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The impact of M-ary rates on various quadrature amplitude modulation detection

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ABSTRACT

The 5G system-based cognitive radio network is promised to meet the requirements of huge data applications with spectrum. However, the M-ary effect on the detection has not been thoroughly investigated. In this paper, an M-ary of quadrature amplitude modulation detection system is studied. Many rates are used in this study 4, 16, 64, and 256 constellation points. The detection system is applied to cooperative spectrum sensing to enhance the performance of detection for various rates of M-ary with low signal-to-noise ratio (SNR). Further, three kinds of signals based 5G system are sensed: filtered-orthogonal frequency division multiplexing (F-OFDM), filter bank multi-carrier (FBMC), and universal filtered multi-carrier (UFMC). The best detection performance is obtained when the M-ary=4 and number of SUs=50 user, whereas the worst detection performance is obtained when the M-ary=256 and number of SUs=10 user, as revealed in the simulation results. In addition, the detection performance for the F-OFDM signal is better than that of UFMC and FBMC signals for SNR <0 dB.

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1. INTRODUCTION

The demand is increasing for spectrum sensing with the huge development in communication services. There is a lack in the spectrum resources since the licensed spectrum is accessed fixedly. To address this issue, the technology of cognitive radio (CR) is exploited. It, across spectrum sensing, measured the features, frequency, and energy. CR helps the communication systems to utilize the licensed spectrum opportunistically while avoiding harmful interferences to primary users (PUs) [1].

In literature, many techniques are used for spectrum sensing (SS) such as energy detection (ED), eigenvalue-based detection, covariance-based detection, cyclostationarity feature detection, or matched-filter detection methods. The ED method is the simplest one but has some drawbacks such as the low signal-to-noise ratio (SNR). Some methods are presented approaches to face these drawbacks and they include modified ED, three-event ED, improved ED in the presence of Laplacian noise, the square of the received signal amplitude in the ED, or adaptive ED algorithms. On the other hand, M-ary rates affect the ED rather than the symbol rate of the sensed signal [2], [3].

In literature, researchers have investigated various waveform M-ary rates for 5G signals. In 2019, the cyclostationarity feature detection (CFD) is considered to detect the generalized frequency division multiplexing (GFDM) waveform [4]. El-Alfi *et al.* [4] have used the spectral correlation function (SCF) to recover the original signal. The proposed system obtained a significant detection performance, but it has a high level of complexity and required coherency. In the same year, the Cholesky decomposition and radial basis function (RBF) are proposed with the support vector machine (SVM) to enhance for classifying the 5G signals [5]. The proposed system obtained a good performance; however, it has a high false-alarm probability (0.3). An interference compressive sensing process is proposed for the 5G-NOMA-based heterogeneous networks (HetNets) [6]. The proposed system performed a good performance of sensing, but it cannot work effectively for low SNR. Also in 2019, a detection system based on matched filter is proposed to sense NOMA waveform [7]. The proposed system is applied for two kinds: 64 M-ary quadrature amplitude modulation (QAM) and 256 M-ary QAM. The benefits of proposed system can sense both kinds effectively, but the proposed system cannot sense for SNR>(-7) dB. In 2020, Jang [8] have used the CFD for the massive multiple-input and multiple-output (MIMO)-based mmWave-5G network. Though the proposed system is effective for different mappers and low SNR, the CFD requires coherency rather than higher complexity.

In this paper, the impact of rates of M-ary on the sensing performance has been studied. A mathematical expression for the M-ary rates has been derived for filtered-orthogonal frequency division multiplexing (F-OFDM), filter bank multi-carrier (FBMC), and universal filtered multi-carrier (UFMC) waveforms. Next, a detection performance is obtained for the previous waveforms based various rates of M-ary. The rates of M-ary are 4, 16, 64, and 256 are applied on the aforementioned waveforms then mixed with AWGN channel. After that, the secondary users (SUs) should sense one of the previous waveforms based on one of rates of M-ary.

In addition to this section, the rest of this paper is organized as follows: section 2 introduces the background of SS technique. Section 3 describes the derived expressions of proposed sensing system for F-OFDM, FBMC, and UFMC based various rates of M-ary. Simulation results are obtained for the derived expressions in section 4. Finally, the conclusions are summarized in section 5.

2. SPECTRUM SENSING PRLI MINARIES

The SS performance can be obtained by evaluating the probabilities of false-alarm P_f and detection P_d (or in negate-manner the probability of miss-detection P_{md}). The relationships of previous probabilities and binary hypothesis, which performs the presence decision, is described simply as $P_f = \Pr\{T > \gamma \backslash H_0\}$ and $P_d = \Pr\{T > \gamma \backslash H_1\}$, where $Pr\{\cdot\}$, T, and γ represent the event probability, test statistic, and pre-defined threshold, respectively. The binary hypothesis includes two hypotheses; H_1 for presence decision of PU signal and H_0 for absence decision of PU signal, where the decision is performed by comparing T with γ. The best SS performance should be obtained with decreasing P_f and increasing P_d. Decreasing P_f leads to maximizing the spectrum access opportunities by SU then increasing the throughput of cognitive radio network (CRN) and increasing P_d leads to minimizing the possibility of causing interference by CRN due to wrong detection [9], [10].

The received signal, $y(n)$, can be reflected in the binary hypothesis as in (1) and (2) [11], [12],

$$y(n) = w(n) \qquad : H_0 \tag{1}$$

$$y(n) = x(n) + w(n) \qquad : H_1 \tag{2}$$

where $w(n)$ and $x(n)$ represent noise and the transmitted signal, respectively. The power density (i.e. test statistic) can be formulated as (3) [13],

$$T = \frac{1}{N^2}\sum_{k=0}^{N-1}|Y(k)|^2 \tag{3}$$

where $Y(k)$ represents the fast Fourier transform of the received signal $y(n)$. Thus, once $T > \gamma$ so the PU signal is present, and once $T < \gamma$ so the PU signal is absent.

To describe the SS performance mathematically [14], [15], (4) and (5) show it,

$$P_f = Q\left(\frac{\gamma - \sigma_w^2}{\sqrt{2/N}\sigma_w^2}\right) \tag{4}$$

$$P_d = Q\left(\frac{\frac{\gamma}{\sigma_w^2} - (\delta+1)}{\sqrt{2/N}(\delta+1)}\right) \tag{5}$$

where N, σ_w^2, and δ represent number of samples, power of noise, and SNR, respectively. $Q(\cdot)$ represents Q-function and is given by (6).

$$Q(l) = \frac{1}{2\pi}\int_l^\infty e^{-u^2/2}du \tag{6}$$

In order to overcome the SS issues, the proposed sensing system considered the cooperative SS (CSS) based on OR-rule. Thus, the sensing performance parameters can be obtained as (7) and (8) [16], [17],

$$Q_f = 1 - \prod_{p=1}^{P}(1 - P_f) \tag{7}$$

$$Q_d = 1 - \prod_{p=1}^{P}(1 - P_d) \tag{8}$$

where P denotes the number of the SUs.

3. FORMULATION OF NUMBER OF SAMPLES

In this section, F-OFDM is regarded as a component of the sub-band multicarrier modulation (MCM) scheme [18] and shows a flexible filtering manner and it is expressed as (9),

$$x_{F-OFDM}[v] = \sum_{b=0}^{B-1}\sum_{m=0}^{M-1}\sum_{l=0}^{L-1}\sum_{n=0}^{N-1} s_{m,n}^{b} g_b[l] e^{j2\pi v\frac{(n-l-mC_P)}{N}} \tag{9}$$

where in $g_b[l]$ indicates the frequency corresponding to the finite impulse response prototype filter for b^{th} block with length l; C_P presents the cyclic prefix size. Additionally, $s^b_{m,n}$ indicates the transmitted data for the b^{th} block, n^{th} subcarrier, and m^{th} sub-symbol [19], [20].

On the other hand, UFMC was regarded as an effective sub-band MCM scheme that displays a special filtering mechanism. Its scheme was best suited for solving the low latency dilemma and it could damp the time-frequency offsets [21], [22]. The UFMC expression is described as (10),

$$x_{UFMC}[v] = \sum_{b=0}^{B-1}\sum_{l=0}^{L-1}\sum_{n=0}^{N-1} s_n^b g[l] e^{j2\pi v\frac{(n-l)}{N}} \tag{10}$$

where s^b_n indicates the transmitted data, and $g[l]$ denotes the frequency value corresponding to the finite impulse response filters.

Furthermore, the FBMC is regarded as the sub-carrier MCM scheme that shows an increasing duration of the pulse shaping in a time-domain filter. It has a good spectrum efficiency in both the frequency and domain time [21], [23]. This FBMC scheme was formulated in the following manner.

$$x_{FBMC}[v] = \sum_{m=-\infty}^{\infty}\sum_{n=0}^{N-1} s_{m,n} g[k - m\tfrac{N}{2}] e^{j2\pi v\frac{n}{N}} e^{j\varphi_{m,n}} \tag{11}$$

Thus, the received (targeted) signal should be one of the following signals.

$$y[v] = \begin{cases} x_{F-OFDM}[v] \\ x_{UFMC}[v] \\ x_{FBMC}[v] \end{cases} + w[v], v = 1,2,\dots,V \tag{12}$$

In order to increase the SNR, the targeted signal will be transformed by using the cosine transform [24], [25],

$$Y[k] = \begin{cases} (-1)^k \sum_{v=0}^{V-1}\sum_{b=0}^{B-1}\sum_{m=0}^{M-1}\sum_{l=0}^{L-1}\sum_{n=0}^{N-1} \frac{s_{m,n}^b g_b[l] e^{j2\pi v\frac{(n-l-mc)}{N}}}{\sqrt{V}} + \\ \sqrt{\frac{2}{V}}\sum_{v=0}^{V-1}\sum_{b=0}^{B-1}\sum_{m=0}^{M-1}\sum_{l=0}^{L-1}\sum_{n=0}^{N-1} s_{m,n}^b g_b[l] e^{j2\pi v\frac{(n-l-mC)}{N}} \cos\left(\frac{\pi k(2v+1)}{2V}\right) \\ (-1)^k \sum_{v=0}^{V-1}\sum_{b=0}^{B-1}\sum_{l=0}^{L-1}\sum_{n=0}^{N-1} s_n^b g[l] e^{j2\pi v\frac{(n-l)}{N}} / \sqrt{V} + \\ \sqrt{\frac{2}{V}}\sum_{v=0}^{V-1}\sum_{b=0}^{B-1}\sum_{l=0}^{L-1}\sum_{n=0}^{N-1} s_n^b g[l] e^{j2\pi v\frac{(n-l)}{N}} \cos\left(\frac{\pi k(2v+1)}{2V}\right) \\ (-1)^k \sum_{v=0}^{V-1}\sum_{m=-\infty}^{\infty}\sum_{n=0}^{N-1} s_{m,n} g\left[k - m\frac{N}{2}\right] e^{j2\pi v\frac{n}{N}} e^{j\varphi_{m,n}} / \sqrt{V} + \\ \sqrt{\frac{2}{V}}\sum_{v=0}^{V-1}\sum_{m=-\infty}^{\infty}\sum_{n=0}^{N-1} s_{m,n} g[k - m\frac{N}{2}] e^{j2\pi v\frac{n}{N}} e^{j\varphi_{m,n}} \cos\left(\frac{\pi k(2v+1)}{2V}\right) \end{cases} \tag{13}$$

where k = 0, 1, …, K-1, and K denotes the corresponding length of the transformation of the targeted signal. After that, a power spectral density (test statistic) should be obtained for every transformed signal and comparing with the predefined threshold for deciding the primary signal presentation.

$$T = Y[k]/K \tag{14}$$

4. RESULTS AND DISCUSSION

The F-OFDM, FBMC, and UFMC waveforms of 5G system are modulated by using various rates of M-ary QAM. The sensing performance is obtained for 10, 30, and 50 SUs, and three low SNRs: (-10 dB), (-20 dB), and (-30 dB). The abovementioned waveform kinds of 5G system and the proposed system have been generated by using MATLAB software. In Figures 1-9, sub-figures that are titled with QAM, 16 QAM, 64 QAM, and 256 QAM, are considered for -10, -20, and -30 dB of SNRs. These titles correspond to the array kind of the QAM modulation, which are used in the F-OFDM, UFMC, and FBMC waveform generation kinds.

Figures 1 to 3 describe the sensing performance for F-OFDM waveform. In addition, Figures 4 to 6 reveal the sensing performance for UFMC waveform. Moreover, Figures 7 to 9 show the sensing performance for FBMC waveform. All figures include four subfigures of the performance; subfigure (a) describes it for 4-QAM, subfigure (b) describes it for 16-QAM, subfigure (c) describes it for 64-QAM, and subfigure (d) describes it for 265-QAM. The power of M-ary QAM affected the sensing of different signals. Since the new signal length is the same for all kinds of arrays, the detection performances are varied according to the number of arrays. The sensing of signal is affected by the number of arrays since the large number of arrays increases the error among symbols.

The sensing performance of proposed system for F-OFDM is better than that of UFMC and FBMC due to it having a long stream of signal. On other hand, the sensing performance of the proposed system for 4-QAM for all type of waveforms is better than that of 16 QAM, 64 QAM, and 256 QAM due to its bit error rate is the lowest. In addition, the sensing performance of the proposed system for 50 SUs for all types of waveforms is better than that of 10 and 30 SUs due to it being the largest number.

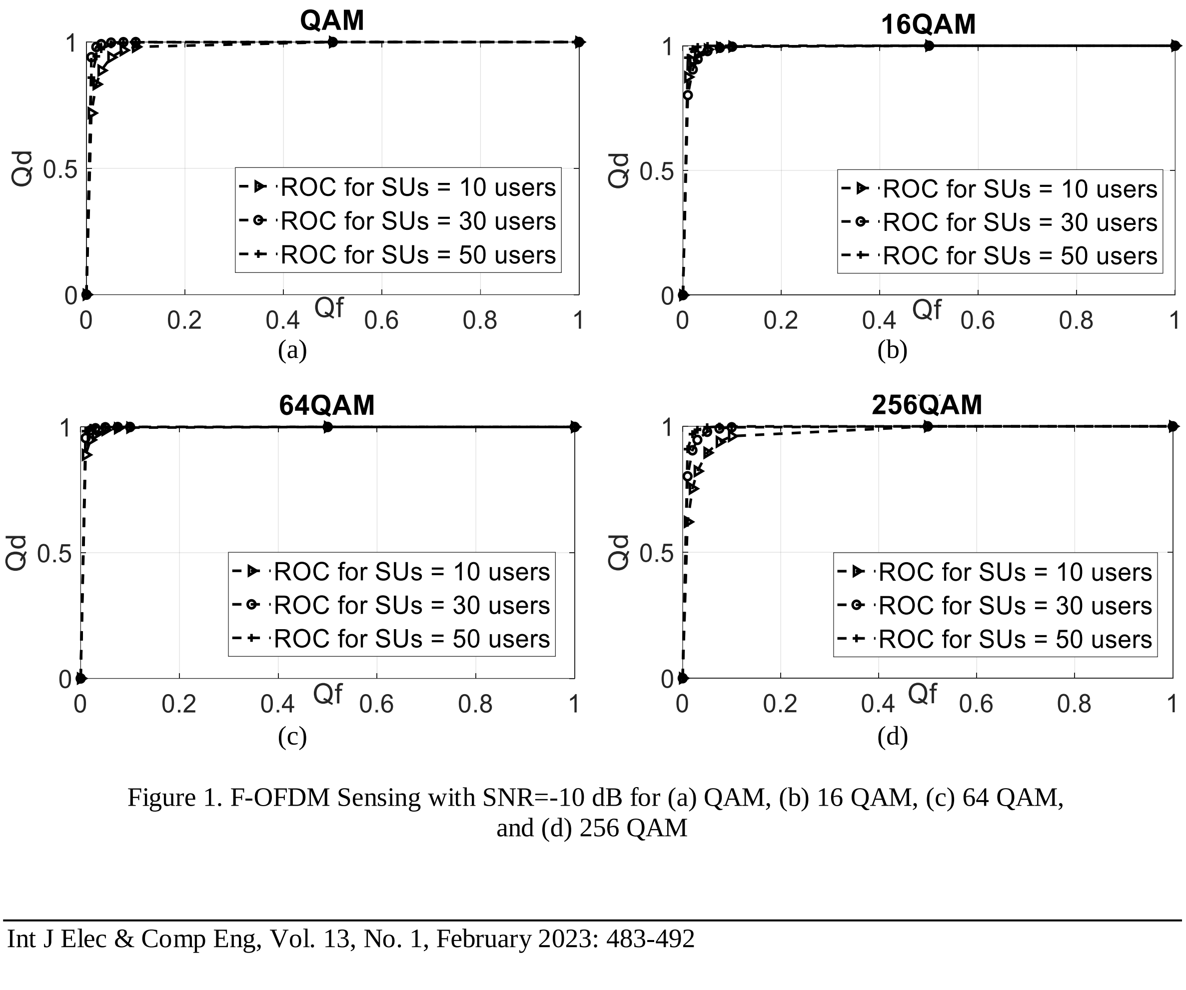

Figure 1. F-OFDM Sensing with SNR=-10 dB for (a) QAM, (b) 16 QAM, (c) 64 QAM, and (d) 256 QAM

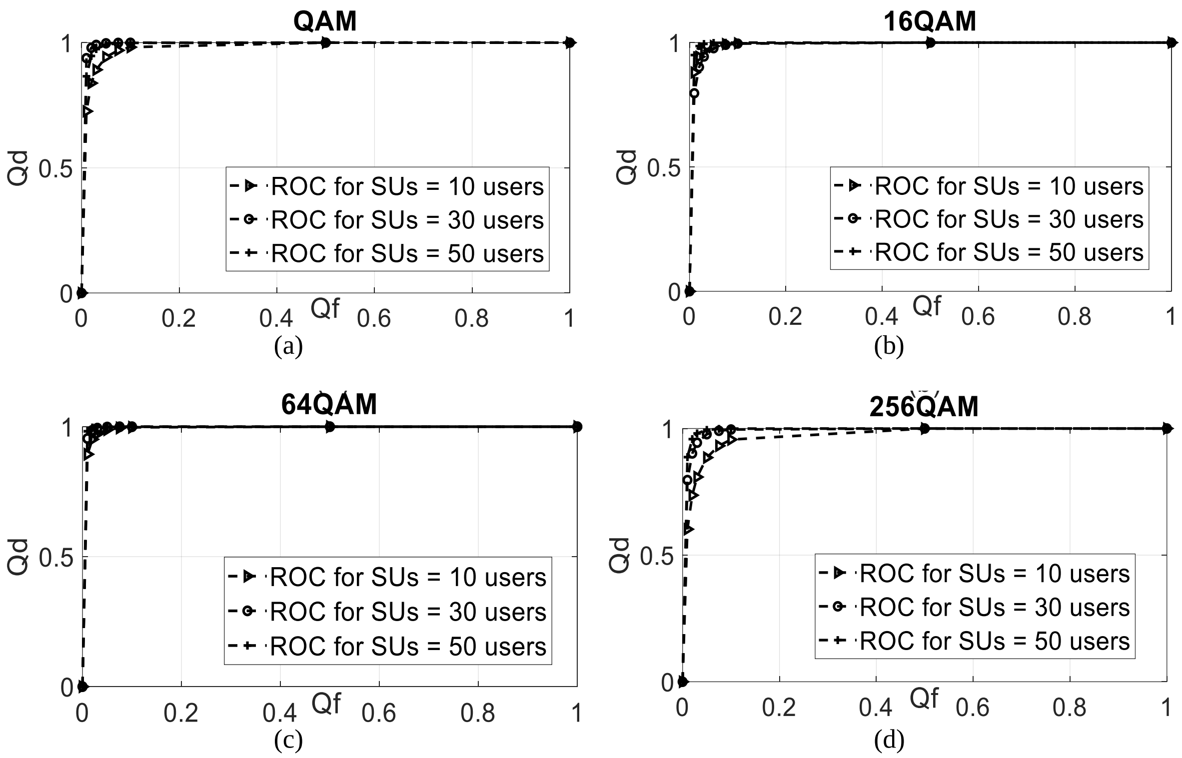

Figure 2. F-OFDM sensing with SNR=-20 dB for (a) QAM, (b) 16 QAM, (c) 64 QAM, and (d) 256 QAM

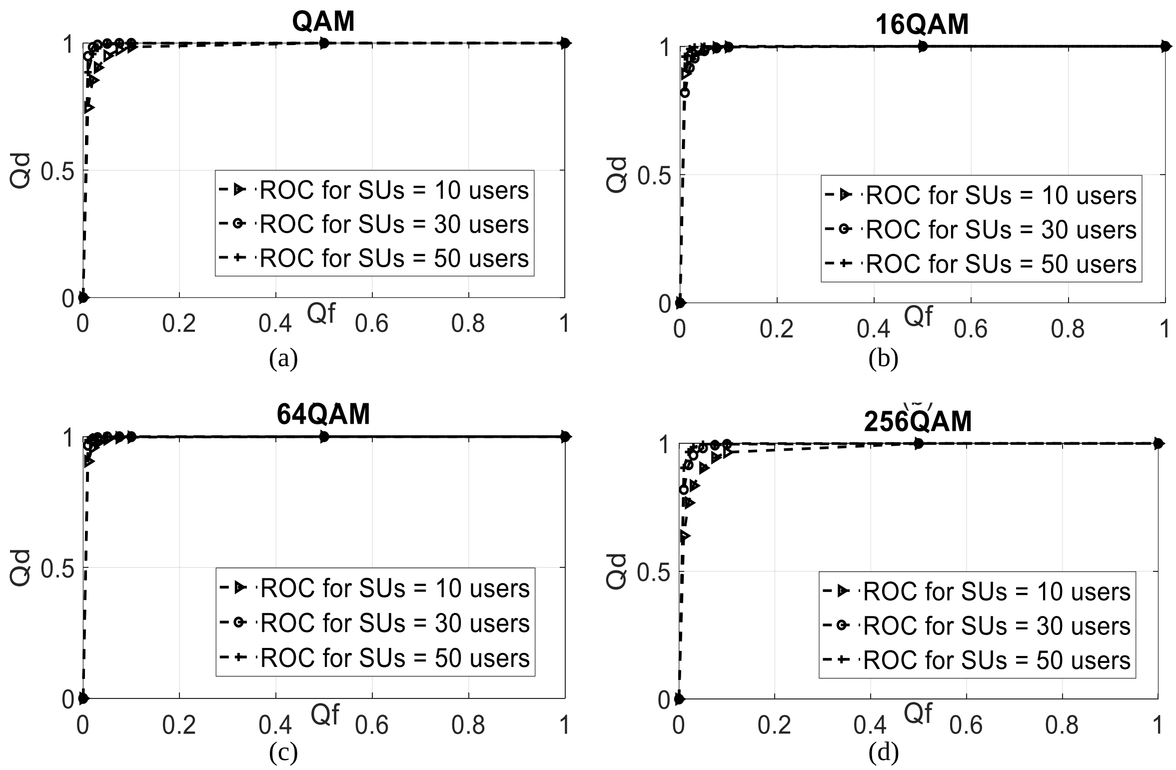

Figure 3. F-OFDM sensing with SNR=-30 dB for (a) QAM, (b) 16 QAM, (c) 64 QAM, and (d) 256 QAM

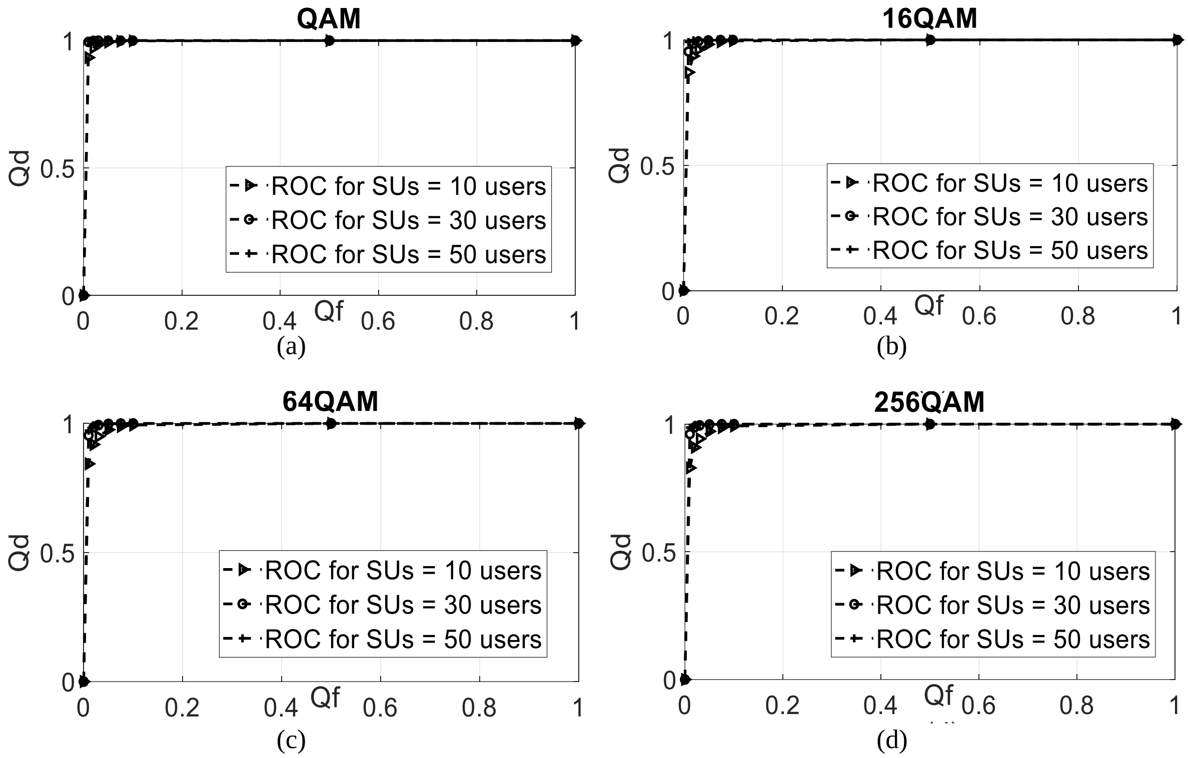

Figure 4. UFMC Sensing with SNR=-10 dB for (a) QAM, (b) 16 QAM, (c) 64 QAM, and (d) 256 QAM

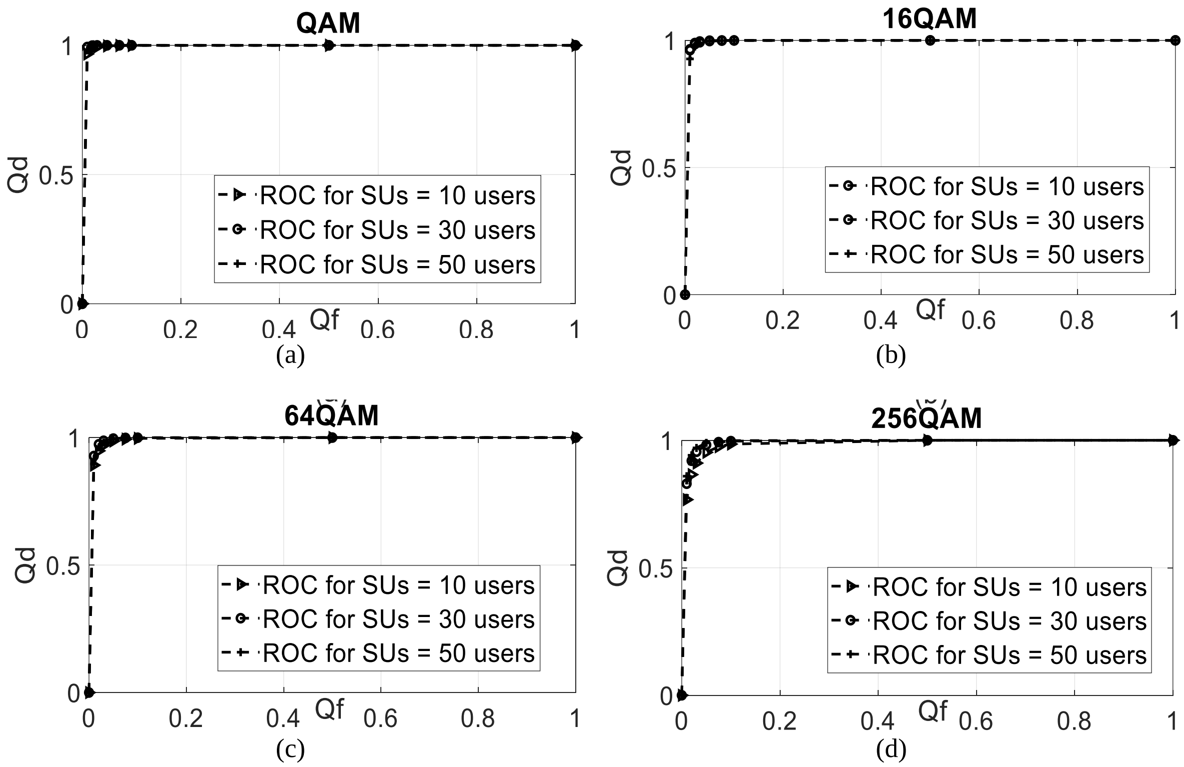

Figure 5. UFMC Sensing with SNR=-20 dB for (a) QAM, (b) 16 QAM, (c) 64 QAM, and (d) 256 QAM

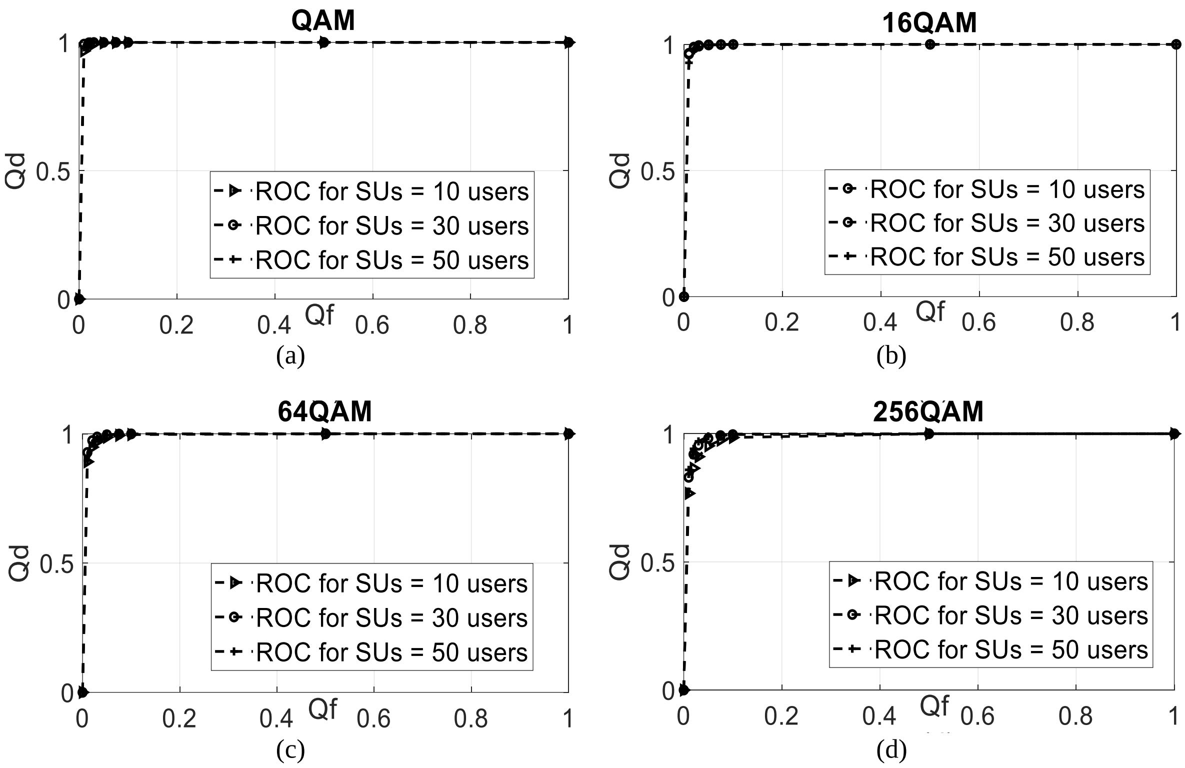

Figure 6. UFMC Sensing with SNR=-30 dB for (a) QAM, (b) 16 QAM, (c) 64 QAM, and (d) 256 QAM

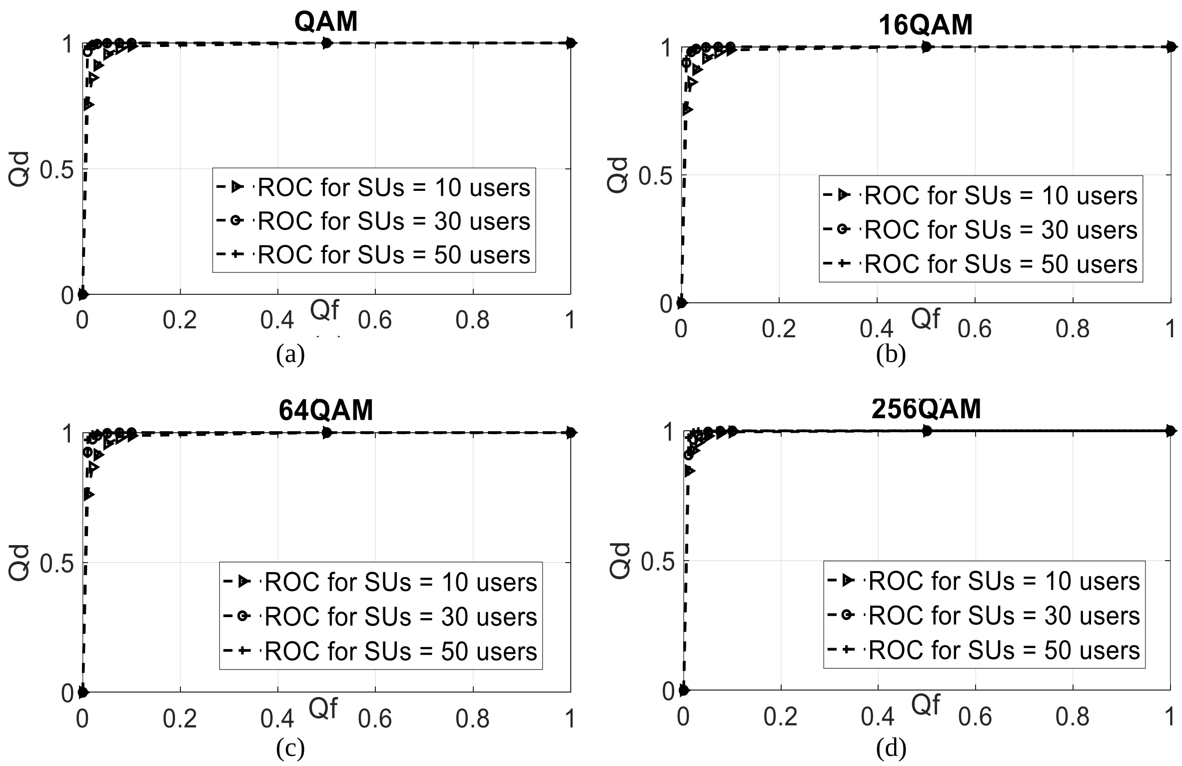

Figure 7. FBMC Sensing with SNR=-10 dB for (a) QAM, (b) 16 QAM, (c) 64 QAM, and (d) 256 QAM

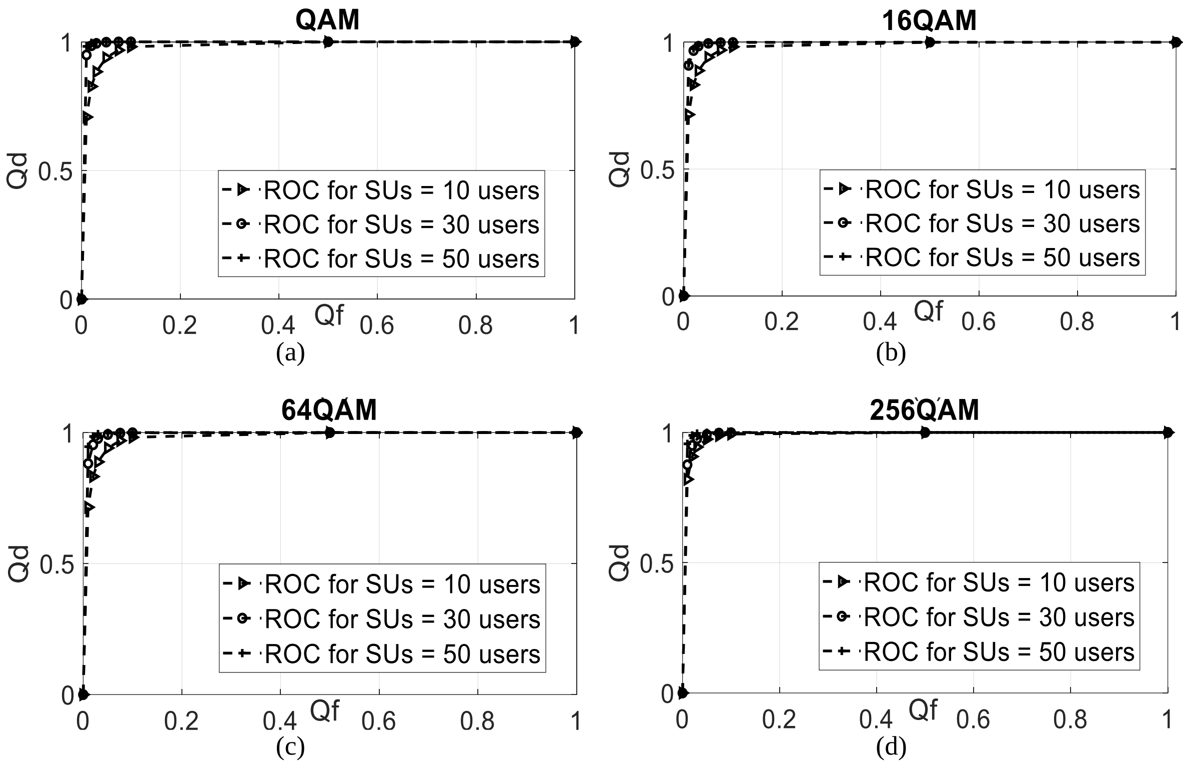

Figure 8. FBMC Sensing with SNR=-20 dB for (a) QAM, (b) 16 QAM, (c) 64 QAM, and (d) 256 QAM

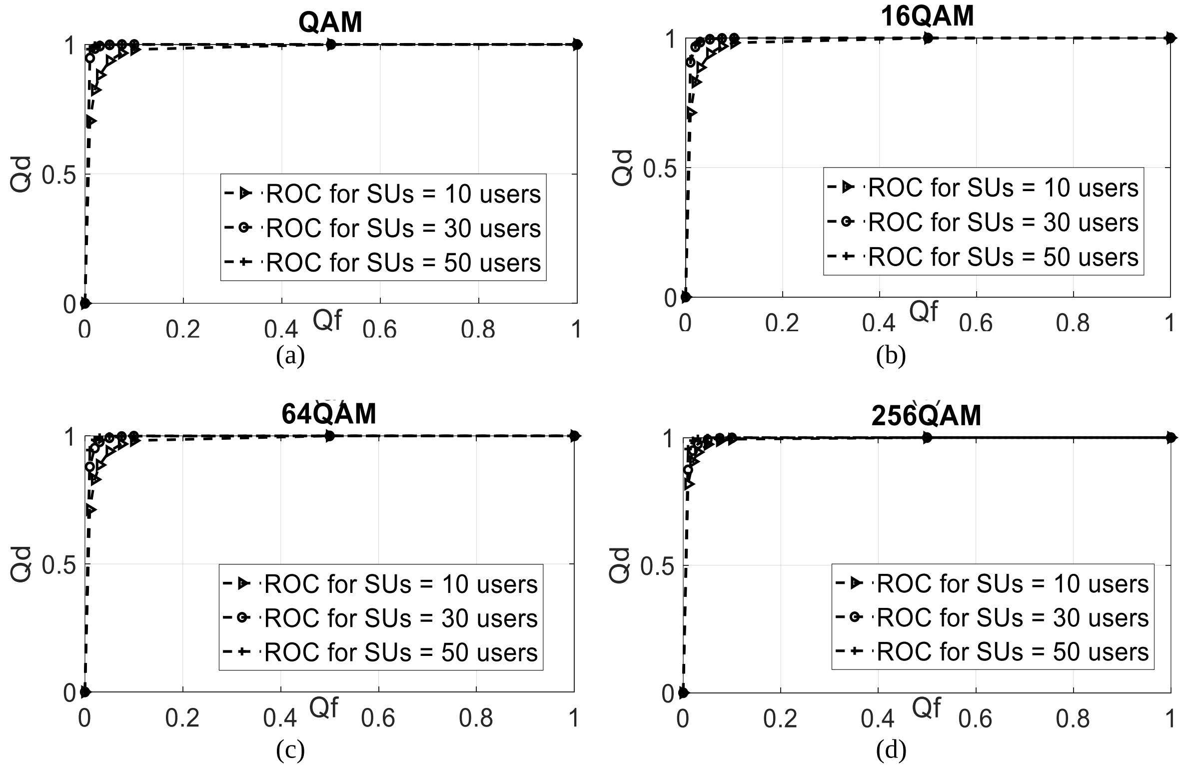

Figure 9. FBMC Sensing with SNR=-30 dB for (a) QAM, (b) 16 QAM, (c) 64 QAM, and (d) 256 QAM

5. CONCLUSION

In this paper, the impact of the M-ary rates on the ED based CSS has been studied. Various rates of M-ary QAM for F-OFDM, FBMC, and UFMC waveforms have been sensed. The graphical results revealed that the sensing performance of 4 M-ary is better than that of 256 M-ary. In addition, it is better for the highest number of SUs. On other hand, the longest signal stream enhanced the sensing performance more than the shortest one. However, a trade-off should be chosen the optimum rate for sensing performance, M-ary rate, type of waveform, and the stream length.

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