

Dynamic QoS Management for Interactive Multimedia in Integrated 4G/5G Networks

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Abstract

INTRODUCTION: Emerging interactive multimedia applications such as VR have some key requirements that communication medium must full fill in order to have a smooth interactive experience. These requirements include higher uplink and downlink throughput requirement, low latency, and consistent throughput even at the cell edge. Present day 4G/5G Network faces a lack of resource availability for highly sophisticated applications like interactive multimedia. While 4G/5G networks do have a QoS mechanism to handle multiple varieties of traffic requirements, they are passive. At best, initial negotiated QoS are changed on a reactive basis.

OBJECTIVES: This work proposes a dynamic QoS management scheme so that the overall necessary resource allocation for interactive multimedia and non-interactive applications can occur.

METHODS: The scheme uses mobile agents which can efficiently predict possible disruption in QoS and help both server and users to adapt to changing network situation. This way user can be notified of an expected or estimated service quality change in advance, timely adaptation is possible. use this information to for efficient QoS negotiation and re-negotiation.

RESULTS: The developed scheme has been tested with different sizes of the 4G/5G networks with several virtual reality users along with other background loads of applications.

CONCLUSION: Results are quite encouraging and the system is practically implementable.

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Keywords: Quality of Service, Interactive Multimedia, 4G/5G Integrated Multimedia Networks

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1. Introduction

Emerging interactive multimedia applications such as Virtual Reality (VR) and Augmented Reality are upcoming important applications in healthcare, autonomous transport, education, tactile internet, and industrial automation. However, these applications face challenges over cellular networks. VR applications have significant throughput requirements for both uplink and downlink. However, the requirement is asymmetric as the downlink data rate requirement is relatively high compared to the uplink data rate. In addition to the high throughput requirement, low latency is another crucial requirement for an immersive experience. For latency, uplink has more

stringent requirements as compared to downlink. For a consistent experience of complete immersion everywhere, consistent throughput is required even at the cell edge. Other issues such as frame structure limitation, propagation delay, packet loss due to wireless error, resource allocation delays, insufficient quality of service provisions, effects on network performance due to multi-SIM devices, and static scheduling algorithms also lead to poor user experience.

There is an increasing need and demand for networks to care for the quality of service for various applications by making necessary resource allocation provisions across network components. Mainly technical issues have emerged in radio resources management, such as bandwidth allocation, call admission control, and Quality of Service (QoS) management. To meet the interactive application's QoS requirement, issues in QoS

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negotiation, and appropriate proactive re-negotiation need to be addressed. In the traditional paradigm, where network infrastructure used to be solely owned and operated by one operator, a network service provider had complete control on various aspects of network component ownership, such as resource management. However, with future networks that offer shared usage and collaborative ownership mode, for example, with the virtual private network concept, one operator does not have a complete end-to-end control over all the required aspects. A common framework is therefore required which can integrate these various types of networks.

1.1. Proposed Idea

4G and 5G networks provide a QoS framework; however, both 4G and 5G independently support a different set of QoS parameters and negotiation procedures. We identified issues in the existing 4G, 5G, and 4G-5G QoS framework for handling interactive VR applications. This research work aims to design solutions to the critical issues in 4G/5G based integrated multimedia networks for interactive applications such as interactive virtual reality applications. To solve these issues in the cellular network, use of agent technology is proposed. As agents can make decisions by themselves on behalf of the user, migrate from node to node, and dynamically resolve issues occurring at various network elements. Thus, a mobile agent-based framework provides an efficient solution to solve multimedia network issues. We propose schemes for use of static and mobile agents for ensuring guaranteed, adaptive bandwidth and latency needs of VR applications. We propose a QoS negotiation scheme and proactive QoS re-negotiation considering past traffic analysis, user history, and network performance parameters. In our proposed scheme, a very active negotiation happens while starting the session, and users are informed about the minimum and maximum available parameters. Once sessions are in progress, there is continuous monitoring of performance. If more resources are available, a mobile agent based system helps in proactive QoS re-negotiation. Mobile agents helps 4G/5G networks overcome challenges inherent in available signaling methods. We notice that by actively suspending non-VR applications that can tolerate delay, overall system performance is improved. So the proposed scheme efficiently improves the user's VR application's performance by using a static agent and mobile agent based interaction across 4G-5G network components like eNB, PCR, S-GW, P-GW, gNB, and UPF. The mobile agent based system effectively enables end to end QoS negotiation and re-negotiation across the different mechanisms supported by 4G/5G networks.

Organization of rest of the paper is as follows. In section 2, existing works for handling issues arising while handling interactive multimedia are discussed. Further in section 3 QoS management issues in 4G/5G networks are discussed. In section 4, we propose an agent based dynamic QoS management scheme which effectively takes of resource needs of interactive VR applications. In section 4.5 analytical model is presented and thereafter simulation and results are discussed in section 5. Finally conclusion is presented in 6.

2. Existing work

Virtual reality applications have specific requirements from wireless networks because of unique traffic characteristics[1]. An agent is an independent software program, which runs on behalf of a network entity [2]. A mobile agent is a program that, once launched by a user, can travel from node to node autonomously and can continue to function even if the user is disconnected from the network. A mobile agent consists of code, state, and attributes[3]. There are multiple options for mobile agent platforms available that provide services like execution, communication, mobility, and security, to mobile and static agents. Mobile agents improve the performance of the distributed internet systems by filtering and retrieving information by minimizing network overload [4]. Mobile agents have been employed in telecommunication networks; for example, in [5], network management using mobile agents is presented. In [6], author essentially utilize multi-connectivity options to use multiple networks like 4G LTE, 5G, WiFi, and WiGig and attempt to make provision for multipath data transfer for improved throughput, and latency aspects needed for interactive VR application. In [7], a new latency control protocol for multipath data delivery with pre-defined QoS guarantees is described. In [8], a QoS management method for 5G wireless networks is proposed, which involves QoE modeling considering user requests and services being offered. In [9], a framework is proposed for an end to end QoS provisioning for a 5G network considering resource types to be differentiated resource types that consist of both wired and wireless domain. This work considers SDN and NFV for network slicing. In [10], the author describes a method in which a relation is made between the user's QoE to network QoS parameters while using applications like video. On comparing performance with other methods, it is claimed that lower latency is achieved using the proposed methods. There are multiple works available with applications of mobile agents in wireless networks such as [11–13]. Few techniques on how best the base stations can allocate resources in the 5G network are investigated in [14, 15]. In [3, 16] intelligent

agents are used to handle issues at network layer for improved processing and round trip time. In [17], mobile agent-based implementation is compared with client/server method, and a comparative evaluation is made. The mobile agent also finds application in wireless multihop networks [18]. It is argued that traditional implementation is not scale-able because it is centralized, and if network management is performed through a mobile agent, it is having high performance and better fault tolerance. Here management responsibility is given to mobile agents, which executes algorithm in distributed manner and without human intervention [19]. Another promising application of mobile agents in network management is mentioned in [20] in which it is proposed to have a navigator agent and task agent for efficient network management. In [21], an interesting observation is made wherein the overhead of traffic generated by the mobile agent-based approach is studied. An optimal decision is made to decide if mobile agent-based network management should be performed.

2.1. Resource Management using Mobile Agents

There are several applications of mobile agent based system for Resource Management. In [22, 23], mobile agent based scheme is presented for bandwidth allocation and call admission control in 5G networks. In [24], author presents a multi agent scheme for efficient resource management and interference coordination for 5G heterogeneous networks. In [25], a multi agent architecture is used to help in spectral sensing for cognitive radio. In [26] Agent Based Call Scheduling Technique with Optimum Resource Utilization in Cellular Controlled Short-Range Communication (CCSRC) Network is proposed which concentrates on scheduling the calls in CCSRC networks by minimizing the energy consumption of mobile nodes and increasing the spectrum utilization efficiency of the network. In [27], an attempt is being made to improve the mobile agent-based system by using Artificial Intelligence (AI) to improve load balancing across networks in energy efficient manner in wireless sensor networks. Mobile agents have recently been used for dynamic channel acquisition in mobile cloud computing, which can dynamically choose users to transmit data based on queue backlog and channel statistics [28]. Mobile agents have also been used along with a new paradigm of software-defined networking [29]. Mobile agents find application in Vehicular network [30] wherein static agent at Road Side Unit (RSU) can track and obtain information about the traffic with help of mobile agents which can migrate from one vehicle to another to aggregate or disseminate information on the status of the traffic. In [31], mobile agents have been used for

cellular service. Further few essential benefits in the form of asynchronous autonomous interaction and decision making, adaptability, robustness and fault tolerance, and support for a heterogeneous environment motivates us to use mobile agents for challenges thrown upon 4G-5G networks while using interactive multimedia applications such as VR [32], [33], [34], [35], [36]. In [37], author propose a mobile agent-based approach to be used along with a software-defined networking controller (SDN), which takes care of routing in a real network environment based on local routing and management of the node state in the SDN environment.

2.2. Network management using Mobile Agents

Mobile agents are also considered to model, simulate, and represent meaningful entities such as rooms or cars, etc. [38]. SNMP has a simple interface to provide sophisticated management services. Agents have been used for authentication, authorization, and accounting during roaming in mobile IP [39], [40] and Session Initiation Protocol (SIP) [41]. For network management in 5G, [42], role of mobile agents in reasoning is explained. The superior efficiency of the MA-based network management has been established [35]. Mobile agents are useful tools to be used in the mobile environment [43], [44]. There have been usage of mobile agents for routing as in [45].

2.3. Handling of security concerns while using Mobile Agents

In [46] an overview of the security issues related to the mobile agent based systems is presented. Author have discussed existing security standards and technologies for mobile agent which takes care of security against a malicious mobile agent. Further security issues in Mobile agents have been tackled in [47], in which the mobile agent code is encrypted using the encryption function and this enables tracing of suspicious execution result. Author claims that using this method, most malicious attacks on mobile agents can be blocked and integrity and confidentiality of mobile agents can be protected. In [48] authors demonstrate how the Blockchain Technology can be used to secure mobile agents in Multi-Agent Systems. Mobile agents have been used [49] for intrusion detection by correlating the cross layer features such as MAC and Network layers and prevention of multiple attacks in wireless sensor networks. In [50] author presents a mobile agents platform called SyMPA, which is compliant with the specifications of the MASIF standard from the OMG, that supports both stationary and mobile agents implemented using the high-level agent-oriented programming language CLAIM.

3. QoS Issues in 4G/5G Integrated Networks

In this section we present QoS issues in 4G, 5G and 4G/5G Integrated networks. Different applications trying to access the 4G network, need additional service guarantees based on the type of application. 4G employs a QoS mechanism to provide QoS guarantees to various applications accessing the network. QoS parameters such as desired jitter performance, throughput, and error rate help make provisions of resources such as buffers and bandwidth across network elements.

While 4G network provide a QoS mechanism to handle multiple varieties of traffic requirements, they are passive. During the beginning of the session, QoS is negotiated, and mostly it remains the same, or at best, it is changed in reactive manner. This means that if the network encounters outage or resource crunch, then QoS is re-negotiated. However, there is a need to have a more proactive approach to QoS management, wherein whenever future events are predicted which will restrict QoS availability, applications are informed about it. This will enable stakeholders to take proactive steps like finding alternate paths. Presently 4G networks do not inform UE of any possible future degradation, so applications find it challenging to change QoS at the last moment.

Disadvantages of 4G QoS Architecture. Even though the 4G QoS mechanism is well defined, it falls short in following areas:

- 4G QoS is bearer centric. QoS guarantee cannot be provided at a lower level than bearer level. For VR traffic, this seems less suitable. Within one bearer, all packets receive the same treatment. Also, as there is one to one mapping of radio bearers to EPS bearers, 4G QoS is not scalable.
- In 4G, there are limited number of QoS classes. So the new generation QoS applications are not supported.
- Simultaneous applications of the same user are not differentiated properly.
- 4G QoS architecture provides static or semi-dynamic rule-based policy enforcement in the core. Therefore existing mechanism in 4G network are incapable of providing a personalized experience.
- 4G doesn't support any notion of predictive QoS inherently, and it is best defined as reactive.
- Mapping is always a challenge because different systems support different methods.

- In 4G, without opening too many bearers, a fine granular QoS cannot be defined for multiple streams within a session.

The 5G core network supports a more granular, flow-based QoS framework compared to the static bearer based QoS of EPC, which means QoS can be assured on an application basis. For example, for the latest real-time services such as AR/VR, the new QoS framework will ensure the optimal user experience level. Also, as 5G supports network slicing feature, the QoS management scheme now has to support the same traffic across multiple tenants. Since 5G network consists of mostly smaller cells, it is quite difficult to provide stable QoS guarantees during high mobility. So challenges related to the quicker adaptation for appropriate QoS for users remains to be solved in 5G networks.

The comparison of issues observed in 4G and 5G QoS architecture for meeting requirements for interactive VR services are given in Table 1.

| Issue | 4G network | 5G network | Ideal behavior (requirement) |
|--------------------------------------|--|---|--|
| Granularity | QoS's minimum granularity is the bearer. | QoS's minimum granularity is flow | Separate uplink and downlink guarantee at flow level needed |
| End to end QoS | Provides QoS support only between UE and PGW | Provides support between UE and UPF | QoS support is needed end to end |
| Signaling overhead | For uplink and downlink separate signaling is required | Reflective QoS provides support to specific uplink QoS without need for separate signaling | Across network such support needed |
| Application-level QoS support | Bearer method require an end to end QoS signaling | QoS flow are created without end to end signaling | Such support is required end to end |
| High QoS for uplink | Uplink latency is more | Improvement is possible | Non Standalone (NSA) mode has a problem, and a universal solution required |
| Differentiating QoS across customers | Do not differentiate same traffic class across customers | With network slices, the same type of traffic classes are supported differently across different customer | Providing a unified mechanism in the 4G/5G network is a challenge |

Table 1. Comparison of 4G and 5G QoS schemes

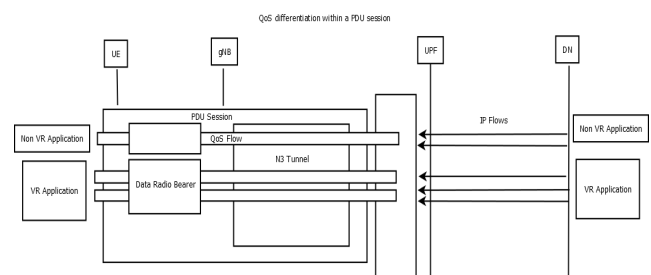


Figure 1. Different QoS to IP flows belonging to PDU Session in 5G

Figure 1, illustrates mapping of different QoS to IP flows belonging to a PDU Session in 5G networks. In 5G networks, separate QoS can be provided at flow level as compared to bearer level in 4G networks. However challenge remains in ability to provide QoS at flow

level as well as ability to provide overall differentiation according to network slices.

Adequate support for proactively informing about a possible reduction in QoS guarantees is required. For example, during the drive, there could be a scenario wherein the network cannot possibly meet presently negotiated QoS parameters, so a proactive mechanism to inform users and applications of possible degradation in the QoS mechanism is needed. Also, mechanisms are required in the 5G network so that alternative arrangements can be negotiated and provisions can be made to meet QoS guarantees continuously.

In the case of the inter-working of integrated 4G-5G networks, integrating different available QoS schemes across the 4G/5G network remains a challenge.

Since interactive multimedia applications have key latency requirements, enough QoS provisions are needed to meet strict latency requirements. For QoS, usually, independent and distinct mechanisms exist within each technology. Integration of different available QoS schemes across the 4G/5G network still remains a challenge in case of interworking of integrated 4G/5G network. Due to different mechanisms, there is a need to mechanisms that allow QoS negotiation and re-negotiation to happen across multiple types of networks.

5G networks are being designed to incorporate newer technology using Software Defined Networking(SDN), Network Function Virtualization (NFV), and network slicing. In general, 5G RAN is implemented using split architecture comprising of central unit and distributed units. Radio access network and core network are virtualized. 5G networks present a new set of challenges. In the 5G network, application-centric bandwidth allocation is needed as the range of applications that are required to be supported has multiplied. The challenge in 5G is to take care of bandwidth allocation with respect to a new architecture having separate control and data plane.

Based on the network's changing state and interactive VR application's QoS requirements, 5G network needs to employ adaptive bandwidth allocation for improved system utilization and it meet network performance requirements by adjusting the bandwidth allocation. Existing mechanisms in 5G network do take care of bandwidth allocation for applications like voice call. However, for applications demanding interactive multimedia with strict bandwidth and delay requirement, existing 5G networks are not sufficient. Therefore, specific solutions are required for the need of AR/VR applications. For example for a time-critical application like autonomous vehicles, which need strict response time of a few milliseconds, the 5G network struggles to ensure adaptive bandwidth allocation.

Resource requirements of VR services. For VR interactive services, the full-view transmission is used in the fair-experience phase. With industry development and an increase of resolution, the FOV transmission solution can be used to minimize the required network bandwidth.

The average bit rate in the full-view transmission solution is calculated as follows:

$$VR_b = (P_t) \times (B_p) \times \frac{(F_r)}{(C)} \quad (1)$$

VR_b = Average bit rate required for VR data P_t = Total pixels in frame B_p = Bits per pixel required F_r = Frame Rate C = Compression Ratio

There are four stages of the proposed agent based bandwidth allocation scheme. First stage is the creation of a static agent followed by required registration in the second stage. In the third stage, resources are allocated for bandwidth management, and in the fourth stage, the agent monitors the traffic situation such as non-interactive load, and takes care of changing needs efficiently. Under the proposed scheme, a static agent is to be created in crucial components like 5G eNodeB and VR application server in the first stage. The second stage is the users' registration through user equipment to the network after receiving requests for session establishment and mobile agents' corresponding movement to UEs. In the third stage, bandwidth allocation is to be performed in uplink and downlink, in collaboration with static agents and mobile agents. In the fourth stage, active monitoring would be performed to adapt bandwidth in a dynamic way for various network scenarios.

4. Proposed Agent based QoS Management Scheme

To address the issues in 4G, 5G and 4G/5G IMNs, an agent based QoS management scheme is presented. First we propose agent based QoS Management scheme for 4G networks. Next we take up applicable scheme for 5G networks and finally we propose solutions for integrated 4G/5G integrated networks.

4.1. Architecture of Proposed Mobile Agent based QoS Management Scheme in 4G

The architecture of the proposed agent based QoS scheme for 4G is presented in Figure 2.

4.2. Proposed QoS Negotiation and Re-Negotiation Scheme in 4G

In the architecture of proposed agent based scheme for 4G, the QoS negotiation scheme is divided into two parts: QoS negotiation and QoS re-negotiation.

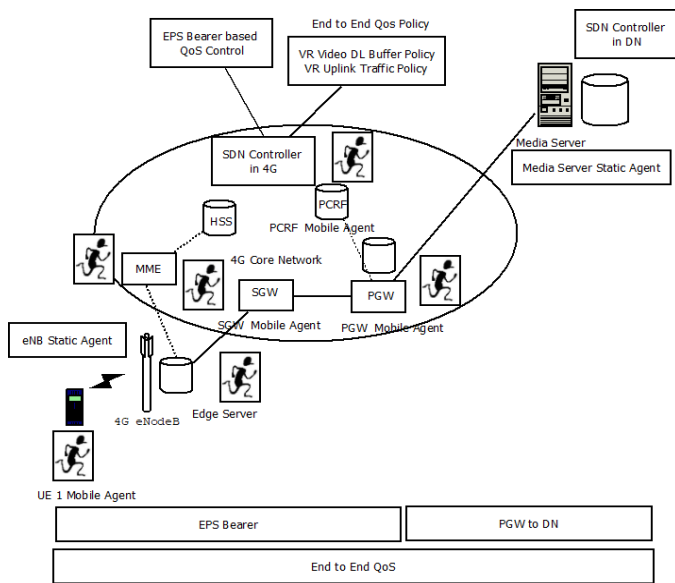


Figure 2. Agent based QoS negotiation scheme for 4G networks

Algorithm 1 4G QoS negotiation using mobile agents

- 1: Begin
- 2: **Input:** New interactive VR request arrives and request for QoS
- 3: **Output:** Allocate resources to meet QoS requirements after negotiation
- 4: Static agent at eNB dispatches mobile agent to S-GW, P-GW, PCRF to get past history
- 5: Mobile agent in UE informs PCRF agent about QoS needs
- 6: Mobile agent in P-GW obtain current load as well as see if all QoS requirement are possible to meet
- 7: Mobile agent in P-GW informs about available QoS parameters
- 8: **while** UE mobile agent compares each QoS parameter **do**
- 9: **if** Available QoS is within min and max range of requested QoS **then**
- 10: UE agent accepts QoS and informs network
- 11: **if** Available QoS are not within and max range of requested QoS **then**
- 12: Select new path in LTE including D2D
- 13: **else if** No path available **then**
- 14: Inform user about current network available QoS
- 15: **if** User accept available QoS **then**
- 16: Continue with minimum supported QoS parameters
- 17: **end if**
- 18: **end if**
- 19: **end if**
- 20: **end while**
- 21: End

In algorithm 1 details about 4G QoS negotiation scheme are mentioned.

In algorithm 2 details about 4G QoS re-negotiation scheme are mentioned.

Algorithm 2 4G QoS re-negotiation when a non-VR application leaves

- 1: Begin
- 2: **Input:** Interactive VR and non interactive session is ongoing
- 3: **Output:** Re-evaluate QoS for VR requests based on load and inform proactively to UE
- 4: Interactive VR and non-VR requests have been allowed buffer and bandwidth as per negotiate QoS
- 5: Agent based system continuously monitors performance
- 6: **while** Periodically check and estimate about future availability of required QoS **do**
- 7: **if** Non-VR application has terminated **then**
- 8: Check how much resources are freed up
- 9: Check which application had poor performance as per rank
- 10: Increase the QoS allocation as per the ratio of rank
- 11: Poorer performance VR connections get allocated more resources
- 12: UE mobile agent is informed about upgraded QoS profile for both uplink and downlink
- 13: UE applies a new QoS filter, and VR connection quality is improved
- 14: **end if**
- 15: **end while**
- 16: End

4.3. Proposed Mobile Agent based QoS Management Scheme over 5G

The agent based proposed QoS negotiation and re-negotiation scheme over 5G is presented in Figure 3. In the proposed architecture, mobile agent based 5G network is designed to take account of various flow information that can be obtained from UPF in 5G core and shared with the mobile agent in SDN controllers distributed in the data network.

The agent based QoS management scheme over 5G is divided into two parts: QoS negotiation and QoS re-negotiation. In algorithm 3, details about 5G QoS negotiation scheme using mobile agents are mentioned.

In algorithm 4, details about 5G QoS re-negotiation scheme using agents are mentioned.

The architecture of the proposed agent based QoS management scheme over 4G/5G IMNs is presented in Figure 4.

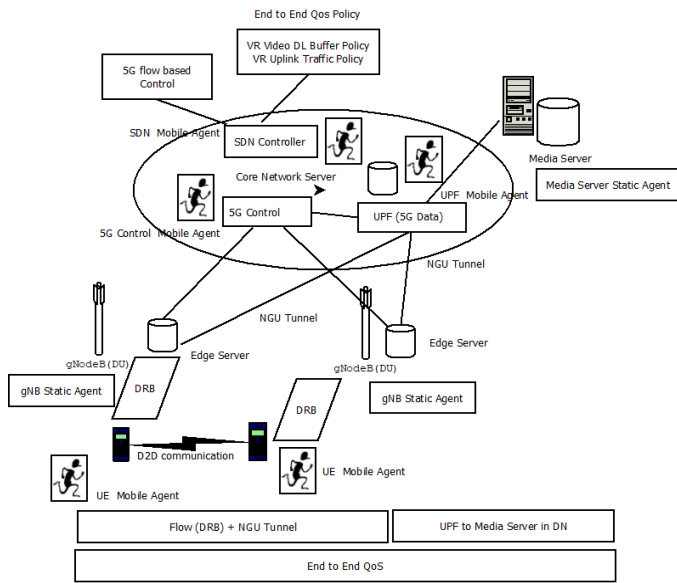


Figure 3. Architecture of proposed QoS negotiation scheme over 5G networks

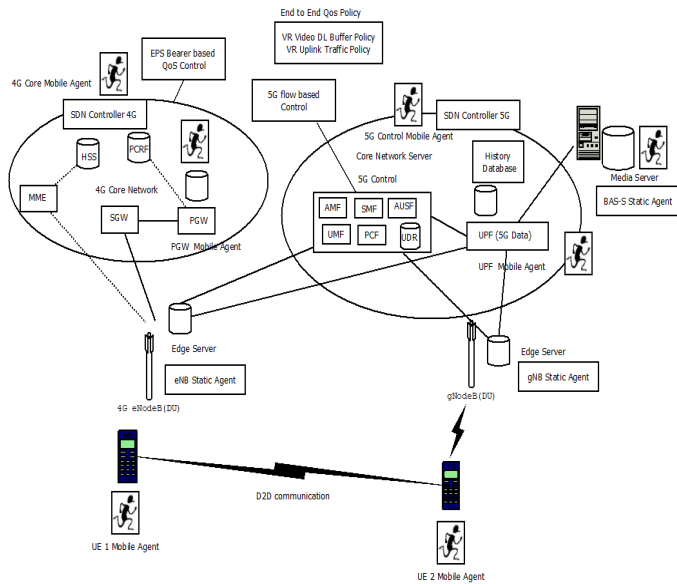


Figure 4. Architecture of QoS management scheme over 4G/5G IMNs

4.4. Proposed Mobile Agent based QoS Management Scheme over 4G/5G IMNs

In the proposed scheme, a mobile agent based 4G/5G network is designed to take account of various flow information that can be obtained from UPF in 5G core and shared with the mobile agent in SDN controllers distributed in the data network.

In algorithm 3, details about 4G/5G QoS negotiation using mobile agents are mentioned.

Algorithm 3 5G QoS negotiation using mobile agents

- 1: Begin
- 2: **Input:** New interactive VR request arrives
- 3: **Output:** Allocate resources to meet QoS requirements after negotiation
- 4: Static agent at gNB dispatches mobile agent to UPF and 5G control and gets data about past history
- 5: Mobile agent in UE informs PCF agent about QoS needs
- 6: Mobile agent in UPF obtains current load as well as checks if all QoS requirements are possible to meet
- 7: Mobile agent in UPF informs about available QoS parameters like QFI
- 8: **while** UE mobile agent compares each QoS parameter **do**
- 9: **if** Available QoS is within minimum and maximum range of requested QoS **then**
- 10: UE agent accepts QoS and informs network
- 11: **if** Available QoS are not within minimum and maximum range of requested QoS **then**
- 12: Select new path in 5G including device to device link
- 13: **else if** No path available **then**
- 14: Inform user about current network available QoS
- 15: **if** User accept offered QoS **then**
- 16: Continue with minimum supported QoS parameters
- 17: **end if**
- 18: **end if**
- 19: **end if**
- 20: **end while**
- 21: End

In algorithm 6 details about 4G/5G QoS re-negotiation when non-Vr application leaves are mentioned.

4.5. Analytical Model

An analytical model is proposed in Figure 5 to analyze the average service time of a UE and the effect of non-interactive load. Proposed analytical model uses a two queued networks model where the first queue represents eNB and the second P-GW with infinite queue size.

Let λ_1 be the arrival rate of interactive VR requests. Let λ_2 be the arrival rate of non-interactive VR requests.

Let the maximum number of non-interactive sessions is N_N .

Let the number of interactive sessions be N_I .

Let total capacity be C and $N_I + N_N < C$

Let new session scheduling rate be T_s .

In LTE $T_s = 0.5ms$.

Algorithm 4 5G QoS re-negotiation when a non-VR application leaves

```

1: Begin
2: Input: Interactive VR and non interactive session is ongoing
3: Output: Re-evaluate QoS for VR requests based on load and inform proactively to UE
4: Interactive VR and non-VR requests have been allowed buffer and bandwidth as per negotiate QoS in UPF and gNB
5: Agent based system continuously monitors performance
6: while Periodically check and estimate about future availability of required QoS do
7:   if Non VR application has terminated then
8:     Check how much resources are freed up
9:     Check which application had poor performance has per rank
10:    Increase the QoS allocation as per the ratio of rank
11:    Poorer performance VR connections get allocated more resources
12:    UE SA is informed about upgraded QoS profile for both uplink and downlink
13:    UE applies new QoS filter and VR connection quality is improved
14:   end if
15: end while
16: End

```

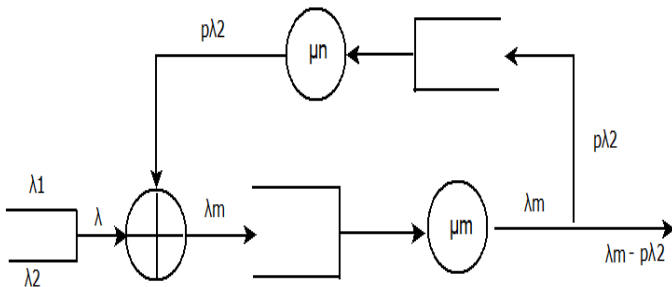


Figure 5. Analytical model for 4G QoS management

Interactive application and non-interactive application sessions arrive according to independent Poisson processes with a rate of λ_I and λ_N , respectively.

VR arrival

$$\lambda_I = \lambda_{1I}, \lambda_{2I}, \lambda_{3I}.. \quad (2)$$

VR departure

$$\mu_I = \mu_{1I}, \mu_{2I}, \mu_{3I}.. \quad (3)$$

NVR arrival

$$\lambda_N = \lambda_{1N}, \lambda_{2N}, \lambda_{3N}.. \quad (4)$$

NVR departure

$$\mu_N = \mu_{1N}, \mu_{2N}, \mu_{3N}.. \quad (5)$$

Algorithm 5 4G-5G QoS negotiation using mobile agents

```

1: Begin
2: Input: New interactive VR request arrives
3: Output: Allocate resources to meet QoS requirements after negotiation
4: Static agent at eNB, gNB dispatches mobile agent to UPF and 5G control
5: Static agent and mobile agent gets data about past history
6: Mobile agent in UE informs PCF agent about QoS needs
7: Mobile agent in UPF obtain current load
8: Mobile agent in UPF informs about available QoS parameters like QFI
9: while UE mobile agent compares each QoS parameter do
10:  if Available QoS is within minimum and maximum range of available QoS then
11:    UE agent accepts QoS and informs network
12:  if Available QoS are not within and maximum range of available QoS then
13:    Select new path in 4G including device to device
14:  else if No path available then
15:    Inform user about current network available QoS
16:  if User accepts offered QoS then
17:    Continue with minimum supported QoS parameters
18:  end if
19: end if
20: end if
21: end while
22: End

```

$$0 < \lambda_I \leq \text{Max interactive rate} \quad (6)$$

$$0 < \lambda_N \leq \text{Max non-interactive rate} \quad (7)$$

Let N be the threshold on the number of total request rates inclusive of VR and NVR requests, beyond which if more non VR requests arrive, they are offloaded to nearby device to device link as shown in Figure 2. Please note that $N \leq C$.

Let α be the ratio of non-interactive VR requests to interactive VR requests.

$$\lambda_2 = \alpha * \lambda_1 \quad (8)$$

Let λ_m be the arrival rate into the main queue, which represents EPS bearer flow across UE, eNB, S-GW, and P-GW. Let μ_m be the service rate of the EPS bearer based on QoS flow. However, as we described in the

Algorithm 6 4G/5G QoS re-negotiation when a non-VR application leaves

- 1: Begin
- 2: **Input: Interactive VR and non interactive session is ongoing**
- 3: **Output: Re-evaluate QoS for VR requests based on load and inform proactively to UE**
- 4: Interactive VR and non-VR requests have been allowed buffer and bandwidth as per negotiated QoS
- 5: Buffer and bandwidth allocation happens in P-GW, S-GW, UPF, eNB, and gNB
- 6: Agent based system continuously monitors performance
- 7: **while** Periodically check and estimate about future availability of required QoS **do**
- 8: **if** Non-VR application has terminated **then**
- 9: Check how much resources are freed up
- 10: Check which application had poor performance as per rank
- 11: Increase the QoS allocation as per the ratio of rank
- 12: Poorer performance VR connections get allocated more resources
- 13: UE mobile agent is informed about upgraded QoS profile for both uplink and downlink
- 14: UE applies a new QoS filter, and VR connection quality is improved
- 15: **end if**
- 16: **end while**
- 17: End

algorithm 2 , while processing interactive VR and non-VR requests, if VR traffic incurs high delay, a fraction of non-VR requests are offloaded. Later these offloaded non-VR sessions are made to wait before they are again admitted into the system. Mean wait happens at μ_m rate, and a fraction of non-VR traffic, which is made to wait and re-enter into service, is given by $p\lambda_2$. From Jackson's theorem, all the queues behave as M/M/1 systems with appropriate mean input arrival rates.

$$\lambda_m = \lambda + p\lambda_2 \quad (9)$$

$$\rho_m = \frac{\lambda_m}{\mu_m} \quad (10)$$

$$N_m = \frac{\rho_m}{(1 - \rho_m)} \quad (11)$$

The delay encountered in the main queue is given by equation 12.

$$Delay_m = \frac{N_m}{\lambda_m} \quad (12)$$

$$\rho_n = \frac{\alpha p \lambda_1}{\mu_n} \quad (13)$$

$$N_n = \frac{r h o_n}{1 - r h o_n} \quad (14)$$

Non VR traffic is returned to get service again after some wait so as to accommodate more interactive VR traffic to meet the QoS requirement of VR traffic. Equation 15 gives delay encountered in a non-interactive traffic queue.

$$Delay_n = \frac{N_n}{\alpha p \lambda_1} \quad (15)$$

$$N = N_n + N_m \quad (16)$$

Equation 17 represents the total delay for both VR and non-VR traffic.

$$Delay_{total} = \frac{N}{\lambda} \quad (17)$$

4G and 5G networks have different frame structures. Slot duration in 5G varies from 1 ms (for 15 Khz SCS) to 0.5 ms (for 30Khz SCS) and 0.0625 ms (for 240 Khz SCS). So for 5G, even though the same model can be used, the rate at which it will be applied will be different.

The new session scheduling rate is $5GT_s$.

where $5GT_s = 1ms, 0.5ms, 0.25ms, 0.125ms, 0.0625m$

Let number of non-interactive sessions in 5G is $5GN_N$.

Let number of interactive sessions in 5G is $5GN_I$.

Total capacity be $5GCC$ and $5GN_I + 5GN_N < 5GC$

5G VR arrival

$$\lambda_I(5G) = \lambda_{1I}(5G), \lambda_{2I}(5G), \lambda_{3I}(5G).. \quad (18)$$

5G VR departure

$$\mu_I(5G) = \mu_{1I}(5G), \mu_{2I}(5G), \mu_{3I}(5G).. \quad (19)$$

5G NVR arrival

$$\lambda_N(5G) = \lambda_{1N}(5G), \lambda_{2N}(5G), \lambda_{3N}(5G).. \quad (20)$$

5G NVR departure

$$\mu_N(5G) = \mu_{1N}(5G), \mu_{2N}(5G), \mu_{3N}(5G).. \quad (21)$$

$$0 < \lambda_I(5G) \leq \text{Max interactive Rate 5G} \quad (22)$$

$$0 < \lambda_N(5G) \leq \text{Max non interactive Rate 5G} \quad (23)$$

As 5G bandwidth is higher than 4G, it can be assumed that

$$\lambda_I \leq \lambda_I(5G) \quad (24)$$

Similarly, due to faster scheduling opportunities in 5G, we get $5G_{T_s} \leq T_s$ and this further gives $\rho_N(5G) \leq \rho_N(4G)$. As a result of this, the 5G network doesn't face overload conditions. Using these in equation 17, we derive delay experienced in 5G networks.

The proposed agent based 4G/5G QoS management scheme can be modeled by Markov Chain as described in section 4.5.

In 4G, bandwidth allocation happens at a slower rate of 1ms, so QoS negotiation also occurs at the same rate. In 5G, bandwidth allocation can happen at a much faster rate, so negotiation and re-negotiation can happen faster, leading to better performance in 4G/5G networks. Due to joint scheduling across 4G and 5G networks, the model can be enhanced to use multiple servers as now uplink, and downlink data can use both 4G and 5G networks. Especially when bandwidth crunch is there in the 4G cell, its capacity can be augmented using a 5G cell.

$$\lambda_I(Combined) = \lambda_I(4G) + \lambda_I(5G)$$

$$\mu_I(Combined) = \mu_I(4G) + \mu_I(5G)$$

$$\rho_I(Combined) = \rho_I(4G) + \rho_I(5G)$$

Using these in equation 17, we derive delay experienced by VR applications in 4G/5G networks.

5. Simulation and Results

The simulation environment used is based on NS3 considered. In the simulation, we have considered the 5G network and the network span a residential society. A virtual reality server has been installed near the base station, which acts as an edge server, and also, there is the main server that lies in the internet domain. VR application has been activated in the server, and it is accessible to all the 100 UE nodes. These UE are spread across networks. Here, as the system capacity reaches a predefined threshold as predicted by the mobile agent-based system, the system takes appropriate action. Here in the simulation, the network starts offloading non-VR requests to nearby links such as a device to device link and ultimately to neighboring gNB.

For 4G networks, in the proposed scheme, as the arrival rate increases for non interactive application request, a portion of non interactive application is made to wait so that interactive VR application can meet their QoS requirement. In Figure 7, it is observed that as non VR application request rate increase in system, there is increase in delay experienced by non interactive VR and interactive VR. However even when non interactive application rate is increasing, delay experienced by VR application is significantly less than delay experienced by non VR application. Simulation results also shows same pattern i.e., using the proposed scheme, delay experienced by non VR application can be reduced to significantly less levels as compared to non VR application.

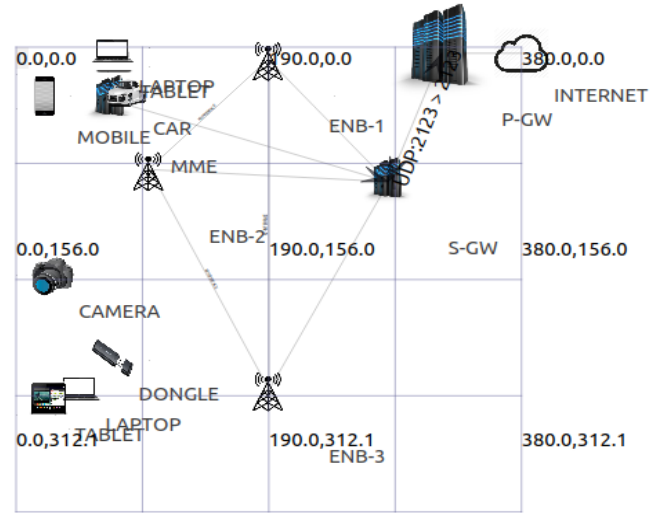


Figure 6. Simulation environment

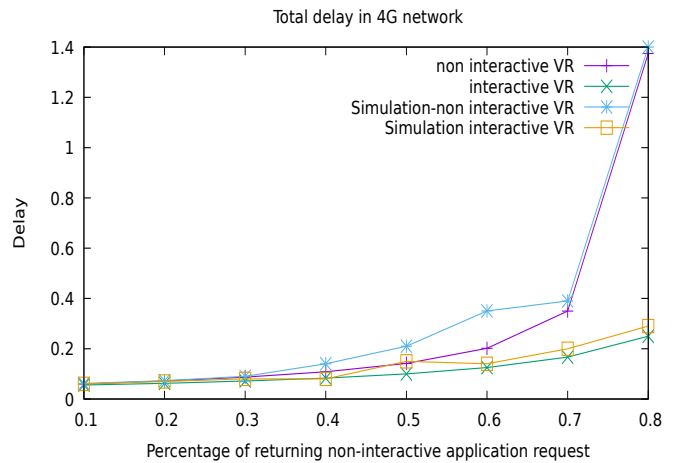


Figure 7. Delay in 4G Network when non VR application request rate increases

For 5G networks, figure 8 shows that there is an increase in total delay when non-VR applications which were put on hold, return to the system after some wait. 5G offers more bandwidth than 4G network, however proposed scheme using agents provides less delay for VR applications as compared to non VR application. Even when non interactive application rate is increasing, delay experienced by VR application is significantly less than delay experienced by non VR application. Simulation results also shows same pattern i.e., using the proposed scheme, delay experienced by non VR application can be reduced to significantly less levels as compared to non VR application.

For 4G/5G networks, figure 9 shows that as a non-VR application request rate increase in the system, there is

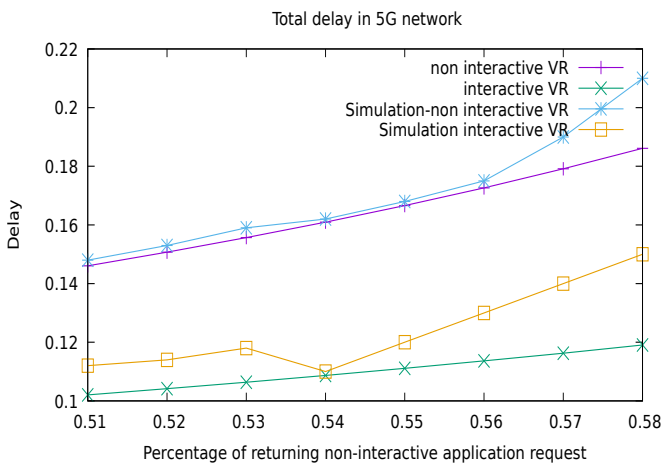


Figure 8. Delay in 5G network when fraction of non VR application are returning after delay

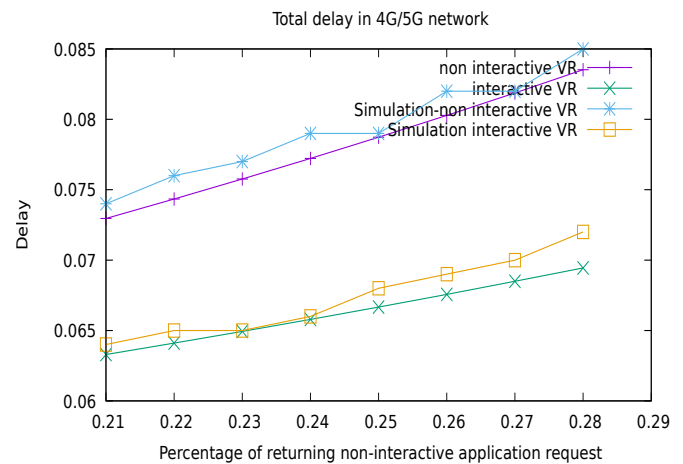


Figure 9. Delay in 4G/5G network as non VR application request rate increases

increased delay experienced by interactive VR and non interactive VR applications. 5G offers more bandwidth than 4G network. In 4G/5G IMNs, application can receive data from both data path of 4G and 5G networks so delays experienced in integrated network are less than delay experienced in 4g only and 5g only network. However proposed scheme provides less delay for VR applications as compared to non VR application because based on proposed QoS negotiation and re-negotiation, non-VR applications which were put on hold return to the system after some wait. Even when non interactive application rate is increasing, delay experienced by VR application is significantly less than delay experienced by non VR application. Simulation results also shows same pattern i.e., using the proposed scheme, delay experienced by non VR application can be reduced to significantly less levels as compared to non VR application.

6. Conclusion and Future Work

Though 4G and 5G networks have a QoS framework; however, they do not support proactive QoS re-negotiation considering past traffic analysis and other factors. In the proposed scheme, a very active negotiation happens while starting the session through static agent at eNB and mobile agent at S-GW, P-GW and PCRF, and users are informed about the minimum and maximum available parameters. Once sessions are in progress, there is continuous monitoring of performance, and if more resources are available or going to be available, a mobile agent based system helps in QoS re-negotiation. Thus through continuous monitoring, VR connections with poorer past performance can get allocated more resources. It may be seen that by actively suspending non-VR applications that can tolerate delay, overall system

performance is improved and delay experienced by VR users is improved. It may be concluded that proposed scheme efficiently enhances the performance of the 4G network, and user's QoE is also improved while using VR applications. Similarly in 5G networks, continuous monitoring of VR application performance is observed by mobile agents and poorer performance VR connections get allocated more resources with help of static agents and mobile agents across network elements such as gNB and UPF. UE Static agent is informed about upgraded QoS profile for both uplink and downlink and as 3GPP doesn't offer as such inherent signaling methods, mobile agents overcome deficiency in standard and are able to coordinate in efficient manner. As may be seen that by actively suspending non VR applications that can tolerate delay, in the proposed scheme overall system performance is improved and delay experienced by VR users is improved. Thereafter, when we evaluate QoS provisions in 4G/5G integrated networks, we find that both 4G and 5G independently support a different set of QoS parameters and negotiation procedures. Also, 4G/5G networks, also don't support proactive QoS re-negotiation considering past traffic analysis and other factors. So the proposed scheme efficiently enhances the performance of 4G-5G network components like eNB, PCR, S-GW, P-GW, gNB, and UPF, and also improves QoE benefits for user's VR application. Also, the mobile agent based scheme effectively enables end-to-end QoS negotiation and re-negotiation across the different mechanisms supported by 4G/5G IMNs.

Proposed QoS management schemes can be further enhanced beyond the cellular 4G-5G network. Non-3GPP technologies support an altogether different QoS framework and ensure QoS maintenance when users move across these technologies; this work can be further

enhanced by taking into account future interactive applications.

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