5G URLLC in Transport and Open RAN: Disaggregation RAN and Functional Splits

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Abstract—* The industry of automobiles is entering the era of advancement. The proliferation of quick advancement in autonomous cars, electric vehicles progression in the market, evolution towards digital platforms, economical resource sharing, massive surge in data, extensive network connection demands and succession towards business models is developing intense change in the sector overall. The next generation of communication (5G) network has the potential to support and accelerate this revolution and can also play role as the backbone network for these advanced Vehicle-to-everything (V2x) automobiles communications. 5th Generation (5G) technology exhibits number of features over previous generations of networks by offering more speed, enhanced bandwidth, much lower latency (also known as ultra-reliable and low latency communications network) and extensive simultaneous connections. Open RAN (O-RAN) architecture is majorly focused on the principles of disaggregation, virtualization and intelligent evolved Radio access Network (RAN). In this paper, we present key radio network requirements of autonomous cars and proposed a 5G radio access network (RAN) architecture suitable for handling such communication. Furthermore, interfaces of O-RAN and proposed solutions are presented as well, which will facilitate the adoption of 5G O-RAN solution for future autonomous vehicles. Finally, we present our experimented and tested results of Open RAN compliant state-of-the-art prototype.

Keywords— 5G, 5G Small Cell, Enhanced mobile broad Band (eMBB), Massive Machine Types communications (mMTC), Open RAN (O-RAN), Ultra-reliable & low latency communication (uRLLC).

I. INTRODUCTION

Cellular wireless communications have evolved from first generation wireless communications (1G) to fifth generation wireless communications (5G) [1]. Unlike previous generations, 5G has multiple salient features like ultra-Reliable & Low Latency Communication (uRLLC), massive Machine Type Communications (mMTC) and enhanced Mobile Broad Band communications (eMBB) [2].5G as compared to its legacy networks, aims to provide significant key enabling services such as massive simultaneous connections at an instant, extensive high data rate (by acquiring high bandwidth) and extreme low latency [3]. Recent years have observed that with the passing of each decade a new generation of cellular mobile wireless communication system emerges. Legacy networks i.e., fourth generation (4G also known as LTE) and third generation (3G also known as UMTS) have already attained the saturation level of their features and services. Furthermore, in legacy networks (4G & 3G) different techniques to improve the capacity and coverage have been implemented which includes band refarming, carrier aggregation (CA) and bandwidth enhancement. The coverage and capacity issues are expected to be addressed, in future by 5G small cell wireless communication systems [4]. This solution (5G small cell) will be proposed exclusively for 5G network densification. In the coming years, it is estimated that there will be an approximate increase of 800 times in the deployment of 5G small cells [5]. This forecasted deployment of 5G small cells will adopt Open RAN (O-RAN) as RAN architecture solution. According to Small Cell Forum (SCF) by 2026 more than 80% of indoor small cells will adopt O-RAN and to reduce the cost this deployment will be hosted by neutral hosts [18]. Evolution in smart vehicle in accordance with artificial intelligence, is increasing regardless of coverage and capacity challenges in 5G cellular communication. According to studies on statistics of road travelling connected cars and their revenue in Europe, there were ~46 million connected cars worldwide in 2018, which is now expected to increase to 125 million (270% of previous count) [6].

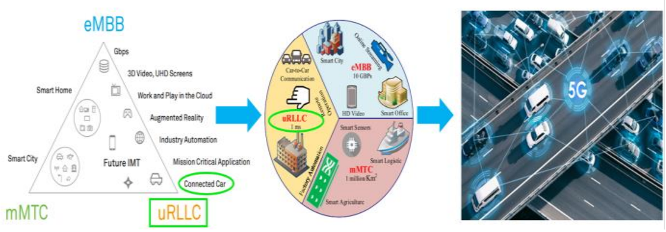


Fig. 1. 5G based Autonomous vehilces Self driving Cars [7] , [19].

This massive increase in numbers is a sign towards hyperconnectivity. The revenue market of the same industry is also expected to grow by five (5) times (as compared to 2019) in the coming years. It is predicted to reach almost $200 billion annually by 2027, from the current annual figure of around $40 billion. According to another estimation, the fatal accidents can be reduced by 90% with the help of autonomous cars just in United states, which will reduce traffic related costs by around 190 billion dollars [6]. These massive forecasted figures will also trigger the data demand which may be in range of petabits equivalent to 2 million gigabits [8]. With the help of 5G network, the massive data rate mile stone can not only be achieved but it will also reduce the data processing from 230 days to 2 days [9]. It is forecasted that autonomous vehicles will be available commercially by 2030 in the world and Global efforts are being undertaken on improvement of public transport under ambition "Autonomous vehicles experience and challenges" [10].

II. Latency in 5G and Legacy cellular networks

In Table 1, we have presented and compared 5G latency bottlenecks with previous legacy networks i.e., 3G and 4G. We realize that 5G technology is advancing over previous networks since it ensures zero latency in some cases. Typically, Latency values in 3G, 4G and even in 5G exclusive feature eMBB are found 100 milli second, 20-30 milli second and ~4-5 milli second respectively. However, 5G provides uRLLC feature which in some cases ensures latency less than ~1 milli second (over air interface) and also ~5 milli second in end-to-end device connectivity [11]. The feature (uRLLC) will be explained in the upcoming section, along with a review of its benefits.

TABLE 1 Latency in 5G and legacy wireless Technologies

Network	Latency (ms)
3G (UMTS)	~100 ms
4G (LTE)	~20-30 ms
5G (eMBB)	~4-5 ms
5G (uRLLC)	~<1ms

III. 5G Network slicing and uRLLC

5G network slicing is a unique feature which helps the Mobile Network Operators (MNOs) to create number of virtual platforms on a shared common physical infrastructure [12]. This feature or virtual platform allows the operators to customize the network according to application, number of users, traffic pattern and type of services. Each network slicing in 5G has unique application and behavior. The idea (network slicing) is in accordance with RAN disaggregation Open RAN (O-RAN) concept. Slicing divides, the physical infrastructure of network into multiple networks which support multiple applications and services simultaneously. The system is capable of optimization as well. In 3GPP standards Rel 16 & Rel 17, uRLLC is discussed as [13-15]. 5G feature uRLLC ensures the requirements of time sensitive devices for time sensitive communications (TSC) like robotics (used in autonomous industry), remote surgeries, driver less cars and similar latency non-tolerant applications. Under this feature of 5G, network will also ensure multiple simultaneous connections with a connected device with the help of massive MIMO spatial diversity [16]. In "Fig. 2", 5G features uRLLC & eMBB are demonstrated and mapped with Split RAN architecture. It is revealed that for latency sensitive application we need high layer split (HLS) i.e. Split 2 and for broad band or data hungry devices we can adopt low layer split (LLS) i.e. Split 7 or Split 8. The details of Split RAN architecture are discussed in upcoming next section.

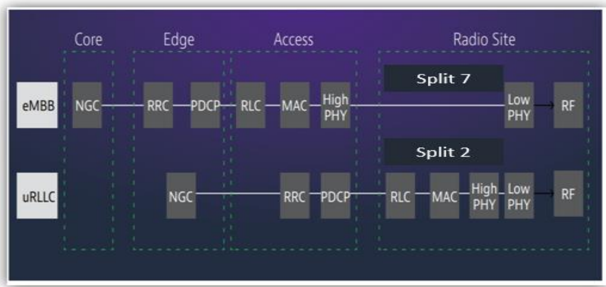


Fig. 2. uRLLC & eMMB and 5G Network Silicing

IV. Open RAN (O-RAN) / Split RAN & RAN Disaggregation

Open RAN (O-RAN) is an evolution of RAN (radio access network) in which base band unit (BBU) of base transceiver station (BTS) is further customized in Open Remote Unit (O-RU), Open Distribution unit (O-DU) and Open Central Unit (O-CU) in such a way that interfaces between these components are open. O-RU is component of O-RAN which will communicate with user equipment (UE) and central Unit (CU) with core network [17]. In case of 5G it can be deployed either 5G standalone (5G SA) or 5G non-standalone (5G NSA). O-RAN is also known as RAN functional split architecture in which the network layers are split into different elements depending upon nature of application, network complexity, cost, bandwidth and data rate requirements. According to the recommendation of 3GPP, O-RAN alliance, and small cell forum (SCF), the high layer split (HLS) is Split-2 which separates the Central Unit (CU) & Distribution Unit (DU) in accordance with separation in control plane and user plane as demonstrated in "Fig. 3". Similarly Lower Layer Splits (LLS) are Split-6, Split-7, and Split-8. Specifically Split-7 is assigned to O-RAN [18],[19]. This feature of RAN disaggregation drives dynamic evolution in RANs, unlike traditional Radio access Network (RAN). It grants mobile network operators (MNOs) the freedom to select and deploy networks based on their specific applications as explained in "Fig. 2". Furthermore, inter-operable, vendor independent, scalable, and self-optimization are salient features and benefits of O-RAN. The evolution in the Radio Access Network introduces cost-effective and flexible hardware solutions, resulting in the reduction of both, the Capital Expenditures (CapEx) and the Operating Expenses (OpEx). O-RAN alliance has defined 11 different working groups along with testing integration focused group (TIFG) for research contribution in O-RAN.

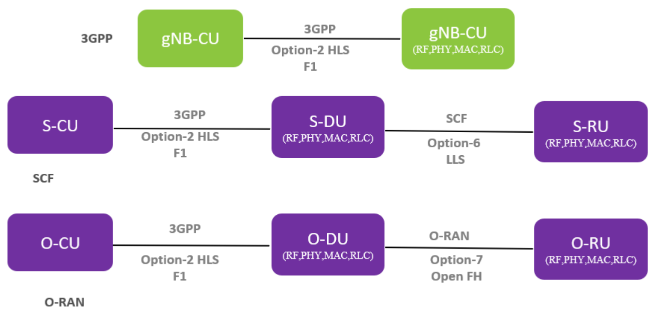


Fig. 3. 3GPP , Small Cell Forum and O-RAN alliance Specifications [18].

V. Open RAN (O-RAN) Interfaces

The evolution in traditional RAN to O-RAN will directly increase the ease of deployment and also reduce the cost. Furthermore, autonomous self-driving cars will directly leverage network slicing and self-optimization capabilities enabled by the O-RAN Component Radio Intelligent Controller (RIC). This feature will reduce the cost and power consumption as well. Recently Vodafone (European Mobile Network Operator), in an O-RAN trial in O-RAN alliance spring 2022 global Plugfest conference, has proven low energy consumption in vendor-diverse environment. This feature will eventually lead to cost reduction [20]. O-RAN will become the direct demand of industry as its revenue (as compared with traditional RAN) is forecasted to be dominant by 2030 both for public and enterprise deployments [21]. In this section we have explained in "Table. 2" the interfaces from access point to core end along with deployment connection ranges [22]. The ease of deployment can be clearly figured out that fronthaul is an open interface (CPRI/eCPRI) among all vendors which ensure the interoperability. Moreover, Central Unit (CU) and Distribution Unit (DU) can be stacked together and placed in the mobile network operator vicinity which ensures the flexibility of deployment in O-RAN. The flexible deployment provides ease to communication service providers (CSPs) and MNOs to deploy less hardware on the site that reduce the operational cost (OPEX) overall. In traditional RAN the fronthaul is not as flexible because of aggregated RAN elements. In future, for quick, scalable, high performance and cost effective 5G RAN deployment, O-RAN can directly fulfill challenges of (5G based) connected autonomous cars industry.

TABLE 2 Open RAN Interfaces details [22]

Variables	Fronthaul DU & RU	Mid haul CU & DU	Backhaul CU & 5G Core
Range	Less than 20 KM	Less than 80 KM	Less than 200 KM
Connection Interface Type	CPRI, eCPRI, O-RAN Interface	F1 Interface (Ether net)	S1 interface (Fiber or MW)
Latency	micro seconds	Milli seconds	Tens of milli seconds

VI. Challenges & Requirments in 5G Autonomous Cars

In this section we will explain six key challenges and requirements for 5G based connected autonomous cars found in the literature [23-26]. 5G radio access network must comply with these requirements. First, we will explain the modes or levels of driver less car as discussed in [25] and later in "Table. 3" we have mapped the modes /levels of self-driving cars on radio access network (RAN) requirements i.e., transmission delay (latency) and data rate [27].

1. Communication in 5G equipped transport must be trust worthy and durable so that it may retain its connection with network even any of its essential operating element malfunctions or even failed.

2. All the sensors (involved) in 5G supported vehicles/transports must be tested in such a way that in case of failure or malfunctioning of any part, the option to transfer the control to human must be viable instantly.

3. The above mentioned switching whenever needed must be quick and seamless.

4. For health and safety measurements perspective, 5G supported (autonomous) vehicles' behavior must be understandable and must be prompt to other road objects.

5. 5G supported autonomous vehicle must be able to sense the human driving behavior in order to respond and manage the situations like sleeping, dizziness and longtime inactiveness.

6. Communication in 5G supported vehicles must be secure and should not be prone to any cyber-attacks or threats.

The key challenges and goals related to "5G in transport" have been discussed. 5G network requirements (time delay and data rate) vs degree of automation for 5G autonomous cars have been explained in Table 3.

TABLE 3 Autonomous car levels and Radio Access network requirements [27]

Driving Level	Degree of Automation	Latency (ms)	Data rate (Mbps) Per autonomous car
1	Assisted/controlled Driving	100-1000	0.2
2	Partial automated driving	20-100	0.5
3	Conditionally automated driving	10-20	16
4	Highly automated driving	1-10	100
5	Complete autonomous car	0-1	100

In "Table.3" it is revealed that for complete 5G based autonomous car we require highly Time sensitive communication (TSC) so that all the functions including sensors may respond and can be controlled actively. For partial automation in 5G autonomous cars the latency bottleneck can be tolerated in between 20-100 milliseconds. On the same hand, assisted controlled driving can be handled with low data rate and high latency i.e., 100-1000 milliseconds.

VII. Proposed 5G RAN Solution for Indoor & Outdoor Smart Time Sensitive Driving

RAN disaggregation feature helps to deploy the network according to 5G application and also eases the deployment time. The Split RAN architecture can be adopted by the 5G application which are sensitive to latency requirements even below 1 msec. The Open interfaces overall improve the performance of RAN network. In "Table.4" a comparison between Split-2, Split-6 and Split 7.2 in accordance with 3GPP, SCF and O-RAN alliance standards is presented. The general cost comparison is also reviewed.

TABLE 4 RAN Functional Splits Comparison

Variable	Split -2	Split -6	Split 7.2
Split Type	High Layer Split	Mid Layer Split	Low Layer Split
Standards	3GPP	Small Cell Forum	O-RAN Alliance
Interface	F1 Interface b/w (CU&DU)	nFAPI	eCPRI/CPRI (Vendor unlock)
5G Application	URLLC	eMBB/URLLC	eMBB
Deployment Cost	High	Medium	Low
Bandwidth / Throughput	Low	Medium	High
Latency Tolerant	High	Medium	Low

From the RAN functional split comparison, it is revealed that Split-2 is best RAN architecture for latency sensitive application. It can be implemented for 5G radio access network in accordance with smart indoor/outdoor autonomous cars. Especially when we need higher autonomous driving level i.e., Level 5 as presented in "Table.3".

For partial and conditional autonomous driving i.e., Level 2 and Level 3 we can move to lower layer split (LLS) either Split-6, Split-7 or Split-8 which is applicable for latency tolerant application. In "figure 4" a shareable (among CSPs) RAN architecture with interfaces, RAN split options (2,6,7) and application is presented. Both indoor and outdoor O-RAN compliant 5G small cells can adopt these scenarios. A Neutral Host induction can further reduce the RAN deployment cost and also speedup the network deployment as this practice is very popular now.

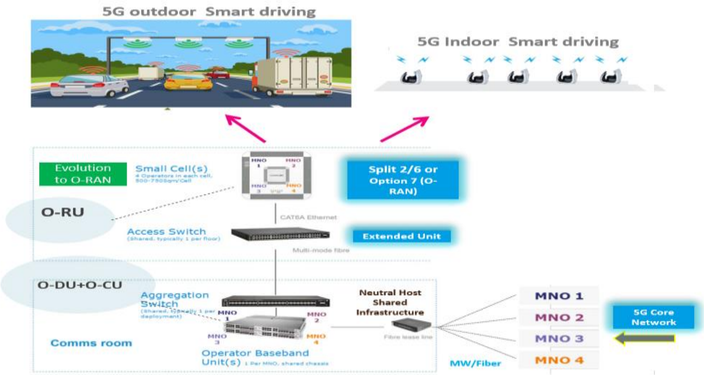


Fig. 4. 5G Split Radio access Network (RAN) /Open RAN (O-RAN) Based proposal for indoor & outdoor smart vehicles communications

VIII. Open RAN Compliant 5G Small Cell (srsRAN) Implementation

srsRAN is currently focused in variety of 5G/6G experimental research studies [28]. To study Open RAN systems in details we constructed a 5G open RAN compliant small cell prototype in the lab environment. The environment consists of srsUE , commercial of-the-shelf (COTS) hardware for O-CU/O-DU, virtualized Open5GS core, srsRAN compliant Software Defined Radio (SDR) Ettus USRP B200, spectrum analyzer, a test sim and internet connection. The schematic diagram of the system is depicted in "figure 5".

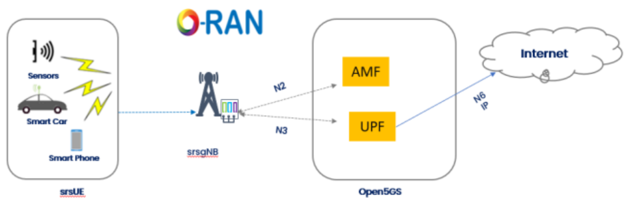


Fig. 5. 5G Standalone (SA) Small Cell srsRAN Labsetup (Open RAN)

The Split RAN architecture selected for experimental studies is RAN Split-8 in which protocol stack (RLC, MAC PHY) is confined in one COTS hardware including Open5GS Core. For signal Processing perspectives, in downlink data flow, the frequency domain signal will be transformed in to time domain by IFFT. To furnish OFDM symbol a Cyclic Prefix (CP) in the time domain will be added. The furnished OFDM symbol will then be transmitted to RF-front-end for Digital Up Conversion (DUC). In RF front end, Digital to Analog (DAC) conversion will be performed. Since we are using "Category A" O-RU so to make the O-RU design simple the precoding functionality will be performed in O-DU in Downlink data flow. Similarly, in Uplink (from srsUE to 5G gNB) after Analog to Digital conversion (ADC), Digital Down Conversion (DDC) will be performed. The signal will be transformed from frequency domain to time domain by Discrete Fourier transform (DFT) and then the Cyclic Prefix (CP) will be removed. The symbols are then transmitted to demodulator to furnish baseband signals. The lab prototype is depicted in "figure 6". The core can either be virtualized in to the same hardware or can be configured in to a separate hardware. Furthermore, wired or wireless connection can be established with srsRAN and 5G core. Wireless connection can adopt mmWAVE or tera hertz radio link as backhaul. Our system is virtualized in the same COTS hardware and the Open5GS core acts as bridge between srsRAN and internet via UPF component of the Open5GS core as shown in figure 6.

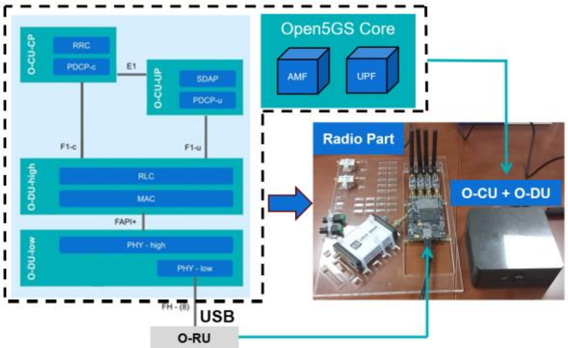


Fig. 6. Open RAN LAB setup deployed Prototype in ACES

We have configured the RAN design parameters as explained in “Table.5” and later in troubleshooting process we observed that the values of the implemented RAN parameters must be consistent at UE, RAN and core end otherwise we observed degradation in accessibility key performance indicators (KPIs) i.e., IMSI attached success rate/ RACH Success Rate. The configured RAN parameters, in the srsRAN system are as suggested for Open RAN compliant 5G Small cell in [19].

TABLE 5 Summary of RAN design Parameters

System Metrics	Value
Operating System	Ubuntu 22.04.
RAN Type	srsRAN, SA Core
RAN Split	8
Carrier Frequency	3408.96
Duplex Mode	TDD
Sub-carrier Spacing	30 KHz
Supported MIMO Layers (gNB)	2x2
UE Type	Samsung A34, 5G
Transmit RF Power	>10 dBm
UE Position w/ Respect to O-RU	Line of Sight (LOS)
Channel Bandwidth	20 MHz
O-RU Category	Category A
PLMN (MCC + MNC)	00101
TAC	7
NR ARFCN	627264
TX & RX Frequency	3408.96 MHz
Band	n78/ C-Band, Sub-6 GHz

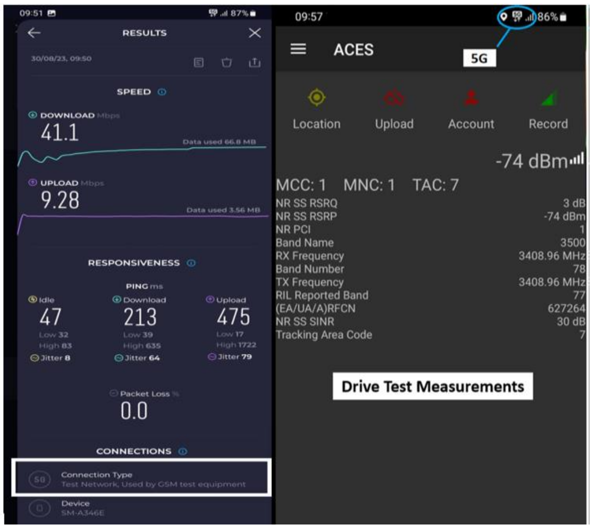
Hosts Run the operating system of Ubuntu 22.4.RAN specification include 2x2 MIMO, C-Band/n78, 20 MHz, TDD, Standalone core, 30 KHz sub-carrier spacing and RAN architecture is Open RAN compliant. The RF front end (RFE) is connected to COTS hardware (O-DU/O-CU) via USB 3.0 interface. For synchronization system is using internal clock. We observed good coverage (Rx level) and appropriate signal quality in the lab environment. The results are presented in the upcoming next section.

IX. RESULTS

We adopted the experimental methodology for Open RAN environment as suggested by Open RAN alliance Test integration Focused group (TIFG) specification document O-RAN.TIFG.E2E-Test.0-v04.00. The Open RAN compliant 5G Small Cell prototype in the lab environment is propagating a low power i.e., around ~10 dBm. We have primarily prioritized KPIs for autonomous cars as suggested by “Table.3”, this includes Latency and UL/DL throughput. We also ensure that accessibility, retainability, availability and mobility of the Open RAN system follows the requirements suggested by Open RAN alliance specification.

(a) (b)

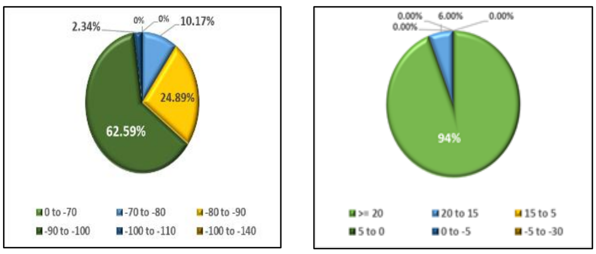
Fig. 7. Screen short for (a) Measuring UL/DL throughput for Connected srsUE in ORAN system (b) Spectrum Analyzer Tuned in C-Band



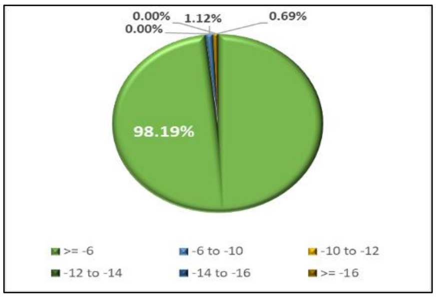
(a) (b)

Fig. 8. Screen short for (a) Speed Test and Latency (b) RAN parameters & KPIs Measurments

“Fig.7” & “Fig.8” depicts the connected UEs to 5G open RAN System and we performed and captured the RAN KPIs (Signal Strength, Signal Quality, Data Rate, latency) at radio network access end.



(a) (b)



(c)

Fig. 9. Measured 5G RAN KPIs (a) Reference Signal received Power (RSRP) (b) Signal to interference and noise Ratio (SINR) (c) Reference Signal Received Quality (RSRQ)

Furthermore, we used RAN drive test software "Nemo Analyzer V8.8" for capturing the RF results as depicted in "Fig.9" to "Fig.12".

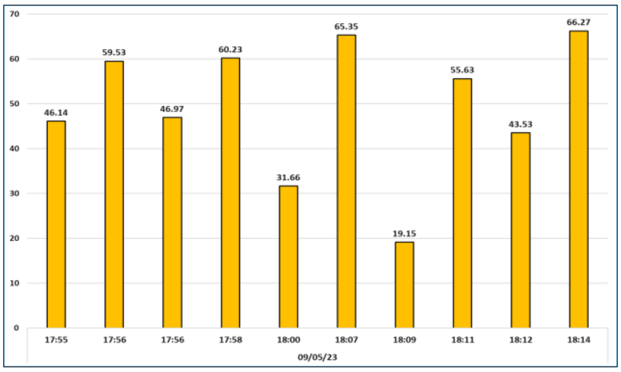


Fig. 10. Downlink Measured User Throughput (Mbps)

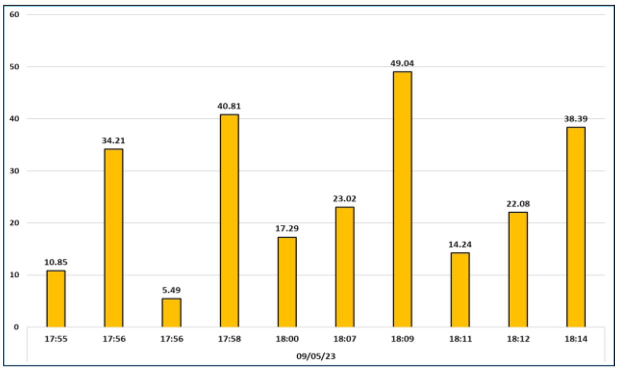


Fig. 11. Uplink Measured User Throughput (Mbps)

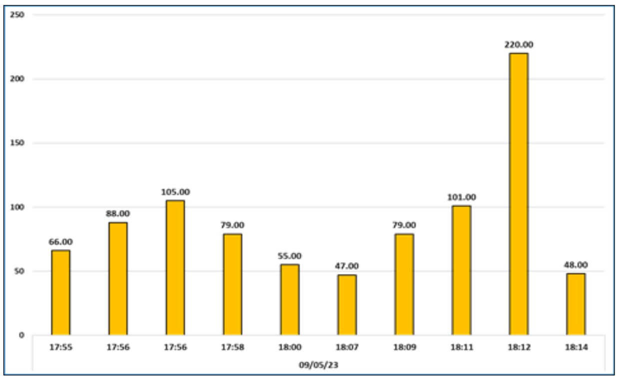


Fig. 12. Measured User Latency (ms)

After plotting the extracted results from the software Nemo analyzer, we have presented the statistics of UL/DL throughput and latency which demonstrate that the system is compliant with autonomous Level 1,2, 3 for data rate and autonomous Level 1,2 for latency perspectives. We consider these results to be highly promising, achieved through experimentation with srsRAN, an O-RAN compliant 5G small cell solution.

TABLE 6 Summary of Measured results and comparison

5G RAN KPIs	Expected Results	Measured Results	Remarks
DL NR SS RSRP (Rx Level)	**>-75 (dBm) to -90 (dBm)**	-74 dBm	Good
DL NR SS SINR	**>25 dB**	30 dB	Excellent
DL Throughput	**0.2 Mbps Level 1**	41.1 Mbps	Autonomous Car Level 1, 2 ,3 Compliant
	0.5 Mbps Level 2		
	16 Mbps Level 3		
	100 Mbps Level 4 & 5		
Latency	**100 (ms) to 1000 (ms) Level 1**	~47 ms	Autonomous Car Level 1 & 2 Compliant
	20 (ms) to 100 (ms) Level 2		
	10 (ms) to 20 (ms) Level 3		
	1 (ms) to 10 (ms) Level 4&5		

CONCLUSION

In this research paper, we have identified the key requirements and challenges of 5G based autonomous connected cars and proposed Split Open RAN architecture. We consider shareable Open RAN compliant 5G small cells solution is suitable and cost effective both for indoor and outdoor smart autonomous driving. We have come to the realization that when it comes to time-sensitive communication (TSC), the implementation of 5G technology with uRLLC compliant hardware, as specified by 3GPP, SCF, and O-RAN alliance, can be achieved through the adoption of a Split-2 RAN architecture. Deploying O-RAN compliant hardware will increase flexibility, ensure quick deployment, and also reduce the CAPEX and OPEX cost. 5G network also ensures and fulfils the requirement of massive simultaneous connections for sensors of autonomous car under its feature mMTC. The flexibility and ease of deployment for radio access network components in accordance with O-RAN will help the service providers to adopt the suitable network for future demands. Open RAN aiming on new 5G industrial demands offers adaptable, flexible and scalable RAN architecture solution.

In the lab prototype we observed exceptional performance of 5G open RAN system with seamless connectivity. We adopted the testing methodology as suggested in Open RAN alliance specification documentation. We experimented Split-8 Open RAN architecture which complies with Autonomous Car levels up to 3. Furthermore, for future work or extension of this work one can enhance the capabilities of testing Higher Layer Split (HLS) i.e. Split 7.2 , Split 6 or Split 2 with enhanced bandwidth to get high data rate and meeting latency requirements. One can also expedite the expertise to interoperability (IOT) testing by using srsRAN Split 7.2 concept and O-RU from other radio suppliers. Such experimental approaches will add significant results to Open RAN research community and 5G applications like autonomous cars, remote surgeries etc.

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