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Downlink Performance of Beamforming for High Mobility Users in 5G Cellular Network

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Abstract

5G cellular infrastructures are supposed to provide higher data rate and lower latency along with the prospects of other various novel applications. But the signal strength seems to fluctuate unexpectedly due to doppler shift resulting in negative impacts on downlink performance parameters over the network for high-speed users. One potential solution to overcome this problem can be the concentration of energy to a particular location using multiple antennas at the base station so that receiving power can be increased for the intended user while suppressing interferences from others. So, this paper has investigated the performance of beamforming with closed loop spatial multiplexing over a specific range of velocity of users. However, the simulation results also demonstrate that by scaling the number of transmitting antennas, beamforming can elevate average throughput, improve quality of service for cell edge users and ensure better spectral efficiency under any existing scheduler with no complexities involved in system designing. Moreover, through the estimations of the channel conditions obtained from the precoding matrix of closed loop spatial multiplexing, the strength of the transmitted signal can be amplified accordingly to improve mean throughput and minimize the bit error rate. Therefore, the proposed scheme of scaling transmitting antennas through CLSM along with beamforming seems to circumvent the repercussions of doppler shift on downlink (DL) performance of high velocity cellular users.

Keywords

5G, Beamforming, User Velocity, Closed Loop Spatial Multiplexing, Proportional Fair, Round Robin

1. Introduction

As the evolution of cellular technology faces a fast-track momentum, the need for newer and better technologies is more significant than before. The increasing number of User Equipment (UE) creates a greater demand for faster data services, which current technologies soon will not meet. In any case, today's information exchange emphasis is expanding to include a broader ecosystem outside the tradition. For cellular networks, restriction accessibility and spectrum reliability are two of the big problems. These challenges act as the catalyst for the improvements of technologies, which will enhance the capabilities of 5G communication and will soon open doors for 6G communication.

The data transmission is corrupted in cellular transmission networks by fading and interference. The advantages of diversity might be lost if the antennas are not spaced far enough apart. A singular antenna is used for transmitting and receiving in traditional wireless communication systems. Single-input-single-output (SISO) systems are examples of such systems [1]. In the case of, a traditional SISO system, one antenna is used to send one particular signal to a specific receptor; however, in the presence of a longer path, the signal becomes weaker due to multipath fading and absence of constructive interference. However, when incorporating beamforming (BF) in SISO, more energy concentration occurs, which provides a higher SINR for the signal. BF is a signal processing method before the actual propagation and receiving directed signals in a sensor array. This is done by sending multiple signals with the same phase relationship from multiple antennas directed to a specific receiver. Because of this directivity nature, BF also helps to reduce destructive interference [2].

The ability to enhance gain and directivity in desirable spatial coordinates while decreasing disturbance gains in unwanted directions makes antenna arrays (BF) appealing in cellular systems [3]. BF is the technology employed to steer the antenna so that the main lobe is directed towards the intended way to improve coverage. This way the side lobes or the auxiliary lobes number is decreased for better performance [4]. Due to the economical rate of phase shifters, analog BF is favored over digital when designing the apparatus. However, vice versa occurs when SINR remains constant. On the other hand, hybrid BF is promising, cost-effective, and dependable technology for 5G cellular infrastructure for its position to give more significant transmission speeds even with low bit error rates. Further in Switched beamforming, the user or system can choose between variously produced beams [5].

A distributed BF relay scheme with a single transmitter-receiver pair and several relaying nodes has been presented in [6], which aligns with our SISO network system. The investigators hypothesized that all relay nodes had perfect channel state information (CSI). It is also anticipated that there is a direct connection between the transmitter and the receiver and that each node in the network has its own power restriction. However, they did not consider multiple transmitters sending the same signal to a particular user, which we are going to use to create a SISO BF network in our study. The authors determined the BF weights to optimize the signal-to-noise ratio (SNR) at the endpoint while keeping the relay strength over a specific threshold level [7], covering two different beamforming network designs. They have created a comparative relation between SNR and transmitting power for beamforming, which will help to understand how SNR behaves in BF networks. The researchers have presented adaptive BF systems for micro and macro-cells [8]. In macro-cells, beamforming gains are restricted to almost 0 dB in the terminal grouping when several user channels contribute with identical directions and timeframes of arrival; however, when it comes to micro-cell networks with the increase in user, the result showed more robustness. This experiment is going to act as a guide for BF behavior in macro-cells. Considering LOS instances with modest velocity, the findings for massive MIMO performance are provided in [9]. According to the results found in [10], the user mobility increases, the average UE throughput under Proportional Fair (PF) and Round Robin (RR) scheduling methods downgrade due to Doppler shift. Furthermore, in PF cell edge throughput drops quickly as the UE mobility rises and eventually reaches null. On the other hand, RR slowly erodes yet can still handle a modest data flow at fast speeds. The authors of their study used both CLSM and OLSM techniques. The Doppler shift diminishes the UE's SINR, which impacts the scheduler's efficiency and, as a result, available bandwidth. Under the CLSM setup, the UE analyses and provides a CQI, RI, and a pre-coding matrix indicator (PMI) to the BS, allowing CLSM to have a better throughput gain. However, in their study, they did not use the concept of beamforming, so the idea of energy concentration was not present. The researchers in [11] suggest cooperative beamforming architecture for the BS antenna array and tilt angle modification. The research aims to maximize energy efficiency in multi-cell multi-user synchronized wireless systems by implementing an iterative solution based on fractional programming; however, there was no specification for mobility in users.

In this paper, we offer a straightforward approach to utilizing a tri-sector-tilted antenna system with spatial multiplexing and beamforming in a macro-cell network by changing the velocity of UE to improve the downlink network performance. We have decided to show a comparison of results between a traditional SISO and SISO with BF in our study. The proposed method will be able to solve the Doppler shift effect for high-velocity users.

In this study, the usage of ULA was tracked to produce directional beams [12]. To improve the efficiency of 5G networks and ensure better coverage using a higher frequency active phased antenna array with beamforming capabilities is desired. Using beamforming methods, significant gains may be attained that help to reduce wireless channel failures such as path loss, reduce entanglement and enhance spatial skills. It may be used in a variety of real-world settings, including radar, earthquake engineering, biomedicine, and sonar, where laser pulses have to be focused on a specific destination [13]. Additionally, the real-life problems of call drops and data loss for users who are currently far away from the base station (BS) can be solved through this, as the BF acts similar to line-of-sight (LOS), which creates a directional signal beam between BS and UE.

The rest of the paper is arranged as follows. In Section 2, various network parameters and network models are briefly described. A simulation model is discussed in Section 3. Simulation Results are analyzed in Section 4 and finally, the last section concludes the whole study.

2. System Model

2.1. Network Model

The network architecture consists of 19 base stations placed in hexagonal arrangement having inter base station separation of 1230 m. Additionally, the base stations are arranged in two tier with tri-sector antennas which are designed with the help of the Kathrein 742,215 antenna model [14]. Moreover, each cell facilitates 10 UEs (user equipment) resulting in total number of 570 UEs in the whole network. **Figure 1** gives a vivid illustration of network architecture.

2.2. Closed Loop Spatial Multiplexing (CLSM)

Through multiplexing, CLSM can split up the whole transmitting data into several independent data streams and send them over spatially separated antennas. A transmitter and receiver system ($T\times R$) can be represented by the following expression [10].

$$M \le \min(T, R) \tag{1}$$

where T is the number of transmitter antennas and R is the number of receiver antennas. Additionally, M is the number of data streams.

2.3. Beamforming

An antenna can be defined as a uniform linear array if the antenna elements are identical and placed in a uniformly spaced plane. Through beamforming, this array of antennas can be steered to send out signals to the specific desired direction. The weight adjustments of phase and amplitude of the signal at the individual antennas can make beamforming possible with various beam patterns. This phenomena can be represented by the following expression where w^H is the weight vector, a is array steering vector and $s(t)$ is the signal at the antenna [15].

$$y(t) = w^H \cdot a(\theta)\cdot s(t) \tag{2}$$

The various beam patterns have been illustrated in **Figure 2**. From there, it can be seen that the antenna gain, an important factor contributing to network performance, increases as antenna elements, N increases.

2.4. Resource Scheduling

Resource scheduling is used to allocate resources among different users in a cell with consideration of different criteria. Here, proportional fair (PF) and round robin (RR) have been adopted for simulation purposes.

The priority of a user can be represented by the following equation [10].

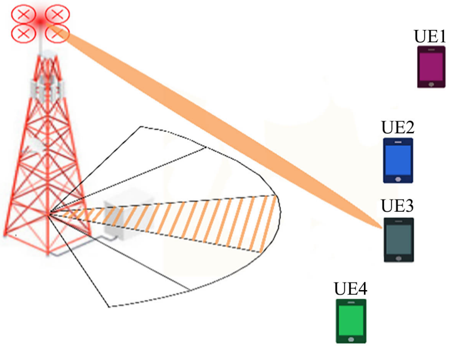

Figure 1. Proposed network architecture.

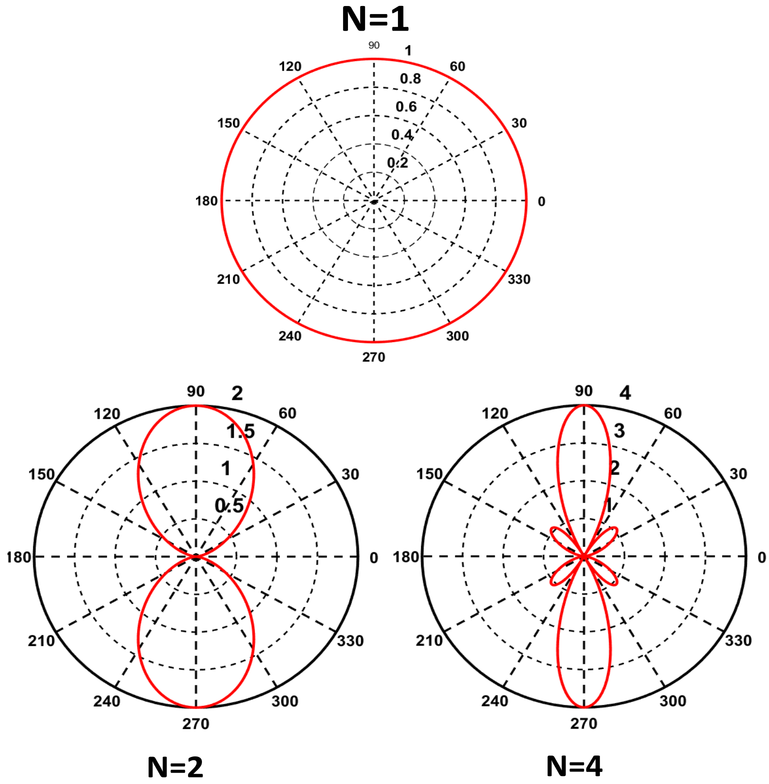

Figure 2. Beam pattern with gain for N = 1, 2, 4.

$$p = \frac{T^{\alpha}}{R^{\beta}} \tag{3}$$

Here, average data rate is defined by R whereas T is the throughput that UE can achieve. Furthermore, PF method implements $\alpha \approx 1, \beta \approx 1$ where UEs are prioritized based on SINR. On the other hand, RR allocates resources in a cyclic fashion, not depending on SINR and follows $\alpha = 0, \beta = 1$. An improved PF algorithm can also be utilized which represents average throughput, T_k by the following equation [16].

$$T_k\left(t+1\right) = \left(1-\frac{1}{t_c}\right)T_k\left(t\right)+\frac{1}{t_c}\sum_{S=1}^{S} R_{S,k}\left(t\right) \tag{4}$$

Here, throughput averaging time window is represented by t_c whereas the throughput of the user k is defined by $R_{s,k}(t)$ at sub band s. The value of t_c can be tuned to bring out an optimized trade-off between system capacity and fairness index.

2.5. Key Performance Indicators

Average UE Throughput

Due to channel condition fluctuations, UE faces ever changing SINR values which results in different values of throughput. Therefore, the average of throughput is usually considered for measuring the performance of the network. The average throughput of a UE, T_{avg} can be calculated following the equation given below where k^{th} user have total throughput of T_k where total number of users is n [17].

$$T_{avg} = \frac{\sum_{k=1}^{n} T_k}{n} \tag{5}$$

Peak Throughput

Peak throughput is the maximum throughput a UE can achieve under favorable RF condition. This throughput can be increased by carrier aggregation. This maximum value of throughput is available in small bursts during transmission activities. SU-MIMO technique shows excellent performance in increasing peak UE throughput.

Cell Edge Throughput

UE feels interferences from the surrounding cells while staying in the edge of the serving cell. Due to this, UE gets very low SINR and throughput sometimes. Usually, cell edge throughput can be found from the five percent of ECDF of UE throughput. It is very important to get continuous coverage in cell edge to get minimum throughput during handover for avoiding call drops.

Spectral Efficiency

The rate of transmitted data over a specific bandwidth defines spectral efficiency. If T_k is throughput for k^{th} user and specific bandwidth is defined by BW, then spectral efficiency, S maintains the following expression [18].

$$S = \frac{\sum_{k=1}^{n} T_k}{W} \tag{6}$$

Fairness Index

Considering fairness index, it can be determined how a UE is getting the resources. Jain's fairness index is utilized usually to examine the fairness among the users. This fairness index can be measured from the following expression for n users where T_k is the average throughput of k^{th} users [19].

$$J(T) = \frac{\left[\sum_{k=1}^{n} T_k\right]^2}{n\left[\sum_{k=1}^{n} T_k^2\right]} \tag{7}$$

3. Simulation Model

In this study, Vienna LTE system level simulator has been utilized for simulation purposes [20]. Both PF and RR have been implemented to analyze the network performance for 4 × 1 and 2 × 1 BF and Single Input Single Output (SISO) schemes under the impact of UE mobility ranging from 0 - 120 km/h. For integration of UE velocity, random walk has been adapted. Moreover, the simulation was done for transmission mode 7 and 1 for better presentation of the downlink performance improvement due to beamforming technique. The remaining simulation parameters are illustrated in **Table 1**.

4. Result and Discussion

In this section, the authors present a detailed analysis of the behavioral pattern of the KPIs under the impact of high UE velocity for CLSM enabled BF antennas 4 × 1 and 2 × 1 and SISO-1 × 1 antenna system to distinctly notice the DL performance of BF for high velocity users under PF and RR resource scheduler operation.

Declining response is observed for average throughput with UE velocity increment in **Figure 3** upon close observation it can be noticed that with higher number of TX antennas the decline in average throughput is reduced significantly for high velocity case. Implementing BF with higher number of TX antennas, the transmitted signal energy following multiple propagation paths can be diligently focused on a particular location, withstanding the adversaries of high velocity. In addition, the momentary estimations of the channel condition available from CLSM render it possible for the network to pack the steered beam with enough power to combat degradation before reaching the intended user. However, at high velocities, the antenna combinations of 2 × 1 and 1 × 1 operated under both PF and RR scheduler and 4 × 1 under PF scheduler have slight variation in throughput. This is because, at high velocity, the predominance of multipath fading impedes the radio signal quality and hampers signal propagation intermittently. The poor condition of SINR asserts a pronounced drop in throughput. Moreover, frequent and rapid changes in the doppler shifts of the multipath components and the transmitted signal make it challenging to provide accurate estimates on channel state conditions, thereby reducing the effectiveness of CLSM. Operated under RR scheduler, the antenna set 4 × 1 provides slightly decent throughput at high velocities. This improvement in throughput can be attributed to RR scheduler's SINR independent resource scheduling.

Users at the cell edge are susceptible to severe interference from the neighboring cells. BF reduces interference substantially by adding the unwanted transmitted signals destructively at the receiving terminals of unintended users. In **Figure 4**, BF antennas operated under PF scheduler at velocities below 40 kmph outperform the other antenna variations. At velocities greater than 40 kmph, cell edge throughput steadily decreases with the proliferation of UE velocity. At high velocities (above 70 kmph) the performance margin among all the

Table 1. Simulation parameters for network model.

Simulation Parameters	
Carrier Frequency	2.14 GHz
Bandwidth	10 MHz
Antenna combinations	4 × 1, 2 × 1, 1 × 1
Number of transmitting antennas	4, 2, 1
Number of receiver antenna	1
Transmission Mode	1 (SIS0), 7 (beamforming)
UE Velocity	0 - 120 kmph
Simulation time	30 TTI
Channel Delay	3 TTI
BS height	25 m
BS transmitter power	40 watt

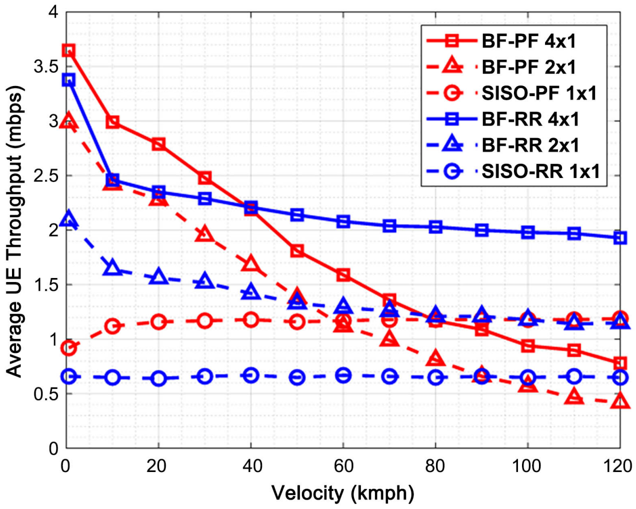

Figure 3. Average UE throughput vs. velocity.

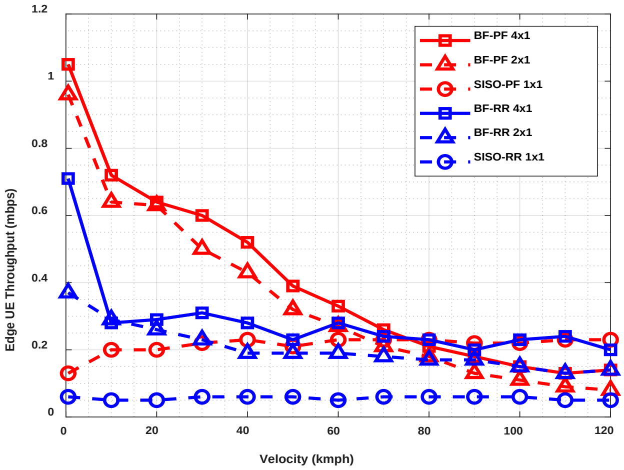

Figure 4. Edge UE throughput vs. velocity.

antenna variations is almost non-existent. Lack of accurate feedback from CLSM and rapidly degrading SINR at high velocities lead to poor throughput in the cell edge and handover is needed to be sought.

BF antenna configurations operated with RR scheduler provide fairly decent peak throughput in all velocities as shown in Figure 5. In fact, the antenna sets under RR scheduler maintain a more or less consistent throughput in all velocities although SISO under RR has the worst performance. The antenna sets 2 × 1 and 1 × 1 have slight fluctuations in all velocities while 4 × 1 maintains a constant peak throughput. For PF scheduler, rapid decline for antenna sets 4 × 1 and 2 × 1 and fluctuations for SISO antenna are found with increase in UE velocity. It is noted that under PF scheduler SISO provides better peak throughput than other antenna variations overall. From the observations, it can be deduced that with increase in number of transmitting antennas, reduced fluctuations and enhanced peak throughput can be achieved with RR scheduler.

Figure 6 illustrates the impact of mobility on spectral efficiency for BF antenna configurations. The simulation results indicate that utilization of the available spectrum improves under PF scheduler for velocities below 50 kmph as the Tx antenna increases from 1 to 2 to 4. But at higher velocities, antenna variations under RR utilize the spectrum by a good margin compared to their corresponding PF antenna sets. It can be anticipated that with further increase in Tx antennas, the spectrum utilization can be improved when operated under RR scheduler at high velocities and PF scheduler for low velocities.

In Figure 7, it can be clearly observed that PF ensures more fairness in assigning resources to the users that RR on every occasion. This is unexpected as RR scheduler is designed to prioritize fairness most while assigning resources. This anomaly can be justified as beamforming is a technology devised to provide a better quality of service to the targeted users disregarding fairness. The enhancement in network gain according to the feedback from CLSM combined

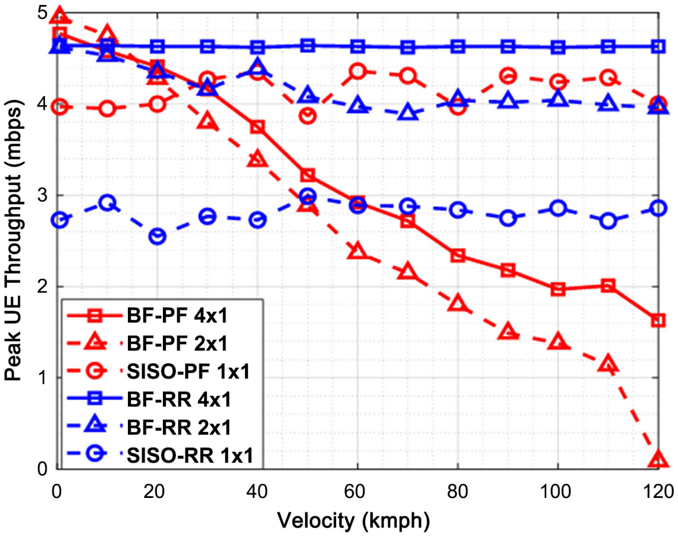

Figure 5. Peak UE throughput vs. velocity.

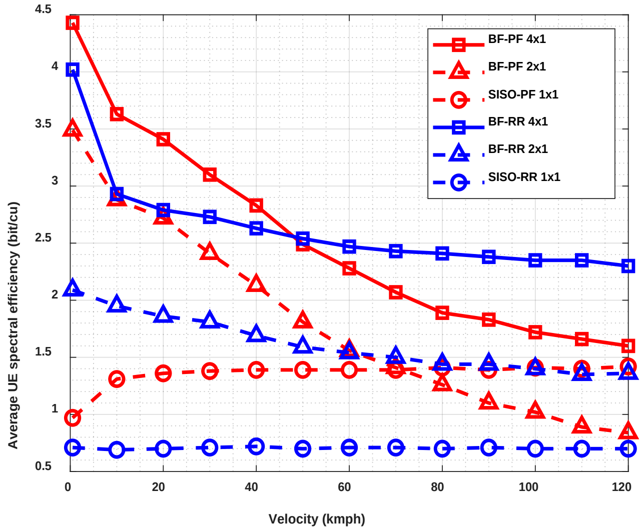

Figure 6. Average UE spectral efficiency vs. velocity.

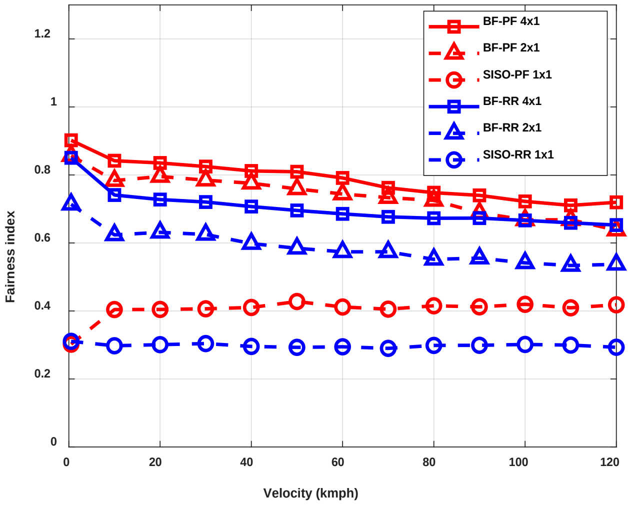

Figure 7. Fairness index vs. velocity.

with the concentration of the transmitted energy in the direction of the intended user can strengthen the radio signal links and the SINR of the targeted UE can be inferred to be high. As PF assigns resources based on SINR, the targeted UE is more likely to acquire the resources whereas RR scheduler allocates resources in cyclic order. This resource allocation friendliness of PF scheduler in BF technology enables the antenna variations under PF to provide better cell edge throughput at low velocities, as seen in Figure 4. As the channel distortion is less at low velocities, transmitted signals can reach the intended users distant from the BS.

From the discussion above, it can be deduced that by scaling the number of transmitters in beamforming antennas, the overall system performance for highly mobile users can be improved by several folds when CLSM is active and operated under RR scheduler and PF scheduler for low velocity users. Regarding fairness in assigning resources to users, PF scheduler triumphs over RR scheduler on every occasion which was not observed in other works where mobility was concerned. CLSM with diversity was proposed in [17] and fairness index was found to perform worse than round robin scheduler. Average UE throughput under PF and RR was less than 0.4 mbps for the velocity higher than 40 kmph for MU-MIMO scheme used in [19] whereas our proposed scheme gave us average UE throughput higher than 0.4 mbps for all combination except PF-2 × 1. Apart from these, mobility based investigations have also been done in other works such as [10] and [18]. But none of them integrate beamforming and did not investigate its performance in high velocity users.

5. Conclusion

This paper investigates the downlink performance of schedulers for beamforming for mobile users in 5G networks. The lossy condition of the wireless environment especially at high velocities adversely impacts the distribution of network resources. The authors of this paper adopted a novel approach to boost the network performance of beamforming at high velocity via CLSM transmission mode. Incorporating the feedback response of CLSM in PF and RR scheduler, the efficiency of beamforming enhances notably. Observed from simulation results SISO system where CLSM has not been incorporated seems to give the worst performance in all cases whereas increasing the number of transmitting antennas appears to provide better performance, especially in terms of spectral efficiency in both schedulers through CLSM. The results from simulations indicate that RR whenever used with beamforming provides optimum performance in high velocity cases and PF with beamforming for low velocity users. So, it can be proffered that scaling transmitting antennas through CLSM with beamforming can be an optimum choice to compensate for the degrading user throughput combating against the doppler shift providing enhanced gain and interference elimination. This scheme can open the door for a single user based direct transmission along with extension of propagation range. Furthermore, direct transmission can provide an opportunity for lower latency than before benefiting real time communication which is one of the objectives of 5G communication. A future direction for improvement of the proposed scheme is to design a hybrid scheduler that can operate like PF scheduler in low velocities and RR scheduler in high velocities.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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