International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V71I6P202

Volume 71 Issue 6, 8-15, June 2023

Original Article

Comparison of Various Modulations in TS-LMS-based TDS-OFDM Frame Structure for Channel Estimation in Digital Terrestrial Television Broadcasting Systems

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Received: 03 January 2023 Revised: 31 May 2023 Accepted: 14 June 2023 Published: 25 June 2023

Abstract *- In various wireless communication applications, such as digital television terrestrial broadcasting (DTTB), orthogonal frequency division multiplexing (OFDM) is the most often used data transmission technique. Time-domain synchronous OFDM (TDS-OFDM), which is based on iterative padding subtraction (IPS), offers good spectral efficiency across fast-fading channels but is computationally complex. Dual Pseudo Noise Stuffing (DPNS) based TDS-OFDM to IPS-based TDS-OFDM, spectral efficiency is sacrificed to lower computational complexity. TDS-OFDM system performance is improved over a quick time-varying channel by using an alternative time-frequency-domain (TFD) entrenched frame building, albeit at a high computing cost. This work offers a unique frame structure for an OFDM-based DTTB system. It manifests the comparison of QPSK, 8-PSK, and 16-PSK modulation techniques using time-domain training sequence (TS) least mean square (LMS) based TDS-OFDM frame structure for channel estimation. The recommended frame structure is constructed on two-stage channel impulse response (CIR) estimation. The first stage aims to compute the CIR helped with the training sequence in guard intervals. Using the CIR obtained in the first stage as a starting point, the initial weights of an adaptive filter are later modified in the second phase using the LMS approach. Even if the provided frame structure outperforms DPNS-based TDS-OFDM in terms of BER, the loss in spectral efficiency is negligible since fewer than 1.5% of all sub-carriers in this frame structure are used as redundant pilots. As opposed to 8-PSK and 16-PSK, the QPSK achieves a higher level of BER.*

Keywords *- Digital Terrestrial Television Broadcasting (DTTB), Time Domain Synchronous Orthogonal Frequency Division Multiplexing (TDS-OFDM), Fast Fading Channel, Channel Estimation, Least Mean Square (LMS) Algorithm, Quadrature Phase Shift Keying (QPSK).*

1. Introduction

Orthogonal frequency division multiplexing (OFDM) is often used in digital terrestrial television broadcasting (DTTB) across a spread spectrum frequency-selective channel. Three types of OFDM block transmission systems may be categorised: time-domain synchronous OFDM (TDS-OFDM) [1], cyclic prefix OFDM [2], and zero padding OFDM [3].

Multiple frame structures exist in an OFDM block, depending on the positioning of the pilot and the guard interval. By interjecting a guard band between two OFDM frames [4], CPOFDM, one of the most well-known and extensively employed frame architectures, decreases inter-block interference (IBI) and inter-carrier interference (ICI) [5]. This guard band is CP. The tail of the frame becomes a prefix and acts as a guard band in CPOFDM. Pilots are inserted into the OFDM frame for channel estimation, which decreases spectral efficiency. In ZP-OFDM, zero padding is employed in place of CP. The primary benefit of zero padding is that it solves the channel null problem [3], [6], [7]. 10% of all subcarriers are employed as pilots in CP-OFDM and ZP-OFDM. As a result, spectral efficiency declines. To maximise spectral efficiency, the guard interval among OFDM data frames is utilised by the pseudorandom noise (PN) sequence. This PN sequence is utilised for channel estimation in addition to synchronisation [1]. For data transmission, the Chinese DTTB standard known as digital television terrestrial multimedia broadcasting (DTMB) [1] uses a frame structure known as TDS-OFDM [8].

TDS-OFDM is preferable regarding frame coordination and spectrum efficiency, although it has an IBI issue. The training sequence (TS) is affected by the IBI with the data block and PN sequence. By using iterative padding subtraction (IPS), it is eliminated [9]. IPS incorporates simultaneous channel estimation and equalisation [9]. TDS-OFDM efficiency drops due to IPS regardless of whether the multipath channel is stationary.

The dual PN Stuffing (DPNS) [10] frame structure is one of the techniques mentioned in the literature to address the interference issue in TDS-OFDM. There are two identical PN sequences in DPNS. The computational intricacy of DPNSbased channel estimation is quite minor, and it is straightforward and dependable. As a result, it is gaining ground on other above-frame structures as a contender for the new DTTB standard [1], [11]. Because of the existence of two PN sequences inside the TDS-OFDM structural frame, DPNSbased TDS-OFDM has a lower spectral efficiency than IPSbased TDS-OFDM. The fact that DPNS-based TDS-OFDM takes a time-invariant channel into account during each symbol interval is a significant drawback. As a result, when employed in fast fading channels, there is performance degradation in terms of bit-error rate (BER).

Linglong Dai et al. provide a signal structure for fast time-varying channels [26] to enhance TDS-system OFDM's performance. To precisely predict the rapidly varying multipath wireless channel, They suggested a signal structure based on the time-frequency domain (TFD) [26]. As per [26], In terms of BER performance, this technique surpasses both DPNS-based and IPS-based TDS-OFDM. This frame structure computes path gain and path latency separately. It only considers path latency from the channel approximation using time-domain TS and ignores the path gain from this estimate. In the OFDM data packet, frequency domain pilots compute the route again from scratch. This results in very high computational complexity compared to other frame structures.

W. Kong et al. proposed a frame structure that moved on an adaptive two-stage approach. It exploits characters of PN sequence and sparsity in frequency and time domain [13]. Another two-stage estimation is proposed by Emad Farouk et al., in which a joint channel estimation algorithm method is employed [14].

In this study, a brand-new frame structure is suggested with the goal of precise channel estimation. The main objective of this work is to obtain a frame structure that has high spectral efficiency, low computational complexity and ensures minimum BER. The following is a list of this paper's main contributions:

- The thorough examination of the QPSK, 8PSK, and 16PSK modulation schemes [15] uses the new frame structure that has been suggested and incorporates time domain pilots inside the OFDM data packet for CIR tuning. It increases BER performance over DPNS-based TDS-OFDM frame structures [10].
- In terms of BER and spectrum efficiency, the suggested frame structure performs similarly to the 2-stage T-F domain-based frame structure [26] but with much lower computational complexity.

The body of the paper is structured as follows: The model of the system and proposed frame structure are described in Section II. Section III explains two-stage channel estimation and equalisation (first utilising TS of the guard interval and later employing LMS to modify the estimate). Section IV presents the simulation findings, while Section V provides the conclusions.

In order to enhance the DTTB system's effectiveness in terms of computational effort and BER over static, rapid fading, and slow fading channels [16], a unique signal frame structure for TDS-OFDM is proposed, as illustrated in Fig. 1. Furthermore, it compares the frame topologies of TDS-OFDM depending on 2-stage T-F Domain and DPNS. It is clear that the time domain OFDM unit and guard band pilots in the suggested frame structure differ from those in the DPNS-based system. The pilots inside the OFDM unit differ from those in the 2-stage T-F Domain-based approach as well. The pilots in the proposed technique are in the time domain, whereas the pilots in the 2-stage T-F Domain-based system are in the frequency domain.

2. Model of the System

2.1. Proposed Signal Structure

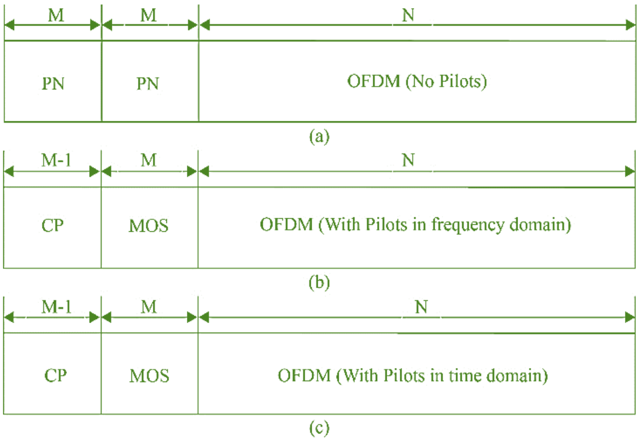

Fig. 1 Comparison of frame structure: (a) DPNP-based TDS-OFDM [4] ; (b) TDS-OFDM [26]; (c) Proposed variant of TDS-OFDM

2.2. OFDM Data Blocks and Guard Intervals Computation

The guard interval arrangement described is adopted in the projected TDS-OFDM frame structure. [26].

The i^{th} symbol of the TDS-OFDM data block,

$$s_i = [s_i, 0, s_i, 1, \dots, s_{i,P-1}]^T$$

consists of a guard interval known a priori,

$$g_i = [c_i, 1, \dots, c_{i,\beta-1}, c_i, 0, c_i, 1, \dots, c_{i,\beta-1}]^T$$

which is of length $2\beta - 1$, and the OFDM data block of length α.

$$x_i = [x_i, 0, x_i, \dots, x_{i,\alpha-1}]^T$$

The guard interval gi is made up of $ci = [ci,0,\ ci,1,\dots,\ ci,\beta - 1]T$, which is defined as a TS of length β and its matching cyclic prefix $[ci,1,\dots,\ ci,\beta - 1]T$.

The time-domain expression for an OFDM data block is $x_i = F_{NH}X_i$, where $X_i = [X_{i,0},\ X_{i,1},\dots,\ X_{i,\alpha-1}]_T$ stands for the FFT of x_i. One TDS-OFDM symbol's whole duration is represented by the value $P = \alpha + 2\beta - 1$.

The new TS c_{i+1} for the $(i + 1)^{\text{th}}$ TDS-OFDM symbol is obtained when one sample is cyclically added to the TS c_i for the i^{th} TDS-OFDM symbol and is given by

$$c_{i+1} = \begin{bmatrix} 0_{1\times(\beta-1)} & 1 \\ I_{\beta-1} & 0_{(\beta-1)\times 1} \end{bmatrix} \tag{1}$$

As a result, TS is not a constant in the system. The use of constant TS for channel estimation has been demonstrated in [17]. The new guard interval for the $(i + 1)^{\text{th}}$ TDS-OFDM symbol can be calculated from (1) as

$$g_{i+1} = [c_i, 0, c_i, 1\ \dots, c_{i,\beta-2}, c_{i,\beta-1}, c_i, 0, c_i, 1, \dots, c_{i,\beta-2}]^T$$

Similar to the final β samples of g_i is the first β samples of g_{i+1}.

The PN sequence of DPNS-based TDS-OFDM has suboptimal autocorrelation characteristics. Consequently, it is not the best for channel estimation. [18], [19]. The TS is adopted using the modulable orthogonal sequence (MOS) [26].

$$c_{i,n} = b(n_1)\exp\left(\frac{2\pi}{\sqrt{\beta}}\, mn_0n_1\right),\ 0 \le n \le \beta - 1 \tag{2}$$

where $0 \le n_0 \le \beta-1$, $0 \le n_1 \le \sqrt{\beta-1}$, $n = n_0\beta+n_1, m$ is a reasonably prime number to β, and $|b(\alpha_1)| = 1$. For convenience, $\beta = 1$ and $b(\alpha_1) = 1$ are used in this paper. The MOS has exact autocorrelation characteristics, which are represented by

$$c_i \otimes c_i = \beta\,[1 \quad 0_{1\times(\beta-1)}]^T \tag{3}$$

All data subcarriers are employed to convey data in DPNSbased TDS-OFDM, as shown in Fig. 1 (a), and no pilot is inserted in the data block [9]–[11]. The suggested signal structure employs α_d data subcarriers and α_p pilots for the OFDM data packet.

The time-frequency domain TDS-OFDM inserts the pilot in the frequency domain, whereas the suggested approach inserts the pilot in the time domain, resulting in a higher degree of complexity [26]. In the equation $\alpha = \alpha_d + \alpha_p$, and α_p is little enough in contrast to α. As a result, the proposed frame structure's spectral loss is minimal.

2.3. Modeling the System Over Fading Channels

Since there is only one sample altered TS, as indicated in (1), it is easy to reconstruct the OFDM data frame from the received frame. The received block exhibits IBI. Recreating the OFDM data block without IBI is possible by employing the add-subtract citation [10] approach. The OFDM data block $y_i = [y_{i,0}, y_{i,1},\dots, y_{i,\alpha-1}]^T$ is received. T in the time domain is determined by

$$y_{i,n} = \textstyle\sum_{t=0}^{L-1} h_{i,n,l}x_{i,(n-n_l)_\alpha} + w_{i,n} \tag{4}$$

Where additive white Gaussian noise AWGN, with a variation of σ^2 and a mean of 0, is represented by the variable wi,n. The path gain is represented by $h_{i,n,l}$. The OFDM block is denoted by i, the subscript l denotes the appropriate path, and n is the time instant. After a delay of n_l (where $n_0 = 0$ is considered in this paper), These path gains do not equal zero. The total number of multipath is L.

In the event that the maximum channel length n_{L-1} is bigger than the TS length β, there may be interference between the OFDM data block and guard band. To prevent this, $n_{L-1} < \beta$. L, the total number of multipaths, is extremely small in comparison to n_L, the maximum channel length, as shown in the, *i.e.*, $L << n_{L-1}$, [20], [21]. This occurs because wireless channels are designed in this way.

FFT of the received sequence is followed by $Y_i = [Y_{i,0},\ Y_{i,1},\dots,\ Y_{i,\alpha-1}]^T$ is [4], which is the frequency domain representation of the OFDM data block.

$$Y_{i,k} = \frac{1}{\sqrt{\alpha}} \sum_{n=0}^{\alpha-1} y_{i,n}\, e^{-j\frac{2\pi}{\alpha}nk}$$

$$Y_{i,k} = \tfrac{1}{\sqrt{\alpha}} \textstyle\sum_{n=0}^{\alpha-1}\left(\sum_{t=0}^{L-1} h_{i,n,l}x_{i,(n-n_l)_\alpha} + w_{i,n}\right)\ e^{-j\frac{2\pi}{\alpha}nk}$$

(5)

$$Y_{i,k} = X_{i,k}\,H_{i,k,k} + \sum_{q=0,q\neq k}^{N-1} X_{i,q}\,H_{i,k,q} + W_{i,k}$$

where $W_{i,k} = \frac{1}{\sqrt{\alpha}} \sum_{n=0}^{\alpha-1} w_{i,n}e^{-j\frac{2\pi}{\alpha}nk}$ is the noise term, and

$$H_{i,k,q} = \tfrac{1}{\alpha}\textstyle\sum_{l=0}^{L-1}\left(\sum_{n=0}^{\alpha-1} h_{i,n,l}e^{-j\frac{2\pi}{\alpha}n(k-q)}\ \right)e^{-j\frac{2\pi}{\alpha}qn_l} \tag{6}$$

The standard TDS-OFDM systems [9]–[11] presumptively include a time-invariant channel within each TDS-OFDM symbol, *i.e.*, $h_{i,0,l} = h_{i,1,l} = \dots = h_{i,\alpha-1,l} = h_{i,l}$ $(0 \le l \le L - 1)$, where $h_{i,l}$ denotes the average path gain for the l^{th} path, *i.e.*, $h_{i,l} = \frac{1}{\alpha}\sum_{n=0}^{\alpha-1} h_{i,n,l}$. As a result, the ICI term $H_{i,k,q}$ $(q \neq k)$ is zero, *i.e.*, $H_{i,k,q} = 0$, and (5) is thus simplified as

$$Y_{i,k} = X_{i,k}\,H_{i,k} + W_{i,k} \tag{7}$$

where $H_{i,k} = H_{i,k,k}$.

Each TDS-OFDM symbol is assumed to have a time-invariant channel under the system model described by [22]. As stated in [4], the channel is time-variant in the real world. If one adopts the system model, performance in terms of BER will suffer [4]. To enhance the functionality of the TDS-OFDM system, this issue was resolved in [26].

3. Channel Estimation and Equalisation

The guard band's TS is used to estimate the channel in DPNS-based TDS-OFDM completely. Path latency and path gain estimations in the time-frequency domain TDS-OFDM are done by TS in the frequency domain and time domain pilots in the OFDM data packet, accordingly. In contrast to these two approaches, the suggested approach estimates a preliminary CIR (both path latency and gain) using TS in the guard interval, which is subsequently fine-tuned by employing pilots in an OFDM data packet in the time domain.

3.1. Employing TS to Estimate CIR

The suggested structure's guard interval is made up of a cyclic extension CP and TS. The received TS $d_i = [d_{i,0}, d_{i,1},..., d_{i,\beta-1}]^T$ is vulnerable to the IBI between the guard interval and OFDM data block because of the CP in the guard interval. Due to the cyclic expansion of CP in the guard interval, the obtained d_i is provided below.

$$d_i = c_i^{(s)} \otimes h_i + v_i \quad (8)$$

The cyclic correlation between the received TS d_i and $c_i^{(s)}$, which is known at the receiver as the channel's rough estimate of bh_i, is calculated as

$$\widehat{h_\iota} = \frac{1}{\beta} c_i^{(s)} \otimes d_i = \frac{1}{\beta} c_i^{(s)} \otimes (c_i^{(s)} \otimes h_i + v_i)$$
$$\widehat{h_\iota} = h_i + \frac{1}{\beta} c_i^{(s)} \otimes v_i \quad (9)$$

The perfect autocorrelation of the MOS described in Eq. (3) is used in Eq. (9). This is the first-stage channel estimate which will be tuned further for better performance.

3.2. Complete CIR Estimation by Pilots in OFDM Data Block

The LMS algorithm [23], [24] then fine-tunes the channel estimate after it has been computed using the TS of the guard interval.

For modifying CIR coefficients using the LMS approach, default values are chosen as the previously computed coefficients in (9).

In the OFDM data block, pilots are inserted as follows: $p_{i,n} = \{p_{i,0}, p_{i,1}, \cdot, p_{\alpha p-1}\}$ where α_p is the total number of pilots put in the OFDM block. α_p should be greater than the maximum channel delays n_L, *i.e.* $\alpha_p \geq n_L$. As shown in Fig. 2, $d_{i,n}$ is the desired output given by,

$$d_{i,n} = h_{i,n}^H \, p_{i,n} + w_{i,n} \quad (10)$$

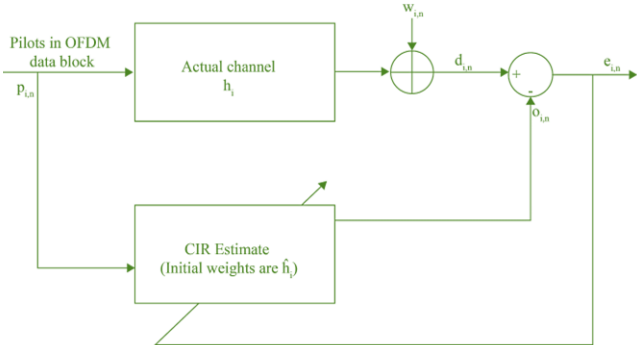

Fig. 2 Block diagram of LMS algorithm for tuning channel coefficients

The symbol for actual channel coefficients is $h_{i,n}$. Similar to this, when the pilots $p_{i,n}$ are sent through the filter b$h_{i,n}$, the resulting $o_{i,n}$ is given by,

$$o_{i,n} = \hat{h}_{i,n}^H \, p_{i,n} \quad (11)$$

Consequently, the description of the estimated error or error signal $e_{i,n}$ is

$$e_{i,n} = d_{i,n} - o_{i,n} \quad (12)$$

The LMS algorithm's tap-weight adaptation is provided by,

$$\hat{h}_{i,n+1} = \hat{h}_{i,n} + \mu \, p_{i,n} e_{i,n} \quad (13)$$

When the range of the step-size parameter μ is provided by,

$$0 < \mu < \frac{2}{\alpha_p \, S_{max}},$$

Where α_p stands for the filter length, and S_{max} is the greatest power spectrum density of the input $d_{i,n}$.

3.3. Channel Equalization

The add-subtract approach, as described in [10], is initially used to reconstruct the CP-OFDM signal from the received TDSOFDM frame. After that, any equalisation technique can be used to acquire the transmitted signal. After the second step of CIR estimation, the one-tap zero-forcing (ZF) equaliser is provided below.

$$\{\hat{s}_{i,n}\}_{n=0}^{\alpha-1} = \frac{FFT_\alpha(\{y_{i,n}\}_{n=0}^{\alpha-1})}{FFT_\alpha(\{\hat{h}_{i,n}\}_{n=0}^{L-1})} \quad (14)$$

4. Simulation Results and Performance Analysis

4.1. Simulation Parameters

To verify the effectiveness of the provided framework, simulations were done using MATLAB 2016. Table I provides a list of the simulation parameters used for channel estimate.

Table 1. Attribute for modelling

Sr. No.	Type of Attribute	Configuration
1	Central frequency	770 MHz
2	Size of an OFDM unit (α)	4096
3	Spectrum of the signal	7.56 MHz
4	Resolvable path (L)	6
5	Size of the guard band	$2\beta-1$; $\beta=256$
6	Modulation technique	QPSK, 8-PSK and 16-PSK
Brazil D multipath channel factor		
Path Number	**Delay (μs)**	**Deflection (dB)**
I	5.93	2.8
II	5.86	0
III	3.05	1.3
IV	2.22	2.6
V	0.63	3.8
VI	0.15	0.1

4.2. Simulation Results

Using the values stated in Table I, we evaluated the performance of the proposed frame structures based on the 2-stage T-F Domain and DPNS-based TDS-OFDM.

The contrast between the channel prediction $\widehat{h}_i$ at stage 1 and the real channel h_i is illustrated in Fig. 3 using the values indicated in Table I at an SNR of 10 dB. The path delay estimate is flawless, as shown in Fig. 3, thanks to the MOS's perfect auto-correlation characteristic. It can be observed that the channel gains of the rough channel estimate $\widehat{h}_i$ deviates from the actual channel h_i. This stage two channel estimation becomes necessary for tuning the rough channel estimate $\widehat{h}_i$for better BER performance.

A comparison between the tuned CIR at stage-2 using the LMS-based technique and the real channel h_i using the settings provided in Table I is shown in Fig. 4 at an SNR of 10 dB. The channel gain estimate at stage 2 is superior to the stage 1 channel gain estimate, as can be shown.

Utilising the factors listed in Table I, the mean square deviations (MSD) for the DPNS-based, recommended based on 2-stage T-F Domain, and based on 2-stage TS-LMS TDSOFDM approaches for static users are shown in Fig. 5.

The maximum MSD between the DPNS-based scheme and the actual channel can be seen. When the channel coefficient of a DPNS-based scheme is tweaked using an LMS-based technique, a significant decrease in MSD can be observed at lower signal-to-noise (SNR) ratios.

Fig. 6 illustrates the BER performance of the recommended 2-stage TS-LMS, 2-stage T-F Domain, and DPNS-based TDSOFDM schemes for static users using the parameters listed in Table I. The suggested methods demonstrate an enhancement in BER performance at all SNR levels when compared to DPNSbased systems. Furthermore, it is evident that the 2-stage T-F Domain-based system outperforms the indicated solutions at all SNR levels. The BER performance of the based 2-stage T-F Domain technique has a little advantage due to the different channel path gain estimation, which makes use of the implanted pilots in the frequency domain in the OFDM data packet. This advantage over the LMS-based technique in BER performance comes at a value of extremely complicated calculation.

Fig. 7 demonstrates the BER quality comparison of various modulation schemes like QPSK, 8-PSK and 16-PSK. For the proposed frame structure BER performance of QPSK is best compared to 8-PSK and 16-PSK. BER performance of 8-PSK and 16-PSK degrades due to decreased distance between their symbols compared to QPSK modulation in the given frame structure.

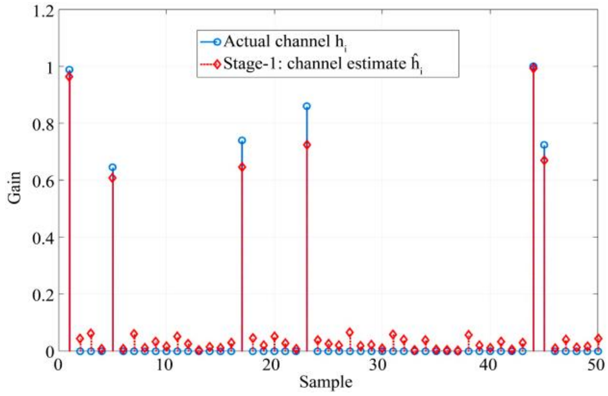

Fig. 3 TS at an SNR of 10 dB is used to estimate path delays

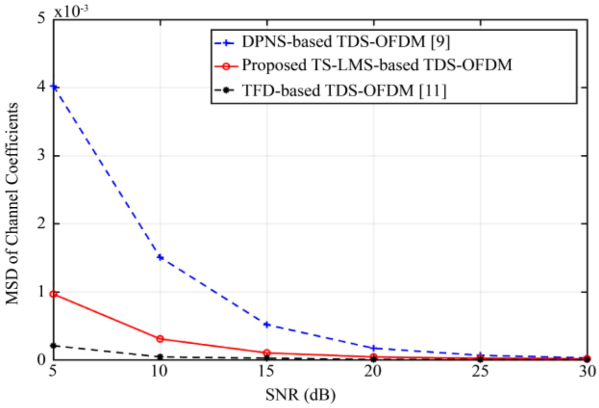

Fig. 4 Comparison of CIR

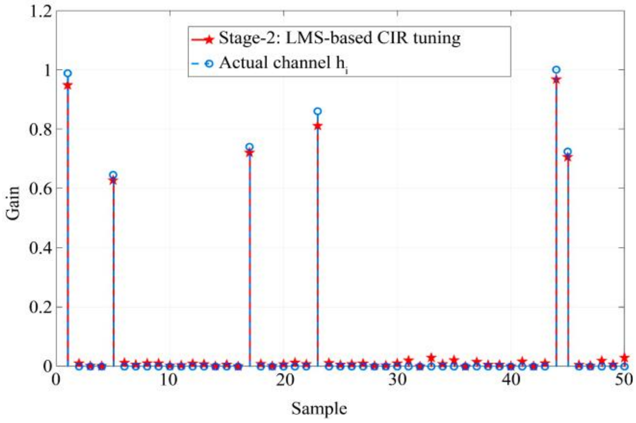

Fig. 5 Deviation in the mean square of the channel coefficients

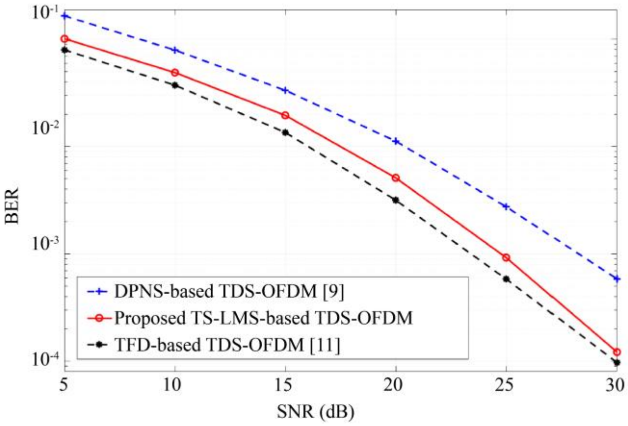

Fig. 6 Analysis of static user BER performance across Brazil's D channel

4.3. Spectral Efficiency

The LMS algorithm is used to tune the CIR. In the frame structure that is suggested, α_p pilots are put into the OFDM data block. LMS algorithm convergence requires that the channel length n_L be less than the inserted pilot α_p. Due to their redundant nature and lack of data information, these pilots reduce spectral efficiency. As a result, this method's decreased Spectrum effectiveness when contrasted to DPNSbased TDS-OFDM [10] provided by

$$E_{loss} = \frac{\alpha}{\alpha+2\beta} - \frac{\alpha-\alpha_p}{\alpha+2\beta-1} \qquad (15)$$

According to Table I, the size of an OFDM block is α = 4096, which is also the size of an FFT. It is preferred to use large-size FFTs [1] in DTTB systems. In the suggested frame structure, sixty sub-carriers called *i.e.* α_p = 60, are used as pilots. It only takes up 1.46% of all sub-carriers. As a result, the number of complex multiplications needed by each approach is listed in Table 2 based on the parameters stated in Table 1.

Table 2. Complex multiplication comparisons

Sr. No.	TDS-OFDM frame structure	Complex multiplications required
1	DPNS-based	2,048
2	2-stage T-F Domain-based	1,54,832
3	2-stage TS-LMS-based	9,428

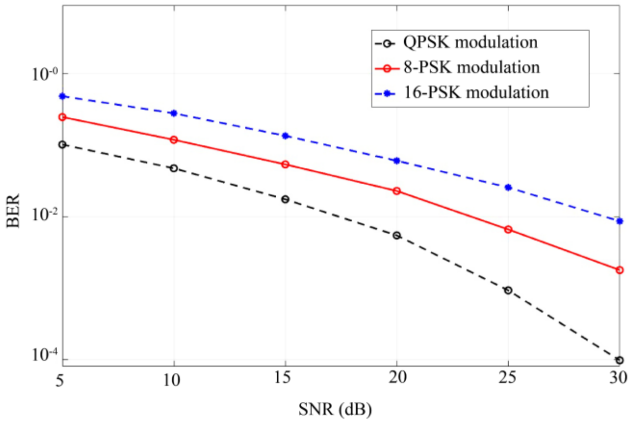

Fig. 7 Comparison of BER performance using 2-stage TS-LMS based TDS-OFDM for different modulations

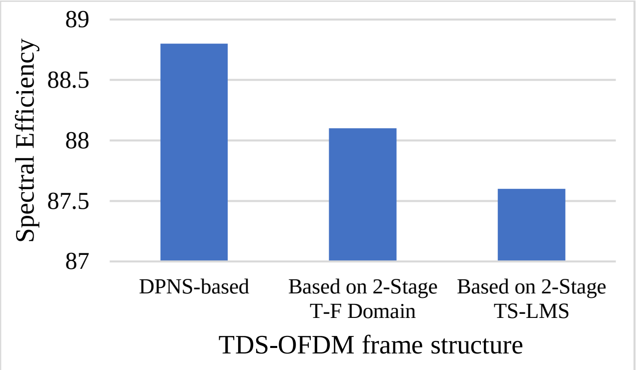

Fig. 8 Comparison of spectral efficiency

4.4. Computational Complexity

The number of complex multiplications is employed to assess the suggested system's computational complexity and evaluate it compared to alternative frame structures. To perform the β-point circular correlation [25], CIR evaluation using the TS of the guard interval in (9) requires one β-point FFT and one β-point inverse FFT (IFFT) [25] (It takes (β/2)log2β complex multiplications to complete one β − point FFT/IFFT). All three of the frame structures mentioned in this paper perform this computation. αp(3αp2 + 11αp + 8) multiplications are needed in the proposed frame structure.

The Moore-Penrose inverse matrix must be computed using 2αgroup(Q+1)2L2+(Q+1)3L3 multiplications for the 2-stage T-F Domain-based TDS-OFDM, and another αgroup(Q+1)L multiplication for matrix multiplication [26]. The quantity of pilots in groups is 2αgroup, the channel's maximum Doppler spread determines Q, and the number of multipath channels is L. Calculating the ICI coefficients [26] also requires 2L(2d+ 1)α multiplications.

5. Conclusion

A unique OFDM frame structure is used to conduct a variety of modulation techniques. In comparison to 8PSK and 16PSK modulation techniques, QPSK modulation approaches perform is the best The effectiveness of TDS-OFDM systems across rapid fading channels is increased because of a unique OFDM framework that enables two-stage channel prediction. This approach estimates the CIR using the TS (one-sample reduction in spectral efficiency is minimal. Fig. 8 provides shifting) inside the guard interval. Using the pilots included a summary of the spectral efficiency of these three frames in the OFDM data packet. The LMS method is utilised to architectures fine-tune the CIR. It leads to boost channel estimates for users who are stationary, moving slowly, and moving quickly. At all SNR levels, our approach beats DPNS-based TDSOFDM systems on the basis of BER over static, slow, time-varying, and fast time-varying channels. Because ICI becomes substantial at increasing velocity, the achievement of BER degrades. From the perspective of BER for static and sluggish users, the suggested approach slightly underperforms based on 2stage T-F Domain TDS-OFDM. The based on 2-stage TSLMS approach has low computational complexity. As an outcome, when computational effort and BER performance are your primary concerns, the suggested 2-stage TS-LMS-based TDS-OFDM is the best approach.

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