Received November 14, 2017, accepted December 14, 2017, date of publication December 25, 2017, date of current version February 14, 2018.

Digital Object Identifier 10.1109/ACCESS.2017.2787200

Dual PHY Layer for Non-Orthogonal Multiple Access Transceiver in 5G Networks

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This work was supported by the COMSATS Institute of Information Technology, Lahore, Pakistan.

ABSTRACT Non-orthogonal multiple access (NOMA) is a promising multiple access technique, proposed in literature for the fifth generation (5G) mobile networks. The NOMA system model consists of the conventional orthogonal frequency division multiplexing (OFDM), as a pulse shaping technique in conjunction with a variable power domain for various users, allocated in proportion to each user's channel gain. OFDM technique based on wavelet filter banks, namely wavelet OFDM (WOFDM) has been utilized in digital communication to improve the system robustness to noise and adjacent channel interference, and is therefore anticipated to be adopted for the NOMA technique. WOFDM in NOMA (WNOMA) outperforms OFDM-based conventional NOMA (CNOMA) with reference to interference mitigation, bandwidth efficiency, spectral confinement, and multi-user capacity. Most of the fourth generation (4G) networks are based on OFDM and its variants. Therefore, in this paper, keeping in view the interoperability with the 4G networks and the latency requirements in 5G, a dual physical layer based on conventional OFDM and WOFDM as pulse shaping methods, is proposed for the NOMA transceiver. Performance of WNOMA and CNOMA is analyzed for bit error rate in the presence of channel impairments including additive noise and IQ imbalance and multiuser capacity is also computed. Comparison of various parameters indicates the advantage of adopting WNOMA over its conventional counterpart for relatively poor channel conditions.

INDEX TERMS 4G mobile communication, data communication, discrete wavelet transform, intersymbol interference (ISI), non-orthogonal multiple access (NOMA), orthogonal frequency division multiplexing (OFDM), PHY layer, pulse shaping methods.

I. INTRODUCTION

Fourth generation (4G) mobile communication systems have revolutionized the voice and data communications and made a global impact using techniques such as long-term evolution (LTE), WiMAX and LTE advance [1]. Most of the mobile networks included in 4G are based on traditional orthogonal multiple access (OMA) schemes such as, time division multi-access multiple access (TDMA), frequency division multiple access (FDMA) and code division multiple access (CDMA). In each of the OMA techniques, the user capacity is constrained due to orthogonality of time slot, frequency band, or code.

With the emerging applications like internet of things (IoT) and ubiquitous mobile connectivity through mobile communication systems, conventional OMA techniques are unable to meet the exponentially growing demands of multiuser capacity [2]. Therefore, researchers have concentrated attention towards the efficient design of the next generation of mobile networks, that is the fifth generation (5G). Non-orthogonal multiple access (NOMA) is a multiple access technique that is considered more suited for 5G networks for resource allocation between multiple users [3]. In power domain NOMA, each user operates in the same band and time slot, while using different levels of transmit power. Various users' information is superimposed at the transmitter side for uplink in NOMA, while successive interference cancellation (SIC) is used to retrieve each user's information in the downlink channel [4]. FFT-OFDM is utilized for pulse shaping in conventional NOMA that has its share of pros and cons. The pros include reduced latency and simplified channel equalization techniques, whereas cons comprise of bandwidth inefficiency due to cyclic prefixing and reduced noise immunity because of rectangular pulse shaped carriers [5].

In 5G multiple access communication systems, exchange-to-exchange (E2E) latency is expected less than 5 $milli\sec onds$, high data rates ranging from 6 $Gbps$ to 50 $Gbps$, and spectral efficiency is expected to be 10 bps/Hz or higher [6]. Of these attributes, higher bandwidth and greater reliability can be achieved using discrete wavelet transform in OFDM (WOFDM) for waveform shaping in NOMA. Wavelet filter bank based OFDM has been established as a pulse shaping technique that offers greater bandwidth, since it does not employ cycle prefix (CP), and offers greater immunity to channel noise due to excellent spectral confinement of its side lobes compared to FFT-OFDM [7]. Therefore, WOFDM can be effectively used as a waveform shaping technique for NOMA in 5G applications [8]. A NOMA transceiver that utilizes FFT-OFDM for pulse shaping, is termed conventional NOMA (CNOMA) in this article, whereas the transceiver employing WOFDM for pulse shaping in NOMA is referred to as Wavelet NOMA (WNOMA).

A. PRIOR WORKS

Filter bank multi-carrier (FBMC)/Offset QAM (OQAM), filtered multitone (FMT) and cosine modulated filter banks (CMFB) are some of the variants of filter banks based multi-carrier modulation (MCM) techniques [5]. Researchers explore linear modulation techniques, as alternatives to the OFDM technique in 5G [9]. Research works have evaluated the performance of WOFDM in various scenarios, and presented it as a robust communication technique in comparison with FFT based OFDM technique [10]. Its high spectral efficiency and spectral confinement, robustness to intersymbol interference (ISI) and inter-carrier interference (ICI) in case of radio frequency (RF) impairment of carrier frequency offset (CFO), make it one of the significant candidates for 5G transmission waveforms [5]. WOFDM based PHY sub-layer has been proposed for powerline communications in IEEE P1901 standard, as one of the dual PHY sub-layers [11].

Authors have explored the possibility of adopting WOFDM as a pulse shaping technique for NOMA in 5G in [12]. They have proposed a wavelet filter bank based NOMA transceiver and presented its supremacy over conventional FFT based NOMA in terms of peak-to-average-power-ratio (PAPR), power spectral density (PSD) and spectral efficiency, through simulated results [12], [13]. Therefore, recent works in literature propose WOFDM as a pulse shaping technique for NOMA, thus providing motivation for its further evaluation and inclusion as a sub-layer in a dual PHY layer structure, as is proposed in this article.

B. CONTRIBUTION

In this article, we aim to acquire the benefits offered by FFT-OFDM as well as WOFDM for NOMA transceivers, therefore we propose a dual physical layer (PHY layer) architecture for NOMA transceiver, of which one layer will be dedicated for conventional FFT-OFDM and the other layer will be for WOFDM, as pulse shaping techniques. The proposed dual PHY layer architecture is presented and its performance is described with reference to various parameters. It is anticipated that this architecture will ensure robustness and spectral efficiency in addition to interoperability and compatibility with 4G communication systems.

C. ORGANIZATION

This article is organized such that section II presents the system model for conventional NOMA, and the significance of pulse shaping techniques is described in section III. Section IV explains the system model of the proposed dual PHY layer NOMA transceiver. Performance comparison of conventional CNOMA with WNOMA for the dual PHY layer NOMA is given in section V. Section VI elaborates future applications and challenges in view of the proposed dual PHY layer NOMA for 5G communication followed by conclusions drawn in section VII.

II. SYSTEM MODEL FOR NOMA

OMA techniques have been widely adopted in various communication standards, for the advantages offered to counter the channel noise and interference through the orthogonality of either time, frequency or code [14]. However, OMA techniques are considered suboptimal compared to NOMA techniques, with reference to the channel capacity. The adaptive allocation of channel subcarriers in OFDMA improves communication reliability, since it allocates lower bandwidth for poor channel subcarriers compared to strong subcarriers, however it compromises bandwidth efficiency. Moreover, there is a stringent requirement for frame synchronization to maintain orthogonality. Therefore, focus for 5G networks shifts towards NOMA, which allocates all available channel subcarriers, whether poor or strong to all users, and ensures reliable communication through variable power distribution [15]. Thus, NOMA is an evolving technology, still in the phase of research and evaluation, that offers enhanced channel capacity compared to OMA techniques [16]. In this section, we present the basics of a conventional NOMA transceiver with power domain multiplexing.

A NOMA technique based communication system is shown in Figure. 1(a). We consider a system model with single input and multiple output (SIMO) having a single transmitting antenna at base station (BS), while there are N number of receiving antennas at the receiver side, that is the downlink NOMA [17]. The system consists of 2 users, where User 1 (U_1) is considered close to the BS, while the other User 2 (U_2) is located at the far end. In addition, it is assumed that both users are multiplexed and paired with each other at various levels of power. This pairing of users represents the main power domain feature of NOMA [18].

At the NOMA uplink, we assume that data is transmitted by the two users, for which the input bits from each of the two users, U_1 and U_2 are loaded in an adaptive manner. Bits are loaded based on channel's signal to noise ratio, and the channel state information is considered known at the

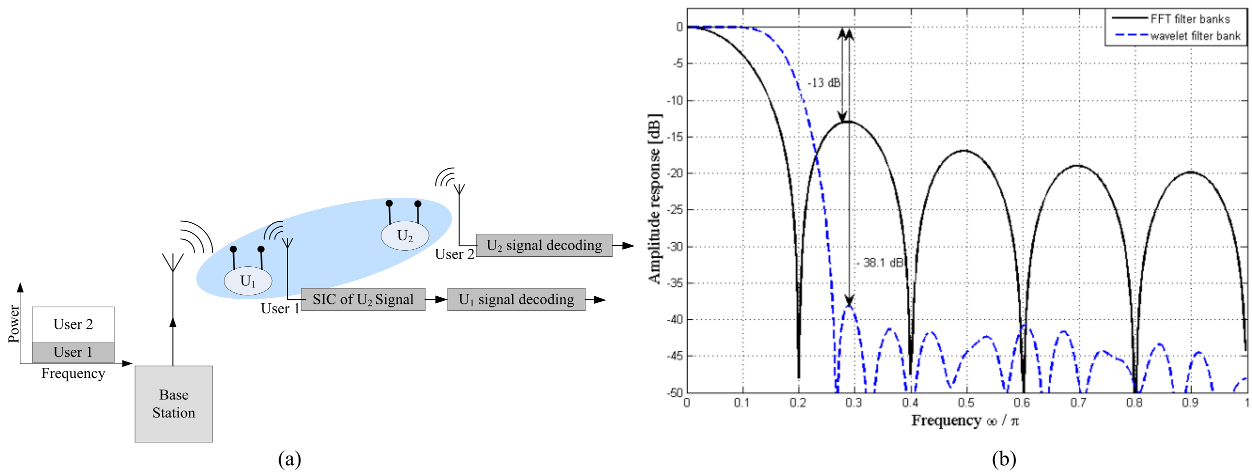

FIGURE 1. **(a) NOMA system model. (b) Sidelobe attenuation of Discrete Fourier transform and wavelet filter.**

transmitter side. Water filling algorithm is used to calculate signal-to-noise ratio (SNR) of all sub-channels.

Sub-channels having greater SNR are loaded with more bits, while sub-channels with lower SNR are filled with fewer numbers of bits. Bits are then mapped to symbols using quadrature amplitude modulation (QAM). Users are assigned variable power levels based on their distances from the BS [13]. The two users' data streams with different allocated powers are superimposed into a single data stream, allowing multiplexing of both users in a non-orthogonal manner and transmitted from the BS over the wireless communication channel, as shown in Figure. 1(a).

Each message signal is exposed to an overall channel distortion and experiences collective channel gain due to the other user [15]. The received signal which has been subjected to multi-path propagation and channel noise is to be retrieved such that each receiver is delivered the corresponding user's transmitted data. Thus, the multiuser interference also affects the received data, due to which the U_1's data stream goes through SIC for decoding. SIC enables the recovery of higher signal-to interference and noise ratio (SINR) signal as well as lower SINR signal. The stronger SINR signal of U_2 is decoded first and then subtracted from the combined signal to decode the weaker signal of U_1 [6]. The received signal for U_2 has the capability to detect its own signal, since the signal from U_1 is a low power signal and is considered with the channel noise.

III. PULSE SHAPING FOR NOMA

The ultimate waveform shape, assumed by the NOMA communication signal holds special significance, since the effect of channel impairments is dependent on the pulse shape of the transmit signal [5]. Moreover, in evaluation of the overall system performance, the transceiver design and complexity are linked with the selected waveform. Common channel impairments, such as multipath propagation effect, which results in ISI, can be countered using an appropriate waveform shape [5]. FFT-OFDM technique offers several advantages. This technique appends a CP to its symbol, thus prevents the deteriorating effect of ISI, and simplifies channel equalization [12]. However, FFT-OFDM produces time-limited rectangular shaped pulses, which result in greater spectral leakage, due to just 13 *dBs* attenuation in side lobes, as shown in Figure. 1(b). This sort of filter bank response gives spectral leakage, and thus results in an enhanced interference scenario. Moreover, these pulse shapes give rise to high values of PAPR, which is an undesired effect that deteriorates the power amplifier efficiency at the transmitter side [13].

In recent literature wavelet filter banks have been proposed as a pulse shaping technique, for improved interference mitigation since the wavelet filters produce low out of band (OOB) radiation. Figure. 1(b) depicts that the wavelet filter banks give as low as 38 *dB* of sidelobe attenuation compared to just 13 *dBs* value for FFT banks [3]. Moreover, wavelet filter banks based multicarrier technologies produce lower PAPR compared to high PAPR values associated with FFT-OFDM. The lack of CP in WOFDM gives greater bandwidth efficiency compared to FFT-OFDM, whereby a CP comprises of redundant transmitted data.

CNOMA and WNOMA are associated with various strengths and weaknesses, since each variant employs FFT-OFDM or WOFDM as waveform shaping technique. WNOMA offers greater immunity to adjacent channel interference compared to the CNOMA, this is due to the inherently excellent spectral localization properties of wavelet filter banks. Moreover, the WNOMA technique may prove to be more bandwidth efficient and robust to ISI contrary to CNOMA. However, CNOMA outperforms WNOMA, where latency and complexity of channel equalization are concerned. Therefore, we have proposed a dual PHY layer system having properties of both WOFDM and FFT-OFDM.

IV. PROPOSED DUAL LAYER TRANSCEIVER ARCHITECTURE FOR NOMA IN 5G

In this work, we aim to utilize the benefits offered by the computationally efficient FFT based OFDM as well as the robust

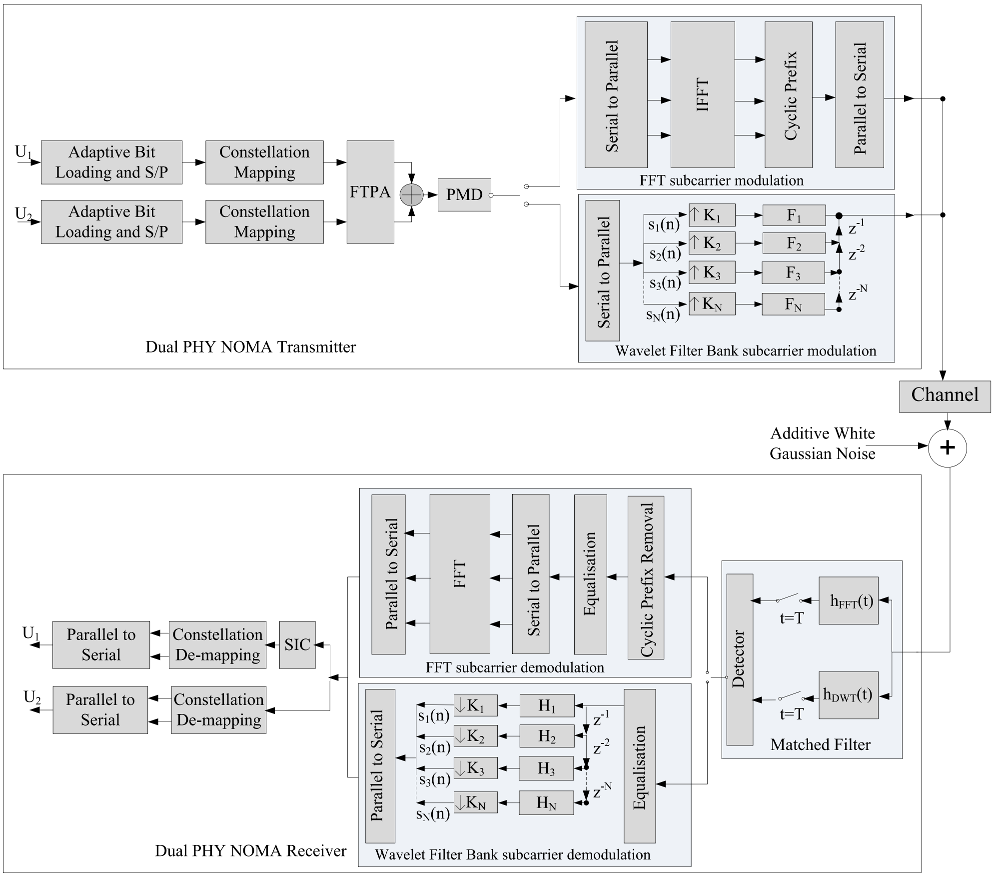

FIGURE 2. **Dual PHY Layer transceiver for NOMA.**

and spectrally efficient based WOFDM transceiver. Therefore, we have proposed a dual PHY layer transceiver for NOMA in 5G. The dual PHY layer will consist of a FFT-OFDM based layer and a wavelet filter-bank WOFDM based layer for pulse shaping of NOMA communication system in 5G. A similar dual PHY layer model has been standardized for power line communication (PLC) as IEEE 1901 for broad-band power line networks [19]. The proposed dual PHY layer transceiver is shown in Figure. 2.

Multi-user data communicated by User 1 (U_1) and User 2 (U_2) is transmitted through the dual PHY layer based transceiver and is consequently detected on the receiver side. For each user, data bits are loaded adaptively in accordance to the channel signal to noise ratio (SNR) and converted to data symbols through constellation mapping. Each user is allocated transmit power in accordance to its proximity from the base station, as prescribed for multi-user data in NOMA in the fractional transmit power allocation (FTPA) block [8]. Multi-user data with variable allocated power is then added to create a composite data stream.

Medium access control layer in an OSI model serves as an interface that connects the upper data link sub-layer, that is the logic link control (LLC) sub-layer and the PHY layer. Figure. 3 shows a common MAC layer for each of the two proposed FFT-OFDM and WOFDM physical layers.

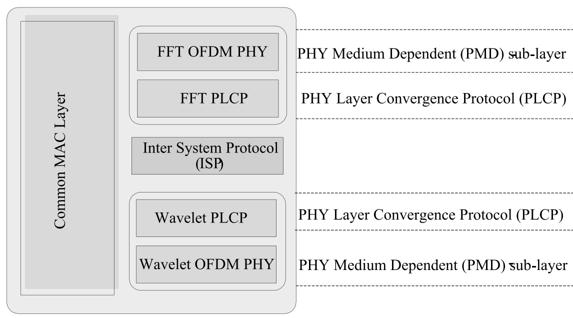

FIGURE 3. **Physical medium dependent sub-layer architecture.**

Physical layer consists of two sub-layers, a physical medium dependent (PMD) sub-layer and a physical layer convergence protocol (PLCP) sub-layer. The PMD sub-layer is responsible for selection of either FFT-OFDM or WOFDM data format, based on channel conditions. It is the PMD sub-layer that performs the basic selection process, that is depicted in the dual PHY layer transmitter in Figure. 2. Since, FBMC allows data pulse shaping which is more robust in high interference and noise scenarios, the PMD sub-layer can opt for WOFDM pulse-shaped data in channel conditions having relatively. lower SINR. Otherwise, the PMD sub-layer may transmit the classical pulse-/shaped data using FFT-OFDM for relatively higher values of channel SINR. Once the PMD has chosen either of the two physical layers, then the PLCP processes the data and converts into a data frame, corresponding to the concerned PHY layer.

Figure. 2 shows the co-existence of OFDM and WOFDM PHY layers that transmit the composite data stream. As depicted in Figure. 2, the FFT-OFDM transmitter converts the serial data stream into parallel sub-streams, maps the data onto subcarriers using inverse FFT, and the data is again converted to a serial complex data stream. The FFT modulation sub-layer then pre-appends a CP to each symbol, prior to transmission over the wireless communication channel in the downlink 5G band.

On the other hand, the wavelet filter bank modulation proceeds with the serial to parallel conversion of the data stream into s_N parallel data sub-streams, that are consequently passed through an octave filter bank. The synthesis filter bank is implemented on the transmitter side after upsampling the input data using K_1 to K_N values, that may be 2, 4, 8 and 8 for a three-level transposed synthesis filter bank structure. The data is then filtered through quadrature mirror filter banks (QMF). These QMF are designed to have complementary frequency response and therefore, possess the ability to cancel the mutual aliasing affect and ensure perfect reconstruction at the receiver side. The discrete wavelet modulated data is then transmitted through the channel.

On the NOMA receiver side, as shown in Figure. 2, the process of data retrieval consists of the reverse process adopted on the transmitter side. The information contained in the received data will help characterize the form of pulse shaping adopted for the transmit data bit stream, thus enabling appropriate demodulation process. The demodulation of PHY data would be carried out either through FFT-OFDM or WOFDM demodulation layer, selected through matched filtering process. Matched filters having FFT-OFDM and WOFDM modulated wave shapes are utilized to correlate and a detector is applied to decide as to which type of pulse-shaped data has been received.

The OFDM demodulation PHY sub-layer processes the received data through removal of CP, channel equalization and FFT. While, the WOFDM demodulation sub-layer passes the received data through an equalizer and analysis filter bank after down sampling it. The data symbols are converted to a serial stream which is decoded by U_1, the near user, after SIC to minimize the interference in the received signal due to U_2, the far user. Consequently, each user data is retrieved after corresponding symbol to bit conversions.

V. PERFORMANCE COMPARISON OF CONVENTIONAL NOMA & DUAL PHY LAYER NOMA

5G applications will be designed keeping in view the aggressively expanding internet and mobile communication traffic, thus requiring such multiple access techniques which will not only support ever-increasing data rate, but will also maintain interoperability with the existing LTE devices in 4G.

TABLE 1. Parameters for simulation of WOFDM & FFT based NOMA.

FFT-OFDM Based NOMA		WOFDM Based NOMA	
Parameters	Values	Parameters	Values
Number of subchannels	256	Wavelet levels	2
FFT Size	256	Wavelet Family	Daubechies
Cyclic prefix	Up to 25 %	Cyclic prefix	Not Applicable
Available Bandwidth	75 %	Available Bandwidth	100 %
Near user channel gain	0, -10 dBs	Near user channel gain	0, -10 dBs
Far user channel gain	-10, -20 dBs	Far user channel gain	-10, -20 dBs
Modulation scheme	M-QAM	Modulation scheme	M-QAM
Number of Users	2	Number of Users	2
SIC	Perfect	SIC	Perfect
Channel estimation	Ideal	Channel estimation	Ideal
Synchronization	Perfect	Synchronization	Perfect

Therefore, the WOFDM based WNOMA technique will not only support the enhanced data rate, but will also maintain interoperability with the existing LTE devices in 4G. Moreover, the Feature Radio Access (FRA) technology targets greater spectral efficiency than provided by LTE. However, LTE based devices cannot be altogether made obsolete. To advocate the implementation of dual PHY layer based NOMA, it is essential to analyze its performance in comparison with a single PHY layer based NOMA. Therefore, we have discussed various parameters and present simulation results for the effective performance evaluation of each PHY layer in this section.

A. ROBUSTNESS TO CHANNEL IMPAIRMENTS

Historically, WOFDM outperforms OFDM, especially when the channel conditions pose impairments such as multipath propagation, ISI and ICI, in addition to channel noise. Therefore, WOFDM based NOMA is more suited to mitigate the channel noise and interference compared to OFDM [12]. Depending upon the utilization of wavelet filter type, WNOMA gives variable value of sidelobe attenuation that is much lower than conventional NOMA. This reduces the ICI, even when there are carrier frequency offsets. The proposed dual PHY layer for NOMA is simulated to evaluate the bit error rate response for near and far users. Since the data is transmitted using either of the FFT based or wavelet filter bank based layers, the receiver is designed to receive the corresponding transmitted signal through matched filtering. The specifications for the simulation of a two user NOMA technique based on the dual PHY layer are described in Table 1.

Figure. 4 shows the bit error rate performance of FFT based NOMA as well as that of WNOMA for a near user U_1 and a far user U_2, such that $|h_1|^2 > |h_2|^2$, where $|h_1|^2$ and $|h_2|^2$ denote the channel gains of U_1 and U_2 respectively. Therefore, the power P_1 and P_2, that are associated with near user U_1 and far user U_2 respectively, are distributed such that $P_1 < P_2$. The WNOMA technique outperforms FFT

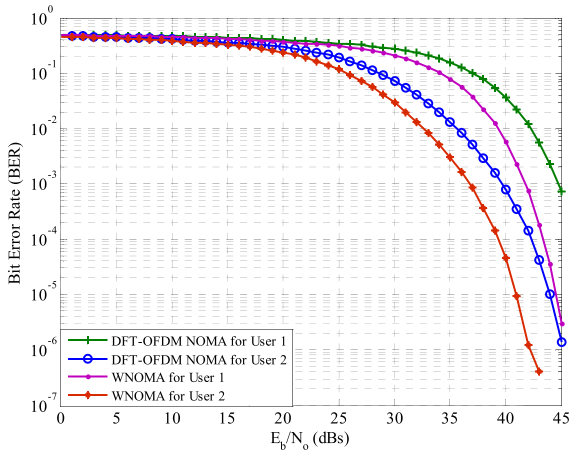

FIGURE 4. Bit error rate comparison of FFT-NOMA and WNOMA techniques.

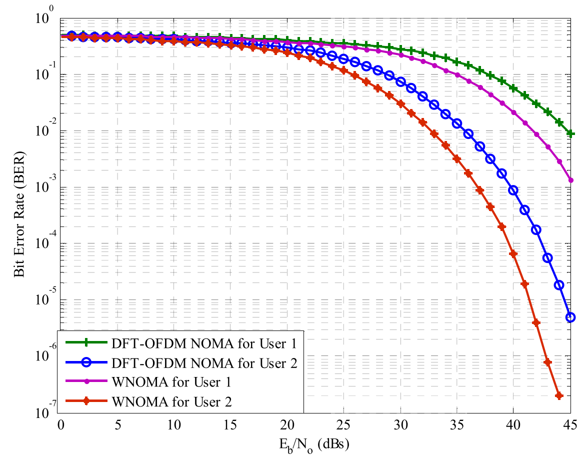

FIGURE 5. Bit error rate comparison of FFT-NOMA and WNOMA techniques for near and far users with IQ imbalance.

based NOMA with reference to BER vs E_b/N_o performance for each of the two users. For both techniques, the BER performance of the far user is better compared to that of the near user, due to large difference in power allocations. Both the users are considered as a pair. For both the near and far users, WNOMA technique gives a gain of $3\,dB$ over FFT based NOMA technique. BER for WNOMA is $1.2e-6$ at $42\,dB$ of bit power to noise ratio, while that for the CNOMA, the same value of BER is achieved at $45\,dB$, in case of the far user. For the near user, the WNOMA gives a BER of $7.4e-4$ at $42\,dB$, while an equivalent BER is produced by the CNOMA at $45\,dB$.

The dual PHY performance evaluation is further processed in the presence of radio frequency impairment of In phase/Quadrature phase (IQ) imbalance. These are the amplitude and phase variations in the received signal introduced in the signal at the time of RF to intermediate frequency (IF) conversion. For performance evaluation, an IQ imbalance of less than 1 in amplitude and about 3 degrees in phase is introduced that deteriorates the BER performance for both PHY layers based NOMA technique. However, the bit error rate shown in Figure. 5 is lower for WNOMA compared to CNOMA. WNOMA gives a gain of $3\,dB$ for both the near and the far users. For the far user, the BER presented by WNOMA is $4e-6$ at $42\,dB$, whereas FFT based NOMA gives the same BER at $45\,dB$.

B. MULTI-USER CAPACITY

A distinguishing feature of NOMA technique proposed by several researchers in recent years is the enhancement of multi-user capacity. As explained for BER comparison, the power allocated to each of the two users depends on their channel gains which varies with the distance from the BS. Therefore, the near user U_1 has a channel gain $|h_1|^2$ greater than $|h_2|^2$, the channel gain of the far user U_2. Hence, the total power allocated P is split such that the user U_2 with the poor channel gain receives greater transmit power compared to the better channel gain user U_1. Hence, the channel capacity of each user is contingent with the allocated power. Capacity of the near user U_1 having signal-to-noise ratio ρ, bandwidth BW and assuming perfect SIC is expressed as [13],

$$C_1 = BW \log_2(1 + \rho\, |h_1|^2\, P_1) \tag{1}$$

However, the user capacity for the far user U_2 is described as [13],

$$C_2 = BW \log_2 \left(1 + \min\left(\rho_2, \rho_{2\to 1}\right)\right) \tag{2}$$

where $\rho_2 = (\rho\, |h_2|^2\, P_2)/(\rho\, |h_2|^2\, P_1 + 1)$, and

$$\rho_{2\to 1} = (\rho\, |h_2|^2\, P_2)/(\rho\, |h_2|^2\, P_1 + 1)$$

where ρ_2 represents the SNR for U_2 when the user can interpret its signal while considering the other user as noise. $\rho_{2\to 1}$ describes the SNR for U_2 when the user decodes its signal after removal of U_1 signal. The overall throughput for NOMA is then expressed as [13],

$$Sum\ Rate = C_1 + C_2 \tag{3}$$

For the proposed dual PHY layer transceiver, the WNOMA sub-layer has the additional benefit of providing robust communication without the use of CP, that is an essential part of CNOMA. The CP in CNOMA facilitates in avoiding ISI at the cost of redundant transmitted data, and its length depends on the channel bandwidth and may be as large as 25 % of the transmitted symbol length [7]. Therefore, for effective data transmission, the bandwidth utilization in CNOMA is up to 25 % less compared to WNOMA technique that foregoes the use of CP. The sum rate for FFT based NOMA and that of WNOMA is plotted versus the SNR and is shown in Figure. 6, which clearly shows that WNOMA gives improved throughput compared to FFT based NOMA for two different sets of channel conditions, specified in Table 1. For relatively poor channel conditions depicted by channel gains $|h_1|^2 = -10\,dB$ and $|h_2|^2 = -20\,dB$ at an SNR of $45\,dB$, the sum rate offered by WNOMA is $8.6\,bps/Hz$ compared to $6.4\,bps/Hz$ produced by CNOMA. Moreover, for relatively fair channel

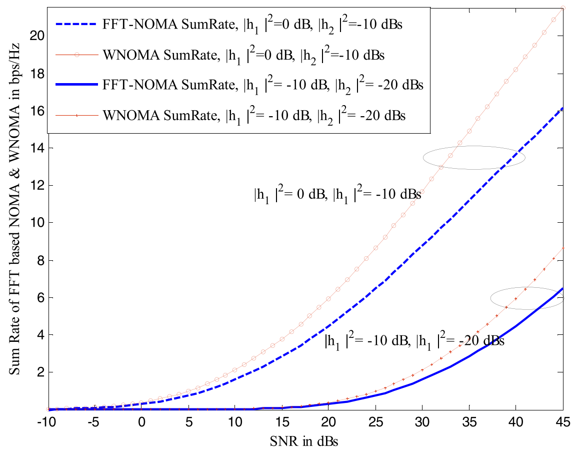

FIGURE 6. **Sum Rate comparison of FFT-NOMA and WNOMA techniques.**

conditions represented by $|h_1|^2 = 0\,dB$ and $|h_2|^2 = -10\,dB$, the sum rate of WNOMA is $21\,bps/Hz$, while that of FFT based NOMA is $16\,bps/Hz$. Therefore, there is a percentage increase of more than 30 % in the user capacity for WNOMA compared to CNOMA. This demonstrates that the spectrally efficient WNOMA allows greater throughput than CNOMA technique.

C. SPECTRAL CONFINEMENT & EFFICIENCY

The PSD of wavelet filter banks is highly confined compared to FFT-OFDM. OFDM systems suffer from high OOB energy radiation due to high side lobes, that consequently give high ICI [21]. Research works have proposed alternatives to the reduction of OOB energy radiation, however these methods, such as weighted carrier cancellation may cause enhancement in BER or PAPR and may also prove spectrally inefficient [22]. However, employing FBMC modulation technique, the spectral confinement is perceived to be much improved due to exceptionally good time-frequency localization of wavelet filter banks [20]. Therefore, with a properly designed prototype filter for a suitable value of overlap in time, these filter banks based MCM techniques exhibit very high attenuation for OOB energy [22]. Moreover, compared to the sync shaped CNOMA waveform, WNOMA offers time-limited wave shapes with side lobes having very high attenuation, thereby discarding the need of CP to overcome ISI, as is performed in OFDM based CNOMA. Figure. 7 illustrates the comparison of a PSD plot for the FFT-OFDM without CP and FBMC having variable time overlap ratios $K_{overlap} = 2, 3, 4$. The FFT size is 1024, $SNR = 12\,dB$, modulation technique is 4-ary QAM, with 212 sub-carriers acting as guard bands. It can be observed that the WOFDM gives high spectral confinement, for $K_{overlap} = 2$ time overlap ratio, the PSD of WOFDM is as low as $-47\,dB$. For greater time overlap ratio of $K_{overlap} = 4$, the PSD is at $-166.5\,dB$, whereas for FFT-OFDM, it is $-31\,dB$$-31$ dB.

In LTE-A, OFDM based devices combat ISI, for which the system pre-appends the CP, thereby causing approximately 20 to 25 % wastage in bandwidth. Assuming a $20\mu s$ OFDM

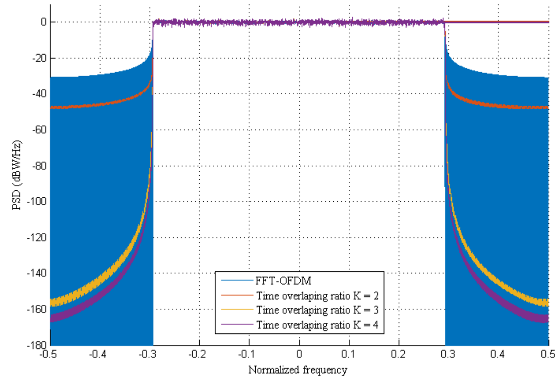

FIGURE 7. **Power spectral density comparison of FFT-OFDM and W OFDM with variable time overlapping ratios.**

symbol duration, for a 1 km cell range, the delay spread is about $3\mu s$ and a $4\mu s$ and CP is utilized to avoid ISI [3]. Therefore, the spectral efficiency of OFDM based NOMA amounts to about 20 % loss. WOFDM symbols overlap in time domain and their higher side lobe attenuation makes the communication system robust, without any CP requirement. WNOMA is therefore, more spectrally efficient compared to CNOMA. The spectral efficiency in conventional NOMA is denoted as SEI_{COFDM}, while that in WNOMA is denoted as SEI_{WOFDM} and both are expressed by [5],

$$SEI_{COFDM} = 1/(T + T_{CP})F = T/(T + T_{CP}) < 1 \quad (4)$$

$$SEI_{WOFDM} = 1/(TF) = 1 \quad (5)$$

where F denotes the spacing between subcarriers, T is the symbol duration and T_{CP} is the CP duration. Optimum value for $SEI = 1$. WNOMA has the best optimum spectral efficiency, whereas that of CNOMA will be lower because of CP length T_{CP}.

D. MODEM COMPLEXITY & COST

For the design of a dual PHY layer system, the modem complexity increases and so does the cost, due to the incorporation of two types of PHY layers. For an FFT-OFDM pulse shaped data in CNOMA, the computational complexity is dependent on the fast algorithm that computes the Discrete Fourier Transform (DFT) using radix-2 algorithm, that follows a divide-and-conquer approach. Therefore, the number of basic operations required to compute FFT for a complex frequency is $N \log_2 N$ multiplications and $3N \log_2 N$ additions [20]. In general, for a constant K, the computational complexity is expressed as $KN \log_2 N$ operations [20]. However, the wavelet filter bank used for pulse shaping in WNOMA represents a different scenario, where computationally complexity is concerned. For a wavelet packet transform, the computational complexity increases with the number of nodes. For a binary tree, the complexity is $KN \log_2 N$ multiplications and additions, since all the nodes are traversed in a binary tree of depth $\log_2 N$. Therefore, for a WNOMA that consists of a binary tree, the computational complexity is of the same order as that of FFT-OFDM based CNOMA. On the other hand, for a wavelet tree, the dyadic filter banks are used, which is a sub-tree of the binary tree, and hence requires $2KN$ multiplications and additions to traverse it [20]. In our proposed system, the WNOMA PHY layer, the composite stream of multi-user data would be propagated through an octave filter bank, thus WNOMA requires fewer computations in this case [12], [20].

For the proposed dual PHY layer transceiver, however there is an additional hardware and computational cost of PMD sub-layer. This sub-layer is involved in decision making process, for the selection of the more suited modulation type in accordance with the channel conditions. Also, the hardware cost of the dual PHY layer transceiver is enhanced since it incorporates two various types of modulation techniques.

E. LATENCY

5G networks are envisaged to have strict requirements with reference to latency, due to the heavy traffic and connection density as well as for remote driving applications. CNOMA performs better compared to WNOMA, since it involves FFT and cyclic prefixing without using further filtering techniques [5]. For WOFDM, the synthesis filter bank requires over sampling which is an important cause of increase in latency. Furthermore, spectral confinement is related to length of filters, greater the filter bank length, better the spectral confinement. Therefore, there is a tradeoff between better spectral confinement and greater latency offered by the WNOMA based communication system.

F. INTEROPERABILITY

Researchers and market operators predict that the 5G deployment cannot be materialized in one go. It is anticipated that the initial roll out on 4G would occur in urban areas, while the backbone communication system would remain based on 5G. Therefore, the stake holders of mobile and data communication would opt for a solution that requires interoperability between 5G and 4G devices.

In LTE and LTE-A, OFDM is utilized as a multiple access technique. NOMA based 5G devices will be at the forefront for multiple access communication in this generation. Therefore, it is essential that the LTE-A and LTE devices can maintain interoperability with 5G devices using NOMA. The proposed dual PHY layer transceiver gives flexibility to support the OFDM based CNOMA, and hence allow utilization of devices working on the principle of FFT-OFDM technique.

G. PEAK TO AVERAGE POWER RATIO (PAPR)

Recent literature on discrete wavelet (DWT) and its application in multicarrier modulation techniques validate that it offers lower peak to average power ratio (PAPR) at the transmitter side compared to the conventional FFT based multicarrier techniques [16]. Khan and Shin [12], present at least $2\,dB$ lower (PAPR) for the WNOMA in contrast to the conventional NOMA. Numerous features are responsible for lower PAPR in the WNOMA based systems. Firstly, there is a tradeoff between greater occupied bandwidth due to higher number of subcarriers and PAPR reduction. Secondly, each wavelet filter bank has a unique shape and variable length wavelet filters may be employed. Longer filter length result in greater values of the PAPR, this is because of the time spread of wavelet symbols. Greater the filter length, more is the time dispersion of wavelet symbols which conventionally means large number of coefficients in each symbol that are then added together, resulting in higher peak values.

An overview of parameters that are significant, in performance evaluation of NOMA based communication system have been presented in this section. CNOMA and WNOMA have been compared in the context of each parameter and it can be concluded that the WNOMA's PHY layer outperforms conventional NOMA regarding noise mitigation, capacity, spectral confinement, spectral efficiency, computational complexity and PAPR, while conventional NOMA's PHY layer is favorable due to lower latency, channel equalizer complexity and cost issues. Therefore, a merger of the two sub-layer is proposed for NOMA in 5G, thus ensuring inter-operability and compatibility with LTE and LTE-A devices.

VI. FUTURE APPLICATIONS AND CHALLENGES

It is expected in near future that the devices connected to the internet will exceed up to 50 billion [1]. Effective and efficient management of data traffic is the need of the hour, in which machine-to-machine communication requires mass connectivity, extremely high bandwidth, high integrity, cross-domain integration, and multiple radio access technologies [8]. 5G (NOMA) would be an effective approach to meet these requirements as an access technique. Compared to LTE in 4G, NOMA in 5G requires 100 times the data rate, especially for high mobility and mass connections [14].

There are several applications that require advanced wireless networks such as a smart home within a smart grid and a range of devices within it that require continuous connectivity, as well as ability to communicate, process, and execute instructions received from a remote operator. Moreover, surveillance of sensitive and inaccessible installations as well as household security necessitates huge data communication over the wireless networks. Also, a user may want to monitor live video streams from remote locations using mobile broadband communication.

IoT in industrial automation is expected to cause exponential growth in the data received from huge number of wireless sensors. Future industrial automation would be monitored through a system of IoT networks. Therefore, their automation and monitoring process would involve huge quantities of data communication.

Through analysis of these applications, the performance criteria for communication access network in 5G is highlighted. The performance of these networks is characterized by very low latency, high density of communication and capacity, greater spectral efficiency and maximum bandwidth. Moreover, data communication between various users in 5G requires robustness to interference and noise and improved spectral confinement, as well as interoperability and compatibility with 4G devices. The proposed dual PHY layer NOMA transceiver is best suited to operate as a multiple access communication technique in 5G networks for applications that would not only require robust, high bandwidth and spectrally efficient communication but also be compatible with low cost, less complex and lower latency devices. The proposed transceivers CNOMA PHY layer may be favorable for applications such as vehicle to vehicle (V2V), vehicle to infrastructure (V2I), result monitoring networks, which require lower latency in communication techniques. On the other hand, smart homes monitoring, IoT things communication and industrial automation and surveillance networks can adopt WNOMA PHY layer solution.

VII. CONCLUSION

Future 5G communication systems will be developed to encompass existing and emerging cellular communication applications, for hundred times increase in traffic capacity and network efficiency, three times greater spectral efficiency and ten times reduction in end-to-end latency. NOMA is a technique, envisaged to achieve the targeted multiuser capacity suited to 5G applications. A dual PHY layer transceiver is proposed for NOMA in 5G, to enable either FFT-OFDM or WOFDM based pulse shaping for the NOMA transmit signal. The two proposed sub-layers can ensure compatibility with 4G LTE devices, improved robustness, spectral efficiency, lower PAPR and confinement, at the cost of complex equalization and enhanced hardware cost. Further investigation and research can be carried out for the utilization of the most suitable wavelet filter banks to achieve optimum results.

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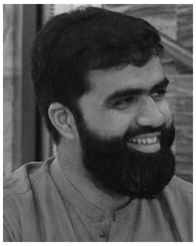

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