Volume 3, Issue 6, June 2013
ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

Packet Scheduling in LTE with Imperfect CQI

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Abstract— ***In this paper, a Kalman filter based packet scheduling scheme with low complexity is proposed for LTE downlink system to adapt to various imperfect channel states. A channel quality predictor based on Kalman filter is developed to estimate the current channel quality information (CQI) from previous CQI value and observed CQI value, and a grouping method is employed to cover the gaps caused by Kalman filter. Based on the simulation results, the estimated CQI values from the channel quality predictor are rather close to the realistic CQI values. A packet scheduling scheme that uses the channel quality predictor together with a grouping method in packet scheduling decisions is introduced. Simulation results show the proposed scheme offers a simple yet more effective way to overcome multiple imperfect CQIs .and the performance benefits of the proposed scheme in maximizing system throughput and decreasing packet loss ratio.***

***Keywords*— LTE, packet scheduling, imperfect CQI, prediction, Kalman filter**

I. INTRODUCTION

To provide a long-term development of the Third Generation (3G) services, the “Super 3G”concept was proposed in 2004 [1]. Super 3G is a standard that expands upon the 3rd Generation Partnership Project (3GPP) specification, and it is called Long-Term Evolution (LTE) within 3GPP. First release of 3GPP LTE specifications (Release 8) was frozen in March 2009 [2] to provide better quality of wireless communication in terms of higher data rate, reduced latency and increased capacity and coverage [3].

In recent years, as high speed wireless technologies are rapidly developed, the design of packet scheduling algorithms based on CQI for efficient packet transmissions has been a crucial research direction. The packet scheduler is performed at evolved Node B (eNB). The aim of packet scheduler is to utilize the available transmission resource efficiently through a reasonable resource allocation for each 1 ms Transmit Time Interval (TTI). In each TTI, each user computes the Signal to Noise Ratio (SNR) on each resource block (RB) based on the reference signals received from the serving eNB. The computed SNR values at each user may vary on each sub-carrier and in each TTI due to the frequency-selective fading nature of multi-path propagation and the time-selective fading nature due to the user movement, respectively [4, 5]. For each RB, a mapping function is used to determine Channel Quality Information (CQI), and then each user reports the CQI feedback to the serving eNB in each TTI. The CQI mapping function helps the eNB to select an appropriate Modulation and Coding Scheme (MCS) for downlink transmission. Thereafter, the highest data rate of each user that can be supported in each RB in a TTI is computed based on the selected MCS. QPSK, 16 Quadrature Amplitude Modulation (16 QAM), and 64 QAM together are used in the MCS for channel coding in order to achieve the high data rates in the downlink LTE [6]. The highest supported data rate is the most important factor that the channel-dependent packet scheduling algorithms rely on.

In practical wireless system, the primary goal of a packet scheduler is to satisfy every user’s Quality of Service (QoS) and fairness requirements by utilizing the radio resources efficiently and accurately. For channel-dependent packet scheduling algorithms that strongly rely on CQI, the performance of the algorithms can be dramatically impacted according to different degree of accuracy of CQI. However, it is difficult to consider a perfect channel quality in practical wireless channels due to their frequency selectivity and time varying nature [7].

In [6], channel prediction was used to mitigate the impact of outdated channel information and improve performance of adaptive OFDM systems while [8] studied the effect of multiple estimations to mitigate the effect of CQI delay as well as the effect of OFDM channel estimation error. Multi-user Orthogonal Frequency Division Multiple Access (OFDMA) downlink performance due to imperfect CQI has been studied in [9, 10]. In [9], the problem of continuous ergodic weighted sum rate maximization for optimal subcarrier and power allocation was considered and a dual optimization framework was used to solve the problem. In [10], a delay-sensitive cross-layer design framework was proposed to maintain heterogeneous users' delay constraints and guarantee a fixed target outage probability in optimal power and subcarrier allocation.

Imperfect CQI can lead to three types of inaccurate CQI: erroneous CQI, outdated CQI and unavailable when the delay of the outdated CQI is longer than the scheduling interval. Outdated CQI is the most common problem due to the feedback and processing delay which cause a mismatch between the current state and the CQI. The effect of outdated CQI has been analysed in [11-13]. In [11], the Probability Distribution Function (PDF) of the CQI corresponding to an estimated CQI was used to improve the Multi carrier Proportional Fair (MPF) algorithm in downlink OFDMA system. In [12], several CQI predictors under realistic delay were studied and the linear prediction with Stochastic Approximation had the best performance and a lower computational complexity. In [13], a joint HARQ and adaptive modulation and coding policy was optimized for scheduling and resource allocation. The numerical results show the improvements in terms of the probability of outage and the achieved spectral efficiency. Results in [14] show that the improvement method can reduce the impact of outdated CQI.

The prediction of multi-user system was investigated in [15]. Wiener filter for iterative channel estimation in OFDMA system, channel estimation performance without memory (Block-Least Squares Estimation, Block-LSE), and channel estimation with memory using Kalman filter is explored in [16], [17], and [18], respectively.

Among the existing packet scheduling algorithms in LTE downlink system, only limited numbers of them have an overall acceptable performance under various imperfect channel states. However, due to the huge computational complexity, the practical implementation of the algorithms is difficult. The aim of this paper is to reduce the detrimental effects caused by various imperfect CQI types while keeping a low implementation complexity. A CQI prediction scheme using Kalman filter together with a grouping method is proposed. The packet scheduling decision is made according to the predicted CQI. Based on this estimated CQI, the packet scheduling is optimized, which results in a performance improvement.

The rest of this paper is organized as follows: The system model is provided in Section II. The prediction based on Kalman filter is described in Section III. The packet scheduling scheme based on Kalman filter is proposed in Section IV. Section V gives the simulation results. Finally, Section VI concludes the paper.

II. SYSTEM MODEL

Kalman filter is an extension of Wiener filter to non-stationary process, Wiener filter needs all the history values to forecast one time step into the future (formally the infinite past was assumed in the theory, but in practice, it is of finite length). Therefore, the implementation of Wiener filter is not easy. In contrast, the computational complexity of Kalman filter is much lower due to the simplicity of the single input value required.

An autoregressive process to calculate how x_m will behave over time is assumed:

$$x_m = ax_{m-1} + \theta_m \tag{1}$$

Suppose an estimate of x_{m-1}, is called $\tilde{x}_{m-1}$, with an estimated error represented by:

$$P_{m-1} = E(\tilde{x}_{m-1} - x_{m-1})^2 \tag{2}$$

Then a forecast of x_m can be made:

$$\tilde{x}_m(-) = \tilde{a}x_{m-1} \tag{3}$$

Without loss of generality, θ_m is assumed unknown and unpredictable. The minus sign indicates that no observation from current time *m* has been considered. The prediction error now can be expressed as below:

$$P_m(-) = E(\tilde{x}_m(-) - x_m)^2 = \sigma_\theta^2 + P_{m-1} \tag{4}$$

This indicates that the initial error propagates forward in time and is additive to the new error from the unknown θ_m. A measurement of x_m with noise is further assumed,

$$y_m = bx_m + \varepsilon_m \tag{5}$$

where the mean of ε_m is 0 and the variance is σ_ε^2, which produces an estimate ${y_m}/{b}$, with error variance $b^{-2}\sigma_\varepsilon^2$. The observation of x_m can be used to improve the estimate of it.

If the new data are very poor relative to the forecast, $\sigma_\varepsilon^2 \to \infty$, the estimate reduces to the observation. In the opposite limit when $\sigma_\varepsilon^2 \to 0$, the new data show a much better estimate.

If there are no observations available at time *m*, then the forecast cannot be improved, $\tilde{x}_{m+1} = a\tilde{x}_m$, and continue with $\tilde{x}_{m+2} = a\tilde{x}_{m+1}$. The Kalman filter permits one to employ whatever information is contained in a model along with any observations of the elements of the system that come in through time. The dimension of the state matrix does not have to be equal to that of the observation matrix. The idea is extremely powerful and a lot of research has been made on it and its generalizations. If there is a steady data stream, and the model satisfies certain requirements, the Kalman filter asymptotically reduces to the Wiener filter [19].

III. PREDICTION BASED ON KALMAN FILTER

A. The Prediction Process

As an optimal autoregressive prediction method, Kalman filter has been applied to channel condition prediction and it enables to forecast current channel state from the state in the last time slot. Specially, the classical Kalman filter method includes two steps: estimation and correction. In the estimation step, the current CQI value is estimated from the CQI in last TTI while the estimated current CQI conditioned on last TTI is improved according to the observed CQI value that is received from each user's CQI report in the correction step. The equations are given below:

Estimation step:

$$X(t|t-1) = \Phi X(t-1|t-1) \quad (6)$$

$$P(t|t-1) = \Phi P(t-1|t-1)\Phi' + Q \quad (7)$$

where $X(t|t-1)$ is the estimate of *X(t)* based on the time *t-1*. *Φ* is transition matrix that connects two consecutive states, *X(t)* and *X(t-1)*, of the system, $P(t|t-1)$ is the covariance of $X(t|t-1)$, and $P(t-1|t-1)$ is the covariance of $X(t-1|t-1)$.The random variable *Q* denotes noise error matrix. The aim of calculating $P(t|t-1)$ is to estimate the accuracy of $X(t|t-1)$. If $P(t|t-1) \to 0$, this means the estimate $X(t|t-1)$ is so close to the realistic CQI value that only limited correction need to be made, otherwise, if $P(t|t-1) \to 1$, this means the estimate $X(t|t-1)$ is considered to be unreliable, and it will reduce to the observation.

Correction step:

$$Z(t) = HX(t) + R \quad (8)$$

$$K(t) = P(t|t-1)H^T[HP(t|t-1)H^T + R]^{-1} \quad (9)$$

$$\tilde{X}(t) = \tilde{X}(t|t-1) + K(t)[Z(t) - H\tilde{X}(t|t-1)] \quad (10)$$

$$P(t) = [I - K(t)H]P(t|t-1) \quad (11)$$

Equation (8) calculates the observed value $Z(t)$ from the realistic channel, where *H* is the channel gain, *R* is observed error matrix. In our situation, Z(t) can be obtained directly from the CQI value reported by the users.

Equation (9) gives the Kalman gain $K(t)$, where the superscript *T* represents transpose. Kalman gain can be regarded as a weight factor that "decides" how much improvement the estimate $X(t|t-1)$ should be made.

From the Equation (6) - (9), we can get the optimal estimation of current state $\tilde{X}(t)$from Equation (10), which is an update from $X(t|t-1)$.

In addition, we need to update the covariance to use in the next packet scheduling interval, and this process is given by Equation (11), where *I* is the identity matrix.

The procedure is shown in Fig. 1.

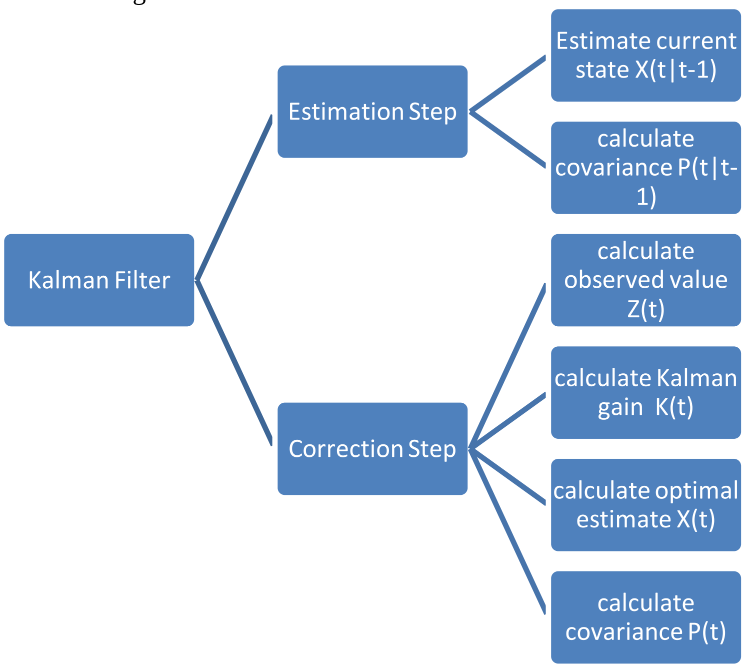

Fig 1: the procedure of Kalman filter

B. *Initialization of Kalman Filter*

Although few papers and books talk about initialization of Kalman filter, it is rather important to mention that if either the matrix *Q* or *R* are disarranged once, they keep disarranged and will not be updated and the Kalman process might give bad predictions [20].

At first, the expressions of state matrix *X(t)* and observed matrix *Z(t)* can be derived from the Taylor series:

$$x(t) = x(0) + \dot{x}(0)t + \frac{1}{2}\ddot{x}(0)t^2 + \cdots \quad (12)$$

where $\dot{x}(0)$ indicates the first derivative of **x** at initial time *t=0*, $\ddot{x}(0)$ indicates the second derivative of **x** at initial time *t=0* etc. The Taylor series is generally reduced to:

$$x(t) = x(0) + \dot{x}(0)t + \frac{1}{2}\ddot{x}(0)t^2 \quad (13)$$

In channel condition prediction, x(0) is the Signal-to-Interference-plus-Noise-Ratio (SINR) of user *i* on RB *j* at scheduling interval 0, denoted by γ_{ij}, we can consider $\dot{x}(0)$ as the change rate of SINR, represented as v_i and $\ddot{x}(0)$ is the gradient of v_i, denoted by b_i. $\gamma_{ij}^{'}$, $v_i^{'}$, $b_i^{'}$ are the observed γ_{ij}, v_i, b_i, respectively. On this basis, the state equation and observation equation can be respectively established as follows, where T denotes the transpose.

$$X(t) = (\gamma_{ij}, v_i, b_i)^T$$
$$Z(t) = (\gamma_{ij}^{'}, v_i^{'}, b_i^{'})^T$$

Then, the transition matrix can be determined as:

$$\Phi = \begin{bmatrix} 1 & t & t^2/2 \\ 0 & 1 & t \\ 0 & 0 & 1 \end{bmatrix}$$

Thereafter, since the observed matrix is directly obtained from the state matrix, the channel gain matrix can be determined as the identity matrix:

$$H = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

After the determination of state matrix, the observed matrix, the transition matrix and the channel gain matrix, covariance matrix of the measurement error R can be initialized Let $X_{e,x}(t)$, $X_{e,y}(t)$, $X_{e,z}(t)$ denote the random variable that describes the measurement error. The error measurement covariance is

$$R = E[(X_{e,x}(t), X_{e,y}(t), X_{e,z}(t))^T (X_{e,x}(t), X_{e,y}(t), X_{e,z}(t))] \quad (14)$$

The elements of the principal diagonal are the covariance of $X_{e,x}(t), X_{e,y}(t), X_{e,z}(t)$ respectively. Other elements are the covariance of each two variables, since each variable is completely independent. The matrix is:

$$R = \begin{pmatrix} \sigma_{e,x}^2 & 0 & 0 \\ 0 & \sigma_{e,y}^2 & 0 \\ 0 & 0 & \sigma_{e,z}^2 \end{pmatrix}$$

Finally, the state matrix $X(t-1|t-1)$ can be simply set to zero. However, it is obvious that it is not zero, hence, we get an error in the first estimation and we can set the covariance matrix of the estimation error $P(t-1|t-1)$ as:

$$P_0 = \begin{pmatrix} {\gamma_{ij}}^2 & 0 & 0 \\ 0 & {v_i}^2 & 0 \\ 0 & 0 & {b_i}^2 \end{pmatrix}$$

IV. PACKET SCHEDULING SCHEME BASED ON KALMAN FILTER

Due to the time-varying nature, interference and other unfavourable factors that affect the channel conditions, the CQI received by scheduler can be damaged severely. By means of Kalman filter estimator and a grouping method, a new packet scheduling scheme is proposed from the point of prediction, which enables to reduce such degradation from these defects.

A. Grouping method

Because Kalman filter usually has a bad performance when the estimated objective changes dramatically, to overcome this detrimental effect, we consider a grouping method[21]. The basic idea of this method is to classify users into two groups based on their average CQI. A max rate algorithm is applied to group A which has higher CQI users to maximize the system throughput while a PF algorithm is used in group B which has lower CQI users to guarantee fairness and packet loss ratio. Then the selected users in these two groups are transmitted alternatively. Figure 2 described the method.

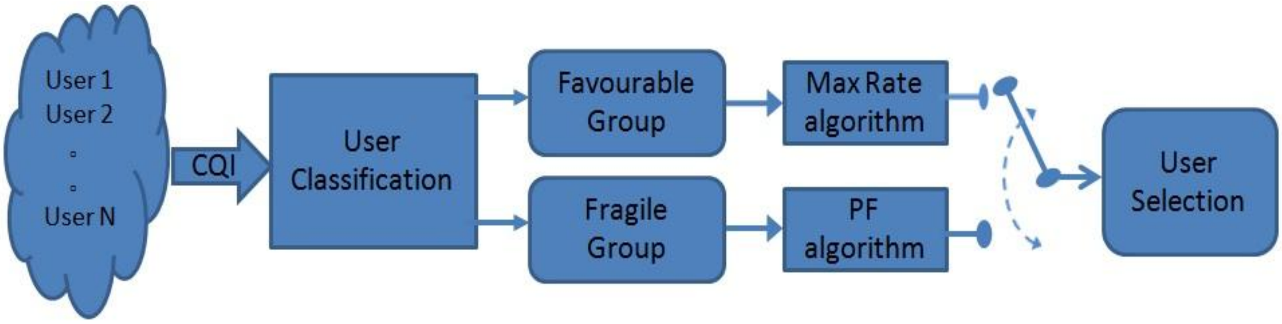

Fig. 2 Grouping method

B. The Proposed Packet Scheduling Scheme

The main principle is: firstly, in each TTI, the optimal estimated CQI value of each user is predicted by Kalman filter on each RB, moreover the highest supported data rate of each user on each RB can be estimated, and then users are classified into two groups employing the grouping method based on the predicted CQI values.

Based on the above analysis, the proposed packet scheduling scheme is described in Fig. 3.

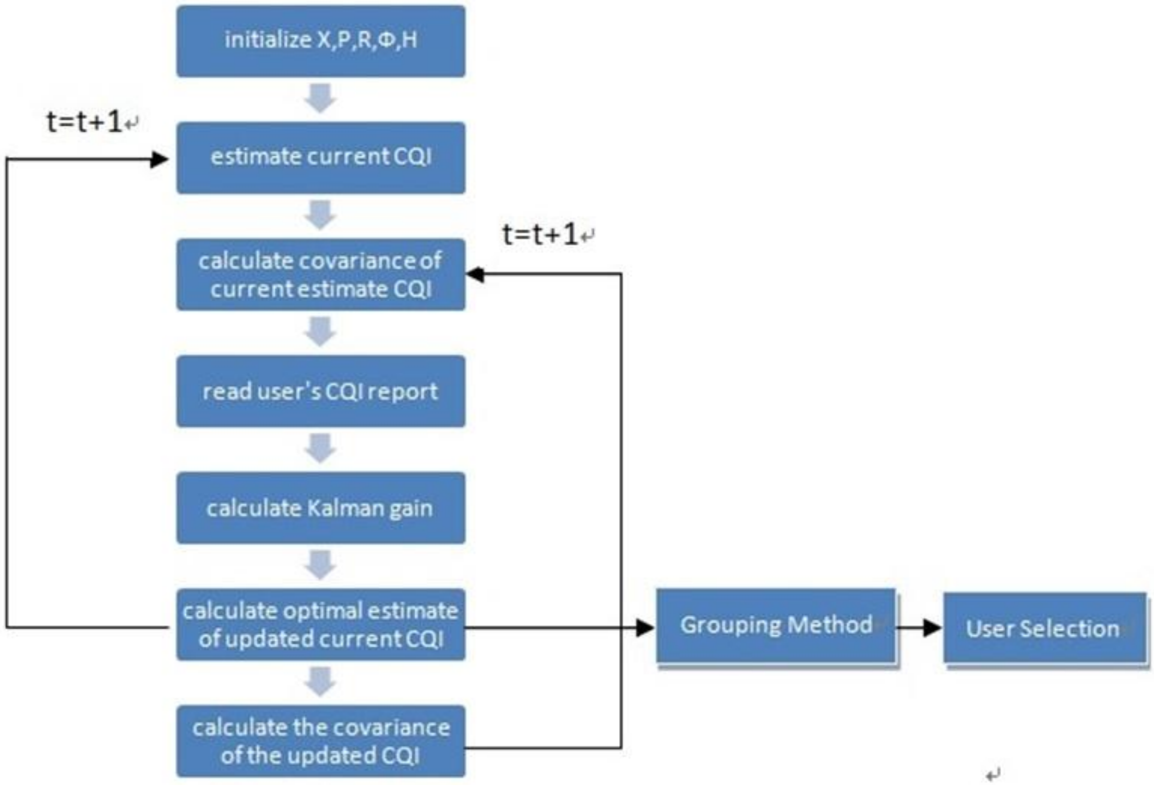

Fig 3: Flow chart of the packet scheduling scheme based on Kalman filter predictor

V. SIMULATION RESULTS

In order to evaluate the performance of the Kalman filter and the proposed packet scheduling scheme, simulation is performed in the LTE downlink environment [22]. The basic simulation parameters are illustrated in Table 1.

Fig. 4 shows the comparison between the realistic CQI values and the estimated CQI values. It can be seen that the estimated CQI values have the same trend with the realistic ones and the estimated CQI values are very close to the realistic CQI values.

Fig. 5 shows the system throughput comparison while Fig. 6 shows the Packet Loss Ratio (PLR) comparison for different packet scheduling schemes under imperfect CQI (outdated CQI and erroneous CQI). From the graphs, it can be seen that Kalman filter has a rather good performance that is close to the perfect CQI situation, and the system performances degrade significantly when there is no channel condition predictor. The detailed performance improvement on system throughput and PLR are given in Table [2] and Table [3], respectively.

Table 1: Main downlink LTE system parameters

System Parameters	***Values***
Cellular layout	Single hexagonal cell
Bandwidth	5 MHz
Carrier frequency	2 GHz
Mode of operation	FDD
Number of RBs	25
Number of sub-carriers per RB	12
Total number of Sub-carriers	300
Sub-carrier spacing	15 kHz
Scheduling interval (TTI)	1 ms
Number of OFDMA symbols per TTI	14 (Normal CP)
Total number of REs	168
Total eNB transmit power	43.01 dBm
User speed	120km/h

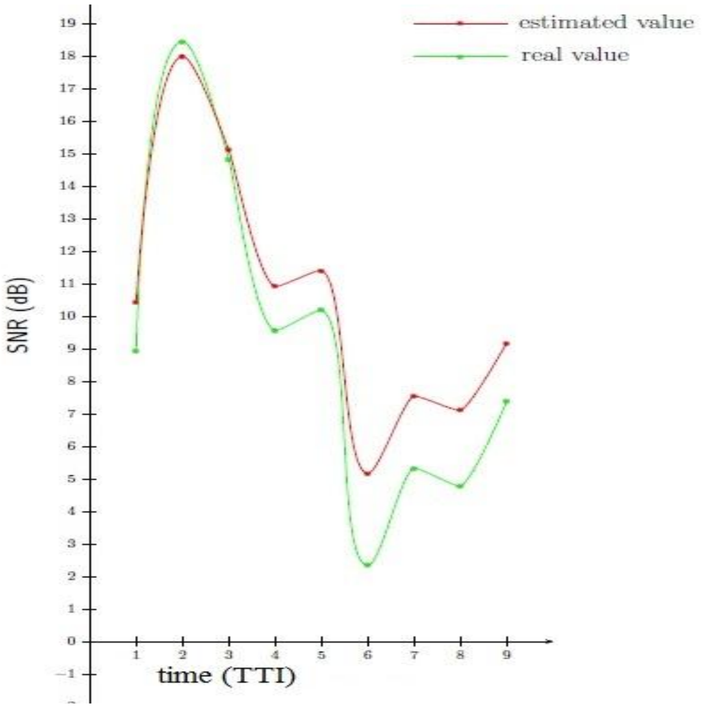

Fig 4 Estimated SNR vs Real SNR

Table 2 System throughput at 80 users

	System throughput (Mbps)	Performance improvement (%)
PF under perfect CQI	6.38	-
Proposed scheme under imperfect CQI	6.06	6.5
PF under imperfect CQI	5.69	-

Table 3 PLR at 80 users

	PLR	Performance improvement (%)
PF under perfect CQI	0.388	-
Proposed scheme under imperfect CQI	0.393	-8.8
PF under imperfect CQI	0.431	-

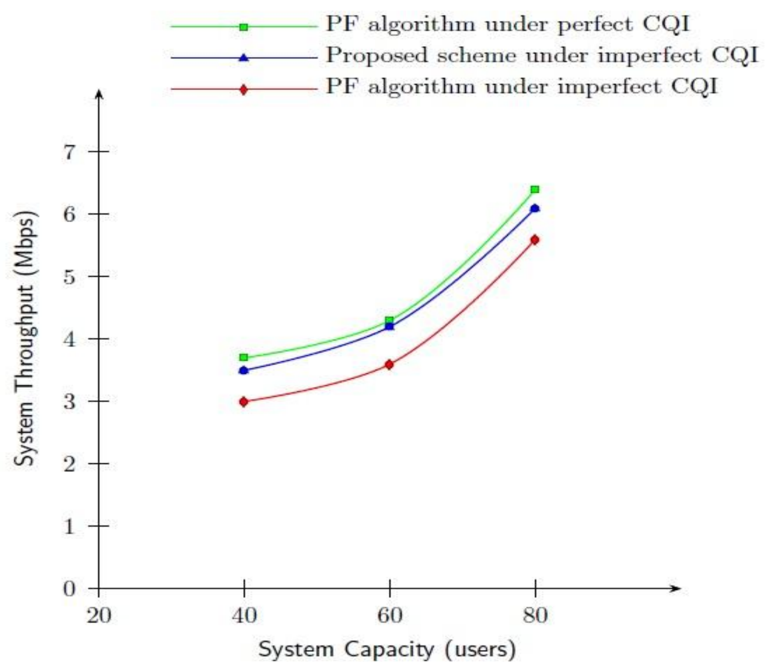

Fig 5 System throughput comparison

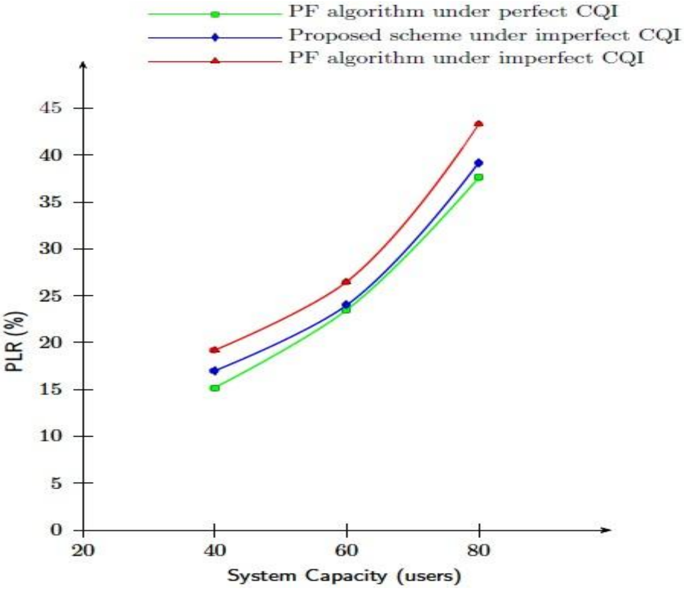

Fig 6 PLR comparison

VI. CONCLUSIONS

Most of the packet scheduling algorithms assume a perfect CQI scenario, however the practical imperfect channel conditions always cause a mismatch between current channel state and the received CQI, which makes the packet scheduling based on the CQI feedback allocates resources inappropriately. By means of Kalman filter, the current state CQI is predicted, and the employment of a grouping method can help improve the prediction accuracy of the Kalman filter. On this basis, the data rate with such predicted CQI is calculated and the subcarriers are allocated with such estimated rate, which will significantly reduce the detrimental effects due to the imperfect channel conditions. Compared with a traditional PF algorithm, the simulation results show that the proposed algorithm enables to improve the system throughput, and reduce the packet loss ratio.

REFERENCES

[1] K. Kinoshita, "Current Status of “FDMA” 3G service and DoCoMo’s B3G Activities," in *ICB3G – 2004*, May 2004, pp. 13-21.
[2] G. RP-090604, "Draft Minutes (V4.0.1) of the 43rd 3GPP TSG RAN meeting," in *MCC*, 2001.
[3] A. M. Rao, A. Weber, S. Gollamudi, and R. Soni, "LTE and HSPA+: Revolutionary and evolutionary solutions for global mobile broadband," *Bell Labs Technical Journal*, vol. 13, pp. 7-34, 2009.
[4] J. Gross, H. Karl, F. Fitzek, and A. Wolisz, "Comparison of heuristic and optimal subcarrier assignment algorithms," in *Proc. of Intl. Conf. on Wireless Networks (ICWN)*, 2003.
[5] A. K. Khattab and K. M. Elsayed, "Opportunistic scheduling of delay sensitive traffic in ofdma-basedwireless," in *proceedings of the 2006 International Symposium on on World of Wireless, Mobile and Multimedia Networks*, 2006, pp. 279-288.
[6] M. R. Souryal and R. L. Pickholtz, "Adaptive modulation with imperfect channel information in OFDM," in *Communications, 2001. ICC 2001. IEEE International Conference on*, 2001, pp. 1861-1865 vol.6.
[7] A. a. K. S. Krishnarajah, "Mobile Communication Systems - Long Term Evolution.," in *University of Technology, Sydney: Sydney*, 2008.
[8] W. Yafeng and Y. Hongwen, "Retransmission priority scheduling algorithm for forward link packet data service," in *Communication Technology Proceedings, 2003. ICCT 2003. International Conference on*, 2003, pp. 926-930.
[9] I. C. Wong and B. Evans, "Optimal resource allocation in the OFDMA downlink with imperfect channel knowledge," *Communications, IEEE Transactions on*, vol. 57, pp. 232-241, 2009.
[10] D. S. W. Hui and V. K. N. Lau, "Delay-sensitive cross-layer designs for OFDMA systems with outdated CSIT," in *Wireless Communications and Networking Conference, 2007. WCNC 2007. IEEE*, 2007, pp. 264-269.
[11] H. Ayoub and M. Assaad, "Scheduling in OFDMA Systems With Outdated Channel Knowledge," in *Communications (ICC), 2010 IEEE International Conference on*, 2010, pp. 1-5.
[12] R. A. Akl, S. Valentin, G. Wunder, and S. Stanczak, "Compensating for CQI Aging By Channel Prediction: The LTE Downlink."
[13] T. Villa, R. Merz, R. Knopp, and U. Takyar, "Adaptive modulation and coding with hybrid-ARQ for latency-constrained networks," in *European Wireless, 2012. EW. 18th European Wireless Conference*, 2012, pp. 1-8.
[14] A. Jalali, R. Padovani, and R. Pankaj, "Data throughput of CDMA-HDR a high efficiency-high data rate personal communication wireless system," in *Vehicular Technology Conference Proceedings, 2000. VTC 2000-Spring Tokyo. 2000 IEEE 51st*, 2000, pp. 1854-1858.

[15] J.-H. Jeon and Y.-H. Lee, "Prediction of channel information in multi-user OFDM systems," in *Circuits and Systems, 2006. MWSCAS'06. 49th IEEE International Midwest Symposium on*, 2006, pp. 468-472.

[16] J. Bonnet and G. Auer, "Chunk-based channel estimation for uplink OFDM," in *Vehicular Technology Conference, 2006. VTC 2006-Spring. IEEE 63rd*, 2006, pp. 1555-1559.

[17] D. Aronsson, T. Svensson, and M. Sternad, "Performance evaluation of memory-less and Kalman-based channel estimation for OFDMA," in *Vehicular Technology Conference, 2009. VTC Spring 2009. IEEE 69th*, 2009, pp. 1-5.

[18] R. E. Kalman, "A new approach to linear filtering and prediction problems," *Journal of basic Engineering*, vol. 82, pp. 35-45, 1960.

[19] C. 6, "Wiener and Kalman Filters," http://www.core.org.cn/NR/rdonlyres/Earth--Atmospheric--and-Planetary-Sciences/12-864Spring-2005/61CFF435-7279-4E13-BDF1-290EDF929664/0/tsamsfmt2_6.pdf.

[20] M. Kohler, *Using the Kalman filter to track human interactive motion: modelling and initialization of the Kalman filter for translational motion*: Citeseer, 1997.

[21] J. Jae-Hoon and L. Yong-Hwan, "Packet Scheduling in the Presence of Channel Estimation Error in Multi-User OFDM Wireless Systems," in *Signal Processing Advances in Wireless Communications, 2006. SPAWC '06. IEEE 7th Workshop on*, 2006, pp. 1-5.

[22] H. A. M. Ramli, "Performance Analysis of Packet Scheduling in Long Term Evolution (LTE)," September 2011, pp. University of Technology, Sydney.

