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Quantization-Aware Greedy Antenna Selection for Multi-User Massive MIMO Systems

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Abstract—Using multiple-Input Multiple-Output (MIMO) configuration is not new in the field of wireless communication to increase the capacity of the system. This configuration is still valid to use nowadays with the modern wireless configuration such as the Fifth generation (5G). Massive MIMO is the key resource of the 5G systems due to its huge ability to increase the capacity of the network and on the other hand its ability to enhance both spectral and transmit-energy efficiency. The need for using Massive MIMO comes from the increase in using smartphones, tablets, and the rise of the Internet of Things. This increasing demand for the use of wireless applications requires networking and Internet infrastructures to meet the needs of current and future multimedia applications which massive MIMO satisfies. The key limitation of using massive MIMO is the cost of installation of these antennas and how to multiplex between them. In addition to this, the Radio Frequency (RF) links are also increased where this increase leads to high system complexity and hardware energy consumption. Because of this, reducing the required number of RF chains is essential to use by performing antenna selection which this paper aims to evaluate without significant performance loss which can be performed by employing low-resolution Analog-to-Digital Converter (ADC) to select an antenna with the best tradeoff between the additional channel gain and increase in quantization error. In this paper, Quantization-Aware Greedy Antenna Selection (QAGAS) algorithm has been proposed and compared with other antenna selection algorithms especially simple algorithms like random selection and Fast Antenna Selection (FAS) algorithm. The achieved capacity is compared with that of a very simple scheme that selects the antennas with the highest received power. The system capacity obtained from QAGAS is evaluated related to the transmit power of the Base Station (BS) and the quantization bits used in the low-resolution ADC. The simulation is also performed for a different numbers of users served by the BS and with the number of antennas at the BS. The simulation results show that the proposed algorithm indicates a potential for significant reductions of massive MIMO implementation complexity, by reducing the number of RF links and performing antenna selection using simple algorithms.

1. INTRODUCTION

The increasing demand for the wireless applications with the large number of users who need to be served with a high data rate is a key feature of modern wireless communication such as Fifth Generation (5G) [1]. Using a large number of antennas which can reach tens or hundreds of antennas at the Base Station (BS) to serve many users in the same network with the same time-frequency resource is a great physical BS development nowadays which is called Massive Multiple-Input Multiple-Output (MIMO) configuration [2]. Using the MIMO concept in wireless networks is not new to enhance the spectral efficiency of the system [3], but using the Massive configuration of MIMO can improve the spectral and transmit-energy efficiency of conventional MIMO by multiples of magnitude. Because of this, Massive

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MIMO is currently considered a leading technology of the 5G networks [4, 5]. The most challenges that Massive MIMO faces are high system complexity and hardware power consumption.

Massive MIMO is a system that uses sub-6 GHz which is considered nowadays an important physical-layer innovation for future wireless communication [6]. The fundamental idea is to utilize a high number of receiving antennas fixed at the BS as represented in Figure 1. This figure shows that the use of massive MIMO makes the serve of hundred of users in the network is applicable with high data rate.

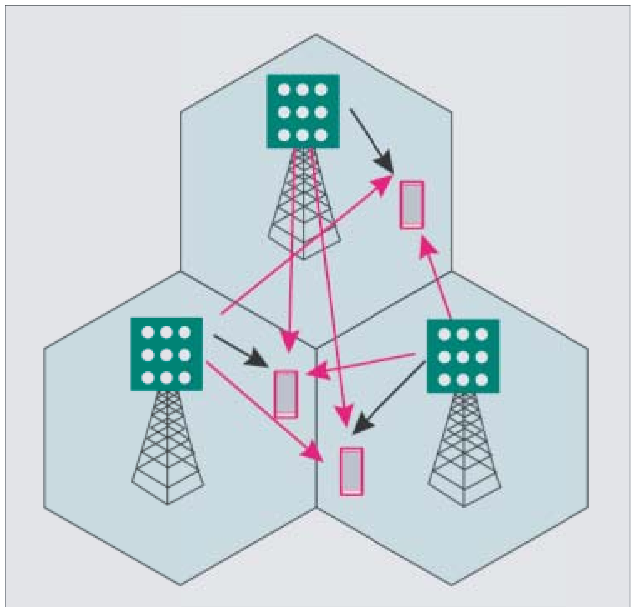

Figure 1. Massive MIMO configuration.

One of the advantages of using multi-user MIMO which is shown in Figure 2 is the scalability and the attractive solutions that it gives.

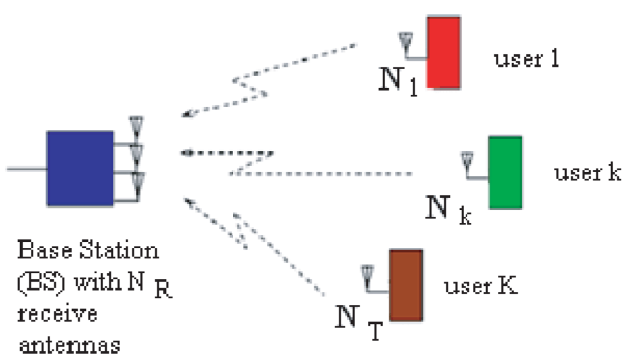

Figure 2. Multi-user massive MIMO.

It can increase the capacity of the system by serving several users at the same time with less interference [7, 8] because of the short wavelength used. This can increase the capacity that the point-to-point configuration gives. The second importance is that it gives flexibility to special separation of the BS antenna configuration to minimize the interference [9].

For massive MIMO, a few parameters should be mentioned and take into consideration when building the network [10]. One of them is the number of Radio Frequency (RF) channels used to transmit data to serve many users in the network while the second one is the configuration of the antennas at the BS and the precoding methods used to decrease the error rate and enhance the spectral efficiency [11, 12]. Then again, regardless the above limitations, two important issues should be taken into consideration which determine the suitable number of transmit antennas to use which means the need of optimization methods to determine this number, called antenna selection methods, and the need of channel estimation methods to enhance the received symbols and simplify the complex calculations.

In simple words, the Inter-Channel Interference (ICI) appeared due to the high number of antennas used and the Inter-Antenna Synchronization (IAS) [13] which appeared because of the encoded strategies used to synchronize the receiving antennas transmission.

There are many techniques used to overcome these issues and have the advantages of using massive MIMO configuration especially the high data rate, high capacity, and the enhancement of spectral efficiency [14, 15].

These techniques can be used in directive beamforming and LoS communication with spatial multiplexing procedures [16] and as using efficient antenna selection algorithms especially because in many cases, the antennas do *not* contribute equally to the overall system capacity enhancement.

The question here is how to optimize the antenna used without decreasing the capacity of the system with no additional complexity process. To answer this, there are several algorithms used to optimize the antenna selection such as the fast antenna selection, random antenna selection, and greedy algorithm. The most important issue for all these algorithms is to ensure that there is no additional complexity process [17, 18]. To satisfy this, a Low-Resolution Analog-to-Digital converter (ADC) at the BS is applied. A generalized hybrid architecture is developed with a small number of RF links and a finite number of ADC bits to have a trade-off between the capacity and power consumption for different numbers of bits and RF chains. The current paper proposes a bit allocation method for multi-user massive MIMO systems under a power constraint using a Mean Square Quantization Error (MSQE) minimization problem. In this paper, we explore reduced-connectivity radio frequency (RF) switching networks for reducing the analog hardware complexity and switching power losses in antenna selection (AS) systems [19–21]. A low-resolution ADC is developed by using quantization-aware antenna selection algorithm to evaluate the capacity performance of the multi-user massive MIMO compared with fast antenna selection and a random one.

This paper generalizes the concept of the quantization-aware algorithm by using it with a greedy antenna selection algorithm to take the advantages of greedy algorithm capacity and the advantages of the low-resolution ADC base station. This algorithm is called Quantization-Aware Greedy Antenna Selection (QAGAS) and compared with the Quantization-Aware Fast Antenna Selection (QAFAS) proposed in the literature.

The rest of the paper is organized as follows. Section 2 describes the system model and methodology for the study. The simulation results of the proposed algorithm concerning transmit power and quantization bits when the numbers of antennas and users in the system are changed are analyzed and discussed in Section 2. The conclusion of this study and the illustration of some future works are given in Section 4.

2. SYSTEM MODEL AND METHODOLOGY

Figure 3 shows the proposed system model in this paper to evaluate the capacity of the proposed QAGAS of the massive MIMO system. There are M antennas at the BS and N users in the network. The selected antennas to be used are denoted by κ. The received signal r for the selected antenna κ can be calculated as:

$$r_\kappa = \sqrt{\rho} H_\kappa s + n_\kappa \tag{1}$$

where κ represents the selected antenna; H_κ is the channel matrix for the selected antenna with $\kappa \times N$ dimension; n_κ indicates the noise vectors; and ρ is the transmit power.

The capacity of the proposed QAGAS can be written as:

$$C\left(H_\kappa\right) = \log_2 \left| I + \rho\alpha D_\kappa^{-1} H_\kappa H_\kappa^H \right| \tag{2}$$

where D_κ is the diagonal matrix with entries equal to:

$$D_\kappa = \mathrm{diag}\left(1 + \rho\left(1-\alpha\right)\left\|f_{\kappa(i)}\right\|^2\right) \tag{3}$$

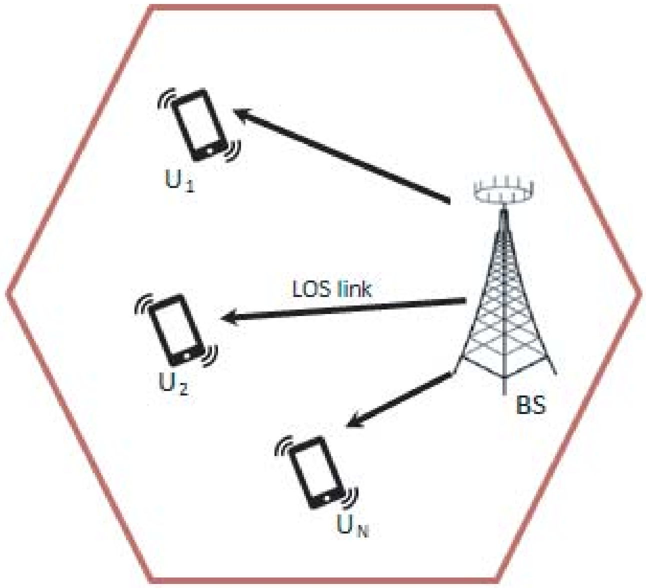

Figure 3. The system model.

where α is the quantization gain and calculated as $\alpha = 1 - \beta$ where β is the number of quantization bits used, $f_{\kappa(i)}$ the ith selected row of H, and i is between 1 and κ.

Algorithm 1 describes the QAGAS which starts from initializing the RF links from the N users in the network and computing the antenna gain with addition to the quantization gain after determining the number of quantization bits used in the BS. The algorithm selects the first antenna by determining the maximum channel gain that can contribute to enhancing the system capacity. The algorithm saves the antenna index and updates the channel. After some iterations, the capacity of the network is calculated using Equation (2).

Algorithm 1: QAGAS algorithm	
1.	Initialize number of BS antennas, Number of users
2.	Initialize Antenna gain, number of quantization bits.
3.	Start to select the antenna that contributes to maximizing the capacity.
4.	Saved the selected antenna index
5.	Repeat for other RF links.
6.	Go to step 4
7.	Calculate C by using Equation (2).

The simulation parameters which are used in this paper are shown in Table 1. The available bandwidth is 10 MHz with 64 and 128 antennas at the BS serving 10 and 20 users in the network. The selected antennas in this study varying among 10, 20, and 40 antennas. The noise distribution is Additive White Gaussian Noise (AWGN). The antenna selection algorithms used are the Fast Antenna Selection, Random Antenna Selection, and QAFAS algorithm proposed in [1].

3. SIMULATION RESULTS AND DISCUSSION

The proposed algorithm is evaluated here in this selection compared with the QAFAS algorithm simulated in [1]. The simulation is performed for BS antennas $M = 128$ and 64 and the number of users in the network $N = 10$ and 20. The channel has AWGN and a characteristic of Rayleigh channel with a zero mean and unit variance. The selected antennas' κ are equal to 10, 20, and 40 to

Table 1. Simulation parameters.

Simulation parameter	Values
Cell radius	2 km
Bandwidth	10 MHz
Carrier Frequency	2.4 GHz
# of the transmitter antenna	64, 128
# of users	10, 20
Noise	AWGN
Path loss coefficient	3
Mobile antenna hight	1.5 m
Base station hight	17 m
Tx-Rx distance	100 m
Transmitter power	$-20 < \rho < 20$ [dbm]
Quantization bits	From 1 bit to 12 bits
Selected antennas	10, 20, 40
Algorithm used	Fast Antenna Selection, Random Antenna selection, QAFAS (Ref. [1]).
Proposed algorithm	QAGAS

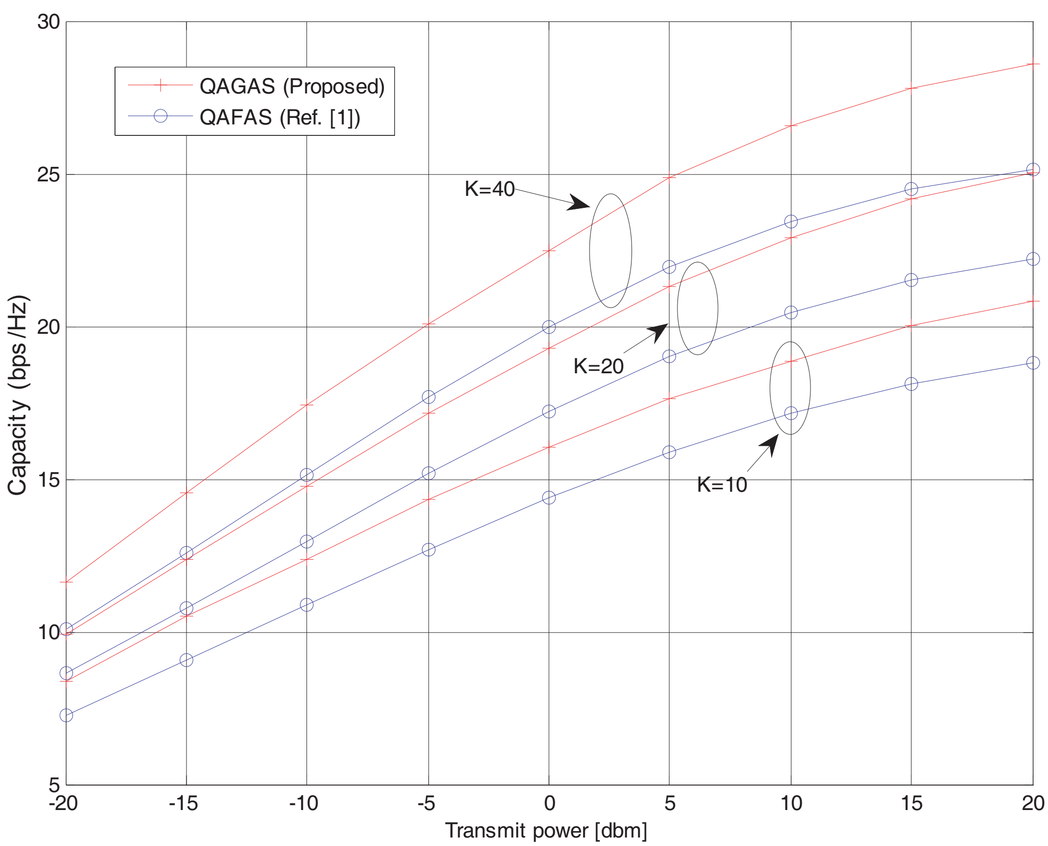

Figure 4. Capacity performance of QAGAS when $M = 128$ and $N = 10$ concerning transmit power.

evaluate the capacity performance of the QAGAS proposed algorithm. The simulation is performed concerning varying transmit power and varying number of quantization bits.

Figure 4 shows the average capacity concerning varying transmit power from -20 dBm to 20 dBm to satisfy low and high values of transmit power. The quantization bits number is fixed and equal to 3 bits to satisfy the low-resolution ADC at BS. The simulation as shown in the figure is repeated for 10, 20, and 40 antennas selections from the 128 antennas placed at the BS. Figure 4 shows that the proposed QAGAS algorithm outperforms the QAFAS selection method. The quantization error becomes dominant that the AWGN at the high values of transmit power which leads to an increase in the gap between the algorithms.

The proposed QAGAS algorithm increases the overall capacity whatever the value of the selected antenna. The capacity reaches 28 bps/Hz at 20 dBm transmit power for the proposed QAGAS while it reaches only 25 at the same transmit power value. Note that the capacity of the system using the QAFAS algorithm at 40 antenna selection gives the same capacity values of the 20 antenna selection when using QAGAS which means minimization of processing becomes from using only 20 antennas instead of 40.

Figure 5 shows the capacity performance of the proposed algorithm compared with QAFAS when changing the number of BS antennas to 64 instead of 128 and 40 antennas for selection. It is logical to say that the overall capacity is decreased as the BS antenna number decreases, but the QAGAS capacity performance still gives a value higher than the QAFAS. The QAGAS response at 64 BS antenna outperforms the QAFAS at the 15 dBm transmit power which also concludes that using QAGAS helps in satisfying the low-resolution ADC with the simple selection process.

Figure 6 shows the capacity performance for the two algorithms when the number of users is changed in the network at 128 BS antennas and 40 antennas for selection. Increasing the number of users for

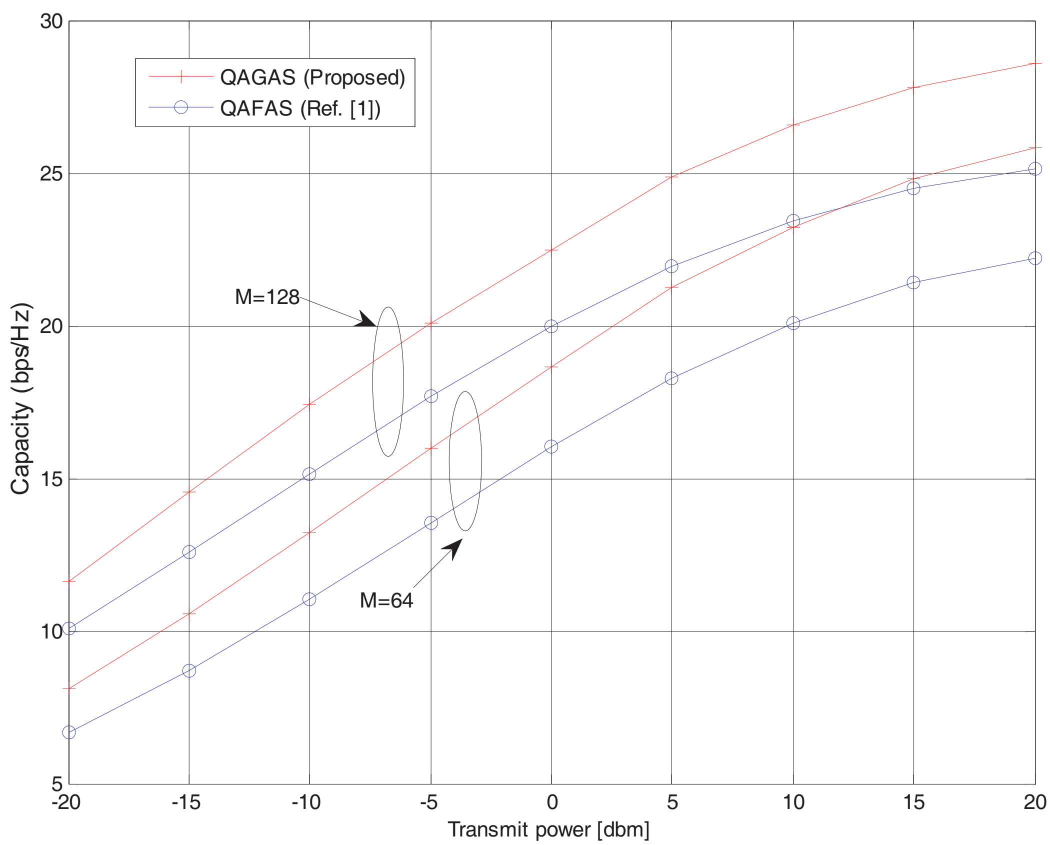

Figure 5. Capacity performance of QAGAS when $N = 10$ and $M = [128, 64]$ concerning transmit power.

both algorithms decreases the capacity performance of the system especially when the transmit power is low because of the increasing interference between users which affects the RF link characteristic which increases the quantization errors. At high transmit power greater than 5 dBm, the capacity is increased as the transmit power increases because there is sufficient power to use for all users. The conclusion that the QAGAS gives better capacity performance than the QAFAS is still valid for any number of users in the network.

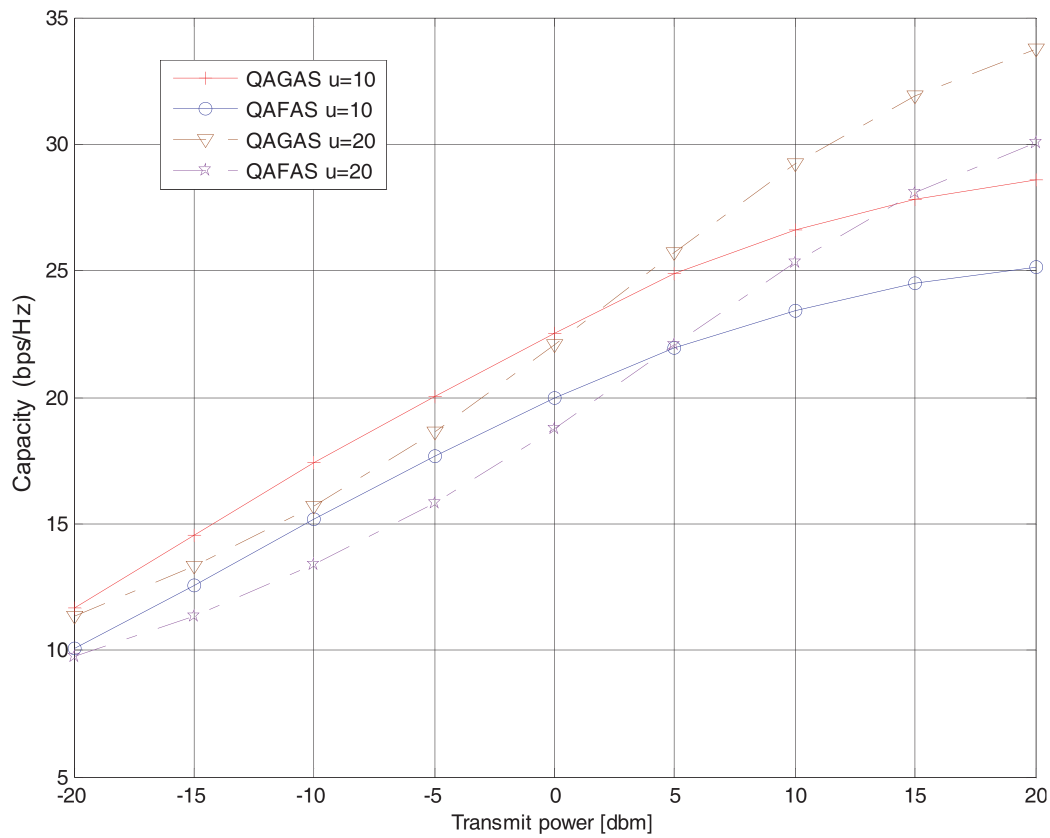

Figure 6. Capacity performance of QAGAS when $M = 128$ and $N = [10, 20]$ concerning transmit power.

Another simulation is performed in Figure 7, Figure 8, and Figure 9 for capacity performance when the number of quantization bits is changed. The transmit power used for all simulations is 5 dBm. It is shown from Figure 7 that the proposed algorithm provides higher capacity and improves the capacity compared to the QAFAS. It reaches 61 bps/Hz at 40 antenna selection while QAFAS performance reaches 57 bps/Hz at the same value of the antenna selection. It is shown that the capacity performance of the QAGAS at low values of quantization bits is better than the QAFAS which means lowering in system complexity.

Figure 8 shows the capacity performance of QAGAS, QAFAS, and Fast selection algorithms when M equals 64 with 10 users in the network and 40 antennas for selection. Results in Figure 8 show the same conclusion that comes from Figure 5 which is a decreasing number of antennas that leads to a decrease in capacity performance. Notice here that the QAGAS algorithm outperforms both QAFAS and fast selection by 5 bps/Hz at a high number of quantization bits. It is clear that at a high number of quantization bits, the performance of QAFAS becomes the same as the fast selection algorithm which means that QAFAS can only be used in low-resolution ADC to enhance the capacity while the QAGAS algorithm works at any level of system complexity.

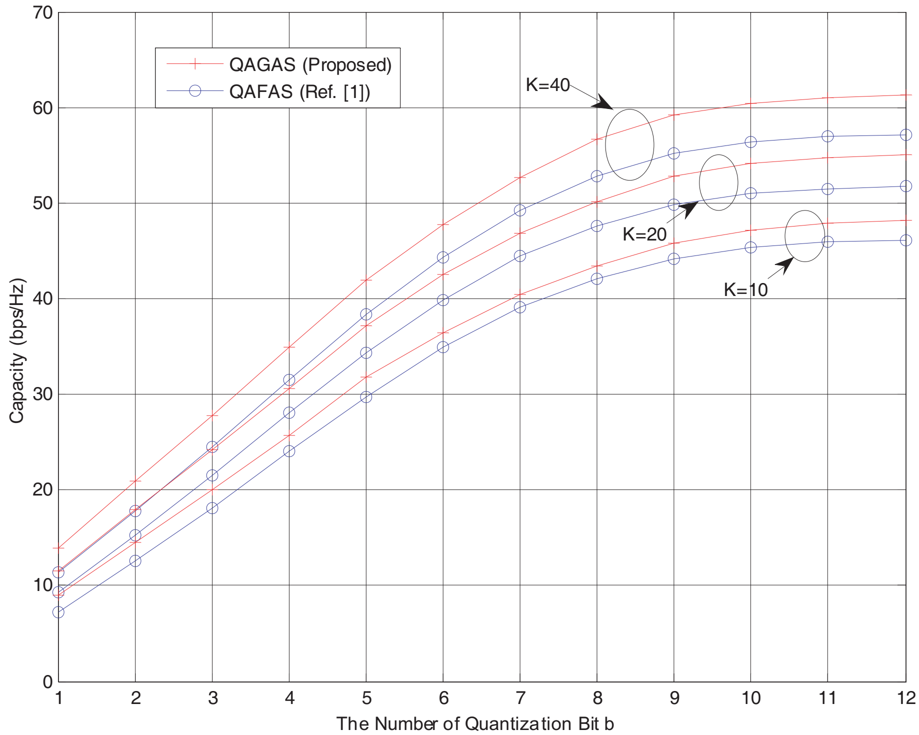

Figure 7. Capacity performance of QAGAS when $M = 128$ and $N = 10$ concerning the number of quantization bits.

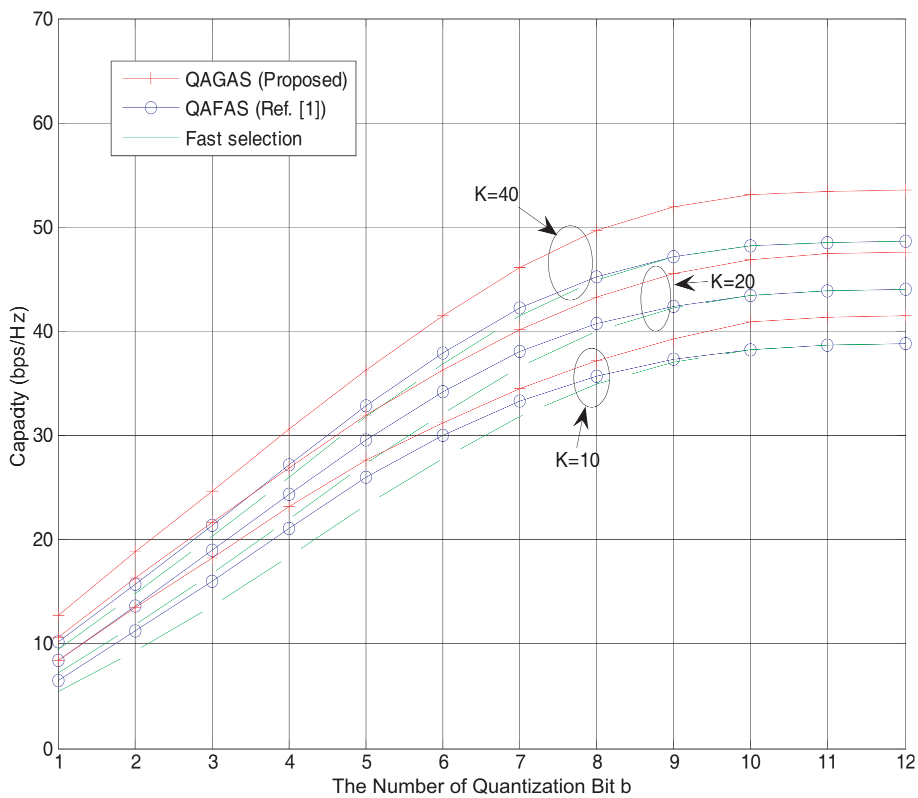

Figure 8. Capacity performance of QAGAS when $M = 64$ and $N = 10$ concerning the number of quantization bits.

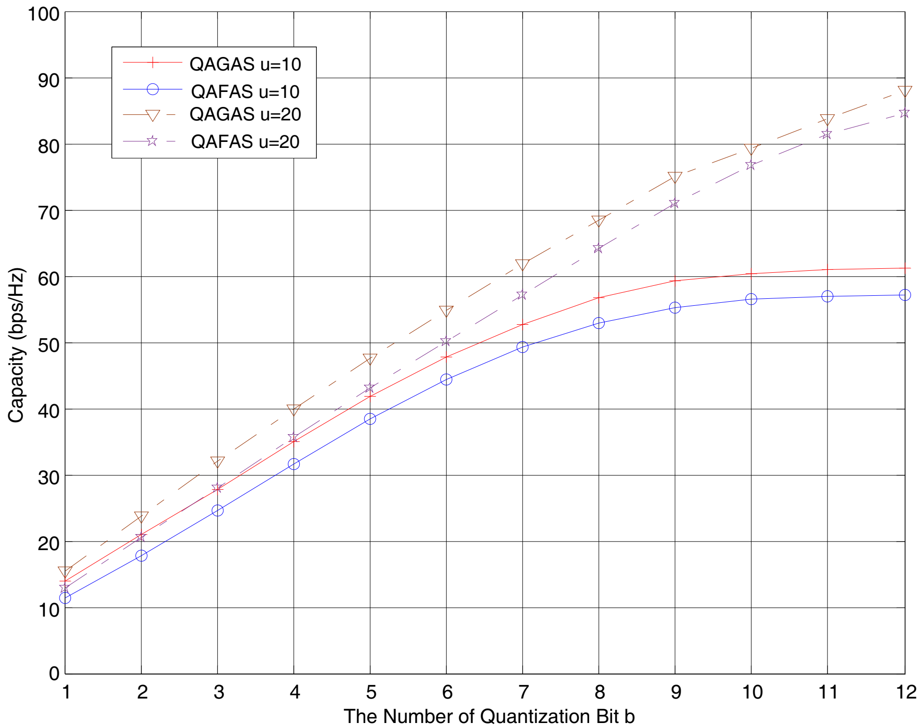

Figure 9. Capacity performance of QAGAS when $M = 128$ and $N = 10, 20$ concerning the number of quantization bits.

4. CONCLUSION

In this paper, the capacity comparison between the proposed algorithm based on Greedy antenna selection with quantization-aware and the Fast antenna selection with quantization-aware has been studied and evaluated. The simulation is performed under the changing number of BS antennas, changing number of users in the network, and changing number of selected antennas. The capacity results are obtained concerning different transmit power values and the different numbers of quantization bits. The simulation results show that the proposed QAGAS gives the higher capacity value than QAFAS whatever the situation is. It is clear to say that the proposed QAGAS can be used in a low-resolution ADC system, besides, to use it with very complex systems. Some of the technologies can be used in future work to satisfy the antenna selection capacity such as considering scheduling with antenna selection to enhance the capacity of the system as the number of users increases, and it is also important to study the use of hybrid beamforming to simplify the antenna selection process in massive MIMO systems.

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