Performance of DVB-T2 Application in High-Speed Train Transportation System

Nicolas Yonara Tarigan
Department of Telecommunication Engineering, Institut Teknologi Telkom Purwokerto, Indonesia
yonaranicolas@gmail.com

Wahyu Pamungkas
Department of Telecommunication Engineering, Institut Teknologi Telkom Purwokerto, Indonesia
wahyu@ittelkom-pwt.ac.id (corresponding author)

Anggun Fitrian Isnawati
Department of Telecommunication Engineering, Institut Teknologi Telkom Purwokerto, Indonesia
anggun@ittelkom-pwt.ac.id

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ABSTRACT

The terrestrial television system in Indonesia has evolved from the first-generation Digital Terrestrial Video Broadcasting (DVB-T) to the second generation (DVB-T2), enhancing broadcast quality and spectral efficiency. This paper focuses on the application of DVB-T2 within High-Speed Train (HST) communication systems, where the unique challenges faced include high Doppler shifts and multipath effects due to the high train speed which exceeds 300 km/h. Multicarrier Orthogonal Frequency Division Multiplexing (OFDM) technology was employed along with 64-QAM modulation for the investigation of the performance under various conditions. The simulations were structured around varying speeds, scatterer counts, and angles, and 15 iterations were conducted for train speeds of 10 m/s, 50 m/s, and 100 m/s. The findings indicate that the error rates varied with speed and environmental complexity. At a lower speed (10 m/s), the system performance showed significant improvement, with a reduction of 322 bits in the error rate. However, as the speed increased to 100 m/s, the performance declined, demonstrating an increase of errors by 414 bits owing to exacerbated Doppler effects. Different scatterer counts also influenced the results. For instance, with four scatterers at 10 m/s speed, the error improved by 245 bits, but at 100 m/s speed and under the same scatterer conditions, the performance worsened, increasing the error by 361 bits.

Keywords-DVB-T2; Doppler effect; High-Speed Train (HST); multipath; OFDM

I. INTRODUCTION

In several countries, technological progress has driven the transition of the television industry from analog to digital broadcasting, adopting the DVB-T2 as the new standard. DVB-T2, an enhancement over the previous DVB-T standard, is a terrestrial digital broadcasting format aiming to improve both the audiovisual quality and the efficiency of spectrum usage [1]. DVB-T2 technology influences fluctuations in the received signals because it is intended for use in conjunction with a range of reception systems, including mobile and handheld devices [2]. In [3], the performance of DVB-T and DVB-T2 technologies was compared and it was found that DVB-T2 could achieve a data rate of 48 Mbps, while DVB-T only provided a data rate of 22 Mbps. Additionally, the latter only generated a data rate of 2.2 Mbps in the mobile receiving system [2]. In this study, the deployment of the DVB-T2 standard was evaluated by using the HST channel, which is integral to the high-speed train communication infrastructure [4, 5]. This channel is characterized by various parameters, such as speed, Line of Sight (LoS), and the effects of multipath interference. The LoS scenario allowed signals to travel unobstructed from the transmitter to the receiver, whereas multipath scenarios involved obstructions such as buildings, trees, and reflections from glass, which could impede signal clarity [6].

One of the challenges on the HST channel is the train speed which reaches or surpasses 300 km/h, which can cause Doppler shift or frequency carrier shift, and it can reduce the signal strength obtained by the receiver [7]. Mobility causes the Doppler effect and frequency shift, which in turn affect the quality of the video on DVB-T2 [8-11]. A patent was issued in [12] for the train movement control on the HST communication system. Regarding broadband communication systems, a greater Doppler effect is present in the Hyper Loop Train communication system [13]. Apart from the Doppler effect on the HST channel, there is also the multipath effect, which could result in delay spread. Delay spread constitutes a measure of the pulse width of the impulse transmitted between the transmitter and the receiver, and it is a natural phenomenon caused by the reflection and dispersion of signals in the communication channel. Delay spread could cause Inter-Symbol Interference (ISI), where the symbols in the transmission overlap, resulting in the flat fading or frequency selective fading [14]. The flat fading effect is a type of channel distortion in which the period of the transmission signal is greater than the delay spread of the multipath. This effect is caused by the time differences in the signal propagation through the multipath [15]. In contrast, the frequency selective fading against the channel has coherence bandwidth, which is narrower compared to the transmitted signal bandwidth. As a result, the received signal includes some variation of the transmitted waveform, with levels of attenuation and different delays, resulting in distortion of the received signal [16]. HST channel modeling for DVB-T2 applications was carried out in [4], while the effect of using HST channels on DVB-T performance is described in [5]. The novelty and contribution of this paper lie in the comprehensive examination of DVB-T2 performance in HST environments, with a particular emphasis given on the high Doppler shift and multipath effects. The present study highlights the efficacy of the channel coding techniques in addressing these obstacles, thereby improving the quality and reliability of DVB-T2 transmissions in high-mobility environments. It provides practical insights and potential solutions for optimizing digital broadcasting in dynamic and challenging conditions, hence advancing the field of telecommunications.

II. RESEARCH METHODOLOGY

This research utilizes simulation to analyze the performance of DVB-T2 applications within the HST communication system.

A. System Model

Figure 1 depicts the block diagram of a DVB-T2 setup that works with HST channels. The recent generation, DVB-T2, is better in many ways than the earlier one, DVB-T. DVB-T2 uses multicarrier OFDM and 64-Quadrature Amplitude Modulation (64-QAM) to make the images clearer and less likely to get lost. The parts for the transmitter and receiver can be seen in Figure 1. The bit stream is made at the emitter and goes through the QAM block Mapper to add frequency to a 64-QAM modulated carrier. After the modulation, the conversion process from serial to parallel is performed. ISI is kept to a minimum at the time of delivery by using a circular prefix that is 1/4 of the total FFT size of 512 bits. Before going through the HST channel, a block of the Inverse Fast Fourier Transform (IFFT) changes the input from the frequency domain to the time domain. When it gets to the other end, the signal goes through the channel and is then checked by the QAM detector block. Before going through the demodulation process by the QAM demodulator, the pilot symbol is taken away and the data are changed to a parallel form. A space between the carrier signal and the data is created, which lets the received bit value be shown.

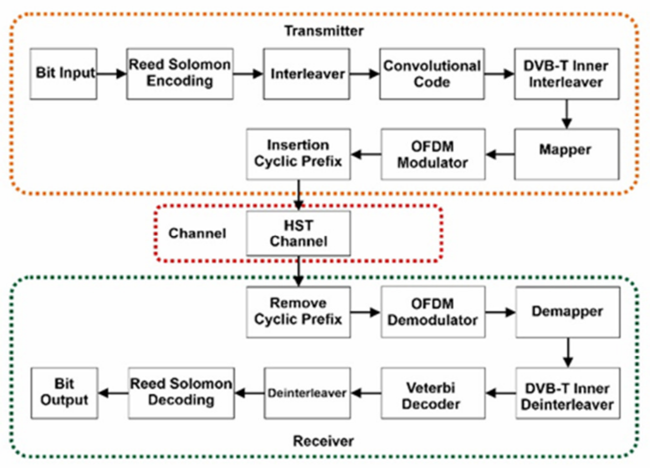

Fig. 1. DVB-T2 system model.

B. Orthogonal Frequency Division Multiplexing (OFDM)

The OFDM is a modulation scheme that is very suitable for high data rate transmission in delay-dispersive environments. This scheme converts a high-speed data stream into several low-speed streams transmitted over parallel narrow-band channels that can be easily compared. OFDM is the result of improvements in Frequency Division Multiplexing (FDM). The reason for the evolution from FDM to OFDM is to save bandwidth [19]. Apart from that, OFDM is a transmission technique that uses several frequencies (multicarrier), which are perpendicular to each other (orthogonal) [19, 20].

Equation (1) was utilized to express the OFDM output [19]:

$$c(t) = \sum_{n=0}^{N-1} S_n(t) \sin(2pf_n t) \quad (1)$$

where $c(t)$ denotes the OFDM signal, $S_n(t)$ is the symbol to be mapped to the selected constellation, and f_n is the orthogonal frequency (Figure 2) [19].

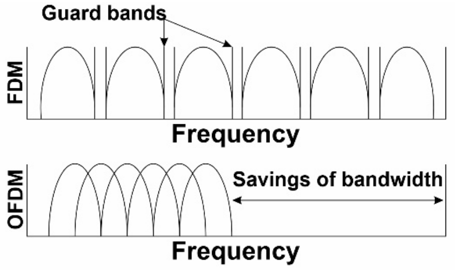

Fig. 2. OFDM and FDM.

C. High-Speed Train Channel Model (HST)

The recent development of HST, as a high-mobility intelligent transportation system, and the increasing demand for broadband services for HST users, introduce new challenges to the wireless communication systems for HST. These involve the different HST environments (Rural Macrocell (RMa), tunnels, bridges, hilly terrain, and U-shaped terrain). Therefore, the channel model used in HST constitutes the Correlation Functions (CF) of non-stationary wideband MIMO channels, while the Geometry-Based Stochastic Model (GBSM) is also deployed [6]. Figure 4 portrays a channel modeled in geometric form, according to (2)-(5) [6]. There are several components in the HST channel, namely the Line of Sight (LoS) and the Non-Line of Sight (N-LoS) [6]:

$$h_{1,pq}(t) = h_{1,pq}^{LoS}(t) + h_{1,pq}^{SB}(t) \tag{2}$$

$$h_{1,pq}^{LoS}(t) =$$

$$\sqrt{\frac{K_{pq}}{K_{pq}+1}} e^{-j2\pi f_c \tau_{pq}(t)} e^{-j2\pi f_{max} t cos(\phi_{Tp}^{LoS}(t) - \gamma R)} \tag{3}$$

$$h_{1,pq}^{SB}(t) = \sqrt{\frac{\Omega_{1,pq}}{K_{pq}+1}} N_{1\to\infty}^{lim} \sum_{n1=1}^{N1} \frac{1}{\sqrt{N1}}\ e^{j(\psi n_1 - 2pf_c \tau_{pq}, n_1(t))} \times$$

$$e^{j2\pi f_{max} t cos(\phi_R^{(n_1)}(t) - \gamma R)} \tag{4}$$

$$h_{i,pq}(t) = h_{i,pq}^{SB}(t) =$$

$$\sqrt{\Omega_{i,pq}} N_{1\to\infty}^{lim} \sum_{n_1=1}^{N_1} \frac{1}{\sqrt{N_1}}\ e^{j(\psi n_1 - 2pf_c \tau_{pq}, n_1(t))} \times$$

$$e^{j2\pi f_{max} t_{cos}(\phi_R^{(n1)}(t) - \Upsilon R)}, 1 < i \ \leq I \tag{5}$$

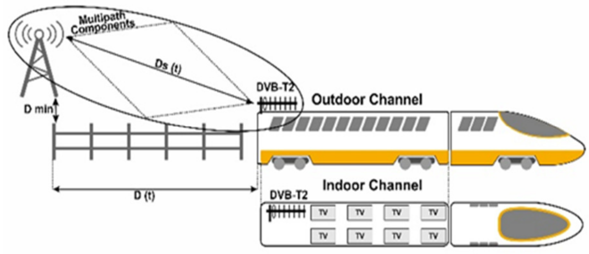

Fig. 3. HST system model.

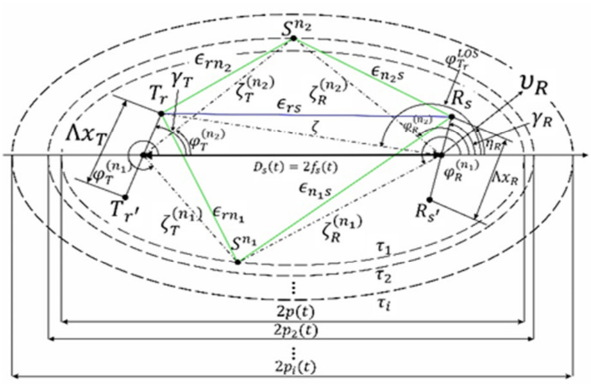

Fig. 4. HST channel.

D. 64-QAM Modulation

Modulation is the process of superimposing an information signal on a carrier signal [21]. The selection of the modulation type is based on the intended application. For instance, DVB-S2 uses APSK modulation [22], whereas DVB-T2 utilizes M-QAM modulation (64 and 256 QAM) [23]. To enhance Bit Error Rate (BER) performance, rotational QAM constellations [24] and non-uniform constellations are also deployed [25]. The 64-QAM is a QAM coding technique with M=64, so the digital input to the modulator is a signal with a total of 6 bits [26]. Figure 5 represents a constellation of 64-QAM. 64-QAM modulation produces a complex-valued modulation symbol containing six bits. Mathematically it can be written as [21]:

$$(i) = 1/\sqrt{}42\{(1-2b(6i))\ [4-(-2b\ \ (6i+2))\ [2-(1-2b\ \ (6i+4))]] + j\ \ (1-2b\ \ (6i+1))\ [4-(1-2b\ \ (6i+3))\ [2-(1-2b\ (6i+5))]]\} \tag{6}$$

E. Digital Video Broadcasting- Second Generation Terrestrial

The DVB-T2 started in 2008. In that generation, most of the DVB-T parameters were expanded, the throughput was improved up to 65%, and the transmission reliability was increased. This increase was also caused by the multicarrier employed in the OFDM [27]. The DVB-T systems constitute a typical transmission network for digital television, where different types of blocks are used to provide efficient and reliable data transfer. Firstly, the input synchronizer aligns and synchronizes the incoming data, then the compensation delay is utilized to deal with bits suffering fixed delays in order not to lose synchronization from the output side. The null-packet deletion block controls the removal of data packets that do not hold useful information and would otherwise act as redundant at a given time to conserve bandwidth, enhancing network performance and efficiency. The guiding principle behind the CRC block is not only to produce a checksum for each frame to allow the receivers to spot them when transmitted from one end and back, but also to detect them while being at rest.

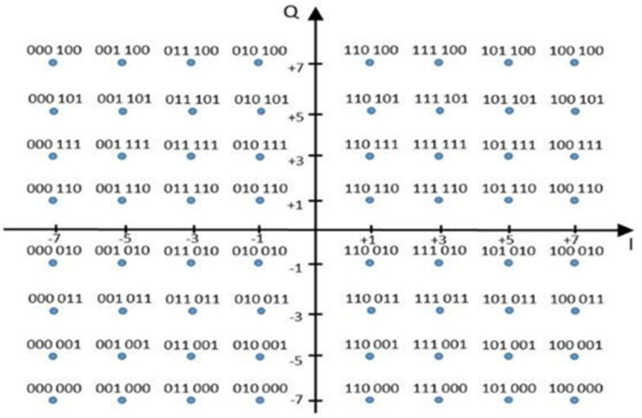

Fig. 5. 64-QAM constellation.

III. RESULTS AND DISCUSSION

To detect the simulation results, the HST channel is validated by deploying a normal distribution and an autocorrelation function. After that, if the channel validation is in accordance with the theoretical assumptions, HST channel modeling is carried out using multicarrier OFDM which produces performance parameters, such as the BER at the receiver position. The speed classification employed is 50 m/s and 100 m/s. The BER value based on SNR is calculated from 0 dB to 30 dB.

A. Validation Channel Gain

The objective of validating the HST channel at this level is to determine whether it can be utilized in accordance with the theoretical foundation. Ensuring channel gain on LoS and N-LoS conditions is the initial stage of validation.

In LoS conditions, the highest amplitude value at a speed of 50 m/s is lower than the one obtained at a speed of 100 m/s, as seen in Figure 6. The highest amplitude value that was attained at a speed of 50 m/s was 0.00155006, while at a speed of 100 m/s, it was 0.00225278 at 0.2 s. Furthermore, the amplitude value at 0.5 s for both speeds reached 0. This occurs because there is no multipath effect in this LoS conditions.

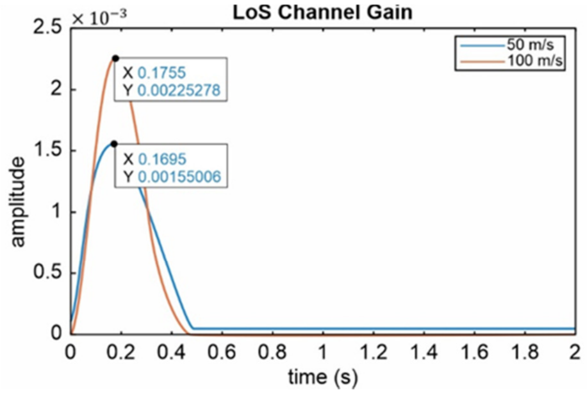

Fig. 6. Channel gain in LoS conditions.

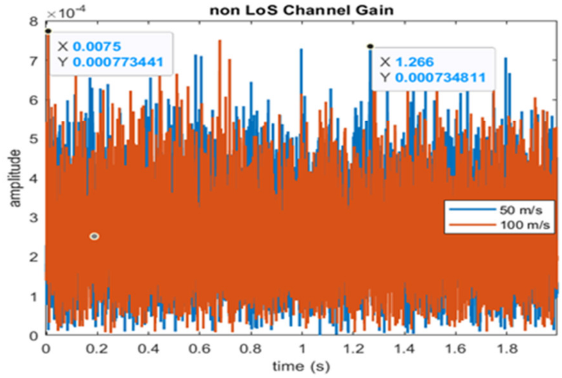

Fig. 7. Channel gain in NLoS conditions.

In N-LoS conditions, the channel character is quite different from that in LoS conditions due to the multipath and Doppler effects, delay, and path loss, which make continuously change the channel. These effects can cause interference, creating errors, reducing range, and using too much power. Likewise, regarding the LoS position, when comparing the speeds of 50 and 100 m/s, it is observed that the amplitude continues to rapidly change every second, as displayed in Figure 7. This happens on the HST channel, evidenced in Figure 4, where many multipath effects as well as the use of a 3-level elliptical can be noted.

B. Validation of the Autocorrelation Function

Autocorrelation is a validation process that compares two identical signals at different times in the HST channel model. The obtained autocorrelation values are normally distributed. When time is 0, the signal is correlated with the same signal, but shifted with the time around the horizontal axis, which ensures that the correlation value decreases by 1. The autocorrelation plot pattern follows the function plot pattern with the Bessel linear and correlation coefficient equals 1 no longer being found except when the sliding time value is equal to 0. Figure 8 illustrates the HST channel output for the autocorrelation function. The obtained results reveal that at time = 0, a highly correlated channel with a value of 0.999771 is observed, while at time =1 it goes to a negative value, meaning that it starts to become uncorrelated, having a value of -0.0843868.

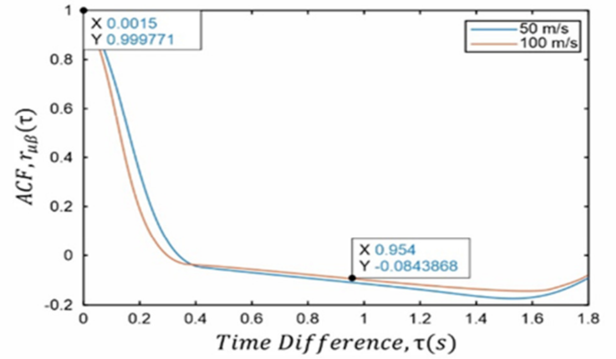

Fig. 8. Channel validation using the autocorrelation function.

C. Normal Distribution

This process aims to validate the distribution on the HST channel using a normal distribution. There is an attempt to determine whether the distribution used is in accordance with the theory or not. Figure 9 demonstrates the results of the channel validation when employing normal distribution at speeds of 50 m/s and 100 m/s, with several (50) scatterers moving within an ellipse. The derived results are in accordance with the normal distribution theory and the acquired curve resembles a bell with a mean value of 0.

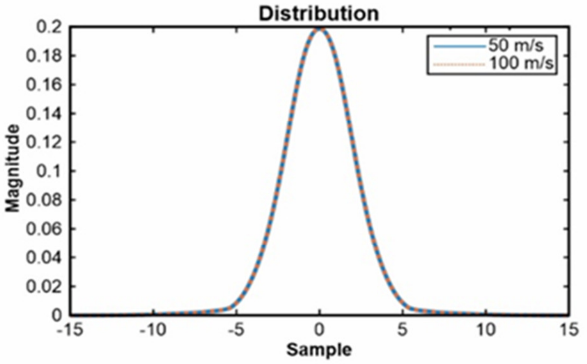

Fig. 9. Channel validation using a normal distribution.

D. Analysis of Complementary Cumulative Distribution Function (CCDF)

The CCDF on a wireless communication channel is a function describing the probability that a random variable, such as the received signal power or Signal-to-Noise Ratio (SNR), has a value greater than a certain value. CCDF is the inverse of the Cumulative Distribution Function (CDF), which measures the probability that a random variable has a value less than or equal to a certain value. Figure 10 presents the curves obtained in the HST channel at speeds of 50 m/s and 100 m/s. The result samples attained at a speed of 100 m/s have a smaller probability value than that at a speed of 50 m/s due to the very fast movement of the train, which has a multipath effect, with 50 scatterers within each ellipse and 3 ellipses being used. It is also displayed that the probability value obtained in sample 9 appears to be smaller at a speed of 100 m/s, namely 0.04375, than at 50 m/s speed, where it is 0.05475.

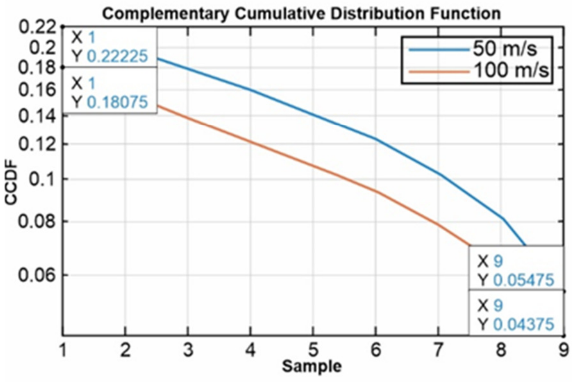

Fig. 10. CCDF curve at speeds of 50 m/s and 100 m/s.

E. Doppler Effect on DVB-T2

In this section, a comparison of the Doppler effect at speeds of 50 m/s and 100 m/s is conducted. The parameters utilized during this process entail 50 scatterers for each of the three ellipses in the HST channel used by the receiver, transmitter, and scatterers in motion. This causes a higher speed, making the perceived Doppler effect on the receiving end higher. Parameters that influence the Doppler effect are the carrier frequency, speed, and angle which is assumed to be 0°. The carrier frequency is 700 MHz and is in accordance with the DVB-T2 technology. Figure 11 presents a frequency comparison chart of the Doppler effect at speeds of 50 m/s and 100 m/s. The faster the train moves, the higher the Doppler effect acquired at the receiving end is. The results obtained at a speed of 100 m/s are twice those achieved at a speed of 50 m/s because the transmitter is not moving as the receiver.

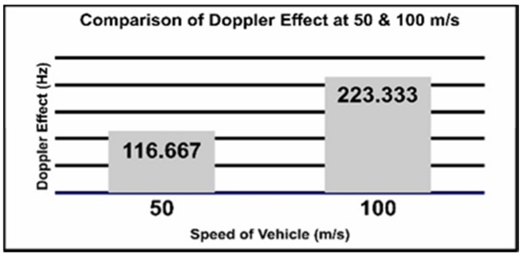

Fig. 11. Comparison of Doppler effect at speeds of 50 and 100 m/s.

F. Error Analysis with Speeds of 10 m/s, 50 m/s, and 100 m/s

This process involves an integration of the DVB-T2 technology with the HST channels using multicarrier OFDM. Figure 12 shows the results obtained at 3 speeds, namely 10 m/s representing low speed, 50 m/s representing medium speed, and 100 m/s representing high speed. At 10 m/s, the total error count is less. For example, at iteration 15, the error difference is 322 bits. At 50 m/s, on the other hand, the difference is big, even though the total error number decreases. For example, at iteration 15, the difference is 83 bits. At 100 m/s, the pattern formed is different, and as the number of repetitions increases, so does the number of errors. At iteration 15, for example, there is an error difference of 414 bits, which is more than the expected 10860 bits. In general, it can be said that the gap between the total number of errors and the expected number of errors decreased as the speed increased until it exceeded the expected number of errors. It is possible for the total error number to be between 4 and 11, at speeds of 10 m/s, 50 m/s, and 100 m/s. A differentiation of the scatterer number is used to run a simulation at this stage. Figure 13 portrays a curve for 4 scatterers, and Figure 14 shows a curve for 11 scatterers.

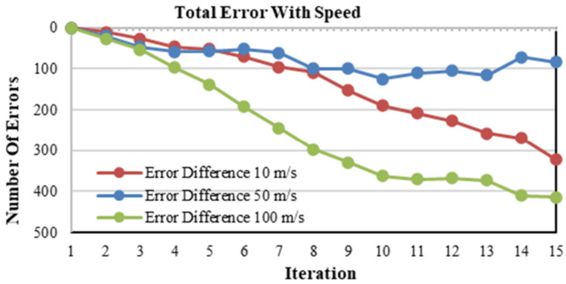

Fig. 12. Error difference curves in terms of speed vs iteration number.

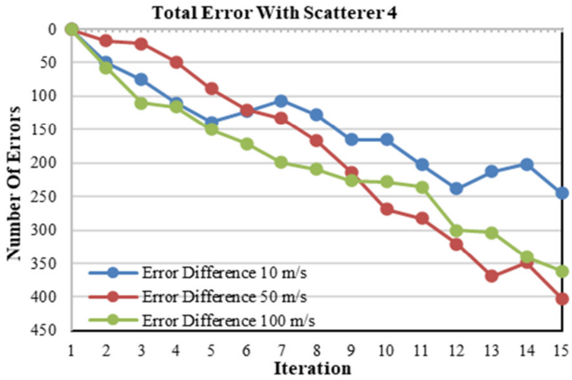

Fig. 13. Error difference curves in terms of scatterers vs iteration number.

The total error at 10 m/s after 15 iterations was 11275 bits, for expected error of 11520 bits. At this speed, the gap is 245 bits bigger. When moving to 50 m/s and 15 iterations, 11313 error bits were found, for expected 11715 errors bits. At this speed, the difference is 402 bits bigger. At 100 m/s and 15 iterations, the overall error was 11191 bits with 10830 expected error bits. On the other hand, at 100 m/s and 15 iterations, the total error bits were 11223, for 11085 expected. This means that the bigger the speed, the closer the error will be to the expected value and sometimes may surpass it, due to the multipath and Doppler effects. So, speed and scatterer number can change the total error in the simulation, and the bigger the error is, the bigger is the change.

Figure 14 presents the simulation error results for speeds of 10 m/s, 50 m/s and 100 m/s with 11 scatterers. At a speed of 10 m/s and 15 total iterations, the error obtained is 11134 bits, while the expected total error is 11655 bits. The difference at this speed is 521 bits which is better than the one at 50 m/s for 15 iterations.

G. Error Analysis with Transmitter and Receiver Angles of 30^o at speeds of 10 m/s, 50 m/s, and 100 m/s

In this simulation process, data were collected for differentiation based on different arrival and delivery angles, namely 30^o for speeds of 10 m/s, 50 m/s, and 100 m/s.

From the acquired results shown in Figure 15, it can be noted that the angle used does not affect the obtained error value.

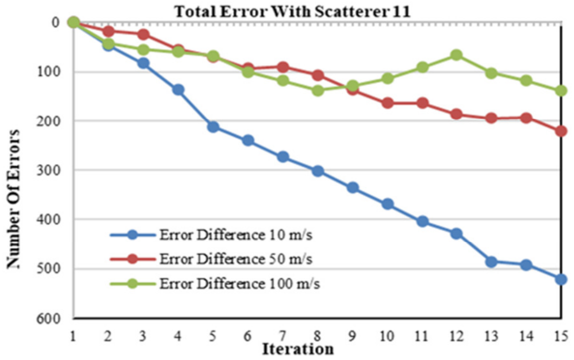

Fig. 14. Error difference curve with 11 scatterers.

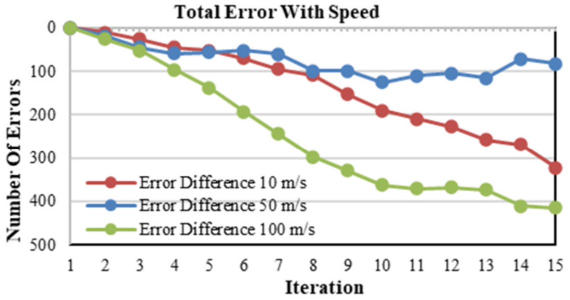

Fig. 15. Total error with an angle of 30^o.

IV. CONCLUSION

In this study, an analysis of the performance of DVB-T2 technology in HST environments was conducted, with particular emphasis given on the issues emerging from high Doppler shifts and multipath effects. This research aims to fill a knowledge vacuum by investigating the impact of these distinctive conditions on the quality of signal transmission and signal integrity in a high-mobility environment. The results indicate that the integration of 64-QAM modulation and multicarrier OFDM technology could substantially improve the quality and spectral efficiency of broadcasts, even in the most difficult environments. It has been shown through meticulous simulations that the implementation of channel coding techniques effectively mitigates the negative effects of high-speed movement and multipath interference, resulting in enhanced signal robustness and error rates.

The uniqueness of this research is its specific application to HST communication systems, which has not been exhaustively studied in the context of DVB-T2. The research offers valuable insights into refining digital broadcasting for high-mobility environments by concentrating on the high-speed mobility aspect. This is especially pertinent considering the ongoing increase in demand for high-quality and dependable broadcasting services, which is concurrent with the advancements in transportation technology. By demonstrating substantial enhancements in transmission reliability and quality, these findings underscore their importance. The novelty of this research is that it confronts the dual challenges of Doppler shifts and multipath effects in high-speed scenarios. Although previous works have investigated the efficacy of DVB-T2 in a variety of contexts, this research offers a focused analysis of HST environments, providing practical solutions for real-world applications.

In conclusion, this paper makes a significant contribution to the field of telecommunications by offering a thorough examination of the performance of DVB-T2 in high-mobility scenarios and by proposing effective strategies to address the corresponding obstacles. The results not only enhance the comprehension of DVB-T2 technology but also establish a foundation for future research and development aimed at optimizing digital broadcasting for dynamic and challenging environments.

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AUTHORS PROFILE

Nicolas Yonara Tarigan completed the Bachelor of Telecommunication Engineering program at IT Telkom Purwokerto in 2024. He has an interest in the field of telecommunications, including wireless and cellular communications, vehicle communications, optical communications, Software Define Radio, multicarrier modulation and Antennas. He is currently working as a Wireless Engineer at Huawei Tech Investment, Indonesia.

Wahyu Pamungkas was born in Purwokerto, Indonesia, in 1978. He obtained his Bachelor Degree in Electrical Engineering, Universitas Gadjah Mada, Indonesia in 2002. He received his Master Degree from the Telkom University, Bandung, Indonesia in 2010. He received a doctorate in electrical engineering (multimedia telecommunications) from the Sepuluh Nopember Institute of Technology, Surabaya, Indonesia in 2021. He joined Institut Teknologi Telkom Purwokerto since 2002, and he is an associate professor now. Apart from being a lecturer, he is also a reviewer in various international journals, TPC at various international conferences in the field of electrical and telecommunications, as well as being a telecommunications consultant in various private companies and government agencies.His research interests include Wireless Communications, Vehicle Communications, Wireless Channel Model and Satellite Communications.

Anggun Fitrian Isnawati completed the Bachelor's program in Telecommunication Engineering at STT Telkom Bandung in 2001 and completed the Master's and Doctoral programs in the Master of Electrical Engineering and Doctor of Electrical Engineering study programs at the Department of Electrical Engineering and Information Technology, Faculty of Engineering, Universitas Gadjah Mada Yogyakarta in 2011 and 2018 in the field of Telecommunications. She joined as a lecturer at the Institut Teknologi Telkom Purwokerto since 2002. Her research focused on telecommunications fields, including wireless and mobile communication, vehicular communication, optical communication, visible light communication, multicarrier modulation, game theory, channel estimation and cognitive radio.