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An Improved Cognitive Radio System Algorithm for Wideband Satellite-Terrestrial Wireless Mobile Network

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Research Article

Abstract

The integration of Satellite-Terrestrial networks to archieve wideband services is one among the challanges posed for Fifth Generation (5G) Wireless Mobile Communication (WMC).This research aimed at synergizing Satellite-Terrestrial Mobile Networks using Centralized Cooperative Spectrum Sensing (CCSS) technique of Cognitive Radio Network (CRN). The CCSS adopted in this work is the Listen-before-Talk (LbT) proactive method. The required threshold and waveform was attained using Feedback Filtered Orthogonal Frequency Division Multiplexing (FF-OFDM) novel scheme as an antidote. The results were validated and compared with those of Spread Slotted ALOHA (SSA) cognitive induced scheme using data transmission efficiency and throughput as performance measures. The throughput of the FF-OFDM CR system with packets transmitted (P_{tra}) was tested under null detection probability (P_{nd}) in a fixed channel state, false alarm probability (P_{fa}) in a fixed channel state, and P_{fa} in dynamic channel state; it was found to achieve an improvement over SSA CRN system by 81%, 83.4%, and 88.4%, respectively.

Keywords
Cognitive Radio Network; Satellite-Terrestrial Mobile Network; Spectrum Detection; Data Transmission Efficiency.

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1. Introduction

History has it that around the labs of twentieth century, precisely in 1894, an Italian scientist by the name of Guglielmo Marconi built up the first apparatus for long distance communication, and it was credited on him as the first inventor of radio (Odhavjibhai & Rana, 2017. Over decades, this wireless communication developed rapidly with the emergence of new devices and technology, but the communication was limited to narrowband terrestrial cellular systems. The demand for more wider and global communication services necessitate the invention of an artificial satellite (Bliley, 2017). The advent of artificial satellite to transduce EMW brought about a remarkable breakthrough in the world of wireless communication in the area of wider coverage, economy, higher data speed and many more (Sharma *et al.*, 2013). The chronicles of satellite elucidations has been really short to date but amazing (Chatzinotas *et al.*, 2015). The prime Geostationary (GEO) earth prop which is just about 50 years was set afloat to pass on communication data (Telstar 1962) (Bliley Technologies, 2017). In fewer years later (1969), Intelsat successfully launched the maiden global commercial satellites that provided telephony and broadcasting services. This giant breakthrough brought about the genesis for satellite communications (Satcom). Live images of the moon landing around the globe using television coverage was also transmitted in the same year. Recorded programme of Neil Armstrong's first steps on the moon was viewed live by over 500 million televisions worldwide. The transformation of Satcom transducers grew rapidly. The development of an Inmarsat (1979) developed a system with worldwide mobile satellite coverage in just a couple of decades, which was first to serve ships, airplanes, and nomadic purposes. The most prominent among them is Mobile Television (MT) broadcasting, which still remains the most important, viable, and economical in application in the satellite industry (Bliley, 2017). Subsequently, broadband internet services surfaced creating new problems in designing and implementing Satcom systems. The forecast for the rise of the demand in broadband frequency services is exponential and all telecommunication sectors have been struggling to accommodate these needs. Radio-communication systems do not cease to multiply to become indispensable (Odhavjibhai & Rana, 2017). In the last twenty years, veritable explosion of telecommunication services from mobile technology to wireless transmission of data was observed. This evolution has been aggravated by an increased demand in broadnand frequency resources, with various applications in entertainment, education, and business.. In order to overcome the limitation in frequencies usage, new dynamic concepts of sharing radio resources were proposed and developed. According to federal Communication Commission (FCC), in more than 70% of cases, the spectrum in both satellite and terrestrial networks is under-used

(Odhavjibhai & Rana, 2017). The restriction in frequencies usage is charaterized by current policy of static spectrum management, equipment limiations, and techonological know-how to attaind wideband services. So, new developed approaches for dynamic spectrum access or access opportunistic method also known as Cognitive Radio System (CR) technology is the most promising because it take cares of the wideband frequency demand of recent wireles gadgets. The idea of cognitive radio was first conceived and presented by Joseph Mitola III in 1998 (Ritu & Malhotra, 2016). According to Mitola "CR is a dynamic radio capable of analyzing the environment, learning, and predicting the most suitable and efficient way of using the available spectrum". Software Defined Radios (SDRs) were the confined software which were capable of handling the emerging technologies of radio. The term SDR coined by Mitola in 1992, is a reconfigurable radio system in which radio parameters support broad range of frequencies, air interfaces, application software, and has ability to change initial configuration to satisfy user requirements. CR does not only offer dynamic spectrum access but also provides ability to reconfigure its parameters according to changing environment conditions. Another advantage of CR is it compatibility with 5G technologies and techniques to produce new mitigation waveforms that could map satellite and terrestrial networks together to achieve wideband communication. The purpose of this research work is to aggresively explore and exploit the Satellite-Terrestrial Mobile Networks using integrated CR technique and FF-OFDM scheme, by converting inteference links seperating these networks into useful cognitive ones to overcome spectral wastage, thereby increasing transmission bandwidth in Gigahertz (GHz) and invariably improve systems throughput.

2. Review of Related Works

This section presents the review of some relevant and recent literature on wideband spectrum sensing. The section explains different techniques and algorithms that were proposed and implemented by other researchers to deal with the challenges of data transmission and throughput. This review provides improvements and also highlighted limitations in various proposed techniques.

Jia *et al.*, (2016) developed a Spread Slotted ALOHA (SSA) novel scheme based on multichannel and multiuser CRN dummy applied to satellite communications. In order to explore and dig out information of Mobile Satellite Earth Stations (MSES), a novel joint collaborative spying approach was also used in the sensing stage. Furthermore, an enhanced SSA strategy in the transmission phase was adopted and compared with the conventional Slotted ALOHA (SA) to obtain greater throughput. The system throughput with imperfect channel detection, perfect channel or fixed idle channel number were used for the simulations, where the important parameters were defined as $\xi = -15$ dB and Pd = 0.9. When NIL = 1, the throughput proneness with Packets Transmitted (P_{tra}) appreciate first and then decline. This is because with the rise in P_{tra}, the amount of packets entering in a slot rises and the throughput also rises. Consequently, it was outrageous for the receiver to gather and interpret the packets because of the rise in amount of the packets entering in a slot on single channel. In view of this, the throughput reduces if P_{tra} surpass a particular stage. In the situation where NIL = 3, the throughput improved as P_{tra} rises because the interference stage was often accommodated. Additionally, it was seen that, when NIL = 0, the SSA transmission dummy is equivalent to conventional ALOHA. It was so glaring that using SSA will obtain more successful transmission and greater throughput. Though, this work gave better approach of the cognitive network by considering the entire narrowband and wideband infrastructures that induced the EM wave in the global radio village which amount the spectrum scarcity in question. Hence the performance degrade with increase of SUs packets in the PU domain which result in some useful bandwidth laying waste. Liu *et al.*, (2016) adopted a Sensing-Before-Transmit Media Access Control Protocol (SBT-MAC), in which an SU may view vacant licensed frequency bands without causing any havoc to the PU via spectrum spying performing before transmission. The authors presented a Cooperative Bandwidth Spectrum Sensing (CBSS) due to the limitations of the Primary Network (PN) outage, where the SU spied the PU's signal in the observation slot, then sent its observation information to a fusion center in the reporting or feed-back slot, and the fusion center made final decision on the occupancy of the PU channel. A weighed cooperative bandwidth spectrum sensing was integrated in the implementation to boost the sensing performance and decrease the interference to the PN throughout in the whole transmission channels of the CRN. The P_d by the weighed and unweighed cooperative sensing methods, with various P_f probabilities was compared. Result showed that P_d improved as P_f decreased. Because P_d and P_f have the same monotony in λ; P_d of weighed cooperative sensing was larger than that of unweighed cooperative sensing with about 0.1%. However, these two methods when incorporated degraded the effectiveness of entire bandwidth, specially when shared in time slots, thus can cause a severe interference to the PU if it reappears suddenly. Lee *et al.*, (2015) proposed a Fast Spectrum Sensing with Coordinate (FSSC) system to obtain both short sensing time and a high rate of detection in order to improve system throughput. FSSC is a novel technique that decomposed a spectrum with high complexity into a new coordinate system of salient features and uses these features in its PU detection process. FSSC allowed the space of a buffer to store the information about a PU avalaibility also make the sensing process fast. The magnitude of this information rises when a PU exists, alternatively, it would fall when a PU does not exist. The communication channel between the transmitter and the receiver was assumed to be an AWGN channel, and the SNR at the receiver was assumed to be between –30 dB and 0 dB. The FSSC algorithm was compared with eight other spectrum sensing technique, whereby the information of a PU was a prerequisite to the bandwidth increased. The parameters that were used in the comparison and simulations were: n = 5,000; L = 10; and Pfa = 0.1. Result showed that FSSC algorithm gave a better detection performance than the other conventional spectrum sensing techniques with an appreciable SNR of -24dB and an average sensing time of 0.0534(ms). In addition, the FSSC algorithm consumes little memory, requires little computational burden, and has a short sensing time. However, FSSC is only suitably applied in narrow bands spectrum technique, hence makes it less effective when adopted in wideband transmission scenarios. Mabrook, (2018) deployed a CR spectrum sensing approach focused on satellite and space commutations to improve system throughput. He proposed a scenario based on cooperative sub-Nyquist wideband sensing. Sub-Nyquist wideband was run on a Nano-Computing process which was highly required to achieve real-time communication for spectrum sensing in cognitive radio due to the intensive required computations. The simulation result of the proposed scenario showed that it efficiently save frequency resources from congestion, overcame spectrum underutilization problem, noise, and interference problems with an accurate reconstruction. Although, the major challenge of these methods was the requirement of Nyquist sampling rate that resulted in implementing Analog to Digital Converters (ADCs) with higher sampling rates, higher consumption of energy, and more design complexity. Hence, this sensing model is more suitably applied to frequency reused scenario, where the demand for an increase radio channel capacity without an increase in radio spectrum in a densely populated area is required. Furthermore, the downlink and uplink analysis was reversed which result to bandwidth wasted and underutilization of channels. Pandi & Kumar, (2017) integrated Cyclostationary Feature Detection (CFD) with an OFDM system to improve spectrum efficiency and also optimizing system throughput. Cyclostationary feature detection was been considered with OFDM scheme because of its unique spectrum sensing skills and also it required less SNR for detection when compared to other methods. Furthermore, it allowed for detection of free portions of licensed user spectrum in its vicinity and it also allocated free spectrum to unlicensed users. The limitation with this work is that, cognitive radio can only detect the cyclostationary signal when both licensed and unlicensed users are cyclostationary in nature. Hence, this affect the bandwidth because it was very difficult to detect the presence of licensed users, when licensed and unlicensed users are transmitting in the same channel. Shobana *et al.*, (2013) employed an uncertainty to improve system throughput, that is, if the signal is present or not could be facilitated if the signal was passed through a filter, which could accentuate the useful signal, sig(t) and suppressed the noise, w(t) at the same time. The filter was designed in such a way that it could pick out the signal component at some instant and suppressed the noise amplitude at the same time. This gave a sharp contrast between the signal and the noise. If the signal, sig(t) was present, the output could appeared to have a large peak at this instant. If the signal was absent at this instant, no such peak could appear. This arrangement made it possible to decide whether the signal was present or absent with minimum probability of error. The filter that accomplished this purpose was the matched filter. From the matched filter output the threshold had been determined as per the discussion above and the signal energy which crosses the threshold was considered to be the primary users' presence. Here the threshold is estimated to be 0.5098. From the matched filter output, it is clear that all the signal symbol energy crosses the threshold, hence the number of detections was 188. Although, the method proved promising in icreasing system throughput, it had the limitation of been effective only on single channel state scenario and less effective when considering neighboring channels in the entire bandwidth.

3. System Modeling

Wireless mobile communication is mainly using synthetic satellites and terrestrial props on the Earth to provide communication links between different points, as presented in Figure 1 (Mabrook, 2018). It plays an important role in the global telecommunication system. WMC is classified into two main parts;

i) The ground segment that is based on users and dynamic or stationary transmission.
ii) The satellite, which is basically the reception and the radio segment.

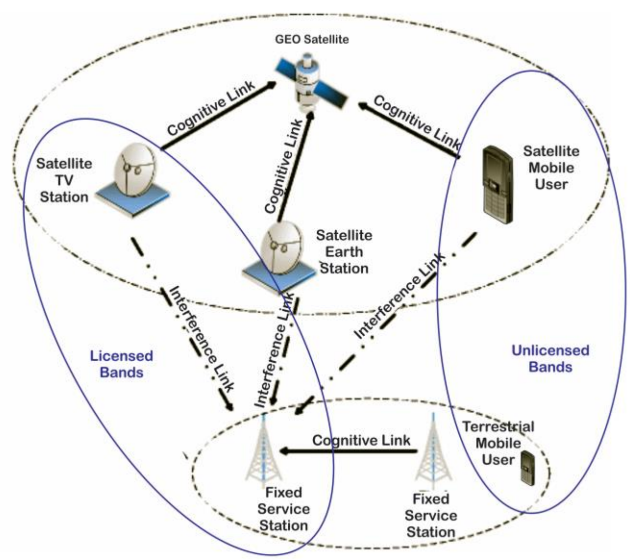

Figure 1: Wireless Mobile Communication Links.

The WMC links include transmitting the signal through a "down-linking process" from the Fixed Ground Station (FGS) to the Onboard Satellite (OS) that receives, amplifies the received signal, then the satellite retransmits the signal to Satellite-Terrestrial Earth Terminals (STETs). These STETs communicate with the FGSs and OSs via an "up-linking process (Jia *et al.,* 2016). The FGS props are the Licensed Users (LUs), while the STETs are the Unlicensed Users (UUs). The OS is the Fusion Centre (FC), while the STETs are the Base Stations (BSs) and Mobile User Equipment (MUE). In this representation, the GEO satellites are the FCs. The model consist of N FGSs, K STETs, and X FCs, which are separated by interference links and connected by cognitive links as illustrated in Figure 1. Many researches are developed to enhance both Fixed Services (FSs) and Mobile Services (MSs). The MSs have been utilized to provide broadband communication services for both stationary and dynamic users at many fields (Jia *et al.,* 2016), such as: mobile networks, aerospace, ships, trains, vehicular, military sectors, and emergency areas where terrestrial networks cannot be deployed (Mabrook, 2018).

4. Channel Modeling

Figure 2 demonstrates the common CCSS shell design as depicted for a CRN, where each shell incorporates of spying slot, N_S feed-back slot, N_R and transmission slot, N_T (Li *et al.,* 2017). The GEO satellite processing time and propagation time are ignored. The performance method adopted for this representation is described in two stages, which are the Detecting Stage (DS) and the Transmission Stage (TS) to obtain an increase in system throughput. The STETs first sense the licensed stations in the sensing stage and then transmits data in the transmission stage via the unused stations using CCSS technique that is integrated with FF-OFDM scheme for optimal spectrum detection and data transmission. To avoid transmission conflict with the LU, the STETs need to deploy a highly effective sensing scheme. The technique of CCSS is been adopted in this research work to control the harmful impact of multipath fading, shadowing, and hidden node problems. To mitigate analysis complexity, the stations between STETs and the GEO props are set as dormant. That means the channel gain, channel noise, and near-far effect are not taken into cognizance. The more optimal the sensing phase, the more spaced is data transmission and invariably increase the system throughput.

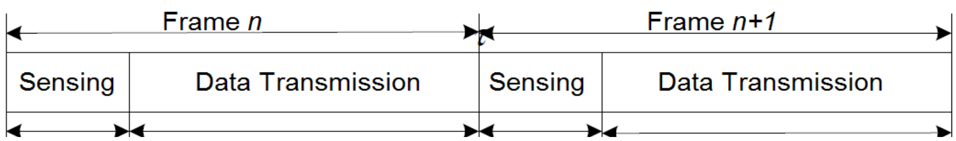

Figure 2: Frame Structure for Optimal Spectra detection and Data Transmission

5. Mitigation Techniques

To address the new challenges in recent wireless devices and 5G network, various types of modulation schemes have been proposed for filtering, pulse shaping, and pre-coding to reduce the signals Out-of-Band (OoB) emission and leakage current caused by adjacently placed antennas or signals (Cai *et al.*, 2019).

In this work, a novel scheme known as Feedback Filtered Orthogonal Frequency Division Modulation (FF-OFDM) has been used to mitigate the effect of Inter Symbol Interference (ISI), Peak to Average Power Ratio (PAPR), and also to avoid transmission conflict. From the scope of this work, CCSS is also adopted to optimize STET's channels detection, especially when the FGS is shadowed or is in severe multipath fading (Liu *et al.*, 2016). The CCSS of CRN is hybridized with an FF-OFDM scheme to improve the STETs channel accessibility and transmission rate in the LUs frequency bands. For example, the STET1's detection performance is inaccurate because of the shadowed FGS, but with the aid of STET2−STETK, STET1 makes an accurate decision through sharing of the sensing information from other STETs to improve throughput as depicted in Figure 3.

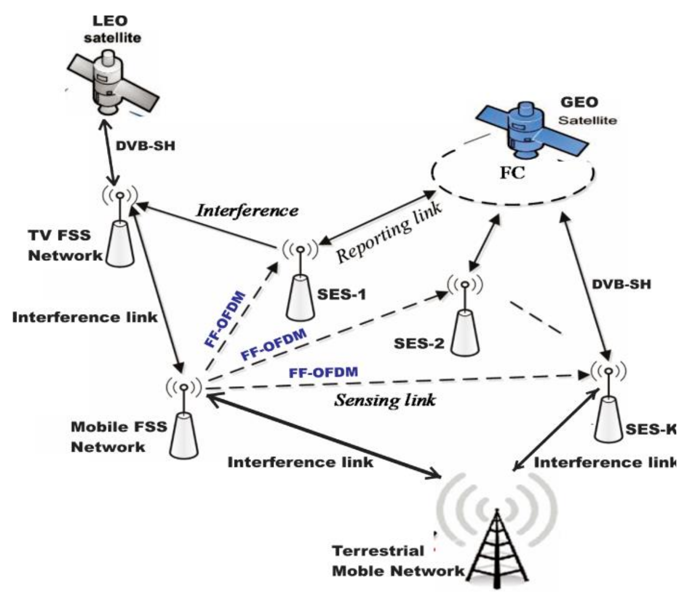

Figure 3: System Model of the CCSS using FF-OFDM.

Each STET in WMC performs channel detection duties during the detecting phase (sensing time and reporting time) by converting interference links into cognitive links using the hybridized FF-OFDM CRN signal waveforms expressed in equation (1). Immediately the GEO satellite receives the spied information from the STETs, it rebroadcasts it to the global STETs to transmit packets on the identified inactive frames. It is essential for the GEO satellite to conduct proper channel observation to avoid failed transmission and also harmful interference with STETs of other PUs. This observation is determined by the probability of minimal false alarm, P_{fa}^{min}, probability of missed detection, P_{md}, probability of spectrum detection, $P_{d,}$ and the probability of spectrum null detection, P_{nd}. If the channel state observation by the GEO prop is considered not perfect, it denotes P_{nd} is not 1 and P_{fa} is not 0. If a frame is unused, GEO prop observe this frame as free with the uncertainty of $1 - P_{d,}=P_{nd}$. Consequently, the GEO prop claims a busy frame as free with the uncertainty of $1 - P_{nd}=P_{fa}$. The relationship between P_{fa}^{min} and P_{nd} for optimal detection of inactive frames (Liu *et al.*, 2016) is expressed as:

$$P_{fa}^{min} \leq Q\,[\sqrt{2\Psi}\xi + 1Q^{-1}(P_{nd})] + \xi\sqrt{\frac{T_{Smf_s}}{2}}\sum_{i=1}^{k} w_i|g_i|^4 \qquad (1)$$

where:

ξ is the ratio to SNR
K is number of SU samples
Ψ is the measurement matrix at l^{th} slot of k^{th} SU.
f_s is the wideband sampling frequency.
w_i is the AWGN and is given as.
g is the signal gain.

$$w_i = |g_i|^2 \Big/ \sqrt{\sum_{i=1}^{k}|g_i|^4} \qquad (2)$$

Q is defined as the Q –function expressed as:

$$Q\,(x) = \frac{1}{\sqrt{2\pi}}\int_{x}^{+\infty}\exp\left(-\frac{y^2}{2}\right)dy, \qquad (3)$$

P_{nd} is the induced FF-OFDM spectrum null detection waveform, considering that the PU is absent and is express as:

$$P_{nd} = 1 - Q\left(\frac{\lambda-(r_{\varphi}g)^T\Psi^T(\Psi\Psi^T)^{-1}\Psi r_{\varphi}g}{\sigma_n\sqrt{(r_{\varphi}g)^T\Psi^T(\Psi\Psi^T)^{-1}\Psi r_{\varphi}g}}\right) \qquad (4)$$

6. Flowchart of the Developed Algorithm

The operational principle of this developed scheme in Figure 4, which is a compressive and detailed version of channel accessibility in Figure 1, 2, and 3, expressed the diagrammatical procedure for improved data transmission and invariably increasing system throughput. The FF-OFDM induced CRN signal in equation (1) is a hybridized signal waveform. The integrated CRN FF-OFDM signal waveform, because of it threshold achieved a frame accessibility which is suitable for 5G network compared to integrated CRN SSA which could only achieve channel accessibility for LTE-A network. This developed algorithm has improvement in reducing the round trip delay and increased the transmission bandwidth to increase system throughput. The hybridized signal also has the following seven properties.

i) It speed up the signal processing in GHz to reduce the round trip delay among UEs.
ii) It adjust transmission dynamically and autonomously, using Dynamic Spectrum Access (DSA) and Software Defined Radio (SDR).
iii) It explore and exploit the entire radio spectrum to maximize the system bandwidth. İt has the ability to switch off it sub-carrier where the PUs exist and continue transmission in next time frame.
iv) Priotized idle chennel because of it threshold, to detect signal at a very low power. This has positive effect of interference avoidance.
v) Has the ability to suppress noise and accentuate useful signals.
vi) Provide seamless operation and switching among UEs.

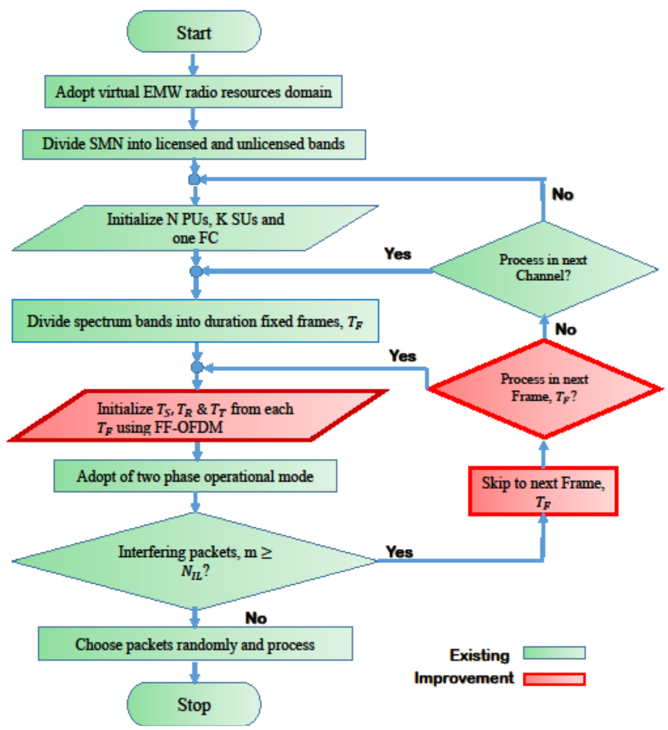

Figure 4: Flow Chart of an Improved Spectrum Detector and Data Transmission using FF-OFDM

7. Data Transmission

To obtain the network throughput, the users' Information Transmission Rate (ITR) is calculated first (Song *et al.*, 2017). Before transmission, the STETs have to wait for the reporting time, T_R information from the GEO satellite after detecting a transmission slot (Jia *et al.*, 2016). When PU's absence is determined, the STETs are immediately assign inactive channels by the GEO satellite to transmit data using the FF-OFDM CRN agility in the transmission phase. If the LU's presence is determined, the STETs have to skip to another inactive frame by simply turning off some subcarriers where LUs exist (Xin *et al.*, 2016).

In FF-OFDM, the transmission nodes are assigned orthogonal codes to avoid collision. Each transmission node has its own code set described by, N_C. The detailed transmission process is illustrated as follows: If a single packet is set up, it is initially assigned randomly among the code sets. It can be seen from equation (5) and (6) that STET accesses an inactive channel broadcasted by a GEO prop at the transmission length time, T_{Tm}, send packet with a specific probability of success, as:

$$T_{Tm}=\eta_1 T_{Sm} \quad (5)$$

where, T_{Sm} is the sensing length time and η_1 is the STETs transmission signal coefficient.

The transmission length time, T_{Tm} is the basic unit of transmission time, T_T which consists of the total number of transmission slots time, N_T expressed as follows (Jia *et al.*, 2016):

$$N_T=T_T/T_{Tm}. \quad (6)$$

Supposing T_{Sm} is equal to T_{Tm}, it is obvious that more than one STET from different FCs transmits packets in the same inactive legacy channel, M which means two or more packets, m_n of different code address may overlap in the same frame. To mitigate this, a lower threshold, N_{IL} generated from FF-OFDM induced waveform is set. It is assumed that the GEO satellite can only detect the presence of PU with priority of one packet appearance per frame, which is observed by the rise in the signal magnitude of the first incumbent occupying a frame. Furthermore, if more than one STET transmitted packets arrived on one inactive frame in a slot, only one STET packets will be processed. Secondly, if the packets are transmitted successfully, the GEO prop announces the feed-back on which frame packets are matched. If the packet is declared as failed transmission, the STET turns off it sub-carrier and shift to another frame to retransmit. Therefore, the CRN's transmission efficiency (Xin *et al.*, 2016) is given as follows:

$$\mathrm{C} = \frac{W_t[P(1-Pfa)f_0+P(1-Pnd)f_1}{W} \quad (7)$$

where:

C is the data transmission efficiency.
P is the SU's transmission power.
W is the PU channel bandwidth.
W_t is the SU transmission bandwidth in GHz.

The number of packets that are transmitted per time slot using FF-OFDM scheme is expressed as follows:

$$m_n = 2^{T_{Tm}} - 1 = N_{IH} \quad (8)$$

Where the transmission window, T_{Tm} has a value of 3ms at 46% improvement in the case of non-contention based FF-OFDM and m_n is the minimum number of packets per frame slot, N_T. Therefore, $m_n = 2^3 - 1 = 7$ interference packets per frame slot.

8. System Throughput

The number of successful packets transmitted per spying slot connotes the throughput, and is the evaluation benchmark of this representation (Jia *et al.*, 2016). The three simple evaluation conditions here are:

i) The SESs under a fixed channel state will give a perfect findings if the PU frames are inactive.
ii) The SESs will give an imperfect findings if some of the PU frames are active under are fixed channel state.
iii) The SESs will also give an imperfect finding if the PU access and channel occupancy rate is dynamic.

The throughput changes under perfect findings (P_{nd}) and imperfect findings of (P_{fa} and P_{md}) under fixed and dynamic channel state.

The dormant frames, M are formulated as the average number of successful transmitted packets within one transmission slot as:

$$S^*_{tot}(P_{tra}, M) = \sum_{i=1}^{M} S^r_{suc}\ \mathrm{M}S^*_{ave}$$

$$=\sum_{z=1}^{N_{IL}+1} \binom{k}{z} \left(\frac{P_{tra}}{M}\right)^z \left(1-\frac{P_{tra}}{M}\right)^{k-z} \left(1-\frac{1}{N_C}\right)^{z-1} \quad (9)$$

Therefore, the throughput of the perfect findings of a fixed channel state (Jia *et al.*, 2016) is depicted as follows:

$$S^*_{sys}(P_{tra}, M) = T_T(T_S^{(-1)} + T_T^{(-1)} + T_T^{(-1)})S^*_{tot}(P_{tra}, M) = T_T(T_S^{(-1)} + T_T^{(-1)} + T_T^{(-1)})S^*_{tot}S^*_{tot}(P_{tra}, M) \quad (10)$$

where:

S^*_{sys} is the system throughput.
P_{tra} are the packets transmitted.
M are the number of free frames.
S^*_{tot} is the total number successful packets transmitted per frame.
T_T are transmission time.
T_S are the sensing time
T_R are reporting time on the sensing phase

Thus, the throughput of a fixed channel system with imperfect findings is:

$$S_{sys}\,(P_{tra}, M) = \frac{\binom{N}{M}(1-Pfa)}{N_{free}(\mathrm{M})} S^*_{sys}(P_{tra}, M) \quad (11)$$

Finally, the system throughput with imperfect findings and dynamic channel states is obtained as follows (Jia *et al.*, 2016):

$$S_{sys}\,(P_{tra}, q)\mathrm{E}[S_{sys}\,(\mathrm{M}, P_{tra})] = \sum_{m=1}^{N} S_{sys}\ (P_{tra}, m_x)\, P_{idle}\,(m_n, q) \quad (12)$$

The percentage improvement of the system throughput versus packets transmitted, P_{tra} of the integrated FF-OFDM CRN scheme over SSA CRN used in the work of Jia *et al.*, (2016) is given as:

$$\text{Percentage Improvement} = \frac{\Sigma New\ Scheme - \Sigma Original\ Scheme}{\Sigma original\ Scheme} \times 100\% \qquad (13)$$

9. Results and Discussion

This section provides the list of parameters used to evaluate the performance of SU's spectral efficiency and throughput for data transmission. It also provides specification for extensive computer simulation using MATLAB R2018a to evaluate the performance of SUs when CSS of CRN is integrated with FF-OFDM. In the simulation, the PU radio bandwidth, W = 3kHz - 300GHz. SU transmission bandwidth, W_t= 10GHz. SU transmission power, σ_s^2 = 10dBmW. Number of FGS, N=10. Number of SESs, K=6. Number of OS, X=1. Noise power, σ_n^2= -10dBmW. Channel gain between PU and SU, h = -10dBmW. Channel gain among SUs, g = -0dBmW. ITR from among SUs = 10Gbps. GEO Satellite height, H = 64,000km. Number of transmission slot, N_T=100. SESs transmission signal coefficient, η_1=120.

Using FF-OFDM scheme as a catalyst, a $\boldsymbol{P_{fa}}$ = 0.02 and $\boldsymbol{P_{nd}}$ = 0.98 was achieved.

These parameters were adopted for the purpose of validating the FF-OFDM CRN MATLAB results with those of SSA CRN of the work of Jia *et al.*, (2016) for optimal spectrum sensing time in MSN.

9.1 Throughput under Perfect Channel Observation in a Fixed Channel System

Figure 5. shows the simulation result of system throughput with pefect channel observation in a fixed channel states tested over SSA CRN scheme versus FF-OFDM CRN scheme using equation (10). Here, the SSA CRN transmission model were compared with the model of this work to see which algorithm performes better in a fixed channel state. It was observed from the result that both models perform closely when the inteference packet, N_{IL} = 1 at low $\boldsymbol{P_{tra}}$ level, but when $\boldsymbol{P_{tra}}$ is large enough, a wide variation is observed. The throughput of the integrated FF-OFDM CRN model outperformed that of the SSA CRN by 81% in terms of higher $\boldsymbol{P_{tra}}$. This was because the SSA CRN scheme has maximum inteference limit of 3 and that of FF-OFDM CRN interference limit attainment is 7 as obtained using equation (8). This has positive effect in improving accuracy and quick channel access because the threshold set by FF-OFDM scheme explored and maximized the entire radio frequency bandwidth usage.

Table 1: Percentage Improvement of Throughput for P_{nd} using FF-OFDM over P_d using SSA.

Scheme	Improvement	
	Average Throughput (GHz)	Percentage Improvement
SSA FF-OFDM	56.7 102.6	81.0%

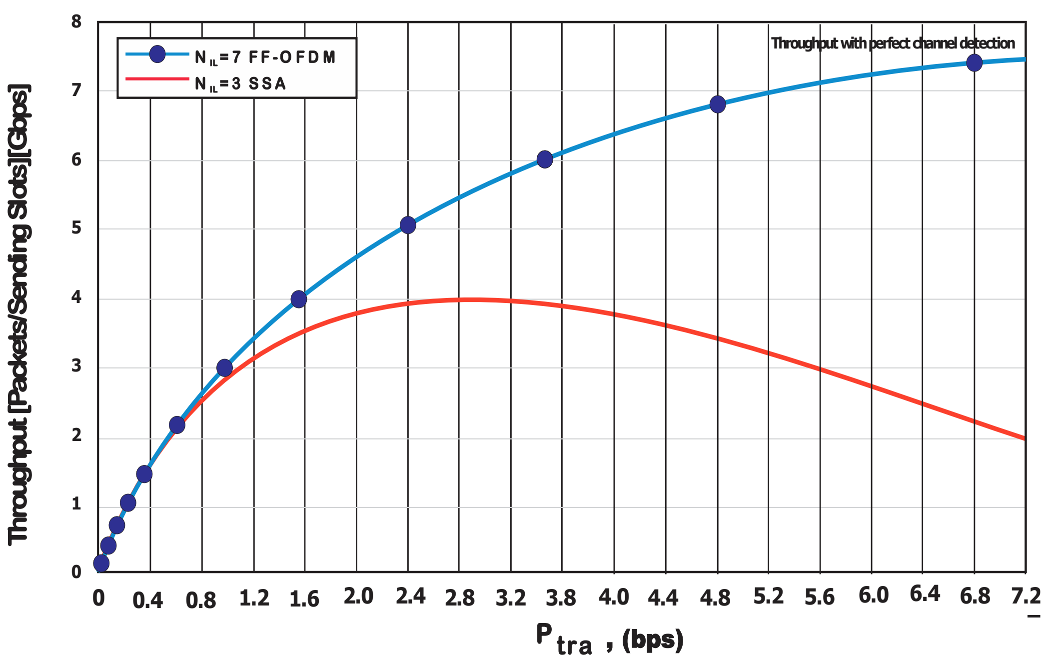

Figure 5: Plot of Throughput with P_{nd} in a fixed Channel State

9.2 Throughput under Imperfect Channel Observation in a Fixed Channel System

Figure 6 denotes system throughput simulation under imperfect stage finding, P_{fa} with fixed dormant channel state. The important parameters are connoted as $\xi = -15$ dB and P_{nd} = 0.98. When N_{IL} = 0, the SSA transmission dummy is equal to conventional ALOHA, but when SSA interference packet is N_{IL} = 3, the throughput with $\boldsymbol{P_{tra}}$ rises first and then declines. This is because the more the boost in $\boldsymbol{P_{tra}}$, the more the number of packets arriving at a slot and consequently, the throughput get boosted. The interfering threshold level makes it more difficult for the receiver to decode and dispread the packets. For this reason, the throughput reduces when $\boldsymbol{P_{tra}}$ exceeds a particular level. In the situation of FF-OFDM CRS where N_{IL} = 7, throughput is boosted with rise in $\boldsymbol{P_{tra}}$ because the interference level is highly accommodated. Thus, it is evident from Figure 6 that the system achieves more successful transmission when FF-OFDM strategy is implemented in an imperfect domain because the scheme has the ability to turn off it subcarriers where the primary user exist and transmit in the next time frame, be it in terrestrial or satellite network. The simulation result of Table 2 was obtained from equation (11).

Table 2: Percentage Improvement of Throughput for P_{fa}^{min} using FF-OFDM over P_{fa} using SSA.

Scheme	**Improvement**	
	Average Throughput (GHz)	Percentage Improvement
SSA	49.9	83.4%
FF-OFDM	91.5	

9.3 Throughput under Imperfect Channel Observation in a Dynamic Channel State

Figure 7 illustrates SUs spectrum utilization efficiency under imperfect channel detection, $\boldsymbol{P_{fa}}$ with dynamic channel state over increased $\boldsymbol{P_{tra}}$. The important parameters are explained as q = 0.4, $\xi = -15$ dB, and P_{nd} = 0.98. The simulation results validated that SU spectral efficiency, C was a unimodal convex function with regard to sensing time, $\boldsymbol{T_s}$. There indeed exist one optimal point for $\boldsymbol{P_{nd}}$ of SU's sensing accuracy and a maximized SU's transmission efficiency as depicted in equation (7). It is observed from the result in Figure 7 that the SE of SSA scheme increased and also decreased when $\boldsymbol{P_{tra}}$ exceeded the interference limit, but for FF-OFDM CRN inbuilt scheme, the interference packets achievement and throughput were higher than that of the SSA using equation (12). This was because 1 - P_{fa}^{min} = $\boldsymbol{P_{nd}}$ = 0.98 at a percentage increase of 88.4 over SSA scheme was attained. The ability of FF-OFDM CRN to detect signal at a very lower power as -10 dB, makes it have a prior information to turn off some subcarriers to avoid harmful interference if PU eventually reappeared, made it to explore all usable bandwidth of the PUs in minimal time. However, this made its performance better than SSA CRN in terms of $\boldsymbol{T_s}$ accuracy and $\boldsymbol{P_{tra}}$ which increased SE as well as throughput.

Table 3: Percentage Improvement of Throughput under Imperfect Channel observation in a Dynamic Channel State.

Scheme	**Improvement**	
	Average Throughput (GHz)	Percentage Improvement
SSA	45.05	88.4%
FF-OFDM	84.85	

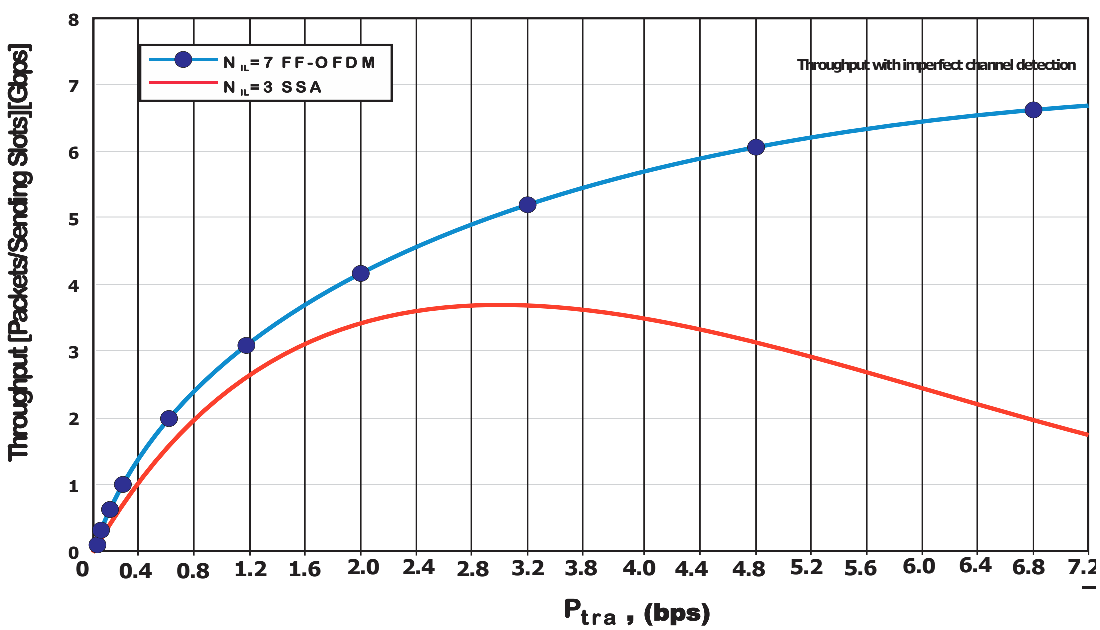

Figure 6: Plot of Throughput with $\boldsymbol{P_{fa}}$ in Fixed Channel State

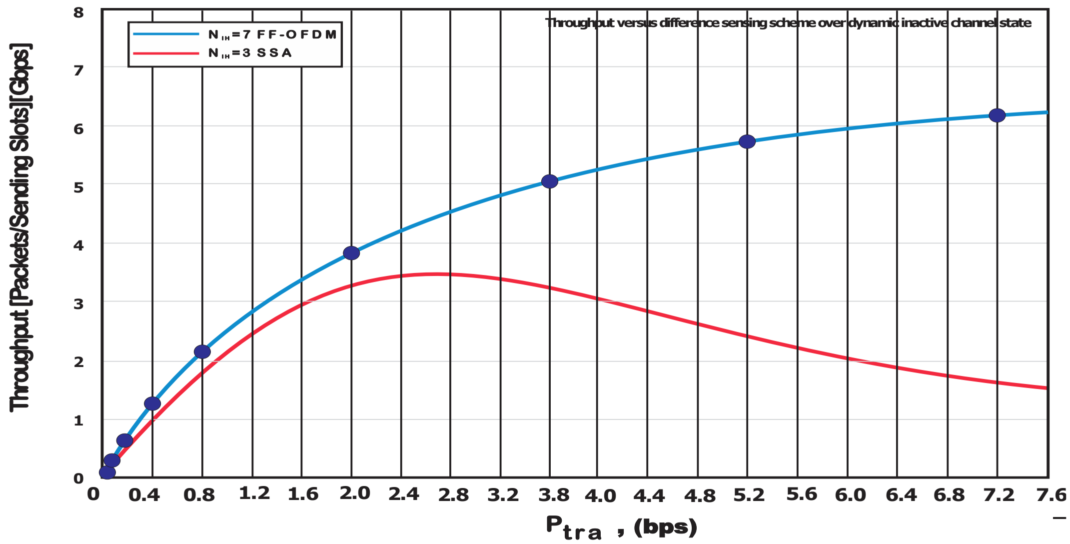

Figure 7: Plot of Throughput with P_{fa} in Dynamic Channel State

10. Conclusion

The advent of new technologies and the proliferation of wireless devices really brought about the need for increase in system throughput in wireless moble network. The successful synergyzation of satellite-terrestrial network in this work has demonstrated a promising technique that proffered a solution for effective utilization of the spectrum for wideband network to meet the requirement of modern devices and services. This was achieved using FF-OFDM novel scheme integrated with CRN to break the inteference links between satellite-terrestrial networks into cognitive links to attain wideband services. From the results obtained, it showed that the integration of CRN with FF-OFDM can solve the problems of data transmission rate and system throughput of recent and future wireless mobile devices.

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