Advanced Radio Link Manager to Support Mission Critical Services in 5G

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***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.**

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

I. Introduction

The evolution of mobile technology generations provide 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 case 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 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 I is the Introduction. Section II covers the reference architecture framework of advanced RLM for 5G O-RAN. Section III discusses ML as key enabler for advanced RLM. Section IV describes example optimisation for commercial network/LTE and some preliminary results from CN side. Section V summarises and concludes the paper.

II. Reference Architecture Framework of Radio Link Manager for 5G Open-RAN

5G SPs need to design network architecture that can guarantee specific MC Service requirements beyond the Long Term Evolution (LTE) networks today. In 5G, the user layer constitute 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.

A. 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

- Responsible for creating, maintaining and terminating VMs from physical resources in NFVI
- Keep catalogs of VMs associated with physical resources
- Performance and management of

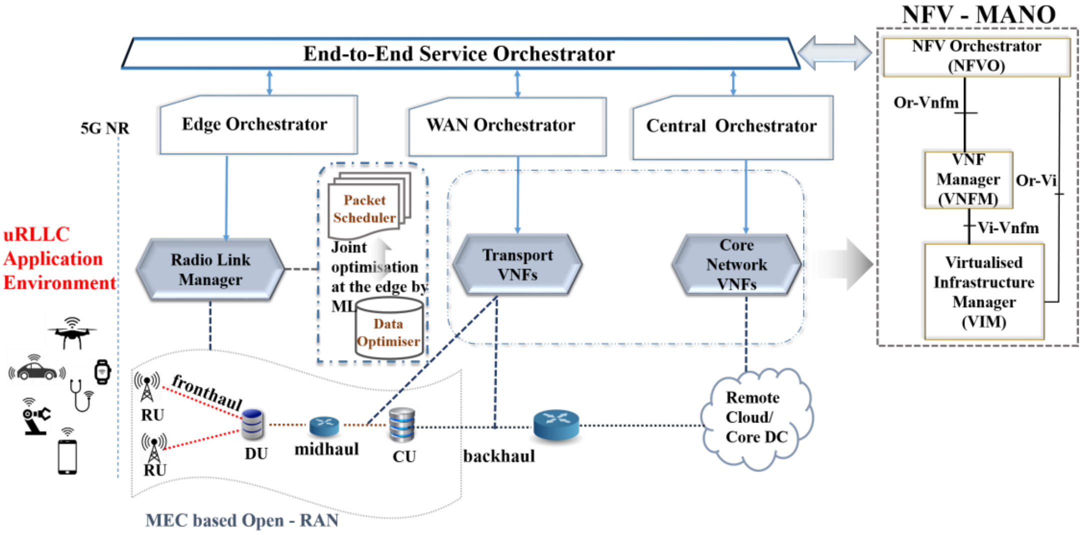

Fig. 1. Reference Architecture Framework for Advanced RLM

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 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:

  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.

B. 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.

C. 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. Table I shows comparative view of both LTE Scheduler and 5G Scheduler.

TABLE I. COMPARATIVE VIEW OF LTE SCHEDULER AND 5G SCHEDULER

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

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.

- **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 ultra-low 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.

D. *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 plays 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.

- **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.

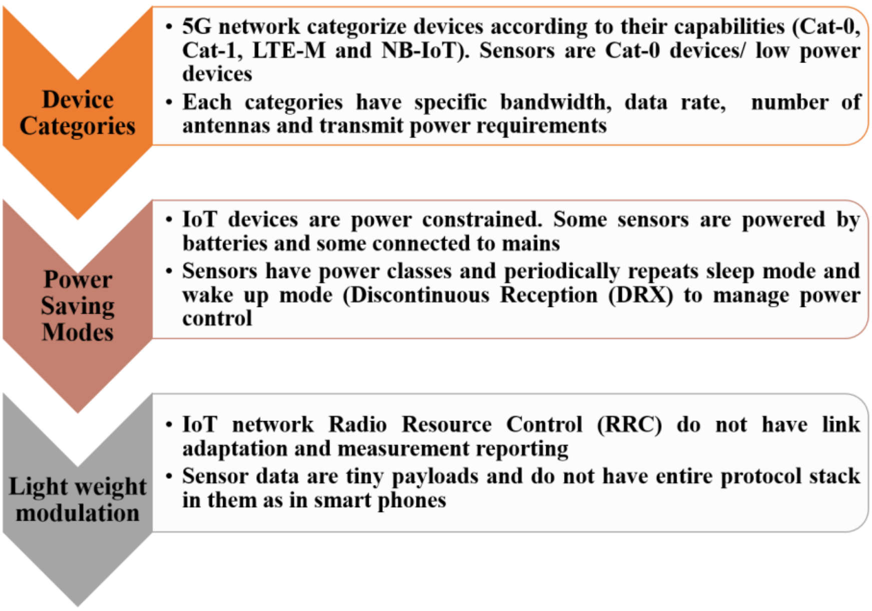

Fig.2. Key Features in Compact RRM

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.

III. MACHINE LEARNING AS KEY ENABLER OFADVANCED 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 applications.

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 show 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 need 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.

IV. Example Optimisation in LTE networks

The following diagrams Fig.3 and Fig.4 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.

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.

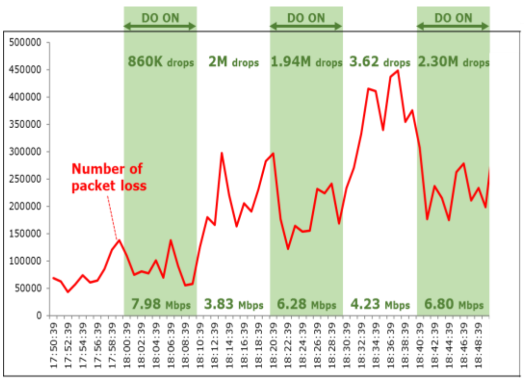

Fig.3. Packet loss observations in LTE networks

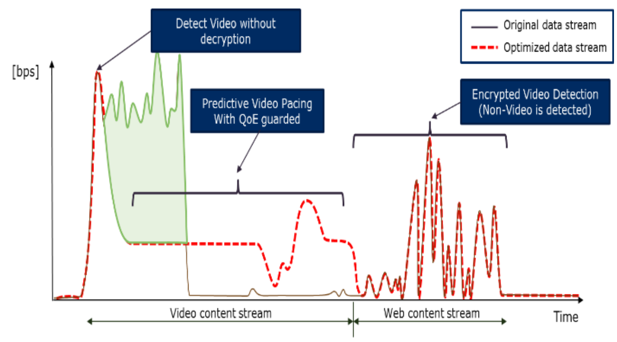

Fig.4. Optimisation using pacing

V. Summary and Conclusion

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.

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.

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