

# Performance Evaluation of OTFS and OFDM for 6G Waveform

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**Abstract.** Orthogonal time frequency space (OTFS) modulation is a coming technique addressing the challenges of 5G and 6G. It's appeared to bring about outstanding error performance in delay – Doppler (DeDo) channels. Still, a really fair comparison with its competitor's direct orthogonal frequency division multiplexing and is extensively used in this participation, we will make a comparison of the performance of OTFS and OFDM with the digital modulation format in terms of bit error rate (BER) versus signal-to-noise rate (SNR) for the 16-QAM technique. From the numerical simulations under MATLAB, the results showed that the OTFS admits a small BER to the OFDM in given cases

## 1 Introduction

New generations of wireless communications are expecting to deliver efficient service with lower latency in high-speed environments. Recently, OTFS modulation has been proposed an effective solution for achieving a trusted wireless communication service [1]. That is because of an optimum choice for vehicular communication at high speed caused by its rise susceptibility to inter-carrier interference, which is attributed to Doppler spreading [2]. OTFS is an extended generalization of classic time and frequency modulation techniques such as time division multiplexing (TDM) and frequency division multiplexing (FDM) and, from a stronger perspective, it conceptually links radar to communications. OTFS waveform technologies are combined with the wireless channel to directly capture hidden physics, leading to a microwave radar image with greater reliability of the constituent reflectors. Therefore, the selected time-frequency channel is regenerated in an associate degree unchanged, divisible, and orthogonal interaction, whither all admitted QAM symbol data undergo the identical specific deterioration, and all delay-Doppler variety parts are summed in a cohesive way. [3].

Basically, OTFS has emerged to overcome the drawbacks that OFDM could not cover. In short, OFDM is a digital modulation technique that uses digital data by encoding onto a number of orthogonal subcarriers. OFDM has become a popular high-bandwidth digital communication technology, applied in many fields for instance digital television, audio transmission service, digital subscriber line (DSL) web access, wireless network, electrical connection, fiber optic networks, and 4G/5G mobile telephony. [4].

Although both, OTFS and OFDM serve the same purpose for QAM method, but technically are different. Studies have demonstrated that the results of [5] show OTFS is stronger Technology against Doppler compared to OFDM. Also, OFDM update for inferior Doppler environments is not effective big for these applications [5]. Furthermore, OFDM is severely limited by synchronization errors, which is an ancient discovery. In comparison, we get that OTFS has great flexibility to such a large residual timing error though it is not totally impervious to it. Thus, it can be understood that the time domain channel estimation provides acceptable flexibility to OTFS against timing errors during compensation [6]. In addition to that, the proportion resource utilized for drivers and general losses in OTFS is lower than that of OFDM, and therefore the spectrum efficiency (SE) of OTFS is greater from of OFDM [6].

Besides, the user data of OTFS (constellation of data symbols) is arranged in the DeDo interval unlike the frequency-time (TF) interval in OFDM. Therefore, the data is propagated through the TF domain using a unitary transformation. It is pursued by the modulation OFDM [7]. The prefix of cyclic [7] or OFDM block [8] is provided to dampen the channel delay spread.

Not to mention that OFDM is not an optimal choice for high-rapidity vehicular communications due to its greater susceptibility to interference between inter-carriers, this is a consequence of Doppler propagation. However, the subcarrier bandwidth in OFDM can be increased to decrease the inter-carrier interference at the cost of spectral efficiency loss.

In the [6], authors show that reduced CP OTFS signals can be generated by interleaving the signal of a block OFDM system. The performance of OTFS in AWGN

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channel is shown, where it is found to be identical with a single carrier as well as OFDM. Moreover, OTFS gives diverse gains in different situations with high-frequency dispersion. Such situations are facing, For example, in millimeter wave systems, both due to the higher phase noise and higher Doppler propagation are encountered there. [7]

In this work, in the first part, we will talk about OTFS modulation. In the second section about OFDM modulation and in the third part, we will assess the yield of OTFS and OFDM codes modulation applied QAM symbols. This comparison is done in terms of BER vs SNR for 16-QAM, and finally, we will give a conclusion and a perspective to our future vision.

## 2 Modulation OTFS

Considering OTFS modulation when  $M$  is a number of subcarriers such that subcarrier bandwidth is  $\Delta f$  and number  $N$  of symbols with symbol duration is  $T$ . the total bandwidth is given by  $B = M \Delta f$  and the total duration  $T_f = NT$ . Additionally, if  $T\Delta f = 1$  the OTFS technique in the case of a critical sample. [11]

According the [1, 2, 6] Quadrature Amplitude Modulation (QAM) modulated the data symbols  $x(k,l)$  on the  $N \times M$  array are coordinated in the Doppler delay range. It is represented on an  $N \times M$  grid,  $X(n,m)$  in the (TF) interval according to the use of the inverse Symplectic Fourier transform (ISFFT),

$$X(n,m) = \frac{1}{NM} \sum_{k=0}^{N-1} \sum_{m=0}^{M-1} x(k,l) e^{j2\pi(\frac{nk}{N} - \frac{ml}{M})} \quad (1)$$

Then the signal  $X(n,m)$  in the time interval is changed to  $x(t)$  from the Heisenberg transform as follows,

$$x(t) = \sum_{k=0}^{N-1} \sum_{m=0}^{M-1} X(n,m) g_{tx}(t - nT) e^{j2\pi m \Delta f (t - nT)} \quad (2)$$

Where,  $g_{tx}(t)$  is transmitter pulse and  $\Delta f$  the subcarrier spacing and  $T$  symbol duration. We have a channel that has a response in the delay-Doppler domain  $h(\tau, \nu)$ , with the variables,  $\tau$  and  $\nu$  are respectively the delay and the Doppler. Therefore The transmitted signal  $x(t)$  is transformed on this channel into a received signal in the time domain  $y(t)$  on the receiver in the following form,

$$y(t) = \iint h(\tau, \nu) x(t - \tau) e^{j2\pi \nu (t - \tau)} d\tau d\nu \quad (3)$$

After using the Wigner transform The signal  $y(t)$ . We find a signal in the interval TF, as follows

$$Y(n,m) = A_{g_{xy}}(t,f) | t = nT, f = m\Delta f \quad (4)$$

$$A_{g_{xy}}(t,f) = \int g_{rx}^*(t' - t) y(t) e^{-j2\pi f (t' - t)} dt' \quad (5)$$

With the receive pulse is of the form  $g_{rx}(t)$ . If the bi-orthogonality condition  $g_{rx}(t)$  and  $g_{tx}(t)$  is

satisfied [2], the equation below represents the input-output function in the TF range

$$Y(n,m) = H(n,m)X(n,m) + V(n,m) \quad (6)$$

Where  $V(n,m)$  represents the noise in TF and  $H(n,m)$  is given by

$$H(n,m) = \int \int_{\tau} h(\tau, \nu) e^{j2\pi \nu nT} e^{-j2\pi \nu n(\nu + m\Delta f)\tau} d\nu d\tau \quad (7)$$

According to the symplectic finite Fourier transform (SFFT), the  $Y(n,m)$  is marked on a map of the DeDo domain signal  $y(k,l)$ , so we have,

$$y(k,l) = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} Y(n,m) e^{-j2\pi(\frac{nk}{N} - \frac{ml}{M})} \quad (8)$$

Starting (1)-(7), the input-output equation is given by [2]

$$y(k,l) = \frac{1}{NM} \sum_{l'=0}^{N-1} \sum_{k'=0}^{M-1} x(k',l') h_w\left(\frac{k-k'}{NT}, \frac{l-l'}{M\Delta f}\right) + v(k,l) \quad (9)$$

Where  $h_w(\nu, \tau)$  is the channel response circular convolution with a windowing function  $w(\nu, \tau)$  and

$$h_w\left(\frac{k-k'}{NT}, \frac{l-l'}{M\Delta f}\right) = h_w(\nu, \tau) | \nu = \frac{k-k'}{NT}, \tau = \frac{l-l'}{M\Delta f} \quad (10)$$

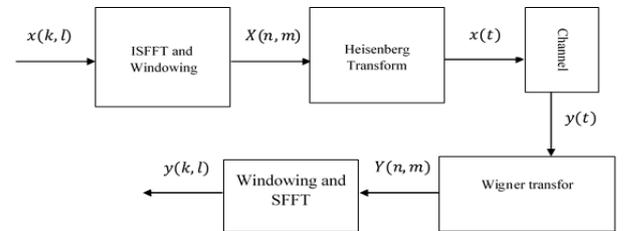


Figure 1 : OTFS modulation scheme.

## 3 Modulation OFDM

Assuming that a block of QAM modulated symbols  $d = (d_0 d_1 \dots d_{N-1})^T$ .

Either the data symbols are numerically independent and identical, i.e.,  $[d_l d_l^*] = \sigma_d^2 ; \forall l$  and  $E[d_l d_l^*] = 0$  while  $l \neq q$ . Let divide  $B$  total bandwidth into  $N$  number of subcarriers where the symbol duration  $T = \frac{N}{B}$  second and  $\frac{B}{N}$  Hz is the subcarrier bandwidth. The transmitted OFDM signal,  $x(n)$ , can be given as:

$$x(n) = \sum_{r=0}^{N-1} d_r e^{j2\pi \frac{rn}{N}} \quad (11)$$

the signal transmitted can be given as,

$$x = W_N d \quad (12)$$

where  $W_N$  is  $N$ -order inverse discrete Fourier transform (IDFT) matrix. Hence, transmitter can be

implemented using N-point IDFT of complex data symbols,  $d$ . IDFT can be computed using low complexity radix-2 fast Fourier transform (FFT) algorithm. When OFDM signal is passed through multipath channel, symbol spreads in time. To ignore inter symbol interference (ISI), a prefix of cyclic (CP) of length  $L_{CP}$  is added. OFDM-CP transmitted signal can be denoted as:

$$x_{cp} = [x(N + L_{cp} - 1):x(N - 1);x] \quad (13)$$

Let,  $h = (h_0, h_1, \dots, h_L)^T$   $L$  is the number of elements of the channel impulse response vector, and  $h_r$ , for  $1 \leq r \leq L$ , is the complex baseband channel factor of  $r^{th}$  trail, which we suppose is a zero mean circular symmetric complex Gaussian (ZMCSC). We too suppose that the channel factors concerning the different trajectories are uncorrelated. We consider,  $N_{cp} \geq L$ .

at the level of the receiver the vector is of length  $N_{cp} + NM + L - 1$  (14)

is given by,

$$z_{cp} = h * x_{cp} + v_{cp} \quad (15)$$

Where  $v_{cp}$  is AWGN vector of length  $N_{cp} + NM + L - 1$  With element variance  $\sigma_v^2$ .

$$\sigma_v^2 = E(v^2) \quad (16)$$

At the receiver, we have:

$$y = [z_{cp}(N_{cp} + 1 : N_{cp} + MN)] \quad (17)$$

The received vector of length  $MN$  after removing the CP can be written as follows,

$$y = HW_N d + v \quad (18)$$

Where  $H$  represents circulant convolution matrix of size  $MN \times MN$ , that we can give like this

$$H = \begin{bmatrix} h_1 & h_1 & \dots & 0 & h_L & \dots & h_2 \\ h_2 & h_1 & \dots & 0 & 0 & \dots & h_3 \\ \vdots & & \ddots & & & & \\ h_L & h_{L-1} & \dots & \dots & \dots & \dots & 0 \\ 0 & h_L & \dots & \dots & \dots & \dots & 0 \\ \vdots & & \ddots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & h_L & \dots & \dots & h_1 & \end{bmatrix} \quad (19)$$

Whereas  $v$  means WGN vector of length  $MN$  with elemental variance  $\sigma_v^2$ .  $H$  can be factorized as,

$$H = W\Lambda W^H, \Lambda = \sqrt{N} \times \text{diag}\{W_N^H h\} \quad (20)$$

where,  $h$  is the first column of  $H$ . This implies that  $\Lambda$  holds channel frequency samples which are sampled at the rate of  $\frac{N}{B}$  samples per Hz in its diagonals.

Hence, received vector after CP removal may be represented as,

$$y = W_N \Lambda W_N^H W_N d + v = W_N \Lambda d + v \quad (21)$$

Further, N-point FFT of  $y$  is computed i.e.,

$$z = W_N^H y = \Lambda d + W_N^H v \quad (22)$$

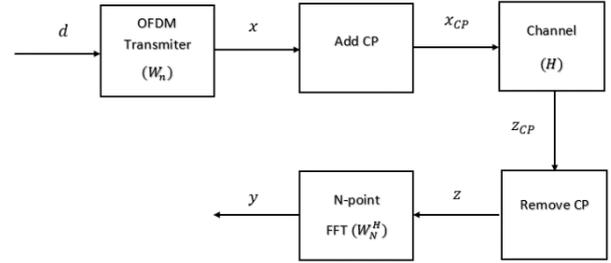


Figure 2: OFDM modulation scheme.

## 4 Results and discussions

In this part, we will compare the efficiency of OTFS and OFDM modulation technique using MATLAB. The comparison was made in term of BER versus SNR for number of subcarriers (OTFS,  $M=8$ ) and (OFDM,  $M=64$ ) with 16-QAM technique.

### 4.1 OTFS modulation results

The simulated results of the BER versus SNR performance for OTFS modulation with 16-QAM is plotted in figure 3. From this figure, the BER is higher for low SNR value and progressively decreases as the SNR increases. Then we can say that the BER performance is not good for a SNR ranges from 0 to 8 dB, but this parameter can be decreased for a high SNR (SNR greater than 8dB).

physically the BER decreases as SNR increases because as SNR increases the signal power becomes high relative to the noise power.

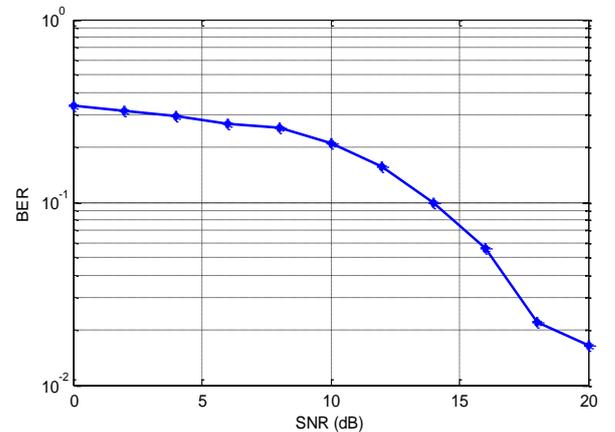


Figure 3: BER Vs SNR for OTFS (number of subcarriers  $M=8$ ) with 16-QAM.

### 4.2 OFDM modulation results

Figure 4 shows the simulation results of BER versus SNR for OFDM modulation with 16-QAM. In this figure, we can observe that as the SNR increases, the BER decreases gradually. We can see also that the variation of the BER according to the SNR from 0 to 8 dB, is very slow and almost noticeable on this interval.

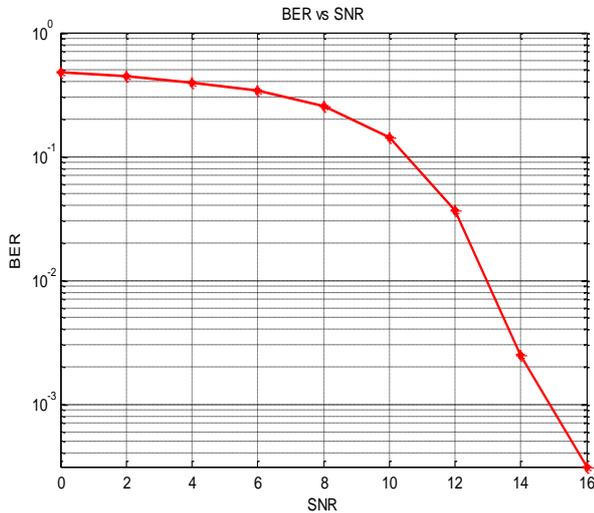


Figure 4: BER vs SNR for OFDM (number of subcarriers M=8) with 16-QAM.

### 4.3 Comparison results

Figure 5, plot BER from SNR variation for OTFS and OFDM with 16-QAM. From this figure, we can see that the BER of OFDM is higher than the OTFS one between 0 and 8dB. From 8dB and more, we observe that OTFS surpasses OFDM in the entire rest of the remaining range as SNR increases. We can say that the performance improvement is very low or null when the signal to noise ratio increases.

In SNR cases higher than 8 dB the BER of OFDM becomes lower than that of OTFS because we used a number of deferent subcarriers for OTFS (N=8) and for OFDM (M=64).

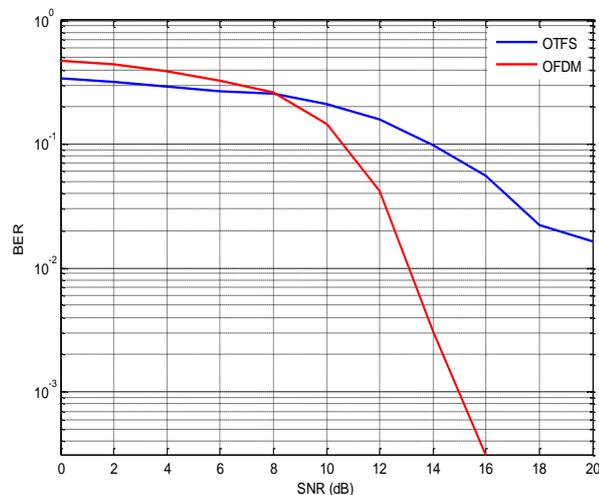


Figure 5: BER Vs SNR for OFDM (number of subcarriers M=64) and OTFS (number of subcarriers M=8) with 16-QAM.

The following table shows the results obtained by comparing OTFS and OFDM using Figure. 5

Table1. comparison OTFS and OFDM

SNR (dB) \ BER	OTFS	OFDM
0	$3.5 \cdot 10^{-1}$	$3.5 \cdot 10^{-1}$
4	$3.5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$
8	$2,8 \cdot 10^{-1}$	$2,8 \cdot 10^{-1}$
10	$2 \cdot 10^{-1}$	$1,5 \cdot 10^{-1}$
12	$1,6 \cdot 10^{-1}$	$4 \cdot 10^{-2}$
14	$10^{-1}$	$3 \cdot 10^{-3}$
16	$5 \cdot 10^{-2}$	0

## 5 Conclusion

According to previous results, the performance of both OFDM and OTFS waveforms are plotted and compared in terms of BER vs SNR for 16-QAM signals using numerical simulation. From the study findings, the OTFS modulation can be preferred for its improved reliability than OFDM one. Furthermore, OTFS is an excellent candidate for modulation and future 6G network requirements. As perspectives of this work, we propose to study the performance of OTFS using NOMA and OTFS combined with Filter Bank Multi Carrier (FBMC).

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