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Spectral Efficiency Evaluation of Massive MIMO System using Cognitive Radio Networks

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Abstract
The increasing demand for high-speed wireless communication and the limited availability of spectrum have driven the need for more efficient spectrum utilization techniques. Massive Multiple Input Multiple Output (Massive MIMO) and Cognitive Radio Networks (CRNs) are two promising technologies that address these challenges. Massive MIMO improves spectral and energy efficiency by employing a large number of antennas at the base station, enabling simultaneous transmission to multiple users through spatial multiplexing. On the other hand, CRNs allow secondary users to access underutilized licensed spectrum bands without interfering with primary users, thereby enhancing spectrum efficiency dynamically.
This paper presents a comprehensive evaluation of the spectral efficiency of a hybrid communication system that integrates Massive MIMO with CRNs. The study investigates the system performance under various parameters such as the number of antennas, users, signal-to-noise ratio (SNR), and spectrum sensing accuracy. Simulation results show that the integration of CRNs with Massive MIMO significantly improves spectral efficiency compared to standalone systems, especially under low primary user activity and accurate spectrum sensing. This hybrid approach demonstrates a robust solution for future wireless networks, including 5G and beyond, by ensuring higher throughput, reduced interference, and efficient use of spectral resources. The paper also highlights challenges and future directions for practical deployment.
Keywords: - Cognitive Radio, Massive System, Spectral Efficiency

1. INTRODUCTION

The limited available spectrum i.e., the spectrum under-utilization problem have motivated a number of initiatives in the regulatory as well as research communities to develop a new

communication paradigm, which can exploit the spectrum bands opportunistically. In addressing the spectrum under-utilization problem, the FCC has recently approved the unlicensed access of the licensed bands [1]. In this context, the term Dynamic Spectrum Access (DSA) has been used to refer to the techniques that implement better spectrum management policies. The key enabling technology that emerges for DSA techniques is the cognitive radio (CR), which is supported by the Software
Defined Radio (SDR) technology. CR is usually built upon an SDR platform and is a context-aware intelligent radio, which is capable of autonomous reconfiguration by learning from and adapting to the surrounding communication environment [2]. Formally, the term cognitive radio (CR) can be defined as follows according to FCC [3]: "A cognitive radio is a radio that can change its transmission parameters based on interaction with the environment in which it operates". From the above definition, the two major characteristics of CR can be defined as the cognitive capability and configurability. The cognitive capability refers to the ability of the radio component to capture (using techniques such as autonomous learning and action decision) or sense information (the temporal and spatial variations in the radio environment and the interference level generated to other users) from its surrounding radio environment. On the other hand, the configurability refers to the ability to enable the transmitter parameters to be dynamically programmed and modified according to the dynamics of radio environment.

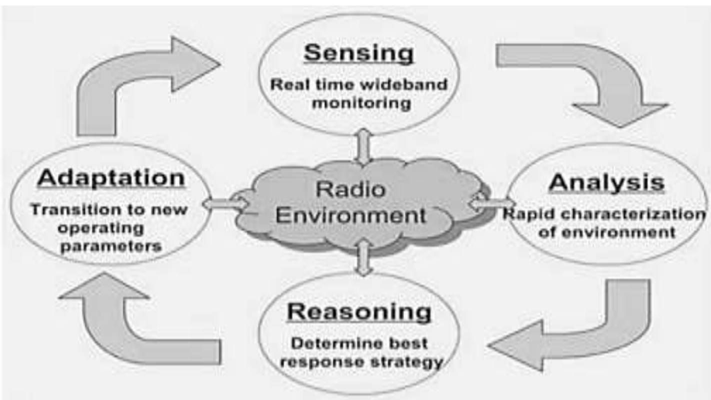

Figure 1: Cognitive Cycle

Therefore, a CR enabled node in the network adapts dynamically to re configure several parameters such as the operating frequency (to take advantage of detected spectrum holes on different frequency bands), modulation and channel coding (to adapt to the requirements of application and the instantaneous conditions of channel quality), transmission power (to control

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the possible generated interference), and communication technology (to adapt to specific communication needs).

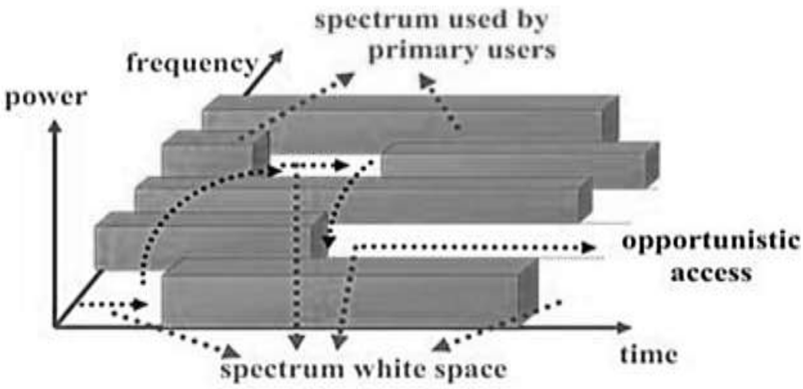

Figure 2: Opportunistic Usage of Spectrum Holes

Depending on the characteristics of the detected spectrum holes, as shown in Figure 1 and Figure 2, the CR enables to switch to different spectrum bands opportunistically [4], while the transmitter and receiver parameters are reconfigured accordingly.

2. CR NETWORK ARCHITECTURE

The possible architecture of a CR network as defined is shown in Figure 3. The components of such CR network architecture can be classified into two groups as primary network and secondary network (i.e. cognitive radio network).

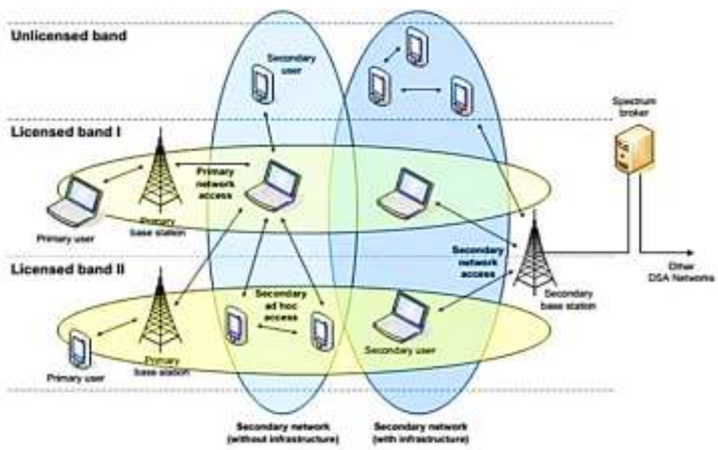

Figure 3: Cognitive Radio Network Architecture

Primary network: A primary network is referred to an existing network infrastructure, where the nodes called primary users (PUs) have authorized license for exclusively accessing a certain frequency band. Examples of such networks include the cellular and the TV broadcast networks. Primary user (PU) activities are controlled through the primary base-stations in infrastructure based the primary network. Since the PUs have their priority in spectrum access, the operations of PUs should not be affected by any other unlicensed or secondary users.

Secondary network: A secondary or unlicensed network is referred to a network, with fixed infrastructure or based on ad hoc communication principle, without license to operate in a desired licensed band. Hence, to share the licensed spectrum band with primary networks, the additional functionalities are used by the nodes called CR users/secondary users (SUs). The infrastructure based secondary networks are equipped with a central entity called CR base station, which implements a single-hop connection to SUs. On the other hand, the secondary ad-hoc networks have no infrastructure backbone and a SU can communicate with other SUs through the ad-hoc connection on both licensed and unlicensed spectrum bands. Furthermore, secondary networks may include spectrum brokers, which can play a role in sharing spectrum resources among different secondary networks.

In the context of network architecture, the spectrum management functionalities are implemented by different entities. For instance, in infrastructure based architecture, the spectrum broker is responsible for coordinating the tasks of spectrum sensing, decision and management (sharing and mobility), while in ad-hoc architecture; CR nodes themselves are responsible for spectrum sensing, decision and management. The former requires a dedicated control channel whereas in infrastructure less architectures use of dedicated control channel is optional.

3. Proposed Methodology

The primary block of the system model's MATLAB software implementation is explained below. A serial process is used to generate a random binary signal. Applying IFFT and converting an OFDM signal from parallel to serial allows for time-domain analysis. Due to the elimination of OFDM symbol interference, the OFDM signal is added to the CP. An AWGN channel is then used to receive this signal. At the receiving location, the OFDM signal undergoes CP removal, serial-to-parallel conversion, and FFT application. After receiving the FFT signal's output, the signal was transformed from parallel to serial and sent to each symbol for frequency domain analysis. The signal is cross-correlated with the time-shifted demodulation signal following demodulation.

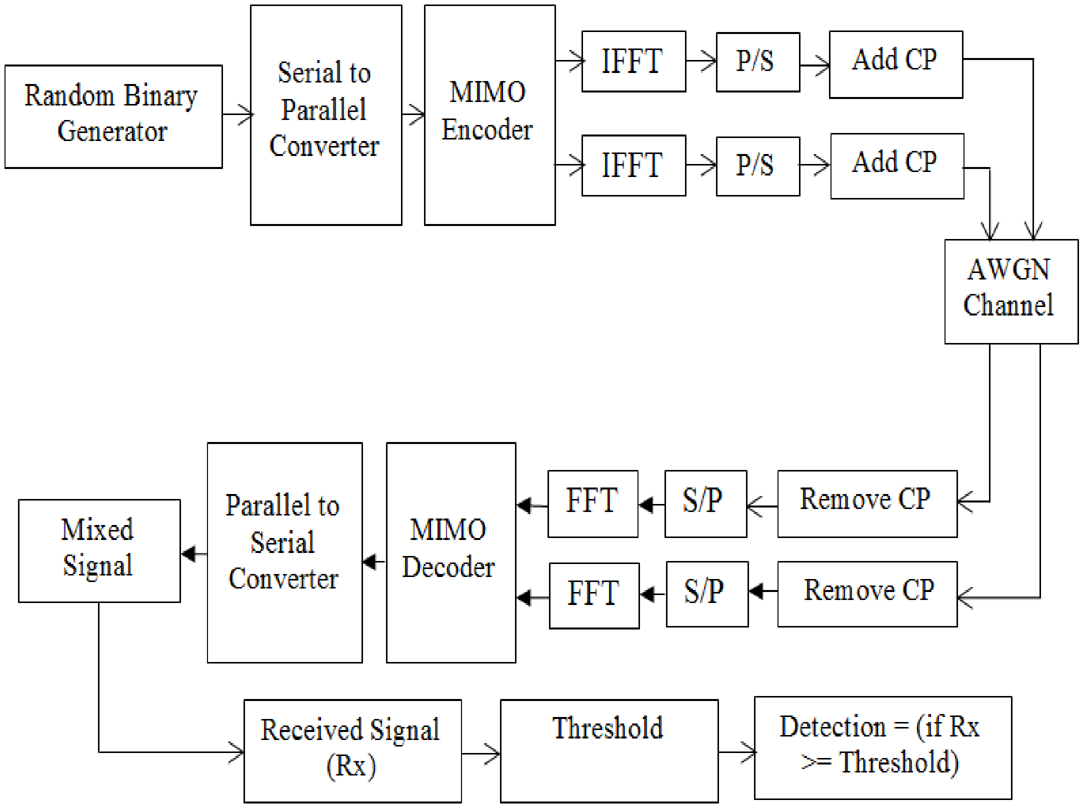

Figure 4: Design of MIMO-OFDM System using Compressive Sensing Cognitive Radio Network

Following the SNR, the received signal is lastly compared to a threshold value (ώ) to determine whether the signal is there or missing; if the received signal exceeds the threshold value, detection will occur; if not, it won't:

This technique uses a secondary user to sense the primary user's received signal power to determine whether the primary user is present or absent. To do the measurement one energy detector is used. Based on the signal strength of primary user's signal it decides that whether the channel is available for the secondary users or not. For this process secondary user doesn't require regarding primary user such type of signal, method is called as a non-coherent.

4. SIMULATION RESULT

Simulation experiments are conducted to evaluate the SNR verse BER performance of the proposed matched filter detection spectrum sensing different system is shown in figure 5. It is clear that the increase in the transmitter and receiver antenna than decrease the total error with

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respect to SNR. Table 1 shows the different value of total error in different SNR for MIMO-OFDM for Matched Filter Detection Spectrum Sensing Method.

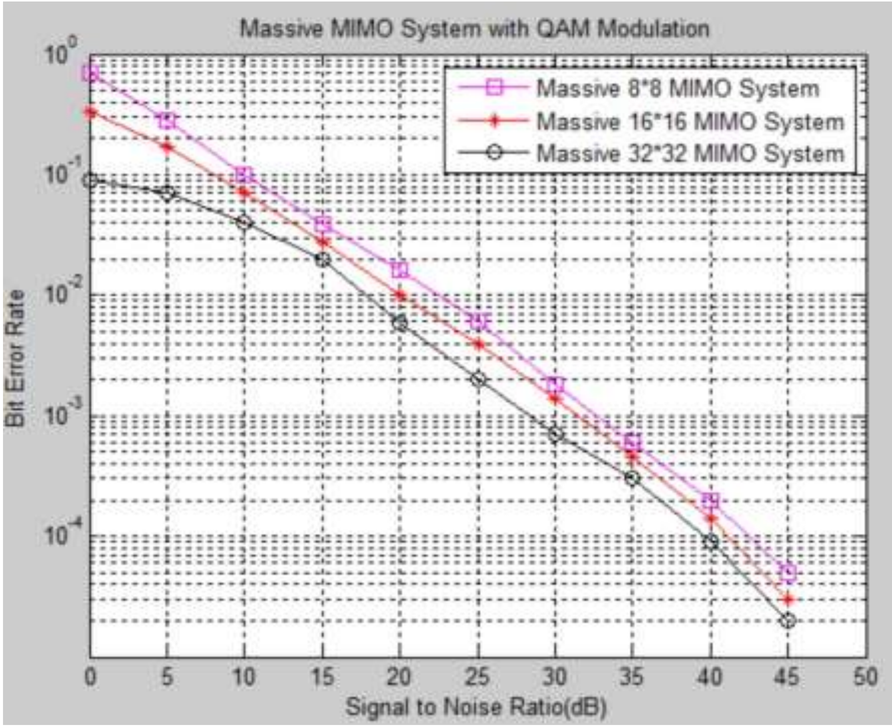

Figure 5: BER vs SNR for Compressive Spectrum Sensing Different System

Table 1: Comparison of BER vs SNR in Different Antenna for Compressive Spectrum Sensing Method

BER	SNR (dB)						
	0	5	10	20	30	35	40
8×8 Massive MIMO System	2×10^{-1}	1.5×10^{-1}	9×10^{-2}	3×10^{-2}	2×10^{-2}	6×10^{-3}	9.5×10^{-3}
16×16 Massive MIMO System	2×10^{-1}	10^{-1}	8×10^{-2}	2×10^{-2}	9×10^{-3}	4×10^{-3}	9×10^{-4}
32×32 Massive MIMO System	1.5×10^{-1}	1.5×10^{-1}	7×10^{-2}	10^{-2}	7×10^{-3}	2×10^{-3}	6×10^{-4}

Simulation experiments are conducted to evaluate the SNR verse relative mean square error performance of the proposed matched filter detection spectrum sensing different system is shown in figure 6. It is clear that the increase in the transmitter and receiver antenna than increase the relative mean square error with respect to SNR.

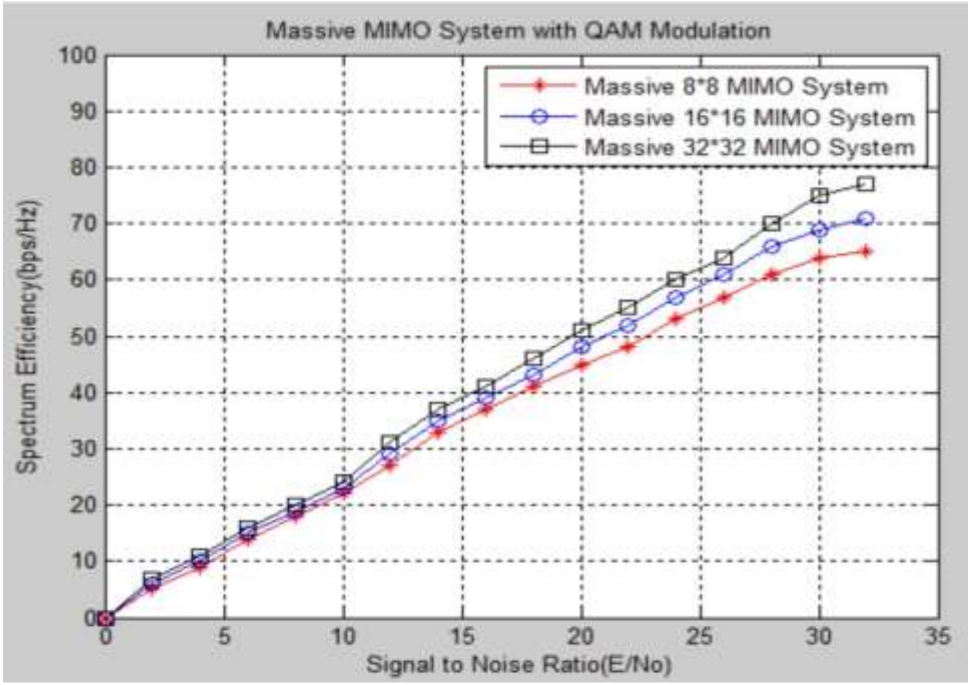

Figure 6: Spectrum Efficiency vs SNR for Compressive Spectrum Sensing Different System

Table 2: Comparison of Spectrum Efficiency vs SNR in Different Antenna for Compressive Spectrum Sensing Method

Spectrum Efficiency	SNR (dB)						
	0	5	10	15	20	25	30
8×8 MIMO-OFDM System	0	6	21	25	45	55	64
16×16 MIMO-OFDM System	0	6.2	21.3	28	48	59	69
32×32 MIMO-OFDM System	0	6.4	21.7	30	50	62	74

5. CONCLUSION

The integration of Massive MIMO systems with Cognitive Radio Networks offers a highly effective solution to the growing demand for spectral efficiency in modern wireless communications. Through dynamic spectrum access enabled by CRNs and the spatial multiplexing capability of Massive MIMO, the hybrid system maximizes spectrum utilization while minimizing interference. The simulation results confirm that such integration significantly enhances spectral efficiency, particularly under scenarios with low primary user activity and high sensing accuracy.

The performance analysis reveals that increasing the number of antennas at the base station improves throughput and signal quality, while cognitive radio mechanisms allow secondary users to exploit unused spectrum dynamically. This combination outperforms standalone CRN or Massive MIMO systems in both static and dynamic environments.

Despite its advantages, the system faces challenges such as pilot contamination, sensing errors, and computational complexity. Addressing these limitations through advanced spectrum sensing algorithms, machine learning-based resource allocation, and hybrid beamforming will be crucial for real-world implementation.

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