

Increasing the Coverage Area Using Microcells in Hybrid GFDM System based on RoF Technology

Asish B Mathews, G. Glan Devadhas

Abstract--- Hybrid architecture based on Wavelength Division Multiplexing Passive Optical Networks (WDM-PON) and Radio-over-Fiber (RoF) technology to deploy Generalized Frequency Division Multiplexing (GFDM) signals in 5G Heterogeneous Networks (HetNet) is proposed in this paper. The proposed RoF technology is the combination of Optical and Wireless communications that is used to reduce the base stations and to provide feasibility in high capacity connections and flexibility over long distance. This paper mainly focuses on increasing the coverage area without much path loss in the densely populated areas. By using microcells in GFDM system, this technology significantly enhances the data capacity of the users and also provides wider coverage area. The performance of GFDM is analyzed by computing the throughput and various parameters that affect the capacity of the system. The obtained simulation results proved that the proposed technique performs much better than conventional techniques.

Keywords--- GFDM, GFDM Improved Proportional Fair, Microcells, Coverage area, Pathloss.

I. INTRODUCTION

Nowadays, there is a robust growth of data traffic due to the increasing number of users as well as the massive usage of wireless devices. This leads to growth of Fifth generation (5G). Recently, there are several emerging application consider using Fifth generation networks (5G) that provides higher data rates. The successful of 5G depends upon enhanced coverage, reducing non-linearity, low cost, quality in transmitting the data, reducing dispersion and so on. Presently, the demanding growth of services led to the massive developments in the field of Optical fiber communications. Optical access network is the robust connection between the backbone network and the end users that gives higher data capacity and higher reliability resources. The Radio over Fiber (RoF) technology has many attentions in the field of 5G wireless communication.

Microcells can used in 30 GHz OFDM wideband photo receivers to improve Signal to Noise Ratio (SNR) (Umezawa et al., 2017). It offered data rate of 14.5 GHz at a range of 10 m with 1×10^{-3} Bit Error Rate (BER) and also detected the highly reflected signals at the range of 5m. Macrocells and femtocells are deployed on Fractional Frequency Reuse (FFR)-OFDM based two tier HetNet to evaluate the throughput and downlink performance of the system (Garcia-Morales et al., 2016). MilliMeter Wave (MMW) small cells within the macrocells were employed in a novel multiband OFDMA Heterogeneous wireless Networks to increase the maximum data capacity during densification. The problem of Long Term Evolution (LTE)

was addressed and solved by applying Greedy algorithm at the time of resource allocation (Niknam S et al., 2016). A hybrid backhaul architecture based on Wavelength Division Multiplexing-Passive Optical Networks (WDM-PON) and MMW communications was used to transmit OFDM signals in HetNet (Ngo et al., 2018). It evaluated the downlink performance by investigating the BER under the influences of various noises like Photo Detector (PD) noise, clipping noise and amplifier noise.

Various novel waveforms are recently discovered for 5G networks. Filter Bank Multi Carrier (FBMC) is used to linearly filter every subcarriers and Offset Quadrature Amplitude Modulation (OQAM) is used to mitigate the Inter Carrier Interference (ICI). These achieved higher spectrum efficiency and lower Out of Band Emission (OoBE). Yet the long filter acts as a hindrance in the usage of these waveforms in the cases of Internet of Things (IoT) applications and MTC. Filtered OFDM (f-OFDMA) localized the spectral waveforms thereby maintaining the interferences such as ISI and ICI within acceptable limits (Abdoli et al., 2015). This f-OFDM provided 46% of throughput over traditional OFDM. The advancement of f-OFDM helps in aggregating the seamless carrier subbands was described. It also achieved demonstrating gapless transmission of downlink and uplink signals over 6Gbps wireless and 20km fiber system. Universal Filtered Multi Carrier (UFMC) is otherwise known as Universal Filtered Orthogonal Frequency Multiplexing (UF-OFDM) is used for filtering the set of sub carriers that are placed orthogonal to each other within the subbands (Bi et al., 2017). UFMC does not make use of Cyclic Prefix (CP) for avoiding Inter Symbol Interference (ISI). It was very delicate to handle time misalignments, resulting in less performance. filtered-Orthogonal Frequency Division Multiplexing (f-OFDM) is one of the types of OFDM based waveforms that deployed subband filtering (Zhang et al., 2015). f-OFDM used CP to overcome ISI in multipath channels unlike UFMC thereby achieving lower OoBE and high performance. f-OFDM deployed one CP per symbol in order to reduce spectrum efficiency especially when there is a requirement of short symbols which is quite similar to OFDM. Generalized Frequency Division Multiplexing (GFDM) is a 5G waveform that relies on subband filtering to lower OoBE. GFDM has an ability to cover the 4G waveforms. GFDM has many pros in giving freedom to improve the performance of waveforms. Densification of users are in need of high speed data that led to the evolution of obtaining the maximum coverage area without losing the average data capacity.

Manuscript received February 01, 2019

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Existing methods like OFDM, F-OFDM do not provide higher performance in covering the maximum distance in the densely populated area. And also do not overcome the dispersion and non-linear effects effectively (Koudouridis et al., 2018). The proposed GFDM uses microcells to reach the maximum coverage area compared to picocells and femtocells. A microcell is a unit that covers the area of ~2km and it has a power control to reduce its range limits and specifications. It is smaller than picocells and helps in reaching maximum area with the support of GFDM (Sivakumar et al., 2018). Typically, microcells are less than 500 m in range and use less transmission power. Microcells are interconnected using transporting facilities like coax, fiber, radio etc. The pros of using microcells include:

- There is a considerable improvement in capacity independent of Radio Fiber (RF) technology.
- Flexibility in coverage and in the design of RF.
- Low cost effective and less transmission power.

Contributions

This paper focuses on solving the issues of hybrid architecture of RoF based networks. The identified issues are coverage area, non-linear effects and dispersion occurred while transmitting the signals. This paper covers the problem of reaching the maximum distance (coverage area) without loss of signals and in low transmission cost. By deploying microcells in the proposed system, it helps to attain the maximum distance of transmission in the densely populated area.

Organization of the paper

Section 2 explains the architecture of the proposed system in detail. This section explains every block present in the architecture of the proposed system. Section 3 explains the performance evaluation of GFDM system. Section 4 illustrates the simulation results and their detailed explanation. Finally the paper concludes at the section 5.

II. PROPOSED SYSTEM

In this section, the system architecture is analyzed and discussed. Further the concepts of GFDM and other parameters are discussed. Figure 1 shows the architecture of the proposed system. This block begins with giving an input signal to the GFDM modulator where it modulates the signal. This modulated signal is converted into optical signal before being sent to the receiver using RoF based technique. An Arbitrary Waveform Generator (AWG) acts as a channel to de-multiplex the optical signals. Standard Single Mode Fiber (SSMF) is placed after the channel to amplify the obtained signals to certain levels required to launch it into the fiber link. Photo Detector (PD) directly converts the optical signals into electrical signals. The obtained MMW signal from PD is filtered, amplified and then fed into the antennas. These antennas are used to transmit the signals to corresponding receivers through MMW links. The received MMW signals are amplified using Low Noise Amplifier (LNA) at the receiver’s end. Finally the signal is reconstructed with the help of GFDM demodulator.

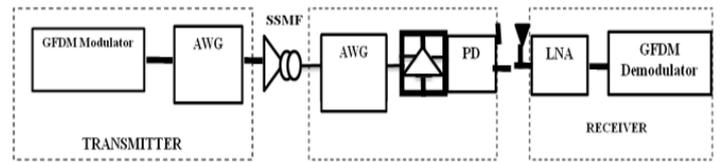


Figure 1: Architecture of the proposed system

Principles of GFDM

GFDM had been used as a flexible multi carrier modulation scheme to overcome the impact of interferences in multicarrier systems [Fettweis et al.,]. The resilience of GFDM scheme has the ability to perform all the functionalities of the conventional schemes like OFDM, Single Carrier-Frequency Division Multiplexing (SC-FDM) and Single Carrier-Frequency Domain Equalization (SC-FDE). GFDM systems has an advantage over OFDM system is that it minimizes the overlapping of neighboring subcarriers to simultaneously run a multiuser applications. GFDM deploys circular filtering at each subcarriers to perform multitasking and minimize the overlapping of subcarriers effectively.

Here in this concept, GFDM systems are used to avoid the ISI and upgrade the performance of the system. The principle of GFDM signal is shown in the figure 2. The input given is binary data which is then modulated by the GFDM Modulator to QAM format (Tian et al., 2018). And then it is divided into KM symbols. Each $d_{k,l}[M]$ symbols are scattered across ‘K’ subcarriers and ‘M’ time slots for transmission where $K=0$ to $k-1$ and $M=0$ to $m-1$ are provided. The data symbols, $d_{k,l}[M]$ are up-sampled by the factor N that leads to the following:

$$d_K^N[n] = \sum_{M=0}^{m-1} d_K[M] \delta[n - MN], n = 0, \dots, Nm - 1 \quad (1)$$

Where $\delta[n-MN]$ – Dirac Function
 N – Up-sampling factor

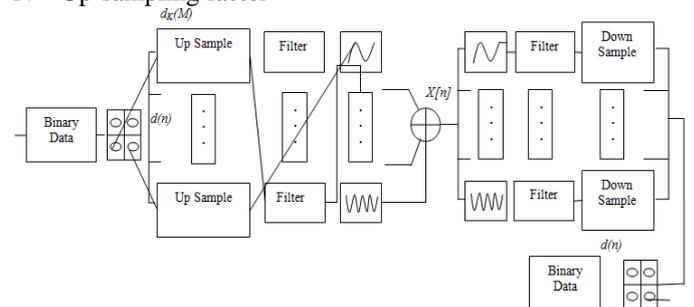


Figure 2: Block Diagram of GFDM Signal

After the up-sampling of GFDM signal by N, the up-conversion and digital pulse shaping transmitted by the GFDM signal is expressed by the following equation (2):

$$X_1[n] = \sum_{M=0}^{m-1} \sum_{K=0}^{k-1} d_K^N[n] g_T[n], g_T[n] = g[(n - MN)[mN]] e^{i2\pi \frac{Kn}{N}} \quad (2)$$

Where g_T - subcarrier signal, $g_T[n]$ -shifted version of circular filter, $g[n]$ Each g_T , subcarrier signal is a shifted version, $g_T[n]$ of circular filter, $g[n]$ obtained by MN and K/N time and frequency domain respectively.



GFDM demodulator conversely performs the operations of GFDM modulator at the receiver's end (Michailow et al., 2012). If $Y[n]$ is the received signal, then the obtained resultant signal at $n = MN$ can be expressed as:

$$\widetilde{d}_K[m] = (Y[n]e^{-j2\pi\frac{Kn}{N}}) \otimes g_{RX}[n] | n - MN \quad (3)$$

Where $\otimes g_{RX}[n]$ – circular convolution with matched filter relative to n .

Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) are used to compute the frequencies in the frequency domain. After the completion of down sampling, the signals are eventually converted into QAM symbols.

III. PERFORMANCE EVALUATION

In this section, the performance metrics of the proposed system are analyzed and discussed in detail. To increase the coverage area, GFDM Improved PF algorithm is preferred to allocate resources simultaneously with better quality channel. To enhance the capacity, NOMA is preferred that provides better usage of data for users.

GFDM Improved Proportional Fair

GFDM Improved Proportional Fair (GFDM Improved PF) is a scheduling algorithm, used in the context of GFDM system to successfully overcome the Successive Interference Cancellation (SIC) at the receiver's end (Hojiej et al., 2018). The PF scheduler treats the resource block independently and keeping the updates of the system in every time slots, However the performance of this scheduler is still limited because PF is not fully optimized for mobility. It can be seen when some user equipment (UE) in a mobility position the throughput will drop significantly with the increasing speed of the UE also it can still retain the fairness for the UE. Due to the issues, Improved PF scheduler will be developed which takes into account the channel conditions of all the users and redistribute the resources accordingly while maintaining significant fairness towards its users. Improved PF scheduler divides a single subframe into multiple time slots and allocates the resource block to each slot for targeted users on CQI feedbacks from UE. This algorithm maximizes the total throughput in the wired or wireless networks while permitting at least a minimal level of services to the users simultaneously. This algorithm outperforms other conventional algorithms like Greedy, Proportional Fair and Round Robin (RR). Improved PF allocates more resources to the users without relatively losing its quality in channels. It helps the GFDM system to provide better channel quality thereby covering long distance. This algorithm also offers higher throughput as well as satisfyingly good fairness.

The transmitter at sender's side provides the feasibility rate or channel rate to the every scheduled users (Viswanath et al., 2002; Kelly et al., 1997). The conventional scheduling Improved PF algorithm monitors the average throughput of each users $T_k(t)$ at every window length. The scheduling slot for user K^+ can be expressed as:

$$K^+ = \arg \max_k \frac{R_k(t)}{T_k(t)} \quad (4)$$

Non-Orthogonal Multiple Access

NOMA assigns a cost function to each possible pair of users thereby increasing either the sum rate or weighted sum rate (Schaefferle, 2010). By doing this enhances the throughput performance of the systems. NOMA outperforms conventional OFDM in providing higher data rates to the users. The fundamental concept behind the NOMA, comprises of user multiplexing at the transmitter and signal multiplexing at the receiver's side (Hojiej et al., 2018). Typically, the NOMA system comprises of 'k' users per cell with total bandwidth, BW is partitioned into several sub-bands, 'SB'.

A subset of users $U = \{k_1, k_2, \dots, k_n, \dots, k_{n(sb)}\}$ is chosen among 'k' users, where it is scheduled over each frequency sub-bands ($1 \leq sb \leq SB$). k_n denotes the nth user scheduled at the sub-band, sb and $n(sb)$ is the number of users non-orthogonally scheduled at sub-band, sb . Every scheduled user's information sequence is modulated and individually coded at sub-band, sb thereby resulting in symbol, X_{sb,k_n} . The resultant signal will be computed for nth users using the following expression:

$$X_{sb} = \sum_{n=1}^{n(sb)} X_{sb,k_n} \quad (5)$$

$$E[|X_{sb,k_n}|^2] = P_{sb,k_n} \quad (6)$$

Here in the equation (P_{sb,k_n} - power allotted to the users at sub-band, sb). The following expression is for the received signal at sub-band, sb . It is defined as:

$$Y_{sb,k_n} = h_{sb,k_n} X_{sb,k_n} + w_{sb,k_n} \quad (7)$$

Where h_{sb,k_n} - coefficient of the channel between the user and the sub-band, sb .

w_{sb,k_n} - Received Gaussian noise and interferences experienced by the users at sub-band, sb .

The sum of the power constraint is computed as follows:

$$P_M = \sum_{sb=1}^{SB} \sum_{n=1}^{n(sb)} P_{sb,k_n} \quad (8)$$

In this eqn (P_M is the maximum power transmitted by the transmitter.

Path loss Model

The primary factors of path loss models are distance and technology or techniques used for minimizing the loss of paths in the system. The massive path losses can be observed on the LTE technologies because of its continuous and speed communication. The Cumulative Distribution Function (CDF) is used for detecting the path losses in the systems of various cellular technologies (Japertas and Grimaila, 2017).

The overall performance of the communication systems are highly depend upon the quality of the channel for transmission and also the performance metrics like delay, throughput, successful link probability.

These metrics are based on the values of SNR and that eventually provide some loss of paths in the channels (Al-Hourani et al., 2017). The path loss model can be expressed using the following equations (9) and (10):

$$P_{los} = 20 \log d + 20 \log f + 20 \log(4\pi/C) + \eta_{los} \quad (9)$$

$$P_{nlos} = 20 \log d + 20 \log f + 20 \log(4\pi/C) + \eta_{nlos} \quad (10)$$

Where d - distance, r -radius given that $d = \sqrt{h^2 + r^2}$ and f -frequency of the system. According to Friis transmission expression, the free space path loss is defined by computing the average path loss and it is explained in the following equations (11) and (12).

$$P_{avg} = P_{los}(\theta) \times P_{los} + P_{nlos}(\theta) \times P_{nlos} \quad (11)$$

$$P_{max} = \frac{Q}{1 + ae^{(-b(\arctan(h/R)-a))}} + 10 \log(h^2 + R^2) + S \quad (12)$$

The above equation is rewritten from the average values of the path losses. Where,

$$Q = \eta_{los} + \eta_{nlos} \quad (13)$$

$$R = 20 \log f + 20 \log(4\pi/C) + \eta_{nlos} \quad (14)$$

IV. RESULTS AND DISCUSSION

The simulation results are obtained using MATLAB 2016a and the given input is an optical signal. Microcells are used in the proposed method to cover maximum distance without losing paths. These microcells are used to cover the region of ~2km thereby sending data to the receiver without losing considerable amount of paths. The comparison is done on Non-Orthogonal Multiple Access (NOMA) against OFDM, where the obtained results shows NOMA is a better technique in the case of comparing the performance of GFDM signal by varying number of users against the rate of users. The performance curves for pathloss and throughput are also obtained where NOMA and GFDM Improved Proportional Fair (PF) outperforms others.

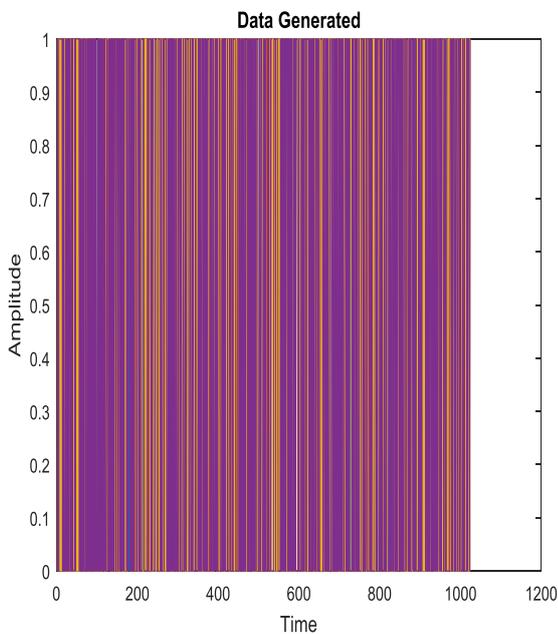


Figure 3: Input Signal

Figure 3 shows the varying amplitude across time is the input signal of the proposed method.

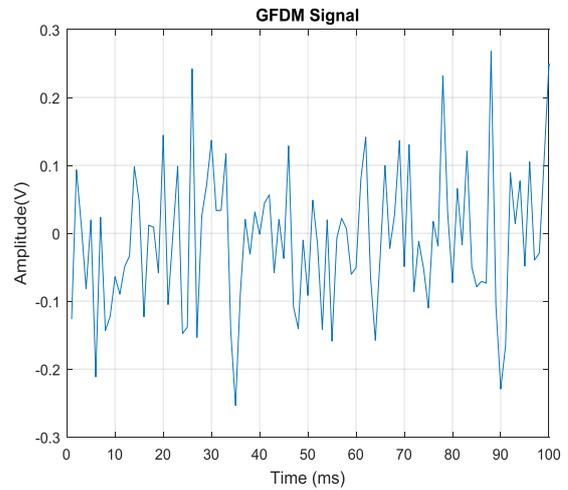


Figure 4: GFDM Signal

The input signal is given to the GFDM modulator where it modulates the signal to produce GFDM signal which is shown in the figure 4. In figure 4, the flexible pulse shaping is produced by Non-Orthogonal Multi Carrier scheme.

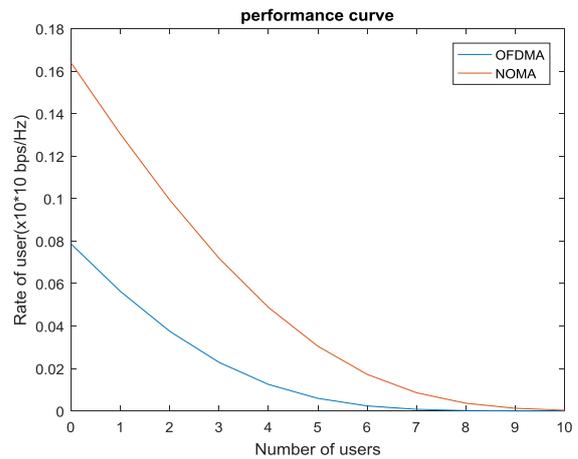


Figure 5: Performance Curve for NOMA and OFDM

The performance curve for the comparison of NOMA and OFDMA is shown in the figure 5. In this figure, number of users is plotted against the rate of users. In OFDMA, when the number of users increases, the rate of users decreases accordingly. In NOMA, when the number of users increases, then the rate of users decreases which provides better performance in providing higher rates than OFDMA.

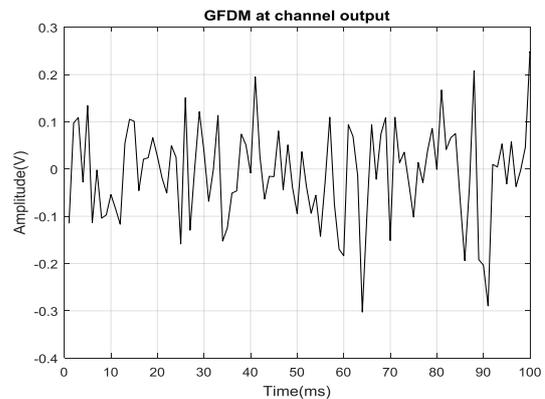


Figure 6: Output of AWG channel

The output obtained from AWG channel is shown in the figure 6. This channel is used de-multiplex the signals and convert them into electrical waveforms. Figure 7 shows the comparison curve of free space path loss according to the varying ranges.

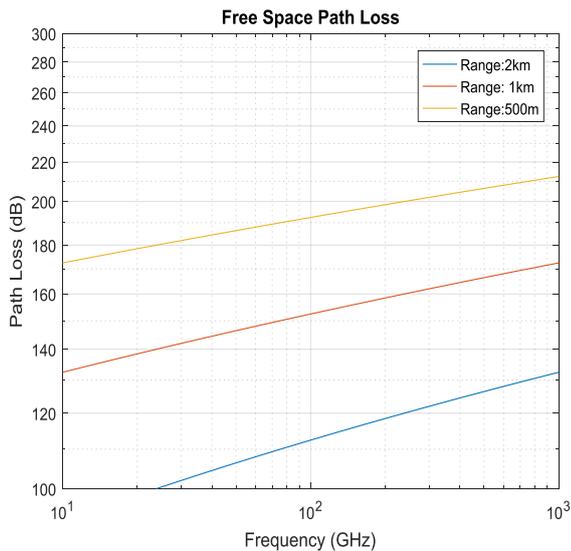


Figure 7: Free Space Path Loss

In figure 7, the performance of free space path loss is computed and it is a function of frequency and propagation distance. In free space, RF signals propagate in all direction at a constant speed of light. It is noticed that the path loss decreases along with range as well as the frequency. The propagation loss is decreased with the help of Greedy algorithm.

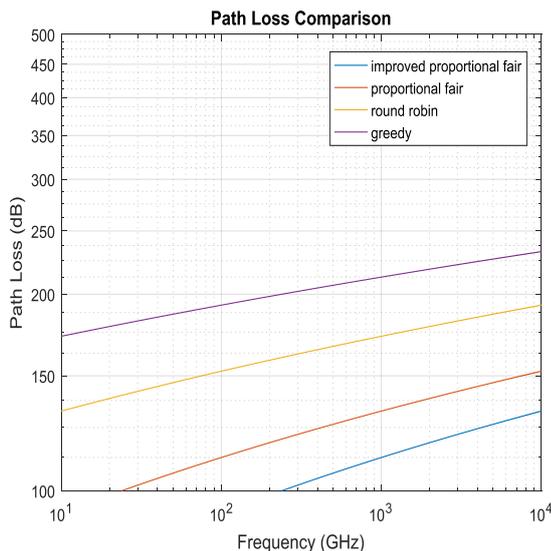


Figure 8: Path Loss Comparison

Figure 8 shows the comparison curve of frequency plotted against the path loss in decibels (dB). The proposed method uses Improved Proportional Fair (PF) to allot the resources with less path loss. With the help of Improved PF, when the frequency increases, path loss also increases. Using Improved PF obtain better results compared to PF, Round Robin and Greedy algorithm applied on them. Improved PF is a scheduling algorithm and it allocates the resources and maintains the maximum throughput at the consistent intervals. Here, the data rates computed at each interval are inversely proportional to the resource consumption.

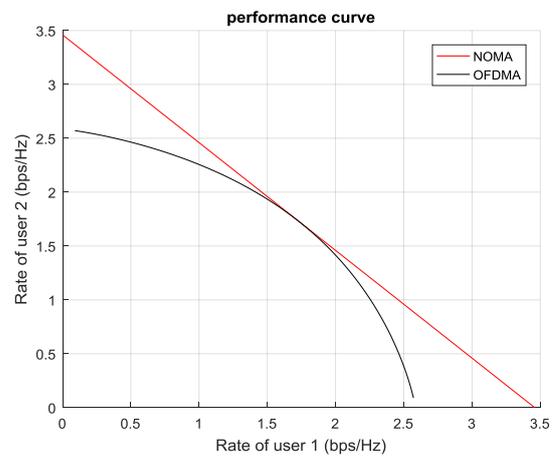


Figure 9: Performance Curve of rate of user 1 vs rate of user 2

Figure 9 shows the performance comparison between the rates of users in bps/Hz. When compared to NOMA, OFDMA outperforms in data rate capacity by the users. Here OFDMA provides lesser energy efficiency and is a better technique. Figure 10 shows the comparison curve of NOMA and OFDMA in terms of spectral efficiency.

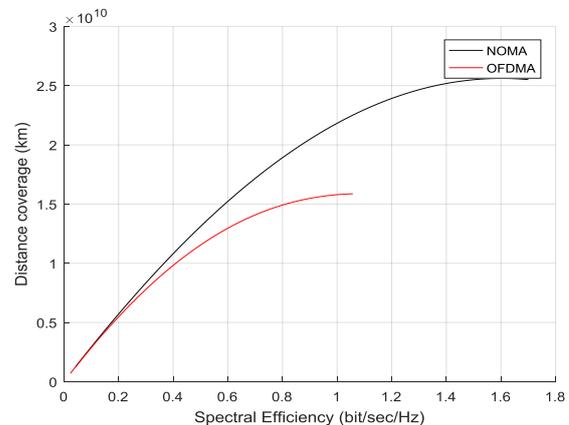


Figure 10: Comparison Curve for spectral efficiency vs distance coverage

In the above figure, it is noted that NOMA outperforms OFDMA by plotting spectral efficiency against the distance coverage. When the spectral efficiency increases, then there is considerable amount of distance has been covered by the NOMA technique.

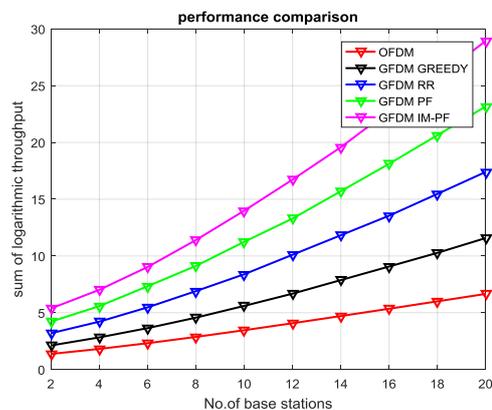


Figure 11: Performance Comparison of various scheduling algorithms of GFDM and OFDM

Figure 11 displays the graph of base stations plotted against the sum of logarithmic throughput. From this graph, when there is increase in number of base stations, GFDM Improved PF performs better scheduling and allocation of resources to the users. The sums of logarithmic values are obtained by adding the total capacity and the actual throughput of the proposed technique.

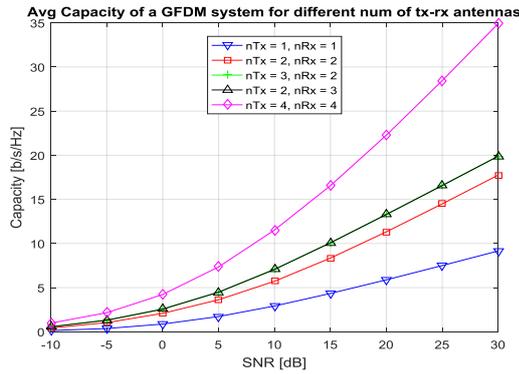


Figure 12: Average capacity of GFDM system for different number of tx-rx antennas

In figure 12, it is noted that the SNR values are plotted against the varying capacity for various tx-rx antennas. When the tx and rx is 1, then SNR varies according to their capacity in b/s/Hz. Generally, when there is increase in capacity, then there is also increase in its SNR. Depending on the number of transmitter (tx) and receiver (rx) antennas, the SNR is plotted against its capacity.

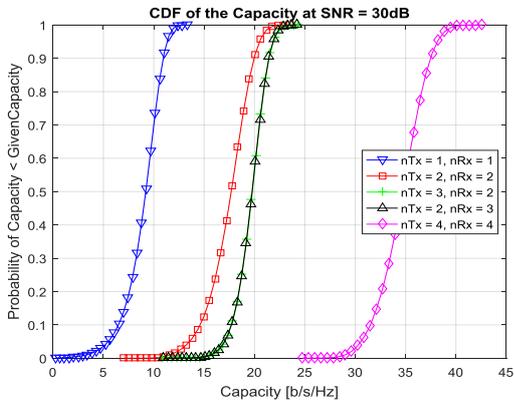


Figure 13: CDF of the capacity at SNR=30dB

Figure 13 shows the Cumulative Distributive Function (CDF) of the capacity when SNR is at 30dB. The capacity is plotted against the probability of capacity lesser than given capacity. This graph shows that the capacity remains constant at the beginning and at the end whereas it increases in between the capacity intervals.

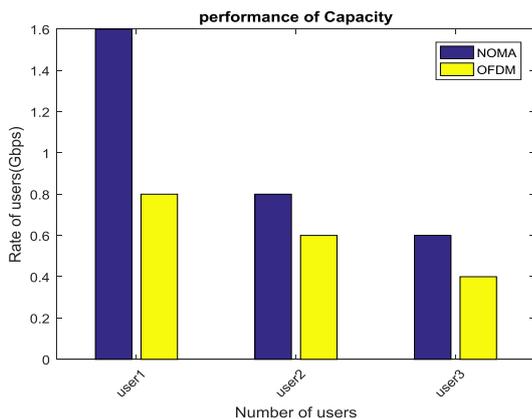


Figure 14: Performance Chart - Capacity

Figure 14 and 15 show the performance bar charts of capacity and throughput of the GFDM system respectively. In figure 14, the performance bars are computed for the number of users using the data capacity. The number of users is compared to the rate of users in bps/Hz. The capacity required by the number of users is computed using GFDM system. Here NOMA outperforms OFDMA in providing capacity to the users at certain rates.

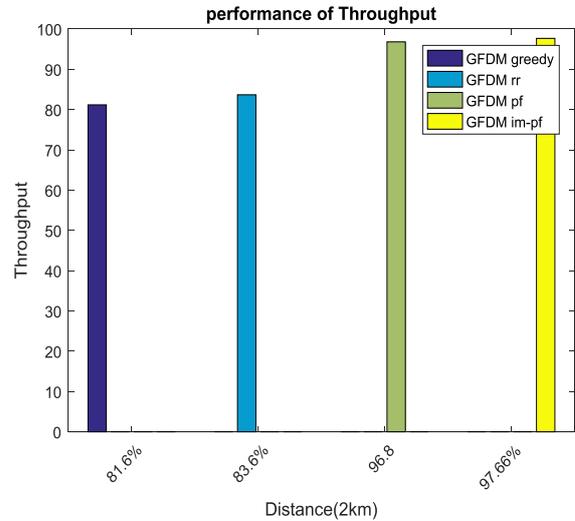


Figure 15: Performance Chart -Throughput

In figure 15, the throughput of GFDM system is analyzed. The throughput is computed for the distance of 2km. By varying the throughput scale, GFDM Greedy has the percentage of 81.6, GFDM RR has the percentage of 83.6, GFDM PF has the percentage of 96.8 and GFDM Improved PF obtained the percentage of 97.66. It is proved that the proposed GFDM Improved PF is a better technique in allocating the resources to the users and improves the performance of the system efficiently.

V. CONCLUSION

The proposed Hybrid GFDM architecture uses microcells to cover a longer distance without losing the consistent data capacity. Various performance factors like throughput, capacity, path loss model, scheduling algorithms for allocating resources were also discussed and successfully evaluated. The obtained throughput performance of GFDM based Improved PF is 97.66% and this enhances the overall GFDM system’s performance. NOMA is compared to OFDM in the case of analyzing and evaluating the performance of capacity. It is proved that the proposed NOMA gives better results.

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