EAI Endorsed Transactions
on Cloud Systems
Research Article EAI.EU

Open RAN Deployment Using Advanced Radio Link Manager Framework to Support Mission Critical Services in 5G

Sree Lekshmi S[1,*], Seshaiah Ponnekanti[1]

[1]Amrita Center for Wireless Networks & Applications (Amrita WNA), Amrita School of Engineering, Amritapuri Campus, Amrita Vishwa Vidyapeetham, India
{sslekshmi, seshaiahp}@am.amrita.edu

Abstract

Next generation networks or 5G will be "network of networks" that can support ultra-reliable and low latency communication, high data rate, huge connectivity and high security. Network transformation stirring towards virtualized Radio Access Network (v-RAN) and intelligent resource management are foreseen as key solutions to realise such varied 5G requirements. Effective Radio Resource Management (RRM) is crucial for Mission Critical (MC) services to underpin communication between smartphone, massive machines and tiny sensor devices. The paper explores pioneering research related to architecture and intelligent RRM that helps Service Providers (SPs) to design reference framework of an advanced Radio Link Manager (RLM) enabled by Machine Learning (ML). One example optimization for commercial network/Long Term Evolution (LTE) and some preliminary results are analysed to understand the reference framework. The paper addresses the general reference architecture framework of advanced Radio Link Manager to support Mission Critical services in 5G. The paper also discusses about the ongoing standardisation activities and open source initiatives in 5G RAN.

Keywords: 5G networks, machine learning, radio link manager, scheduler, mission critical services.

Received on 02 February 2019, accepted on 10 March 2019, published on 15 March 2019

doi: 10.4108/eai.15-3-2019.162140

1. Introduction

The evolution of mobile technology generations provides greater capacity and data rates to the end users. The tremendous increase in mobile data usage place unparalleled demands on telecom industries in terms of efficiency, flexibility and scalability of the network. In future, 5G or next generation technology is expected to improve network performance and support various new services such as machine type and ultra-low latency communications. To address such services, most of the significant requirements in 5G will be related to enhancing the radio links. This enhancement leads to change in the entire Radio Access Network (RAN) infrastructure. Currently, the distributed RAN architecture consists of Remote Radio Heads (RRH) and Base band Units (BBUs) colocated at the cell sites and backhauled to the Core Network (CN). With 5G, Service Providers (SPs) are migrating towards Open –RAN (O-RAN) architecture with essential protocol split within RAN. The idea is to utilise the Software Defined Networking (SDN) and Network Function Virtualisation (NFV) principles to virtualise, split and shift some RAN functions to the cloud. This RAN evolution helps the network operator to provide higher data rate, higher reliability and reduce end-to-end latency.

Ultra-reliable Low Latency Communication (uRLLC) is one of the diverse use cases in 5G which will cater latency sensitive or Mission Critical (MC) services such as telemedicine, autonomous cars and smart factory etc [1]. In future, the network will support both multicast and broadcast techniques referred to as Multimedia Broadcast/Multicast Services (MBMS) based mission critical services to offer voice, video and streaming

*Corresponding author. Email: sslekshmi@am.amrita.edu

applications. There will be variety of radio links including user-to-network, vehicles-to-network and robots-to-network. Hence, 5G requires an advanced Radio Link Manager (RLM) to provide cost and energy efficient Radio Resource Management (RRM).

The paper explores the importance of an advanced RLM facilitated by Machine Learning (ML) and essential resource management scheme such as joint optimisation of packet scheduler and data optimiser to be implemented at 5G gNodeB or at the network edge in concurrence with the end to end network Orchestration. The paper is organized as follows. Section 1 is the Introduction. Section 2 covers the reference architecture framework of advanced RLM for 5G O-RAN. Section 3 discusses ML as key enabler for advanced RLM. Section 4 describes example optimisation for commercial network/LTE and some preliminary results from CN side. Section 5 summarises the standardisation activities and initiatives ongoing in different standard organisations. Section 6 summarises and concludes the paper.

2. Reference Architecture Framework of Radio Link Manager for Open RAN

5G SPs need to design network architecture that can guarantee specific MC Service requirements beyond the LTE networks today. In 5G, the user layer constitutes very tiny sensors or low-end devices as well as high end devices to underpin different use cases. Unified implementation of intelligent scheduling as well as Resource Manager at every level of the network is utmost important to meet stringent requirements like ultra-low latency and ultra-reliability. There are multidimensional features in 5G demanding an advanced RLM framework as shown in Fig.1.

2.1. NFV-MANO

Network Function Virtualisation (NFV) runs Virtual Network Functions (VNFs) on the top of general-purpose hardware replacing dedicated network appliances. With NFV, network operations such as routing, load balancing, and firewall becomes network function software delivered by Virtual Machines (VMs), which are dynamically instantiated in the network on demand. The NFV network management is different to traditional monolithic network architecture consisting of one Network Management System (NMS) supported by Operational Support System (OSS). On the other hand, NFV network requires several managers and NFV Management and Orchestration (MANO) realise the management part [2]. The three main functional blocks/ Managers of NFV-MANO are:

- NFV Orchestrator (NFVO): NFV orchestration involves automating and management of NFV Infrastructure (NFVI). The important functions of orchestrator are:
  - On-boarding new VNFs
  - Life Cycle Management (LCM) of network slice
  - Resource provisioning and management of both hardware and software resources

  Multiple domains within the network are likely to use layered orchestration covering Edge, Wide Area Network (WAN) and Core/Central Network. The end-to-end Service Orchestrator does the topology management of service instances called VNF

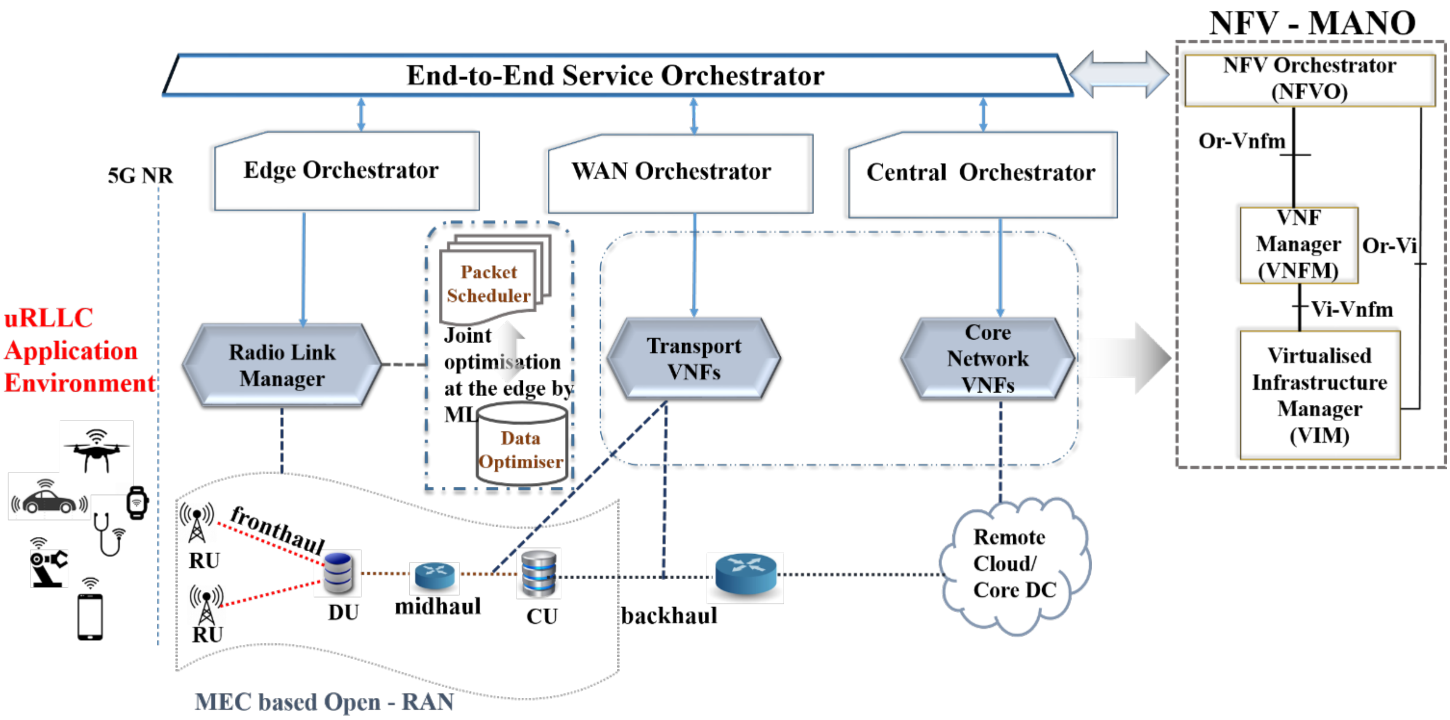

Figure 1. Reference Architecture Framework for Advanced RLM

forwarding graphs to create an end–to-end service with different VNFs (Core Network VNFs and Transport network VNFs)

- VNF Manager: The main functionalities include:
  - Coordination and Life cycle Management of VNFs
  - Control of the Fault, Configuration, Accounting, Performance, and Security (FCAPS) of VNFs

  There will be multiple VNF Manager for separate VNFs or single VNF Manager to control several VNFs.
- Virtualised Infrastructure Manger (VIM): Responsible for the management of NFVI. NFVI constitute Physical resources (server, compute, storage and network resources), Virtual resources (VMs) and Software resources (Hypervisor/Virtualisation Layer that abstracts applications from underlying hardware). The key functions of VIM are:
  - Responsible for creating, maintaining and terminating VMs from physical resources in NFVI
  - Keep catalogs of VMs associated with physical resources
    Performance and management of resources (hardware, software and virtual) in NFVI domain (from RAN to the Core Network)

There will be several VIMs within an NFV architecture to manage corresponding NFVI domain.

2.2 Mobile Edge Computing (MEC) based Open-RAN

Current Radio Access Network (RAN) or e-Node B constitute Baseband unit (BBUs) at the base and Remote Radio Head (RRH) located at the top of the tower. 5G requirements to enable various use cases lead to Open-RAN architecture shifting several RAN functionalities to the cloud. The concept is to migrate maximum or entire baseband processing towards Data Centre (DC) infrastructure using NFV-MANO principles and hosting only the RRH/antennas and radios at the cell site. 5G RAN constitute radio Base Stations (BSs) or gNodeB consists of functional units [3] like:

- Radio Unit (RU) / antenna site – close to users
- Distributed Unit (DU) – Small DCs
- Centralised Unit (CU) – Large DCs

The fabric connecting RU to DU is called fronthaul. The interface between DU and CU forms midhaul. Backhaul is the interface between CU and the 5G Core Network (5G CN). The location of DUs and CUs depend on the network topology. This distributed DC approach supports very high frequencies or 5G mm wave enabling higher data rate. There are different functional splits or protocol split option possible within RAN in 5G [4]. These multiple split options are not fixed concept, and depends on the type of service or QoS requirement, network topology (user density in geographical area) and the transport network availability.

MEC architecture enables cloud computing capabilities close to users or at the network edge [5]. Edge refers to the DCs close to the RAN. The edge computing reduces core network traffic, signalling load and end–to-end latency thus improving service environment and user experience. MEC can expand both coverage and bandwidth as information processing is done locally instead of cloud based or remote DCs.

2.3 Packet Scheduler

The scheduler strategy for MC services in 5G demands novel packet scheduler framework that can meet the stringent service requirements in terms of reliability, latency and availability of the network. Fig.2 shows comparative view of both LTE Scheduler and 5G Scheduler.

The control loop should be at the edge assisting MC services with the following changes resulting in the complete redesign of scheduler at RAN.

- **RAN Slicing**: The resource mapping and management involves RAN slicing. RAN slices can provide radio resources in the form of NFs as per the service requirements on the top of shared network fabric [6]. RAN becomes slice aware with explicit and implicit identifications such as type of devices, type of transport, RRH/RUs and protocol stack required for every application to cater the specific use case demands. 5G integrate different medium access technologies and operate in multiple bands and bandwidths to support 5G requirements - such as ultra-low latency and ultra-high reliability. For example, one network slice can be optimized for ultra- reliable services with reserved bandwidth. Another slice can be optimized for maintaining massive number of active IoT devices with best effort throughput services.
- **Compact RRM** to cater the needs of IoT/ Cyber physical systems: The RRM functionalities to serve the use cases are different to one another. There will be wide ranging set of radio links in the 5G network including humans to network, machines to network and vehicles to network. The sensor devices in IoT network are low powered,

energy efficient and require low data rate. Hence, RRM varies for IoT network with respect to cellular network. Certain key features have to be considered to deliver RRM functionalities to serve IoT use cases in 5G as shown in Fig.3.

LTE Scheduler	5G Scheduler
•Scheduler sits at the eNodeB/Base Station providing RRM and dynamic scheduling based on **▪Channel quality measurements from UE** **▪Listens to the Policy Charges and Rules Function (PCRF) to understand the QoS requirements of the service type**	**•Tool Box Approach: Scheduler design involves several enablers/technologies such as** **▪SDN/NFV** **▪CUPS** **▪MEC** **▪v-RAN** **▪Orchestrator** **•Service differentiated scheduling algorithm supported by machine learning based on real-time cognitive approaches** **•Integrated Approach for RRM/ Compact RRM**
•Quality Class Identifier (QCI) bearers for QoS management. Every service has dedicated QCI bearers which are categorised based on QCI characteristics such as **▪Guaranteed Bit Rate (GBR)/ Non-Guaranteed Bit Rate (Non- GBR)** **▪Priority** **▪Packet error rate** **▪Packet delay** **•QoS is effectively implemented at the network level by the Core Network and the transport network**	**•Unified Network Fabric** **▪same network fabric support both commercial as well as critical use cases** **▪technologies work in holistic manner at various layers from the RAN to the Core Network** **•QoS implemented with Network Slicing Concept** **▪dynamically adapt to service requirements (latency, data rate, reliability) - high priority for mission critical services** **▪Design new end to end slice template for MC services**

Figure 2. Comparative View of LTE and 5G Scheduler

- **Centralising or Distributing Network Functions (NFs)** from use case point of view to meet the specific service requirements. MEC based Open RAN enables certain CN functions/ CN VNFs to be executed at the edge isolated from other parts of network to provide local access to resources and data. Slice aware RAN can instantiate Control Plane (CP) functions such as Policy Control Function (PCF) or Mobility Management Entity (MME)/ Access and Mobility Management Function (AMF) close to users or at the edge to underpin ultralow latency and ultra-reliable services. For example, in case of massive IoT or machine type communication involve huge amount of CP processing than the related User Plane (UP) data rate needed, whereas MC application like telemedicine/remote surgery which are sensitive to end-to-end latency, needs higher bandwidth and higher user plane processing data rate for streaming real-time high-resolution video. The open/disaggregated and virtualised network infrastructure can enable dynamic provision of CP/UP processing resources to serve specific service requirements.

2.4 Data Optimiser

Massive number of device usage in the network results in large amount of data. Huge amount of data relating to both UP/CP can be collected from UEs, RAN, CN and the external Data Network [7]. This voluminous data from multiple heterogeneous sources need to be processed in real-time. Therefore, data analytics and optimisation play key role in 5G MC services which demands low latency and high-performance rate. To perform optimisation, an insight of different types of data in the cellular network is required.

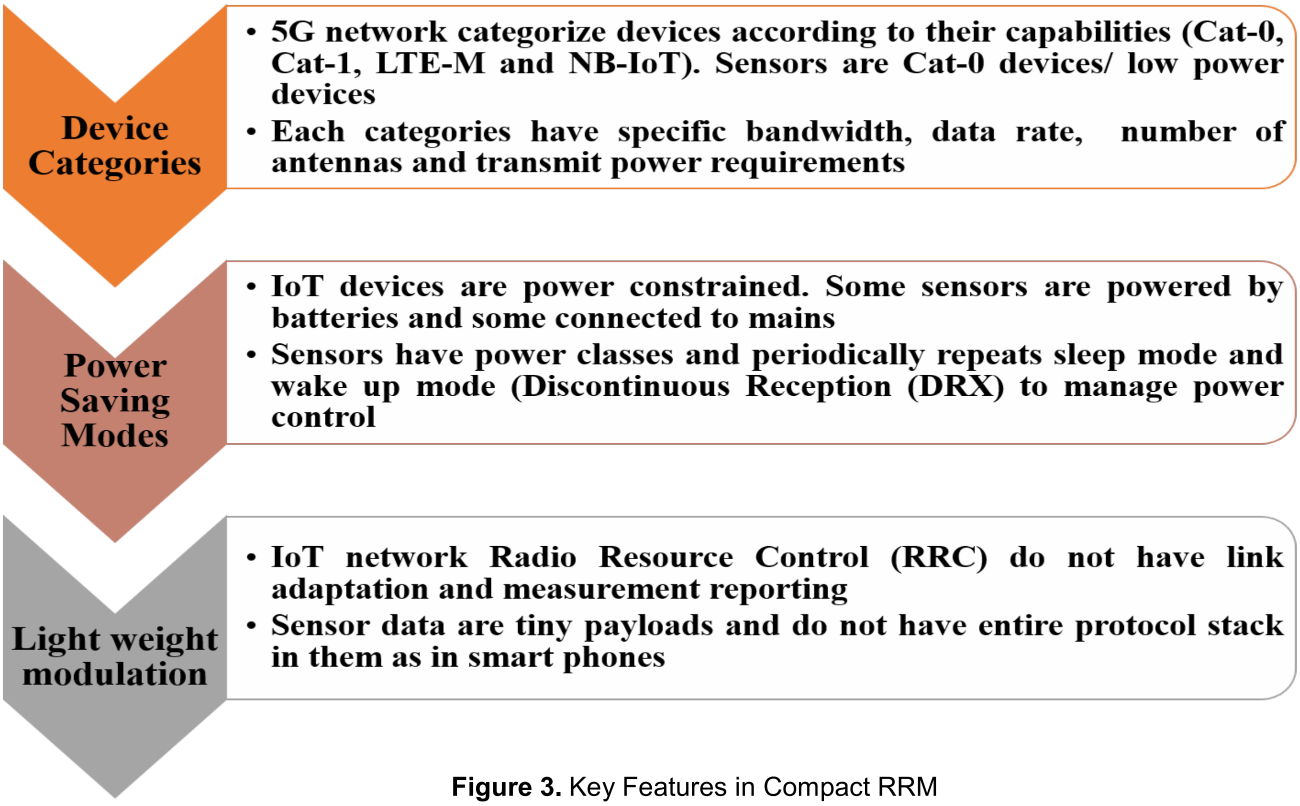

Figure 3. Key Features in Compact RRM

- **User Data**: This covers user level information like user's profile, location, sensor data, mobility and communication behaviour. With the emergence of smartphones, APP related services increased rapidly, resulting in massive application level data in the network from the APP installed in UEs.
- **Network Operator Data**: Network operator collects data from the CN and RAN.
    - CN include bearer data indicating network performance and QoS.
    - RAN provides cell level information such as eNodeB configuration, mobility, link quality; signalling message between UE and eNodeB like RRC connection establishment and handover messages and information about Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ).

These data from various sources need to be efficiently processed and optimised to improve network performance. It is worthy to have data optimiser close to end users meeting the latency and reliability requirement of 5G applications/services.

Radio Link Manager becomes central point to the disaggregated and open 5G RAN enabling simplified network management, maintenance and increased resource utilisation efficiency. Advanced RLM can implement virtualised RRM in an NFV enabled MEC based Open –RAN architecture. The advanced features of RLM are as follows:

- High capacity and flexible transport which will be mix of fixed, mobile, optical, microwave and IP transport technologies support NFs close to users.
- Radio Resource Manager at CU, DU and RU managing the VNFs across the functional nodes.
- End-to-End Service Orchestrator and joint optimisation framework of scheduler and data optimiser at the edge together underpin an advanced RLM to meet the stringent requirements of MC services.
- RLM assisted by Artificial Intelligence (AI) / Machine Learning (ML) based Radio Resource Management strategies is needed to dynamically adapt to the service requirements.

3. Machine Learning as Key Enabler of Advanced Radio Link Manager

Machine Learning (ML) is data analysis method that enable machines to exploit data and take predictive and proactive decisions in real time [8]. ML can play significant roles in learning the wireless environment variations, categorizing the problems, expecting the challenges, predicting the results and exploring possible solutions/decisions/actions. ML framework can exploit the data from different types of UEs to predict the traffic volume and allocate dynamically the available network resources. In 5G, RRM framework at the RAN include various control functions based on radio measurements and other observations by numerous user devices or network elements. Current RAN are reactive and base stations runs algorithm in centralised server to meet the user demands. However, in 5G, even milliseconds of delay can make huge impact. To enable certain Mission Critical applications like remote robotic surgery, 5G network should be predictive, proactive rather than being just reactive. In Open-RAN, the computing and storage capabilities should be distributed in the different DCs that can host ML algorithm to serve the users proactively. To underpin advanced RLM, demands an efficient implementation of ML based traffic optimization that can handle large volume of data in 5G networks. This learning framework would be capable of autonomously running algorithms to handle RRM functionality meeting latency and reliability requirements of users. The data collected from

RAN will be considered as source to generate RRM algorithms and improve over time. There exist different types of learning [8] to predict and take decisions proactively based on the data collected from the application environment.

- Supervised Learning: Training to predict future based on known input and output data
- Unsupervised Learning: It is used to draw conclusions from data collected consisting of input data without labelled output or prior guidance.
- Reinforcement Learning: To learn, act and make decisions dynamically by continuous trials.

The varying radio conditions in the RAN, huge number of connected devices operating in multiple bands and bandwidth are major challenges for ML framework. These factors radically affect the design of ML based RRM algorithm. This leads to flexible and dynamic packet scheduler that make scheduling decisions as per the varying network conditions. To facilitate learning techniques for RRM, database should assist Radio Management by capturing trends of ARQ, call drops, BER, number of users at location, number of RBs allocated. The type of learning technique to be incorporated in 5G together with IoT era (such as mMTC, uRLLC) depends on certain features like device categories, resource constraints, computational capabilities and QoS demands of each application.

Some of the areas where ML can play significant role in RRM are the following:

- Link Adaptation: Current networks adapt to configurable parameters like transmission power, modulation and coding based on the quality of the wireless link. Adaptation is based on certain key performance metrics such as Block Error Rate which indicates the reliability of the communication link.
- Location: Due to massive number of devices/users and multiple antennas in 5G, it is crucial to understand the context of the communication environment to select context aware or adaptive techniques and data optimization decisions. Some location always shows call drops and such location information can be mined using reference signal probing mechanism to train or get some baseline parameters in the location.
- Resource Block (RB) allocation: Effective RB allocation and utilization based on priority of service can be performed with online learning.
- Beamforming for massive MIMO: Beamforming is used to enhance signal strength in desired direction. The beam pattern needs to be optimised which depends on the network topology and traffic variations. ML can enable adaptive and intelligent beamforming with MIMO reducing interference and enhancing the capacity.
- Automatic Repeat Query (ARQ): ARQ error control method in data transmission retransmits packets based on acknowledgements and timeouts. This mechanism involves feedback to transmit packet with high reliability. ARQ success or failure rate can be diagnosed to improve reliability of service with ML techniques.
- Intelligence at the network edge: The knowledge gathered about network totally utilising ML techniques can be used at the edge in controlling, monitoring and coordinating different distributed DCs.

4. Example Optimisation in LTE Networks

The following diagrams Fig.4 and Fig.5 depicts the effect of Data Optimisation observed in an example LTE network. The first part covers the packet loss improvements and later part shows the effect judicious video pacing [9].

These are preliminary results given to visualise the indicative effect of optimisation from the Core Network point of view. In the next step of simulations, it is anticipated that combining the Data Optimisation with the Radio Link Manager approach, as proposed in this paper, will yield better capacity within the 5G distributed RAN deployments.

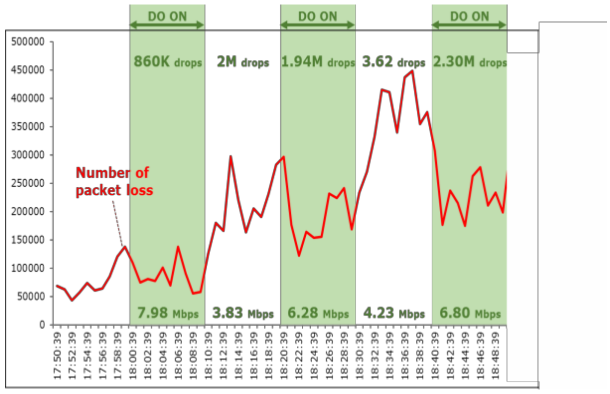

Figure 4. Packet loss observations in LTE

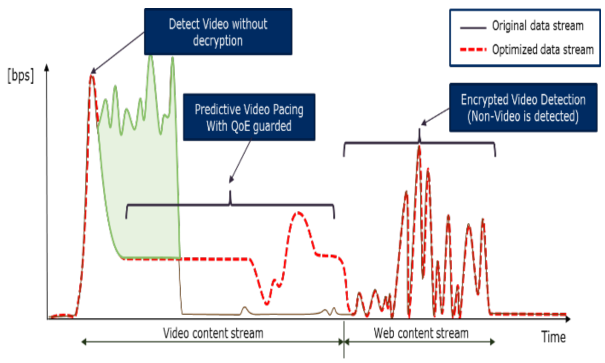

Figure 5. Optimisation using pacing

5. Standardisation Landscape for Open RAN

Radio access network transformation has been taking place rapidly in the 5G arena. At the same time, standardisation bodies and forums are paving the way for open and cost-effective architecture and interfaces. This is likely to facilitate effective interoperability and smooth migration towards disaggregated RAN by reducing capital expenditure (CAPEX) and operating expenses (OPEX). In this context, analysis of standardisation landscape is important in the research work as shown in Fig.5. Some of the standard bodies and their initiatives are summarised.

- **ORAN:** ORAN Alliance members work on two key principles to evolve RAN namely, openness and intelligence [10]. RAN infrastructure will be built on virtualised and Common-Off-the-Shell (COTS) platform with standard interfaces that embrace intelligence and openness enabling RAN Intelligent Controller (RIC). They develop reference designs that consist of more open, interoperable and standard interfaces. ORAN have the following technical specification Work Groups (WGs).
    - *Non-Real Time and RAN Intelligent Controller and A1 Interface WG*. This group has been enabling non-real time intelligent RRM and providing intelligent (AI/ML) models to near real-time RIC.
    - *Near-real-time RIC and E2 Interface WG:* Defines architecture based on near real-time-RIC supporting control and optimisation of RAN and activities over E2 interface.
    - *The Open Fronthaul Interfaces WG:* The objective is to deliver open fronthaul interfaces, where multi-vendor DU-RU interoperability can be enabled.
    - *Stack Reference Design WG:* The goal is to develop the software architecture, design and provide plan for the O-RAN Central Unit (O-CU) and O-RAN Distributed Unit (O-DU) based on O-RAN and 3GPP specifications for the 5G New Radio (NR) protocol stack.

O-RAN Alliance recently joined up with Linux Foundation to form O-RAN Software Community (O-RAN SC) to provide open source software application layer at RAN enabling 5G RAN solutions. The key side of O-RAN SC is to set up collaboration with open source projects such as Open Network Automation Platform (ONAP), Open Day Light, and Open Stack.

- **Facebook Telecom Infra Project (TIP):** The goal of TIP is to bring innovations in components (hardware/software) as well as in operations by introducing openness [11]. TIP aims to develop programmable RAN solutions that can improve connectivity and flexibility in RAN architecture. TIP constitute various Project Groups (PGS).
    - The *PG Edge Computing* in TIP focus on implementation of applications at the network edge, utilise open architecture, software libraries and stack and MEC into platform.
    - *Open RAN PG* objective is RAN solutions based on General Purpose Processing Platforms (GPPPs).
    - *The vRAN Fronthaul PG* focus on RAN virtualisation solutions that can operate over current backhaul/transport infrastructure (for non-ideal backhaul) such as microwave, Ethernet etc. The project aims to provide urban/sub-urban and rural connectivity.

- *Crowd Cell PG* led by Vodafone aims to commercialise the Open RAN concept. This is achieved by utilising General Purpose Processing (GPP), hardware/software disaggregation and open source strategies to develop cost effective small cell solutions. The Open Cellular PG will focus on open source wireless access platforms (including cellular) and related technologies for enabling rural connectivity. It supports group of open source projects, system integrators and distributors to develop solutions on Open Cellular platforms. The mission is to bring internet to rural community around the world.

The document [12] discusses the use case of edge computing and radio network data exposure enabling service aware RAN to improve RRM and Quality of Experience (QoE).

Presently, mobile networks have little knowledge about its application traffic and this cause challenges to end-to-end network optimisation, affecting the QoE of the application users. In 5G Core, Application Function (AF) and Network Exposure Function (NEF) are introduced to interact with applications and reduce the gap between mobile networks and applications. In future, Network Data Analytics Function (NWDAF) [12] can collect more edge RAN data improving radio resource management and Quality of Service (QoS) provisioning.

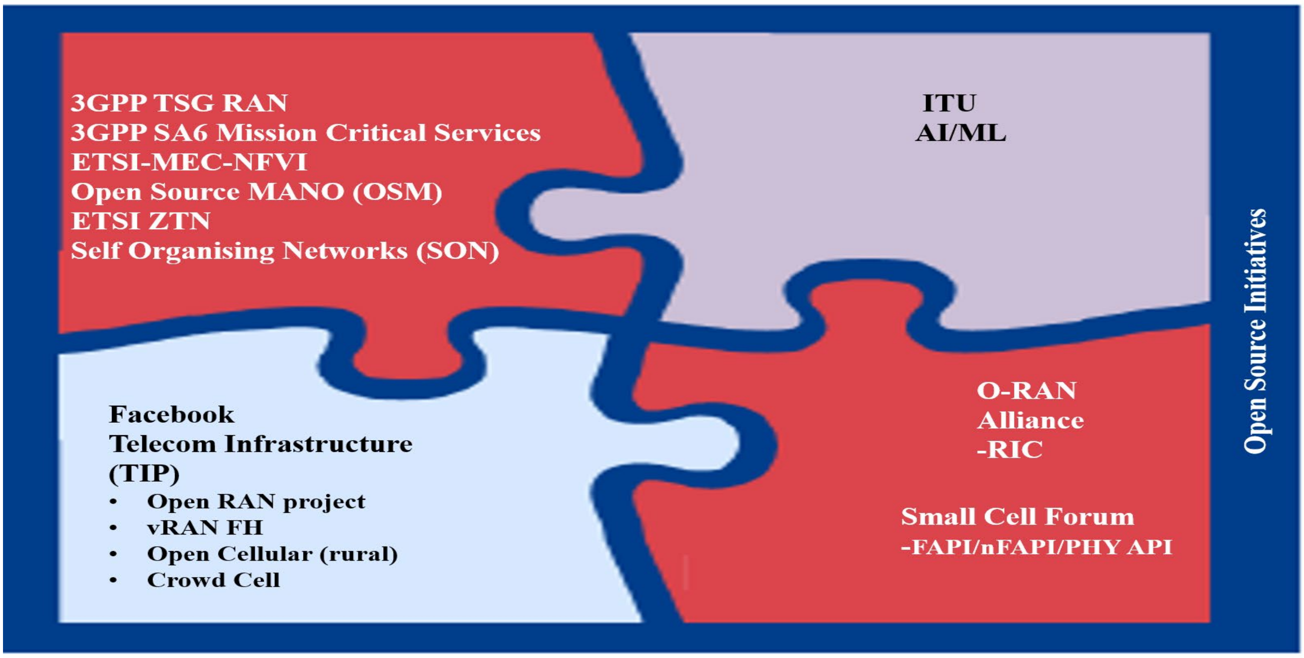

Figure 6. Standards and Open Source Initiatives for 5G Open RAN

- **3GPP TSG RAN:** 3GPP Technical Specification Group (TSG) RAN is in charge for defining radio characteristics, functions, requirements and interfaces of RAN architecture. The study proposal item [12] aims to:
  - Study use cases and advantages of RAN data utilisation
  - Find standard impact on configuration and collection of measurement quantities (UE measurements, RAN node measurements and signalling procedures)
  - Identify metrics to be newly defined or refined on top of current RRM measurements
  - Understand important procedures in use cases such as edge computing, enhanced RRM and URLLC optimisation

ONAP: ONAP project include members from leading international Service Providers, vendors and firms/companies joined to contribute to open source framework for network automation. ONAP group works to provide automation platform for network infrastructure enabling 5G, IoT and cloud services.

- **ETSI-MEC-NFVI/MANO:** European Telecommunication Standards Institute (ETSI) MEC framework together with 3GPP form the basis of edge compute at the access and completely standardised solutions for enabling applications at the network edge and innovative business models. The framework includes application/service description framework, guidelines for developing and documenting standard Application Programming Interface (API) framework, service exposure through standard APIs and management & orchestration of platform services and authorised applications. Open Source MANO (OSM) [13] delivers MANO stack for NFV. OSM Release FIVE have new features extending OSM's network management and orchestration ability to transport networks, physical and hybrid network components. One of the key features of release FIVE is network slicing concept that improves the resource utilisation.

- **Small Cell Forum (SCF):** SCF is in the forefront of developing innovative deployments, especially in opening up RAN [14]. Fronthaul interface between radios and DU is critical and open specifications such as Functional Application Platform Interface (FAPI) can enable protocol stacks, basebands and radios from multiple vendors, realising disaggregated, virtualised and open RAN. FAPI is an internal interface / set of common APIs enabling interoperability between 3G/4G/ 5G PHY and software components such as scheduler. Recently, the forum published PHY API [14] for 5G that provides open and interoperable interface between PHY and MAC layer. PHY API is applicable to all functional split options and may be within DU/CU components. SCF also maintains networked FAPI (nFAPI) for 5G version enabling MAC/PHY split or 3GPP split option 6. nFAPI is the network interface between DU/CU supporting virtualised small cell networks controlled by virtualised and centralised baseband units. Open specification like nFAPI allow to mix DU and CU from different vendors.
- **ETSI-ZTN:** Zero Touch Network (ZTN) are designed for next generation network infrastructure that address zero touch management and operation (fully automated). The goal is to define an end-to-end operable framework enabling qualitative and automatic (ideally 100%) execution of tasks such as deployment, configuration, service delivery and optimisation [15]. ETSI ZTN offer guidance in implementing and coordinating management interfaces to realise automated end-to-end architecture and management solutions, which can support service management in multi-vendor environment.
  The standard will perform feasibility study by reviewing and reusing current standard solutions applicable, evaluating and considering deliveries from open source projects. With these inputs, the standard can identify reference architecture framework for end-to-end network and service management. It is planned to collaborate with other standard bodies and open source projects with interoperability testing specifications, test platforms, in the vision of end-to-end management and automation.
- **3GPP SA6 Mission Critical Services:** 3GPP SA6 Working Group (SA6 WG) [16] has expanded its activities for standardisation of new vertical applications/ MC applications, supporting adoption of 5G technology across various vertical industries. In Release 15, Common API Framework (CAPIF) was introduced to support unified Northbound API framework to ensure single and harmonised entry point for vertical applications. CAPIF evolved to eCAPIF in Release 16 to support 3rd party API providers to use CAPIF framework. Release 16 also introduced Service Enabler Architecture Layer (SEAL) to support V2X applications.
- **ITU ML:** ITU Standard ITU Y.3172 [17] form the basis for the integration of Machine Learning into 5G network architecture. The standard describes architectural framework for ML in future/5G networks, specific requirements and the components needed to satisfy the requirements. The components are ML pipelines/logical nodes that form ML applications and ML Function Orchestrator that manages these nodes. This standard focus in ML to improve the network management and orchestration enabling effective network optimisation. Understanding from the network generated data, ML can predict to support optimisation of network operations.
  The standard works with common language and terminology for ML functionalities and their relation with Information and Communication Technologies (ICT) networks. ML Sandboxes are one of the key components that form isolated environment introducing distinct ML pipelines to train, examine and evaluate ML applications before deploying in live network [17].
- **Self-Organising Networks (SON):** 3GPP Release 15 document specifies the requirements for SON in Operations and Management (OAM) systems as well as in multi-vendor environment. SON solutions enable autonomous operations [18].
- **Open Source Tools/Labels:** At the virtualization hypervisor layer, VMware and KVM have been implemented. Container based systems using Docker. In the MANO part, there are activities namely, Open stack, Open baton, ONAP and ETSI open source MANO.

6. Summary and Conclusions

With the evolution of IoT, various vertical industries like healthcare, Industrial IoT, Smart Utilities are rapidly advancing. 5G cellular network technology is expected to meet the stringent demands of these verticals in terms of latency and reliability. Innovative resource management framework incorporating an Advanced RLM is required to support delivery of MC services on top of 5G network fabric. The new framework combines distributed intelligence approaches and specific computation capabilities close to the users or at the network edge. The paper discusses 5G reference design framework of advanced RLM facilitated by ML for enabling MC services. The paper also examines an example data optimisation with preliminary results from CN side.

For the research work addressed in this paper, RIC in ORAN Alliance is one of the relevant standardisation activities. Individually standardisation activities are ongoing at TSG RAN, initiatives for edge orchestration at MEC and long-term standardisation activities for ML framework at ITU AI/ML. Standardisation at every network level are crucial and likely to offer invaluable connections to novel research methodologies. However, in future, these activities will coalesce into an integrated framework to realise an overall uRLLC end-to-end network slice with underlying MC Scheduling strategies.

The future steps include identification of key performance metrics like throughput, Signal-to-Noise-Interference Ratio (SINR) and latency to support dynamic resource management for MC services. Mathematical modelling and validation of new optimisation strategy to serve MC services need to be performed with appropriate simulation tool.

Acknowledgements.
The authors deeply thank the support and inspiration provided by the Chancellor of Amrita Vishwa Vidyapeetham, Mata Amritanandamayi Devi (known as “Amma”). This paper has materialized due to her constant guidance. The authors would also like to express their gratitude to Dr. Maneesha Vinodini Ramesh for providing immense research support in completing this work.

References

[1] H. Ji, S. Park, J. Yeo, Y. Kim, J. Lee and B. Shim, "Ultra-Reliable and Low-Latency Communications in 5G Downlink: Physical Layer Aspects," in *IEEE Wireless Communications*, vol. 25, no. 3, pp. 124- 130, JUNE 2018.

[2] M. Shin, S. Lee, S. Lee and D. Kim, "A way forward for accommodating NFV in 3GPP 5G systems," *2017 International Conference on Information and Communication Technology Convergence (ICTC)*, pp. 114-116, 2017.

[3] Harutyunyan, Davit & Riggio, Roberto, “Flex5G: Flexible Functional Split in 5G Networks: *IEEE Transactions on Network and Service* Management, pp. 1-1. 10.1109/TNSM.2018.2853707, 2018.

[4] Line M. P. Larsen, Aleksandra Checko and Henrik L. Christiansen., “A Survey of the Functional Splits Proposed for 5G Mobile Crosshaul Networks”, IEEE Communications Surveys & Tutorials, Vol. PP, No. 99, 2018.

[5] Y. Yu, “Mobile edge computing towards 5G: Vision, recent progress, and open challenges”, *in China Communications*, vol. 13, no. Supplement2, pp. 89-99, N/A 2016.

[6] P. L. Vo, M. N. H. Nguyen, T. A. Le and N. H. Tran, “Slicing the Edge: Resource Allocation for RAN Network Slicing, *in IEEE Wireless Communications Letters*, vol. 7, no. 6, pp. 970-973, Dec. 2018.

[7] P. Kiran, M. G. Jibukumar and C. V. Premkumar, "Resource allocation optimization in LTE-A/5G networks using big data analytics," *2016 International Conference on Information Networking (ICOIN)*, Kota Kinabalu, 2016, pp. 254-259.

[8] Sun, Yaohua & Peng, Mugen & Zhou, Yangcheng & Huang, Yuzhe & Mao, Shiwen, “Application of Machine Learning in Wireless Networks: Key Techniques and Open Issues”, 2018

[9] S. Swetha and D.Raj, “Optimized video content delivery over 5G networks”, *2017 2nd International Conference on Communication and Electronics Systems (ICCES),* Coimbatore, 2017, pp. 1000-1002

[10] Excerpts from ORAN Alliance website, “Operator Defined Next Generation RAN Architecture and Interfaces”, https:// www.o-ran.org

[11] Excerpts from TIP website, https://telecominfraproject.com/

[12] 3GPP TSG RAN WG3#101bis, R3-186040, “Use Case of Edge Computing and Radio Network Exposure”, available at www.3gpp.

[13] ETSI Open Source MANO, “Osm release five documentation,” ETSI

[14] 5G PHY API Release, available at https://www.smallcellforum.org/5g-phy-api-release/

[15] Excerpts from ETSI website, https://www.etsi.org/technologies/zero-touch-network-service-management

[16] Mission Critical Services in 3GPP, available at https://www.3gpp.org/specifications-groups/sa-plenary/sa6-mission-critical-applications

[17] ITU-T Rec.Y.3172: “Architectural framework for machine learning in future networks including IMT-2020”, available at https://www.itu.int/rec/T-REC-Y.3172/en

[18] 3GPP TS 32.500, “Self-Organising Networks (SON) Concepts and Requirements”, available at www.3gpp.