A Novel Latency Reduction Scheme for SIC based NOMA Systems

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Abstract- Non-Orthogonal Multiple Access (NOMA) is being researched as a critical technology in fifth generation (5G) mobile systems. Successive Interference Cancellation (SIC) has been an efficient detection scheme for NOMA systems. Non-orthogonal nature of signals with variation in their power levels could be best exploited by SIC detection to detect signals. However latency (delay) occurs in detection as users are detected in descending order of their power profile. Latency has been an impediment in the way of SIC for its practical implementation in NOMA systems as there could be thousands of devices attached to a single cell site. In this paper a dynamic SIC detection scheme has been proposed which not only decreases the latency manifold but also reduces the bit error rate (BER) to a great extent.

Keywords- NOMA Systems, Multiuser detection (MUD), SIC, OMA.

I. INTRODUCTION

Conventional Orthogonal Multiple Access (OMA) schemes like CDMA and OFDMA, could not accommodate a large number of users in different 5G scenarios such as Machine-to-Machine (M2M) communications and Internet-of-Things (IoT)[1-3]. Moreover spectral efficiency of OMA schemes is low as bandwidth resources are divided among different devices including devices with low CSI (channel state information) and there could be upto 1 million devices in a 5G scenario. It has also been observed that OMA schemes could not exploit the channel capacity to the optimum level[4-5]. In contrast to conventional OMA, NOMA can accommodate a large number of users which in turn increases the system throughput. It has also been shown in [4-5] that NOMA is more spectrally efficient in comparison with OMA. Moreover NOMA scheme could achieve the capacity region of multiple access channels up to the optimum level. NOMA could be made compatible with the different communication systems easily without any major modification. The two key features of 5G are its low latency (below 1ms) compared to 10 ms in fourth generation (4G) mobile systems and data rate of 10 Gbps. Several NOMA schemes have been investigated in recent years[6-7]. NOMA scheme can be broadly classified into two categories, namely power-domain NOMA and code-domain NOMA. NOMA is fundamentally different from OMA schemes where we do not have to transmit data on orthogonal subcarriers (OFDMA). NOMA has been classified into two major categories, power-domain NOMA and code-domain NOMA. In power-domain NOMA, each user operate simultaneously in the same band like CDMA but differentiated by their power levels. In code-domain NOMA users are differentiated by non-orthogonal codes unlike CDMA where orthogonal codes are used. Superposition coding is used in NOMA to differentiate different users at the transmitter end [8]. It has been observed that superposition coding at the transmitter end and SIC detection at the receiver end in NOMA, outperforms the conventional OMA schemes in terms of optimally achieving the capacity region [9].

SIC detection is employed in power-domain NOMA systems to detect signals of different users [1-7]. Direct demodulation methods can also be employed in NOMA but that method will introduce error propagation whereas in case of SIC there are no errors if signals are received with sufficient SNR (signal to noise ratio). Moreover for SIC detection power levels of the signals can be quite close which is not the case with direct modulation methods. Performance of SIC could be achieved upto Shannon capacity provided perfect channel estimation is there [10-14]. But SIC detection has following drawbacks.

- Latency, as users are detected in a successive manner.
- If the power profile of users changes in the middle of detection, the users need to be rearranged again according to their power levels.
- Also, sometimes it may happen that two or more users may have equal power levels/channel conditions, which becomes difficult for the detector to arrange the users according to their power levels.
- If any error occurs during SIC process, it will propagate to successive steps.

In this work a novel detection scheme based on multiple SICs is presented in which SIC detectors are dynamically added based on the number of users in the cell site in uplink. In this proposed system non-orthogonal signals of different users are received by multiple SIC detectors in the uplink. In this scheme number of SICs which are connected to the receiver depends upon the number of users in the cell site. It is a novel scheme as SICs are added dynamically according to the number of users in the cell site.

The methodology and contribution of this research paper has been listed below:

- In this work a NOMA detector with 3-SIC has been compared with 2-SIC NOMA detector and 1-SIC NOMA detector. It has been observed that latency could be reduced to a great extent with the multiple SIC based NOMA detector.
- To select the number of SICs, an algorithm has been designed which selects the total number of SICs to be connected to the NOMA detector on the basis of total number of users in the cell site.
- BER could also be reduced to a great extent with this proposed scheme.
- Spectral efficiency could be increased with this proposed scheme.
- This scheme could be effectively implemented for IoT networks as we know that there could be thousands of users/devices in an IoT network.
- This scheme is very simple and could be easily implemented in the uplink.
- Latency problem of NOMA detectors has not been addressed earlier as per our knowledge.

Section II presents the earlier work on SIC detectors and NOMA systems. BER analysis of SIC detector has been done in section III. Proposed system model has been described in section IV. Simulation and results have been presented in section V. Results shows that proposed method not only reduces the latency and BER to a great extent, but also enhances the spectral efficiency of NOMA systems. Conclusions have been discussed in section VI.

II. RELATED WORKS

The work on SIC detectors has been extensively done, but work on latency reduction in SIC detection has been considerably low. In [9], it has been demonstrated that spectral efficiency performance of NOMA is much better than OMA. We know that successive interference cancellation is a very efficient technique when users are received with different power levels. Moreover channel estimation is not required in SIC detection [10-12]. In [13-14], performance of SIC has been analyzed for CDMA and Multicarrier CDMA (MC-CDMA) and it has been demonstrated that SIC is an efficient technique in wireless environment affected by white Gaussian noise and multipath interference, but issue of latency has not been addressed. In [15] a scheme is proposed where users are grouped into single or multiple clusters on the basis of channel gain differences among users, in order to enhance the throughput of the system. In [16], a triangular SIC (T-SIC) concept was used to enhance the performance of NOMA systems but it does not addresses the core issue of latency in SIC based NOMA systems. In [17], a new scheme has been proposed to combat error propagation in SIC based NOMA systems but it introduced more complexity and at the same time latency of the system has not been reduced. Similarly in [18], a concept based on code division multiplexing has been applied on SIC based NOMA to increase the system throughput but nowhere it has addressed the issue of latency. In [19], a power back-off scheme is investigated to enhance the performance of uplink NOMA system.

III. BER ANALYSIS of SIC

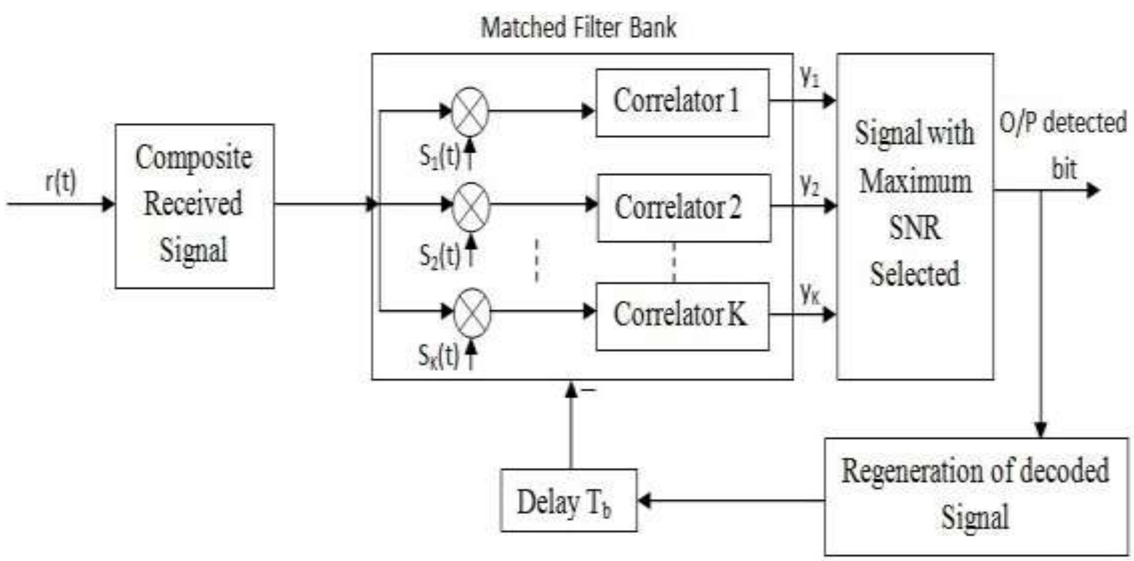

Fig.1 SIC Multiuser Detector

Fig. 1 shows the SIC multiuser detector, where orthogonal signals are detected by different correlators by multiplying the composite signal with different spreading codes [10-12]. In SIC, users are arranged in descending order of their power level and users are cancelled serially with strongest user first and weakest user in the last. The estimated bit of user *j* is given as

$$\hat{b}_j = sign\left(y_j - \sum_{k=j+1}^{K} A_k \rho_{kj} \hat{b}_k \right) \quad (1)$$

The BER of K[th] user for matched filter in CDMA based Gaussian channel can be given as [9]

$$P_K(\sigma) = P[b_K = +1]P[y_K < 0 | b_K = +1] + P[b_K = -1]P[y_K > 0 | b = -1]$$

$$= \frac{1}{2^{K-1}} \sum_{e^1 \in \{-1,1\}} .... \sum_{e_j \in \{-1,1\}} .... \sum_{e_K \in \{-1,1\}} Q(\frac{A_K}{\sigma} + \sum_{j \neq K} e_j \frac{A_j}{\sigma} \rho_{jK})$$

$$P_K(\sigma) = Q(\frac{A_K}{\sqrt{\sigma^2 + \sum_{j \neq K} A_J^2 \rho_{jK}^2}}) \quad (2)$$

Where A_K is the amplitude of user *K* bit, σ is the background noise (white Gaussian noise) and ρ is the cross-correlation between successive users and Q is a monotonically decreasing error function.

Similarly BER for SIC can be given as [20-22].

$$p_k^{SC}(\sigma) \approx Q(\frac{A_k}{\sqrt{\sigma^2 + \frac{1}{N}\sum_{j=1}^{k-1} A_j^2 + \frac{4}{N}\sum_{j=k+1}^{K} A_j^2 P_j^{SC}(\sigma)}})$$

BER if number of users are finite

$$P_k^{SC}(\sigma) \approx Q(\sqrt{\frac{E[y_k]^2}{\text{var}[y_k]}}) \quad (3)$$

$$E[y_k]^2 = A_k$$

where *E* is the expected value of y_k

and var[y_k] is the variance, which can be given as

$$\text{var}[y_k] = [\sigma^2 + \frac{1}{N}\sum_{i=2}^{K} A_i^2](1+\frac{1}{N})^{k-1} - \frac{1}{N}\sum_{i=2}^{k}(1+\frac{1}{N})^{k-i} A_i^2$$

where *N* is the spreading factor

It can be observed from equation (3) that if term var[y_k] is increased then BER for SIC detector is decreased. It implies that users are to be received with a large difference between their power levels (SNR) for lesser BER. This is the basis of our research work. In this work, variations in power levels of users has been exploited to design a robust NOMA detector in the uplink to reduce the latency as well as BER.

IV. PROPOSED SYSTEM MODEL

Equation (3) implies that if variation in power levels of users is large then an optimum BER performance can be achieved. The proposed system model shown in Fig. 2 is based on this concept. In this model matched filter outputs are given to dynamic separator which arranges all the outputs into descending order of their power levels. Dynamic separator then distributes these outputs to the attached SICs in a successive manner i.e. strongest user to the 1st SIC, next strongest to the 2nd SIC and so on. After the last SIC, next user is connected to 1st SIC again and this process is repeated till all the outputs are connected. The biggest advantage of such an arrangement is that now there is a large variation between power levels of adjacent users as they are connected to different SICs and as a result, users connected to a single SIC have a large difference between their power levels in this scheme. This is a dynamic scheme which can be made adaptive according to the system requirement. The sequence of steps for allocating the users to different SICs are as follows.

1. Calculate the number of users connected to dynamic separator.
2. Calculate the number of SICs required to maintain the required latency ($\mathcal{T}_L$) and the required minimum threshold power level difference (δ_P) between two adjacent users to maintain the desired BER.
3. Assign users one by one to all SICs in a successive manner.

Latency ($\mathcal{T}_L$) and and threshold power difference (δ_P) could be set according to the system requirement. Fig. 3 shows the flow diagram of the proposed scheme.

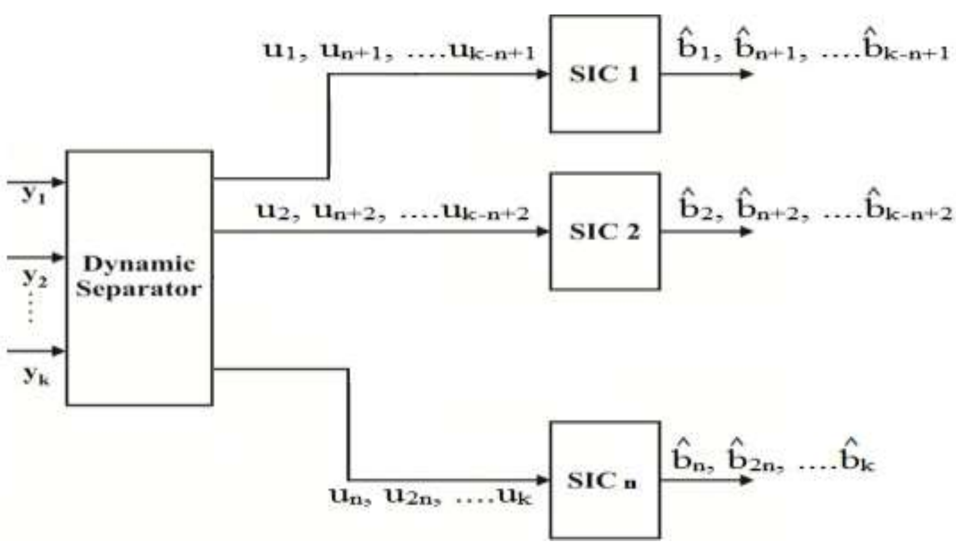

Fig.2 Proposed SIC based NOMA System

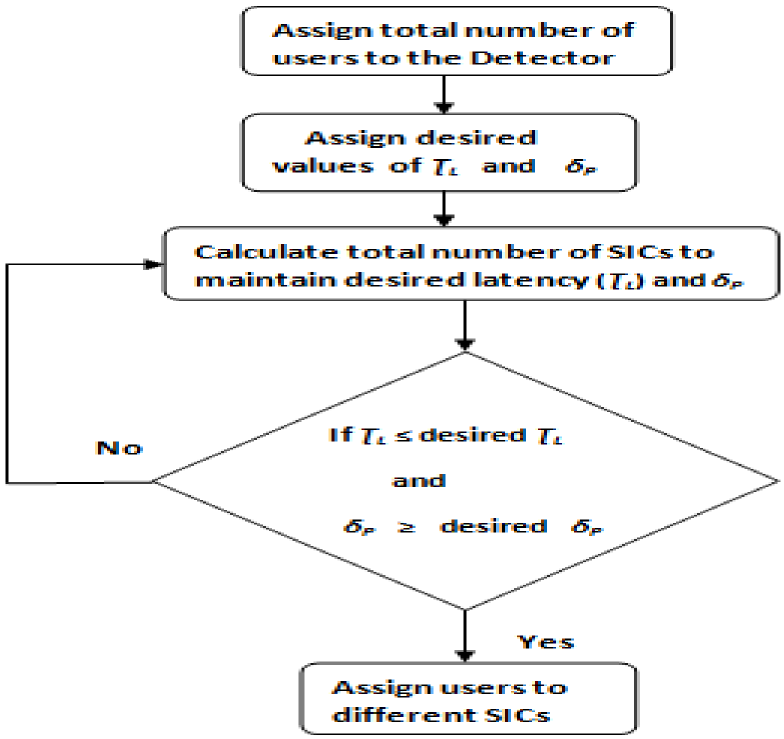

Fig.3 Flow diagram of proposed scheme

Fig. 4 (a) below shows the latency when a single SIC is used. It can be observed from the Fig. 4(a) that latency of the system is in linear relationship with the number of users. So in a scenario where data is transmitted at the rate upto 10Gps (5G networks), such a latency could not be tolerated. Moreover when number of users increases latency also increases. Fig. 4 (b) shows that when 3 SICs are used, latency of the system reduces to 1/3 with our proposed scheme. This scheme is very much feasible in the uplink where more number of SICs could be added according to the requirement.

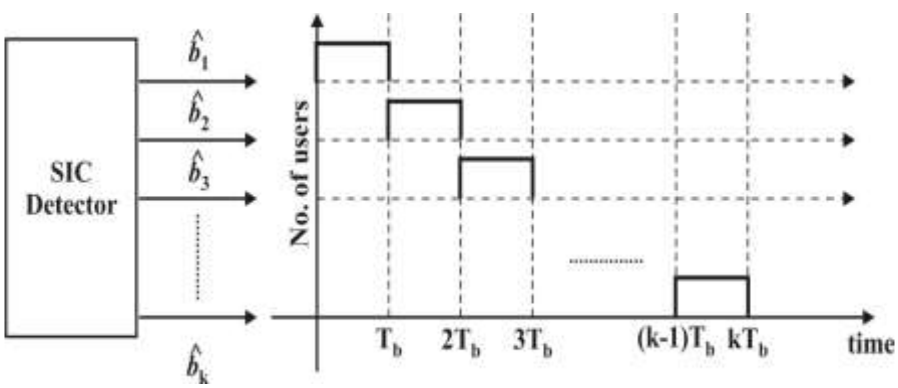

Fig 4(a) Latency using one SIC

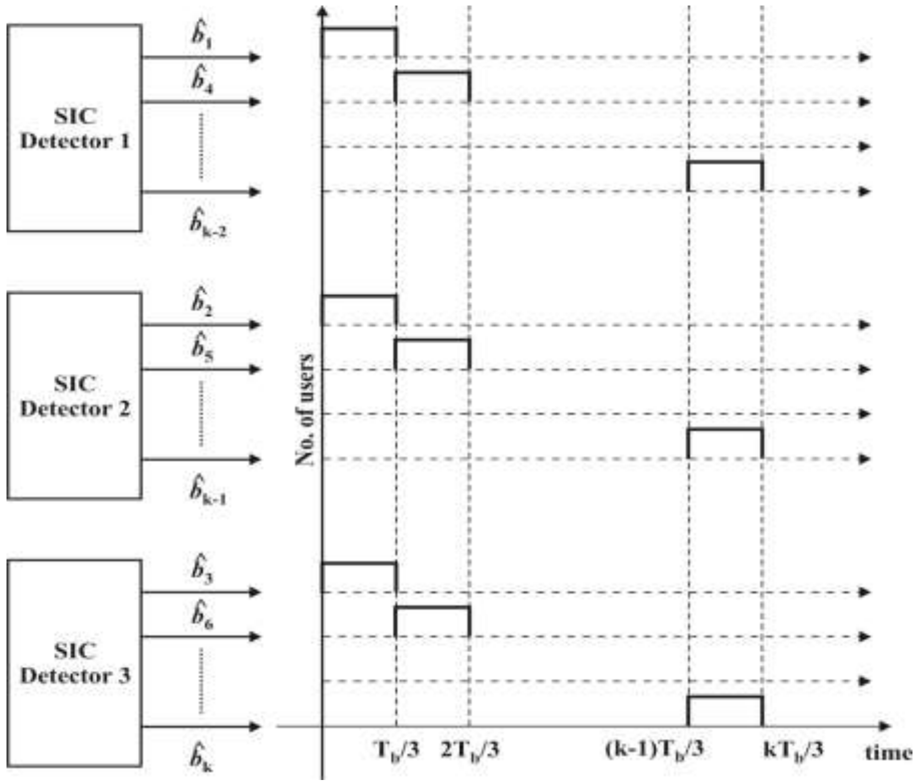

Fig. 4(b) Reduction of latency with multiple SICs

V. SIMULATION

In this scheme an uplink NOMA scenario is created with one single base station (BS) with K users U_i, with $i \in \{1, 2, ..., K\}$. It is assumed that independent and identical (i.i.d) additive white Gaussian noise (AWGN) and rayleigh fading is present in the channel. The channels are arranged as $0 \le |h_1|^2 \le |h_2|^2 \le ... \le |h_i|^2 \le ... \le |h_K|^2$

Where h_1, $h_2, ...h_K$ are channel gains.

The BS allocates power (a fraction β_i, where $\beta_1 + \beta_2 + \beta_3 + ...\beta_K = 1$) of total power to each user. It may be noted that in this scenario a strong user (with better channel condition) gets a lower transmit power and weak user (with poor channel condition) is assigned more power. In the uplink SIC is performed at BS. The strongest user is decoded first as described earlier also and in the next stage decoded signal is subtracted from the received signal according to equation (3). The composite received signal can be given as

$$y = h_1 \sqrt{p\beta_1} S_1 + h_2 \sqrt{p\beta_2} S_2 + ...h_K \sqrt{p\beta_K} S_K + w$$

here user U_i is having signal S_i and transmits with power $p_i = \sqrt{p\beta_i}$, w is the AWGN with zero mean and variance (σ). Modulation used is 16-QAM (Quadrature Amplitude Modulation). Desired latency T_L is taken as 1 ms and desired δ_P is 4 dB.

We have taken four parameters for performance evaluation viz; BER performance, outage probability performance, throughput performance and power spectral density (PSD) performance.

BER Performance:

BER performance of NOMA systems has been observed by taking different number of users (16, 32 and 64) and different number of SICs. Fig. 5 shows the BER performance for 16 number of users, Fig. 6 shows the BER performance for 32 number of users and similarly Fig. 7 shows the BER performance for 64 number of users. BER performance is compared by taking one SIC, two SICs and three SICs. It can be observed from all three figures that BER reduces as number of SICs are increased in a NOMA system. It happens because with the increase in number of SICs in a NOMA system, power difference (δ_P) between successive users becomes large which in turn reduces the BER according to equation (2). Moreover with the increase in number of SICs, latency of the system decreases as there are lesser number of users attached to a single SIC. It can also be observed that with the increase in number of users, BER increases as it can be seen from Fig. 7 that BER is higher in comparison with Fig. 5 and Fig. 6 as in this case there are 64 numbers of users attached to a single SIC, two SICs and three SICs. It can be clearly observed that when more number of SICs are employed, both latency and BER reduces to a great extent.

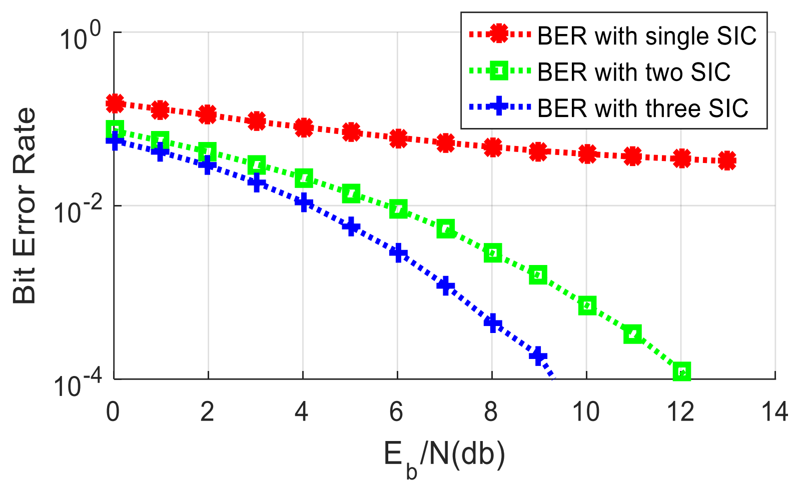

Fig. 5 BER Performance with 16 users

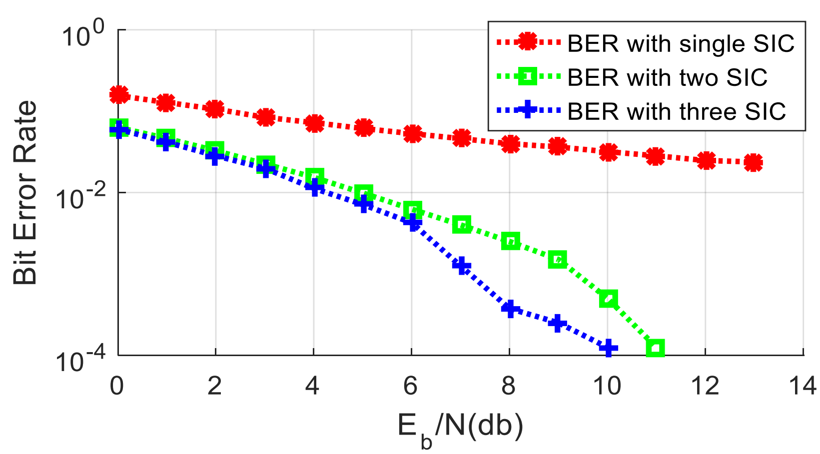

Fig. 6 BER Performance with 32 users

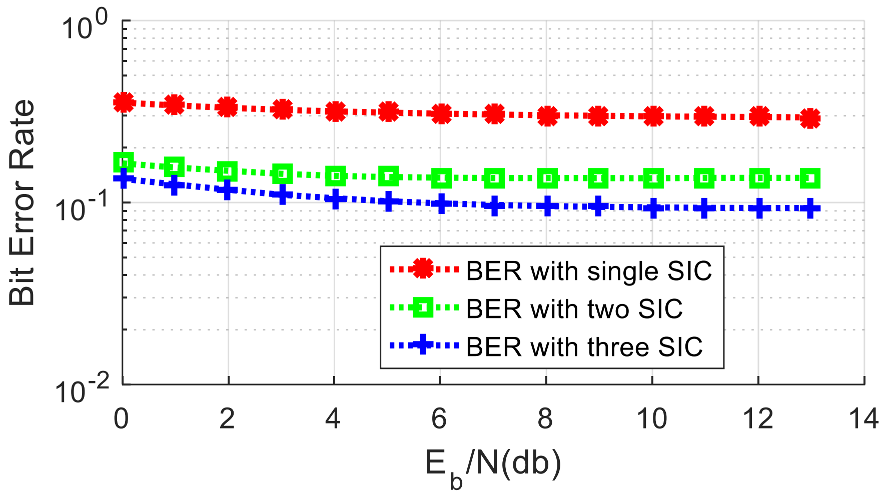

Fig. 7 BER Performance with 64 users

BER performance of single and multiple SICs is again tested with scatter plots as it can be seen in figures below. Scatter plot displays different dots and if dots are concentrated around its original constellation points, are equal distance from each other and fit perfectly in the frame then it is assumed that bits are received at the receiver with minimum error. In this case 64 number of users are taken. It can be observed that dots are closely packed in Fig. 10, in comparison with Fig. 8 and Fig. 9. So it is again validated that BER and latency reduces if multiple SICs are employed in the uplink.

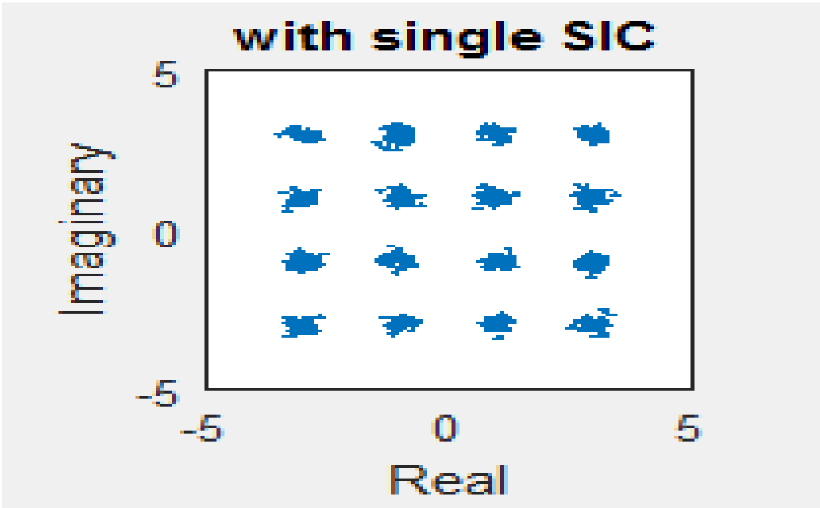

Fig. 8 Scatter plot BER Performance with single SIC

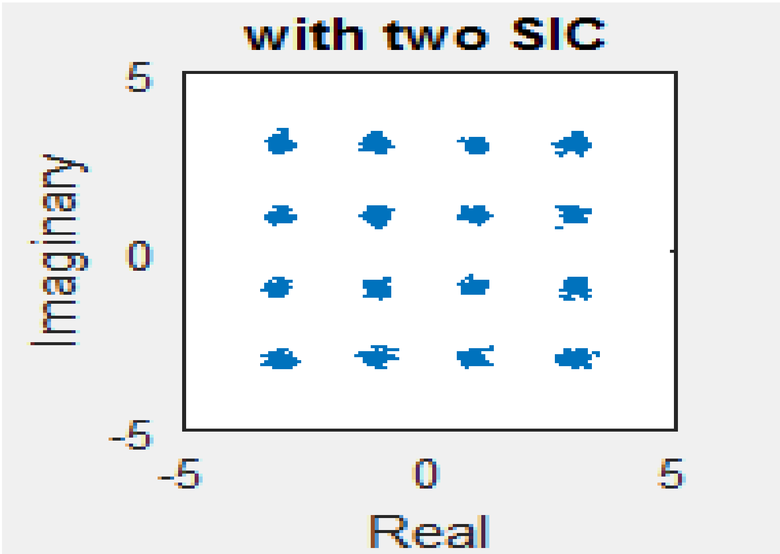

Fig. 9 Scatter plot BER Performance with two SICs

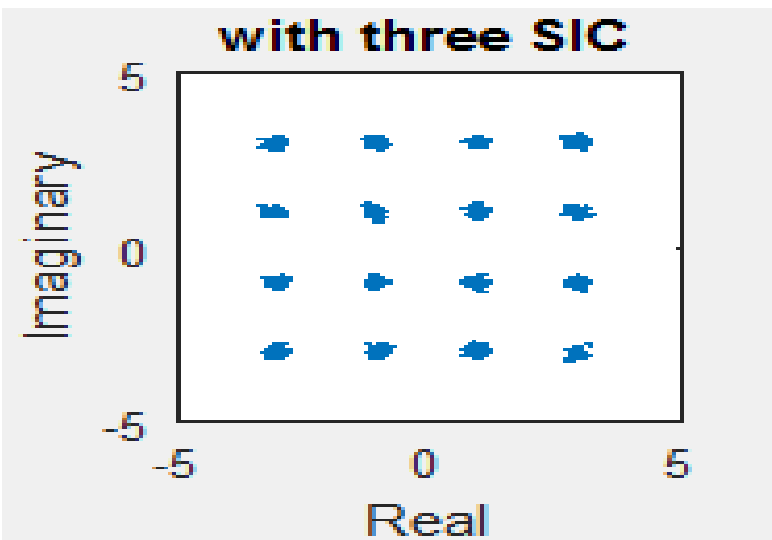

Fig. 10 Scatter plot BER Performance with three SICs

Outage Probability Performance:

Outage probability is another performance parameter which is used for quality of service requirements [1-5]. The outage probability for i^{th} user can be given as

$p_i^{og} = \frac{\tau_i}{i}\eta^i(\Psi_i^*)$, where $\tau_i = \frac{K!}{(i-1)!(K-i)!}$

where K is number of users

symbols η and Ψ_i^* represents the complexity-accuracy trade-off (which depends upon radius of cell site R_D) and the maximum SNR corresponding to data rate of i^{th} user, respectively. In this case 6 randomly deployed users are taken with R_D = 90 m. The value of η is taken as equal to 8.

The total transmit power is 16 watt and noise power is equal to -40 dBm. In this case one weak user with targeted data rate 0.2 BPCU (bits per channel use) and one strong user with 0.8 BPCU is taken. It can be noted that in worst case outage probability is always equal to one. In this case outage probability performance has been taken jointly for all the users. It can be observed from the Fig. 11 below that NOMA system with three SICs gives excellent performance. It has already been observed in earlier work on NOMA that it outperforms OMA in terms of outage probability performance [1-5].

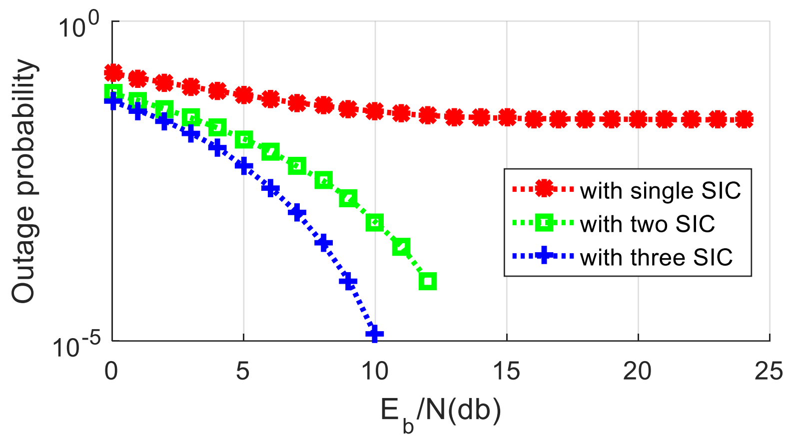

Fig.11 Outage Probability Performance

Throughput Performance:

In this case number of users taken is equal to 64 and all other parameters are same. It can be observed from the Fig. 12 below that NOMA system with three SICs is having higher throughput in comparison with NOMA with two SICs and single SIC NOMA. So it can be seen that multiple SICs based NOMA system exhibit high throughput capacity.

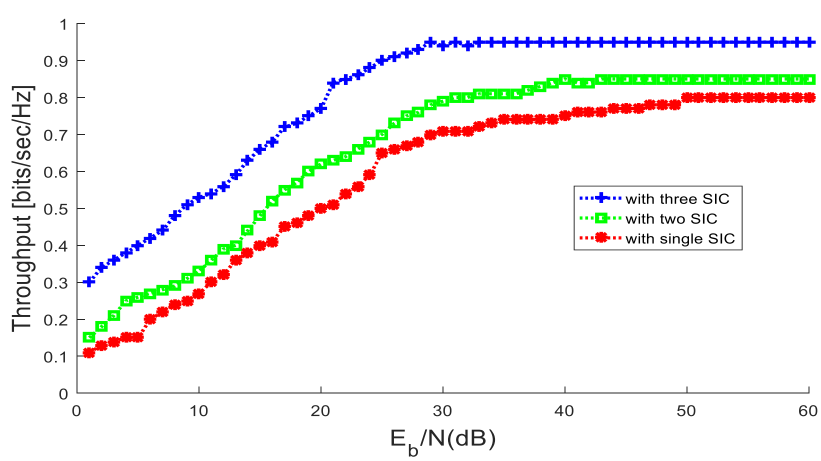

Fig. 12 Throughput Performance

Power Spectral Density (PSD) Performance:

All the figures shown below gives the PSD performance of NOMA with three SICs, two SICs and a single SIC. In this case again 64 number of users are taken. It can be clearly seen that that there is a long spike of pulse in case of two SICs NOMA and single SIC NOMA, which indicates that signals are received with error. It can be observed that in Fig. 13, there is no spike pulse and in Fig. 15 spike pulse is long as it is a single SIC NOMA. In Fig. 14 spike pulse is shorter in comparison with Fig. 14, as it is a two SICs NOMA.

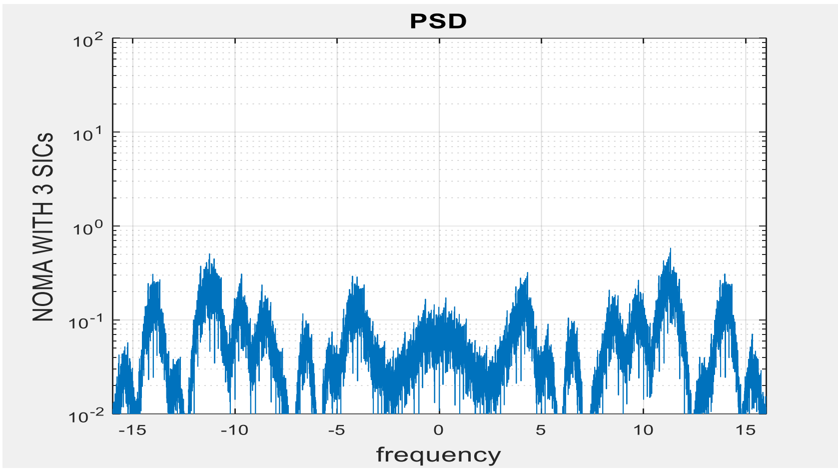

Fig. 13 PSD Performance with 3-SIC NOMA

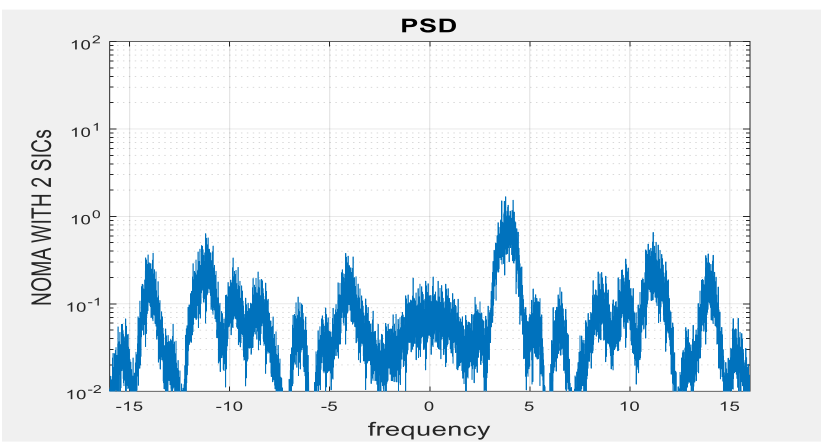

Fig. 14 PSD Performance with 2-SIC NOMA

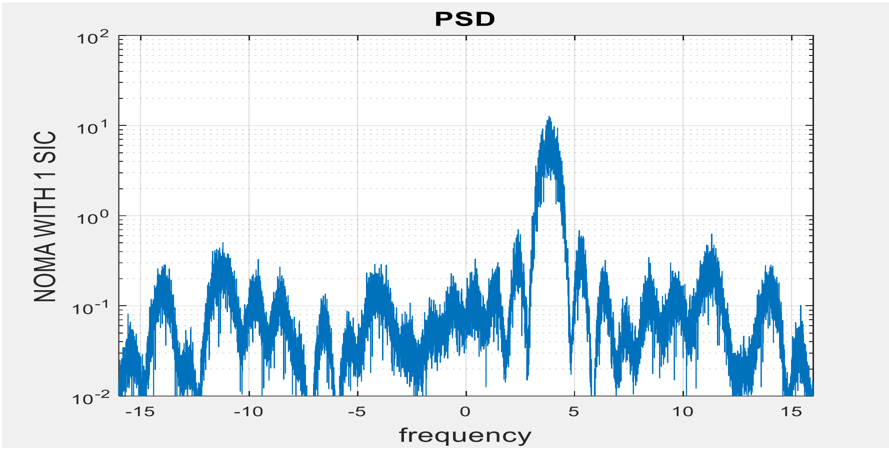

Fig. 15 PSD Performance with 1-SIC NOMA

VI. CONCLUSION

Simulation results show that latency and BER of power-domain NOMA could be reduced to a great extent with our proposed scheme. The ambiguity of the users having same power levels can also be resolved as adjacent users are attached to different SICs. Moreover with the reduction of latency, probability of change in power profiles of users in the middle of detection is also reduced. Propagation of error can also be curtailed with our proposed approach. This paper discuss, how multiple SICs can be used to reduce latency and BER as large number of SICs could be added dynamically in the uplink. Moreover multiple SICs NOMA system in the uplink could be employed for IoT networks as it could increase the capacity of a dense network. This work could be used as a platform to design next generation 5G networks.

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