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Mitigation of Inter-Carrier Interference (ICI) in Mobile DVB-T2 Technology Using Zero Forcing Equalization

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Abstract — Orthogonal Frequency Division Multiple Access (OFDM) is the transmission mechanism employed in DVB-T2 digital broadcasting systems. However, under mobility conditions, Doppler shift becomes a major factor limiting OFDM performance. The Doppler effect induces Carrier Frequency Offset (CFO), which disrupts the orthogonality among subcarriers and generates Inter-Carrier Interference (ICI). This issue causes frequency mismatches between the transmitter and receiver. In this study, a DVB-T2 system configuration is used with 2k mode, guard interval 268, cyclic prefix 1/4, and 64-QAM modulation. To evaluate mobility effects, simulations were performed with maximum Doppler frequency variations ranging from 2.87 Hz to 40.18 Hz and SNR ranges from 0 dB to 40 dB. On the receiver side, equalization was applied using a Zero Forcing Equalizer. Simulation results indicate that without equalization, the BER remains approximately 0.5 across all Doppler variations. Conversely, with the application of Zero Forcing Equalizer, BER decreases significantly at SNR ≥ 20 dB. This method proves effective in mitigating ICI in DVB-T2 systems under mobility conditions, achieving an average performance improvement of 98.42% with BER approaching zero at low to moderate Doppler frequencies.

Keywords – DVB-T2, OFDM, doppler effect, ICI, *zero forcing equalizer,* BER.

I. INTRODUCTION

The advancement of digital broadcasting technology, particularly Digital Video Broadcasting–Second Generation Terrestrial (DVB-T2), has enabled the provision of superior audio-visual quality, higher spectral efficiency, and support for interactive services. Nevertheless, in mobile reception scenarios, signal quality is often degraded due to Inter-Carrier Interference (ICI), which arises from Doppler spread and user mobility. ICI significantly reduces the performance of Orthogonal Frequency Division Multiplexing (OFDM), the core modulation scheme in DVB-T2, thereby lowering overall service quality [1].

One of the widely used approaches to address ICI is the implementation of Zero Forcing (ZF) equalization, which compensates for channel distortion by inverting the channel response. This study focuses on applying Zero Forcing Equalization to improve the performance of mobile DVB-T2 systems by mitigating ICI, aiming to provide a practical solution for enhancing the reliability of mobile digital broadcasting services.

This method is particularly suitable for dynamic scenarios in DVB-T2 transmission systems employing OFDM, as it offers spectrum efficiency and signal reception flexibility [2].

II. RESEARCH METHOD

A. *DVB-T2*

DVB-T2 was developed as the evolution of DVB-T, offering improved spectral efficiency, higher data rates, backward compatibility with DVB-T, support for high-quality content, and potential as an innovation for future broadcasting services. This technology is designed to support both fixed and mobile reception and is able to adapt to diverse environmental conditions. Moreover, transmission costs can be reduced by lowering the Peak-to-Average Power Ratio (PAPR) during the signal transmission process [3][4]. Compared to DVB-T, DVB-T2 provides a minimum capacity increase of 30%. This enhancement is supported by the use of an additional 256-QAM modulation option, allowing each symbol to carry up to 8 bits. Consequently, system capacity can be significantly reinforced, approximately 25–30% higher than its predecessor [5][6].

B. OFDM

The signal spectrum can be divided into multiple orthogonal subcarriers through Orthogonal Frequency Division Multiplexing (OFDM). OFDM is a multi-carrier transmission technology that optimizes the use of available bandwidth in the telecommunications sector. Unlike other transmission techniques, OFDM distributes the available channel bandwidth into orthogonal subcarriers. Digital modulation schemes such as Phase Shift Keying (PSK) or Quadrature Amplitude Modulation (QAM) are typically applied to each subcarrier [7].

C. Pilot Insertion

The set of pilot symbols embedded in OFDM is referred to as scattered pilots, with their arrangement influenced by carrier frequency and OFDM symbol duration. In DVB-T2, the guard interval (GI) and fast Fourier transform (FFT) size determine the spacing between pilot and OFDM symbols. Both GI and FFT affect the accuracy of channel estimation and spectral efficiency. The maximum Doppler frequency and maximum multipath delay spread are crucial parameters when determining pilot symbol patterns [8].

D. Doppler Effect

In wireless communication, the movement of the receiver relative to the transmitter alters the frequency and wavelength of the signal. This variation degrades signal quality at the receiver. When there is a frequency mismatch between the transmitter and receiver, Carrier Frequency Offset (CFO) occurs due to Doppler shifts and phase variations. CFO degrades received data quality and destroys the orthogonality of OFDM subcarriers [9].

E. Zero forcing Equalizer

In digital communication systems, *zero forcing* is an equalization technique that eliminates the effects of interference between symbols (ISIs) caused by channel distortion. The basic idea behind *zero forcing* is to use equalization filters to reverse the channel response.

$$C(Z) = \frac{1}{C_h Z} \quad (1)$$

where the channel transfer function is denoted by . In order for the received signal to ideally reconstruct the original signal, ZF strives to eliminate the ISI completely. Low $C_h Z$*Signal to Noise Ratio* (SNR) channel conditions result in lower *Zero Forcing* performance . However, due to the mathematical simplicity and outright elimination of ISIs, *zero forcing* is still used in systems with favorable channel characteristics [10].

The performance of *the Digital Video Broadcasting-Terrestria* (DVB-T2) transmission system was analyzed using a simulation methodology based on MATLAB Simulink 2016b. Using *Zero Forcing Equalizer* to reduce Inter Carrier Interference (ICI), this study modeled the *baseband* system with 2K mode and 64-QAM modulation and tests the impact of the Doppler effect on system performance. System design, simulation development, testing, and analysis of simulation test results are some of the stages in this study. The system design process begins with a literature survey.

F. Research Flow

The design of the Simulink DVB-T2 model and the determination of the parameters is the first step. Then, modeling is carried out under certain conditions, such as providing the condition of the AWGN *Multipath Rayleigh fading channel* to simulate the conditions of the Doppler effect that occurs.

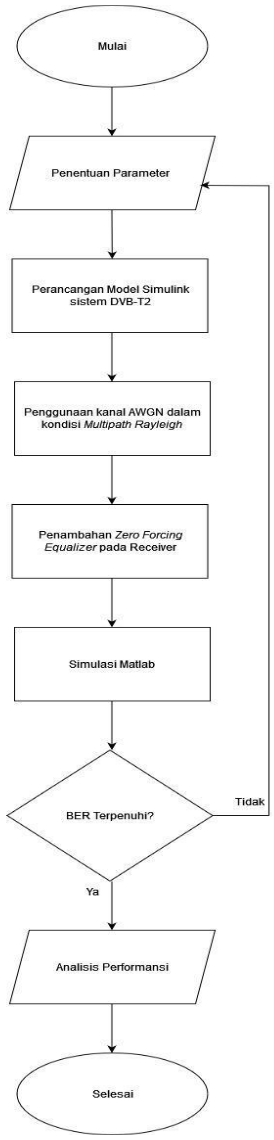

Fig 1. *Flowchat* DVB-T2 system used in the study.

The simulation is then run, if the results are judged not to be in accordance with the standard, then the parameters or modeling used will be changed to get the best results. After the simulation results are obtained, the data will be examined to see a comparison graph of BER and SNR, which will then be compared and matched with the theory before drawing conclusions based on the data. The flow of the research can be seen in Figure 1.

G. Research Scenarios

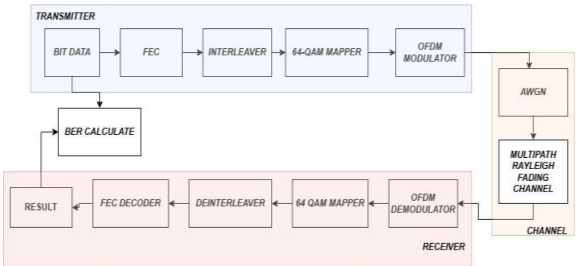

Fig 2. Test scenario 1

Before processing, the original data will be recognized. To make the data more robust, it will then be restructured using *forward error coding* (FEC) and given additional parity bits. *The interleaved* will re-shuffle the data to withstand *burst errors*. The data bits will then be mapped in the form of *a quadrature* constellation, with 64 QAMs which means each symbol can contain up to 6 bits of data with an 8x8 grid organized into 64 different symbol points. QAM then divides the data into two parts: amplitude and phase.

In addition, data is fed into the pilot symbol, which is often placed into a specific subcarrier along with the OFDM symbol, so that the receiver can recognize the data. In addition, CP 1/4 and IFFT 2K are applied in OFDM demodulators. After data transmission through the AWGN channel, the receiver performs the reverse process, starting with the OFDM demodulator and ending with the bit error calculation procedure.

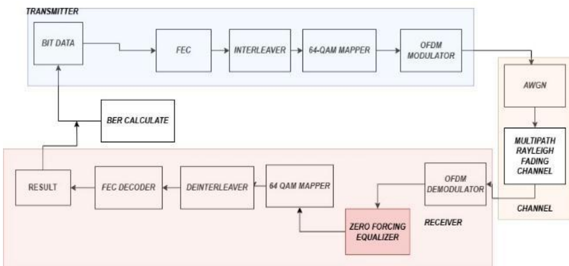

Fig 3 Test scenario 2

To simulate the Doppler effect and cause the system to experience CFO, which then results in an ICI, a Multipath Rayleigh Fading Channel is included in the second test case.

$$f_{dmax} = \frac{v f_c}{c} \qquad (2)$$

where is the relative velocity between the sender and receiver, is the carrier frequency, C is the speed of light, and is the maximum Doppler shift. This equation was used in seven tests with data of 5 km/h, 10 km/h, 20 km/h, 30 km/h, 45 km/h, 60 km/h, and 70 km/h. The changed parameters are relative. This speed is chosen to give an idea of the performance of the DVB-T system. This speed was chosen to give an idea of how well a DVB-T2 system moves with dynamic mobility will work.

After the OFDM *demodulator* processes the data, a zero forcing equalization block diagram is added. Perform channel estimation prior to equalization by first analyzing the system, IFFT, CP, *pilot*, and number of *subcarriers* delivered. After the channel estimation is completed, *zero forcing* is applied by inverting the data from the transmission process that is matched with the data from the channel estimate. The data returned by the *zero forcing equalizer* will then be processed.

H. Parameter

Table 1 Parameters Evaluation used in the Study

No.	Parameter	Value
1	Modulation Type	64-QAM
2	Bit Input	1095000 bit
3	*Frequency Carrier (Fc)*	620 x106 hz
4	Canal	AWGN+Multipath Rayleigh Channel
5	FFT *length*	2k
6	*Cyclic prefix (CP)*	1/4

Table 1 is the characteristics used to construct the DVB-T2 system in this study. Due to the very large *video input bit* of 1095000 bits and a carrier frequency of 620 MHz, the 64-QAM modulation type is required to increase the data rate while remaining within the frequency band that is between 478 and 694 MHz, which is the legal range of the government that governs broadcasting. AWGN+ *multipath Rayleigh fading* channels are used to simulate the doppler effect and user mobility. High spectrum efficiency and compute savings are features of the FFT 2K length. CP 1/4, which maintains subcarrier orthogonality and is strong against *multipath delay*.

III. RESULT AND DISSCUSSION

A. Scenario Testing 1

The DVB-T2 system was initially tested using the parameters listed in Table 1 to evaluate system stability. In the first scenario, DVB-T2 simulation was performed without ICI. The data collected in the form of BER, total errors, and total bits showed a BER of 0 with no errors out of 1,095,000 received bits. This result demonstrates that the system operated correctly and maintained stability when transmitting data under ideal conditions.. This indicates that the system can function properly and the stability of the system can be maintained while the data is being transmitted. Figure 4 shows a block diagram for the first ske nario.

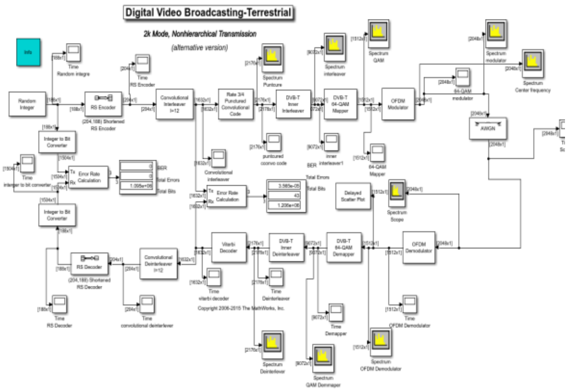

Fig. 4 Testing scenario 1

FEC processes data that is included in random integer blocks. The FEC used in the tested system uses RS *encoder* and convolution code, both of which are used due to their generally lower complexity and high resistance to *burst* errors. The block diagram then uses the parameters in Table 1 to handle the data as seen in Figure 4. The excellent quality of the final data indicates that the transmitted data is perfectly received by the receiver.

B. Testing Scenario 2 with ICI

To explain the moving nature of the dvb-t speed, the Doppler test is performed by varying the relative speed, which is parameterized as 5 km/h, 10 km/h, 20 km/h, 30 km/h, 45 km/h, 60 km/h, and 70 km/h.

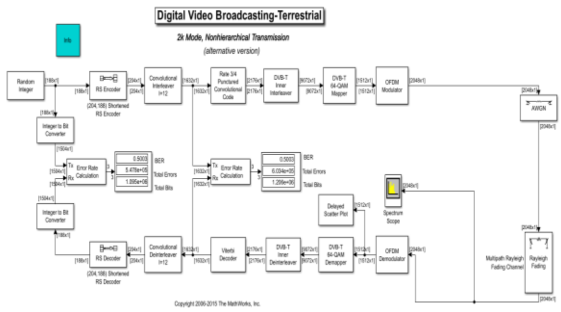

Fig. 5 Simulation of the Doppler effect that produces ICI on the DVB-T2 system.

The Doppler effect caused by the multipath channel Rayleigh fading will test the DVB-T2 system in Figure 5. The test is carried out by varying the parameters of different Doppler effect conditions to see the stability of the data transmission process which will be oriented with the error *rate* bits. The frequency of the carrier, the relative speed of the source and receiver, and the speed of light are the three factors that determine the Doppler effect. The middle frequency in this test assumes the carrier frequency because the simulated system tested uses baseband signals and carrier frequencies are not the parameters that build the DVB-T system.

Table 2 DVB-T System Test Data Results with ICI

No	*Fd max (hz)*	ABOUT
1	2,87	0,5008
2	5,47	0,5003
3	11,49	0,5
4	17,23	0,4998
5	25,92	0,5003
6	34,30	0,4998
7	40,18	0,4999

The purpose of the speed adjustment is to test the DVB-T2 system in a variety of scenarios. Table 2 illustrates the impact of the Doppler effect on signal transmission. BER values range from 0.4 to 0.5, with the lowest BER values being 0.4998 at fd max 17.23 Hz and 34.30 Hz and the highest BER values being 0.5008 at fd max 2.87 Hz. This indicates that only about 50% of the transmitted data is received, which is still far from the expected BER value of 10-3. As a result, the DVB-T2 system needs to be optimized.

C. Testing the performance of zero forcing equalizer in mitigating ICI

The addition of zero forcing to DVB-T2 requires channel estimation to be able to determine the characteristics or parameters of the DVB-T2 channel system. In this test, the ofdm modulator block and the ofdm demodulator block were converted into matlab functions which were then reassembled to be able to include the pilot with more detailed carrier data.

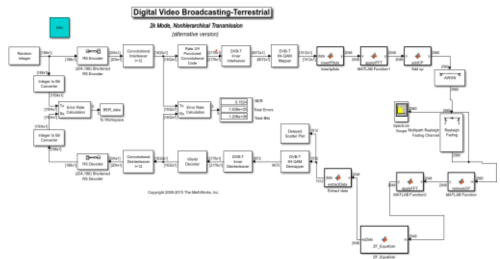

Fig. 6 *Mobile* DVB-T2 with Zero Forcing Equalizer

The DVB-T2 system was evaluated at SNR = 25 dB, which is theoretically a fairly good condition, based on the findings of seven experimental tests conducted in a no-force equalization scenario. The BER value obtained in the first test without the use of an equalizer was very high, averaging about 0.5 in all seven test scenarios. This indicates that although the SNR is quite high, the system cannot demodulate the signal properly if *the multipath* effect is not addressed. This suggests that increasing the SNR on its own, without the use of fading mitigation tools such as equalizers, is not enough.

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Table 3 BER Value Results After *Zero Forcing* Equalization with 25 SNR

No	*Fd max (hz)*	About	Repairs (%)
1	2,87	0	100%
2	5,47	0	100%
3	11,49	0,0102	97,96%
4	17,23	0,0074	98,52%
5	25,92	0,.0071	98,58%
6	34,30	0,0084	98,32%
7	40,18	0,0122	97,56%

Zero Forcing Equalizer is added to the receiver side for additional testing. The findings show that BER has declined significantly. BER decreased sharply to between 0.0071 and 0.0122 in the other five situations, while BER was lowered to zero (0) in two situations. When compared to performance without *equalizers*, the average BER after the use of *equalizers* is 0.0065, which shows an increase of about 98.56%.

D. Performance Testing of zero forcing Equalizer in mitigating ICI with Variable SNR.

This test was performed to assess the performance of the DVB-T system against various Doppler frequency fluctuations, including SNR variations from 0 to 40 dB and fd max = [2.87, 5.47, 11.49, 17.23, 25.92, 34.30, 40.18] Hz.

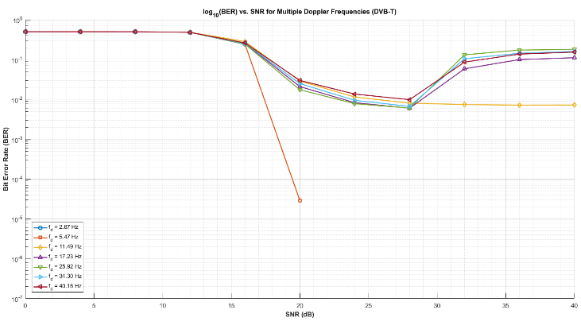

Fig. 7 Comparison of BER and SNR for maximum values of Doppler and SNR motion varies.

All curves show high BER values close to 0.5 in the low SNR band (0 to 12 dB). This indicates that the dominance of noise and interference of *the multipath* channel causes the system to be unable to complete the coding operation correctly. Increasing SNR has not been able to eliminate interference at this point, particularly in systems that do not use an adaptive equalization approach.

All graphs show a sharp drop in BER when the SNR reaches the mid-range (16 to 24 dB). The system can perform more accurate *decoding* in channel conditions that do not change very quickly, as seen in the most prominent drop in the Doppler frequency of 5.47 Hz, which approaches BER to 10^{-5}.

BER decreases are negligible in the high SNR range (28 to 40 dB). In reality, BER actually increases once again at high Doppler frequencies, such as 40.18 Hz. Doppler-induced ICI is starting to take center stage, pointing to the typical shortcomings of DVB-T systems in handling dynamic channel conditions. With BER values decreasing as SNR increases, the system operates best overall at low to moderate Doppler frequencies (2.87-11.49 Hz). However, *zero forcing equalizers* cannot completely eliminate ICI at high Doppler frequencies (more than 25 Hz), thus demonstrating their ineffectiveness in high-mobility systems.

IV. CONCLUSSION

Using the Simulink MATLAB 2016b platform, this study builds a DVB-T2 system based on a DVB-T system with 64-QAM modulation, FFT 2048 length, and guard band 268 on both sides of the spectrum. In this configuration, 1512 subcarriers are modulated using OFDM for orthogonal transmission on AWGN channels with an SNR ratio of 25 dB. Based on the simulation results, the DVB-T2 system designed has a maximum *Bit Error Rate* (BER) of 0 and *a total error* of 0 when operating on a trouble-free channel.

The ICI effect is simulated by adding *a fading Rayleigh multipath* channel to mimic the Doppler effect induced by mobility. With speed fluctuations ranging from 5 km/h to 70 km/h, BER values vary from 0.4991 to 0.5006 when compared to performance without ICI. Nonetheless, *the zero forcing equalizer* works very well, especially at low to moderate Doppler values. In some cases, this *equalizer* is able to lower the BER to zero, and in the other five cases, it is able to lower it to between 0.0071 and 0.0122. Assuming a good channel estimation and no dominance of *noise*, the average BER after equalization was 0.0065, showing a 98.56% improvement in system performance compared to without equalization.

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