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Performance Evaluation of Doppler Effect in High-Speed Trains at mm Wave in 100 GHz Sub-Band with Presence of Distortion and Addition, White Gaussian Noise

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ABSTRACT

Managing Doppler effects is a critical technical challenge to ensure stable and efficient communication over millimeter Waves (mm Wave) in 5G networks, especially in high-mobility environments. The combined effects of Doppler shift and AWGN highlight the need for robust receiver designs that can handle both challenges simultaneously. This paper provides an analysis that considers the combined impact of Doppler shift and AWGN on the system performance presented by BER. The proposed system model was tested under various scenarios It improves the quality of communications in high-speed communication systems, such as high-speed Railway (HSR) We the design and simulation of advanced algorithms to analyze channel performance and address the Doppler effect on wireless signals using mathematical models and advanced simulation techniques to achieve stable and reliable communication in high-speed environments. where both Doppler shift and distortion are in the presence of AWGN. Different levels of SNR and Doppler shifts were simulated to observe their joint impact on system performance. The combined presence of Doppler shift and distortion resulted in a more significant increase of BER rather than each factor considered individually. The results demonstrate that at high speeds (large Doppler shifts) and low SNR (high noise), the BER increased dramatically, underscoring the challenges of maintaining reliable communication in such environments.

Keywords: Doppler Shifts, Gaussian White Noise (AWGN), High-Speed Railway, Wm wave in 5G, Signal-To-Noise Ratio (SNR)

1. Introduction

The signal-to-noise ratio (SNR) significantly impacts wireless communication quality and data transmission performance, leading to higher bit error rates and resource wastage. Lower SNR can render automatic repeat request protocols ineffective and exacerbate the effects of Doppler frequency shift[1]. Doppler shift has a substantial impact on wireless signal transmission, particularly when there is relative motion between the transmitter and receiver. This necessitates the use of advanced modulation techniques to mitigate the negative effects of Doppler shift [2]Wireless communications is one of the fastest-growing engineering disciplines today. The rapid advancement of wireless communication systems, services, and applications has drastically transformed the way we live, work, and communicate. Over the past few decades, the vast and dynamic field of wireless communication has spurred tremendous excitement and technological progress. As the demands on wireless communication technology continue to grow daily, engineers face significant challenges in designing efficient wireless systems [2,3].There is a pressing need for networks capable of supporting a wide range of use cases and scenarios. From a technical perspective, this requires the implementation of new radio technologies, such as 5G New Radio (NR), alongside enhancing existing frequency bands with higher frequency ranges. For instance, NTT DOCOMO's 5G technology improves communication speeds through Dual Connectivity, enabling the simultaneous use of NR and LTE/LTE-Advanced protocols, achieving downlink peak throughputs of 3.4 Gbit/s and 4.1 Gbit/s [4]. Future wireless communication systems are expected to feature reduced latency, increased speed, improved energy efficiency, and enhanced reliability[5] .However, additive white Gaussian noise (AWGN) remains one of the most significant sources of interference in wireless channels, as it can drastically reduce the SNR. In wireless communications, various forms of interference, including Gaussian white noise, significantly degrade signal quality. Gaussian white noise, characterized by random amplitude variations, introduces a fundamental level of interference that lowers the SNR, making it more challenging to distinguish between the desired signal and noise, especially in high-frequency applications [6].Additionally, co-channel interference, where multiple signals share the same frequency, complicates signal separation and can severely impair communication quality, particularly near cell edges where interference from adjacent cells is pronounced. Given the combined impact of these factors on communication system performance, this research aims to model the effect of Doppler frequency shift on SNR in the presence of white Gaussian noise. By understanding this relationship, the design of wireless communication systems can be improved, and more effective strategies can be developed to address the challenges posed by motion and interference in various communication environments [7]. Furthermore, the combination of motion-induced Doppler frequency shift effects and phase noise induced by high-frequency oscillators presents significant challenges for OFDM wireless transmissions, particularly in terms of channel estimation, phase noise tracking performance, and the associated overhead[8] . Orthogonal Frequency Division Multiplexing (OFDM) is widely used in modern wireless communication standards, such as the 3GPP LTE families and IEEE 802.11 standards, due to its robustness against multipath fading and ease of implementation[9]. The OFDM technique divides the signal into multiple narrow-band, low-rate, frequency-selective subchannels, allowing the simultaneous transmission of multiple symbols. This enhances transmission rates, mobility, and network resource utilization [10]. The Doppler shift arises from frequency changes caused by relative motion between the transmitting and receiving antennas, which distorts the orthogonality of OFDM subcarrier waveforms [11]. In high-speed rail communications, inaccurate Doppler shift measurements can adversely affect MIMO channel estimation and tracking performance. Researchers have established a relationship between mean squared error (MSE) gain and loss for channels with dominant line-of-sight paths. While Doppler shift measurement errors severely impact stronger line-of-sight or faster time-varying channels, a dominant line-of-sight path can yield significant gains in high SNR systems[12] .Several studies have proposed estimation and compensation algorithms to mitigate the effects of Doppler shift and improve error rate performance, thereby reducing the impact of Doppler shift on bit error rate loss [13[14]. Figure 1 illustrates the Base Station and Relay Station Configuration for Wireless Communication Systems in a high-speed railway communication system [15].

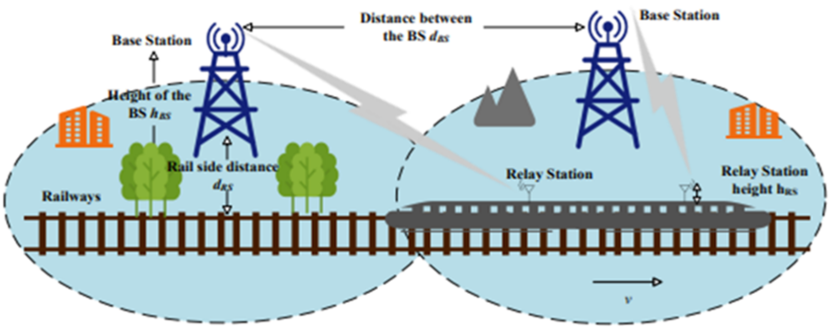

Figure 1. High-Speed Railway Communication System[16]

Table 1 Demonstrates the Studies that use these Techniques and How they Face the Doppler Effect in their Studies

Study	Topic	Objective	Methodology or Technique Used	Results
Guo et al., 2019[17]	Doppler Effect on Communications	Mitigate Doppler effect using directional balancing	Antenna design and transmission beamforming	Improved performance in high-speed scenarios

Zakia et al., 2020[12]	Impact of Erroneous Doppler Shift	Analyze the effects of errors in Doppler estimation	MIMO channel and least-squares analysis	Doppler errors increase tracking inaccuracies
Ramachandran et al., 2020[18]	OTFS Modulation in High-Doppler Environments	Enhance performance in high-Doppler environments	Simulation in 4 GHz and 28 GHz bands	OTFS outperforms OFDM in high-Doppler cases
Kim et al., 2021[19]	ML-based Doppler Estimation	Improve estimation accuracy and reduce complexity	Using Reference Signal Received Power (RSRP)	Accurate estimation with lower computational cost
Zhigang Wang et al., 2022[20]	Tunneling Scenarios in High-Speed Rail	Enhance transmission efficiency	Joint Doppler and channel estimation	Improved efficiency in tunnel scenarios
Suguru Kuniyoshi et al., 2023[21]	High-Speed Rail Channel Estimation	Develop precise channel estimation tools	Delay and Doppler Profiler	Enhanced channel estimation for HSR systems

2. Literature Review

In recent years, the effect of Doppler frequency shift on wireless communication systems has been widely studied, especially in high-mobility scenarios such as high-speed trains and composite networks[21]. Zhao et al. (2022) developed a channel model for train-to-train communication systems with multi-path propagation using ray tracing techniques to accurately estimate channel parameters. Their study highlighted the challenges posed by high-speed mobility, especially the effect of Doppler shift on the angular power spectrum and direction of arrival (DOA) estimation. The Bartlett beamformer and MUSIC algorithms were compared, with the latter showing better spatial accuracy in static scenarios, but both were affected by motion-induced errors[22]. Fig. 2 shows an example of two UEs sending frequency-misaligned uplink signals with Doppler shifts, assuming the base station is at the satellite[23] .

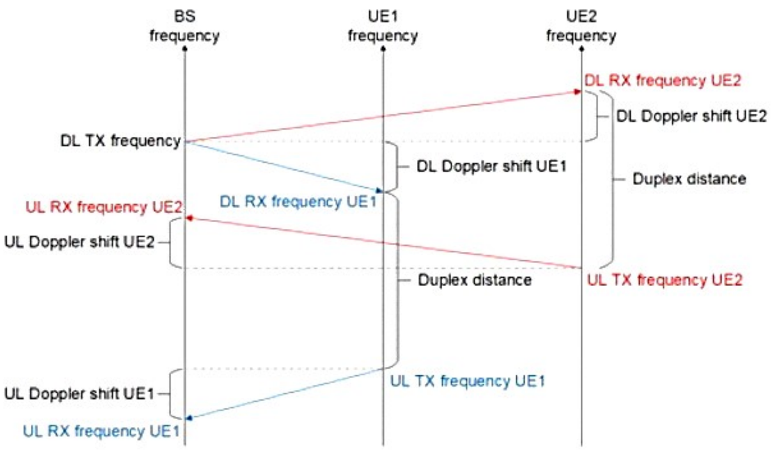

Figure 2. An example of two UEs sending frequency-misaligned uplink signals with Doppler shifts, assuming the base station is at the satellite [23]

Suguru Kuniyoshi1, et al. (2023) [21] presented a new channel estimator based on the Delay and Doppler Profiler (DDP) for 2x2 MIMO systems targeting high-speed railway applications. Their proposed estimator, optimized for a 500 km/h speed scenario with 30 kHz subcarrier spacing, demonstrated superior performance compared to conventional linear interpolation estimators in the time domain. This work emphasizes the importance of accurate Doppler shift compensation in preserving signal integrity and improving channel estimation accuracy in fast-moving environments. Moreover, the introduction of orthogonal time-frequency space (OTFS) modulation by Liu et al. has shown promise in high-mobility scenarios, providing robust performance against Doppler effects[24]. However, the detection complexity in OTFS systems has been a major challenge. Liu's team proposed an orthogonal block (OB) detection scheme based on graph theory, which significantly reduces the detection complexity without sacrificing performance. This approach, which is particularly effective in two-path channels, underscores the potential of advanced modulation schemes in mitigating Doppler-related issues[25].In addition various studies have explored the effect of (AWGN) on signal transmission in wireless channels. AWGN is often used as a basic noise model due to its simplicity and ubiquity in practical communication systems. Wei et al. examined the interaction between AWGN and Doppler effects, focusing on how these factors jointly affect the (SNR) in diff of modern wireless communication systems, especially with regard to their joint effect on SNR. The present work aims to bridge this gap by developing a detailed model that simulates the interaction between Doppler frequency shifts and AWGN, providing insights that can inform the design of more resilient communication systems in high-traffic scenarios. High-speed mobility challenges wireless communication systems due to Doppler shift and inter-symbol interference. Accurate estimation and compensation are crucial for reliability. Mobile communications are expanding rapidly, requiring reliable, efficient systems designed with radio channel characteristics in mind[16,26].

3. Methodology

This section describes the methodology employed to model and analyze the effect of Doppler frequency shift on the SNR in a wireless channel, considering the presence of AWGN. The methodology is structured into several key components, including the channel model, the simulation setup, and the performance metrics used for evaluation.

3.1 Doppler effect

To understand how motion impacts signals sent over wireless channels, we need to know the Doppler equation. This is a synopsis of how bandwidth, frequency shift, and the Doppler effect interact in a broadcast. Channel: The Doppler equation illustrates how the speed of the source or receiver affects a signal's wavelength (Δ). Where the expression of the Doppler equation is[27]. "Eq. (1)"

$$\Delta f = v/c * fc \qquad (1)$$

Where fc carrier frequency Here, Δ f represents the Doppler frequency shift V, is the relative speed, and C is the speed of light, c =3* 10^8 m/s which together define the changes the signal undergoes due to motion effects in the channel, where the Doppler effect causes a shift in the frequency of the transmitted signal depending on the relative velocity V between the transmitter and the receiver. The received signal y(t) will undergo a frequency shift Δ f.

3.2 Relation between Doppler Shift & Transmission Bandwidth

The Doppler effect changes the BW bandwidth when a signal is sent over a certain transmission channel. This is due to a change in frequency. When the relative speed is high, significant frequency changes occur, leading to distortion or frequency interference in the received signal[28]. This makes the transmission BER higher. If the bandwidth is too narrow, even a small change in frequency due to the Doppler effect can cause significant problems with the signal. However, if the bandwidth is sufficiently large, managing frequency changes becomes easier. When the relative speed between the source and the receiver is higher, there is a larger frequency deviation. This may mean that a wider bandwidth is needed to get rid of the distortions and improve the quality of the communication [29].

3.3 Multipath Propagation

Multipath propagation, which occurs due to multiple signals paths, adversely affects radiocommunication and navigation systems. It leads to a reduction in the signal-to-noise ratio, increases synchronization errors, and complicates time and frequency synchronization processes [30].

A theory section should extend, not repeat, the background of the article that has already been dealt with in the introduction and lay the foundation for further work. In contrast, a Calculation section represents a practical development from a theoretical basis.

4. System Model

In this section, we will explain the system model used to analyze the impact of Doppler Shift and Additive White Gaussian Noise (AWGN) on the performance of wireless communication systems. The main goal is to understand how these factors affect the Bit Error Rate (BER) and overall signal quality [31].

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4.1. Basic System Components:

- Transmitter (Tx): Sends the signal through the wireless channel.
- Receiver (Rx): Receives the signal after it has been affected by distortions and noise.

Wireless Channel: The medium through which the signal travels, subject to effects such as: [28].

- **Doppler Shift:** Occurs due to relative motion between the transmitter and receiver, causing a change in the received signal's frequency.
- **Distortion:** Caused by channel characteristics like attenuation and reflections.

Additive White Gaussian Noise (AWGN): Random noise added to the signal as it travels through the channel

"Fig. 3," Here is a schematic of what a system model of a wireless communication system might include under these circumstances

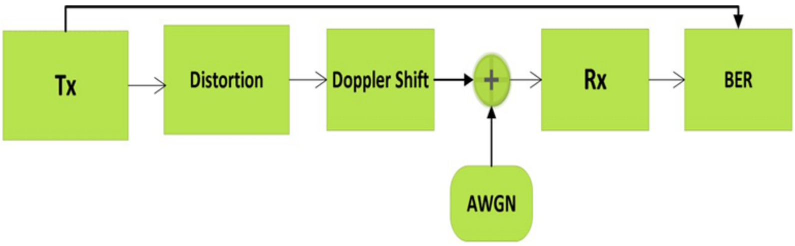


Figure 3. system model

4.2. Doppler Shift

- When there is relative motion between the transmitter and receiver (e.g., high-speed trains or vehicles), the frequency of the received signal changes due to the Doppler effect.
- The frequency shift is calculated using "Eq. (2)" the following equation:

Where: $\Delta f = \frac{v \cdot fc}{c}$ (2)

where:

- Δf: Frequency shift (Doppler Shift).
- v: Relative velocity between the transmitter and receiver.
- fc: Carrier frequency of the signal.
- c: Speed of light. = 3*10^8

4.3. Additive White Gaussian Noise (AWGN):

- Random noise is added to the signal as it travels through the channel, degrading signal quality.
- The noise is typically modeled as Gaussian noise with a zero mean and constant variance.

4.4. Bit Error Rate (BER):

- **BER** is a key performance metric, calculated as the ratio of incorrectly received bits to the total number of transmitted bits.
- **BER** is calculated using the "Eq. (3)" following formula:

$$\text{BER}=\frac{\text{Number of incorrectly received bits}}{\text{Total number of transmitted bits received bits}} \quad (3)$$

BER is significantly affected by Doppler Shift and noise, especially in high-mobility environments or under high-noise conditions.

5. Channel Model

The Binary Symmetric Channel (BSC) model is used to represent the effect of noise on the signal this model, the channel flips bits (from 0 to 1 or vice versa) with a certain probability (pp) due to noise"Fig. 4," Binary Symmetric channel (BSC) is ideal sed model used for noisy channel[32]**.**The matrix that shows the transition probabilities between the inputs and outputs in the channel is represented in Table 2[33].

Table 2. It Shows the Equalizers' Tap Gains for Four Types of Channels Using The Design Procedure[33]

Channel	$\sqrt{y}$	$\sqrt{1-y}$
A	$\sqrt{1}$	0
B	$\sqrt{0.7}$	$\sqrt{0.3}$
	$\sqrt{0.3}$	$\sqrt{0.7}$

6. Result

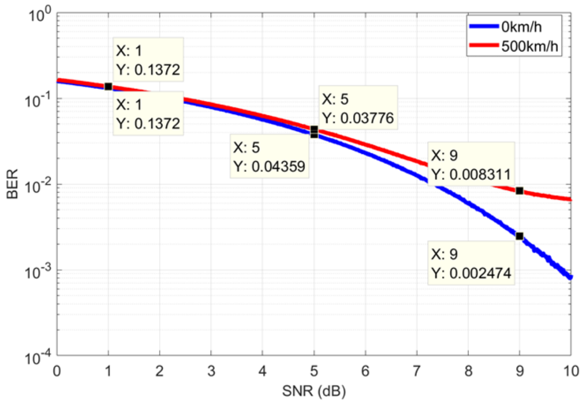
This section presents the results of the simulation and analysis based on the system model previously described. It discusses how the Doppler frequency shift and AWGN (Additive White Gaussian Noise) impact the signal-to-noise ratio (SNR) and overall system performance in a wireless communication channel

We will use two types of frequencies, 30 GHz and 100 GHz, at two speeds, 120 km/h and 500 km/h, for four channels, according to the attached Table 3.

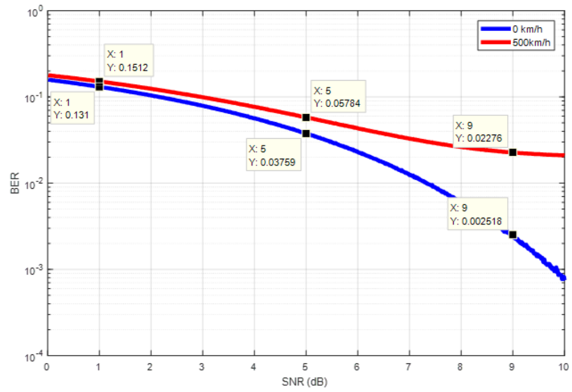
Table 3 Key Parameters and Characteristics of Communication System Operation

property	**Value/Description**
Frequency Range (FR)	FR2, FR2-3
Transmission Type	TDD
Direction	UL/DL
Main Carrier Frequencies (GHz)	28, 61.3, 97.1 GHz
Channel Bandwidth (B_W)	400 MHz
Spectral Efficiency (SPEff)	0.8-**bit**/s/Hz **&** 0.45-bit/s/Hz
Receiver Speed (km/h)	0 and 120 km/h **&** 0 and 500 km/h
Link Throughput (L_th)	0.45 bit/s
Doppler Shift	Calculated per frequency
Lost Bits (Pedop)	Based on Doppler calculation
Noise Power (np)	Ranges from 0 to approx. 10 dB
Bit Error Rate (BER)	Calculated for each configuration

7.1 Channel A Without Distortion Channel For Speed 0km -500 km/h



(a) 30 GHz bassline speed 500Km/h



(b) 100GHz Sub-Band and speed

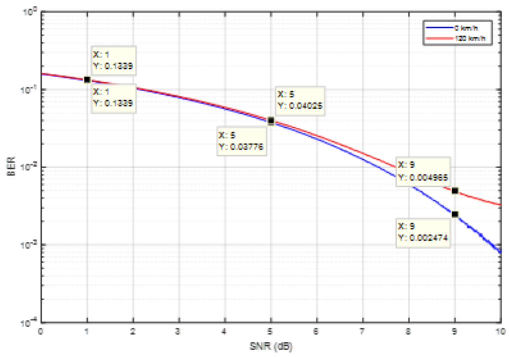
Figure 5. Channel A Without Distortion Channel for Speed 500 km/h -0 Km/h

To evaluate the performance of channel A without distortion by simulating without distortion channel, at 500 km/h, and using the relationship between signal-to-noise ratio and bit error rate, we can see that:

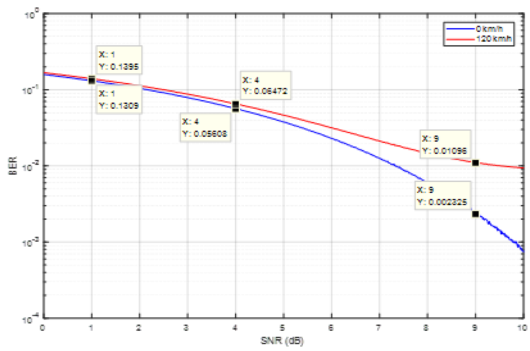
Under additive white Gaussian noise (AWGN) conditions, the graphs show the relationship between the bit error rate (BER) and the signal-to-noise ratio (SNR) of channel A at different frequencies (30 GHz and 100 GHz). This shows the performance of the channel as noise levels change. The changes in performance across frequencies show that the sub-frequency band affects the performance of the channel. The differences in signal-to-noise ratio and bit error rate between 30 GHz and 100 GHz indicate that higher frequencies may exhibit distinct distortion characteristics and error rates, which may affect the quality of the communication.

Noise effects: Communication performance is significantly affected by the presence of additive white Gaussian noise.

7.2 Channel A Without Distortion Channel for Speed 120 km/h -0 Km/h



(a)30GH/z Bassline Speed 120KM/h

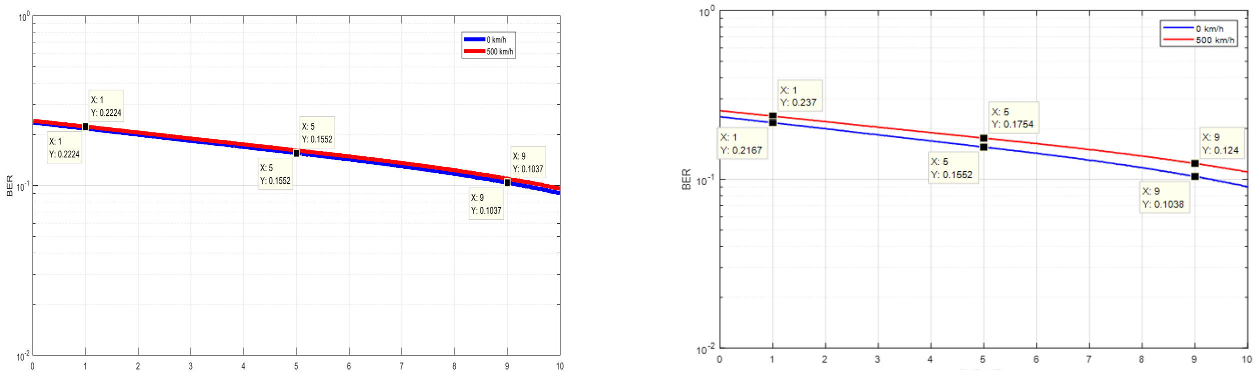


(b)100GH/z Sub-Band an Speed 120KM/h

Figure6. Channel A Without Distortion Channel For Speed 0km - 120 km/h

To evaluate Channel A's performance without distortion at 120 km/h versus 0 km/h. According to the findings, at specific speeds, channels in the 30 GHz and 100 GHz sub-bands perform steadily and distortion-free. This implies that high-frequency bands can preserve signal integrity under ideal circumstances, which is essential for communications, particularly in situations involving high speeds. It follows that more research is required to determine the effects on channel quality and distortion potential as the frequency rises (from 30 GHz to 100 GHz). The absence of distortion at these frequencies up to 120 km/h may mean that these bands are suitable for high-speed communications, but practical applications will require real-world testing to validate these results. Efficiency of operations: The channel characteristics and performance at varying speeds emphasize.

7.3 Channel B Low Distortion in Presences of AWGN For Speed 500 km/h -0 Km/h

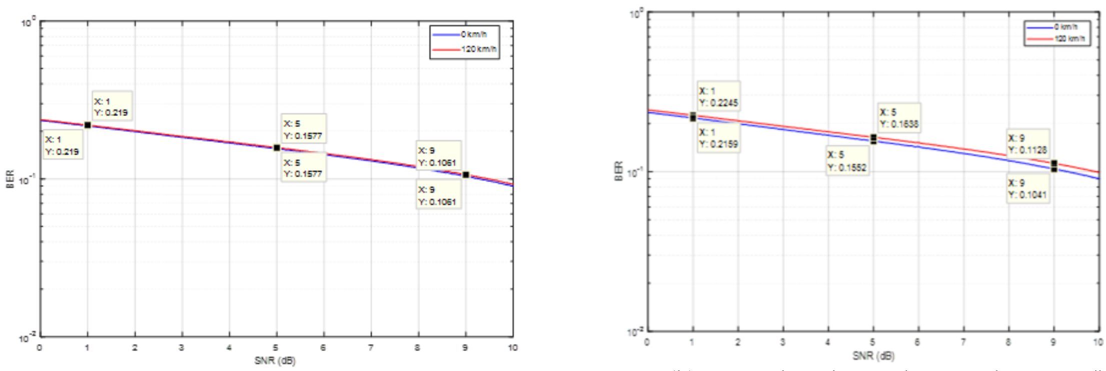


(a)30GH/z Bassline Speed 500KM/h (b)100GH/z Sub-Band a speed 500KM/h

Figure 7. Channel B Low Distortion in Presences of AWGN For Speed 500 km/h -0 Km/h

To evaluate the low distortion B channel's performance between 500 km/h and 0 km/hThe relationship between bit error rate and signal-to-noise ratio is demonstrated by the low distortion simulation with AWGN present at 500 km/h to 0 km/h:Low distortion on a regular basis: When exposed to AWGN, all three frequency bands (30 GHz, 100 GHz) show modest distortion characteristics at 500 km/h. This shows that there is little to no signal quality loss when the channel is used for high-speed applications in various frequency bands. The graphic demonstrates that the channels continue to operate consistently over various frequency ranges. To ascertain whether one frequency band performs better than the others in real-world situations or for particular applications, further data could be required. It is evident that the frequency band selection maybe impacted by additional elements like rules, equipment capabilities, and propagation characteristics. Therefore, even though all bands achieve low distortion, these extra factors may influence practical deployment choices.

7.4. Channel B Low Distortion in Presences of AWGN For Speed 120 km/h -0 Km/h

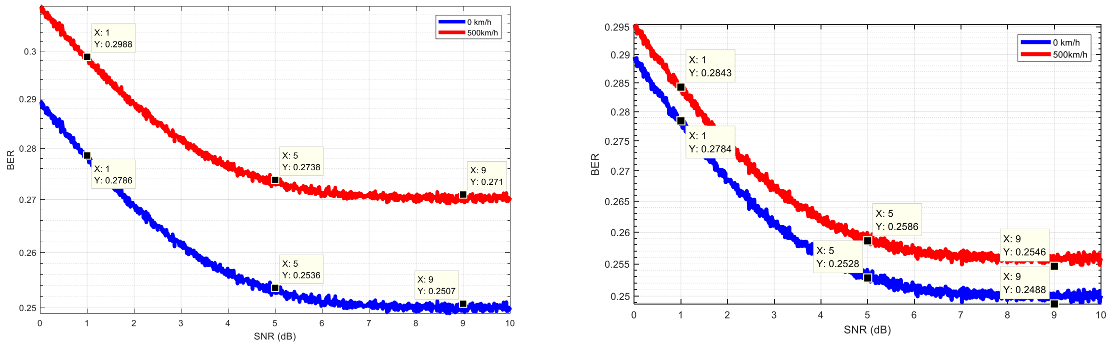


(a)30GH/z Bassline Speed 120KM/h (b)100GH/z Sub-Band a Speed 120KM/h

Figure .8 Channel B Low Distortion in Presences of AWGN For Speed 120 km/h -0 Km/h

Performance comparison of low distortion channel B for 120 km/h to 0 km/maintaining signal integrity is made more difficult by the Doppler effect at 120 km/h, particularly at higher frequencies where relative motion effects can be more noticeable. AWGN and Doppler effects cause different levels of performance degradation at different frequencies. This may indicate the need for careful selection of frequencies based on the specific requirements of the communications system being designed. The figures indicate that changing the carrier frequency significantly affects the signal-to-noise ratio and the bit error ratio. Higher frequencies may be subject to more attenuation and noise, thus affecting the overall performance of the system. It has been shown through simulation that each frequency range operates under similar conditions, allowing comparison

.5 Channel C balanced distortion Channel for Speed 500 km/h -0 Km/h

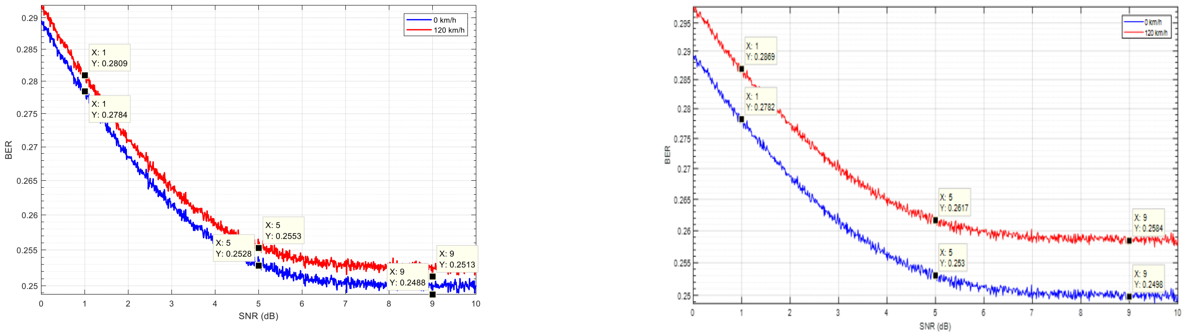


(a)30 GH/z Basline for Speed 500km/h (b)100GH/z Sub-Band a Speed 500km/h

Figure 9. Channel C balanced Distortion Channel for Speed 500 km/h -0 Km/h

To evaluate the channel's balanced distortion performance at 500 km/h versus 0 km/h when AWGN is present at 500 km/h, Channel C's performance remains comparatively consistent across the various sub bands. The bit error rate (BER), which is especially significant at low signal-to-noise ratios (S/N), is gradually increased by the Doppler effect. Both the BER and TER steadily increase as the S/N ratio does, suggesting that signal quality is crucial for enhancing performance. Effective error correction techniques guard against considerable performance loss brought on by noise and relative motion in all sub bands. Although performance enhancements are required for operations under weak signal conditions, particularly at lower frequencies, the system generally demonstrates usefulness in fast-moving situations, such as trains and automobiles. The main band at 100 GHz displays a little bit more.

7.6 Channel C balanced distortion Channel for Speed 120 km/h -0 Km/h

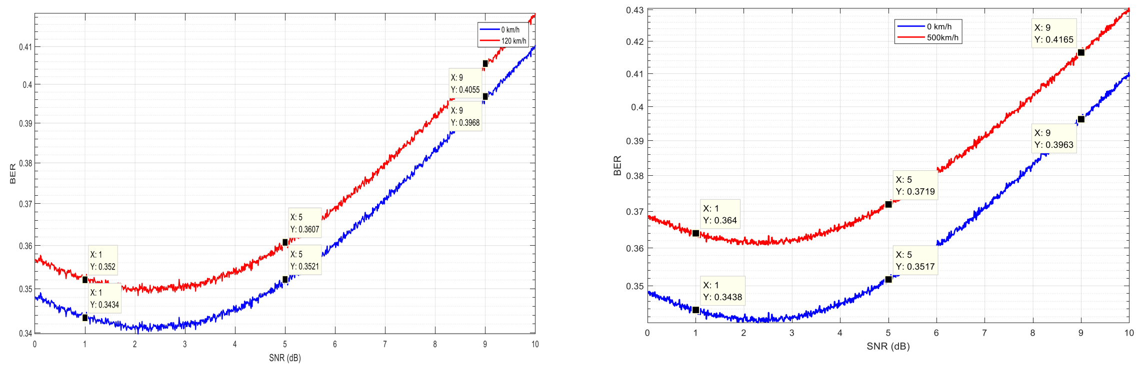


(a) 30 GHz bassline speed 120Km/h (b)100 GHz Sub-Band speed 120Km/h

Figure 10. Channel C Balanced Distortion Channel for Speed 120 km/h -0 Km/h

To evaluate a balanced distortion C channel's performance between 120 km/h and 0 km/h When subjected to additive white Gaussian noise (AWGN), each frequency band displays the distortion properties of the balanced channel. At a specified speed of 120 km/h, these effects are clearly depicted in Figures A and B. The sub-frequency bands have different distortion properties. The documentation indicates that as the frequency increases from 30 GHz to 100 GHz, the channel behavior changes, which may affect the quality of data transmission. The analysis emphasizes the importance of considering both speed and frequency when evaluating channel quality and distortion effects, indicating potential trade-offs for communications systems operating at high speeds. It leads to a comprehensive investigation of how high frequency and mobility interact within.

7.7 Channel D high distortion Channel for Speed 500 km/h -0 Km/h



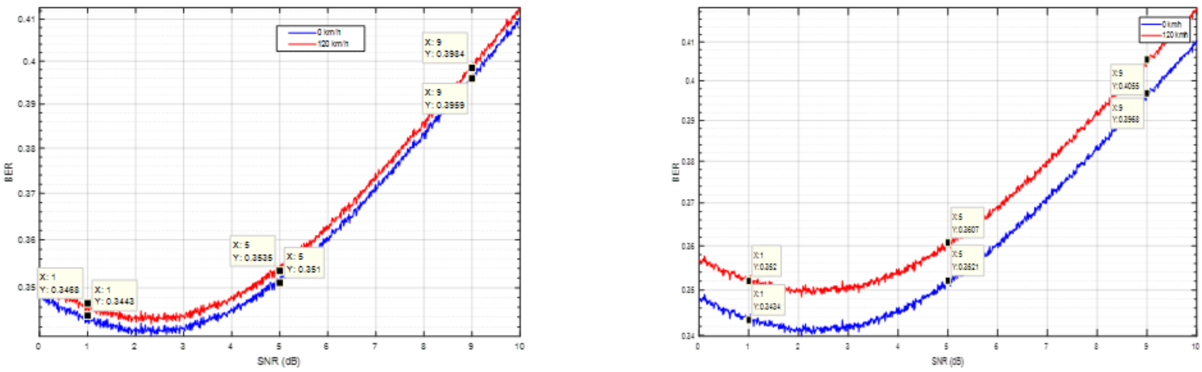
a) 30 GHz Bassline Speed 500Km/h

(b)100 GHz Sub-Band Speed 500 Km/h

Figure 11. Channel D Balanced Distortion Channel for Speed 500 km/h -0 Km/h

To evaluate how well a high distortion channel performs at 500 km/h versus 0 km/h when AWGN is present, High levels of distortion in channel operation can have a significant impact on the reliability and quality of the connection.Presence of AWGN: The analysis recognizes the effect of additive white Gaussian noise (AWGN) on the channel, which can degrade signal quality, thereby impacting signal-to-noise ratio (SNR) and bit error ratio (BER).Overview :Emphasizes the importance of understanding how high distortion and AWGN affect D-channel performance at high speeds and across sub-band and main-band Figure 11 (A,B) illustrates the task of analyzing and comparing the efficiency of a communication channel under different conditions. This information is vital to improving the connection.

7.8 Channel D high distortion Channel for Speed 120 km/h -0 Km/h



(a) 30 GHz bassline speed 120Km/h

(b)100 GHz Sub-Band speed 120Km/h

Figure 12. Channel D high distortion Channel for Speed 120 km/h -0 K

To evaluate how well a channel with substantial distortion performs when AWGN is present for speeds between km/h and 0 km/the findings demonstrate the stability of performance under the specified conditions by showing that the bit error rate stays constant at 2.5*10^-3 even as the signal-to-noise ratio (SNR) increases.Effects of noise:Additionally, it demonstrates that the channel has a high level of interference, which prevents performance from potentially improving when noise levels are high. The significance of assessing performances in various bands: The analysis demonstrates the significance of taking performance in various frequency bands into account, as physical and environmental factors have a significant impact on the outcomes.

Table 5. that illustrates the impact on the signal in the four channels when speed and frequency change

Channel	Speed (km/h)	Frequency (GHz)	Bit Error Rate (BER)	Observations
Channel A	120	30	Low	Stable performance with low or no distortion, especially at lower speeds.

Channel	Speed (km/h)	Frequency (GHz)	Bit Error Rate (BER)	Observations
	120	100	Low	Good performance with low distortion, indicating suitability for high frequencies.
	500	30	Moderate	Increased BER due to Doppler effect, but performance remains acceptable.
	500	100	Moderate to High	Noticeable increase in BER due to high speed and high frequency.
Channel B	120	30	Low	Low distortion with AWGN noise, stable performance.
	120	100	Low	Low distortion with AWGN noise, good performance at high frequencies.
	500	30	Moderate	Increased BER due to high speed, but distortion remains low.
	500	100	Moderate to High	Increased BER due to high speed and high frequency.
Channel C	120	30	Moderate	Balanced distortion with AWGN noise, moderate performance.
	120	100	Moderate	Balanced distortion with AWGN noise, moderate performance at high frequencies.
	500	30	Moderate to High	Increased BER due to high speed and balanced distortion.
	500	100	High	Significant increase in BER due to high speed and high frequency.
Channel D	120	30	High	High distortion with AWGN noise, poor performance.
	120	100	High	High distortion with AWGN noise, poor performance at high frequencies.
	500	30	Very High	Significant increase in BER due to high speed and high distortion.
	500	100	Very High	Significant increase in BER due to high speed, high frequency, and high distortion.

8. Conclusions

This paper is presented. Doppler shifts and inter-symbol interference (ISI) are two problems faced by wireless communication systems, especially in high-speed mobility settings, where they can affect the quality of communications. In wireless communication systems, Doppler shifts can cause frequency misalignment, especially when the transmitter and receiver are moving relative to each other. If this frequency shift is not adjusted adequately, the effective signal-to-noise ratio (SNR) can be reduced. Speeds of 500 km/h and 120 km/h were used in the simulation, along with frequencies (30 GHz and 100 GHz) and four channels to demonstrate how the model can accurately assess signal-to-noise ratios and error rates - two critical factors in determining the reliability and effectiveness of a system in digital data.

9. References

[1] Y. Liu *et al.*, “Enhancing Communication Reliability from the Semantic Level under Low SNR,” *Electron.*, vol. 11, no. 9, 2022, doi: 10.3390/electronics11091358.

[2] Y. Zhang *et al.*, “Scanning the Issue,” vol. 109, no. 10, pp. 1626–1627, 2021, doi: 10.1109/JPROC.2021.3108375.

[3] S. Kumar, *Wireless Communication-the fundamental and advanced concepts*. New York: River Publishers, 2022. doi: 10.1201/9781003340058.

[4] J. T. Yuta Sagae, Shinsuke Sawamukai, Yusuke Ohwatari, Kohei Kiyoshima, Keiichi Kanbara, “Social Problems and Achieving Social Transformation 5G Network,” *NTT Tech. Rev.*, vol. 18, no. 12, pp. 86–96, 2020.

[5] L. Yang, Y. Shao, A. Chang, and L. Ren, “Joint DFO and channel estimation scheme for RIS assisted OFDM systems,” *Phys. Commun.*, vol. 63, no. January, p. 102299, 2024, doi: 10.1016/j.phycom.2024.102299.

[6] E. V. Proshchenok and A. Y. Rodionov, "Modern types of signal manipulation analysis of wireless communication systems," 2023. doi: 10.55648/1998-6920-2022-16-4-43-58.

[7] Adheed H. Sallomi, Sazan Kamiran Hasan, and Jaafar Qassim Kadhim, "Maximizing Signal Quality for One Dimensional Cells In Mobile Communications," *Wasit J. Comput. Math. Sci.*, vol. 2, no. 3, pp. 86–92, 2023, doi: 10.31185/wjcms.160.

[8] F. Linsalata and N. Ksairi, "On the Joint Estimation of Phase Noise and time-Varying Channels for OFDM under High-Mobility Conditions," *ICASSP, IEEE Int. Conf. Acoust. Speech Signal Process. - Proc.*, vol. 2023-June, 2023, doi: 10.1109/ICASSP49357.2023.10094589.

[9] T. Kageyama, O. Muta, and H. Gacanin, "Performance Analysis of OFDM with Peak Cancellation under EVM and ACLR Restrictions," *IEEE Trans. Veh. Technol.*, vol. 69, no. 6, pp. 6230–6241, 2020, doi: 10.1109/TVT.2020.2982587.

[10] M. K. Elmezughi and T. J. Afullo, "Performance Analysis of OFDM Scheme with Channel Estimation and Doppler Shift Effects," no. January, pp. 1–8, 2021.

[11] O. Lang, C. Hofbauer, R. Feger, and M. Huemer, "Effects of Doppler-Division Multiplexing on OFDM Joint Sensing and Communication Systems," *IEEE Open J. Signal Process.*, vol. 5, pp. 229–237, 2024, doi: 10.1109/OJSP.2023.3343308.

[12] I. Zakia, A. Kurniawan, and Iskandar, "Impact of Doppler shift error on least-squares MIMO channel estimation for high-speed railway," *IET Commun.*, vol. 14, no. 2, pp. 206–218, 2020, doi: 10.1049/iet-com.2018.6259.

[13] E. Shareef and M. Dawood, "A non-iterative time-domain sidelobe suppression in doppler shifted LFM waveforms," in *2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting*, IEEE, Jul. 2019, pp. 369–370. doi: 10.1109/APUSNCURSINRSM.2019.8888500.

[14] M. J. Khan, R. C. S. Chauhan, I. Singh, Z. Fatima, and G. Singh, "Mobility Management in Heterogeneous Network of Vehicular Communication With 5G: Current Status and Future Perspectives," *IEEE Access*, vol. 12, no. April, pp. 86271–86292, 2024, doi: 10.1109/ACCESS.2024.3409832.

[15] P. Zhao, X. Wang, K. Zhang, Y. Jin, and G. Zheng, "Doppler Modeling and Simulation of Train-to-Train Communication in Metro Tunnel Environment," 2022.

[16] Q. Zhang, Y. Zhao, H. Dong, and J. Zhao, "A reconstruction and recovery network-based channel estimation in high-speed railway wireless communications," *Digit. Commun. Networks*, 2024, doi: 10.1016/j.dcan.2024.06.006.

[17] W. Guo, W. Zhang, P. Mu, F. Gao, and H. Lin, "High-Mobility Wideband Massive MIMO Communications: Doppler Compensation, Analysis and Scaling Laws," *IEEE Trans. Wirel. Commun.*, vol. 18, no. 6, pp. 3177–3191, Jun. 2019, doi: 10.1109/TWC.2019.2911508.

[18] M. K. Ramachandran, G. D. Surabhi, and A. Chockalingam, "OTFS: A New Modulation Scheme for High-Mobility Use Cases," *J. Indian Inst. Sci.*, vol. 100, no. 2, pp. 315–336, 2020, doi: 10.1007/s41745-020-00167-4.

[19] T. Kim, K. Ko, I. Hwang, D. Hong, S. Choi, and H. Wang, "RSRP-Based Doppler Shift Estimator Using Machine Learning in High-Speed Train Systems," *IEEE Trans. Veh. Technol.*, vol. 70, no. 1, pp. 371–380, 2021, doi: 10.1109/TVT.2020.3044175.

[20] Z. Wang, Z. Wang, F. Zhu, Z. Luo, F. Li, and H. Liu, "Joint Doppler Shift and Channel Estimation for High-Speed Railway Wireless Communications in Tunnel Scenarios," *Wirel. Commun. Mob. Comput.*, vol. 2022, 2022, doi: 10.1155/2022/6804412.

[21] S. Kuniyoshi, R. Saotome, S. Oshiro, and T. Wada, "Delay and Doppler Profiler based Channel Transfer Function estimation for 2x2 MIMO Receivers in 5G system targeting a 500km / h linear motor car," vol. 23, no. 9, pp. 8–16, 2023.

[22] W. Liu, Y. Ding, C. Li, and L. Hanzo, "Optimal Low-Complexity Orthogonal Block Based Detection of OTFS for Low-Dispersion Channels," *IEEE Trans. Veh. Technol.*, vol. 72, no. 4, pp. 5419–5423, 2023, doi: 10.1109/TVT.2022.3224848.

[23] X. Lin, Z. Lin, S. E. Löwenmark, J. Rune, and R. Karlsson, "Doppler Shift Estimation in 5G New Radio Non-Terrestrial Networks," Aug. 2021, [Online]. Available: http://arxiv.org/abs/2108.07757

[24] G. W. Wagaye, "Performance investigation of channel noise effect in data transmission medium using Signal to Noise Ratio (SNR)," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 11, no. 2, pp. 419–423, 2018, doi: 10.11591/ijeecs.v11.i2.pp419-423.

[25] Z. K. Adeyemo, A. A. Badrudeen, and R. O. Abolade, “Intersymbol Interference Distortion Cancellation Using a Modified Maximal Ratio Combiner in Mobile Wireless Communication,” vol. 3, no. 8, 2013.

[26] M. Razaul, S. Mushfiq, and M. Asif, “Comparative Analysis of Various Wireless Digital Modulation Techniques with different Channel Coding Schemes under AWGN Channel,” *Int. J. Comput. Appl.*, vol. 161, no. 3, pp. 30–34, 2017, doi: 10.5120/ijca2017913139.

[27] A. I. Zreikat, K. Al-Begain, and K. Smith, “A Comparative Capacity/Coverage Analysis for CDMA Cell in Different Propagation Environments,” *Wirel. Pers. Commun.*, vol. 28, no. 3, pp. 205–231, Feb. 2004, doi: 10.1023/B:WIRE.0000032254.68767.db.

[28] H. Mou, T. Wu, Y. Liu, S. Song, L. Zhao, and L. Guo, “Turbulence-Resistant Free Space Optical Communication via Chaotic Block-Matching and 3D Filtering,” *ICAIT 2023 - 2023 IEEE 15th Int. Conf. Adv. Infocomm Technol.*, vol. 32, no. 7, pp. 166–170, 2023, doi: 10.1109/ICAIT59485.2023.10367223.

[29] S. Benouadah, L. Mishra, and N. Kaabouch, “Doppler Shift Effect on Bandwidth Availability for UAV Communications,” in *2024 Integrated Communications, Navigation and Surveillance Conference (ICNS)*, IEEE, Apr. 2024, pp. 1–6. doi: 10.1109/ICNS60906.2024.10550636.

[30] J. B. Gros, G. Lerosey, F. Lemoult, M. Lodro, S. Greedy, and G. Gradoni, “Multi-path fading and interference mitigation with Reconfigurable Intelligent Surfaces,” 2022, [Online]. Available: http://arxiv.org/abs/2206.08290

[31] R. Mishra, D. Vasal, and H. Kim, “Linear Coding for AWGN channels with Noisy Output Feedback via Dynamic Programming,” pp. 1–27, 2021.

[32] A. B. Gadicha, V. B. B. Gupta, V. B. Gadicha, K. Kumar, and M. M. Ghonge, “Multimode Approach of Data Encryption in Images Through Quantum Steganography,” 2021, pp. 99–124. doi: 10.4018/978-1-7998-7160-6.ch005.

[33] Bo Wang and T. Adali, “Time-domain equalizer design for discrete multitone systems,” in *2000 IEEE International Conference on Communications. ICC 2000. Global Convergence Through Communications. Conference Record*, IEEE, pp. 1080–1084. doi: 10.1109/ICC.2000.853664.