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Performance Analysis of 4G LTE Sidelink Communication applied in Railway System

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Abstract

The Wireless Train Backbone (WLTB) is an evolution of the Ethernet Train Backbone (ETB) that permits direct consist-to-consist communications in wireless technology. Although current internal train communications are mostly reliant on wired networks, in order to offer harmonised inter-operability connection with other train to ground communication applications, it is essential to integrate wireless communication into WLTB. Since 4G LTE technology is currently most widely deployed over all type of applications due to its maturity and its efficient radio access management, this can be a solution for this issue.

In this study we analyze the performance of LTE Sidelink communication under different realistic based scenarios for WLTB by implement related scenarios and simulate in a ns3-based simulator. The goal of this analysis is to highlight the capability that LTE V2X SL communication support and also demonstrate the difficulties it experiences under challenging circumstances. Obtained results indicate that 4G LTE is a potential technology for end devices communication in the train communicatoin, however performance suffers under certain rigorous situations.

Table of Contents

List of Tables

List of Figures

1. Introduction

The Next Generation Train Control and Monitoring System (NG-TCMS) is investigating wireless communication in terms of improving communication reliability, incorporate wireless technologies and simplify the number of computing devices in the train. The projects CONNECTA-2 and Safe4RAIL-2, part of the Shift2Rail initiative, funded by Horizon 2020, intend to provide novel capabilities for the railway industry through research and innovation for a variety of purposes, including maintaining security by controlling traffic, ensuring passenger safety by combining various forms of sensor surveillance and providing entertainment([5]).

The International Electrotechnical Commission (IEC) has introduced the concepts of WireLess Train Backbone (WLTB) and WireLess Consist Network(WLCN), which are intended to replace wired Train Control and Monitoring System (TCMS) by a wireless architecture, as wireless communication in the WLTB can increase the flexibility, ease inter-operability, and reduce the cost when comparing to the currently used wired solution. Consequently, it would be possible to address the requirement from railway communication. Furthermore, a direct connection among WLTB components would reduce structural complexity and delay.

LTE V2X Sidelink communication defined in 3GPP Rel.14 is considered the main technology to support considerable amounts of applications, most of these can be applied in Railway communication, such as sensors data collection and diagnostics(Radar, Lidar, Camera, Ultrasonic), situation awareness, road safety, control traffic management, and infotainment. These applications utilize safety, navigation, and entertainment services all together. Besides introducing cellular network in Sidelink communication can enable cooperation with other communications such as Train to ground(T2D) link, therefore a globally harmonised Wireless Train Control Monitoring System (WTCMS) could be achieved.

To the best of our knowledge, very few researches have been done on LTE V2X in train communication. Although there has been some LTE-Railway(LTE-R) related-works, for instance [6] investigated in LTE-R technology which is only corresponding to emergency conditions by providing voice, data and video services, meanwhile no sidelink communication has been proposed. [7] firstly addressed the requirements of LTE equipment for integration in WLTB in order to deal with wireless train inauguration. This is further developed by [8] which summarised the architecture of wireless communication of 4G and 5G in WLTB, meanwhile analysed a theoretical performance compared with the requirements from both industrial and WLTB communication. However, no research has yet been proposed to analyse the actual performance of LTE V2X Sidelink WLTB communication under realistic and challenging circumstances.

The rest of the paper is organized as follows: Section 2 describes the LTE-V2X networks, the railway communication system and its requirements. Section 3 explains the proposed scenarios and the key environmental element setting. Section 4 lists detailed simulator parameter setting and scenario topology configuration. Section 5 presents the results and analysis of proposed scenarios under 4G-LTE technology in WLTB. Finally, Section 6 presents the conclusions of the presented work.

2. Background

2.1 LTE-V2X Communication Technology

Over the years 3GPP has proposed and updated LTE-V2X related standards, starting from 3GPP Rel.12, which added new features aimed at enabling UEs to communicate directly with one another, also known as LTE D2D communication. Following Release.13(eD2D), they developed a key catalogue as an enhancement of D2D proximity services(ProSe). In the next stage, 3GPP Rel.14 became the first standard proposed on V2X-specific LTE communication. This release proposed a diverse studies related with architecture enhancement, application layer support, band combinations etc. For resource allocation, four modes are assigned, in particular Mode 3 and 4 are being used for LTE V2X communications. It should be noted that in LTE-V2X Sidelink, broadcast is the only cast type that is supported.

2.1.1 Physical layer structure design

LTE-V2X divides resources into sub-frame of size 1 ms in time domain; within each sub-frame, out of 14 symbols, only 9 can be used for data as 4 of them are reserved for Demodulation Reference Signals (DMRS) and the last one is a guard symbol which can be used, for instance, for AGC (Automatic Gain Control)processes2.1. Apart from that, two modulation orders are allowed specifically QPSK (2 bits per symbol transmitted) and 16-QAM (4 bits per symbol transmitted).

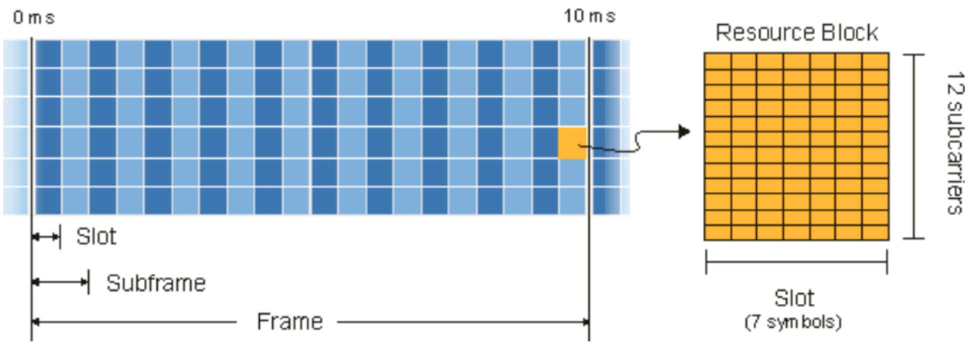

Figure 2.1: LTE physical layer layout

In frequency domain, LTE-V2X utilizes single-carrier frequency-division multiple access (SC-FDMA) with 10 MHz–20MHz channels. A number of resource blocks (RBs) are allocated to the vehicles for their transmission, within each RB comprises 12 sub-carriers with fixed spacing size of 15 kHz. RBs (Resource Blocks) are either grouped into sub-channels to compose control information and mapped into Physical SideLink Control Channel(PSCCH), or for user data purpose which mapped in Physical Sidelink Shared Channel(PSSCH). A set of Sub-channel size and number of sub-channels permitted within bandwidth are defined and specified in 3GPP standards.

2.1.2 Resources allocation and management

LTE-V2X applied mode 3 and mode 4 to dynamically assign and manage resources during communication. Mode 3 as a supervised mode, management is centralised at base station(eNB), which determine and supervise resource selections for each sidelink connection. Alternately mode 4 works without infrastructure, UEs themselves can select resources based on their collected knowledge of current communication statue. As the focus of this study is on V2X sidelink communication in a train system, mode 4 is applied. The following steps outline the detailed approach for this sensing-based semi-persistent scheduling (SB-SPS) which stated in Release 14, and illustrated in Figure.2.2:

- Sensing procedure: This runs within a sensing window with a duration of the last 1000 sub-frames (1 sec), during which the UE decodes SCI messages sent by other UEs to collect and exclude resources that are currently occupied; meanwhile UE also exclude resources which results in a higher reference signal received power(RSRP) than a given threshold.
- Resource reservation : After the previous detection, UE obtains a list of all available accessible resources, these resources have least prone for collision and suffer interference by other communications.
- Resource Selection : UE then randomly choose a certain number of resources from the previous list as final decision, these reservation is selected periodically every Resource Reservation Interval (RRI). Within these UE can start its transmission.
- Reselection: a UE can trigger reselection procedure if a randomly assigned reselection counter is reached to zero. If this is triggered UE will repeat the previous procedure from the beginning.

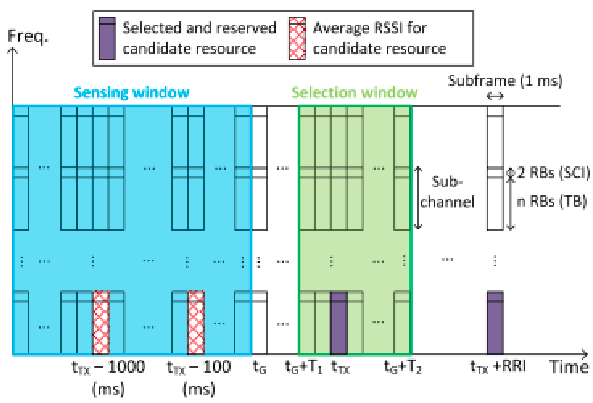

Figure 2.2: LTE V2X illustration of mode 4 sensing-based SPS scheduling ([2])

2.2 Wireless Train Backbone State-of-Art

The Wireless Train Backbone (WLTB) is an evolution of the IEC 61375-2-5 to provide a wireless alternative to the Ethernet Consist Network(ETB). In particular, the major innovation in WLTB is to provide direct wireless communication between consists in order to avoid time losses due to manual coupling and improve the infrastructure capacity.([3]) The WLTB architecture proposed by [4] is represented in Fig. 2.3, as each consist composed of one WLTB node for each ECN plane, whose job is to facilitate single hop and multi-hop wireless communication between WLTBN of multiple consists of a same railway train body. Within train communication, WLTB is also capable of communicating with other trains. As a result, WLTB must be capable of short and long-range industrial wireless communications, as well as single and multi-hop communications. The WLTBN will be connected to a Consist Switch (CS) for WLTB-ECN interconnection.

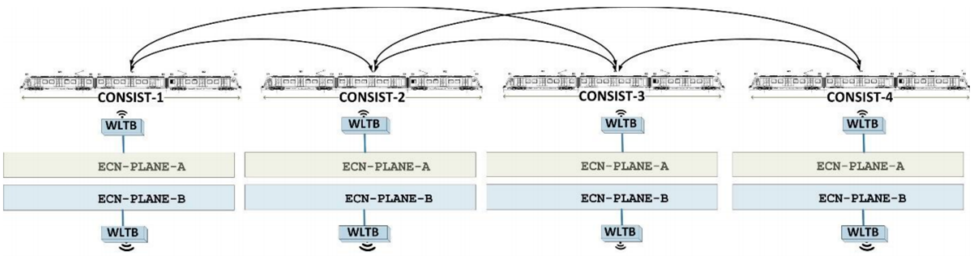

Figure 2.3: Proposed Mesh Topology Architecture for WLTB ([3])

As defined by CONNECTA-2, wireless train backbone communication(WLTB) mainly focusing on supporting TCMS (Train Control and Monitoring System), TCMC is a subsystem of railway vehicles which is required for the functional inboard integration. Fig. 2.4 shows its requirements as both periodic and aperiodic patterns are required. Periodic traffic denotes deterministic cycle times, such as 1ms for Time Sensitive PD, 10ms for Normal PD, and 50ms for Supervisory Data. Aperiodic traffic, on the other hand, behaves in a non-deterministic fashion.

As evidenced by the requirement, WLTB aims to provide high robustness and reliability for train communication, with a data rate of up to 100 Mbps or more and a latency of levels as low as 16 milliseconds. On top of satisfy these standards, some primary objectives are also expected, such as cost reduction, improved maintenance and diagnostics, and the ability to enable creative applications inside train communication. Therefore developing and implementing a cellular sidelink network is an unavoidable trend in WLTB communication research.

	TCMS			
	Process Data		Message Data	Supervisory Data
	Time Sensitive	*Normal*		
Data Size (bytes)	1432	1432	65388	1500
Cycle time (ms)	1	10	N/A	50
Data Rate (Mbps)	100	100	10	10
Latency (ms)	16	32	500	16
	Periodic		***Aperiodic***	***Periodic***

Figure 2.4: CTA-2 traffic performance values. Inter consist (WLTB) ([4])

3. 4G-V2X on Wireless Railway Backbone Analysing

3.1 General Parameters Setting

Preliminary to covering each scenarios with more details, we firstly provide common parameter assumptions that will be considered throughout this study, as listed in Table.3.1. Most parameters are set to default or commonly used features, except some points need to be addressed in the following.
Frequency band used for LTE V2X is reported in [9], the ITS spectrum is not openly available to the rail industry for its Wireless communications. Officially, WLTB cannot use the channel 180/181 (5.895Ghz – 5.905Ghz) due to restrictions to automotive traffic safety related communications, and IEEE channels 172 and 174 are reserved for non-safety related communication. Upper channels IEEE 182/184 are so far restricted to urban rails and cannot be used by WLTB radio devices. On the other hand, 3GPP restricts LTE V2X to operate only on C-ITS spectrum, without specifying which channel. Accordingly, this study will not comply with spectrum restriction and assume, without loss of generalities, the following frequency band: WLTB channel – 5.895-5.905Ghz, 23dBm maximum Tx power.

For traffic aspect, although Roll2Rail D2.1 describes Train communication data of flexible sizes, ranging between 80 bytes up to 1432 bytes. Nevertheless, SAFE4Rail D2.2 specifies a default 190-byte packet size restriction for LTE V2X, so we used that value to facilitate our research. In terms of packet generation time, CONNECTA 2 D1.1 as well as Roll2Rail D2.1 propose 10ms and 20ms. Considering that the mean delay for LTE V2X rel.14 is 10-20ms, it is unlikely that these generation times are supported by LTE V2X Rel. 14 technologies. Accordingly, this study will evaluate WLTB radio with packets under default 10Hz (100ms generation time) average packet generation rate and leave more stringent evaluation to further studies.

Parameters	Value(Baseline)
UE TX Power	23 dBm
UE Noise Figure	9 dBm
Operation Frequency	5.9GHz
Channel Bandwidth	10 MHz
RB/Sub channel	16
Propagation Model	Los+NLos Propagation
Modulation	QPSK 1/2
Packet Size	179 bytes
Packet Rate per Transmitter	10 ms

Table 3.1: Channel Model Setting Table

3.2 Key Performance Indicator(KPI)

In this study, we principally focus on the following KPIs to evaluate LTE V2X performance in train communication. As:

- Packet Reception Rate :Packet Delivery Ratio is the percentage of received packets over total transmitted packets, as a main KPI we rely to assess performance, this value indicate a direct performance quality in general.

- Channel Load: Channel load represents the average occupation of the current channel over a certain determined time interval. This KPI helps to evaluate mobility scenarios, however this value would stay unchanged for immobile scenarios.

- Delay : Although packet average delay is an important requirement indicator to evaluate the performance of the system. However in this study, as will be precised in next chapter, the main character that impact on delay performance is the scheduler, meanwhile plus the codification/de-codification processes this would act as a fix value of delay. We will shortly provide the result of this value, otherwise performance analyzation are mainly referring to PRR.

3.3 Scenario Proposal

In order to analyse 4G-V2X performance in WLTB under realistic and challenging conditions, we proposed four scenarios, comprising the majority of situations in reality where WLTB will be confronted:
• Busy Depot/Junction – This situation corresponds to critical coordination between consists under immobile circumstance, and subject to potentially heavy communication density.
• Idle/busy Station – This situation replicates radio conditions at stations with one train passing by with relatively low speed, either under idle or busy circumstances, LTE-V2X communication will be confronted to varying communication densities both in time and space.
• Moving trains – This situation will evaluate WLTB under medium and high train mobility.

• Tunnel – This situation correspond to WLTB under fully heavy tunnel channel conditions. The following sub-chapters listed the detailed topology and parameter settings.

3.3.1 Scenario-Depot

This scenario correspond to a stable station, which comprise a large amount of consists(UEs) located on each track. Topology parameter settings are listed in Table 3.2.

Overall topology consists of a 2D lattice shaped constellation of consists as shown in Figure 3.1. Considering the distance differences between the length of a consist (26m) and the inter-track distance (5m), therefore communication between consists is asymmetrical on the X and Y axis. Consists at busy depots or junctions are expected to move at low speed, but without loss of generalities, we will not consider mobility at all in scenario, considering that low speed will neither impact the topology nor the channel performance.

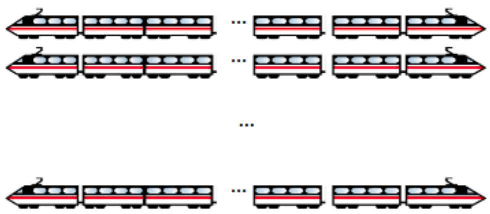

Figure 3.1: Topology of Depot Scenario

This scenario is experiencing both light and heavy consist-to-consist communication, we achieved this by selecting transmitting consists(UEs), either only one header is broadcasting to all other consists, i.e light communication, or all consists are broadcasting their messages to every other consist, which represents heavy communication.

For delay, there is a constant average delay result as 9.28 ms in the system. This delay is mainly caused by scheduler which executed within 10 ms, the affect by channel model and other criteria are too minor to be considered. Since the same delay would apply in all scenarios, we will primarily refer to PRR as the key performance indicator in the following section.

Parameters	Value
Topology	2D lattice, tracks on the Y axis, consists on the X axis
Inter-track distance	3m
Inter-consist distance	26m
Density	10 tracks, 32 consists per track
Mobility	N/A

Table 3.2: Depot Scenario Topology

3.3.2 Scenario - Station

This scenario aims to analyse the impact on transmission quality when a train is travelling through a train station. According to Table.3.3 topology is managed as one moving train is passing by the station with a speed of 50km/h, as an medium speed limit in reality when passing by train stations, several trains are located in parallel in a stable state at the train station, number of trains is correspondence of idle or busy state scenarios (Figure.3.2). Each train is embodied with 32 consists(UEs) as transmitters or/and receivers in communication.

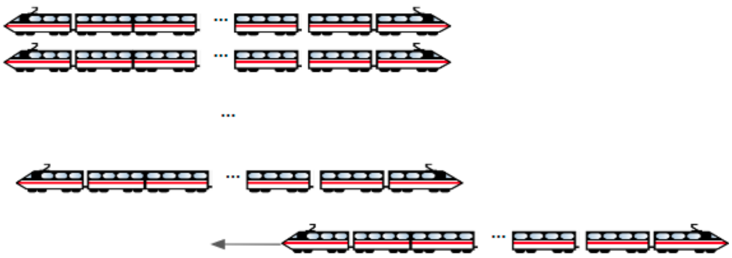

Figure 3.2: Topology of Station Scenario

In this scenario, it is expected that the selected moving train will experience a varying communication load, from a low channel load before entering the train station, a maximum communication load while at the train station, and eventually again a decreasing communication load while leaving the train station. It is also expected that a uncontrolled interference from non-railway LTE V2X devices might be present.

Parameters	Value
Topology	2D lattice, tracks on the Y axis, consists on the X axis
Inter-track distance	3m
Inter-consist distance	26m
Density-Idle Station	1 tracks, 32 consists per track
Density-Busy Station	9 tracks, 32 consists per track
Mobility	Train station: 0 m/s; mobile train: 50km/h

Table 3.3: Station Scenario Topology

3.3.3 Scenario - Moving Trains Head-to-Head

The goal of this scenario is to examine the influence of track-based mobility in overall communication performance. Multi-consist train is travelling along a track and may potentially cross other multi-consist trains on the opposite track, as shown in Fig.3.3. A train's inter-distance between consists is fixed to 1 meter.

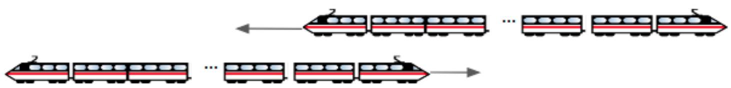

Figure 3.3: Topology of Moving Train Head to Head Scenario

The train's speed and the distance between consists will be crucial. In this scenario, we presented two speeds of 55 km/h and 108 km/h to see the variations produced about by different levels of movement, consist distance is fixed as default value as 26 m. Meanwhile this scenario only considered in an open-air environment, a further study related to channel model including the impact of Doppler and multi-path fading on the LTE V2X communication performance is proposed on tunnel scenarios.

Parameters	Value
Topology	2D lattice, tracks on the Y axis, consists on the X axis
Inter-track distance	3m
Inter-consist distance	26m
Density	32 consists per track
Mobility	Speed low-55km/h; speed high-108km/h

Table 3.4: Moving Trains Head-to-Head Scenario Topology

3.3.4 Scenario - Tunnel

This last scenario aims to analyse the impact on performance of WLTB communications inside tunnel conditions, parameter settings are listed in Table 3.6. According to [1] tunnel is one of the most challenging and diverse environments for communications in railway traffic, as tunnels shape and material is heavily influencing the propagation impact, meanwhile this work carried out an in-depth reality test in different tunnel environment, it concludes that train communication under tunnel scenario is experiencing a heavier path-loss and worse latency in average.

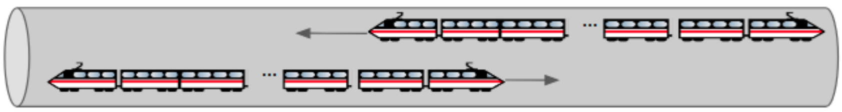

Figure 3.4: Topology of Tunnel Scenario

In order to provide a first-stage simplified scenario for our study, we create tunnel environment as multi-consist trains would be fully inside a tunnel as illustrated in Figure 3.4. Within which , we ignore the strong changes in topology and radio interference between a tunnel and leaving a tunnel, Meanwhile to introduce the test results, we manually added tapped delay line and applied a precalculated traced fading model which adapted to current train speed.

No.of TAP	Delay	station	Tunnel	Open-Air
1 (Los)	0	0	0	0
2	12.5	13.7	12.8	12.8
3	25	19.9	18.9	18.8
4	37.5	11.9	11.3	11.3
5	50	12.7	13.1	12.0
6	62.5	15.1	14.5	14.5
7	75	12.7	12.1	12.1
8	87.5	17.1	16.2	16.2

Table 3.5: Multipath components for Inter-Consist link [1]

Parameters	Value
Topology	2D lattice, tracks on the Y axis, consists on the X axis
Inter-track distance	3m
Inter-consist distance	26m
Density	32 consists per track
Mobility	55km/h
Tapped Delay Line	2 taps
Propagation Model	Line-Of-Sight + No Line-Of-Sight + Pathloss

Table 3.6: Tunnel Scenario Topology

4. Performance of LTE Network in WLTB Communication

In this section, we examine at how LTE V2X communication performs in a variety of train traffic circumstances. All simulations are conducted in the NS-3 simulation framework with settings configured as described in the following chapter. Based on the findings, we may draw conclusions regarding the benefits and drawbacks of LTE communication.

4.1 Simulation Integration of LTE-V2X in WLTB

In this study we apply Network Simulator 3 (NS-3) platform to realised simulation according to our proposed scenarios, as an open-source packet-level simulation platform, NS-3 is widely adopted also due to its flexible simulation framework and integrated tools for performance evaluations.

NS-3 natively contains a 3GPP LTE architecture and models developed by the LENA team at CCTC[10] . It has been later extended to support 3GPP LTE rel.12 D2D by the NIST[11]. And more recently, through a cooperation between EURECOM and NXP, the 3GPP LTE rel.14 V2X has been integrated. Figure.4.1 depicts the protocol architecture of the 3GPP LTE stack in NS-3 and shows the added extensions to support SL communications and LTE V2X. In NS-3, each LTE UE net-device is an independent agent, which will attached to an Application generating traffic. The net-device will handle the channel access and NS-3 will gather all data traffic from all net devices at each time step and emulate a wireless channel. At the end, ns-3 delivers data traffic to the right LTE UE agents. Mobility and Channels can be changed, either by direct control or by importing external models.

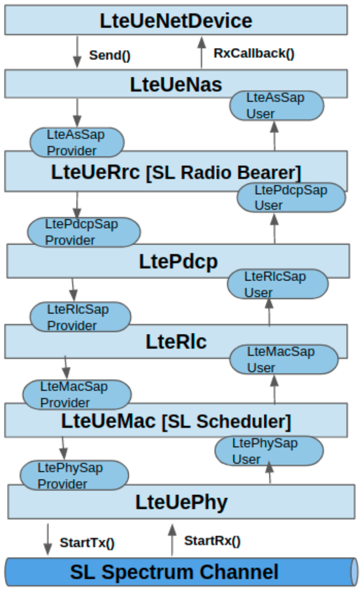

Figure 4.1: LTE Sidelink Architecture in ns-3

4.2 Depot Scenario Result

Figure.4.2 summarised PRR result of this scenario, considering both light and heavy traffic scenarios under dense depot topology. In this part we ignore the channel load indicator because there is no mobility involved and the value would remain constant over simulation time.

Figure.4.2(A) considering only one single WLTB consist transmitting to all others, the objective of this part is to evaluate the impact of the fading, without the contributions of packet collisions. As it can be seen, the PRR remains at 100% until around 250m, where the channel attenuation makes the received SNR weaker and generates packet losses.

On contrary, in Figure.4.2(B) considers all WLTB consists transmitting and accordingly includes the impact of packet collisions as well as half-duplex impairment. As expected, the PRR is significantly weaker and reaches 93% at 100m, and worsen at 200m less than 90% due to the fact that an automotive domain scenario under a comparative high density of 200 vhl/km more packet collisions are generated, meanwhile as half-duplex impairment placed in a worse performance result generated.

From result we can deduce that one hop distance is rather limited for LTE V2X communication, and such depending on reliability requirements, for instance a highly reliability this one-hop distance can be limited to approximately 80m, typical length train (850m) would necessitate at least 10 hops to cover from head to end. Therefore to expand the coverage of a V2X transmission system to a greater distance requires development of efficient routing mechanism, concurrently we can refer to result for future WLTB packet routing mechanism study. Furthermore, in a dense depot scenario, communication conditions are severely impacted due to resource exhaustion and transmission interference, a better scheduling scheme would required in order to achieve a higher capacity within V2X LTE network.

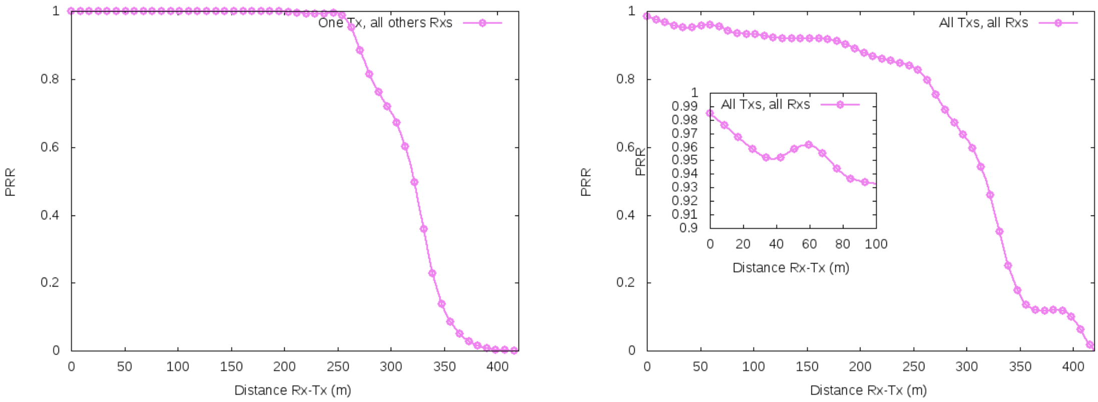

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Figure 4.2: Depot Scenario in Idle state Result

4.3 Station Scenario Result

In this section, we evaluate the performance of the WLTB of moving train passing by station, under either a sparse or challenging dense train station.

Result figures illustrated in Figure3.2 should be read from left to right. At -500m, the moving train is too far from the train station to be impacted. A 0m distance indicates the moving train entering station, thus the moving train starts being impacted by the train station trains. Then distance increasing till its reach a fully overlapped position with station trains(around 800m) then departs totally from train station till it travels too far from the station to be impacted.

In this scenario all consists are performance as transmitter and receiver, therefore half-duplex impact is featured. Two station environments are considered, for idle station only one train is located meanwhile busy station has 9 trains located in parallel. Furthermore results are considered from moving train's perspective, two PRR standpoints are calculated in respect of source of transmitted packets is whether from moving train itself or station trains. A channel load result also provided from moving train perspective.

Idle station results summarised in Figure 4.3. First Figure 4.3(A) shows Packet reception rate from two transmission perspectives, green line represent TX-RX both from moving train, an average PRR shows approximately 60%, this low rate is due to it includes very weak PRR for large distances.Although we could also show the PRR for only short links, we believe that integrating any tx/rx distances is a better reflector of the true performance of the WLTB. And as it can be guest, such PRR is too low, and one strategy to improve it would be to rely on shorter wireless links over multi-hops. In the meantime overall PRR stays stable during the passing by movement. The unstable oscillation is due to channel propagation interference in addition of system randomness. The purple line shows transmitted by station consists correspondingly received by moving train, which illustrates the evolution of the channel load as a function of the distance. As it can be observed, PRR increases or decreases in a positive relationship with the average distance between the train and the station, pro tem the highest PRR is approximately the same as moving train to itself. Figure 4.3(B) shows the channel load(as traffic density), we can

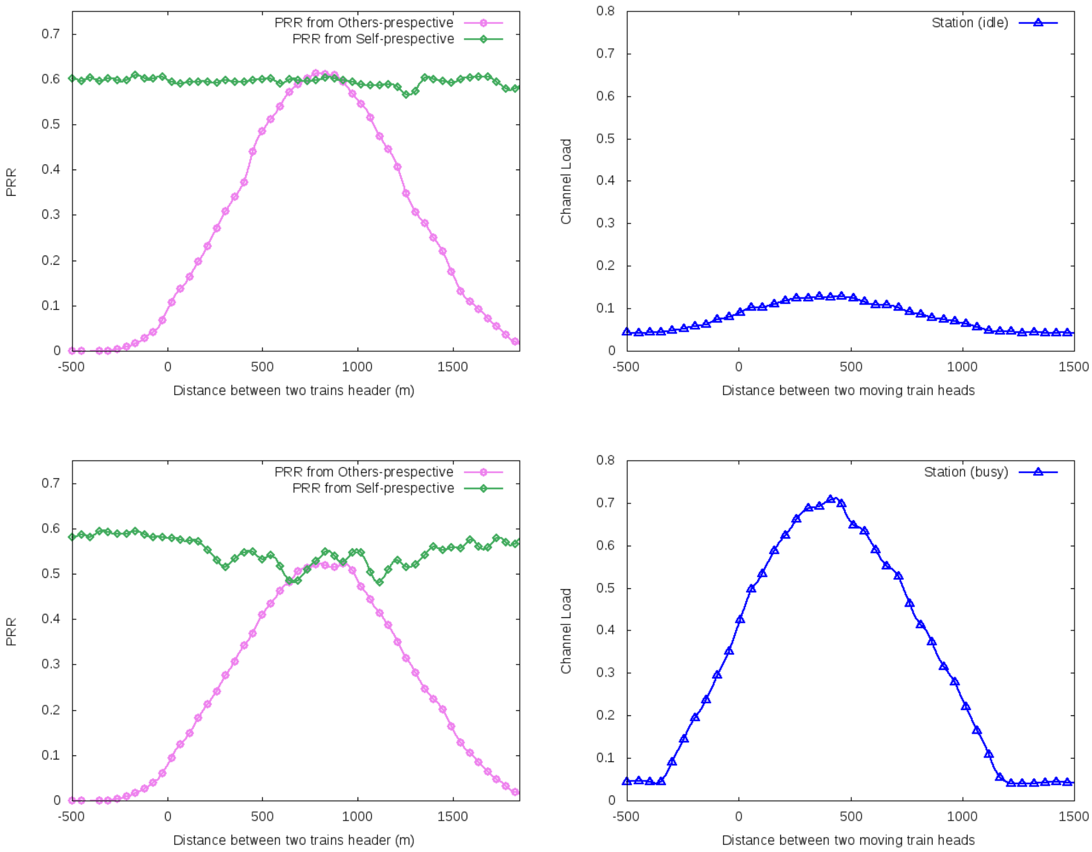

Figure 4.3: Station Scenario Result

see that impact by idle station to overall channel load is comparatively low.

Busy station results illustrate in Figure 4.3(C) and Figure 4.3(D), in comparison with idle station, we can observe a significant oscillation toward dropping of PRR experience on moving train itself perspective when passing by train station. As indicated in channel load over distance in Figure 4.3(D), a significant raise and fall in overall traffic load can be observed, busy station prompt heavy traffic load which reproduce more packet collision, resource exhaustion, and other tendencies consequently lead to communication failure, consequently a busy station has a significant impact on overall performance.

4.4 Moving Train Head-to-Head Scenario Result

This section scenario corresponds to a situation commonly found in open tracks. The objective is to evaluate the impact of the WLTB for inter-consist communication within the train, or, two multi-consist trains are crossing each other on opposite tracks and the objective is first to evaluate the wireless link performance between consists, as well as the impact of different speed crossing on the inter-consist WLTB communications on both trains.

Figure 4.4(A) firstly depicts the PRR for both inter-consist and inter-track communication among consists. Green line represents the inter-consist PRR reception, as within one moving train, all consists are transmitting and receiving from other consists from the same train. The line tendency indicate a stable reception including movement of two

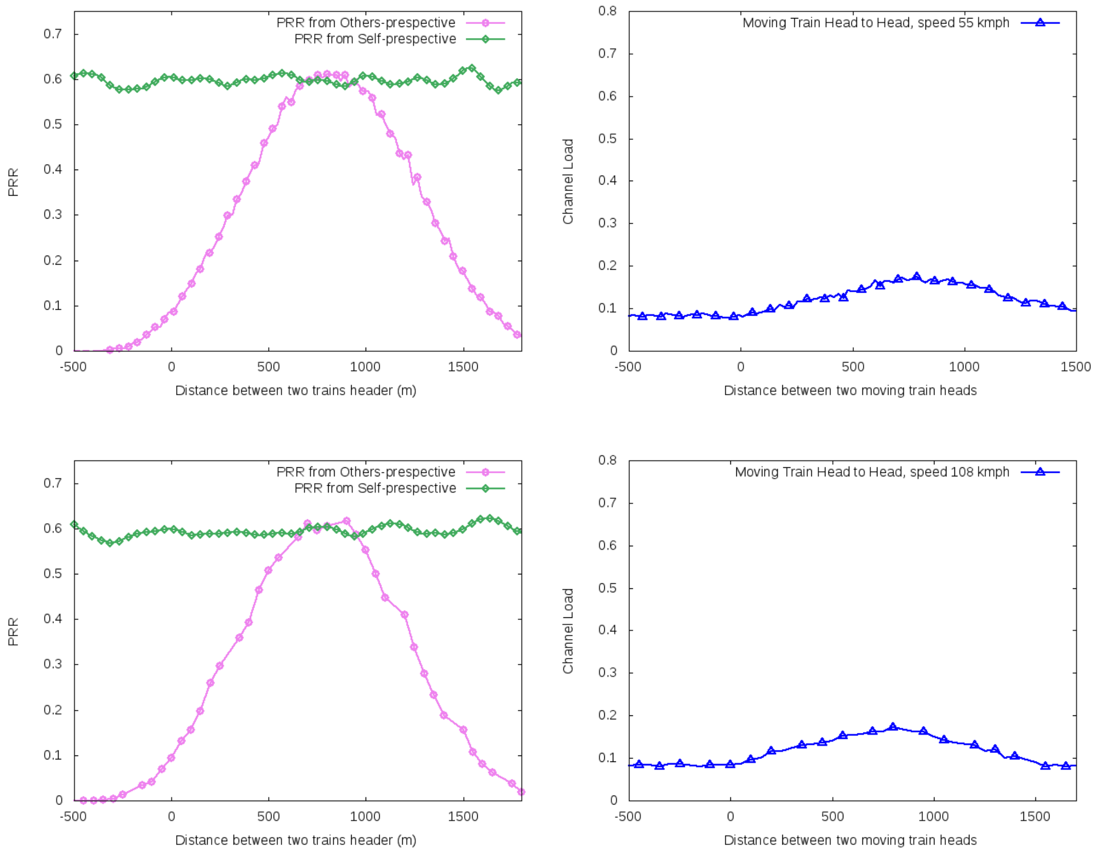

Figure 4.4: Moving Train Head to Head Result

trains passing by each other, we can conclude the impact brought by other passing by train is comparatively insignificant. Moreover similar as previous scenario, the PRR integrates all Tx/Rx distances, leading to only a 60% PRR. The unstable oscillation is due to channel propagation interference in addition of system randomness.

Whereas line in purple represents the inter-track PRR reception, this calculate the reception rate of packets which are transmitted from other passing-by train and received by current train. As two trains getting closer, the number of consists that enter in the feasible communication range from the other train's perspective is raising as well, therefore the reception rate of PRR is raising correspondingly, a peak local maximum around 62% reached when two trains reach a parallel position. We can observe this value is slightly higher than peak reached inter-consist PRR, this is due to the fact that the distance between two trains is much less as only 3 meters, therefore the consist density within the communication range is higher to obtain a higher PRR. After passing by, a decreasing number of consists are able to communicate with one another, causing the PRR to drop, till its reach zero as trains travel outside of the communication zone. A channel load is illustrated as function of trains interval distance illustrated in Figure 4.4(B), indicating that a collision failure is unlikely to occur.

Correspondingly a similar simulation executed with a higher train speed as 108 kmph, PRR results illustrate in Figure 4.4(C), compare with previous lower speed, we can observe the inter-consist PRR stays approximately the same, however a less smooth raising and falling for inter-train PRR, aka heavier oscillation over the simulation, this is owing to the fact that at a faster relative speed, the topology changes rapidly, causing the overall reachable number of consists within range to change dramatically as well, resulting in a heavier fluctuation.

Accordingly, we can conclude that a passing-by train has approximately no impact on current track inter-communication, however for a inter-track communication is difficult to achieve a stable high quality link, moreover the increase of the channel load generated while both trains are aligned on both tracks also impacts the reliability of the WLTB. To improve the performance of the WLTB under this condition would be efficiently limit communication into a narrow time interval , another solution is to rely on directional antennas.

4.5 Tunnel Scenario Result

For tunnel scenario we applied Moving Train head to head Scenario, acting as two trains fully positioned inside tunnel and heading toward each other. In order to inspect the impact by different environment of tunnel brought to the simulation, we figure results with reference of previous section, as illustrated in Figure.4.5. The light green and purple lines indicate the reference result in open-air condition, dark green and dark purple lines representing results from self-perspective and other-perspective communication respectively under tunnel environment. As demonstrated, the overall tendency are approximately the same, as tunnel condition experience a marginally deterioration throughout the simulation, this is due to the worse channel propagation condition applied, meanwhile taking into account of Doppler effect which evidently product heavier interference.

The actual tunnel scenario, as previously noted, is significantly more complicated than this simplified study. Tunnel investigation could produce completely different results depending on factors such as whether trains are fully or partially positioned inside the tunnel, the actual manifested influence of the tunnel, and train mobility in terms of direction and speed. Our research provides a day-one analysis, as we can see that under tunnel settings, with three multi-path fading and a pre-configured Doppler effect, performance is marginally worsened.

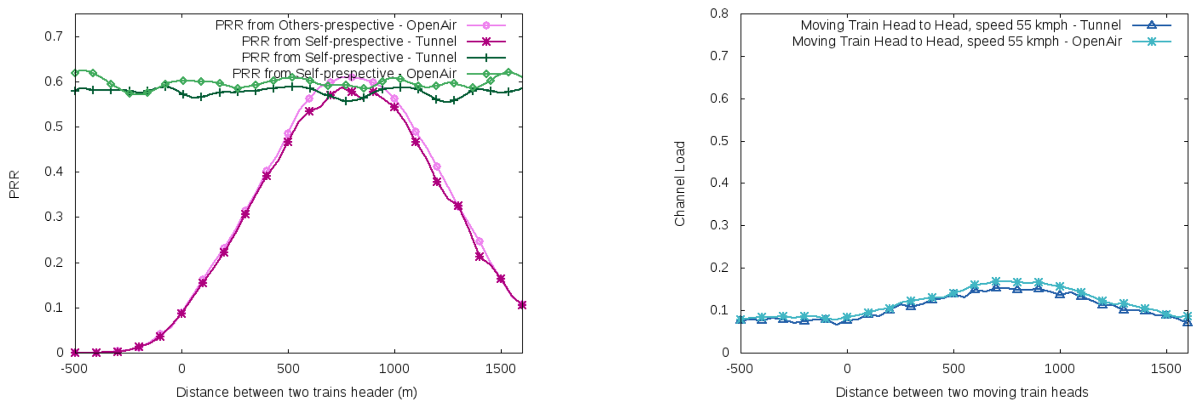

Figure 4.5: Tunnel Result

5. Conclusion

In this work, we proposed a thorough analysis of direct sidelink communication using LTE-V2X technologies under both a normal and challenging state. According to our proposed four real-world-events-based sub scenarios, we firstly demonstrated the limitation in range and traffic capacity of one-hop broadcasting communication in a busy depot scenario, indicating that in the following stage of research, a multi-hop effective routing mechanism should be studied. For the next step, we discovered that a congested station can have a significant impact on the passing train's communication quality. We also proved that inter-train communication degrades, while trains are traveling at a relatively high speed, and it is difficult to achieve an optimal quality. Furthermore, if trains are traveling through tunnels, the situation can deteriorate and becomes far more complicated to analyse, such that the overall environment is complicated by tunnel scenarios, making analysis incredibly hard.

All in all, we provide a referable result for the next stage of research for cellular train sidelink communication. While 4G Sidelink communication provides certain good criteria such as high speed and low latency compared to previous technologies, we can see that when compared to the requirements set forth by the WLTB, 4G technology struggles to meet the demands of the most demanding traffic situations. For this reason, the deployment of 5G Sidelink, which promises low latency and ultra-reliability (URLLC) communication, will be the primary focus of future research.

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Bibliography

[1] Horrizon-2020 JU Roll2Rail, D2.2, *Characterisation of the Railway Environment for Radio Transmission*, 2019.

[2] M. H. C. Garcia, A. Molina-Galan, M. Boban, J. Gozalvez, B. Coll-Perales, T. Şahin, and A. Kousaridas, "A tutorial on 5g nr v2x communications," *IEEE Communications Surveys Tutorials*, vol. 23, no. 3, pp. 1972–2026, 2021.

[3] J. Härri, A. Arriola, P. Aljama, I. Lopez, U. Fuhr, and M. Straub, "Wireless technologies for the next-generation train control and monitoring system," in *2019 IEEE 2nd 5G World Forum (5GWF)*, pp. 179–184, 2019.

[4] Horizon-2020 JU CONNECTA 2 D1.1, *Specification of evolved Wireless TCMS*, 2020.

[5] A. Larranaga, A. Arriola, I. Martinez, P. Aljama, J. Härri, I. Lopez, U. Fuhr, and M. Straub, "5g technology for next-generation wireless consist networks in railways," in *Nets4Cars Nets4Trains Nets4Aircraft 2021, International Workshop on Communication Technologies for Vehicles,* (Springer, ed.), 2022.

[6] Y. Mahn-Suk, L. Sung-Hun, L. Chang-Kyo, C. Soo-Hyun, and K. Wan-Jin, "Performance test of lte-r railway wireless communication at high-speed (350 km/h) environments," in *2018 Tenth International Conference on Ubiquitous and Future Networks (ICUFN)*, pp. 637–640, 2018.

[7] Horizon-2020 JU Safe4Rail2 D2.1, *Requirements of LTE Equipment and ETBNs for wireless TCMS*, 2019.

[8] Horizon-2020 JU Safe4Rail2 D2.4, *Advanced Wireless Technologies and Applications for Wireless TCMS*, 2021.

[9] Horizon-2020 JU Safe4Rail2 D2.3, *LTE Equipment under Challenging Wireless Scenarios – V1.2*, 2020.

[10] G. Piro, N. Baldo, and M. Miozzo, "An lte module for the ns-3 network simulator," *Proceedings of the 4th International ICST Conference on Simulation Tools and Techniques: March 2011*, 01 2011.

[11] R. Rouil, F. Cintrón, A. Ben Mosbah, and S. Gamboa, "Implementation and validation of an lte d2d model for ns-3," pp. 55–62, 06 2017.