

Vehicular Networks Performance Evaluation Based on Downlink Scheduling Algorithms for High-Speed Long Term Evolution—Vehicle

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Abstract—Moving is the key to modern life. Most things are in moving such as vehicles and user mobiles, so the need for high-speed wireless networks to serve the high demand of the wireless application becomes essential for any wireless network design. The use of web browsing, online gaming, and on-time data exchange like video calls as an example means that users need a high data rate and fewer error communication links. To satisfy this, increasing the bandwidth available for each network will enhance the throughput of the communication, but the bandwidth available is a limited resource which means that thinking about techniques to be used to increase the throughput of the network is very important. One of the techniques used is the spectrum sharing between the available networks, but the problem here is when there is no available channel to connect with. This encourages researchers to think about using scheduling as a technique to serve the high capacity on the network. Studying scheduling techniques depends on the Quality-of-Service (QoS) of the network, so the throughput performance is the metric of this paper. In this paper, an improved Best-CQI scheduling algorithm is proposed to enhance the throughput of the network. The proposed algorithm was compared with three user scheduling algorithms to evaluate the throughput performance which are Round Robin (RR), Proportional Fair (PF), and Best-CQI algorithms. The study is performed under Line-of-Sight (LoS) link at carrier frequency 2.6 GHz to satisfy the Vehicular Long Term Evolution (LTE-V) with the high-speed scenario. The simulation results show that the proposed algorithm outperforms the throughput performance of the other algorithms.

Keywords—LTE-V, best-CQI, round robin, proportional fair, LoS

1 Introduction

In few years ago, the capacity of the need of wireless networks has been increased due to the increase of mobiles, tablets, mobile applications, and the use of Internet-of-Things (IoT) [1]. Besides the capacity increasing, vehicular communication has a great

development process in the field of infrastructure such as using multi-Radio Access Technologies (Multi-RAT) in heterogeneous networks, using massive Multiple-Input Multiple-Output (MIMO) configuration in the main Base Station (BS), and in the field of controlling the huge coming data from available vehicles [2]. Vehicular network is one of the 3rd Generation Partnership Project (3GPP) that use Long-Term Evolution (LTE) as a the technology of covering wide range of communication area instead of IEEE 802.11p networks which is suitable for short range covering [3]. Using LTE with vehicular links leads to have LTE-V networks where V indicates Vehicle [4]. The main features of this type of networks are the high bandwidth, the low latency required for Quality-of-Service (QoS), and high throughput to meet the high data rate transmission [5].

This is important to meet all these requirement features in the same available high bandwidth because of the bandwidth limitation. However, vehicular communication needs to have high spectral efficiency in order to meet the high capacity users in the network [6]. One of the main constraints that affect the spectral efficiency is the channel condition between vehicle to the BS which is called the Vehicle-to-Infrastructure (V2I) link that suffers from path loss and huge number of scatterers surrounding the user which degraded the QoS of the network [7]. There are a lot of techniques used to overcome the limitation of the bandwidth by enhancing the channel conditions. One of them is the multiplexing techniques used to reduce the effect of multipath signals and to enhance the spectral efficiency of the system [8]. It is a very powerful techniques used to enhance the channel conditions, but it is limited when the network becomes large which means there is high dense vehicles on the road want to connect with BS.

The second solution is to use scheduling algorithms that are responsible to reduce the multipath effect and to elect the best QoS signal with best communication link to deal with [9]. This process reduces the computational complexity needed for the multiplexing techniques and also makes the use of spectrum available more efficiency [10]. The question here is how to choose the best scheduling algorithm in order to enhance the throughput of the system? This question can be simply answered by using QoS-aware scheduling algorithms that are useful to be used in enhancing the channel conditions [11]. The new question now is what the best QoS-aware scheduling algorithm which can be used in high-speed vehicular communication where high effect of Doppler shift appears, and high changeable channel conditions is introduced that affects the interference level in the network. High-speed moving between BS makes the links between BS and the vehicle more complicated because the high scatterers come from the surrounding area of the network [12]. The scattered signal causes several multipath signals which leads to an increase in the interference between users [13]. This increase in the interference level leads to thinking about techniques that use the available resources to enhance the performance of the network without affecting the spectrum available [14] which is the use of scheduling algorithms.

The main objective of this paper can be summarized as to evaluate different number of scheduling algorithms to enhance the throughput of the LTE-V network and then to propose a new QoS-aware scheduling algorithm depends on decreasing the interference level. Because of this, this paper aims to propose an algorithm called Improved Best-CQI (IBCQI) to enhance the throughput of the high-speed scenario without affected by the density increases. It can be used to enhance the throughput of the best-CQI

algorithm and to evaluate the performance of using different user scheduling algorithms such as Round Robin (RR), Proportional Fair (PF), and Best-CQI used in LTE-V networks to make a performance evaluation of the QoS of some scheduling algorithms. It depends on the Best-CQI architecture with a modification of putting the interference level on the channel into consideration to determine the best CQI to be used from the CQI table. If the interference level is less than the threshold level, the throughput is recorded, but if the interference is above the threshold level, the scheduler searches again for good channel conditions and the best CQI to use to enhance the throughput. The contributions of this paper can be:

- i. Propose a new QoS-aware scheduling algorithm suitable to use in high-speed LTE-V network whatever the density of the network is.
- ii. Enhancing the throughput of the LTE-V network by considering the interference level of the communication channel between vehicle and BS. This technique is a developing of the Best-CQI scheduling algorithm which is widely used in vehicular communication.
- iii. Evaluating the proposed algorithm with other scheduling algorithms used in this filed. This is to be sure that the proposed algorithm outperforms the throughput response of other algorithms.

The rest of the paper is organized as: Section 2 gives some literature review; section 3 describes the proposed algorithm. Section 4 describes the system model, the methodology for the study, and the simulation parameters used. The simulation results of the proposed algorithm concerning throughput are analyzed and discussed in section 5. The conclusion of this study and the illustration of some future works are given in section 6.

2 Literature review

User scheduling is one of the modern wireless communication techniques used to reduce the interference between users in high dense networks and enhance the spectral efficiency of systems especially when a free spectrum is available [9]. The need for using scheduling increases when users are in moving because the number of user interference that comes from the scattered signals increases with the moving users along the road. The importance of using user scheduling is to enhance the throughput of the system to make sure that each user has a sufficient amount of throughput [15]. For V2I links, there are many scheduling techniques used to enhance the network throughput. The most basic one is the exhaustive search, which records every one of the subsets of users and it has complex computational in dense networks [16]. This technique will increase the overload on the BS due to the heavy number of scheduling requests, because of this, using imperfect scheduling techniques have been proposed to simplify the computational process and to give a throughput value near to that that exhaustive search gives [17]. The scheduling process of the QoS aware scheduling starts from performing a connection to the eNodeB of the LTE, then the LTE node examines the coming signal and all its features to perform scheduling according to the QoS performance [18] and [19].

The scheduling process depends on choosing the user that can give the maximal enhancement of the throughput in every communication link which can enhance the whole performance of the network [20]. The question here is how to choose the best scheduling algorithm to enhance the throughput of the system? The answer is to use the QoS-aware scheduling algorithm that depends on the quality of the communication link where this paper aims to perform to evaluate several scheduling algorithms depending on the throughput of each one, especially for the high-speed networks as a simulation scenario. The basic and well-known scheduler is the RR algorithm, which is considered the basic one and the simplest to implement [21]. Its main characteristic is the concept of the channel-blind, which means that its performance does not affect changing the channel conditions by assigning BS to each user in the network without any consideration of his channel condition [22].

The Best-CQI algorithm is also a widely used scheduler in the LTE-V network. It depends on Transmission Time Interval (TTI) to allocate BS to users which means that the channel conditions are in the consideration of this scheduler, because of this, it is called a channel-aware algorithm [23]. Due to the characteristic of getting the best channel condition to perform scheduling, it guarantees to give the highest value of throughput compared with other LTE-V schedulers [24]. The drawback of this algorithm is that when the user's channel is poor, the user may not be able to perform scheduling. Proportional Fair (PF) algorithm is also one of the famous scheduler used in LTE networks [25]. It is widely used for Code Division Multiple Access (CDMA) systems and then used for the Orthogonal Frequency Division Multiplexing (OFDM) systems [26]. It is considered a complex algorithm compared with others and it hard to use in a real-time system, but it is still a channel-aware algorithm as Best-CQI but affected by the density of the network [27].

All the above-mentioned schedulers used in the LTE-V network are useful to be used. However, satisfying all the QoS requirements of the LTE-V network is not achieved yet such as using these algorithms in a high-speed scenario without affecting the complexity, throughput level, and stability for all Signal-to-Noise Ratio (SNR) values [11]. It is important to study this scenario of communication because modern life is almost in motion and the LTE-V network is becoming more important to implement and to enhance. Yildiz and Sokullu [28] evaluate the RR schedule by developing a Mobility Aware downlink Scheduling algorithm (MAS). They evaluate the throughput and Block Error Rate (BLER) of the system where the results show an advancement of the use of MAS instead of RR. While Marinčić and Šimunić [29] evaluate some scheduling algorithms used in LTE such as RR, PF, Best-CQI, and Maximum-Minimum algorithm. They evaluate the average throughput of each user using the Vienna LTE System Level Simulator. Nsiri, et al. [30] compare the performances of different scheduling algorithms such as RR, PF, Best-CQI, and Max throughput, in downlink transmission for LTE cellular network. They evaluate these algorithms according to the throughput of the system. Their results show that the PF algorithm gives a high throughput with guaranteed fairness between the users.

Choi and Evans [13] discusses the performance of user scheduling under low ADC with massive MIMO antennas used at the base station. They use a greedy scheduling algorithm to decrease the computational process of the scheduling process. The results show that the greedy algorithm enhances the capacity of the system. While the spectrum efficiency as one of the QoS parameters in wireless communication has been studied in

Esswie and Pedersen [31] by dealing with scheduling when there is an important issue in the network. Hu [32] examines the QoS of the system by dealing with the interference comes from the channel and other users that affects the scheduling process and affect the response of the scheduling algorithm used. They evaluate the scheduling process using the greedy algorithm which limits the interference comes from the surrounding area.

3 The proposed algorithm

The proposed scheduling algorithm for high-speed vehicular communication is called Improved Best-CQI (IBCQI). It is based into the Beest-CQI algorithm but with an addition of interference level testing before choosing the channel of scheduling or simply before deciding to perform scheduling process. It is considered as one of the channel-aware algorithms. It uses the channel indicator process that indicates the channel condition that carries the information. The algorithm is responsible to determine whether it is good or bad channel to be used as scheduling channel. After determining the channel status, the final test which is proposed to add is to test the interference level of the communication channel. This test can help allocate the resource block of the communication each time without any care about fairness. The IBCQI enhances the throughput by selecting the channel with highest CQI as show in equation 1 subjected to the lower interference level.

$$M_{k,n} = \arg \max_k (CQI_{k,n}) \tag{1}$$

Subject to:

$$L_{k,n} \leq Th$$

Where

$M_{k,n}$	Maximum value of channel quality indicator.
$CQI_{k,n}$	The Value of the channel quality indicator.
k	User index.
n	Resource Block (RB) index
L	Interference level of the channel
Th	The threshold value of the interference level

The process of using IBCQI is as in the flowchart shown in Figure 1. Each vehicle wants to communicate with eNodeB sends its packet size, packet types, and the requested delay to inform the eNodeB about the channel quality and requesting of scheduling. The eNodeB creates an array contains the resource block of the vehicle. It chooses the largest element to each vehicle on a specific resource block. After that, all other values of the CQI values sets to be zero. Before choosing the best CQI value, the system tests the channel quality by measuring the interference. If it is less than the pre-defined threshold value, it chooses the CQI as the best one, but if it is larger than the threshold value, the system tries to find another best value of the CQI. These steps are repeated for all users. This algorithm is described in Algorithm1 below.

Algorithm 1

1. **Input:** CQI feedback of the users, Requested Delay, Packet Size.
2. **Estimate:** Average throughput and Necessary delivery time for each user.
3. **Test:** for each user:
4. **if** Interference smaller than the threshold level
5. Throughput is obtained
6. **else**
7. Search for another CQI from the CQI table
8. **Estimate:** Return to step 2
9. **Return:** maximum Throughput value.

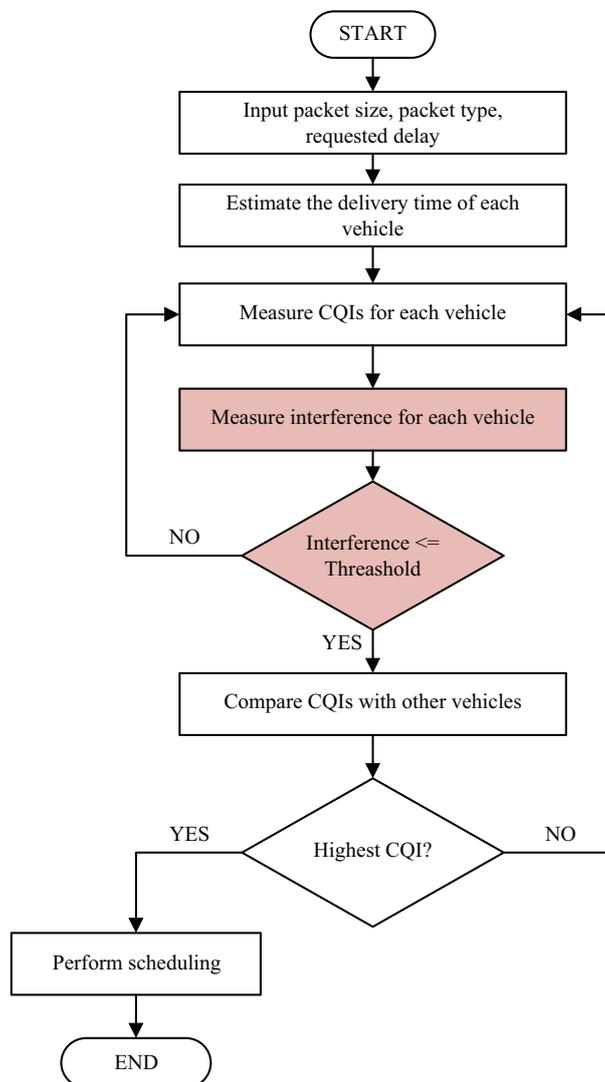


Fig. 1. Flowchart of the proposed algorithm

4 System model and methodology

Figure 2 shows the simulation scenario of the proposed work. It consists of one eNodeB serving several numbers of vehicles traveling in high-speed to satisfy the Multi-User Single-Input Single-Output (MU-SISO) network to simplify the computation process. The received signal from each user can be described as the received signal (r) can be expressed as:

$$r = \sqrt{\rho}Hs + n \tag{2}$$

where ρ is the channel gain, H is the channel matrix and well-known at the BS to reduce the computations, s is the transmitted signal, and n is the Additive White Gaussian Noise (AWGN).

The simulation is performed using the Vienna LTE System Level Simulator. It starts to ask about the network initialization which means asking about the number of users at each BS, the bandwidth used, and the channel estimation technique. In addition to this, the simulation asks about the velocity of the user which here equals 100 km/h to satisfy a high-speed moving. The simulation also asks about the SNR values to calculate the throughput of the network when applying the three different scheduling algorithms and the proposed one. The modulation used is Quadrature Phase-Shift Keying (QPSK) because of its suitable features in most of the wireless communication and less of its error rate.

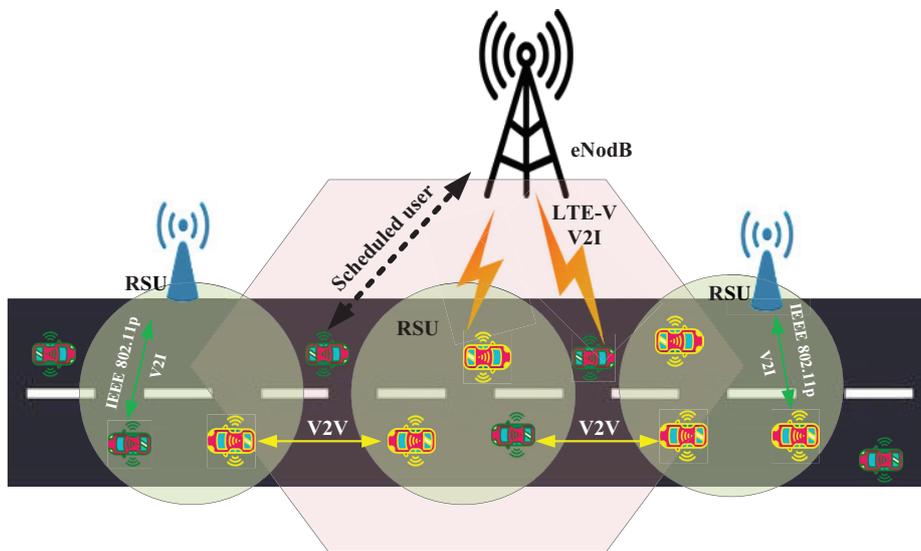


Fig. 2. Simulation scenario

The process starts from determining the SNR values which start from -5 dB and reached 60 dB to evaluate the scheduling algorithms for low and high values of SNR. The velocity as said is equal to 100 km/h and the channel model is used to be suitable with that high-speed traveling to reduce errors. The throughput is calculated for different values of SNR. All the simulation processes are repeated for different number of scheduling algorithms which are RR, PF, Best-CQI, and the proposed IBCQI algorithm which is described in Algorithm 1.

The simulation parameters that the code requests are mentioned in Table 1. One of these parameters is that the number of users simulated in this paper, which is 20, 50, and 80 to satisfy the situation of high dense BS. The carrier frequency used is 2.6 GHz to satisfy LTE. The subcarrier spacing equals 15 kHz to mitigate interference between sub-carriers. The Fast Fourier Transform (FFT) size used is 1024 with an available bandwidth of 20 MHz. The estimation method is Minimum Mean Square Error (MMSE) and the communication links are Line-of-Sight (LoS).

Table 1. Simulation parameters

Simulation Parameter	Values
System bandwidth	20 MHz
Carrier frequency	2.6 GHz
Estimation methods	MMSE
Modulation	QPSK
Communication links	LoS
Speed	100 km/h
Scheduling algorithms	RR, PF, Best-CQI, and proposed IBCQI
Number of users	20, 50, 80
Number of BS	1
SNR [dB]	$[-5 : 60]$

5 Simulation results and discussion

For the proposed IBCQI algorithm, the throughput results from the use of LoS and NLoS links are near similar except at the range of 25 dB to 45 dB SNR which considers the range of normal power level to noise in LTE network, they differ on each other by 1 dB for the NLoS channel because of the multipath effect as shown in Figure 3. The similarity between the two-channel conditions comes from the high-speed traveling where no blind BS node for each user, so there is no need for NLoS links, and the simulation continues using LoS links.

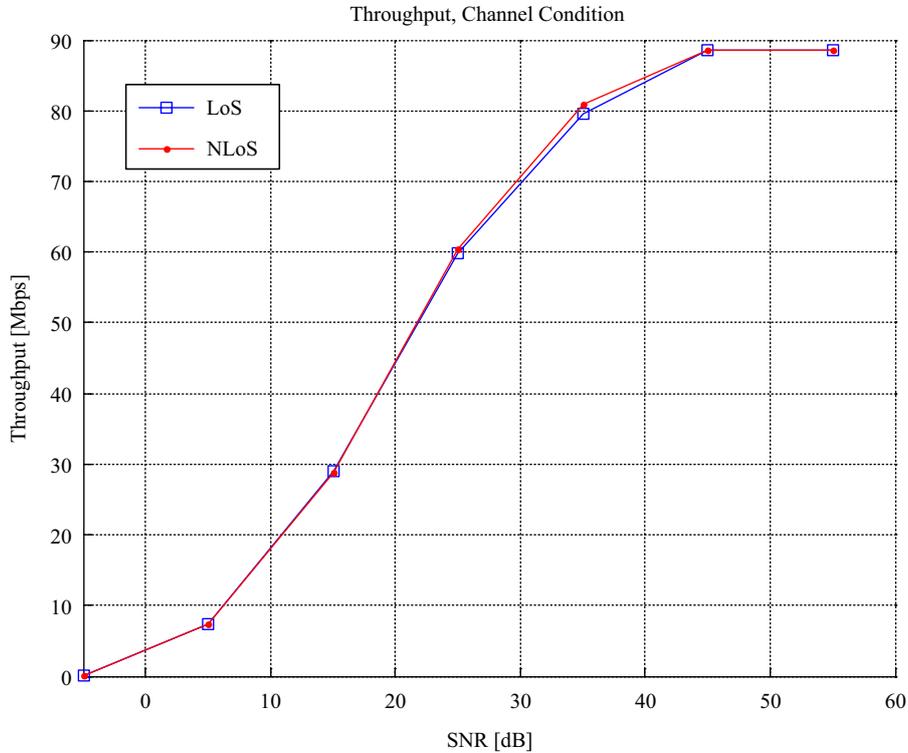


Fig. 3. Comparison between LoS and NLoS channel for the proposed IBCQI

Figure 4 shows the throughput evaluation of the LoS links between RR, PF, Best-CQI, and the proposed IBCQI algorithms. Figure 4 shows that the RR algorithm becomes constant at 14 Mbps whatever the channel condition is because it is one of the scheduling algorithms that does not give the channel condition any attention. While the throughput comes from the use of the PF algorithm varies with the channel conditions and the SNR levels but it gives a maximum of 10 Mbps. This is because it was hard to use PF in real-time applications which is the backbone need of high-speed communication. Best-CQI algorithm performance fluctuating below 20 Mbps when the SNR values are small, while it increased linearly when the SNR values become high and reach 81 Mbps at 35 dB SNR and reach their maximum value of 89 dB at 55 dB SNR.

Figure 4 shows that the proposed IBCQI algorithm outperforms all the other algorithms in two things; the first one is it gives high throughput through the SNR values are small, and the second one is that its performance is less fluctuating during all the SNR values which mean more robustness against the changeable channel conditions. There is an 18% increasing in throughput when using the proposed IBCQI compared with Best-CQI at 30 dB SNR.

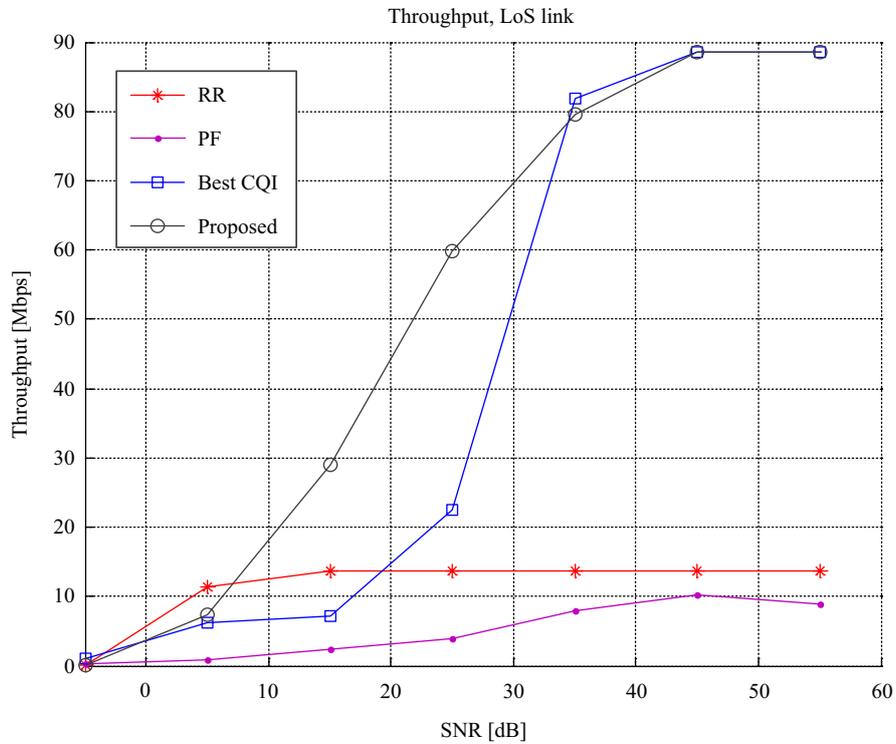


Fig. 4. LoS throughput performance

It is important to evaluate the performance of the proposed algorithm when the density in the network increases. Figure 5 shows the throughput performance when the density increased from 20 users to 50 users. All the algorithms' performances decreased due to the increase of the density. This is logical because it is hard to get good channel quality at high-speed traveling with increasing users in the same BS due to the increasing interference and transmission errors that come from increasing collusion between users' signals and overhead on the single BS available. Figure 5 shows several important things; the first one is that increasing the number of users does not affect the performance of the RR scheduler. It still gives near 14 Mbps which means that it is not affected by the channel conditions. The second notice is that the PF scheduler gives more throughput values when increasing the number of users, this can lead to saying that PF can be used with high-density networks, and this can be obtained from Figure 5 when the user's number reaches 80.

The third notice is that the Best-CQI scheduler is less fluctuating at low SNR values and still gives a high throughput value. This leads to say that this scheduler can be used

also for high-density networks. The performance of our proposed scheduler is still constant and does not affect by the user increasing. So, we can say that it is robust against changeable channel conditions and the increasing density in the network.

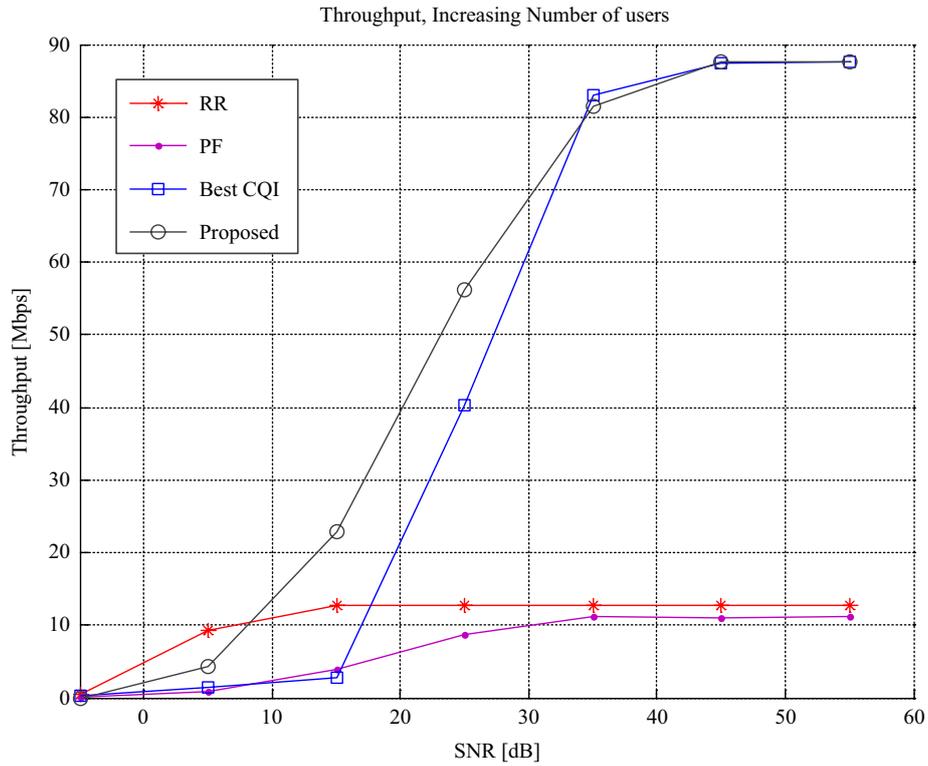


Fig. 5. Increasing number of users to 50 users

When an increasing number of users again to be 80 users for the single BS available. The throughput performance of all scheduler is as shown in Figure 6. It is clear from the figure that the response of the RR scheduler is still the same because of its channel-blind characteristics. The proposed IBCQI scheduler still gives high throughput values compared with others. The most important notice here is the response of PF. It outperforms the response of RR and gives near 15 Mbps at middle and high values of SNR. This ensures that it can be used with the high-density networks to enhance the throughput of the network but with some consideration on the network complexity.

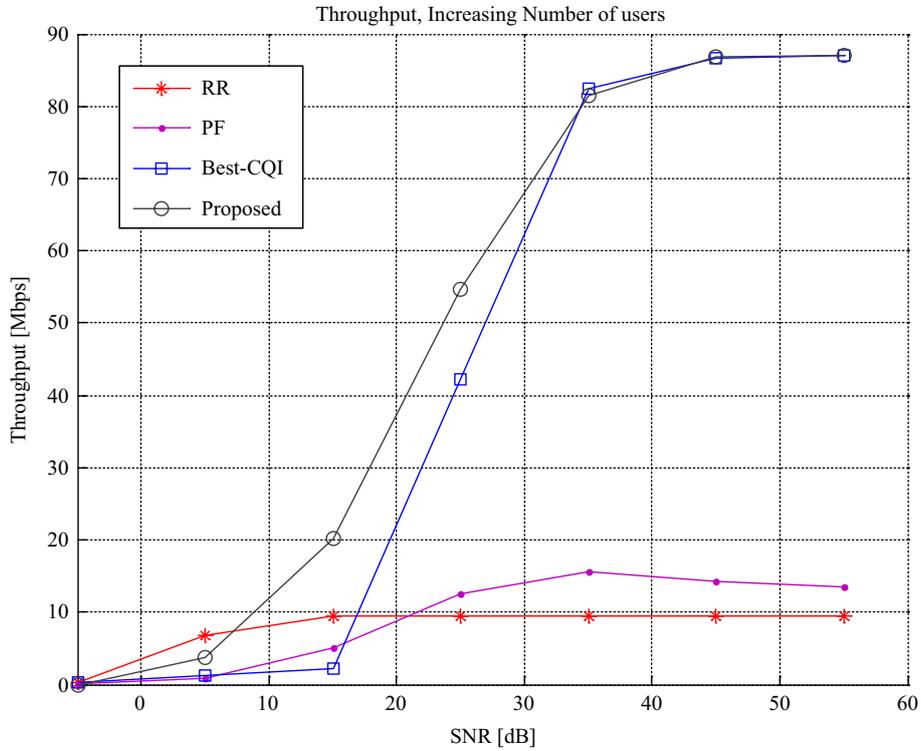


Fig. 6. Increasing number of users to 80 users

For an overall comparison between the four schedulers in this paper, Figure 7 shows the throughput comparison at 20 dB SNR to take a look at the performance of the schedulers in the middle range of SNR. As said before, Figure 7 shows that the throughput performance decreases as the density increases except for the PF algorithm which means it can be used with high-density networks. the Best-CQI performance also increases as the density increases but it still gives the same value of maximum throughput as shown in Figure 4, Figure 5, and Figure 6.

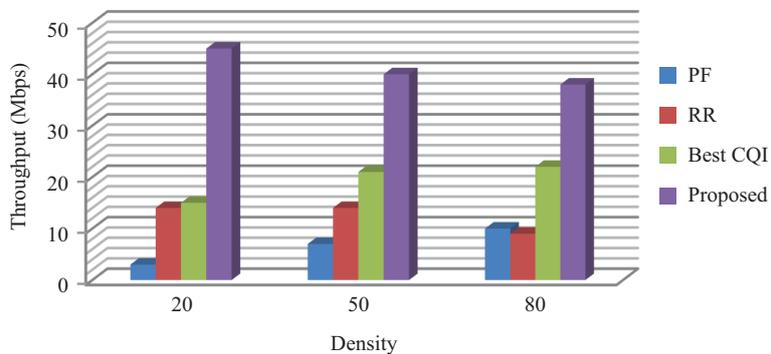


Fig. 7. Throughput comparison between the schedulers at 20 dB SNR

6 Conclusion

In this paper, the improved Best-CQI algorithm is proposed to enhance the performance of the Best-CQI algorithm in the high-speed scenario. The performance evaluation is performed using three different user scheduling algorithms used in LTE-V networks which are RR, PF, and Best-CQI. The throughput performance is the simulation metric in this paper because it is important to enhance the throughput of the LTE-V network to meet the high demand and high capacity of the network. Simulation results show that the proposed algorithm outperforms the performance of others by the throughput value and the robustness against the changeable channel conditions. It still gives the high throughput value when increasing the density of the network without high fluctuation on the performance at low values of SNR compared to the Best-CQI algorithm. RR scheduler gives a stable performance for any channel condition because of its channel-blind characteristics. Simulation results also show that the PF scheduler is suitable to use in high dense networks with some attention to the network complexity. The simulation results meet the objectives of this paper which aims to enhance the throughput value based on the best-CQI algorithm. It also shows that this algorithm is suitable to be used for any density on the road which is also one of the paper objectives. Generalizing the concept of the LTE-V schedulers to be used in MIMO and Massive-MIMO networks is the future work of this study where a lot of RF signals are in consideration.

7 References

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