

# SNR based Predictive Packet Scheduling in LTE with Varied CQI

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## Abstract

In this work, a method is proposed to schedule the resources while considering SNR values along with CQI in a view to provide a better packet scheduling. A threshold based method is also proposed with multiple packet scheduling algorithm. A novel Kalman filter based CQI estimation algorithm is designed using SNR values. Different packet scheduling algorithms are decided for varied CQI levels. Simulation results show that the proposed method would improve the link level performance and average throughput of the system. Furthermore, the effect of improving quality is highlighted on user experience and applications are suggested which might change the way we will use Internet in near or far future.

**Keywords:** Channel Allocation, Fair Queuing, Imperfect CQI, LTE, Packet Scheduling, Proportional Fair, Resource Blocks

## 1. Introduction

Next Generation of Wireless Networks, for example, Long Term Evolution (LTE) targets to utilize spectrum efficiently by optimizing network as well as source parameters. In order to provide best available resources to UEs, LTE uses predictive resource allocation schemes including but not limited to Adaptive Modulation and Coding (AMC), Channel Quality Index (CQI) and Hybrid Automatic Retransmission Request (HARQ) as discussed in <sup>1</sup>.

Recent literatures<sup>2-4</sup>, provide a way to use Kalman filter in packet scheduling in measurements, estimation and traffic proportionate methodologies. In order to provide a way to schedule traffic, estimation is necessary for network level as well as application specific network organization and resource allocation. One can also predict the rotten CQI value from the SNR measurements available and thereby using both the metrics to create a strategy well suited for end user.

A network can be used for uplink (towards the network from UE) or as a downlink (from the network to the UE). In Time Division Multiplexing (TDM), the available bandwidth is time divided among users while

in Frequency Division Multiplexing (FDM) frequency bands are used to separate different communicating users (separable by guard band). Multiple users can use the FDM simultaneously using FDMA (Frequency Division Multiple Access). In LTE and LTE-A, Orthogonal Frequency Division Multiple Access (OFDMA) is used to achieve higher data.

For scheduling the resource, in LTE, RBs (Resource Blocks) are designed where user can hop from one RB (time and frequency block) to the next RB. Scheduling these hopping users in different RBs is a challenge as different users have different QoS (Quality of Service), delay, throughput, loss and bandwidth requirements. A user might want to use two or more RBs simultaneously to achieve one or more of the above goals.

Methods to allocate resources in different domains such as frequency or time are also designed for real-time sensitive applications in<sup>5</sup>. While the packet scheduling is important, the reordering of the information at the receiver is equally important as real-time applications cannot cross the delay threshold which makes the application obsolete (for example real-time stock trading).

Another important challenge in designed a scheduler is providing a battery efficient solution as mobile battery

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draining is known problem for decades. An approach to solve this problem is presented in <sup>6</sup> which proportional fair algorithm along with the QoS parameters.

Most of the packet schedulers are designed to solve the intermittent problems of congestion and network instability while very few have focused on link-level problems with the network feedback. In this paper we present an approach to use link-level feedback to calculate CQI levels using Kalman filter and use the information to schedule the packets with the help of Proportional Fair (PF), Blind Equal Throughput (BET) and Inverse Weight Fair Queuing (IWFQ)<sup>1</sup>.

The paper is organized as follows: Section II briefs about the Kalman Filter and its Applications. Section III describes about the SNR based CQI estimations with the imperfect or missed CQI levels. Section IV elaborates about the proposed packet scheduling scheme. Section V shows the simulation results and analyses their research content. Section VI concludes with an emphasis on future work.

## 2. Kalman Filter and its Applications

Kalman filter is used to estimate non-stationary process using the previous data<sup>2</sup>. For estimation, using known inputs,  $x(t)$ , and noise,  $w(t)$ , we can construct state estimates  $\hat{x}(t)$ . Figure 1 shows a basic input-output flow of Kalman filter wherein  $x_{k-1}$  along with the previous input produces  $x_k$  and therefore producing the output we are interested in.

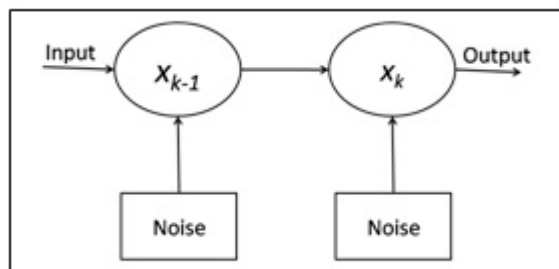


Figure 1. Kalman estimator input and output.

The standardized Kalman filter moves towards the Weiner filter for a steady flow of inputs. Kalman filter is used in many applications such as tracking objects (e.g. moving objects in a video), navigation; computer vision

and so on. In this work, we use Kalman filter to estimate SNR values of an LTE channel using the raw CQI values.

## 3. SNR based CQI Prediction

While we can always use a Forward Error Correction (FEC) algorithm, it requires the information of CQI for best algorithm usage at the UE side. In FEC approach, there should be an optimal way of creating FEC packets. For simplicity of approach, we can use two levels of prioritized queues for creating FEC. For example, if queue is greater than the threshold, the FEC is set to Max\_FEC/2 while if the queue length is less than the threshold, the FEC is kept at its Maximum level as illustrated below.

QueueLength > Threshold  $\rightarrow$  FEC = MaxFEC/2

QueueLength < Threshold  $\rightarrow$  FEC = MaxFEC

The priority of the queue is added as either 0 or 1, wherein if the priority is high, the FEC packets are set to maximum while in other case they are set to minimum. The FEC frames shown in Figure 2 provide us an indication that the number of frames can be varied depending upon the requirement presented by the application or we can even carry the investigation on error, channel conditions etc. In this case, the CQI (Channel Quality Indicator) plays a major role where if CQI is high, the frames inserted should be less. In the following figure, we consider CQI to review the strategy presented in the previous figure.

Therefore, if channel condition is good, the number of FEC inserted gets reduced and all the maxFEC are converted to maxFEC/2 as follows:

If(CQI > 0.5 and FEC = maxFEC)

FEC = maxFEC/2

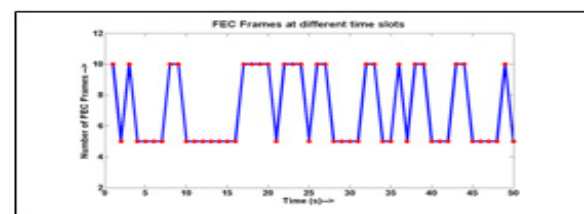


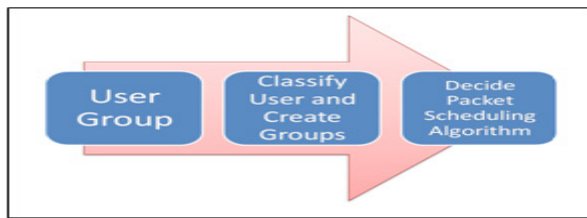
Figure 2. FEC frames at different time slots.

This approach of portioning of FEC works well in case of a perfect CQI level, while for imperfect CQI levels, we

need a much robust approach which is presented in the next section.

## 4. Packet Scheduling

In order to overcome the situation of imperfect CQI or varied level of CQI, we classify users based upon their estimated CQI levels and choose the appropriate packet scheduling algorithm for each group as illustrated in Figure 3.



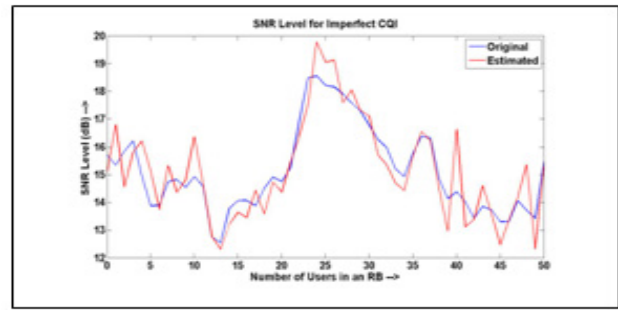
**Figure 3.** User classification and scheduling.

We use the classification methodology for assigning different scheduling algorithm as per the merit of user group. The algorithms used are Maximum Throughput (MT), Proportional Fair (PF), Inverse Weighted Fair Queuing (IWFQ) and Proportional Inverse Weighted Fair Queuing (PIWFQ)<sup>1</sup> as described below in brief.

- A. Maximum Throughput: This is assigned for user group experiencing best channel conditions.
- B. Proportional Fair: This is used with channel aware Blind Equal Throughput and MT.
- C. Inverse Weighted Fair Queuing: This is used to provide more resources to the striving users and vice versa.
- D. Proportional Inverse Weighted Fair Queuing: This merges IWFQ along with PF to provide fair resources to striving users without compromising with existing user's throughput.

## 5. Results and Discussion

We use MATLAB and its tools for simulation in this paper. As shown in Figure 4, SNR levels for imperfect CQI are extracted and plotted for the Kalman estimates. The original and estimated values suggest that the values are worth considerations in a noisy channel condition and therefore can be used to provide better resource allocation at the network. The estimation works out because the change in a channel occurs at a gradual level and the model is able to capture the same.



**Figure 4.** SNR level for imperfect CQI.

Once the SNR levels are generated, we can use the following Table 1 to decide the algorithm usage for different group of users. The choice is reasonable because when the users who are already at highest SNR levels can just be provided resources proportionately and they would be able to get good throughput owing their better channel conditions as compared to the ones who are struggling with resources as well as with the channel conditions.

The algorithm here assumes that all users are non-premium and equal for the network and network takes best care of all of them provided their SNR and CQI levels. Also, one can see that the algorithm would switch quite frequently in response to the channel conditions (which are always uncertain); therefore, a user who is in MT might be in IWFQ group in the next instant.

In case, we consider the priority of premium users, we can quickly enhance the method by using a pre-fixed amount of floating bandwidth for priority users which can be allocated to others when not in use. Therefore, the scheduling will not be affected for others. There might also be case when the user groups are disparate for a long time and in this case the overall average throughput will be low for the network.

**Table 1.** Choice of scheduling

| User Group           | User Groups and their scheduling |          |         |            |
|----------------------|----------------------------------|----------|---------|------------|
|                      | SNR Highest                      | SNR High | SNR Low | SNR Lowest |
| Scheduling Algorithm | PF                               | MT       | IWFQ    | PIWFQ      |

In this paper, we have equally divided the scales of SNR in order to assign the required scheduling algorithm. The same can also be proportionately divided and is an area left for exploration in future. Figure 5 depicts

that the average throughput for users employing our proposed scheme is much higher than traditional methods of throughput splitting based upon SNR levels. Also, one must observe that our system heavily relies upon the imperfect CQI levels which are a common scenario in wireless channels.

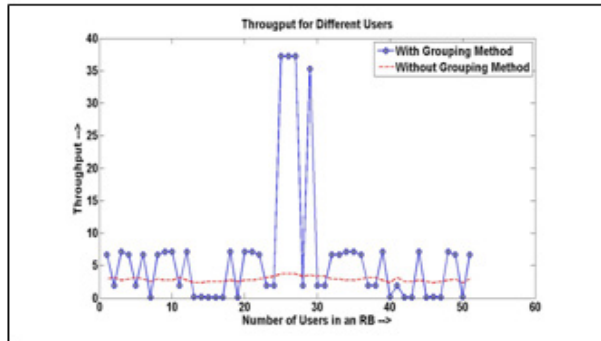


Figure 5.

Table 2 demonstrates the LTE simulation parameters which are considered while developing the algorithm.

Table 2. LTE simulation parameters

| Parameter         | Value         |
|-------------------|---------------|
| Layout            | Hexagonal     |
| Number of RBs     | 25            |
| #Users in RB      | 50            |
| TTI               | 1 ms          |
| Max. Throughput   | 100 Kbits/sec |
| Mode of Operation | FDD           |

## 6. Conclusion and Future Work

In this paper, a novel Kalman filter based CQI estimation algorithm is designed using SNR values. Original CQI values are used and affected CQI values are corrected using

the proposed method. In order to provide better network usage opportunities for UEs in the network, packet scheduling algorithms are decided for varied CQI levels. Results are shown to ascertain the modeling approach and the overall system showed improved performance. The method therefore leaps a path towards a scalable and UE Quality of Experience (QoE) friendly network design which would enable a better Internet experience in future networks such as LTE. Our future work includes creating optimized algorithms for accurate prediction of CQI values irrespective of end-link bandwidth

## 7. Acknowledgement

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## 8. References

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