation, and significant benefits may come from developing new schedulers. We show here the potential of a Self-organizing TDMA scheduler for NR-V2X mode 2(a). STDMA has originally been developed by [9] and standardized at ETSI as a potential alternative to the WiFi V2X CSMA-CA scheduler [10]. Several studies showed its salient features and it has been investigated also as a potential alternative scheduler for LTE-V2X [11].

As it can be seen in Fig. 8, although the SP-LBT and the STDMA schedulers have close match performance at low communication densities, the STDMA scheduler shows an increased resilience when the load (i.e. vehicle density) increases. As is also shown in Fig. 8, the 99% bound corresponds to the impact of half-duplex impairments on both schedulers. Without full duplex radio front-ends, such limitations cannot be fully cancelled, but it is possible to improve the schedulers by choosing which UE would conflict.

TABLE V. LTE-V2X, NR-V2X AND WLTB FEATURES

Requirements	LTE-V2X	NR-V2X	WLTB
Service Discovery	No	Yes	Yes
Group Com.	No	Yes	Yes
Multicast/Broadcast	Broadcast	Unicast/ Groupcast	Unicast/ Groupcast
Retransmission	Blind	HARQ	HARQ
Spectrum access	5.9GHz	6GHz & 60GHz	6GHz & 60GHz
Scheduling	Infra.	Deterministic	Deterministic
	Ad-hoc	Random	Random/ Deterministic
Latency	>10ms	<1ms	<1ms
Mesh	higher layer	Rel. 18,19	Required

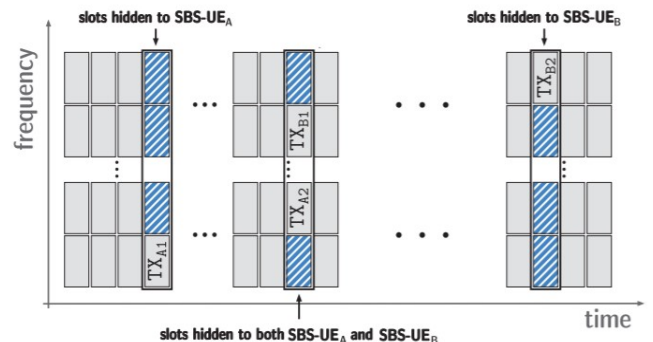


Fig. 7. Half-Duplex impairments for LTE/NR V2X, where blue packets are 'hidden' (lost) to any station transmitting on the same subframe.

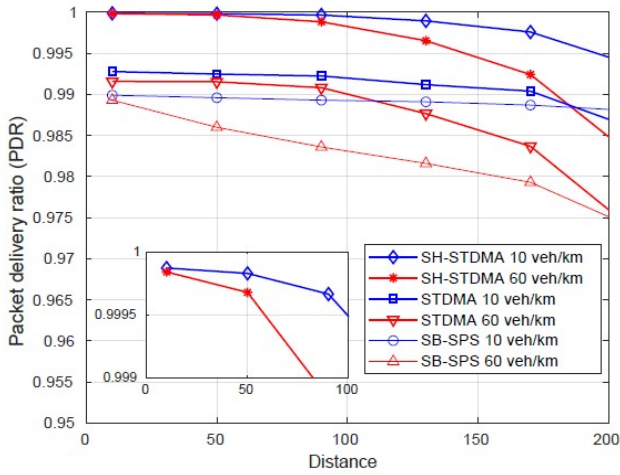


Fig. 8. Packet Delivery Ratio (PDR) comparison between SP-LBT, STDMA and SH-STDMA for different communication loads.

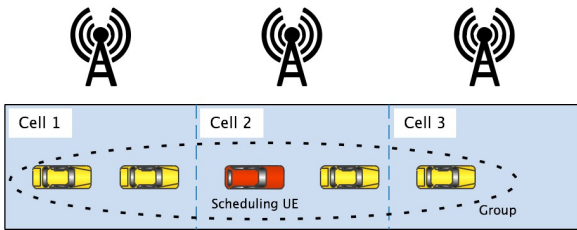


Fig. 9. 5G-V2X mode 2(d) cluster-based scheduling in a platooning scenario [12].

A recent proposal, called SH-STDMA [11], places resources conflicting from half-duplex as far away as possible, thus mitigating effective packet losses. Accordingly, SH-TDMA manages to reach  $\sim 99.9999\%$  Packet Delivery Ratio (PDR), thus meeting one of the criteria for Ultra-Reliable and Low-Latency (URLL) V2X communications.

On the other hand, NR-V2X mode 2(d) allows UEs to select resources for other UEs, therefore enabling infrastructure reliability and dependability in an autonomous mode. However, UEs coordinating resource allocations for other UEs must select their UEs carefully, and plan the resource pools efficiently in order to avoid collisions or interferences. To address this issue, new directions are investigated, where resource allocation is carried out re-using resources depending on the geographical zone where UEs are clustered. In [12], depicted also in Fig. 9, a clear example of this proposal for vehicle platooning is shown. Following this approach, resource allocation for each working zone is different, which increases network capacity. This strategy is applicable to scenarios where several WLTBs are operating in close vicinity (e.g. stations or depots).

## VI. SUMMARY

In this work the suitability of 5G technology for a Wireless Train Backbone has been analyzed. Both infrastructure-based and V2X alternatives have been explored, and theoretical analyses and simulations have been

presented to indicate the performance of these technologies in high load scenarios. Obtained results indicate that 5G is a suitable technology for the WLTB, but WTLB requirements will need to be scaled down in order to cover trains with a large number of consists. Future research activities in 5G-V2X have also been outlined in the paper.

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## REFERENCES

- [1] Shift2Rail, "Multi-Annual Action Plan (Final)", 2016, Available: [https://shift2rail.org/about-shift2rail/reference-documents/attachment/maap-final\\_final/](https://shift2rail.org/about-shift2rail/reference-documents/attachment/maap-final_final/)
- [2] J. Härrri, A. Arriola, P. Aljama, I. Lopez. U. Fuhr, M. Straub, "Wireless Technologies for the Next-Generation Train Control and Monitoring System", IEEE 5G World Forum, Dresde, October 2019.
- [3] Safe4RAIL-2, "D2.1 – Requirements of LTE Equipment and ETBNs for wireless TCMS", Available: <https://www.safe4RAIL.eu>
- [4] CONNECTA-2, "D1.1 – Specification of involved Wireless TCMS", Available: [https://projects.shift2rail.org/s2r\\_ip1\\_n.aspx?p=CONNECTA-2](https://projects.shift2rail.org/s2r_ip1_n.aspx?p=CONNECTA-2)
- [5] Safe4RAIL -2, "D2.2 – LTE equipment: Design, implementation and impact analysis on ETBNs", Available: <https://www.safe4RAIL.eu>
- [6] CONNECTA, "D3.1 – Drive-by-Data Network Requirements", Available: [https://projects.shift2rail.org/s2r\\_ip1\\_n.aspx?p=CONNECTA](https://projects.shift2rail.org/s2r_ip1_n.aspx?p=CONNECTA)
- [7] ETSI, "5G; NR; Physical layer procedures for data (3 GPP TS 38.214 version 15.3.0 Release 15) 2018, Available: [https://www.etsi.org/deliver/etsi\\_ts/138200\\_138299/138214/15.03.00\\_60/ts\\_138214v150300p.pdf](https://www.etsi.org/deliver/etsi_ts/138200_138299/138214/15.03.00_60/ts_138214v150300p.pdf)
- [8] M. Gonzalez-Martín, M. Sepulcre, R. Molina-Masegosa and J. Gozalvez, "Analytical Models of the Performance of C-V2X Mode 4 Vehicular Communications," in IEEE Transactions on Vehicular Technology, vol. 68, no. 2, pp. 1155-1166, Feb. 2019
- [9] Katrin Sjöberg, "Predictable and Scalable Medium Access Control for Vehicular Ad Hoc Networks", PhD Thesis, Göteborg University, 2009, url: <https://www.diva-portal.org/smash/get/diva2:346006/FULLTEXT01.pdf>Thesis
- [10] ETSI TR 102 861, Intelligent Transport Systems (ITS); STDMA recommended parameters and settings for cooperative ITS; Access Layer Part.
- [11] Laurent Gallo, Jérôme Härrri, "Analysis of a S-TDMA distributed scheduler for ad-hoc cellular-V2X communication", Ad Hoc Networks, Volume 88, 2019, Pages 160-171.
- [12] R1-1912422, 3GPP TSG RAN WG1 Meeting #99, Reno, Nevada, November 18th - 22th, 2019