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LTE MAC Scheduler Analysis based on QoS Aware Proportional Fair Scheduling Algorithm

Badri Nayak[1], Dr. A. M. Prasad[2], Mohamed Niaz M[3]

M. Tech, Dept. of ECE., Jawaharlal Nehru Technological University Kakinada, AP India[1]

Project Intern at L&T Technology Services, Whitefield, Bangalore, Karnataka, India[1]

Head and Professor, Department of ECE, UCEK, JNTU Kakinada, AP, India[2]

Sr. Technical Architect at L&T Technology Services, Whitefield, Bangalore, Karnataka, India[3]

ABSTRACT: An optimal multiuser resource scheduling algorithm for Long Term Evolution (LTE) is proposed and analysed in different scenarios. The proposed scheduler is to provide efficient distribution of radio resources to User Equipments (UEs) as per Quality of Service (QoS) of the radio bearers.The scheduler behaviour is analysed via simulation with various load scenarios and also rectified with APIs. The MAC Scheduler API Interface is incorporated for its further application. The performance of the scheduler is compared with conventional schedulers such as Maximum Throughput and Channel Aware scheduler. The results show that the proposed scheduler guarantees provision of QoS to UEs and achieves an acceptable performance in terms of system throughput. The scheduler ensures fairness among users based on the QoS.

KEYWORDS: Proportional Fair Scheduler Algorithm; QoS; MAC Scheduler Interface; Packet Scheduling; Radio Resource Management

I. INTRODUCTION

LTE (Long Term Evolution) or the E-UTRAN (Evolved Universal Terrestrial Access Network), introduced in 3GPP R8, is the access part of the Evolved Packet System (EPS). The main requirements for the new access network are high spectral efficiency, high peak data rates, low latency as well as flexibility in frequency and bandwidth. In order to fulfil this extensive range of requirements several key technologies have been considered for LTE radio interface, of which the most important areOrthogonal Frequency Division Multiple Access (OFDMA)in downlink, Single Carrier-Frequency Division Multiple Access (SC-FDMA) in uplink and multiple-antenna technology with support for Spatial Diversity, Spatial Multiplexing and Beamforming.

EPS uses the concept of bearer, which is basically the flow for traffic with defined Quality of Service (QoS) requirements for the User Equipment (UE). According to 3GPP standards, the QoS parameters for LTE systems areQoS Class Identifier (QCI), Allocation/Retention Priority (ARP), Guaranteed Bit Rate (GBR), Maximum Bit Rate (MBR),Prioritized Bit Rate (PBR) and Aggregate Maximum Bit Rate (AMBR). The QCI defines for each bearer, the bearer Resource type(GBR or Non-GBR), Priority, Packet Error Loss Rate and Packet Delay Budget. Scheduling of radio bearers is done in eNodeB of E-UTRAN, which allocates radio resources according to their QoS requirements and radio resource availability in eNodeB. The eNodeB manages the radio resources as it is the intermediate node between User Equipment and core network.

The MAC scheduler is part of MAC from a logical view and the MAC scheduler should be independent from the PHY interface. For the MAC scheduler interface specification a push-based concept is employed, that is all parameters needed by the scheduler are passed to the scheduler at specific times rather than using a pull-based concept (i.e.

fetching the parameters from different places as needed). The parameters specified are aligned with the 3GPP specifications.

II. RELATED WORK

In [1], the authors have discussed about the various scheduling strategies. They have classified as: A. Channel Independent Scheduling Strategies, B. Channel Dependent/QOS unaware Scheduling Strategies and C. Channel Dependent/QOS aware Scheduling Strategies. Besides the pros and cons discussed in the paper, the latest strategies is found suitable for the emerging LTE technology. Also being foremost unrealistic for LTE networks, they are typically used in conjugation with channel-dependent strategies to improve system performance.

In [2], the authors haveproposed the algorithm of finding the priority among the users based on history scheduled bits. It guarantees the fairness among the users since a long waiting user is getting opportunity over the resources without dividing into different types of services. Those two mathematical expressions are alsotaken into consideration at the proposed algorithm to calculate priority among Non-GBR Bearer.

In [3] Multi-QoS-aware Fair Scheduling for LTE and [4] A QoS-Aware Scheduling Algorithm Based on Service Type for LTE Downlink, authors have proposed the algorithm considering different services possess different QoS needs in LTE system. These different services are classified by 3GPP into several types at [5]. In [3] authors have shown the Sector Throughput, UE fairness and UE delay comparison with the conventional PF algorithms and the proposed PF algorithm. Last two parameters are upgraded with the expense of sector throughput. Three different services (FTP, VoIP and Video) were considered to simulate the analysis. These schedulers have taken different considerations into account such as throughput and fairness when deciding the allocation of the scarce radio resources.

III. PROPOSED ALGORITHM

A. *Design Considerations:*

- Two different Resource Types (Radio Bearers) are considered.
- QoS parameters are taken into considerations. Bucket Size Duration is taken as equal to the Packet Delay Budget as estimated by standards.
- Un-serviced bits are considered to the next TTI to be serviced
- Prioritized Bit Rate (PBR) is taken into consideration to control the starvation of resources among the active users.
- Three different buckets are considered: One for GBR Bearer and two for Non GBR Bearer
- Initially GBR Bearers are taken into consideration and then Non GBR bearers, for resources scheduling.
- Both Frequency scheduling and time scheduling are considered into simulation.
- Channel Quality Indicator (CQI) is considered to calculate the RBs required for the buffered data.
- MAC interfaces with MAC Scheduler via API interface.

B. *Description of the Proposed Algorithm:*

Aim of the proposed algorithm is to maximize the fairness among the users under limited resources.The proposed algorithm is consists of following main steps.

Step 1: Calculating Prioritized Bit Rate (PBR): The idea behind prioritized bit rate is to support for each bearer, including low priority non-GBR bearers, a minimum bit rate in order to avoid a potential starvation. Each bearer should at least get enough resources in order to achieve the prioritized bit rate (PBR) [6]

In the simulation it is calculated as:

$$PBR(i) = \frac{GBR(i)+MBR(i)}{2} \qquad \text{eq. (1)}$$

Where PBR(i) is the PBR of i^{th} channel.

Step 2: Mapping of QCI: QCI is in an integer ranging from 1 to 9, in accordance with [5] table 6.1.7, which indicates nine different QoS performance characteristics of each bearer. QCI values are standardized to reference specific QoS

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characteristics, and each QCI contains standardized performance characteristics (values), such as resource type (GBR or non-GBR), priority (1~9), Packet Delay Budget (allowed packet delay shown in values ranging from 50 ms to 300 ms), Packet Error Loss Rate (allowed packet loss shown in values from 10-2 to 10-6); Refer table: [5].

The Packet Delay Budget (PDB) defines an upper bound for the time that a packet may be delayed between the UE and the PCEF. For a certain QCI the value of the PDB is the same in uplink and downlink. Hence Corresponding Packet Delay Budget is mapped for Bucket Size Duration (BSD) to guarantee the services.

Step 3: Calculating Bucket Size:

For GBR Bearer: Bucket size is given as:

$$bucket(i) = PBR(i) * BSD(i) \qquad \text{eq. (2)}$$

Where bucket(i) the bucket size, PBR(i) is the Prioritized Bit Rate and BSD(i) is the Bucket Size Duration of i^{th} bearer.

For Non-GBR Bearer: Two buckets are defined for Non-GBR Bearer. First bucket will try to server PBR and if Resources available then will be served by second bucket with enhance fairness within the connected bearers.

$$bucket1(i) = PBR(i) * BSD(i)$$
$$bucket2(i) = (UE_{AMBR(i)} - PBR(i)) * BSD(i) \qquad \text{eq. (3)}$$

Step 4: Calculating Committed Bit: Based on bearer information, the algorithmdetermines the committed bit to be served at each TTI. It helps to guarantee prescribed rate.

For GBR Bearer: Random number is generated between PBR and MBR and make sure that the sum of these number should be equal to the bucket size within BSD. In simulation it is calculated as,

$$committedBits(i) = Random\ number\ between\ PBR(i) and\ MBR(i) \qquad \text{eq. (4)}$$

MATLAB in-built rand() function is used which generates uniform random distribution values.

Also, it must satisfy below equation.

$$\sum_{j=1}^{BSD(i)} sum(i) = bucket(i) \qquad \text{eq. (5)}$$

Where j is Transmission Time Interval (TTI), sum(i) is the summation of committedBits.

Step 5: Calculation of Scheduled Bits: Based on buffer inflow rate and committed rate, scheduling is done for particular bearer. Following mentioned steps are followed by algorithm to schedule the bits for bucket and bucket1 as stated above.

Step I: Determine the schedule bits to be scheduled
Step II: Find the particular CQI and calculate the required RBs. Refer: [7]
Step III. Check for the available RBs and assign the rate.

For bucket2:

Step I: Priority is calculated among the buffered channels as stated above expression.
Step II: Higher priority is scheduled first and then goes for thereafter lower and so on, if RBs are available.

IV. PSEUDO CODE

Step 1: Scan Buffered Logical Channel: First GBR and then Non-GBR
Step 2: Committed Bit Rate is determined based on GBR, MBR and AMBR to guarantee the services
Step 3: Priority is calculated for 2nd Bucket of NGBR to enhance the fairness. It is calculated as:

$$Pi(t) = \frac{ri(t)}{Ri(t)} \qquad \text{eq. (6)}$$

Where $P_i(t)$ is the priority for channel i at slot t, $r_i(t)$ represents the request data rate, and $R_i(t)$ is the average data rate of channel i at time slot t. $R_i(t)$ is the average of the last 3 rates of that channel. It is given as:

$$Ri(t) = \frac{Ri(t-3) + Ri(t-2) + Ri(t-1)}{3}$$
$$0\ for\ t < 4 \qquad \text{eq. (7)}$$

Step 4: Schedule as:
if (RBsAvailableFlag = = ‘True’ && BearerTypeFlag= =’True’)

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Schedule the GBR Bearer.
elseif (RBsAvailableFlag = = 'True' && BearerTypeFlag = = 'False')
Schedule the Non-GBR Bearer
else
Schedule the rest GBR and Non-GBR bearer as Zero
end

V. SIMULATION RESULTS

The simulation studies involve the use cases of 6 UEs each having two different bearer types. The proposed fairness efficient algorithm is implemented with MATLAB. The second bucket of Non-GBR bearer is treated in a special way as stated by the algorithm. We have considered different scenarios and observed the scheduled rate. The different cases are listed below:

I. Case 01: Low Inflow Rate with Moderate CQI
II. Case 02: High Inflow Rate with Moderate CQI
III. Case 03: High Inflow Rate with the best CQI
IV. Case 04: High Inflow Rate with bad CQI
V. Case 05: High Inflow Rate with one UE varying up to the worst CQI

I. Case 01: Low Inflow Rate with Moderate CQI

In this case, Inflow rate was maintained low compare to the committed rate which resulted in getting less scheduled rate for that instance. Each UE's CQI was set to be in the range of moderate class. The pending bits were added to the inflow rate for the next TTI. In this case, pending bits would be rare. Inflow rate were getting served at the same instance without having any wait time. Each UE was getting opportunity over the radio resources.

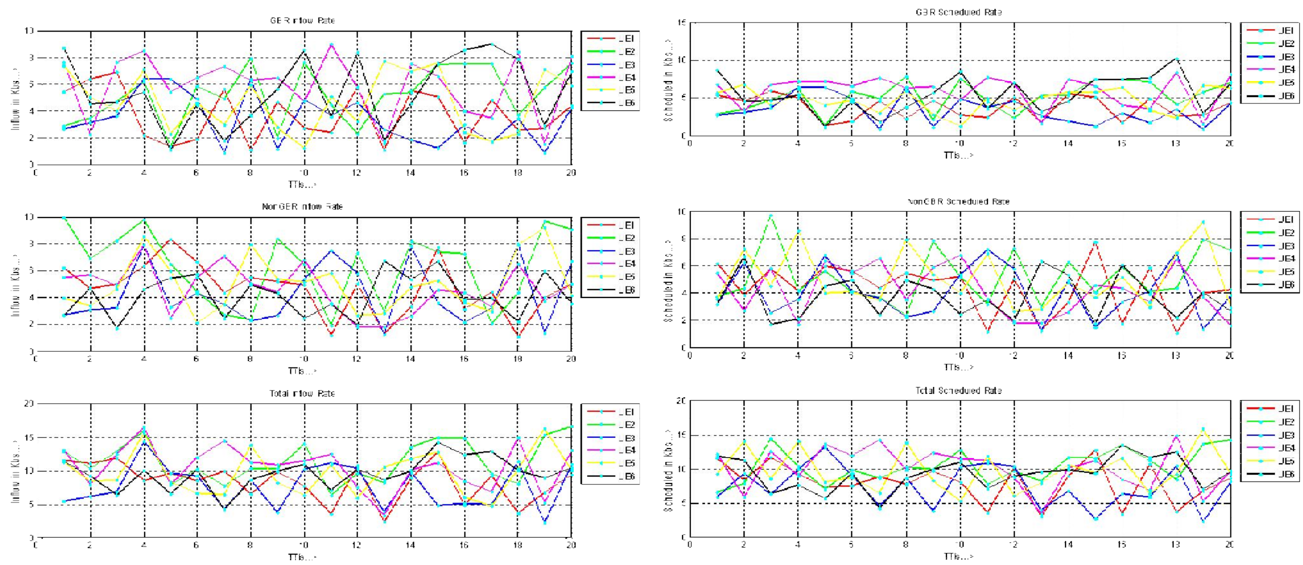

Fig1. Low Inflow Rate Vs Scheduled Rate in each TTI having moderate CQI values

In the figures above, the leftmost column depicts inflow rate and the rightmost column shows the scheduled rate by the scheduler on TTI wise. Each inflow rate and scheduled rate is depicted with GBR bearer, Non-GBR bearer and total bearers rate by 1st, 2nd and 3rd row of the figure. X-axis represent transmission time interval (TTI) which is of 1millisecond interval. Y-axis represents size of data in kilobits (kbs) at each TTI. Six different UEs were scheduled at each TTI which have been represented by different colour patterns as indexed. The similar representation is used for other cases also.

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Case 02: High Inflow Rate with Moderate CQI

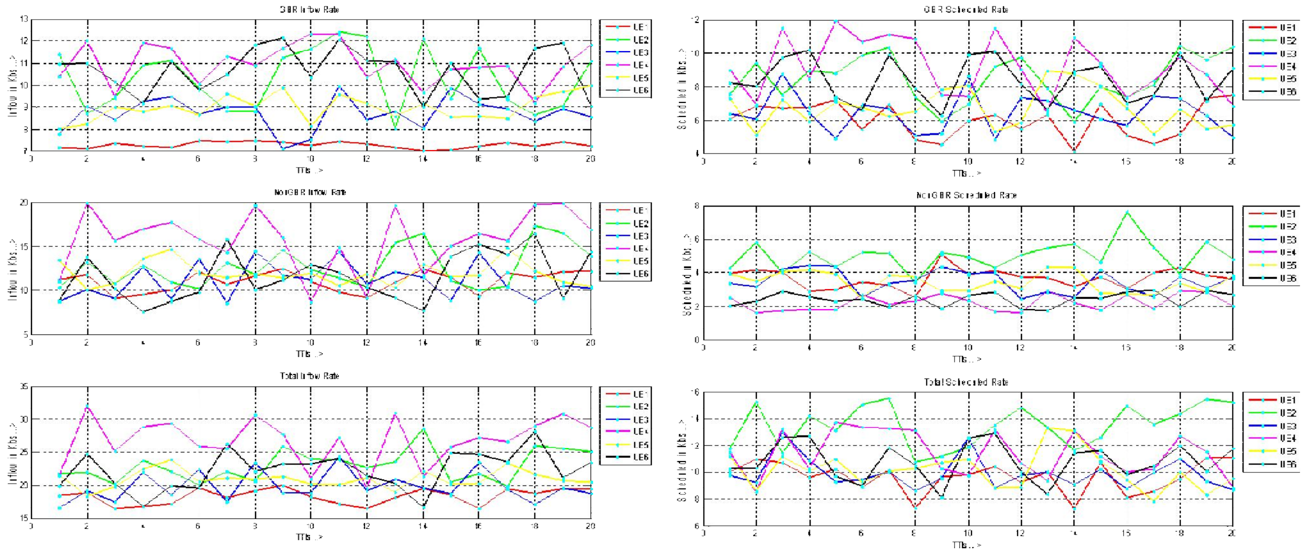

Fig2. High Inflow Rate Vs Scheduled Rate in each TTI having moderate CQI values

In this case, Inflow rate was increased up to more than committed rate which resulted in getting increased scheduled rate for that instance. Each UE's CQI was set to be the same as that of case 01. The pending bits were added to the inflow rate for the next TTI. It was clearly seen at the graph where the pending bits were getting scheduled at next TTI.

III. Case 03: High Inflow Rate with the best CQI

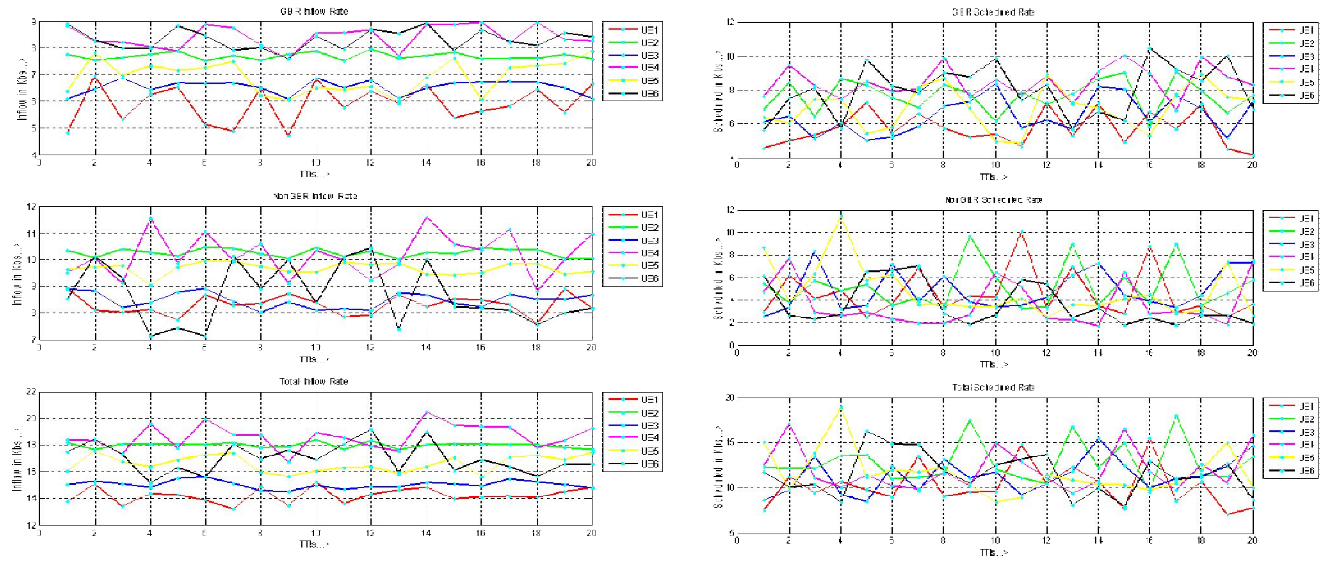

fig3. HighInflow Rate Vs Scheduled Rate in each TTI having best CQI values

In this case, each UE's CQI was set to be in the range of best class. It was observed that system level throughput getting increased. In this case the CQI for the UEs have been set to best class, which indicated better channel conditions between eNB and UE.

IV. Case 04: High Inflow Rate with bad CQI

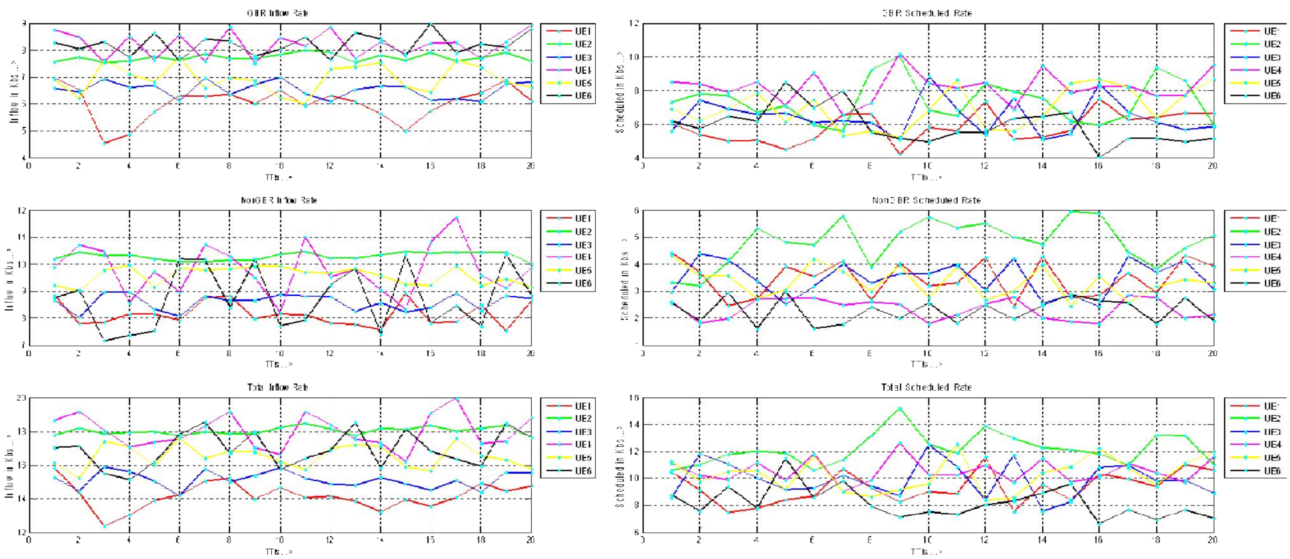

fig4. High Inflow Rate Vs Scheduled Rate in each TTI having bad CQI values

In this case, inflow is overloaded ascase 02 and case 03. In this case, each UE's CQI was set to be relatively bad, which simulates poor channel condition between eNodeB and UE. It was clearly observed that the system throughput getting reduced drastically. But resource scheduling was performed fairly, in spite of the channel condition which was resulted in decreasing the system throughput.

V. Case 05: High Inflow Rate with one UE varying up to the worst CQI

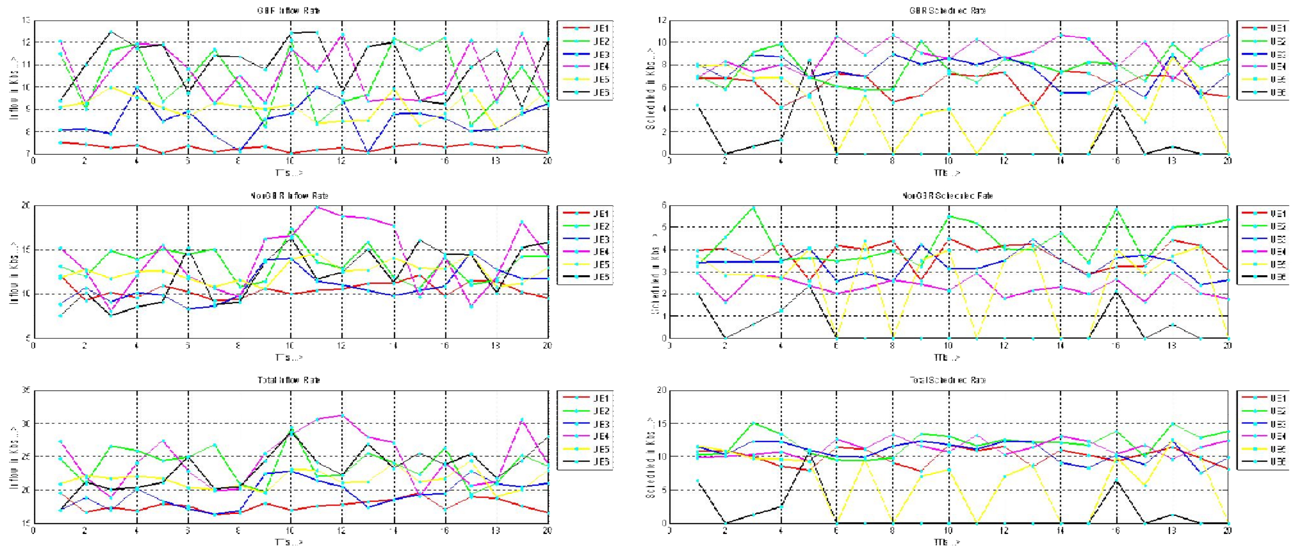

fig5. High Inflow Rate Vs Scheduled Rate in each TTI having UE4 downgrading CQI values

In this case, inflow rate was overloaded as in the previous case. However, the CQI is retained better for the UEs excluding UE4, for which the CQI was degraded relatively. It was observed that the particular UE4 was getting adequate resource scheduled in spite of the poor CQI. However, this impacts the overall system throughput, as the efficiency is reduced to serve the UE4.

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VI. CONCLUSION AND FUTURE WORK

The simulation results showed that the proposed algorithm performs better in terms of fairness. The fairness in resource scheduling is ensured in peak as well as off-peak load conditions. When a particular UE suffers poor channel conditions, the scheduler still ensures fairness to the UE with minor reduction in overall system throughput. When all the UEs are experiencing better channel conditions, the scheduler is able to maintain fairness in resource allocation with improved system throughput.

This simulation can be extended to NS3 Simulator. The scheduler is planned to support more number of UEs with selection of subset of UEs in each TTI for schedule. It has been also planned to extend the simulator for TDD duplex mode.

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BIOGRAPHY

Badri Nayakis an M.Tech student in the Electronics and Communication Department, Jawaharlal Nehru Technology University Kakinada, AP India. His specialization is in Computer and Communication. He has awardedB.E in 2010 from Pokhara University, Nepal. He has performed LTE MAC scheduling analysis as Project Intern at L&T Technology Service, Whitefield Bangalore laboratory. His research interests are Wireless Communication, LTE, 5G, IoT, Network Security, Virtualization and Cloud Computing. He loves to involve in Research and Development works.

Dr. A. Mallikarjuna Prasad has completed his Ph.D and is currently working as Head and Professor of ECE Department, University College of Engineering Kakinada, JNTU Kakinada, AP India. His interest field is Antenna and Instrumentation. He has published 20 papers in International Journals, 10 papers in National Journals and presented 5 papers in International Conferences and 5 papers in National Conferences.

Mohamed Niaz has completed his M.Tech from B.M.S College of Engineering Bangalore. He is currently working as Senior Technical Architect with Larsen & Toubro Technology Services, Bangalore. He has experience in development of Wireless Communication Modems for Telecommunication and Defence. He is currently working with LTE Radio Access Network. His research interests include LTE, 5G, Network Security and MANET.