# Interference Mitigation Technique in Cognitive Radio Systems using Spatial Modulation-A Survey

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*Abstract*— **The tremendous growth in wireless communication has increased the spectrum usage, thereby raised the spectrum scarcity and security issues. The real problem is the inefficient spectrum allocation and its usage. Cognitive Radio is considered to be the key enabling technology for such problems. Spectrum sensing is the main aspect of cognitive radios. In this paper, a survey of Interference mitigation techniques by using Spatial Modulation in cognitive radio is studied. To protect both the primary as well as secondary user transmission, beam forming techniques is used. Such a scheme can be employed in the 5G technologies by the deployment of GFDM. Also, a comparative study on other 5G multicarrier transmission schemes such as FBMC and UFMC is done**.

***Index Terms*— Cognitive radio, FBMC, GFDM, Spatial Modulation, Spectrum Sensing.**

## I. Introduction

The requirement for higher information rates is increasing day by day. It becomes obvious that the current frequency spectrum allocation cannot accommodate the requirements of an increasing data rates device. So an innovative technique called Cognitive Radio (CR), which exploits the available spectrum, came into existence. It is considered to be an enticing answer for the spectral congestion problem by introducing the smooth usage of the frequency band which is not occupied by the Primary Users (PU) [1]. According to the Federal Communication Commission(FCC), cognitive radio is defined as "*Cognitive radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference ,facilitate interoperability, access secondary markets"* [2]. In CR terminology, PU is defined as the users who are having higher priority or legacy rights on the spectrum usage, whereas the Secondary Users (SU) are those having lower priority. A spectrum hole is defined as a frequency band in which an SU can transmit without disturbing the primary receivers crosswise over all frequencies. An overview of CR has been studied in [3]-[6]. Based on the searched results, the SU can dynamically tune its transmitter and receiver parameters to identify spectrum hole for communication. So the cognitive capability has been equipped in SUs, with the primary objective of causing no disturbance to the communication of PU.

Spectrum sensing is one of the important characteristics of cognitive radio. Its main task is to obtain awareness about the spectrum usage and the existence of primary users in a geographical area. It is obtained using geolocation and data base using beacons or local spectrum sensing [7]. In [8] a comparative study of all spectrum sensing algorithms has been made. It is found that Energy Detector (ED) has fewer complexities when compared to other sensing techniques, but it has very less accuracy. The presence of co-channel interference will make the noise to be a stationary. In such conditions, ED fails while cyclostationarity based algorithm is not affected. As a solution to problems due to noise uncertainty, fading, and shadow, cooperative sensing is proposed. CR is divided into clusters and data is sent to cluster head in slots of frames assigned to a particular cluster. It can decrease sensing time.

Orthogonal Frequency Division Multiplexing (OFDM) is one of the most widely used technologies in a current wireless communication system which has the potential of fulfilling the requirements of cognitive radios inherently or with minor changes. Although it provides some advantages such as robustness to frequency selective fading and easy implementation but. It fails to address the requirements of 5G networks such as very high spectral efficiency, relaxed synchronization, very low latency and low Out-Of-Band (OOB) emission [9]. So an alternative multicarrier transmission scheme called Generalized Frequency Division Multiplexing is proposed. GFDM is a potential candidate for 5G technology [10- 11]. It focuses on combining the simplicity and flexibility of OFDM with the mechanism of stronger interference reduction. However, the signal suffers from Inter-Carrier Interference (ICI) from the adjacent subcarriers and Inter-Antenna Interference (IAI) and can cause harmful interference to PU operating within the spectral band spanned by the GFDM subcarriers. The bit

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error rate performance of MIMO-GFDM is inferior to that of MIMO-OFDM due to the presence of ICI and IAI [12].

The above-discussed disadvantages like ICI and IAI can be avoided by Spatial Modulation (SM). SM is a novel MIMO technique, which employs the transmit antenna indices to carry additional information bits [13]. In SM, input bits select the constellation point in the signal set and the index of the activated transmit antenna. At each transmit interval, the selected antenna transmits the selected symbol and other antennas do not take part in transmission, i.e., remain silent. As a result, IAI and ICI are avoided.

Virtual Antenna Array (VAA) enables to optimize the structure and parameters of the real antenna array so that to minimize its directional pattern distortion by the carrier's body. The virtual antenna concept using relay system is shown in Figure 1a. This system is known to be a Virtual MIMO system. The signal s will be collected and forwarded by relay to the user of interest. So the relay station can be considered to be a virtual transmit antenna. One of the important characteristics of wireless communication is multipath propagation. The signal components along with corresponding transmitted delays will be equivalent to the signal transmitted by virtual antennas, as shown in Figure 1b. Thus virtual antenna concept in Figure 1a and 1b can be apparently introduced temporal and spatial diversity. The modern wireless communication network allows the BS to be equipped with a large number of antenna elements as in Figure 1c. For the remote network, those physical antennas will not be totally deployed. Anyway they would adaptively selected to meet those necessities such as coverage, impedance, interference mitigation and so forth [14].

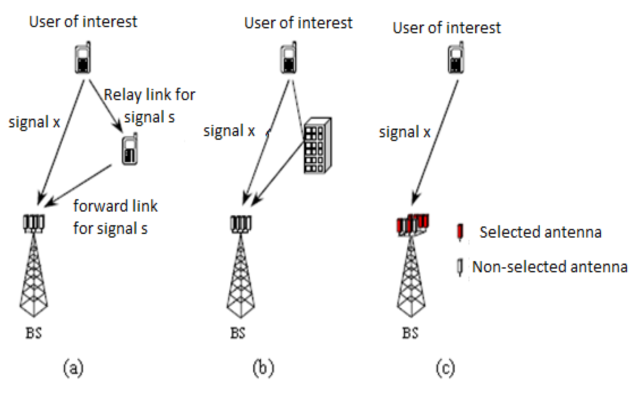


Figure 1: Virtual antenna deployment and physical antenna selection for interference mitigation.

In a certain geographical region, where the maximum tolerable interference threshold to the PU is satisfied by the SU, both the PU and SU transmission will take place simultaneously. So the SU transmission can be severely hampered by the interference arising out of PU transmission [15]. The interference from the PU transmission to the SU transmitter would corrupt the signal received by the SU receiver in that geographical area. In order to protect both PU and SU transmission, Cognitive beam forming technique is used.

This paper is sorted as follows. We start with a brief discussion on VAA based SM-GFDM system in section II. Other 5G multicarrier transmission schemes are studied in III and conclusions are presented in IV.

## II. VAA BASED SM-GFDM SYSTEM

A new approach called VAA is introduced to implement multi-element array into a mobile terminal. It emulates MIMO systems and implements within a mobile communication system by taking the benefits of the extraordinary spectral efficiency of MIMO systems [16]. In [17], a distributed method to select multiple relay mobile terminals in an opportunistic way. The mobile terminals are equipped with heterogeneous interfaces and VAA allows the transmission between the mobile terminals through cooperation. Link capacity study for VAA is done in [18]. The capacity of a network where each terminal maintains single link to the base station increases drastically. It suggests that the number of transmit antenna at the base station should be less than the number of antenna elements accessible within a VAA group. Anders Mannesson et al analyzed VAA for the performance of DOA estimation and the results show that larger antenna array can provide a significant gain in DOA estimation accuracy [19].

In [20] a new transmission approach called SM which entirely avoids ICI with no synchronization required at the transmitting antenna. The idea is to map a block of information bits into constellation points in the signal and the spatial domain. It uses the spatial domain to convey information. At the receiver side by using iterative–Maximum Ratio Combining (i-MRC) technique, it estimates both the transmitted signal and the transmit antenna number. The number of bits that can be transmitted depends on the used constellation diagram and the given number of transmit antennas. The result shows that it can achieve high spectral efficiency. A novel strategy to overcome the constraints in SM is presented in [21]. An algorithm to optimize the antenna combination selection is proposed. The same symbol will be sent from more than one transmit antenna at a time and the number about transmit antenna be a force of 2 in order to achieve high spectral efficiency. A low complexity algorithm for multiuser Generalized SM (GSM)–MIMO signal detection and channel estimation is proposed in [22]. It is based on message passing at the base station. For same spectral efficiency, the multiuser GSM-MIMO can outperform conventional MIMO by several dBs'.

GFDM is a multi-carrier system, based on the traditional filter bank approach. In [23], it presents a GFDM scheme that defines transceiver architecture and a PHY concept, which exploit white space for wireless communication. This approach exhibits a high degree of spectrum fragmentation. It combines advantages of both specific subcarrier allocation and low PAPR. Thus the power consumption and hardware cost are reduced. CR not only detects an incumbent active transmission, it can also detect other opportunistic signals. GFDM has a low out of band radiation into the adjacent frequency bands. Thus it makes suitable for CRs. GFDM has better spectral shaping and sensing characteristics when compared to OFDM [24]. Time windowing combined with synchronization preamble in order to preserve the spectral property advantages of GFDM is studied in [25]. A window that can provide considerable reduction in spectrum side lobes is presented. In order to satisfy low OOB emission, it uses preamble consisting of two identical parts and it is combined with windowing process. Ersin Ozturk et al recommend a novel multicarrier scheme by joining GFDM with Index Modulation (IM). IM provides a flexible system design with an adjustable number of active subcarriers. The combined GFDM-IM system model could essentially attain better BER performance than classical GFDM. Without expanding the complexity at the transmitter the information bits are conveyed in the spatial domain using the indices of the GFDM subcarriers [26].

One of the main issues in the wireless networks which impact the performance of the system is interference. This is tremendously crucial in the case of CRs, which promise secure transmission of PU system without causing any interference. The impact of interference caused to the PUs is investigated in [27]. This paper focuses on different interference models such as interference range model, protocol model, capture threshold, aggregate model etc and their comparison. It is found that capture threshold and aggregate model are more accurate depending on SINR of the incoming signals. A novel method of agile spectrum evacuation is proposed in [28]. It ensures continuous transmission of SU until the PU returns. The sensing process goes on simultaneous by using a dedicated set of users working in a cooperative manner. This method provides better interference protection and improved utilization of RF spectrum. GFDM suffers from ICI due to its non- orthogonal nature, which can change its BER performance under low SNR. When MIMO is applied to GFDM, its BER performance is affected due to IAI. To mitigate these interferences, SM is applied [29].

In cognitive radio, the deployment of multiple single-antenna terminals and arranging them in clusters is very cost- effective. Within each cluster, the single antenna terminal will form a VAA. Such VAAs collections can be controlled by a central controller acting as the cognitive engine (CE), which is used for updating a pre-existing geographical information. The information database will contain the location information of the PU transmitter, SU receiver, and spectrum band activity status. To activate an SU transmit cluster, the CE will estimate the Direction of Arrival (DOA) and transmission power of the received PU signal. Block of bits is sent to the selected cluster, in which each sub-blocks pattern will encode the clustered index to be activated. The subsequent sub-blocks pattern will contain the selected symbol index to be transmitted. Finally, the beam forming technique is applied to the VAA of the selected cluster [30]. Such combination will improve the performance of multipath environment.

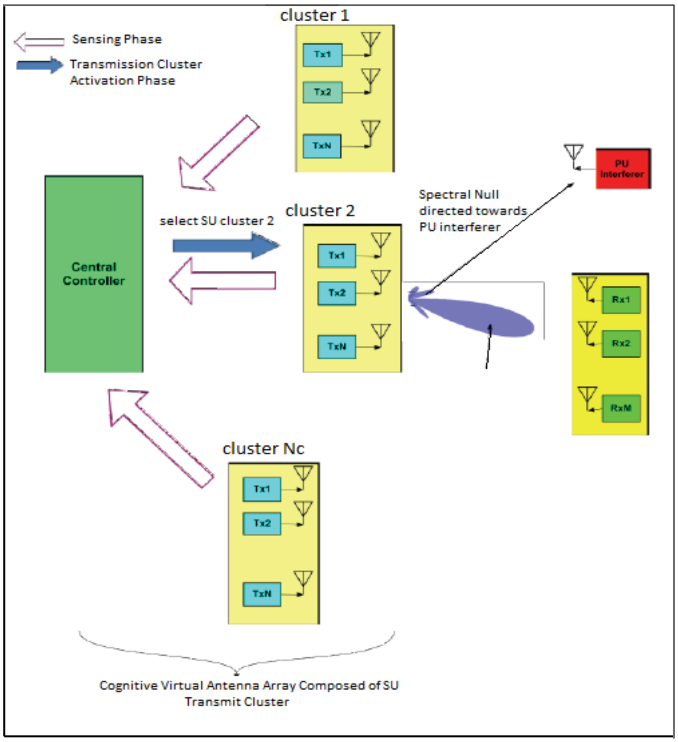


Figure 1: Beamforming using VAA

In order to solve the disturbance from the same frequency and multipath problem, the method of Spatial Spectrum Estimation Direction Finding (EDF) is more suitable. The Method of EDF can simultaneously estimate several signals' directions of arrival. Among them, Multiple Signal Classification (MUSIC) method, a high-resolution subspace method performs excellent performance with less computational algorithm [31]. In [32], an improved DOA estimation method is proposed. The MUSIC algorithm is combined with the Forward-Backward Spatial Smoothing (FBSS) technique for virtual MIMO array signals in extreme fluctuating scenarios. The resolution capability is improved compared to conventional MUSIC algorithm for the moving sources with limited array elements and also DOA can be estimated accurately when the source is much closely spaced.

Beam forming is a signal transforming system utilized within arrays for directional signal transmission or gathering. It is attained by joining elements in antenna arrays in such a way that signals at specific angles experience constructive interference. The signals in other angles will experience destructive interference. In [33], it forms an average beam pattern with side lobe peaks substantially smaller than those of the average beam pattern of the collaborative conventional. It aims to maximize the received signal power in the direction of the intended receiver while reducing the power impinging on the unintended receivers located in other directions. In order to achieve spatial selectivity, it can be used at both the transmitting and receiving ends.

In CR, PU and SU can coexist with each other. Therefore interference is a critical issue because of the spectrum sharing. So various interference cancellation techniques have to be applied to both transmitter and receiver. By exploiting SM at both Primary Transmitter (PT) and Secondary Transmitter (ST), mutual interference can be avoided. An ST is equipped with multiple antennae will act as a half-duplex decode and forward relay for the primary system. There will be 2 phases. During 1st phase, SM is invoked at PT while the ST is kept silent. By using the i-MRC technique, the ST will de-map the information block. During 2nd phase, an ST will forward the PT's data. By using i-MRC, the secondary receiver will recover its own data by detecting the transmit antenna indices of the secondary transmitter. Thus mutual interference is avoided and the primary and secondary receiver is no longer need for interference cancellation. Also, the primary user does not need to lease its time or spectrum to the secondary user for cooperation [34].

## III. Other 5G Transmission Schemes

The need for new 5G waveforms is studied in [35].The key challenge for 5G systems is the flexible and efficient utilization of non-contiguous unused spectrum available in the existing sub-6 GHz radio bands [36]. OFDM is the most widely used modulation scheme in wireless radio system below 6GHz. It exhibits some drawbacks like frequency leakage due to rectangular pulse shaping, spectral efficiency loss, need for perfect synchronization to preserve orthogonality. To overcome these limitations, several studies on various alternative waveforms such as GFDM, Universal Filter Multi-Carrier (UFMC), and Filter Bank Multi-Carrier (FBMC) etc are done over past few years. A comparison of 5G waveforms with OFDM is done in [37]. This paper evaluates the complexity of different waveforms and assesses peak-to-average power ratio, spectral efficiency, power spectral density and robustness to asynchronous multiuser transmission. It also highlighted the benefits of these waveforms for the foreseen 5G use.

### *A. UFMC*

UMFC is a derivate of OFDM combined with post filtering. It is a generalization of filtered OFDM and FBMC modulations. The full band is divided into sub-bands. The full band is filtered using filtered OFDM and individual subcarriers are filtered using FBMC. This grouping allows the reduction in filter length. To retain its orthogonality, UFMC uses QAM. UFMC transmission with Active Interference Cancellation (AIC) is presented in [38]. The advantages of AIC are incorporated into UFMC. By inserting some interference cancellation subcarriers on both sides of the PU, AIC can offset the interference to the PU caused by the SU. The proposed scheme has better BER performance and it can also reduce inter sub-band interference. In [39], cycle prefix based UFMC system is analyzed. It is analyzed in the absence of transceiver imperfections under the conditions for interference-free one tap equalization. Based on the analysis, a new channel equalization algorithm is proposed. The proposed algorithm improves the UFMC system performance. Comparison of UMFC and OFDM is done in [40]. The study clearly shows that UFMC has better performance when compared to OFDM in terms of PAPR and spectral efficiency. The guard band is no longer needed because UFMC symbols are not disturbed by the side lobe interference.

### *B. FBMC*

FBMC is considered as an alternative waveform to OFDM. It offers ways to overcome the known limitations like reduced spectral efficiency and strict synchronization requirements of OFDM. These advantages made it be considered as one of the modulation schemes for 5G technology. The waveform consists of a set of parallel data that are transmitted over a bank of modulated filters. FBMC filters each subcarrier modulated signal in a multicarrier system. The prototype filter is characterized by the overlapping factor i.e., the number of multicarrier symbols that overlap in the time domain. Prototype filter is the basis for other subcarrier filters. Comparison of FBMC and OFDM performance in multi-relay CR network is analyzed in [41]. FBMC performs better than OFDM. Network resources are optimized using dual decomposition techniques to maximize the achieved capacity while maintaining the interference introduced to the PU under a pre-specified threshold value. An FBMC scheme running at symbol rate with PAM modulation is introduced in [42]. This scheme runs at the same symbol rate that of OFDM but the number of the sub-channel is doubled. It provides a high level of spectral separation between users in the case of multi-users. Moreover, it doesn't require cycle prefix. This scheme found to appropriate for frequency domain sub-channel equalization. In [43], cognitive overlay system based on FBMC is presented. It mainly focuses on the design of a cognitive overlay system implemented on a heterogeneous Software Defined Radio (SDR) platform consisting of a laptop and USRP X310.To ensure high flexibility and low out of band emission. FBMC is used as physical layer waveform. Using feedback information on the PU error rate, the detection thresholds are optimized.

## IV. Conclusion

In this survey paper, a system of spatial modulation combined with GFDM is studied. GFDM is considered to be a potential candidate for 5G technologies. GFDM will result in self ICI and IAI when it is deployed in MIMO. In order to avoid IAI and ICI, spatial modulation is applied to the system in which the only antenna is activated at a time. Also to protect both LU and SU transmission, beam forming technique is applied to VAA. Other 5G transmission schemes such as FBMC and UFMC are also studied. The benefits of these waveforms are utilized for the 5G technologies. When compared to OFDM, UMFC is better in terms of PARP and spectral efficiency. Also, the length of the filter is constrained to that of the length of cycle prefix. GFDM and FBMC go a further step forward. Both use Offset QAM as a modulation scheme. Thus it has less distortion and reduced amplitude fluctuation.

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