International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-5, January 2020

Anticipatory QoE Mechanisms in 5G Radio Intelligent Controller

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***Abstract*—3GPP which is working on the 5G specification is also working on the NWDAF (Network Data Analytics Function) which is used for data collection and data analytics in a centralized manner in the 5G Core. ORAN (Open Radio Access Network) is also working on the Radio data collection entities for better handling of the Radio Resource Management which is termed as the Radio Intelligent Controller (RIC). The 5G Network elements and/or the OAM (Operations and Network Management) can decide how to use the data analytics provided by NWDAF and/or the RIC to improve the overall system performance. In this paper we show how to develop anticipatory QoE mechanisms by using the data available at the RIC and the NWDAF. We show that anticipatory AI functionality will help address QoE in a mobile video streaming use case.**

***Keywords*—5G, Mobile Video Streaming, QoE, NWDAF**

I. INTRODUCTION

As the 5G NR specifications takes shape in 3GPP, the focus is now on the 5G Core network components and how they can provide qualitatively different service environment for different services. 5G will be characterized by increasing number of service types, coexisting radio technologies and device types and as such a need for flexible end to end network/service orchestration capabilities will be crucial. A new network function, called Network Data Analytics Function (NWDAF) has been introduced in [1] which is anticipated to be used for data collection and data analytics in a centralized manner. Operators are expected to use this functionality for policy adjustments initially but the NWDAF functionality can grow based on specific usage that operators envisage. The NWDAF functionality is still growing and the specification is yet to see a final phase. Additional network control functions are expected to be added in subsequent releases. ORAN [9] is also working on the Radio data collection entities for better handling of the Radio Resource Management which is termed as the Radio Interface Controller (RIC). RIC is an acronym for RAN Intelligent Controller. The RIC will be used for customization in the RAN in support of fine grain network optimization to support emerging 5G NR use case environments. A few examples are provided in the following:

Manuscript published on January 30, 2020.
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1. Industrial IoT: Orchestration of private 5G slice/namespace for businesses on industrial campus, Security services.
2. Connected Car: QoS enforcement to provide low latency, high bandwidth to vehicle applications.
3. Logistics, Tracking, Asset Management: Management of battery power of IoT devices.

This paper presents extensions to RIC and the NWDAF functionality to address the issues of QoE in 5G systems. As 5G is expected to support a host of service types, assured QoE across multiple users and service types is very important. QoE maintenance is also complex as it depends on a lot of parameter inputs which may not necessarily be available.

To handle qualitative aspects of user experience, in this paper we apply Fuzzy logic algorithms to deal with user experience factors. The QoS / KPIs are used along with user experience factors to address the issues of QoE. The fuzzy algorithms will also address issues of possible information uncertainty at the NWDAF level given that the evolving NWDAF specifications does not provide all possible information about the radio access network.

The key contributions of our paper are the following. We show how to use RIC / NWDAF to address QoE issues and address the specific issue of Video Streaming QoE. We show that anticipatory mechanisms are indeed necessary to address QoE.

A brief introduction to the 5G Core network is provided in the figure 1.

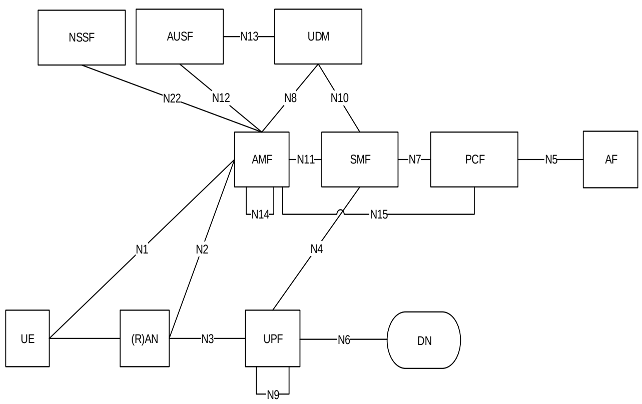

Figure 1: 5G Core Network (Source: 3GPP TS 23.501)

The key network functions in the 5G core networks of interest to us in this paper are the following:

• Policy Control function (PCF): This entity supports the policy framework for controlling the network behavior specifically it provides rules for the control plane functionality.

• The Session Management Function (SMF) supports selection and control of User Plane (UP) functions, and the User Plane Function (UPF) provides support for packet routing - forwarding, QoS handling for user plane and packet inspection and related policy control.
• The Radio Congestion Awareness Function (RCAF) updates the PCF about congestion issues in the radio access network.
• The Network Exposure Function (NEF) provides APIs to applications / network servers to inform the network about their services requirements.
• The Network Slice Selection Function (NSSF) binds a UE with a specific network / functional slice.
NWDAF is a new 5G core network function[2]. The NWDAF achieves policy modifications (Supposedly in real time) based on the information available such as load levels per slice, so in effect the NWDAF provides slice specific network data analytics to the PCF and the NSSF over the interfaces Nnwdaf, Nnssf and Npcf [2]. PCF will use the NWDAF inputs for policy optimizations. The NSSF will utilize the NWDAF's inputs to maintain the UE to slice mapping for the different data flow characteristics.
The RIC has two components, the Near Real Time RIC that will reside close to the CU (Central Unit) and the Non Realtime RIC that typically resides at the Application level. The near real time RIC is shown in the figure 2, this collects all the data from the gNBs to assist any possible RRM optimizations. The Near RT RIC gets the policy advice from the Non RT RIC.

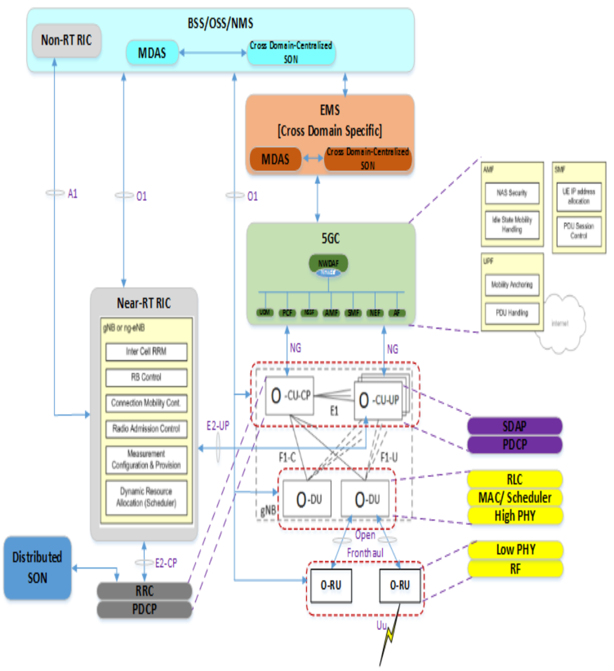

Figure 2: 5G Network Architecture with the ORAN RIC

Figure 3 explains the placement of the near RT RIC in the protocol stack architecture. The E2 interface will collect the data from the gNBs that can be used for the application of the Radio Resource Management (RRM) algorithms.

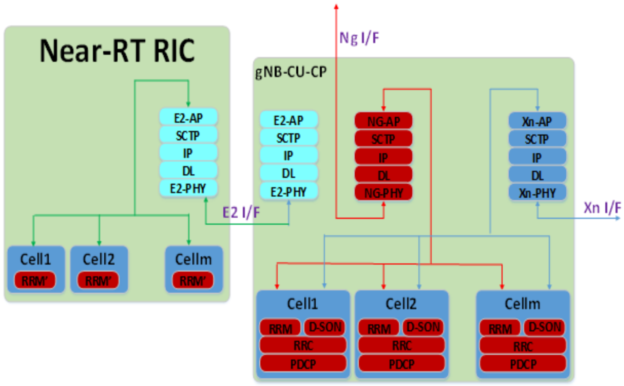

Figure 3: The 5G NR gNB CU-CP with the ORAN RIC

A.QoE Definitions

The QoE definitions for 5G NR is still evolving in the 3GPP forum, the work is expected to progress in Release 17. We present a quick survey of recent QoE studies. Different mechanisms have been presented for obtaining QoE, for instance, the work presented in [3] investigates new architectures for QoE-driven resource control for long-term evolution (LTE) and LTE-advanced networks, including a selection of KPIs to be monitored in different network elements. A new QoE server has been described where the new QoE server is responsible for:

1. Collecting performance indicators from different network elements,
2. Estimating the QoE for specific data services from previous performance indicators,
3. Triggering potential actions (depending on the use case).

On the other hand, in [4] the QoE Influence Factors (IFs) are categorized into five dimensions:

1. Technology performance on four levels: application/service, server, network, and device;
2. Usability, referring to users' behavior when using the technology;
3. Subjective evaluation;
4. Expectations; and
5. Context.

The EU Qualinet community lists the following QoE Ifs-

Human IFspresentsany time varying property and or the characteristic of a human user. Examples include demographic and socioeconomic backgrounds, the user's emotional state (visual and auditory acuity, age, motivation, emotions).**System IFs** refer to the attributes that affect the technically produced quality of applications or service. **Context IFs** are the factors that capture the situational property and could cover a the user's environment (physical, temporal, social, economic) and technical characteristics" (e.g. movements, time of day, privacy mode).

In summary the QoE definitions are qualitative and handling QoE requires Qualitative analysis solutions. To provide QoE solutions that address the issues of Human and Context IFs, we look at the below attributes for obtaining appropriate QoE objectives:

1. *Context*: defines the type of information considered toforecast the system evolution.

2. *Prediction*: specifies how the system evolution is forecastfrom the current and past context.
3. *Optimization*: describes how prediction is exploited tomeet the application objectives.

It must be also noted that these attributes are also discussed in the literature under the "Anticipatory Networks" as mentioned in [5]. In this paper we use the network attributes available at the RIC / NWDAF to achieve the anticipatory QoE objectives. Some of the attributes assumed at the RIC / NWDAF are derived attributes at the different 5G Radio Network nodes and the architecture facilitating the collection of all the required attributes at the RIC / NWDAF is not the subject of this paper. From a network QoE perspective, the context information that we use for the QoE analysis of video streaming are the following:

1. Location Context, covering mobility (Space Time prediction) and Location patterns / trajectories.
2. 2. Link Context which is the prediction of the evolution ofthe physical wireless channel and the combined Channel and mobility context.
3. 3. Traffic Context covering traffic characterization and load.

1 and 2 above can be termed as the Channel-mobility context.

II. PROBLEM FORMULATION AND ANALYSIS

A. QoE analysis at RIC / NWDAF, idea and contribution

In this paper, we address the problem of QoE for video streaming in 5G networks. 5G networks are anticipated to handle not just conventional video streams but 360 degree video, AR/VR video streams as well. The objective is to be able to address the issue of QoE for Video streaming in a LTE/5G Heterogeneous network (Figure 4). The QoE is evaluated at the NWDAF node in the 4G/5G Network.

QoE analysis at the NWDAF has to deal with a vast amount of data collected at each network node and the UE. We need a mechanism to filter data at each node and pass it to NWDAF entity.

The two key video streaming parameters that will have to be controlled are the Video Rate and Freezing. Some of the parameters that affect Video Rate and Freezing are the Link Context (SINR, Bandwidth Availability), 5G cell availability, number of handover or switching between LTE and 5G termed as mobility context (as the 5G cells will be sparse in the initial deployment), the Traffic Context and the UE Context (Available Buffers etc) apart from the human factors (ex: tendency and frequency change in view angle). The above parameters are monitored and mapped to required video rates and possible Freezing probabilities to take corrective actions.

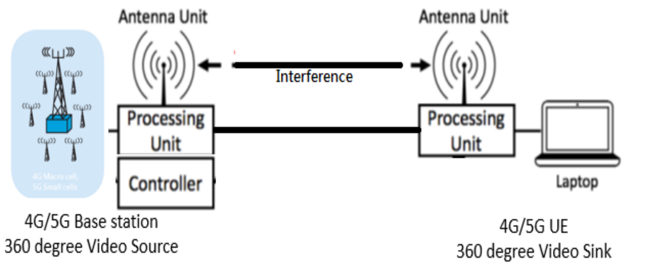

Figure 4: The simulation setup

In this paper we use two factors that affect video quality in a 5G network scenario

1. Combined channel and mobility context
2. Congestion (Traffic Context)
3. Human factors (Head tilt for view angle change)

B. Channel Mobility Context Prediction:

To find the Channel Mobility context, we use fuzzy logic to find the best candidate UEs that are likely to handover soon. It must be noted that the RIC / NWDAF is assumed to obtain the location information of the UEs through the location servers. These interfaces between the NWDAF and the Location servers are yet to be definedin the 3GPP specifications but are a potential input to the specifications in the future. We identify UEs that are far enough for the center ofthe cell and most likely to handover to another target cell soon. We identify the devices that are atcell boundary and calculate the handover possibility based on the differentreadings of their signal to noise ratio (SNR), radio distance(RD) and round-trip time (RTT).

We use a fuzzifier to quantize these parameters, the membership functions of inputs and its location decision functions are shown in the figure 5.

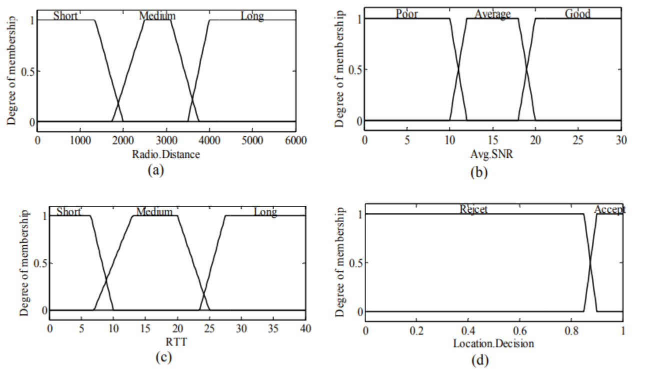

Figure 5: The membership functions for Channel / Mobility Prediction

The membership functions and the inference rules are motivated by the Base Station coverage and the radio distance that can be reached with the maximum allowed transmission power.

C. Calculation of the Congestion Level

Just as in the previous section we apply fuzzy logic to find the congestion levels in the system (4G/5G network).

We capture the Inter Packet Gaps (IPG) of the incoming packets into the network to qualify congestion, we term it as T_S and the packets exiting the 4G/5G network be T_C.

In a congested network the Inter Packet Gaps will be dispersed. Which results in T_C being greater than T_S.

The measure of the network congestion is provided by the difference between T_C and T_S. The degree of congestion in the network is indicated by the extent of the difference.

The rate of data transfer from the application into the network, and the client receiving rate from the network are calculated as R_S and R_C, respectively,the difference between the two rates, R_D, can then be calculated as:

$$R_D = R_S - R_C.$$

The network congestion level, C_L, can subsequently be calculated as:

$$C_L = \frac{R_D}{R_S}.$$

The Delta $C_L$which represents the difference between the current and the previous values of C_L are calculated. The inference rules are based on the values of C_L and the Delta C_L are shown in Figure 6 and figure 7.

Delta CL

Value	Meaning
NVH	Negative very high
NH	Negative high
NM	Negative medium
NL	Negative low
Z	Zero
PL	Positive low
PM	Positive medium
PH	Positive high
PVH	Positive very high

C_L

Value	Meaning
CL	Low
CM	Medium
CH	High
CVH	Very high
CEH	Extremely high

Figure 6: Linguistic variables for Delta $C_L$and C_L

Delta C_L/C_L	CL	CH	CH	CVH	CEH
NVH	SPH	SPM	SPL	SZ	SNL
NH	SPM	SPL	SZ	SNL	SNM
NM	SPL	SZ	SZ	SNM	SNM
NL	SPL	SZ	SNL	SNM	SNH
Z	SZ	SNL	SNM	SNH	SNH
PL	SNL	SNL	SNM	SNH	SNH
PM	SNL	SNM	SNH	SNH	SNVH
PH	SNM	SNH	SNH	SNVH	SNVH
PVH	SNM	SNH	SNVH	SNVH	SNVH

Figure 7: The Inference Rules for congestion

We use the Handover / Signal strength (Combined channel and mobility context) and the Congestion (Traffic Context)defuzzifier outputs to map to the required Video Rates and Freezing through another inference rule table.

The below diagram provides the achieved effective bit rate over time in the simulation setup. It is found that with the right handover prediction into a 5G cell is critical to maintain the required throughput to handle freezing. This work also provides a means to estimate the distribution of the 5G cells necessary over an average mobility pattern of users to handle issues of QoE in a given geography. It was found that an effective bitrate must be maintained wither in an LTE cell or in a 5G NR cell. Due to congestion in an average LTE cell, the availability of frequent 5G Cells given a mobility pattern is critical for video applications such as 360 degree video or AR/VR streams.

D. Modeling Social Context

It has been shown [10] that there is a direct correlation between bad video quality and a user's emotional state. During a video content consumption, bad video quality is the reason for users to click away. Long loading times, constant buffering, and rendition changes are the ones that interrupt playback. Content delivery issues account for nearly 70% of viewers' frustrations with online video and a third of those users claim that interruptions (re-buffering) are the most irritating aspect of video consumption. Both startup buffering and the mid-stream interruptions are issues to be handled.

In order to model user behavior, we model the average effective playtime (meaning time spent consuming content and not waiting for content to load) of a video stream. The effective playtime rises as the error percentage goes down. Average effective playtime was 38% higher at 2.5% error frequency than at 5% error frequency [10]. Based on the above assertion, we model the user behavior (effective playtime probabilities) at different error rates. The error rate feedback is available at the near RT RIC. In the table-1 the above values are seen to be biased the number of handovers.

Table 1: Percentage failure of packets in video clips (biased by mobility factor)

Video Clip	Time Duration minutes	Percentage of failure packets	mobility factor (no. of 4G/5G Switches)
Video Clip 1	1:32	4.79%	4
Video Clip 2	1:27	3.43%	1
Video Clip 3	1:06	1.52%	1
Video Clip 4	1:54	4.68%	3
Video Clip 5	1:26	1.79%	2
Video Clip 6	1:32	2.55%	2
Video Clip 7	1:43	2.76%	3
Video Clip 8	1:21	1.83%	2
Video Clip 9	1:17	2.60%	2
Video Clip 10	1:07	0.96%	1

The figure 8 shows that as the correction lead time increases the QoE decreases.

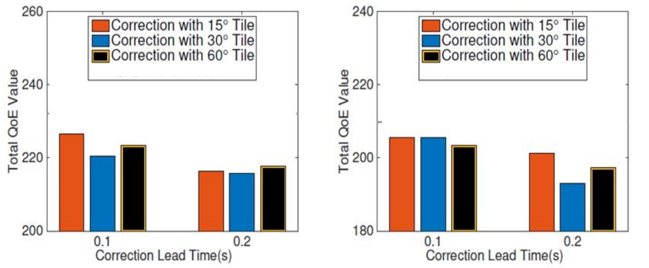

Figure 8: Correction Lead times (s) in a 4G/5G network deployment

III. CONCLUSIONS AND FUTURE WORK

In this paper, we developed a fuzzy logic mechanism to handle 360° videostreaming for 4G/5G wireless deployments. We calculate the Channel/Mobility context and the traffic context, then combine them again using a set of fuzzy rules to calculate the needed data rates to effectively utilizethe high bandwidth available in 5G and cope with high bandwidthvolatility in a 4G/5G network scenario.

Retrieval Number: E6207018520/2020©BEIESP
DOI:10.35940/ijrte.E6207.018520
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

The so-called Human IFs are still not accounted for in this work i.e. the user head tilt and its effects on the buffer flush at the client side will have to be accounted for. We provide a mechanism to calculate the optimalrate allocation between the 4G and the 5G cells and across the video base tier and enhancement tier. In heterogeneous 4G / 5G networks, it is evident that the 5G channelcan be used in a cost-efficient manner to not just compensate for the low throughput in 4G cells but also retransmit chunksthat cannot be delivered in time through 4G cells. Further work will focus on the RIC / NWDAF architecture for Realtime data collection from the network entities and video correction.

Future work will also cover the development of a hierarchical fuzzy logic system to account for multiple levels of information granularity between the radio network nodes and the NWDAF entity.

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