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The IoV Meets Open RAN: An O-RAN-based IoV Architecture

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Abstract: The race towards a better-connected world has led to innovations in network connectivity and the embedding of intelligence into various types of devices. Intelligent devices require an intelligent network infrastructure and design in order to reach their maximum potential. Recently, the concept of Open Radio Access Networks (Open RAN, O-RAN) has gained a lot of attention with the formation of the O-RAN Alliance which seeks to usher in the next phase of cellular network interoperability, intelligence and design. Another key concept that has emerged in recent years is the Internet of Vehicles (IoV) which has been described as a driver for next generation Intelligent Transportation Systems (ITS). This paper proposes an architecture that brings together these two concepts and explores how the design principles of the O-RAN can be incorporated into the IoV by using a bottom-up approach. It also discusses the benefits of an O-RAN-based IoV, some perceived challenges with its implementation and the way forward.

Keywords: Intelligent transportation systems, internet of vehicles, O-RAN, Open RAN

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1. INTRODUCTION

The ubiquitous nature of the Internet of Things (IoT) is transforming the entire world into a more connected place. This has also led to the growth of the open-source movement which had sought to battle the use of proprietary technologies in the areas of networking, software and product development. One of the key areas which has gained attention in recent years is the incorporation of intelligence into vehicles and the evolution of existing telecommunication networks to meet the trend. The concept of the Internet of Vehicles (IoV) has become very prominent feature of the above trend. It is built onthe use of cellular technologies as means of connecting vehicles to each other and their immediate environments.As new trends have emerged in cellular technologies, they have been incorporated into the IoV architecture to improve its efficiency and the services related to it. Some challenges of current IoV architectures include the difficulty in migrating IoV related information to the cloud, the lack of a standardized communication protocols and a limited ability to apply AI/ML-based resource allocation and task offloading strategies in rapidly changing vehicular environments.

This paper proposes an architecture based on the next phase of the principles of open- source which has emerged in the area of Radio Access Networks (RAN) by relating it to the IoV. It begins by taking a look at the concept of vehicular intelligence and proceeds to track the evolution of the architectures that have supported it so far. The rest of the paper outlines the principles of Open Radio Access Networks and explores how they work within the context of the vehicular environment. This is done by examining how the components of an Open Radio Access Network architecture for vehicles would function. The paper concludes by taking a look at the benefits, challenges and the way forward integrating the IoV with Open Radio Access Networks. The main contributions of this paper are highlighted in Figure 1.

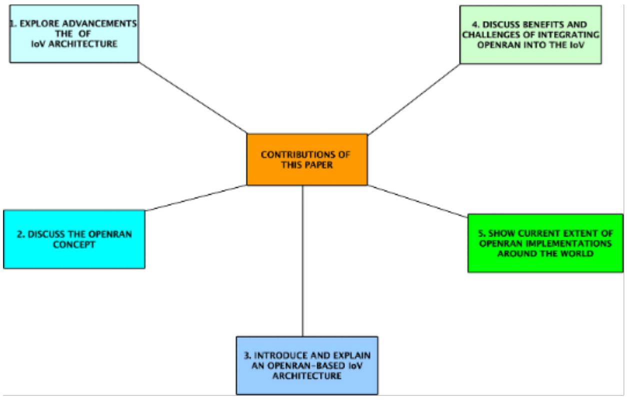

Figure 1. Contributions of this Paper

2. THE INTERNET OF VEHICLES

As a subset of the field of the ITS, the IoV is a term that is used to describe the various forms of communication that exist between a vehicle and its environment [1]. There are three broad forms of communication within the IoV. These are inter-vehicular communication, intra-vehicular communication and vehicular mobile internet [2]. The generic architecture of the IoV, is based on the broad architecture of the ITS. According to [3], a typical ITS consists of:

i Vehicles
ii Communications Infrastructure
iii Centre Station

As such the initial proponents of the IoV architecture proposed an architectural design that consists of:

i The Perception Layer
ii The Network Layer
iii The Application Layer [4].

A simplified form of the IoV architecture can be seen in Figure 2.

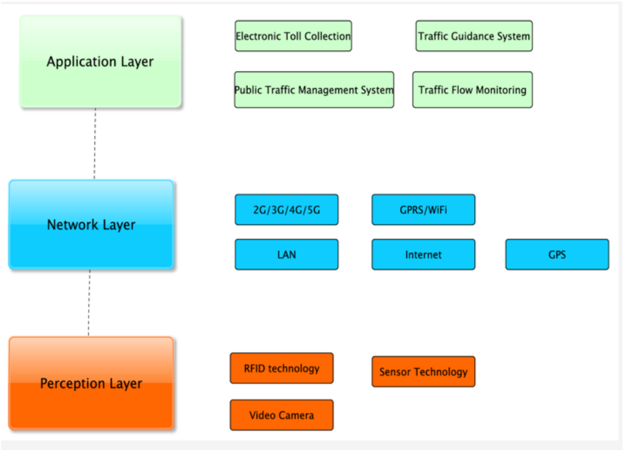

Figure 2. Internet of Vehicles (IoV) Architecture; Author's Construct

The Perception layer is the lowest layer of the IoV architecture. It primarily consists of sensors that are used to collect information from the vehicle's immediate environment. Connectivity within the IoV is facilitated by the Network Layer. It contains options for 3G,4G, 5G as well as Bluetooth, wireless local area networks and wireless fidelity (Wi-Fi).

The Application Layer is the part of the IoV architecture that supports vehicular applications such as traffic management, smart behavior and entertainment. It makes use oftools for polling the information from the vehicles. This information is stored, processed and analyzed to ensure efficient decision making with respect to vehicular behavior on the road network or the services that can be provided by vehicles. Of all the interactions that occur between vehicles and telecommunications infrastructure a technology known as V2X has become very popular. V2X is a term thatis used to describe short range communication between a vehicle and anything in its environment [5]. The "X" in the term represents anything in the vehicle's environment. The term Vehicle to Everything Communication is commonly used in reference to V2X communication [6]. Common V2X variants include Vehicle to Infrastructure(V2I), Vehicle to Vehicle(V2V), Vehicle to Pedestrian(V2P), Vehicle to Cloud(V2C) and Vehicle to Network(V2N). The most widelyused of these are V2V and V2I [7].

3. EVOLUTION OF THE IOV ARCHITECTURE

Continuous innovation with respect to the intersection between ITS and V2X has led to the concept of Intelligent Transportation-based Cellular Communication. This is an adaption of V2X technology within the cellular communication space which allows for bidirectional communication between multiple vehicles and telecommunication infrastructure over a wide area. This adaptation allows vehicles to be integrated with cellular communication networks and brings the processing power and coverage abilities cellular networks to bear on vehicular networks.

Cellular-V2X(C-V2X) as it is commonly called allows vehicles to partake in human voice, data and video communications with improved data communication rate and lower latency [8]. The 4th Generation Long Term Evolution (LTE) standard was the first cellular technology to incorporate V2X based standards known as LTE V2X and LTE eV2X which support autonomous driving and vehicle safety. The integration of cellular communication and V2X technology allows data packets to be transferred on the back of V2I, V2V and V2P connections. It also facilitates efficient communication for highly mobile vehicles at about 500km/h.

The IoV architecture has evolved quiet rapidly over the past few years in line with various technological advancements in the cellular networking world. At the core of this evolution has been the adaptation of various cellular-based technologies within the IoV. The four major architectures in this evolution are:

i The Traditional architecture
ii The SDN-NFV architecture
iii The MEC architecture
iv The AI/ML-based architecture

3.1 The Traditional Architecture

The traditional IoV architecture basically maps all inter and intra-vehicular connections to Road Side Units (RSUs). These RSUs are linked to a central base station that is connected to a cloud server. This architecture became well- known during the advent of cloud computing. It integratesthe power of cloud computing and its advantages into the design of applications for the IoV hence promoting faster design of IoV applications and low-latency transmission of IoV-related data. Figure 3 shows the traditional IoV architecture.

3.2 The SDN-NFV Architecture

The advancement of Software Defined Networking (SDN) and Network Functions Virtualization (NFV) brought about the SDN-NFV architecture for the IoV. The SDN-NFV architecture for IoV is based on the presence of an intelligent device called a controller which manages the underlying vehicular communication network using specified interfaces and the OpenFlow protocol.

The SDN-NFV architecture introduced the principles of open source into the IoV. Hence the design of IoV specific applications became available to third party developers and users.

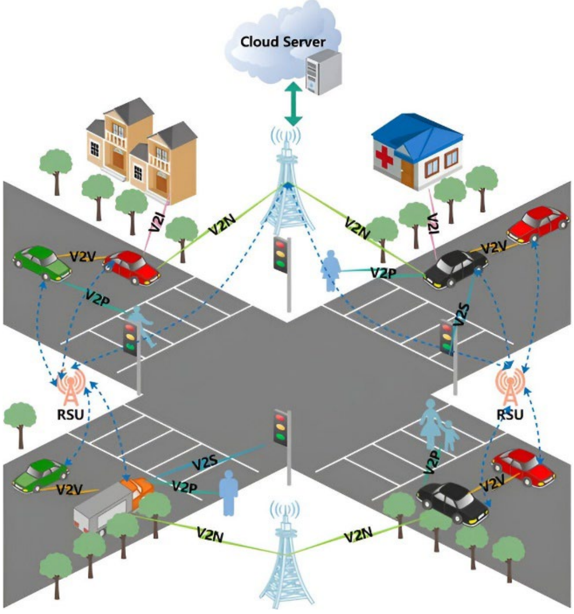

Figure 3. Traditional IoV Architecture [9]

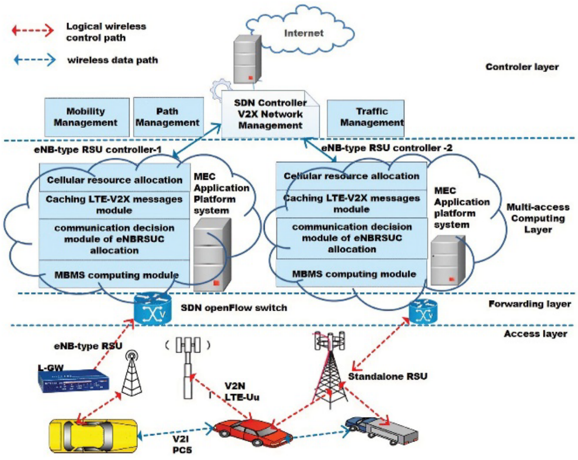

Figure 4. SDN-NFV IoV Architecture [10]

3.3 The MEC-based Architecture

The next most significant IoV architecture is based on Multiaccess Edge Computing (MEC). In this architecture, RSUs which are connected to base stations facilitate low-latency communication between vehicles and the core network of a telecommunication service provider. The cloud and the MEClayer are fused to reduce the resource bottleneck issue that arises from increasing requirements for data and network- related resources in the IoV. The SDN-NFV and the MEC- based IoV architectures are shown in Figures 4 and 5.

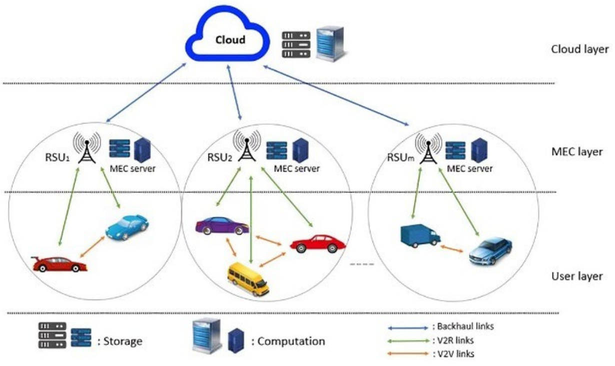

Figure 5. MEC IoV Architecture [11]

3.4 The AI/ML-based Architecture

The AI/ML-based architecture is an improvement on the MEC-based architecture. The architecture makes use of an agent that observes and determines policies for managing the IoV using data from sensors, roadside cameras, RSUs and other connected devices in the vehicular environment. This facilitates efficient communication resource and traffic management, the design of IoV-based applications and the use of data analytics in the IoV. This architecture is also key to the advancement of autonomous driving, resource optimization and enhanced Quality of Experience (QoE) for vehicular users. Figure 6 shows the AI/ML IoV architecture.

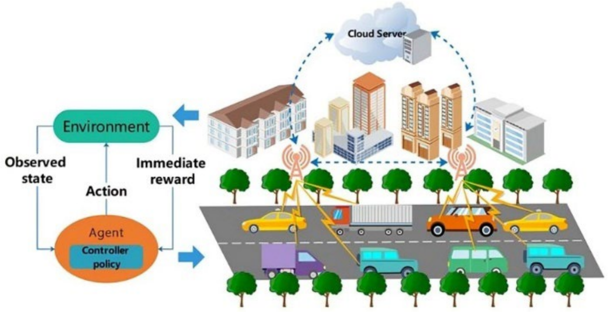

Figure 6. AI/ML IoV Architecture [11]

From these advancements it can be seen that as scope of cellular networks have evolved, its integration into the IoV has also evolved. In line with the above trend, this paper proposes a new architecture based on the next proposed phase of the evolution of cellular networks known as OpenRAN.

4. THE OPENRAN CONCEPT

OpenRAN also known as O-RAN is a new standard in the radio access networks that has been proposed by the Telecom Infrastructure Program Group. The aim of this group is to totally redefine 2G, 3G, 4G and 5G Radio Access Networks (RAN) using open interfaces, vendor-neutral hardware and software [12]. OpenRAN can be defined as a radio access network where hardware from any equipment supplier can be used with software and Application Programming Interfaces (APIs) from different suppliers. The four main features of OpenRAN are:

i A shift from proprietary hardware to commercial-off- the-shelf hardware.
ii Splitting of key RAN functions among different nodes to manage real-time and non-real-time services. This is known as disaggregated RAN.
iii A software enabled network.
iv The migration of traditional applications from local installations to web-based equivalents. This is known as Cloudification [13].

OpenRAN has the aim of reducing the operational cost involved in setting up radio access networks while ensuring quick operationalization of network services and features [14]. It also aims at preventing vendor lock-in, reducing time to market and building an intelligent network. The O-RAN Alliance is a group of mobile network operators, contributors, vendors and experts that is committed to making sure that mobile network technology is fully open, smart, secure and flexible. It is involved in the design of specifications related to OpenRAN. The O-RAN Alliance is also responsible for the development of open software for the RAN as well as testing and integration of O-RAN implementations. The Alliance organizes exhibitions which allow its partner companies to showcase implementations of O-RAN based solutions.

5. OPENRAN-IOV ARCHITECTURE

The development of the O-RAN standard and design principles has a great bearing on C-V2X technology and the IoV. This paper delves into the merger between the principles of O-RAN and the IoV and proposes an O-RAN-based IoV architecture based on specifications described in [15]. Figure 7 shows the proposed O-RAN based IoV architecture. A bottom-up approach will be used to describe the architecture and its supporting interfaces as follows:

i Vehicle to RAN Communication
ii Disaggregated RAN Communication
iii Near Real time Intelligent Controller
iv Orchestration and Automation

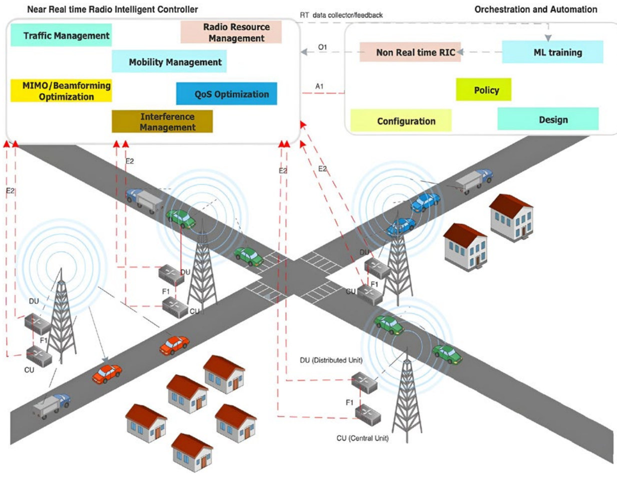

Figure 7. Proposed O-RAN IoV Architecture

5.1 Vehicle to RAN Communication

Vehicle to RAN communication sits at the base of the architecture. Modern vehicles communicate with the RAN by means of a vehicle On-Board Unit or Equipment (OBU or OBE). This device typically consists of a transceiver, a processor, a Global Position System (GPS) and an interface to the vehicle's systems and its human interface. The OBU gathers data and sends it to the RAN through a series of snapshots [16]. This data is transmitted through the OBU to the Central Unit (CU) of the RAN which serves as the first point of contact between IoV related data and the ORAN architecture. From here, the IoV related data is transferred to the Distributed Unit (DU) through the F1 interface which links it to the CU. The E2 interface then forwards the data to the Near Real-time RAN Intelligent Controller where radio and traffic related functions are carried out. The automation and orchestration framework finally collects the data and sends feedback to the Near Real-time RAN intelligent controller through the O1 and A1 interfaces. Each of the above-mentioned processes are described in further detail in the subsections below.

5.2 Disaggregated RAN Communication

The disaggregated RAN is the first unique characteristic of the O-RAN concept. It is based on the splitting of the functions of the RAN into a Distributed Unit (DU) and a Central Unit (CU). The Distributed Unit (DU) is a logical node that is responsible for carrying out the lower layer functionalities of the RAN such as modulation, coding and rate matching. It is also responsible for the scheduling and allocation of resources and segmentation. These functions are carried out in the High-PHY, RLC and MAC layers of the RAN. The two key protocols that exist within the DU are Automatic Repeat Request (ARQ) and Hybrid Automatic Repeat Request (HARQ).

The DU is the first point of inter- action between the OBU of the vehicles and the OpenRAN architecture. It facilitates the lower-level exchange of data from vehicles to the RAN as compared to the aggregated structure used in other IoV architectures. The CU is responsible for upper layer functionalities of the RAN such as Quality of Service (QoS) flow handling, robust header compression and security. It facilitates interconnection between the RAN and the virtualized edge computing platform through use of public land mobile network (PLMN) selection, paging and connection to Layer 3 networks.

The key protocols that facilitate this connection are the Packet Data Convergence Protocol (PDAP), Service Data Adaptation Protocol (SDAP) which is unique to 5G and the Radio Resource Control (RRC) protocol. The interconnection between the DU and CU is carried out via the F1 interface. This interface shares information with respect to resource sharing and the status of the vehicles connected to the RAN and can connect one CU with multiple DUs.

The Disaggregated RAN concept allows both the CU and the DU to communicate independently with a logical node known as the Near Real time Radio Intelligent Controller (RIC) via the E2 interface. The connection between the E2 interface, the RIC, CU and DU form an E2 node. The E2 interface is bidirectional and is responsible for transmitting near real time vehicular data from the CU and the DU to the RIC through optimization and control protocols. Integrating the disaggregated RAN into the IoV guarantees faster conversion of lower-level communication units into data packets. Since one CU can interface with multiple DUs there is a wider scope of communication and a more efficient management of network-based resources due to provision of redundancy in the network.

5.3 Near Real time Radio Intelligent Controller (Near-RTRIC)

This node is responsible for the intelligence of the O-RAN design. It is the successor to the controller used in the SDN-NFV IoV architecture. The Near-RT RIC is a logical function that facilitates near real-time control and optimization of the all services in the IoV. The Near-RT RIC primarily operates using the policies and data obtained from the non Real- time RIC to generate analytical information from the vehicles connected to the RAN. It works hand-in-hand with the E2 interfaces service model to monitor, override, control and stop the functions related to the underlying vehicular envi- ronment. It does this through fine-grained collection of data and the implementation actions within the IoV through the use of xApps. xApps are applications that can be deployedin the Near-RT RIC for resource optimization. The five key functions of the RIC as seen in Figure 7 are:

i Interference Management
  In an IoV network where small cells might be utilized for key applications, the Near-RT RIC can be used to reduce the interference by detecting interference based on Received Signal Strength Indicator (RSSI) from vehicles. This can be used to formulate policies for offloading vehicles to nearby small cells using service priority and RSSI. This principle can also work in non-heterogeneous networks where proactive interference management can be used to implement predictive solutions to interference related issues before they affect applications used by vehicles in the IoV. In the context of 4G-based IoV networks, interference management within the Near-RT RIC facilitates dynamic usage of frequency and would reduce the effect of challenges posed by increasing density of vehicles in the IoV.

ii MIMO/Beamforming Optimization
  The Near-RT RIC supports beamforming in the vehicular use case by providing operators the flexibility to configure policies that improve the aggregation and coverage capacity in heterogeneous networks that are made up of small and macro-cells. This approach allows for the use of the changing mobility parameters in the vehicular network to allocate beams between cells. This will result in better handover performance, improved performance at the cell edge and lower inter-cell interference in the highly mobile vehicular environment. Onekey vision of this function of the Near-RT RIC in the IoV is the ability to directly send optimal parameters via the E2 interface to the DU and the CU. This optimization is based on the use of real-time AI/ML models which are constantly trained and optimized based on the state of the underlying vehicular network.

iii QoS Optimization
  The provision of specific QoS for varied applications for vehicles in the IoV is of paramount importance. The scheduler in a typical RAN uses the principles of network slicing to allocate Physical Resource Blocks (PRBs) to ensure an optimal allocation of resources based on the needs of applications in the IoV. To achieve Service Level Agreements (SLAs), the Near-RT RIC works with the Non-RT RIC to implement policies that control the allocation of PRBs. This is done through the A1 interface. QoS optimization in the IoV is therefore a function of the constant monitoring of the application services and the adjustment of their behavior in response to changing situations. This feature is critical in ensuring that telecommunication companiesfulfill service level agreements and creates opportunitiesfor vehicle manufacturers to improve and diversify the kinds of services offered by vehicles.

iv Radio Resource Management
  The radio resource management paradigm of the Near-RT RIC in the IoV involves the allocation of resources for the management of network slices. The allocation of resources in a highly dynamic environment where vehicles may have different application requirements will require the use of traffic patterns, location, time and the type of application as metrics. The Near-RTRIC relies on these metrics obtained through the E2 interfaces and forwards them the Non-RT RIC. Quota policies determined by the accumulation, trainingand prediction of demand patterns can then be usedto allocate resources based on changes in the state of vehicular traffic such as emergencies, accidents, failure of applications and more. Real-time data analytics of vehicular volumes and the nature of applications being requested by the vehicles can serve as a means of introducing new service streams for vehicle manufacturers.

v Traffic Management
  Traffic Management within the context of the IoV involves the ability of the Near-RT RIC to support and satisfy the requirements of different vehicular access technologies such as 5G, LTE, NR, and Wi-Fi. Each of these access technologies have unique frequency bands which carry huge volumes of traffic. The Near-RT RIC uses policy-based traffic steering to enforce redefined policies and configurations for each of the above-named access technologies. It does this by interpreting actions and policies received from the Non-RT RIC which determine control and user plane al-locations, radio bearer handling and QoS targets for the access technologies that are being implemented by the underlying vehicular network. Traffic management provides a common ground for both network operators and vehicle manufacturers to collaborate and innovate based on specific access technologies which might be used in vehicles.

The Near-RT RIC is linked to the orchestration and automation framework of the OpenRAN IoV through specialized APIs.

5.4 Orchestration and Automation

The Orchestration and Automation framework in the IoV-based ORAN architecture falls under the O-RAN concept of Service Management and Orchestration (SMO). SMO refers to the use of an intelligent platform for automating all the services in a cloud-based network. Hence the SMO acts asan enhancement of the cloud-based IoV architecture and includes of database that stores data from the underlying vehicular network.

The SMO is responsible for lifecycle management and automation through the O1 and A1 interfaces. The O1 interface is responsible for fault detection and correction, configuration and operation, accounting and billing, performance assessment and optimization as well as security assurance and protection. In addition to the above, the O1 interface is responsible for collecting and assessing the Key Performance Indicators (KPIs) of the DU and the CU. The main advantage of the SMO concept in the O- RAN design is that the standard A1 and O1 interfaces are open. This allows for interoperability within the multi- vendor ecosystem which in the case of the OpenRAN IoVis made up of vehicle manufacturers and telecommunication network providers. It also provides fine-grained end-to-end management of the entire network whiles facilitating the integration of AI/ML models for optimization based on the use of real-time data and analytics obtained from the IoV.

The Orchestration and Automation framework of this architectureis made up of the following modules:

i Non Realtime RIC

It is an internal function of SMO that is responsible for facilitating the optimization of the RAN through policies, ML models and the use of standardized databases. All intelligent resource management functions related tothe RAN are also performed by the non-RT RIC. It is composed to two main modules which are the non-RT RIC itself and Non-RT RIC Applications which are also known as rApps. These applications use data from the non-RT RIC to trigger actions within the Near RT RIC via the A1 and O1 interfaces. The interface between therApps and the non-RT RIC is the R1 interface.

ii ML training

Within the context of SMO for the IoV, ML training follows a six-step approach known as the AI/ML workflow. Based on the principles discussed comprehensively [13],we adapt an AI/ML workflow for the OpenRAN-based IoV.

a) Data collection and processing

In this phase, data from the underlying vehicular environment is collected from the CU and the DUvia the E2 interface to the Near-RT RIC which passes it on to the Non-RT RIC through the O1 and A1 interfaces. The data is stored as large-scale datasets with proper data reporting solutions. This portion of the AI/ML workflow also carries out data preprocessing to prevent problems associated with poorly formatted data.

b) Training

In the training phase, different types of ML models are used for classification, analysis, prediction and the development of policies related to the vehicular environment. The O-RAN design principles prioritizes the deployment of pre-trained models. Hence offline training can be used to ensure that the issues related to the deployment of poorly trained IoV models are effectively minimized. However, the O-RAN design principles encourage the use of online training as a means of fine-tuning models that are trained.

c) Validation and publishing

The trained models from the previous step are then validated to determine the most effective policies for controlling and managing resources in the OpenRAN-based IoV. This can be done by testing using previously unseen data, the use of diverse traffic patterns and vehicular demand use cases in which available frequencies and bandwidths may vary. This phase is key for determining the solution which is most suitable for specific use cases.

d) Deployment

The validated models for specific vehicular instances are typically deployed in the Near-RT RIC, the DUor the CU using containerization. They can also be deployed using a file-based application which forwards the inferences made from the model to the O-RAN application (xApps or rApps).

e) Execution and Inference

In this phase, the deployed models interface with both the Near-RT RIC and the Non-RT RIC to perform varied tasks in the IoV-based RAN using control loops that are managed by the E2 and A1 interfaces. This loop is clearly illustrated by the grey dashed arrows in Figure 2.

f) Continuous operations

This phase of the AI/ML workflow is implemented toensure that the all forms of deployments within the OpenRAN-based IoV can be monitored and analyzedwith respect to their influence on network performance. This phase is critical for the improvement, re-training and fine-tuning of poorly performing modelsin order to minimize instances of data and service downtime.

iii Policy

A policy is defined as the guidelines that control the network's operation and behavior. The policy is at the heart of the network's adaptation to varying changes anddemands. Within the context of this architecture, policy management is key to ensuring optimum efficiency and performance of the IoV. The policy controls the proper functioning of services deployed in the OpenRAN IoV using Application Programming Interfaces (APIs). Services interact with a Policy Agent in the Non-RT RIC using a REST API to control aspects of service management, types of policies and their managementas well as a repository for the Near-RT RIC.

iv Configuration

Configuration within the Non-RT RIC is carried out using virtual machines with remote connections to other devices. These virtual machines also contain software that which automate the management and deploymentof containerized applications for the IoV. Docker and Kubernetes are two examples of containerization platforms used for the operations and management of the non-RT RIC.

v Design
The aspect of design within the non-RT RIC has to do with the definition and objectives related to all policies, services, network functions, AI/ML workflow, security and the allocation of network and data-related resources within the OpenRAN-based IoV.

Overall, the use of RAN splitting, an intelligent real-time control agent as well as an orchestration and automation framework make the OpenRAN architecture suitable for the dynamic vehicular environment and a potential successor to existing IoV architectures. The potential of the OpenRAN concept to improve the IoV can be seen in the various non- IoV use cases highlighted in the section below.

6. USE CASES FOR OPENRAN

Various implementations of the OpenRAN concept have been explored over the years. In [17], authors leveraged an OpenRAN design to detect jamming attacks in a 5G network. The authors made use of the O-RAN design's ability to have direct access to the physical layer obtained Channel Quality Indicator (CQI) values and Reference Signal Received Power (RSRP) from user equipment. The data set from these values were then analyzed by an application to detect whether jamming had occurred.

[18] implemented a method for early detection Denial-of-Service attacks in mobile networks. Just like in the previous paper, the OpenRAN framework is provided the authors with direct access to air interface measurements which facilitated the dynamic classification of genuine or malicious traffic. In addition to the above, the work by [19] designed a 5G network monitoring and control framework using the principles of OpenRAN which deployed telemetry-based applications that monitor various aspects of the network. This framework provides a flexible means of defining new service models within the O- RAN ecosystem for increased innovation. The concept of programmable slicing is explored and implemented using O-RAN design in [20]. The researchers built a platform that is capable of allocating network resources based on varying service requests. The platform provided statistics of network resource usage and allowed for near real-time monitoring of network performance. In [21], an application was created using the principles of O-RAN for traffic steering and load balancing. The authors sought to achieve guaran- teed throughput for a user equipment in a mobile network. The paper implemented O-RAN-based AI/ML techniques to carry throughput prediction at various cells as a means of selecting the most appropriate cell for user equipment handover. Although the ORAN-Alliance published a white paper on the vertical applications of the OpenRAN concept in the vehicular industry, there is no work to the best of our knowledge on a specific IoV use case scenario.

7. BENEFITS OF THE IOV-ORAN SYNERGY

Based on the use case scenarios cited in the previous section, it can be seen that a synergy between the IoV and ORAN technologies are will lead to enormous benefits. A critical look at Figure 1 shows that there are many forms of connections that exist between a vehicle and its environment. Each of these connections are supported by the connection to the RAN. Hence, incorporating O-RAN technology into the IoV will open up an era of unprecedented innovations in the Vehicle to Pedestrian (V2P), Vehicle to Vehicle (V2V), Vehicle to Sensor (V2S) and Vehicle to Infrastructure (V2I) spaces. It will offer telecommunication operators the opportunity to design specific value-added services and applications related to each of these technologies while providing a means of automating and reconfiguring network policies based on the changing dynamic of the network.

Another area of benefit which is hardly discussed has to do withthe vehicles themselves. The synergy between O-RAN and the IoV will also result in improvement of vehicular design.It will push manufacturers to incorporate more intelligent design paradigms that will suit the capabilities of the O-RAN leading to smarter, more comfortable and safer cars. Also, this synergy will lead to greater levels of safety and quicker reactions to emergency services on roads and will reduce the effects of accidents on lives and economic activity.

8. CHALLENGES AND THE WAY FORWARD

According to [22], there are five critical areas which pose challenges to the full-scale adoption and implementation of O-RAN design principles and this could potentially affectits integration into the IoV.

The first of these has to dowith the application of the SMO concept in the current multi-vendor telco environment. The key challenges in this area have to do with the interoperability, administration and maintenance of solutions from different vendors as well as the determination and location of appropriate AI/ML models, resource requirements and deployment modes based on time and scale. Secondly, O-RAN implementation faces a huge challenge in the area of performance due to issues relatedto energy consumption at the small cell and DU levels.

Another key performance issue relates to resource management which might arise from the heterogeneous nature of traffic in current cellular networks. The third issue with the implementation of O-RAN has to do with security. Confidentiality of information being fed into xApps and rApps can be comprised [23]. Also [24] raises concerns with respect to the risk related to the use of data in anera of open-source software and hardware.

Another major issue with the implementation of O-RAN technologies has to do with deployment and operations. It has been realized that there are very few testbeds that implement end-to- end Open RAN systems due to the fact that SMO and Near-RT RIC solutions are typically provided by different software providers. As such, typical use cases cannot befully evaluated. Work has however been carried out with the proposal of solutions like Open RAN Gym testbed whichhas been extended with frameworks that provide end-to-end Open RAN functionality [25, 26, 27].

Last but not least, the implementation of Open RAN could be hampered by standardization problems. As more third-party software designers propose varying solutions through applications, there is a risk related to regulation, control and continuous updates of these solutions as the network changes. All of these challenges could affect the implementation of the proposed OpenRAN IoV architecture in adverse ways due to the highly volatile and mobile nature of the IoV. However, they also offer the opportunity for greater collaboration between stakeholders to design solutions which could best fit the IoV and its complexities.

This paper did not come across a definitive implementation ofthe IoV-ORAN synergy, however, the sturdy growth of O- RAN in the telco-ecosystem points to the fact that it might happen sooner than later. In [28], the O-RAN Alliance shows there are 12 major deployments of O-RAN systems most of which are located in the United States of America and Canada. There are 26 field trials spread over the worldin countries such as the Democratic Republic of Congo,Brazil, Japan, the United Kingdom and Turkey. Testing is also being carried out in 14 locations in Mozambique, South Africa, France, South Korea and Taiwan. In addition to the above, O-RAN has been launched commercially in the 15 locations around the world. These areas can be found inthe United States of America, Germany, Peru and Japan. Memoranda of Understanding (MoUs) have been signed in 17 other locations in India, France, Germany, Spain, the United Kingdom, South Korea and Japan. These statistics show that even though O-RAN is in its early stages of deployment, it is gaining traction in most of the developed countries of the world. This is an indication of its potential to reach other parts of the world very soon.

9. CONCLUSION

The synergy between the IoV and O-RAN is just near the horizon. It is the next phase in the evolution of vehicular intelligence driven by the changes occurring in the design of the RAN. This work has presented an overview of how O-RAN design principles can be incorporated into vehicular networks by examining the various parts of an O-RAN-based IoV architecture and the improvements it has over existing architectures. In as much as there are challenges with respect to O-RAN implementation, its gradual adaptation in major economies of the world is an indication that it has come to stay and soon enough, the O-RAN will play a key role in all forms of vehicular connectivity.

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