

SemanticIC for Reducing the Effect of Jamming Attacks in UAV
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SemanticIC for Reducing the Effect of Jamming Attacks in UAV Communications

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Abstract

Unmanned Aerial Vehicles (UAVs) communications encounter jamming challenges due to a high level of interference that impacts their reliability and performance. This paper considers the semantic interference cancellation (SemanticIC) technique to enhance the UAVs dependability and communication quality when the UAV is operated at noisy jamming signal environment. Our framework is structured by extending semanticIC with Principal Component Analysis (PCA)-base compression to reduce jamming noise sensitivity, and attention blocks to prioritize critical semantic features for selecting relevant information. Also, enhanced Low-Density Parity-Check (LDPC) decoding with Log-Likelihood Ratio (LLR) damping and clipping is employed in the framework to improve stability during iterative decoding. The performance of the integrated UAV with semanticIC system is evaluated in terms of Peak Signal-to-Noise Ratio (PSNR), Bit Error Rate (BER) and Euclidean Distance (ED) metrics for more insight analysis. The results show that the framework significantly improves the system performance particularly under low SNR and high-interference

conditions, offering a practical and scalable solution for anti-jamming attacks.

Keywords: UAV, Semantic, Jamming Noise.

تقليل تأثير هجمات التشويش على نضام اتصالات الطائرة بدون طيار باستخدام تقنية إلغاء التداخل الدالي

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الملخص

أنظمة الاتصالات المستخدمة في الطائرات بدون طيار تواجه تحديات جمة ناتجة عن التشويش الذي يؤثر على أدائها وموثوقيتها. تتناول هذه الورقة استخدام تقنية إلغاء التداخل الدالي لتعزيز موثوقية وجودة نظم اتصالات الطائرات بدون طيار التي تعمل في بيئة ذات ضوضاء تشويش عالية. يتكون إطار العمل المقترح من تقنية إلغاء التداخل الدالي مضاف إليه نظام الضغط القائم على تحليل المكونات الرئيسية لتقليل حساسية التشويش وضمان إليهم أيضاً نظام تشفير مطور لتحسين الاستقرار خلال فك التشفير التكراري. هذا الإطار نصب على منظمة اتصالات الطائرة سوا على متنها او في محطة التحكم الارضية. تم تقييم أداء النظام المتكامل عن طريق معايير قياسية عدة منها احتساب معدل الخطأ في البيانات، المسافة الاقليدية وقمة نسبة الإشارة الي الضوضاء وذلك لإجراء تحليل أكثر عمقاً ودقة. تُظهر النتائج المُتحصل عليها أن إطار العمل المقترح يُحسن أداء النظام بشكل ملحوظ خصوصاً عند التداخل العالي للتشويش مما يقدم حلاً عملياً وقابل للتطوير لمواجهة هجمات التشويش.

الكلمات المفتاحية: طائرة بدون طيار، إلغاء التداخل الدالي، ضوضاء التشويش

Introduction:

The rapid evolution of unmanned aerial vehicle (UAV) technology has facilitated its expanding deployment across critical applications, including military reconnaissance, disaster response, communication relaying, intelligent transportation, and emerging integrated space-air-ground networks [1]. The increasing operational dependence on UAVs consequently necessitates wireless communication links that provide high stability, reliability, and efficiency, particularly in mission-critical and dynamic environments. The UAVs, owing to their high mobility, flexibility and capabilities, have attracted considerable attention in recent years [2]. End-to-end wireless communication links of the UAVs have to be secure and reliable; however, the openness of wireless signal propagation makes UAV-based communication systems particularly vulnerable to malicious jamming attacks originating from outside the legitimate users [3,4]. In particular, high-power jamming signals generated by hostile sources can severely interfere with legitimate UAV communication links, resulting in significant

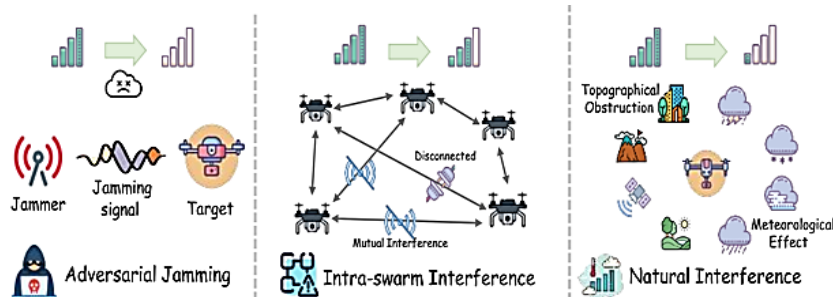


Figure.1 UAV communication systems interference types [6]

performance degradation. Consequently, UAV communication systems are particularly susceptible to external malicious interference that severely degrades the signal-to-interference-plus-noise ratio (SINR) at the UAV receiver. Such jamming attacks can increase energy consumption, degrade communication quality, reduce transmission reliability, and potentially cause complete

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communication outages [5]. The main interference types and their characteristics are described in [6] and shown in Figure.1.

In safety-critical scenarios, prolonged or severe interference may further compromise UAV control and navigation, potentially resulting in loss of connectivity, mission failure, or even UAV crashes. The current anti-jamming techniques face substantial challenges in resource-constrained and contested environments. Conventional countermeasures, including spread-spectrum techniques and transmit-power control, often demand considerable hardware, computational, and spectral resources. In wartime scenarios, where spectrum availability is limited and highly contested, such approaches may become less effective and can potentially generate secondary interference with friendly communication systems [7].

To overcome this issue, several techniques have been employed. Some of them are used to mitigate the interference and other improves the performance of the UAV while they operate under jammed conditions. A direct method is used to increase the transmission power to improve the SINR at the receiver. Also, an avoidance technique is utilized to escape the impacted range of interference that includes frequency hopping which involves switching to other unjammed channels when interference occurs [8]. The signal processing techniques, including adaptive filtering and blind source separation [9], have been used to mitigate the impact of interference on UAV performance.

Dynamic feasible trajectory is generated for chaotic jammer distribution scenarios in [10] to improve the communication reliability. The UAV mobility and environmental circumstances have not been fully considered in the aforementioned approaches without hardware and software complexity and cost. Recently, advanced methods such as Deep Processing-Assisted Semantic Interference Cancellation, which leverages semantic features and large language model prompts to enhance interference cancellation in interference wireless environments [11]. Similarly, the Semantic Signal Interference Cancellation (SemanticIC) approach extracts high-level meaning from received signals to distinguish overlapping

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transmissions, significantly reducing decoding errors in multiple access networks [12].

SemanticIC proves its capability to mitigate the interference in different propagation environments. Therefore, this technique is employed to reduce the jamming effect on UAV communications. The proposed framework is built by implementing SemanticIC onboard of UAV and a ground control segment enhanced with LDPC as channel codes and PCA-base compression for reducing the noise sensitivity. Python simulation environment reinforced by UAV and semanticIC is used to model our framework. The remainder of this article is organized as follows: Section 2 describes the system model of the proposed framework, in particular for the integration of semanticIC with UAV and the UAV wireless channel models. Section 3 focuses on the simulation setup for the framework and optimizing its parameters. Section 4 presents the obtained results and discussion about how the system is improved. Finally, Section 5 concludes our framework.

1 System Model and Proposed Framework

Semantic communication has been proposed for UAV to reduce the utilized bandwidth [13]. In this work, semantic interference cancellation is used onboard the UAV in which is enhanced with LDPC and PCA-based to mitigate the jamming effects. Air-to-ground wireless link is considered in our investigation where the information is sent from UAV to the ground control station. The integration of semantic communication and UAV as a unity system is depicted in Figure. 2.

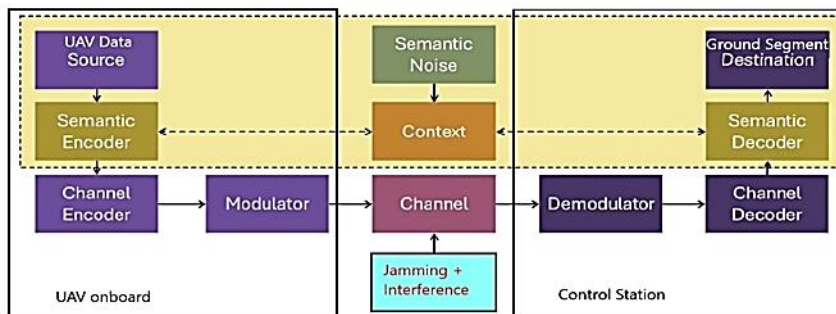


Figure. 2 UAV integrated with Semantic communication

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The semantic encoder is implemented in the UAV onboard transmitter while the ground segment decodes received the semantic information. The SemanticIC is basically based on Wyner-Ziv model [14] in which the information that is required to be transmitted is learned by neural networks as saved as parameters at the decoder. Both the encoder and decoder are paired with a channel decoder LDPC. The encoder extracts the semantic information and then is sent through the channel where it encounters jamming and interference. At the receiver, interference can be eliminated to a certain extent when extracting information features from semantic parameters [15], leverages prior knowledge or context to reconstruct the intended message with fewer errors.

The semantic encoder and decoder function is based on the Wyner–Ziv rate–distortion function $R_{WZ}(D)$ is defined as the infimum of mutual information terms [14] which can be described as:

$$R_{WZ}(D) = \min[I(U; X) - I(U; Y)] , \quad (1)$$

Over an auxiliary random variable U which represents the compressed information X and satisfying the expected distortion constraint

$$\mathbb{E}[d_r(X, \hat{X})] \leq D \quad (2)$$

Where X is the principal source of information and Y is semantic information. The reconstruction function at the receiver is given by $\hat{X} = g(U, Y)$ and has to satisfy equation (2).

Different wireless channel models were investigated for UAV communications; however, the UAV wireless channel model that has been proposed in [16] for several scenarios of propagation environment is adopted in our framework. The propagation signal scenario in our system is shown in Figure. 3, where terrestrial obstacles are presented which cause scattering of the UAV transmitted signal. As shown in Figure.3, h_U, h_S, h_G, h_J represents the height UAV, scatterers, ground station, and the jammer, respectively. The distances between the UAV and ground station, jammer are d, d_J , respectively, and the elevation angles of UAV and jammer are θ, θ_J , respectively.

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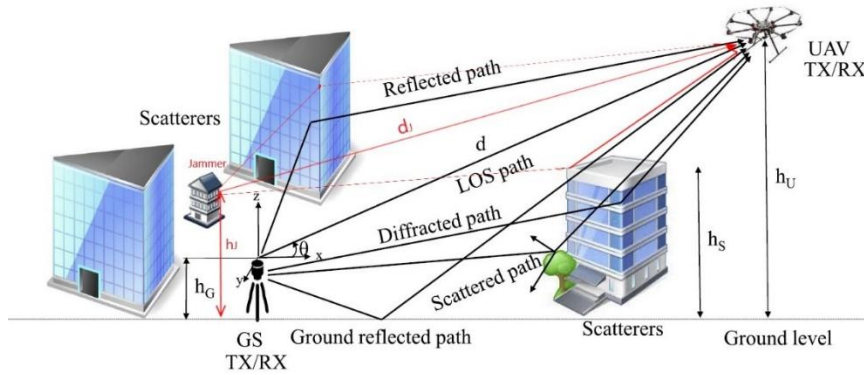


Figure.3 UAV and Jammer wireless signal propagation scenarios [16]

The received power at receiver side is computed as:

$$P_R = P_T + G_T + G_R - PL \quad (3)$$

Where P_T is the transmission power, G_T is the transmission gain, and G_R is the receiving gain. The Path Loss (PL) including LOS and NLOS components is described as [16]:

$$PL = 20 \log \left(\frac{h_U - h_G}{\sin \theta} \right) + 20 \log f - 27.55, dB \quad (4)$$

Where f is the frequency of the signal in MHz. Equations (3) and (4) can be used to calculate the received power and path loss for the legitimacy user and the jammer received power will be random. At the receiver, the AWGN noise is added to the received signal and jamming signal. Equations (3) and (4) can be used for both transmission direction up and down links. The performance of the semanticIC framework is evaluated using several metrics which is commonly used for such systems [17]. The metrics include BER as a function of the SNR, the Euclidean distance (ED), and the peak signal-to-noise ratio (PSNR) for quantifying both signal domain and semantic domain. ED measures the mean squared distortion between the transmitted and reconstructed data using semanticIC which can be described as [17]:

$$ED = \frac{1}{MN} \sum_{i=1}^M \sum_{j=1}^N |I(i,j) - K(i,j)|^2 \quad (5)$$

Where $I(i,j)$ is the information of the transmitted image and $K(i,j)$ for the reconstructed image. It can be conclude that as the ED decreasing, that means semanticIC framework is well performing. PSNR quantifies the ratio between the maximum possible power of the desired signal and the power of the noise that has contaminated the desired signal [12]. Accordingly, PSNR is defined in a logarithmic scale as:

$$PSNR = 10 \log_{10} \frac{MAX^2}{MSE} \text{ dB} , \quad (6)$$

Where MAX denotes the maximum possible number of image pixels and MSE represents the mean squared error between the transmitted data and the reconstructed data. As Better performance is provided by our framework, less MSE is expected and hence high PSNR values we will get.

2 SemanticIC Framework Simulation Setup

As shown in Figure. 2, the simulation setup is based on integration between UAV system and semanticIC technique. We suppose that the output of UAV data source is chosen as CIFAR-10, consisting of 60,000 RGB images divided into 50,000 for training and 10,000 for testing [18]. Semantic encoder and decoder have been implemented with three convolutional layers in which the output semantic feature map size is 16x23x23. LDPC channel coding uses codeword with length of 900 bits and configured parameters $dv = 2$ and $dc = 3$. We assume that the system is operating at low SNR range which is considered between -5 dB and 10 dB. To minimize processing delay, number of iterations for jointing LDPC and semanticIC is only 7. The training process and simulation environment are configured to ensure that the optimal performance and high reliability of the proposed SemIC system are achieved. The optimized parameters are chosen to provide high quality and robustness in both semantic feature extraction and transmission accuracy. The simulation parameters are summarized in Table.1. The optimized parameters are meticulously selected to

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provide optimum performance. Each parameter value contributes to enhancing system reliability, semantic fidelity, and overall communication efficiency. The key enhancements are summarized as follows: Increasing the number of training epochs and refining the LDPC decoding process will significantly reduce the bit error rate (BER), particularly under low-SNR scenarios. The integration of Principal Component Analysis (PCA) for compression coupled with attention mechanisms enables the system to more effectively capture and preserve critical semantic features that will improve the reconstruction quality.

Table.1 Training and Network Simulation Parameters

Parameter	Original	Optimized	Expected Effect
Epochs	20	20	Increase training, less BER
Batch Size	1	4	Improve stability and convergence
Learning Rate	N/A	0.0001	Enhance accuracy, reduce oscillation
PCA Technique	Not used	N components =0.99	Reduce data loss and better features representation
Attention block	Not used	Implemented	Better focus and improve semantic features
Weight decay	Not used	$1e^{-6}$	Prevents overfitting and improves generalization
PSNR	Not used	Added custom code	Enable accurate quality measurements

The other advantage of PCA is reducing the interference, thereby enhancing the system robustness against jamming. A custom Peak Signal-to-Noise Ratio (PSNR) computation module is also implemented to provide an objective metric for assessing the quality of reconstructed data. Attention Blocks is implemented to improve semantic focus by selectively emphasizing relevant information and suppressing extraneous data during processing. Decoding techniques such as Log-Likelihood Ratio (LLR) damping and clipping are applied LDPC to stabilize the decoding process and maintain high accuracy. Increasing batch size, application of weight decay, and extended training epochs contribute for better model generalization and reduced risk of overfitting. In general, the parameters are optimized for a cohesive strategy of our framework

that ensures high-performance outcomes across multiple evaluation metrics.

3. Framework Simulation Results and Analysis

The performance of the proposed framework for improving UAV QoS using SemantIC technique as shown in Figures. 2 and 3 is evaluated in terms of BER, ED, and PSNR as a function of the number of iterations and SNR. Assuming that the UAV operating distance is $d = 3 \text{ Km}$ and the jammer distance is $d_j = 4.5 \text{ Km}$. The heights of UAV, control station and jammer are $h_u = 1 \text{ Km}$, $h_G = 10 \text{ m}$, $h_j = 5 \text{ m}$ and $\theta = 20^\circ$. The frequency band is 20 MHz centered at 2.5 GHz .

The transmitted power is $P_t = 30 \text{ dBm}$ and AWGN and jammer noise power are calculated as $-174 + 10\log(f) = -99 \text{ dBm}$. The path loss and small-scale fading are calculated using the equations (3) and (4). The transmitted and received gains are $G_T = G_R = 30 \text{ dB}$ and the receiver gain is adjusted to get the required SNR range. A total of 60,000 images have been used in the simulation, where 50,000 are used for training and 10,000 for testing. The simulation is firstly done using the original parameters of Table.1 for verification and then the optimized model parameters are utilized to obtain an improved results at low SNR range and jamming interference.

The performance of the proposed framework is evaluated with several metrics as a function of the number of iterations and the SNR at the receiver. The obtained results are detailed as following: The BER is a critical measure for any communication system. In our framework, the BER is examined in terms of number of iterations and SNR for both original and optimized system parameters as shown in Figure. 4. It is clear that the BER is decreasing function with number of iterations up to 6. For that reason, the maximum number of iterations is limited up to 7 for processing time optimization purpose.

Also, it can be noted that optimized SemantIC configuration exhibits a substantial reduction in BER for the two chosen values of SNR compared with the conventional LDPC-only decoding scheme. For instance, at SNR= 5 dB, the proposed framework achieves BER

reduction of about 33.9%, underscoring its superior bit-level reliability and convergence stability. This performance enhancement is primarily attributed to the synergistic interaction between the LDPC decoder and the semantic feedback mechanism, which jointly refine bit estimations and mitigate jamming effects propagation throughout the decoding process. Euclidean distance (ED) is another important metric for measuring the quality of reconstructing images by measuring pixel-level intensity differences or spatial structural variations between a reference image and a distorted or processed image.

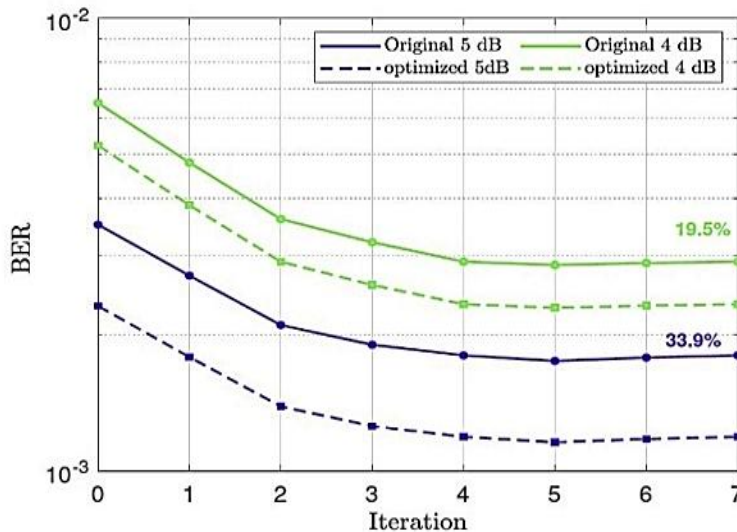


Figure.4 BER performance as a function of iteration number for SNR= 4 and 5 dB

Furthermore, the edge strength extracted based on ED is sensitive to jamming noise, which quality assessment mainly care for. When jamming noise is introduced, there is a distinct difference between the luminance of current point and its surroundings, the proposed method can effectively calculate the jamming noise. The ED is calculated using equation (5) and the results are shown in Figure.5 as a function of SNR.

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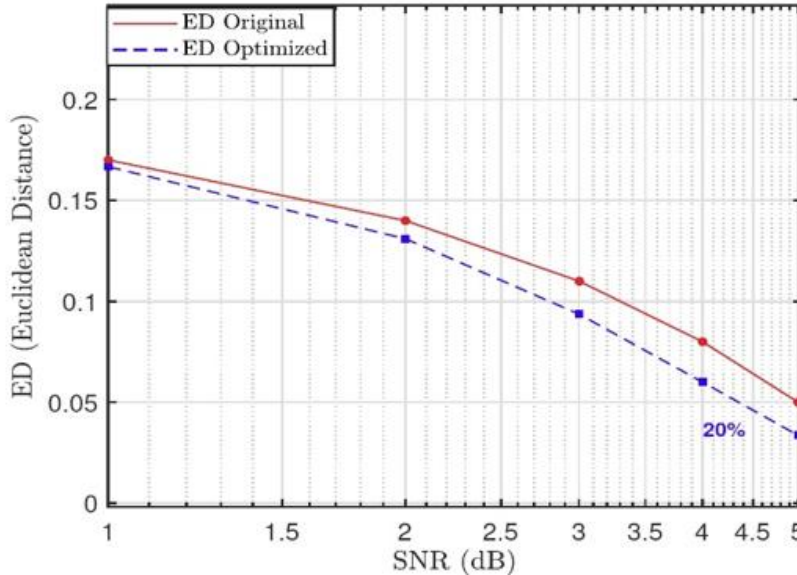


Figure.5 ED as a function of SNR for original and optimized parameters

As seen in figure. 5, the optimized configuration consistently achieves a lower ED compared to the original model with an average of improvement about 20%. Such reduction in ED signifies enhanced convergence behavior and improves structural fidelity in the reconstructed images. The semantic-assisted LDPC decoding framework plays a pivotal role in this improvement by leveraging semantic feedback to iteratively refine bit-level estimates, thereby reducing pixel-wise distortion caused by jamming effects. The ED is also examined in terms of iteration number for specific values of SNR as depicted in Figure.6. The ED is improved for more iteration is conducted which means that the semanticIC is mitigating jamming noise by increasing the number of iterations.

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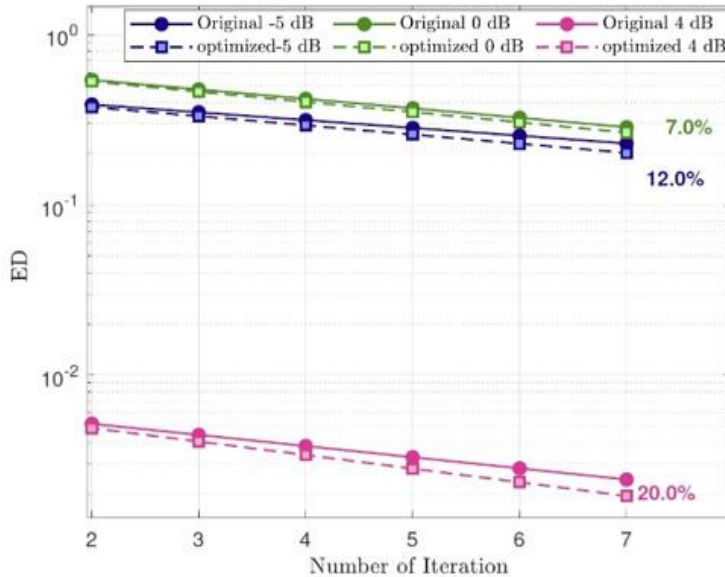


Figure.6 ED vs number of iterations for several values of SNR using original and optimized parameters

The optimized parameters achieves an average jamming distortion reduction of approximately 20%, highlighting the effectiveness of the attention-based mechanism in maintaining semantic integrity and preserving fine-grained visual structures within the reconstructed images. PSNR is one of the simplest and commonly used for testing image reconstruction quality. PSNR is computed using equation (6) as a function of SNR and number of iterations. PSNR is plotted in terms of SNR in Figure.7 for both original and optimized parameters. The PSNR is increasing function of SNR because as SNR increases the image quality gets better, which means lower MSE. Even in the low SNR region, our proposed framework achieves an improvement of 95%. Moreover, the observed monotonic increase in PSNR with rising SNR values underscores the robustness and scalability of the proposed architecture across diverse jamming conditions.

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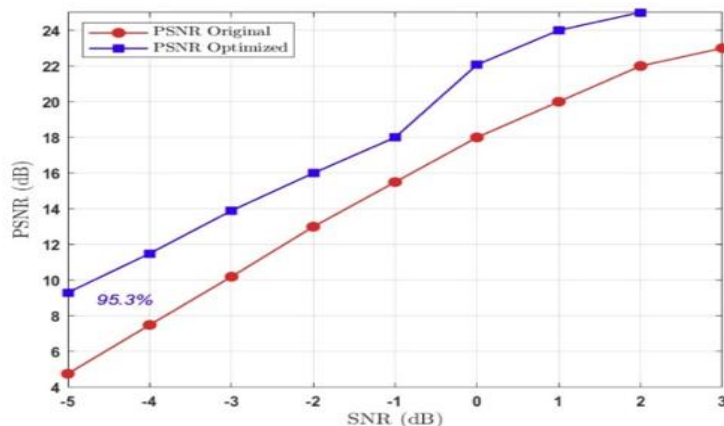


Figure.7 PSNR as a function of SNR for original and optimized parameters

The PSNR metric is tested in terms of iteration numbers for different values of SNR and both system parameters. The obtained result of this test is shown in Figure. 8. It is clear that PSNR is slightly improved as more iterations are conducted. However, a 2 dB improvement is noted by conducting 7 iterations that is significantly helpful for image reconstruction in a jamming environment.

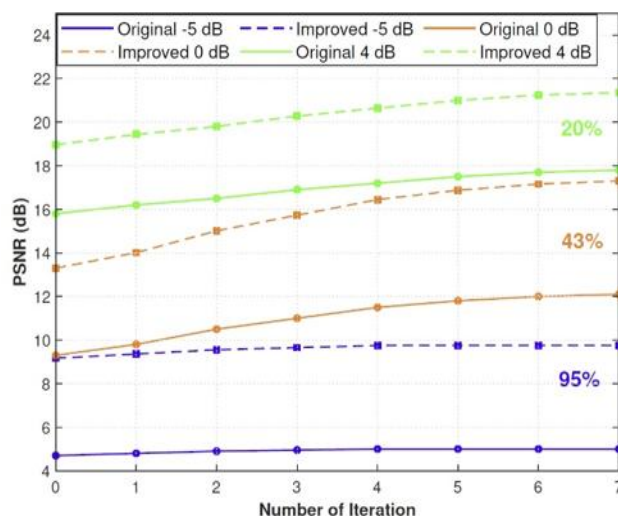


Figure.8 PSNR vs number of iterations for SNR = -5, 0 and 4 dB using original and optimized parameters

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A visual examination is done for a sample of transmitted images. An interesting result is that the jamming noise is significantly diminished and images become more clear as more iterations are conducted. Such promising results of reducing the ED as the number of iterations increase can be observed in Figure. 6. The positive impact of reducing ED can be clearly seen in Figure. 9 by comparing received images for one iteration process in (a) and seven iterations in (b). The images shown in Figure. 9 (b) can be easily recognized; however, the images depicted in Figure. 9 (a) with low ED are noisy and it is hard to extract any information. The achieved improvement by our proposed framework is obvious that implies the efficient use of semanticIC for mitigating the jamming noise.

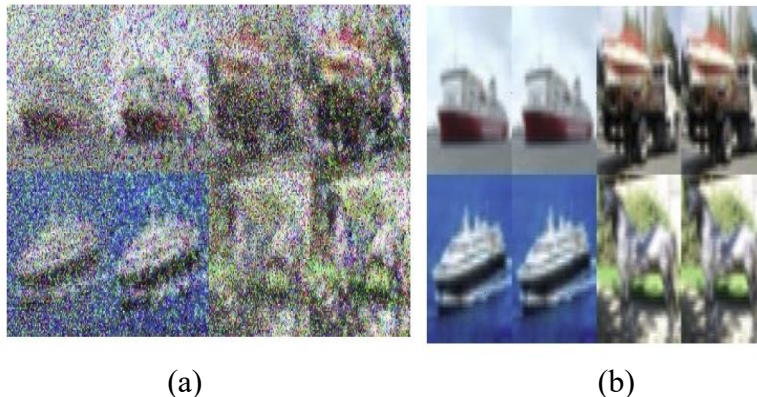


Figure. 9 A visualized results for eight transmitted images at SNR=2 dB
(a) for one iteration and (b) seven iterations

4 Conclusion

This paper has presented a framework that can be employed to mitigate the effect of jamming attacks on UAV communication systems. The framework is based on integration of semanticIC technique included LDPC coding and PCA-compression with UAV system. The framework has been evaluated using python code simulation where a large set of images is utilized in which part of it for training and the other for testing. There were two system configuration parameters have been used which are called original and optimized parameters for comparison. The evaluation was done by traditional assessment metrics for image quality which are BER,



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ED and PSNR. The results have shown that the assessment metrics have been significantly improved by using the proposed framework. For instance, PSNR is increased by 95% while ED is diminished by 20% and the BER is reduced by 33.9%. The transmitted images can be easily recognized as more iterations are conducted; however, the overall system is going to become more complex and the processing delay is expected to be longer. Above all, the proposed framework has demonstrated a high capability of mitigating the jamming noise and making UAV system more reliable.

Conflict of Interest

This statement is to certify that all authors have seen and approved the manuscript being submitted and to declare any competing interest.

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