

Enhanced QoS-Aware Uplink Scheduling Algorithms for Improved LTE-A Performance

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Abstract

Long Term Evolution (LTE) aims to revolutionize mobile broadband technology by offering higher data rates, improved power efficiency, low latency, and better Quality of Service (QoS). Its backward compatibility with legacy cellular networks has garnered wide acceptance within the telecommunications industry. LTE delivers high-speed mobile broadband data at a lower cost per bit, reduced latency, and an enhanced customer experience. The primary goal of LTE's uplink scheduling algorithms is to ensure service fairness across different traffic classes by efficiently allocating bearers over LTE-Advanced (LTE-A) and 5G networks. Scheduling disciplines are crucial for network performance as they manage the fair distribution of network resources. This research focuses on designing and developing an enhanced QoS-aware uplink scheduling algorithm, implementing it in a simulator, and analyzing the results. The proposed user-explicit algorithms (1, 2, & 3) aim to minimize average upload time and maximize average data rate while maintaining QoS during resource allocation. The new model, based on First-In-First-Out (FIFO), Priority Queuing (PQ), and Weighted Fair Queuing (WFQ) scheduling algorithms, was tested in three different scenarios. A simulation model using the Optimize Network Engineering Tool (OPNET) and Microsoft Excel was developed. The results demonstrate that the proposed algorithm significantly enhances LTE-A uplink performance while ensuring Quality of Service.

Keywords: QoS-Aware, Uplink Scheduling, LTE-A, 5G Networks

1. Introduction

The evolution of mobile broadband technology has been rapid, with Long Term Evolution (LTE) emerging as a pivotal development. LTE was designed to meet the growing demand for higher data rates, improved power efficiency, low latency, and better Quality of Service (QoS). By being backward compatible with existing cellular networks, LTE has achieved widespread acceptance and adoption in the telecommunications industry. LTE provides high speed and high mobile broadband data capacity at a lower cost per bit, low latency and improved customer experience. Prior to the emergence of LTE, wireless technology generations has been delivering functionalities like voice, short message service (SMS), video calls and data file transfers (Freeman & Henry, 2023).

The first-generation wireless technology (1G) was successful in moving the basic mobile voice, while the second generation (2G) introduced higher capacity and coverage than the 1G. Thereafter, 2.5G was introduced to pave way for the data connection on cellular network, thus, change the adoption of data connection on the cellular network till date (Božanić & Sinha, 2021). Third generation (3G) Mobile Technology was created to support Internet connectivity and packet-switched services as well as circuit switched services. High-Speed Packet Access (HSPA) is a collection of protocols that extend and improve the performance of 3G mobile protocols. It has High-Speed Downlink Packet Access (HSDPA) and High-Speed Uplink Packet Access (HSUPA) standards (Jiang & Han, 2024). The third generation (3G) brought the search for data at higher speeds to open the gates for mobile broadband experience which was further realized by the fourth generation (4G).

Scheduling disciplines play a significant role in the performance of networks since they are responsible for distributing the network resources fairly (Yilmaz & Yoon, 2020). Resource allocation mechanisms require that routers execute a scheduling discipline that manages buffering of packets during waiting time. Various scheduling algorithms may be implemented to govern packet transmission and control packet loss in wireless network. The

fourth generation (4G) cellular standards have incorporated both orthogonal frequency division multiplexing (OFDM) and multiple input and multiple output (MIMO) techniques to provide high data rates (DRs) in wireless networks (Ishteyaq & Muzaffar, 2022).

Moreover, LTE is backward compatible with legacy cellular networks and hence has obtained wide acceptance from the telecommunication industry. It is a pure Internet Protocol (IP)-based protocol and can be easily integrated with existing wired technologies. However, all the mature routing protocols of IP networks are easily implemented in the backbone LTE networks. LTE-based cellular Networks (LCNs) are already being implemented and are looked upon as the cellular standard of the future. It was proposed by (3GPP) under the International Telecom Union (ITU). And it is now a commercially available protocol which is easy to deploy and provides high data rate. However, long-term evolution-based cellular networks are prone to congestion due to transport of bandwidth consumption services like video and data transfers especially at peak hours and in emergency situations, wherein the number of subscribers utilizing the cellular network is much more than what the network is designed to handle (Kuboye, 2018). One of the critical aspects of LTE's performance is the uplink scheduling algorithm, which is responsible for allocating network resources to various users. Effective uplink scheduling is essential for maintaining service fairness among different traffic classes and ensuring optimal use of network resources. The primary challenge lies in managing the diverse and often conflicting requirements of various applications and services, which range from real-time voice and video to bulk data transfer.

Quality of Service (QoS) is a fundamental requirement in LTE networks to guarantee the performance of different types of services (Abubakar & Ibrahim, 2021). QoS parameters include throughput, latency, jitter, and packet loss, all of which are crucial for maintaining the integrity and performance of applications. Traditional scheduling algorithms like First-In-First-Out (FIFO), Priority Queuing (PQ), and Weighted Fair Queuing (WFQ) have been used to address these needs, but they often fall short in dynamic and high-demand environments.

With the increasing demand for mobile broadband, there is an urgent need for advanced uplink scheduling algorithms that can dynamically adjust to changing network conditions and user needs. Improved QoS-aware scheduling algorithms are essential for optimizing network performance, reducing average upload times, and maximizing average data rates. These algorithms must efficiently distribute resources while ensuring fairness and meeting the QoS requirements of various applications (Khan, Zeeshan, Farid, & Usman, 2020).

This research aims to design and develop an enhanced QoS-aware uplink scheduling algorithm for LTE-Advanced (LTE-A) and 5G networks. The proposed solution involves creating user-explicit scheduling algorithms that incorporate elements of FIFO, PQ, and WFQ to address the limitations of existing approaches. By simulating these algorithms using the Optimize Network Engineering Tool (OPNET) and Microsoft Excel, the study seeks to evaluate their effectiveness and compare them to traditional methods. The ultimate goal is to demonstrate significant improvements in LTE-A uplink performance while ensuring high-quality service delivery.

2. Related Works

Nasralla and Rehman (2018) analyzed uplink scheduling algorithms, focusing on metrics like average throughput, system fairness, packet loss ratio, and spectral efficiency. They showed how QoS Class Identifier (QCI) parameters affect delay-aware scheduling and proposed improved algorithms (Log-rule, Linear-rule, and M-LWDF) incorporating QCI parameters to enhance QoS for different traffic classes, achieving better overall performance. Simulations confirmed improved QoS for both real-time and non-real-time traffic. The rise of 4G and LTE technologies, alongside smartphone advancements, has enabled high-bandwidth applications such as live video streaming and online gaming. This surge presents challenges in delivering personalized services in dynamic environments, prompting the development of downlink scheduling and resource allocation strategies to maximize user Quality of Experience (QoE) (Sinopides, 2017).

Mamman (2019) proposed a novel downlink resource allocation algorithm that addresses performance degradation by using QoS requirements and channel conditions. Formulated as an optimization problem, this algorithm allocates network resources based on user priority and schedules according to channel status to meet QoS demands. Simulation results showed that this algorithm outperformed others, including RR, PF, EXP-PF, and MLWDF, in terms of metrics like total sector throughput, average user throughput, fairness, packet delay budget

(PDB), and packet loss ratio (PLR). Using the Vienna system-level simulator, the proposed algorithm demonstrated superior data throughput and minimized PLR and delay for video and VoIP traffic, achieving better performance compared to legacy algorithms, especially under stable network conditions. Chafika Tata (2020): Developed a new uplink scheduling approach for LTE-A and 5G networks to ensure service fairness among traffic classes and increase the number of admitted users by dynamically managing service priorities. Low-priority traffic was favored during specific intervals based on average waiting time. Simulations showed improved QoS for low-priority classes without significantly affecting high-priority classes.

More so, He C. Y. (2020) proposed a new uplink scheduling algorithm addressing insufficient bandwidth for low-priority traffic and overall QoS in multi-class traffic scenarios. Using a priority adjustment algorithm for emergency users and a multi-class traffic scheduling algorithm for eNodeB, their approach maximized MAC throughput and met QoS constraints. Simulations with OMNET++ showed significant performance improvements. Nasralla (2020) introduced hybrid QoS-aware downlink scheduling approaches for LTE that balance QoS delivery across different traffic classes. Their taxonomy classified scheduling algorithms into delay-aware, queue-aware, target bit-rate aware, and hybrid-aware classes. Simulations revealed that hybrid scheduling rules provided balanced QoS for various traffic types, delivering high QoS for different traffic classes.

Each of these studies contributes to the ongoing effort to optimize scheduling algorithms in LTE and beyond, addressing specific challenges related to QoS, resource allocation, and traffic management..

3. The Proposed Conceptual Model

This section presents the proposed conceptual model of the paper

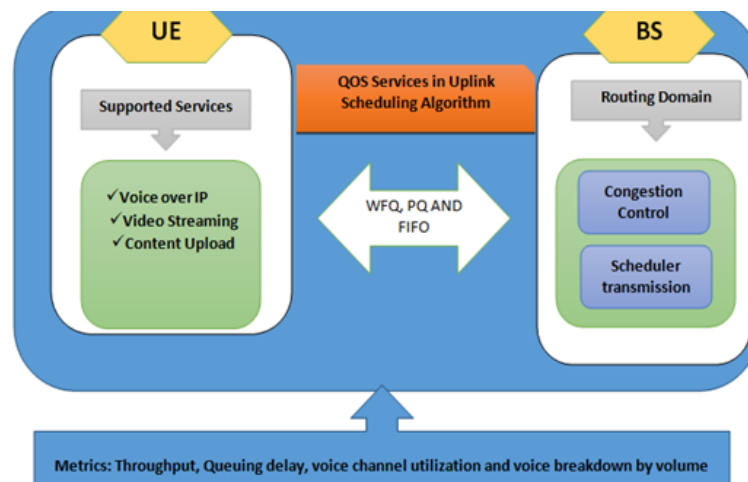


Figure 1 The proposed conceptual model

Figure 1 shows that the proposed conceptual model is based on distribution of resources in LTE-A networks; the goal is to enhance allocation of resources to the uplink transmitters which results in higher data rates, extremely low latency and power consumption. The communication standards of Fourth Generation (4G) of mobile telecommunication standards use different techniques to deal with these bottlenecks. Long Term Evolution Advanced, is a promising standard for 4G mobile networks, and it uses different technologies to enhance users' performance regardless of their location in the coverage area. LTE-A employs Coordinated Multi-Based station technique particularly to provide high data rate services for cell-edge users with enhancement in Quality of Service.

1) Applications and Services supported by the proposed Conceptual Model

Different applications and services place different demands on the network, and together these are driving the need for a comprehensive approach to QoS. Here are just a few examples.

- a. Voice over Internet Protocol (VoIP) over mobile VoIP is a technology for supporting voice communications over packet networks, such as the Internet. With modern encoding techniques, voice traffic requires relatively low bandwidth, but to deliver acceptable quality, the packets must

be transmitted with minimum latency and jitter, or variation in latency. Packets associated with voice traffic must, therefore, be given very high priority and assigned to a guaranteed bandwidth channel to ensure delivery within an acceptable delay limit. Within voice traffic, differentiated, high-priority service might also be provided for important calls, such as emergency “911” calls and critical communication among emergency service personnel (based on user ID, or source and/or destination).

b. Video Streaming

The dramatic growth in mobile network traffic is being caused primarily by bandwidth-hungry video traffic. Real-time, user-generated and on-demand video streaming applications, such as YouTube and Hulu, are therefore a significant factor in QoS in mobile networks. For quality video/audio streaming, the network must deliver high bandwidth, but with less stringent latency and jitter requirements than VoIP. Streaming can be either person-to-person or content-to-person, and can be either real-time or recorded all of which impose different QoS requirements. For example, real-time, person-to-person video streaming requires high bandwidth on both the uplink and downlink. So to support applications like Skype (which also uses VoIP), the network will need to provide such bi-directional QoS.

3.1 Proposed Algorithms

Figure 2 illustrated the flowchart of the proposed work; while the implemented algorithms are shown on Algorithm with different routes from User Equipment-one to User Equipment-two via different Base Station. The flow chart of the algorithm starts when the user equipment sends an Upload Request message to its neighboring base stations, when the base station receives the upload request message it will validate the request using the data in the routing table, when the validation is successful it will send a handshake message to the user equipment.

User explicit-1: This algorithm represents data flow in a route from UE1 to Base Station-one, from Base Station-1 then to Base Station -2, from base station 2 to base station 3 and finally from base station 3 to user equipment two; the metainfo file was sent through this route after successful upload and validation then it is received by user equipment two

Algorithm 1: User explicit-1

Start

UE1 sends an UploadRequest message :----> neighboring nodes

UE1 <-----> BS1, BS4

Upon message received: Message validation <--- BS1, BS4

If message valid BS1:

Then: BS1 <----- UE1: reply by Handshake message to UE1

UE1 <----- sends: MetaInfo ----> BS1

Else: message discarded

For every UploadRequest: BS ----> Acknowledge

Acknowledgement: Bitfield message tells the UE about the delivery

BS1 <---- BS2 <----BS3

BS3 <---- UE2

UE2 send acknowledgement ----> UE1

If the UE2 does not acknowledge the receipt of the message

Then: UE1 re-send the message to UE1

Do: ----> 3 times

Else: stop

Stop

User explicit-2 : algorithm two follows the route from user equipment one to base station 4, from base station four to base station five, from base station five to base station six, and finally from base station six to user equipment two; the metainfo file was sent through this route after successful upload and validation then it is received by user equipment two.

Algorithm 2: User Explicit 2

Start

UE1 sends an UploadRequest message :----> neighboring nodes

UE1 <-----> BS4

Upon message received: Message validation <--- BS4

If message valid BS4:

Then: BS4 <----- BS5: reply by Handshake message to UE1

BS5 <----- sends: MetaInfo ----> BS4

Else: message discarded

For every UploadRequest: BS4 ----> Acknowledge

Acknowledgement: Bitfield message tells the UE1 about the delivery

BS5 <---- BS6

BS6 <---- UE2

UE2 send acknowledgement ----> UE1

If the UE2 does not acknowledge the receipt of the message

Then: UE1 re-send the message to UE1

Do: ----> 3 times

Else: stop

Stop

3.1 Simulation Environment

Network is simulated using OPNET Modeler known as Riverbed Modeler Academic Edition 17.5, which is extensive and powerful simulation software tool with wide variety of capabilities. It enables the possibility to simulate entire heterogeneous networks with various protocols. The simulated communication network designed which consists of six scenarios, three scenarios for measuring Average data rate and three scenarios for measuring Average upload time.

Each of the three algorithms described in section 3 was implemented in Riverbed Modeler Academic Edition 17.5. The goal was to evaluate the performances of the algorithms with respect to QoS in LTE-A upload streaming. Several Simulations were run for each scenario.

4 Result Analysis and Evaluation Metrics

To evaluate the effectiveness of the proposed QoS-aware uplink scheduling algorithms, several key performance metrics were considered:

Average Data Rate

Data rates define the speed of data transmission in wireless communication. The data rate can be referred to as the number of bits transmitted from one device to another or over a network per second. Data rates are usually expressed in bits per second or bytes per second.

Average Upload Time

An upload time is defined as the total time it takes to upload a digital file from a computer to a server or vice versa. An upload time helps you to determine the amount of time needed to transfer a specified set of data or a file of specified size. An average Upload Time is measured in seconds.

a) Average Data Rate of the Proposed and Existing Algorithm

In this scenario, the communication channels of data upload follow the route of User Equipment 1 (UE1) through Base Station (BS: 1-2-3) to User Equipment 2 (UE2).

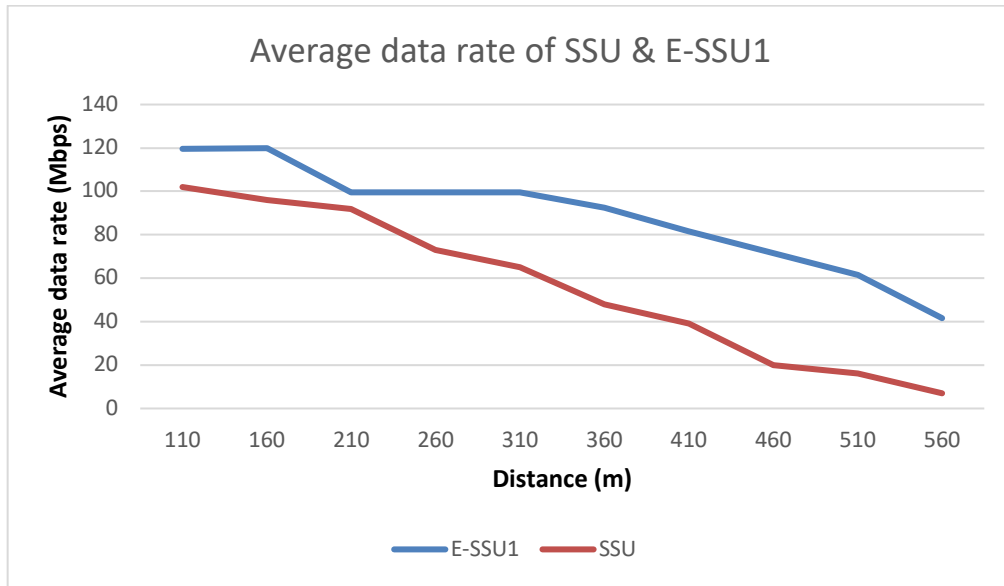


Figure 2: Average data rate vs. Distance from BS

Figure 2 shows the proposed algorithm1 with WFQ QoS (E-SSU1) and without QoS (SSU) which produces better results compared to the existing algorithm (SSU). The (E-SSU1) produces better results because it takes less time (time complexity) while running to complete and it consumes less space (Space complexity) compared to the existing algorithm.

b) Average Data Rate of the proposed and Existing Algorithm

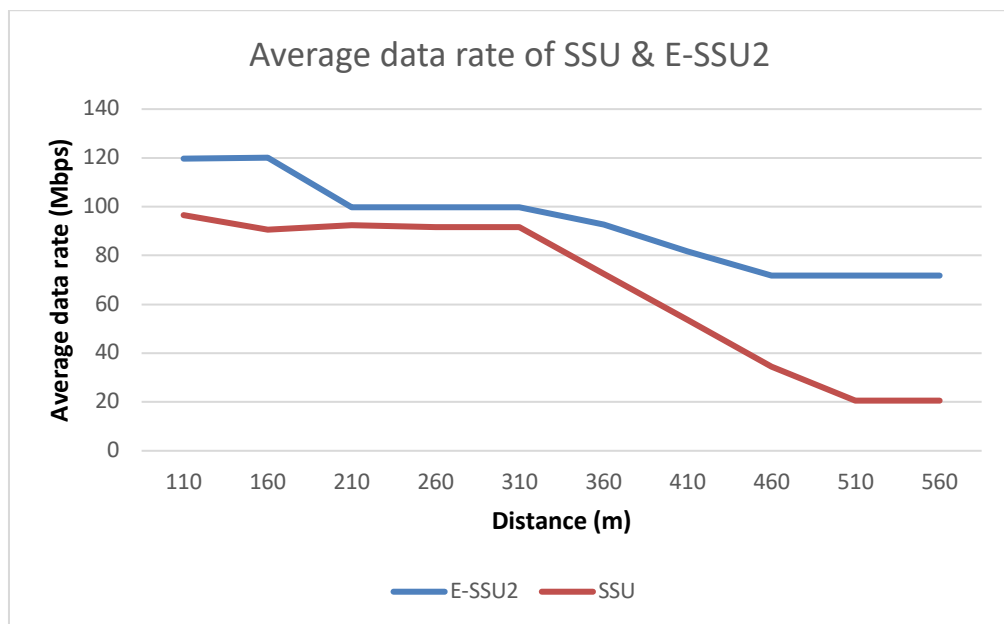


Figure 2: Average data rate vs. Distance from BS

Figure 2 shows Algorithm 2 with the Qos of Priority Queuing (E-SSU2) and without QoS (SSU) The enhancement of average data rate on the implementation of QoS on algorithm 2 produce better results compared to the one obtained from the base paper.

c) Average Upload Time Performances of proposed and existing model

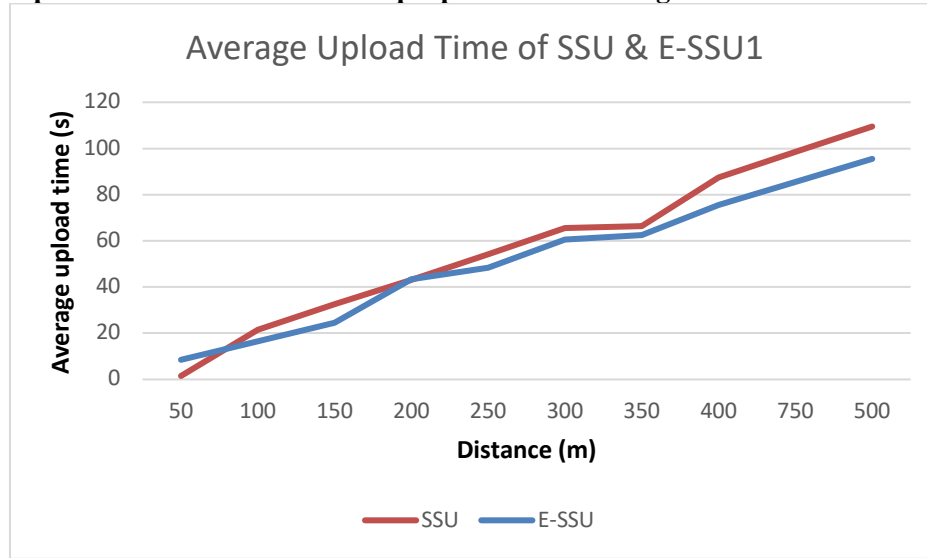


Figure 3: Average file upload time vs. Distance from BS

Figure 3 shows Algorithm 1 measuring Average Upload Time of the E-SSU1 and SSU. The proposed algorithm E-SSU1 was compared with the SSU and it was observed that there is a significant effect on the average upload time (s). And the proposed algorithm produces better result because it yields less time (time complexity) when uploading the file.

CONCLUSION

QoS provisioning has been defined as a major objective in LTE-A radio access networks. Therein, MAC layer scheduling which is a substance function in Radio Resource Management (RRM) entity of LTE network architecture. This paper presented the design and development of an enhanced QoS-aware uplink scheduling algorithm for LTE-Advanced (LTE-A) and 5G networks. By integrating and optimizing traditional scheduling strategies such as FIFO, PQ, and WFQ, the proposed user-explicit algorithms (1 & 2) were able to dynamically adapt to varying network conditions and user requirements. The simulation results, conducted using the Optimize Network Engineering Tool (OPNET) and Microsoft Excel, demonstrated significant improvements in average upload time, data rate, and overall QoS performance compared to existing algorithms. The proposed approach effectively balanced the QoS delivery across different traffic classes, ensuring fairness and resource efficiency. This research contributes to the advancement of mobile broadband technologies, providing a robust solution to the challenges of uplink scheduling in modern wireless networks. Future work may focus on further refining the algorithms and exploring their applicability in real-world network deployments.

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