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Analysis of FBMC Waveform for 5G Network Based Smart Hospitals

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Abstract: Nowadays, many prevalent frameworks for medical care have been projected, studied, and implemented. The load and challenges of traditional hospitals are increasing daily, leading to inefficient service in the health system. Smart hospitals based on advanced techniques play a crucial part in advancing the health services of rural people. It spares the time and money involved in travel, and patient medical reports can be shared instantly with the experts regardless of geographical constraints. Currently, the role of technology in hospitals is limited due to various restrictions, such as the obtainability of a high spectrum, low latency, and high-speed network. In this paper, we focused on the implementation of an advanced waveform with high spectral performance. Filer Bank Multi-Carrier (FBMC) is considered a strong contender for the upcoming 5G-centered smart hospitals due to its high data rate, no leakage of the spectrum, and less sensitivity to frequency error. In addition, a comparison of the spectral utilization of orthogonal frequency division multiplexing (OFDM) and FBMC in terms of bit error rate (BER), peak power (PP), power spectral density (PSD), noise-PSD, capacity and magnitude, and phase response is illustrated. Numerical results show that the FBMC achieved a throughput gain of 1 dB and its spectral performance is better than the OFDM; hence, it is a better choice for the proposed application compared to the current standard OFDM.

Keywords: smart hospitals; 5G; OFDM; FBMC

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1. Introduction

With the rise in advanced technologies, there is a maximum possibility that the future intelligent hospitals will enhance the quality of medical services, such as remote surgery, diagnosis, instant sharing of reports to the best experts in the world, and health monitoring. In recent years, 4G network has been utilized to support the smart health care system. However, it has not developed all over the globe [1]. The implementation and regularization of 5G are taking place all over the world. The 5G communication system is taking the level of communication to the next standard by increasing the speed, efficiency, safety, and latency [2]. In the upcoming years, 5G networks will enhance their service in different sectors such as manufacture, education, wellness care, transportation, and so on. Hence, the upcoming advanced network should carry through the demands of different sectors, and the demands of these sectors are different from each other. The advanced radio network design, new infrastructure, towers, picocell, and microcell are considered a huge challenge while minimizing the project's cost. Hence, the 5G standard will be a combination of current and future developments [3]. The integration of 5G, the Internet of Things (IoT), and smart hospitals can improve the quality of medical services. The IoT machines can continuously monitor the conditions of the patient and analyse the data.

However, in the present scenario, the use of IoT and wearable devices is less due to the low spectrum, speed, and bandwidth. Hence, it is important to explore 5G advanced waveforms with low leakage, high data rate, and high bandwidth capabilities [4]. In several years, the use of technologies has improved the measures of health monitoring at a modest scale. It is expected that advanced technologies will further enhance the performance of smart hospitals. Advanced technologies such as the Internet of Things (IoT); advanced waveforms, including non-orthogonal multiple access (NOMA), millimetre wave (mm-wave), filter bank multi-carrier (FBMC), and cognitive radio will play a key role in healthcare [5]. In the present scenario, healthcare systems are facing enormous pressure to meet the demands of patients. With the increase in the population, it is becoming difficult for conventional hospitals to execute their services efficiently for the mass population. It is seen that the conventional hospitals are being digitized, but still, the hospitals are not completely digitized. It is important to enhance the infrastructure in smart hospitals and implement an advanced healthcare system empowered by essential advanced technologies, which can deliver an advanced facility that was not accessible previously [6]. Currently, orthogonal frequency division multiplying (OFDM) is employed in the 4G framework. OFDM suffers from 11% spectrum loss due to the use of cyclic prefix (CP). There are several other disadvantages due to which OFDM may not be considered for the upcoming 5G radio network [7]. Hence, in recent years, more advanced waveform techniques are being researched. FBMC is a technology that has grabbed the attention of researchers due to its characteristics, such as spectral efficiency and high data rate. In recent studies, it has been seen that FBMC is compatible with massive MIMO. The structure of FBMC consists of a group of filters, FFTs and IFFTs. One of the important parameters affecting the performance of Smart hospitals is the fast transmission of medical data and images. The medical scans and reports consist of large amounts of memory. Hence, if the data speed and bandwidth are low, it will create a delay in getting the medical expert's opinion. This further leads to a delay in the treatment of the medical patient. Therefore, to transmit a large number of medical files, the speed and bandwidth should be high. However, the transfer of medical files and reports requires a high data rate and high network bandwidth, which is not guaranteed by the current fourth-generation standard (4G) [8]. Among several requirements, high spectral efficiency is one of the significant needs of smart hospitals [9]. The transfer of medical data videos and huge scan images requires high bandwidth and low latency, which can be largely assisted by advanced 5G radio [10]. Hence, it becomes necessary to design a 5G radio, which can provide a fast data transmission rate and high bandwidth as required for several applications such as smart hospitals, IoT, smart cities, industries, and so on. In [11], it is also assumed that the use of 5G will hurt the environment and the human body. However, till today, there is no substantial evidence to prove that the frequency used in 5G may cause severe or deadly disease. In the upcoming 5G-based health care system, the medical team will secure rapid access to the huge stock of patient information at any time. This will allow the medical team to analyse the real-time data of the patients. Additionally, the advance smart hospitals will provide a facility to seek advice and monitor the condition of patients using 5G devices for remote health care, allowing medical experts of different countries to work. The objectives of 5G smart hospitals are shown in Figure 1. The reliable rollout and combination of cloud-assisted services at the machine and network level. The protection of large medical information stored in the cloud needs to be considered. Technologies such as 5G and IoT will play a crucial role in the health monitoring framework. Although there are some concerns, such as implementing IoT healthcare's system privacy and information trade-off. The combination of 5G and IoT can be used in several applications such as digital remote healthcare, cognitive manufacturing, robust communication between rural and urban areas, autonomous vehicles, and intelligent architecture for building [12]. The regularization of 5G-based applications demands a high spectral efficiency [13].

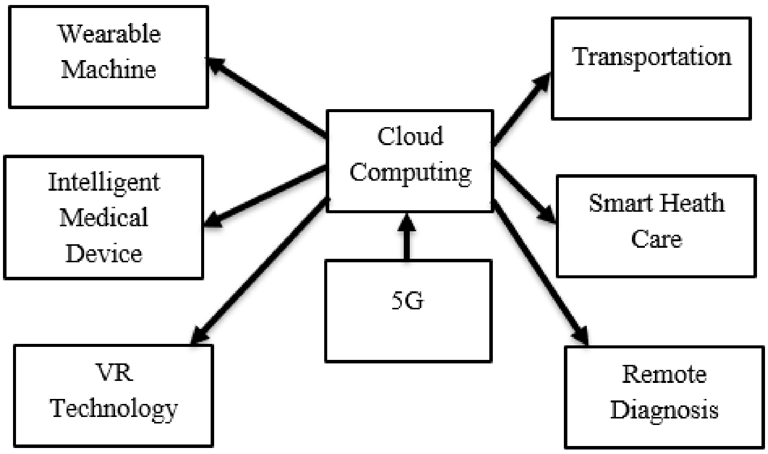

Figure 1. Objectives of Smart hospitals.

The challenges of future smart hospitals are as follows:

a. The implementation of medical machines for merchant secured management. This framework will help to share the information between several intelligent medical machines utilizing different protocols.
b. There is a constraint on functional smart medical devices to process the large quantity of data in the network. The network management of the distribution of resources is also considered one of the major concerns in smart hospitals.
c. It is important to ensure that the various medical machines are connected 24/7 from different locations and with mobility.
d. The utilization of resources and design of an energy-efficient device are the major concerns in the implementation of the modern medical system.

The future smart hospital will be 24/7 associated with a number of small cells, machines, sensors, and IoT to ensure the quality, coverage, and throughput of the framework. The objective of the projected work is to analyse a highly efficient waveform for 5G-based smart hospitals. To the best of our knowledge, this is the first time the projected work has been explored.

- The key objective of the proposed work is to study the several characteristics of 5G smart hospitals in [7,14–26].
- A significant enhancement in bandwidth is accessing and data rate is accomplished in the projected waveform schemes. It is seen that, by introducing filters at the transceiver of the system, the ideal spectral performance is obtained. The spectral performance of the system is greatly enhanced by integrating the OFDM and FBMC waveforms and thus makes it suitable for 5G radio. The enhancement of capacity, BER, and bandwidth is regarded as vital to support the facilities associated with smart hospitals.

2. Related Literature

In recent years, it has been noted that health monitoring in the real environment can be accomplished by implementing a new architecture consisting of a wireless sensor network (WSN), IoT, and 5G systems. This type of framework can monitor the heartbeat, oxygen, and pulse, as well as alert the patient to nearby hospitals and healthcare staff [14]. In [15], the MIMO-OFDM system is implemented for different transmission methods; it is analyzed that the bit error rate (BER) performance of the BPSK is superior to the other schemes. It is concluded that the spectral efficiency of the projected framework reduces due to the insertion of CP. The use of guard bands in OFDM results in wastage in the spectrum. Cognitive radio (CR) can improve the spectrum scarcity problem by allocating the ideal spectrum of license users to secondary users. In [16], cognitive radio (CR) is integrated with the OFDM framework to enhance the system's spectral efficiency. It is understood that the combination of CR and OFDM can upsurge the organization's bandwidth usage, capacity, and BER performance. The spectral efficiency of the multicarrier waveform (MCM) is degraded due to the presence of phase noise in the OFDM/FBMC system. In [17], the phase distortion is overcome by decomposing noise into the reception and symbols of adjoining sub-carriers. It is seen that the spectral efficiency of the MCM is increased by reducing the phase spectral distortion of the system. One of the methods to enhance the bandwidth efficiency of FBMC is by expanding the time period of the burst. The study [18] aims to evaluate the spectral efficiency of the FBMC and OFDM framework. The simulation result shows that the FBMC has no leakage of the spectrum due to the use of the filter where the high sidelobe and spectrum leakage are observed in the OFDM system. An overview of spectral performance and throughput of FBMC and OFDM is studied [19]. The experimental outcomes revealed that the performance of the FBMC is better than the OFDM system and is regarded as one of the best choices for advanced radio communication systems. The authors of [20] looked into the spectral efficiency of the NOMA system for advanced radio cellular systems. It is seen that the bandwidth of NOMA can be enhanced by allowing multiple users to access the channel in the time and frequency domain. The overall throughput of the NOMA system is more eminent than the OFDM structure. In [21], the peak power and spectral efficiency of the NOMA are improved by using a hybrid reduction algorithm at the transmitter terminal of the NOMA. It is observed that the high peak power results in leakage of the spectrum and degrades the quality of service of the system. Various works on the conception of the novel and spectral-efficient waveforms have been completed all over the world in recent years. Table 1 outlines the contributions of the investigations connected to 5G smart hospitals available in the literature.

Table 1. Related Literature.

References	Contributions
[22]	In [22], the authors review the importance of latency and bandwidth for 5G and IoT-based modern hospitals. A hybrid detection algorithm was proposed to improve the latency and throughput performance of the NOMA 5G waveform. The authors discussed the contributions of advanced technologies, such as IoT, advanced waveform, small cells, and software-defined networks to the upcoming smart hospitals. Advanced technologies will play a significant role in the smart health system. In the first part of the work, the requirements and challenges of the smart hospital were discussed. The second part of the work noted that 5G alone could not fulfill the needs of the smart health framework. Hence, 5G hospitals will consist of the integration of several networks and technologies. Finally, the experimental results reveal that the quality of real-time information can be improved by reducing the latency to 1ms. Hence, detection algorithms will play an important role in future 5G intelligent hospitals.
[23]	With the increase in technology and infrastructure, the smart system is developing at a rapid rate. Unlike conventional hospitals, the role of technologies will increase drastically in the upcoming healthcare system. IoT can be integrated with wearable devices and 5G to track patient conditions. The patient can stay home and get all the medical reports and information. This will save the patients' time and money entailed in traveling from one location to another location. In this article, the authors presented the role of IoT in the 5G smart healthcare system. It is concluded that the choice of 5G waveforms, small cells, antennas, and spectrum sensing techniques will soon significantly improve medical services.
[24]	In this work, the IoT is integrated with a cloud capable of monitoring and predicting patient conditions and illness with its austerity range combined with 5G and blockchain algorithms. The projected system will evaluate the medical data through wearable devices affixed to patients. The patient's medical reports and data will be kept in the cloud, and the blockchain system will transmit the information securely and efficiently. Finally, neural algorithms can be used to predict the illness of the patient.
[25]	In the present scenario, there are significant challenges faced by the current health care system due to the increase in the illness of populations. The quality of medical services is not sufficient due to the increase in expenditure on medical treatments, insufficient resources, poor administration, and the bad experience faced by patients. However, advanced technologies are being constantly designed to solve present challenges. In this review article, the authors focused on the role of 5G radio in future modern hospitals. The authors also projected the challenges faced by the employment of 5G in the smart health framework.
[26]	The proposed article discussed the role of the 5G network in smart hospitals, IoT, and the automation industry. It is seen that the rollout of 5G will enhance the quality of services and health care. High spectral networks, low propagation delay, and fast data speed are a few concerns about the future of modern health care. The current technologies, such as 4G and OFDM, cannot fulfill the requirements. Hence, it is important to explore a new radio for the 5G network.

Table 1. *Cont.*

References	Contributions
[7]	The high peak to average power ratio (PAPR) reduces the efficiency of the power amplifier and hugely increases the power consumption of the 5G network. Hence, PAPR is considered one of the major problems in implementing 5G assisted hospitals. In this work, the authors projected a genetic algorithm-based selective mapping PAPR algorithm for future smart hospitals. The outcome of the work reveals that the projected algorithm enhanced the BER and PAPR performance of the system.
Proposed Work	In this work, we highlighted the contributions of researchers in the field of smart hospitals. Further, we have analyzed and simulated the FBMC waveform based on different parameters such as bandwidth efficiency, throughput, and spectrum density, which is the first time investigated and proposed.

System Model

The role of the 5G waveform for future modern hospitals is shown in Figure 2. Table 2 indicates the role of 5G in smart hospitals:

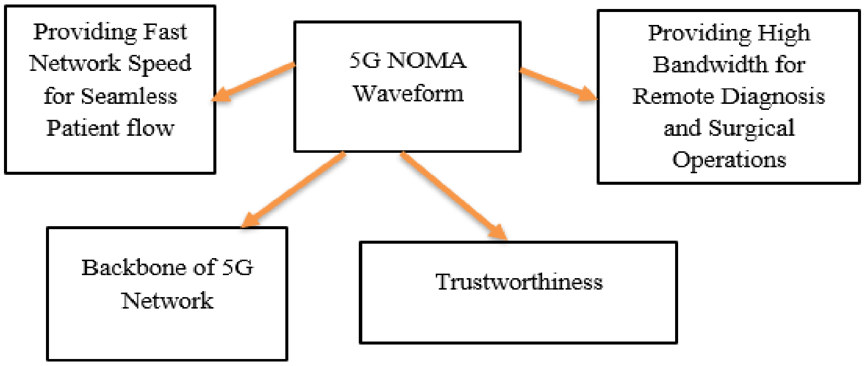

Figure 2. Role of FBMC in Smart hospitals.

Table 2. Expectation from 5G services for modern hospitals.

Sectors	Facilities
Pervasive 5G engagements	Enormous streaming of data, virtually advanced susceptibility, latency < 1 ms
Intelligent 5G engagements	Congested zone care, client created computation.
Worldwide 5G engagements	Robust special machine, health maintenance, intellectual town, house, and industry
Unified 5G engagements	Intellectual transfer, Drone formation, 3D empathy
Community 5G	Superior scrutiny, Holocaust Regulator, Alternative services

FBMC is based on a multi-carrier technique and is considered as one of the strong contenders for advanced 5G waveforms. The CP is not utilized in FBMC. Therefore, large amounts of data can be transmitted, and the spectrum is also not wasted. FBMC enhanced the spectrum utilization and capacity of the system, which is considered as one of the important requirements of smart hospitals, and it is a more selective framework. The structure of FBMC is given in Figure 3. In this framework, the single carrier is divided into several sub-carriers through which the information is transmitted. The PAPR results can explained due to the presence of a large number of sub-carriers. An IFFT of the random modulated signal is performed to estimate the PAPR of FBMC signals. A group of filters is applied to each sub-carrier to reduce the interference between the sub-carriers. Thus, the signal with low peak power is transmitted over the channel. At the receiver, the signal is demodulated. It is implemented by using a combination of M-IFFT, M-FFT, and clusters of the filter at the sending and receiving parts of the FBMC structure. In comparison to OFDM, FBMC achieved the separation between the signals by applying a filter to the number of sub-carriers. Hence, the loss of spectrum due to the insertion of CP in OFDM is overcome in the FBMC waveform [27].

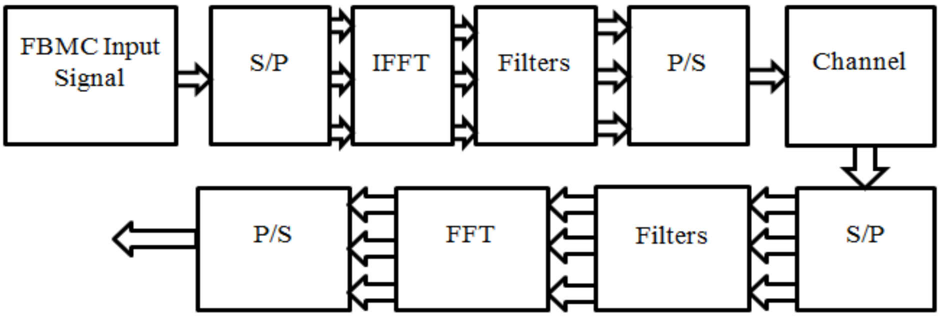

Figure 3. Structure of FBMC waveform.

Let N be the number of sub-carriers in the FBMC framework. For an individual sub-carrier $L \in \{0, \ldots, N-1\}$, the modulated signals $O_{L,m}$ are combined in the clusters of $M/2 \in M^*$ signal. The M-IFFT is applied on $\frac{M}{2}$ FBMC signals, which results in $Q_{L,m}$. A CP of length l is inserted, which increases the size of the signal $Q_{L,m}$. The FBMC signal $Q_{L,m}$ on every individual sub-carrier L is expressed as:

$$Q_{L,m} = exp^{i2\pi M(L+1)} \sum_{K=0}^{\frac{M}{2}-1} O_{L,\ K,I}\ exp^{i2\pi mK/M} \quad \forall \in S_I \tag{1}$$

where S_I denotes the cluster of FBMC signal of $Q_{L,m}$ and can be written as:

$$S_I = \{(I-1)(M+l),\ \ldots,\ I(M+l-1)\} \tag{2}$$

$(M+l)$ is the size of the I^{th} block and $O_{L,\ K,\ I}$ represents the symbol $O_{L,\ K}$, sent to the block of size M. The FBMC signals $Q_{L,m}$ are applied to the modulator, given as:

$$y(n) = \frac{1}{\sigma_y} \sum_{L=0}^{N-1} \sum_{m=-\infty}^{m=\infty} Q_{L,m} C_f(n - mN/2) exp^{\frac{i2\pi L(n-\tau)}{\tau}} exp^{i\theta L,m} \tag{3}$$

$C_f(n)$ is the cluster of PHYDYAS filter with the size of $l = LN$, such that $L \in N^*$, known as an overlapping factor, τ is the latency represented by $\tau = \left(L_{Cf} - 1\right)/2$ and $\theta L, m$ represent the phase of the signal, given by:

$\theta L, m = 1.57(m+L) - 3.14$ mL. The optimization element σ_y is used to make sure that the output power of the transmission system is unity, represented as ${\sigma_y}^2 = B\,[M,\ l] Avg\left(|O_{L,m}|^2\right)$ and $B\,[M,\ l]$ is defined as the mean of the data transmitted in FBMC sub-blocks of length (L) over one period [28]. The FBMC signal $y_L[n]$ for L number of subcarriers is given by:

$$y_L[n] = \frac{1}{\sigma_y} exp^{\frac{i2\pi L(n-\tau)}{\tau}} \sum_{m=-\infty}^{m=\infty} Q_{L,m} exp^{i\theta L,m} C_f(n - mN/2) \tag{4}$$

The PSD of the FBMC signal $y(n)$ without considering complex phase $exp^{\frac{i2\pi L(n-\tau)}{\tau}}$ is expressed as [28]:

$$Y(f) = \frac{2}{{\sigma_y}^2} C_f(f) B\left(\frac{N}{2} f\right) \tag{5}$$

$C_f(f)$ is the Fourier transforming factor of $C_f[n]$ and f is the frequency.

3. Results

In the proposed article, we have used an overlapping factor (L = 1, 2, 3, and 4), 64-QAM transmission technique, PHYDYAS filter, 64-sub-carriers, Rayleigh channel, and bandwidth of 10 MHz. This study aims to analyze the throughput and high spectral efficiency of FBMC waveform to regularize in 5G-based smart hospitals. The PSD of the FBMC signal for L = 1, 2, 3, and 4 are given in Figure 4. It is observed that there is a minimum sidelobe in the FBMC spectrum. Hence, there is no spectrum leakage problem, and spectrum efficiency is high. However, the best spectral performance is noticed for overlapping factor L = 4.

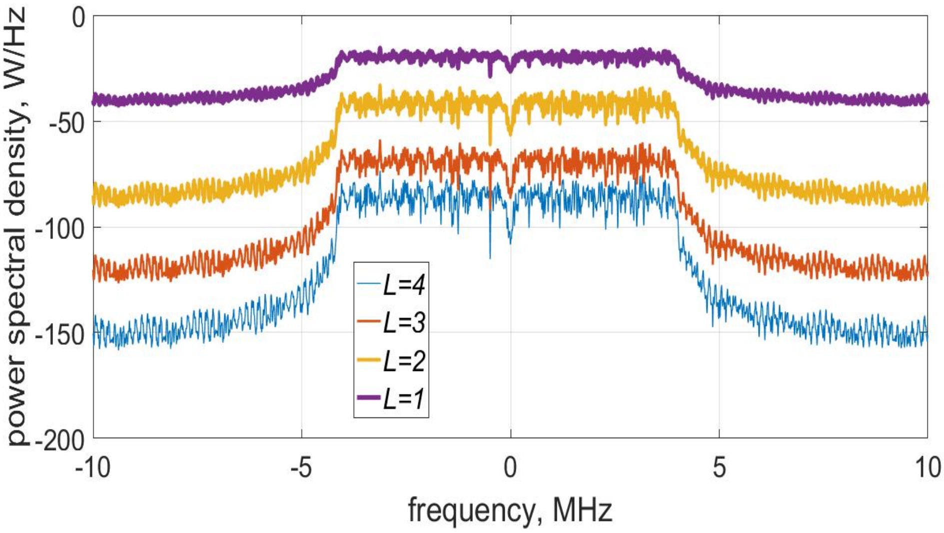

Figure 4. PSD of FBMC for L = 1, 2, 3, and 4.

The amplitude and phase response of FBMC and OFDM is given in Figure 5. It is observed that the magnitude and phase of the OFDM are approximately constant to normalized frequency, whereas the peak and phase of FBMC decrease with the increase in frequency. Hence, it is concluded that the OFDM is more prone to multipath fading as compared to the FBMC waveform.

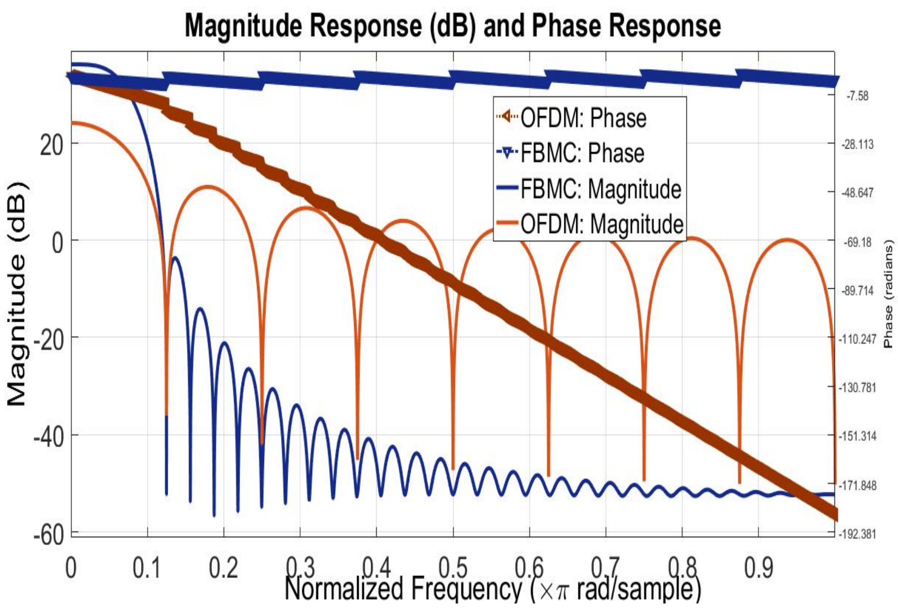

Figure 5. Amplitude and phase characteristics.

The PSD of the FBMC and OFDM is analysed in Figure 6. The spectrum of the OFDM waveform remains constant, whereas FBMC decreases with the increase in frequency. Therefore, the transmission power requirement is less for the FBMC structure than the OFDM.

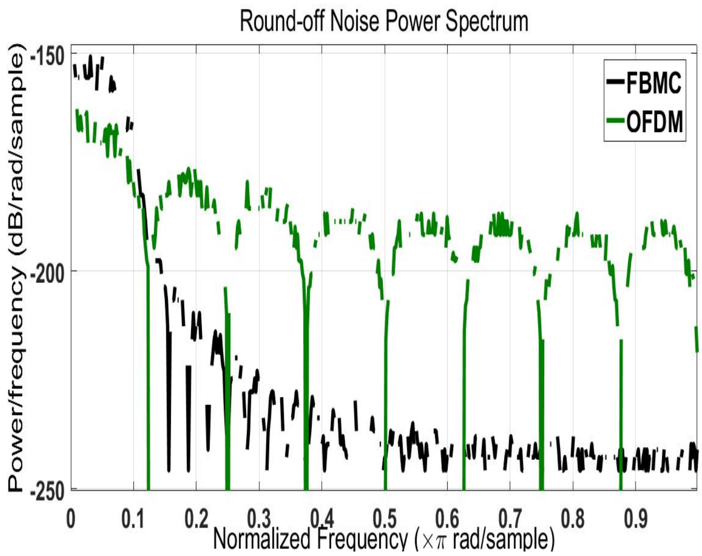

Figure 6. Noise PSD.

The capacity performance of FBMC is better than that of OFDM, as given in Figure 7. According to Shannon's theorem [29], the capacity of the system is directly proportional to bandwidth. In the FBMC structure, there is no use of CP, due to which 11% of the bandwidth is utilized, unlike the OFDM employed CP where 11% of the bandwidth is wasted.

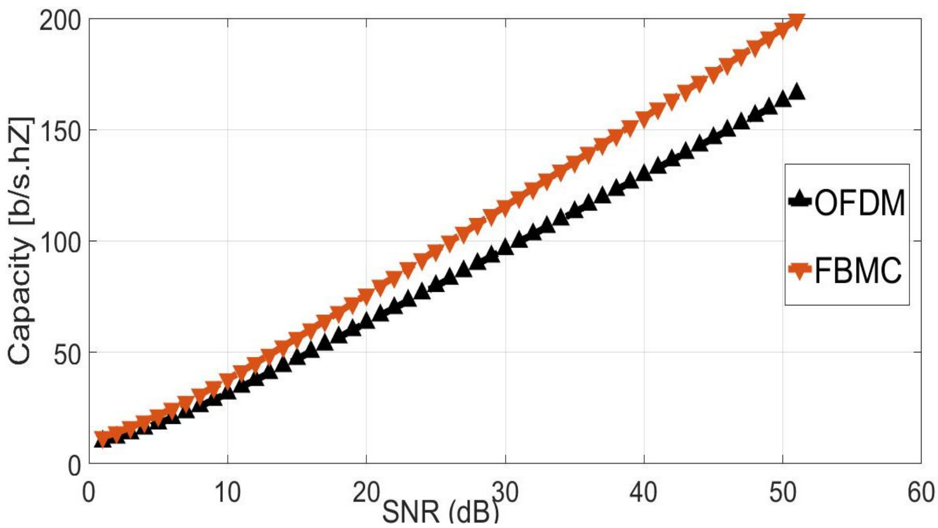

Figure 7. Capacity.

The throughput of the OFDM and FBMC structures is analyzed by estimating the BER performance, indicated in Figure 8. At BER of 10^{-4}, the SNR of the FBMC and OFDM is 8 dB and 9.1 dB, respectively. Hence, the FBMC accomplished a gain of 1 dB as compared to the OFDM framework.

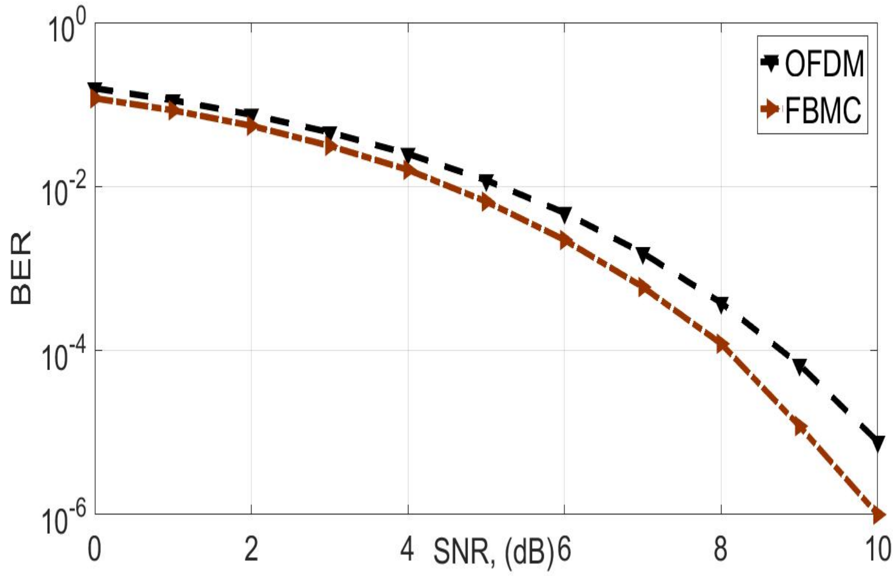

Figure 8. SNR Vs. BER.

The PAPR performance of the waveform techniques is given in Figure 9. At the complementary cumulative distribution function (CCDF) of 10^{-2}, the PAPR of the FBMC structure is significantly lower compared to the OFDM. However, it is noted that, at CCDF of 10^{-4}, the PAPR performance of both waveform schemes is approximately the same.

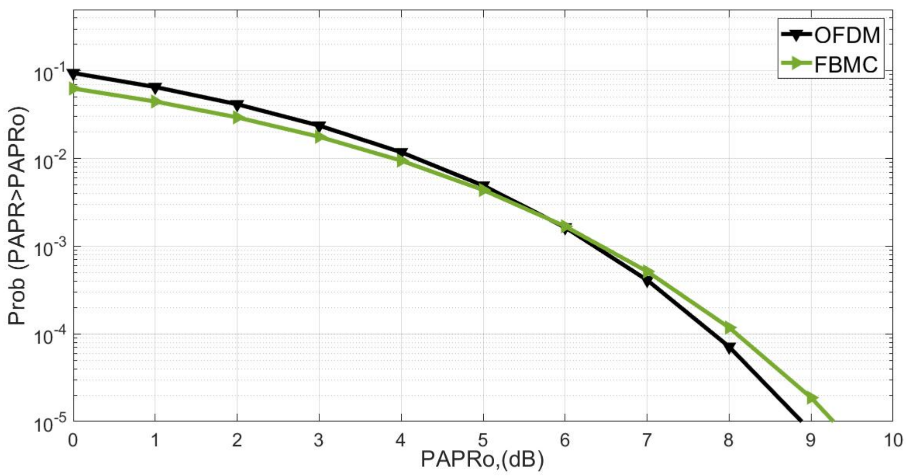

Figure 9. PAPR curves.

4. Conclusions

This article explored the research and studies related to the different outlooks of future 5G smart hospitals. It is noted that high bandwidth is one of the most important requirements of 5G-based smart hospitals. A huge amount of data on patients can be shared immediately with the availability of sufficient bandwidth. For the OFDM structure currently being utilized in 4G, the spectral performance is inadequate for several reasons, such as the use of CP, the presence of phase distortion, sensitivity to time inaccuracy, and so on. In this work, we have analyzed and projected an FBMC waveform for an advanced radio. The spectrum, throughput, PAPR, noise PSD of OFDM, and FBMC are compared, studied, and simulated. It is noted that the projected FBMC waveform is far superior to the OFDM system. Hence, it is concluded that the FBMC is considered to be a strong candidate for 5G-based smart hospitals.

Author Contributions: B.R. was involved in designing the paper. A.K. wrote the paper and experimented. S.C. edited the paper, and M.M. perform av over-analysis of the paper and experiments, and M.B. was involved in the analysis part of the paper. All authors have read and agreed to the published version of the manuscript.

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