Doppler Shift Effect with Non-Orthogonal Multiple Access Technology for 5G System

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Abstract. Non-orthogonal Multiple access (NOMA) is a 5G wireless connectivity technology. It aims to improve user (UE) service at cell edge (CE) by pairing with the UE at cell center (CC). User velocity is an important component of 5G communication systems. This paper investigates the presence of a Doppler shift effect (DSE) for the movement of a user in NOMA cell. Also, the emphasis in this search is on DSE for users (UEs) at the CC and on the user's velocity at 180km/h. The method used for the simulation, Link (LL) Level emulator for Vienna 5G. Through the NOMA principle, the results demonstrate that DSE was evident on the UE in center of the cellular network. When changing user's speed from 0 to 180 km/h, the user's efficiency changed from 4.937 Mbit/s to 0.6418 Mbit/s at transmitted Power of eNB equal 25dBm. In other expression, due to an increase in the UE's speed and DSE, the user's throughput decreases by nine times his efficiency at speed = 0 km / h. By increasing number of eNB antennas, MIMO (8X2) has achieved 4 times better user efficiency improvement than MIMO (2X2). The number of UE antennas is increased antennas to four and changing number of eNB antennas, MIMO (2X4) enables to maintain user's throughput at high speed and DSE. In this type of MIMO, the user's efficiency has reached a result close to that of UE when his motion is stationary.

Keywords: 5G, NOMA, MIMO, Doppler Effect, UEs, velocity.

1 Introduction

A large number of technologies have been specified for the 3G (3GPP) Partnership Project. This is aimed at achieving high data and high performance on mobile 4G systems [1]. Recent developments in the area of ICT (Information and Communication Technologies) have highlighted the current generation of wireless communication experiences. In future, smart things in intelligent homes, offices, streets and cities in the intelligent world are expected to be in the new generation [2].To meet these future communication requirements [3].

3GPP was a candidate for a 5G wireless communication system for submission to the International Telecommunications Union (ITU) of 5GNR new radio specification [4]. Along this development, 5G networks should support three major families of applications, including

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enhanced (eMBB) mobile broadband, massive machine (mMTC) type communications and ultra-reliable and (URLLC) low-latency communications. Multiple access (MA) schemes are being explored to meet these new requirements [5]. The approaches can be classified orthogonally and non-orthogonally in MA techniques. Signals from different UEs are not interference in orthogonal approaches, and they can be accomplished by time- division, frequency-division and orthogonal-frequency division (TDMA, FDMA, and OFDMA)[6]. Orthogonal multiple access (OMA) technology used in 4G, which is the basis for the work of Long-Term Evolution (LTE) networks, and in 5G this technology and non-orthogonal multiple access technology are used [7].

The proposal was made, and is extensively studied, NOMA. In contrast to OMA, NOMA superposes multiple symbolic data sources by distinguishing their transmission power [3]. Furthermore, when compared to OMA schemes, NOMA can greatly increase user fairness and spectral performance [8]. NOMA allows access to multiple users who share a block of resources, such as time and frequency [9]. The allocated resources are shared in NOMA where the channel is shared between users by coupling the user at CE (has weak signal) with the user near from eNB (has strong signal) i.e. using same bandwidth (BW). As for the orthogonal multiple access (OMA) technology, the bandwidth is divided by the number of users, thus sub-carriers are divided and the transfer efficiency of the cell decreases [8]. Technologies and new ideas are required to improve capacity and provide high data rates. Because of their ability to split a frequency selective channel into several narrowband flat fading sub-channels, OFDM (Orthogonal Frequency Division Multiplexing) has been widely used in multi-carrier wireless systems [10].

High mobility communications were taken into account as part of 5G communications [11]. Mobility is the mobile station's maximum speed which fulfills a defined Quality of Service (km/h). The successful mobility evaluation will meet the packet error ratio and spectral efficiency threshold for mobility (120 and 500) km/h [4].

It is worth mentioning that the supremacy of NOMA over OMA is the importance of high speed in 5G. Therefore, the researchers were interested in this technology and examined it. Also, they presented challenges and addressed problems facing users within NOMA technology.

2 Related Work

E. A Feukeu et al. [12] analyzed and designed a Direct Development Method (DDM) for combating the effect on the vehicle network of Doppler shift (DS). DDM shows that the best communication connection of two mobile phones moving up to 250 km/h is possible if taking the prescribed threshold into account.

P. Fan et al. [13] sought to present a survey of 5G high-traffic wireless technologies. A key aspect of the research is to develop an optimal cell association metric taking into account various factors such as signal quality, interference, traffic loads and mobility. Traditional association metrics supported signal strength, but the signal-to-noise ratio wouldn't be sufficient for the longer term 5G high mobility HetNets.

T. Levanen et al. discussed several issues in [14]. They discussed ways to obtain high-resolution location information on high-speed train networks. An example of a high-speed train system with a carrier frequency of 30 GHz, the estimate of Doppler distortion is examining.

T. Ahmed et al. proposed the generally power allocated system (GPA) for different users. The simulated BER performance of the wireless system for NOMA using different modulation techniques has similar results to other conventional GPA formulation validation schemes [10].

D. Feng compared the performance of different NOMA schemes through tapped delay line (TDL) channel with typical and high UE speed. The simulation results display that NOMA schemes have a better BLER performance than OMA under these channel assumptions. The high UE speed channel conditions of BLER for NOMA schemes are different from normal speed conditions [15].

H. Ahmad et al. analyzed the study of the performance of NOMA in comparison with OMA in pedestrian and vehicle environments. Also, the performance of users is evaluated. NOMA performed 50% better for CC users than OMA, while OMA outperformed NOMA 56% for CE users [16].

This enables better connectivity of the paired NoUEs of NOMA. S. Mounchili et al. proposed a new NOMA user pairing program based on the user's distance [17]. Also, a common energy allocation strategy was subsequently proposed, which takes the conditions of its user channel into account. Around 80 percent of users have been paired with NOMA from the simulation results.

D. Deshmukh et al. [18] provided algorithm to allocate resources based on the resource block technique. The resource block provides the power allocated (PA) as per the user demand. It usually suppies equal power to all types of UEs. The simulation uses MATLAB software. The results show that the proposed approach is better than OFDM and the existing NOMA. The proposed approach achieves a 50% greater sum rate in terms of power and a 20% higher sum rate in terms of NoUEs.

B. E. Y. Belmekki et al. [19] studied performance and interference of vehicle communications (VCs) with the NOMA. They also compare VCs performance at crossings, roads and demonstrate that VCs performance at crossings is worse than on highways. VCs are also compared. Monte-Carlo simulations validate all the analysis results. The Doppler Effect appears when the user’s speed increases. This effect is in the throughput of UEs.

In this paper, NOMA is used to improve throughput for UEs and ensure their service at high speed. A NOMA downlink scenario for users with varying speeds is used. In addition, we show the effect of high speed on user efficiency in terms of the Doppler Effect. This paper focuses on the users at the cell center because they are most affected by the Doppler.

3 NOMA AND DOPPLER SHIFT

3.1 NOMA

The NOMA idea is presented toward future improvements of spectrum efficiency in lower frequency bands for downlink of 5G system [6]. When two users are paired by pairing methods in [20]. In NOMA system, the Superposition Coding (SC) is deployed at the transmitter and the Successive Interference Cancellation (SIC) is performed at the receiver [17],[21],[22],[23],[6]. NOMA techniques can mainly be divided into two categories, namely, code-domain NOMA and power- domain PD- NOMA [21]. in this paper, we focus on PD for DL. Power allocation takes into account two system preferences; users’ fairness and users’ QoS requirements. In order to make sure that all users are fair, UEs are ordered under channels; users with bad channel gains are assigned higher power levels and those with good channel gains are allocated less power levels [22].

3.2 DOPPLER SHIFT

The Doppler shift (DS) on the received signal will lead to a discrepancy between transmitter and receiver frequencies, and this is called carrier frequency offset (CFO). It should be noted that, even for systems without DS, small CFO may also occur due to the instability of oscillators in wireless transceivers. In multi-carrier systems such as OFDM, CFO will destroy the orthogonally among the subcarriers, and introduce inter-carrier interference (ICI). The performance of OFDM systems is seriously degraded by ICI. In addition, since the DS in high mobility systems change with respect to time, the CFO is time-varying, which is difficult to track and compensate[11].

This section addresses the Doppler shift effect (DSE) and related issues, one of the most challenging issues in the 5G network. Specifically, DE causes two problems, Doppler frequency offset (FO) (or CFO) and fast fading. Due to the movement between transmitter and receiver, the carrier frequency of the received signal will be shifted from its original value as shown in Fig. 1. [13]

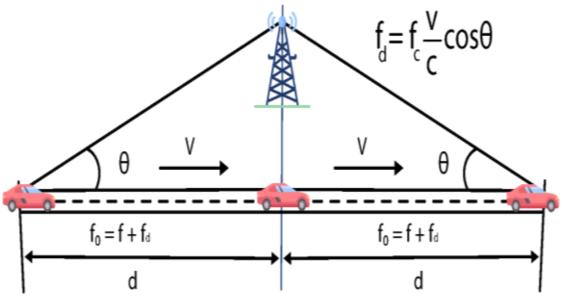

Fig. 1. Doppler effect.

The Doppler shift in frequency can be written as

$$f_d = \pm f_c \frac{V}{C} \cos\theta \ . \tag{1}$$

Where f_d is the change in source frequency seen on the receiver, fc is the source frequency, V is the difference in velocity between transmitter and source, C is the speed of light and θ is the angle of speed vector. The frequency change is maximum if θ=0. The OFDM symbols are extremely sensitive for this change. The change in frequency is also known frequency shift [12].

4 Methodology and Simulation results

The LL simulator uses to show DSE on user throughput. The simulation model contains four users. Two users in the CC called near-users, and two users in the CE called far-users. The pairing used in a NOMA cell is of the different channel gain types. The emulator supports types of Doppler models, namely (uniform, discrete Jake, Jake). The Jake type is used when the user's velocity is greater or equal to zero. The distance between UE and eNB is determined by path loss (PL) per link between them. The PL for the UE1, UE2, UE3 and UE4 is (80, 90, 100, 110) dB respectively.

In this section, the results obtained with the NOMA scenario LL simulator are reviewed. It also includes how the problem is noticed and how to treat it. The simulation shows the DE when high mobility for UE.

4.1 Change the velocity of UEs and DE (Doppler effect)

The velocity of UEs was altered from (0-36-72-108-144-180) km/hour as exposed in Table (1) with some transmitter and receiver antennas fixed to the number two (MIMO (2X2)) in each change for the velocity of UEs.

Table 1. The simulation model parameters.

parameter	value
Doppler model	Jake
TxPower eNB	43 dBm
Center frequency	2.5 GHz
MIMO	(2x2)
Velocity	0, 36km/h, 72km/h, 108 km/h ,144km/h, 180km/h
Bandwidth channel/subcarrier spacing frequency	1.4 MHz / 15 KHz
NOMA receiver	Minimum Mean (MMSE) Square-Error
Estimation channel model	Approximate-Perfect

The following Figures (2), (3), (4), (5), (6), (7) show the relationship of the eNB station's transmission power with the user's throughput in NOMA technology. The user moves at different speeds (0-36-72-108-144-180) km/h when moving a pedestrian and in a vehicle. Figure (2) shows that when UEs’ speed is zero, the movement is stationary, there is no DE (no fluctuation) in the user's throughput.

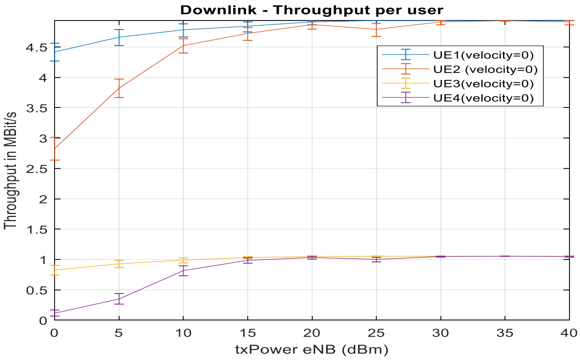

Fig. 2. Throughput of UEs when velocity=0

DE appears when UE speed increases, as exposed in Figures (3, 4, 5, 6, 7). For near users from eNB, their efficiency decreases and fluctuates. In far away, the speed of the users does not affect them due to the user's distance from the eNB station that makes the speed change relatively and has little effect. It can be seen that the DE is not only on efficiency fluctuation but also affects the amount of transport efficiency of users close to eNB.

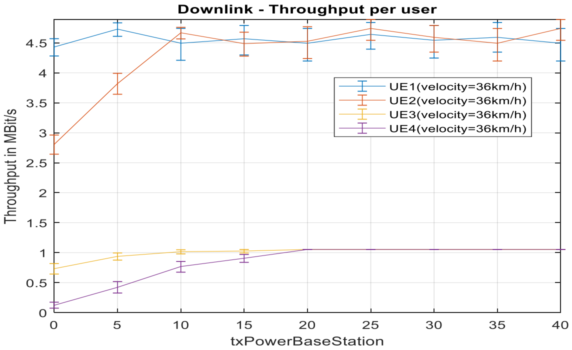

Fig. 3. Throughput of UEs when velocity=36 km/h

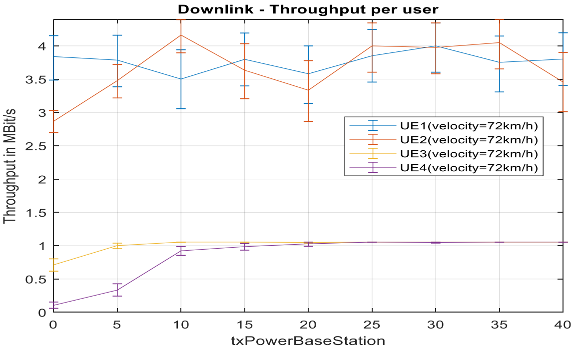

Fig. 4. Throughput for UEs when velocity=72km/h

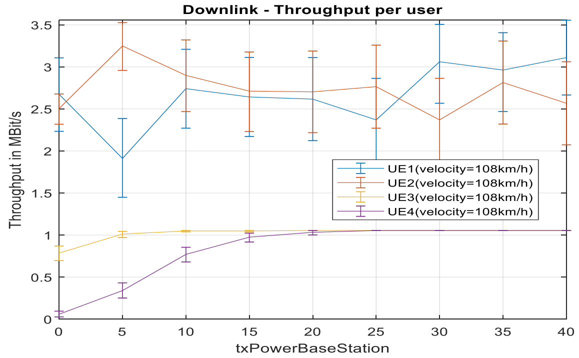

Fig. 5. Throughput for UEs when velocity=108km/h

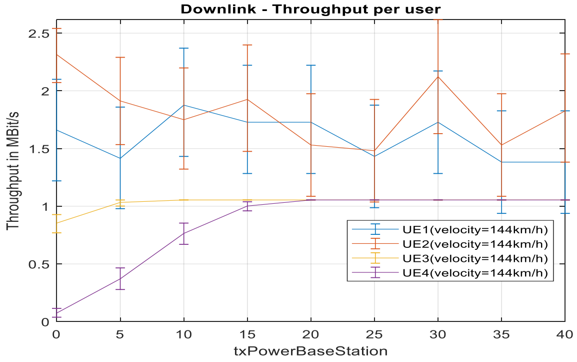

Fig. 6. Throughput for UEs when velocity=144km/h

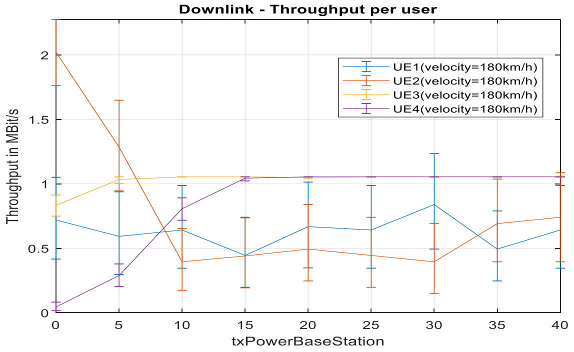

Fig. 7. Throughput for UEs when velocity=180km/h

From the previous results, it is clear that the Doppler effect appears strongly on users near the station. So the focus is on the results of nearby users who have a strong signal. The results of the first user are examined to show the effect. The DE observed as shown in Fig. 8. The problem of the first user has appeared. The same means the case for the second user then the Doppler is reduced on the whole NOMA cell.

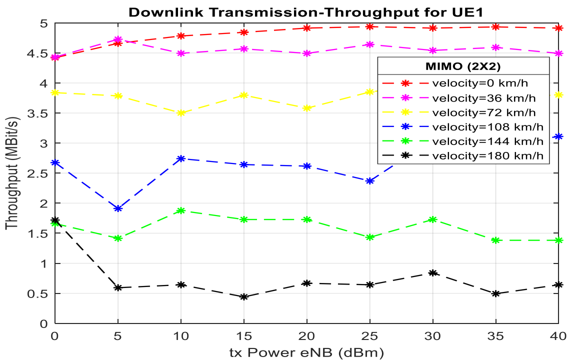

Fig. 8. Throughput for UE1 in different velocity

4.2 Increase the number of eNB antennas

It is proposed to increase the number of eNB antennas and indicate its effect on the transmission efficiency of the UE1. The number of eNB (NoeNB) antennas varies at different speeds for users shown in Table (2). The use of the same parameters which displayed in Table (1).

It is worthy of attention that the NoUE antennas are two and fixed. Different speeds were taken for each type of MIMO.

Table 2. The antenna numbers at the user's side equal two.

parameter	value
Number of user	4users (2user in CC , 2user in CE)
MIMO	(2x2),(4x2),(8x2),(16x2)
velocity	36km/h ,72km/h,180km/h

Figure (9) shows that when using MIMO (2X2), the first user near eNB suffers from DE at different speeds

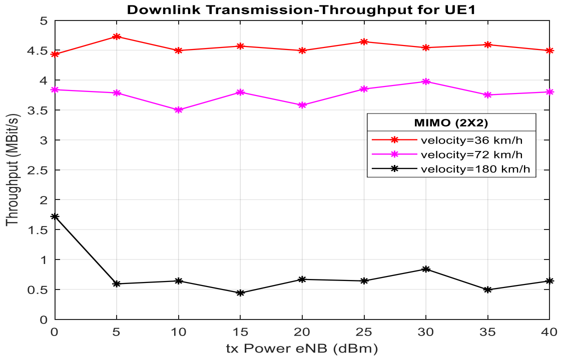

Fig. 9. relationship between txPowereNB and throughput using MIMO(2X2)

Figure (10) shows a noticeable improvement by reducing DE at velocity UE = 36, 72 km/h. In both Figures (11) and (12), DE is reduced by 100% at a user speed of (36, 72) km/h. It is interesting to see in the four figures (9), (10), (11), (12) that increasing the number of eNB antennas from 2 to 4 showed a decrease in DE at the user's speed (36, 72 km/h). However, when increasing the number of eNB antennas from 4 to 8 to 16. The DE doesn't reduce at the user's speed (180 km/h).

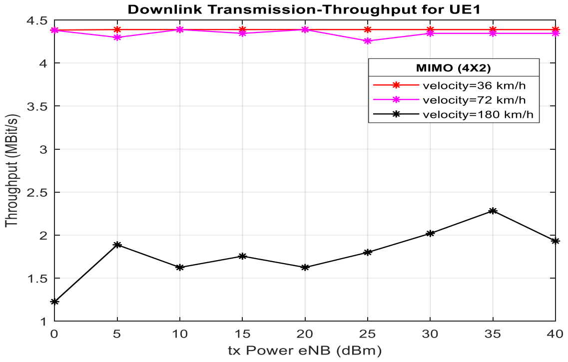

Fig. 10. relationship between txPower and throughput using MIMO(4X2)

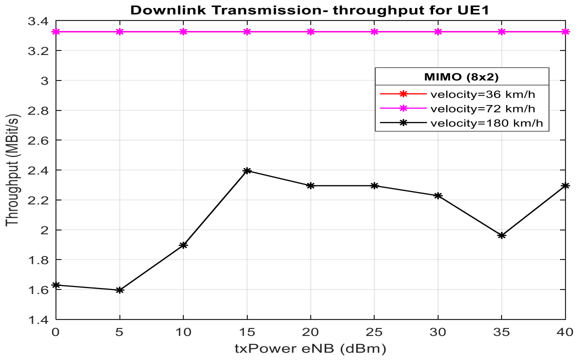

Fig. 11. relationship between txPower and throughput using MIMO(8X2)

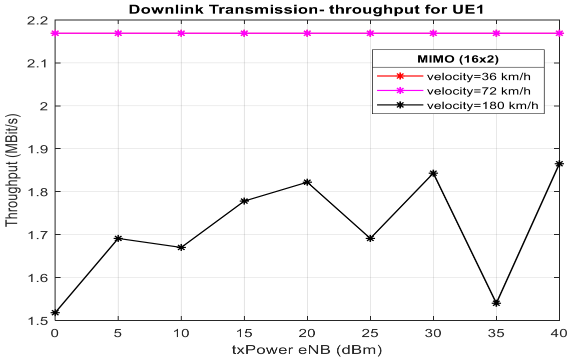

Fig. 12. relationship between txPower and throughput using MIMO(16X2)

In the previous Figures, the DE is observed. Figure (13) shows the value of the UE transmission efficiency by altering the user speed (36, 72, 180) km/h. The efficiency of the first user observed at txPower eNB = 30dBm for the different numbers of eNB antennas.

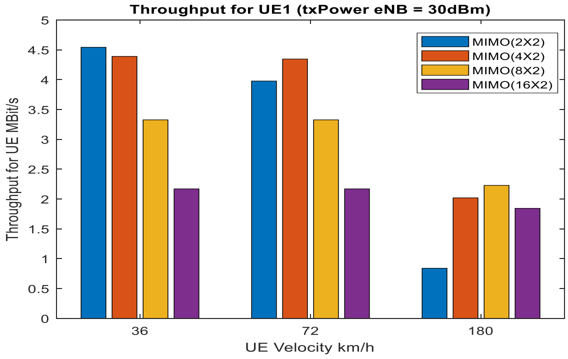

Fig. 13. compare throughput UE1 between different MIMO and different velocity

It is worthy that a user's efficiency is 4.542Mbps when used MIMO (2X2) and a speed equal to 36 km/h. Also, the efficiency decreases by 0.566Mbps at 72km/h. When increasing the speed to180km/h, the throughput decreases by 3.7027Mbps compared with 36km/h. In other words, the user's transmission efficiency is 4.345Mbps when used MIMO (4X2) and a speed equal to 36 or 72 km/h. At a speed of 180km/h, its efficiency is reduced by 2.326Mbps.
The UE’s efficiency in MIMO (4X2) is less than MIMO (2X2) at 36km/h by a little 0.153Mbps. But at 72km/h, it is 0.369Mbps higher than MIMO (2X2), and the cause for the decrease and increase is the DE.

The decrease in user efficiency was also observed at MIMO (8X2) and (16X2). The DE is improved, but the cost is user efficiency. Therefore, it suggested increasing the number of UE antennas to four.

4.3 Increase the number of receiver antennas

The same constraints of Table (1) use with the parameters in Table (3). The number of UE antennas fixed to four. Besides, the number of eNB antennas varies (2-4-8-16) antennas.

Table 3. The antenna numbers at the user's side equal four.

parameter	value
MIMO	(2x4),(4x4),(8x4),(16x4)
velocity	36km/h ,72km/h , 180km/h

The users' speed is 180km/h to see the effect of MIMO on Doppler at this speed. Figure (14) shows the DE for the user at 180km/h with changing the number of eNB antennas. Very little DE was observed at MIMO (2×4). Despite the increase in txPower, a user efficiency decrease in MIMO (4X4), (8X4), (16X4) due to the occurrence of ICI.

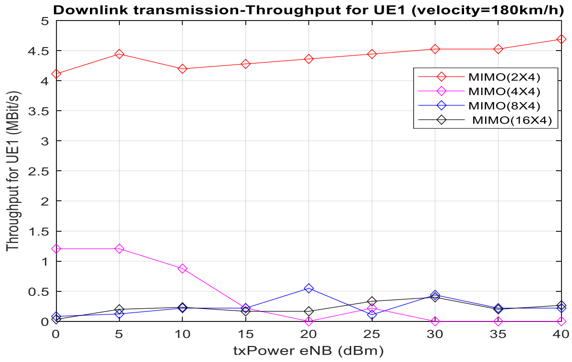

Fig. 14. Throughput UE1 using different MIMO and velocity=180km/h

4.4 Compare MIMOs for various sending and receiving antennas

Figure (15) shows a comparison of the DE for both MIMO (8X2) and MIMO (4X4). There is an effect on both but in terms of user service by eNB MIMO (8X2) is better than MIMO (4X4). At txPowereNB = 25dBm, MIMO (8X2) is more user-efficient (2.0756 Mbps) than MIMO (4x4).

Figure (16) compares the DE for the first user between MIMO (2x4) and MIMO (4x2). MIMO (2X4) achieved a UE transfer efficiency (2.644 Mbps) more than MIMO (4X2) at txPowereNB = 25dBm.

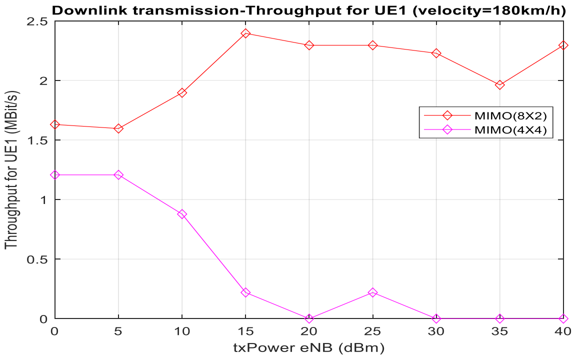

Fig. 15. Compare MIMO(8X2) and MIMO(4X4) in term of Doppler effect

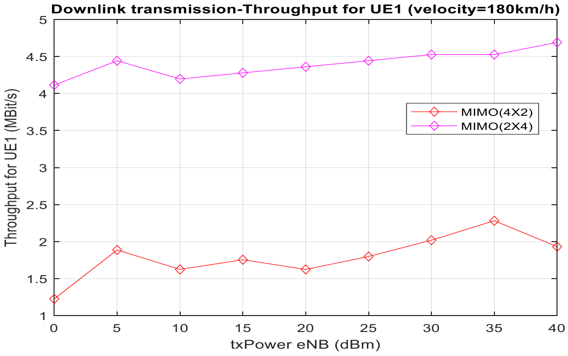

Fig. 16. Compare MIMO(4X2) and MIMO(2X4) in term of Doppler effect

A comparison was made for MIMO between speed and user efficiency at txPowereNB = 30dBm shown in Figure (17). In MIMO (4x4), a user efficiency at speed 36km/h (7.607Mbps). When increasing UE's speed to 180km/h, there is deterioration in the user service as his efficiency drops to 0.1Mbps. Same case in MIMO (8x4), (16x4).

At 180km/h, the user efficiency MIMO (2X4) increases by 4.1266, 4.0871, and 4.426Mbps over MIMO (4X4), (8X4), and (16X4) respectively.

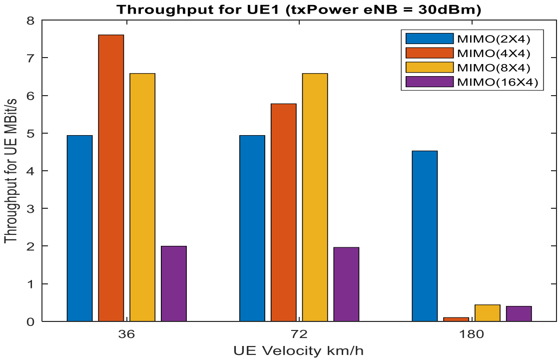

Fig. 17. Relationship Between throughput UE1 and velocity for different MIMO

5 CONCLUSION

In this section, simulating a NOMA scenario in the LL simulator is used to evaluate users 'performance at high speed. DSE appears when the user moves at a certain speed (user speed may be in a pedestrian or vehicle). The results show the DSE on NOMA technology, for users at CE at high speed, the fluctuation caused by the DSE reduced due to the limited space in which the user wanders at his speed. As for users in CC, the DSE was very high at high mobility. Thus, this affects cell efficiency which is dependent on the principle of NOMA technology. To maintain the permanency of the user's service in the cellular network, it proposed to increase the No. of eNB antennas from 2-4-8-16 antennas. DSE was reduced at speeds less than 180 km/h. At 180 km/h, the impact was evident despite the increased No. of eNB antennas. DSE addressed a speed equal to 180 km/h by proposing to increase the No. of UE antennas from 2 to 4. The simulation results express that MIMO (2X4) has better user efficiency performance than MIMO (4X4), (8X4), (16X4) at 180km/h. That is, MIMO turned out to be one of the ways to treat the DSE.

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