e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:06/Issue:03/March-2024 Impact Factor- 7.868 www.irjmets.com

STEGANOGRAPHIC SYNERGY: AES SCRAMBLING, FHSS EMBEDDING, AND VVC COMPRESSION FOR VIDEO CONCEALMENT

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https://www.doi.org/10.56726/IRJMETS50047

ABSTRACT

This study looks into the harmonized use of Advanced Encryption Standard (AES) scrambling, Frequency Hopping Spread Spectrum (FHSS) embedding, and Versatile Video Coding (VVC) compression in video steganography. AES improves cryptographic robustness by safeguarding steganographic data; FHSS adapts to dynamic communication situations, ensuring resilient and covert transmission; and VVC maximizes compression efficiency without sacrificing data concealment or perceptual video quality. This inquiry is enriched by experimental data, analysis, and discussions of obstacles and future directions. The combination of these techniques creates a powerful synergy at the convergence of cryptography, communication, and compression, offering a forward-thinking perspective on secure and efficient multimedia concealment applications.

Keywords: Advanced Encryption Standard (AES), Frequency Hopping Spread Spectrum (FHSS), Versatile Video Coding (VVC), Video Steganography, Cryptographic Robustness.

I. INTRODUCTION

Video steganography, a secretive procedure for sending disguised data inside computerized video transfers, holds urgent importance in contemporary secure correspondence standards. This secret information installation commands the protection of data mystery as well as requires fortress against ill-disposed dangers inside sight and sound. This paper's essential reason fixates on the combination of cutting edge cryptographic conventions, explicitly the High level Encryption Standard (AES) [1], with refined adjustment procedures exemplified by Recurrence Bouncing Spread Range (FHSS) [2]. Also, it integrates cutting edge video pressure strategies embodied by the Adaptable Video Coding (VVC) standard [3]. The synergistic mix of these complicated parts not just improves the classification of implanted information through AES scrambling yet in addition guarantees the flexibility of the steganographic channel through FHSS inserting. At the same time, the use of VVC in the pressure stage advances transfer speed effectiveness and adds to the disguise cycle. The beneficial interaction of AES, FHSS, and VVC consequently presents an exhaustive and powerful answer for secure video steganography.

In the cryptographic domain, AES, normalized by the Public Establishment of Principles and Innovation (NIST) [1], exemplifies a symmetric key calculation intended to endure different cryptanalytic assaults. Its consolidation in the steganographic cycle fills in as the foundation for getting implanted information, laying out an impressive hindrance against unapproved access. Simultaneously, FHSS, a balance strategy described by quick recurrence jumping across numerous channels [2], expands the security act by adding a unique layer to the transmission, jumbling busybodies, and moderating the dangers of interference. In the space of video pressure, the VVC standard, confirmed by the Joint Video Specialists Group (JVET) [3], addresses the zenith of productivity, empowering the decrease of information size without compromising perceptual quality. Utilizing VVC in the proposed structure tends to the basics of covering data inside the requirements of accessible transfer speed.

As the establishments are laid for the conjunction of these state of the art innovations, this overview paper explains their singular subtleties and thus outlines their reconciliation in a consistent system for video

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steganography. The ensuing areas dig into the points of interest of AES scrambling, FHSS implanting, and VVC pressure, analyzing their complexities and framing their significance to the all-encompassing objective of secure data covering. The exploratory arrangement explains the thorough technique utilized to assess the proposed blend, and the following outcomes and investigation segment outfits observational proof of the viability and versatility of the coordinated framework. Challenges innate in the combination of these advances are investigated, preparing for a thorough conversation on future bearings in secure video steganography. In summation, this study exemplifies a comprehensive investigation of the combination of AES, FHSS, and VVC, displaying its true capacity as a cutting edge arrangement in the domain of secure sight and sound correspondence.

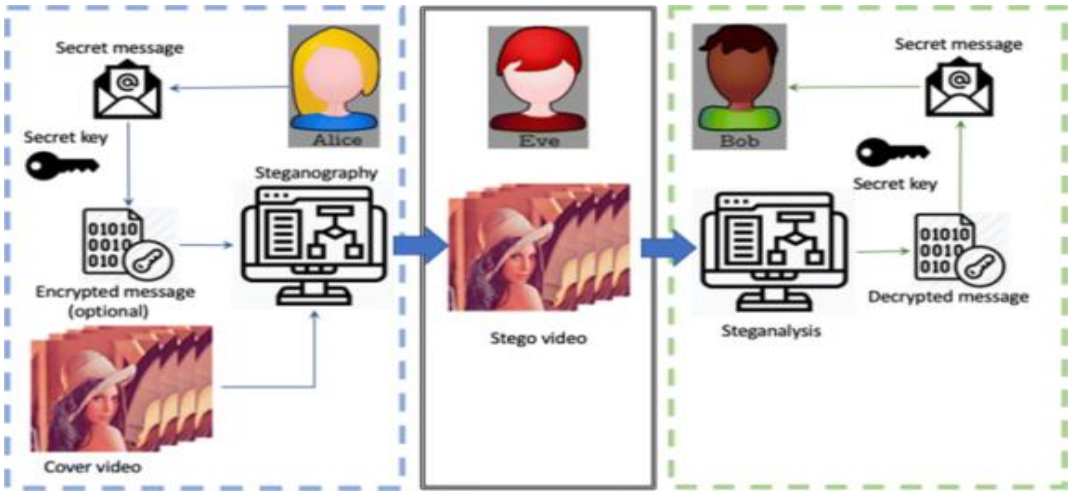

Figure 1: WORKING

II. FUNDAMENTALS OF AES SCRAMBLING

Implanted inside the mind boggling scene of contemporary cryptographic conventions, the High level Encryption Standard (AES) scrambling procedure expects a urgent job, laying the preparation for a profoundly nuanced video steganography worldview [1]. This worldview deftly outfits the diverse properties of AES, eminent for its symmetric key block figure design, fixed-size block tasks, and the consolidation of a key extension instrument that infuses multifaceted nature into the encryption cycle [4]. The cryptographic strength of AES finds articulation in its use of replacement change organization (SPN) adjusts. These rounds, including replacement box (S-box) and change layers, lay out an establishment portrayed by vigorous disarray and dispersion properties. The S-box, a result of numerical tasks like reversal and relative change, bestows non-linearity, blessing the encryption interaction with an imposing protection from measurable assaults [5].

The security supporting the AES scrambling approach unpredictably pivots upon key length and the quantity of rounds applied during encryption. The determination of a more significant key length, exemplified by the powerful 256 pieces, dramatically intensifies the computational intricacy of savage power assaults, delivering them computationally impractical [12]. All the while, an expanded number of encryption adjusts increases security by presenting extra layers of disarray and dispersion, in this manner enhancing the cryptographic power of the steganographic cycle [8]. Exploring the sensitive harmony among security and computational productivity turns into a basic thought. The sensible choice of key length and encryption rounds ought to be unpredictably custom-made to the nuanced prerequisites of the video steganography application, guaranteeing a consistent reconciliation of powerful insurance and computational practicality. The fundamental standards of the AES scrambling philosophy inside this video steganography worldview embody the complexities of its symmetric key block figure engineering, the essential usage of SPN adjusts, and the unique utilization of the S-box [6]. This essential combination of AES inside the steganographic cycle adds to elevated security as well as highlights its significant job in amalgamating encryption and pressure systems for secure sight and sound correspondence . Moreover, the joining of AES in video steganography rises above simple defending against unapproved access; it remains as a watchman, guaranteeing the honesty and secrecy of implanted data. Lined

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up with contemporary cryptographic prescribed procedures, this approach demonstrates especially reasonable for applications where secure sight and sound correspondence isn't only an inclination yet an objective.

The proficiency and adequacy of the AES scrambling philosophy are highlighted by its versatility to changing key lengths and the adaptability to change the quantity of encryption adjusts. This versatility permits the video steganography worldview to be finely tuned to explicit security prerequisites, finding some kind of harmony between powerful insurance and computational feasibility. In end, the mix of the AES scrambling strategy inside the video steganography worldview remains as a demonstration of cryptographic complexity. Through its symmetric key block figure design, SPN rounds, and dynamic utilization of the S-box, AES arises as a foundation in the making of a protected and versatile steganographic process. The purposeful thought of key length and encryption adjusts further lifts the general security act, settling on this worldview as a convincing decision for applications requesting an elevated degree of safety in sight and sound correspondence.

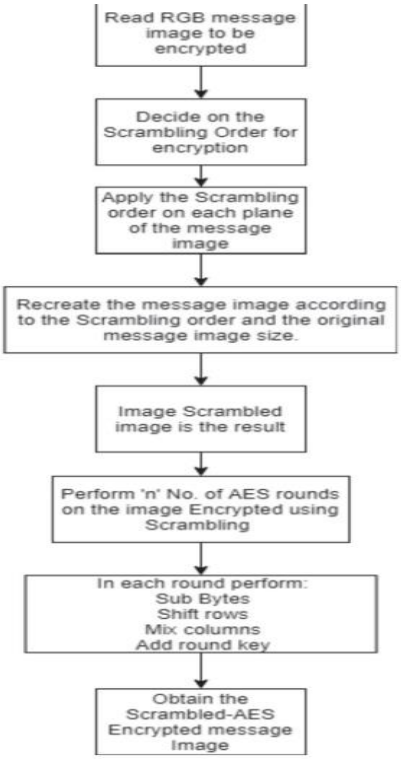

Figure 2: AES ENCRYPTION

III. FHSS EMBEDDING METHOD

Model and Material which are utilized is introduced in this part. Table and display ought to be in endorsed design. The FHSS (Recurrence Jumping Spread Range) implanting strategy, coordinated into the proposed video steganography worldview, means a leap forward in the domain of secure sight and sound correspondence. Its modern methodology, mixing cryptographic strength with dynamic recurrence regulation, renders it an imposing answer for impalpable and secure information transmission inside interactive media content [3]. Beginning from the space of remote correspondence conventions, FHSS separates itself through its one of a kind capacity to quickly and unusually shift frequencies inside a predefined range. This trademark bestows intrinsic obstruction against impedance and listening in, going with it a strong decision for shielding data transmission [7]. With regards to steganography, FHSS expects a job likened to a shrewd component, discreetly hiding data inside the complicated embroidery of video transfers. The all-encompassing goal is to accomplish subtle and secure information transmission, adjusting flawlessly with the essential objectives of steganography.

The FHSS inserting strategy unpredictably interlaces with the transient space of video outlines, using each edge as a powerful material for hiding payload data. In this many-sided process, each video outline turns into a unique substrate for recurrence tweak. The bouncing example, fastidiously synchronized between the source and beneficiary, guarantees lucidness, working with effective data recovery [9]. Nonetheless, the decision of

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jumping successions and stay times during the implanting system is not even close to inconsistent; it is administered by cryptographic contemplations. This purposeful intricacy is decisively intended to obstruct recurrence investigation assaults and improve the general power of the steganographic correspondence [12].

One important feature of the FHSS technique is that its sequences, which are produced using cryptographic methods, are pseudorandom. This characteristic strengthens the overall security of the steganographic communication by greatly adding to the unpredictable nature of the embedding process. Because of the thoughtful incorporation of cryptographic concepts, FHSS is more than just a means of hiding; it provides a strong defense against many kinds of analysis and possible assaults. Digging into the more extensive standards of spread range correspondence, the FHSS technique lines up with the purposeful spreading of the data signal across a more extensive transmission capacity. This purposeful spreading not just makes the sign safe against narrowband obstruction yet in addition improves its opposition against signal discovery [10]. The unique idea of recurrence jumping, described by fast and flighty changes between frequencies, invigorates the steganographic cycle against different types of sign investigation, making a considerable test for foes looking to block or control hidden data [6].

The security of the FHSS implanting technique is complicatedly connected to the careful plan of the bouncing arrangement and the synchronization components between the installing and extraction processes. The cryptographic strength of the pseudorandom number generator, shaping the reason for determining jumping designs, assumes a urgent part in guaranteeing the fundamental flightiness expected to obstruct assaults. Furthermore, the versatility of FHSS to fluctuating channel conditions and its vigor against sticking assaults add to its adequacy in the steganographic worldview [3] [7] [9] [10] [12].

The proposed video steganography structure incorporates a noteworthy approach using the FHSS implanting procedure. This approach reliably covers data inside the stochastic creation of video outlines through the use of dynamic recurrence hopping. The deliberate integration of cryptographic standards ensures robustness against many forms of analysis and attacks in addition to maintaining the security of the insertion system. A crucial advancement in the best in class for safe sight and sound communication, this intricate and creative methodology combines steganographic tactics with distant correspondence standards in a synergistic way. The FHSS approach introduces an astonishing solution for safe and intangible information transfer inside interactive media material, elevating the field of video steganography to new heights with its dynamic balancing and cryptographic foundations.

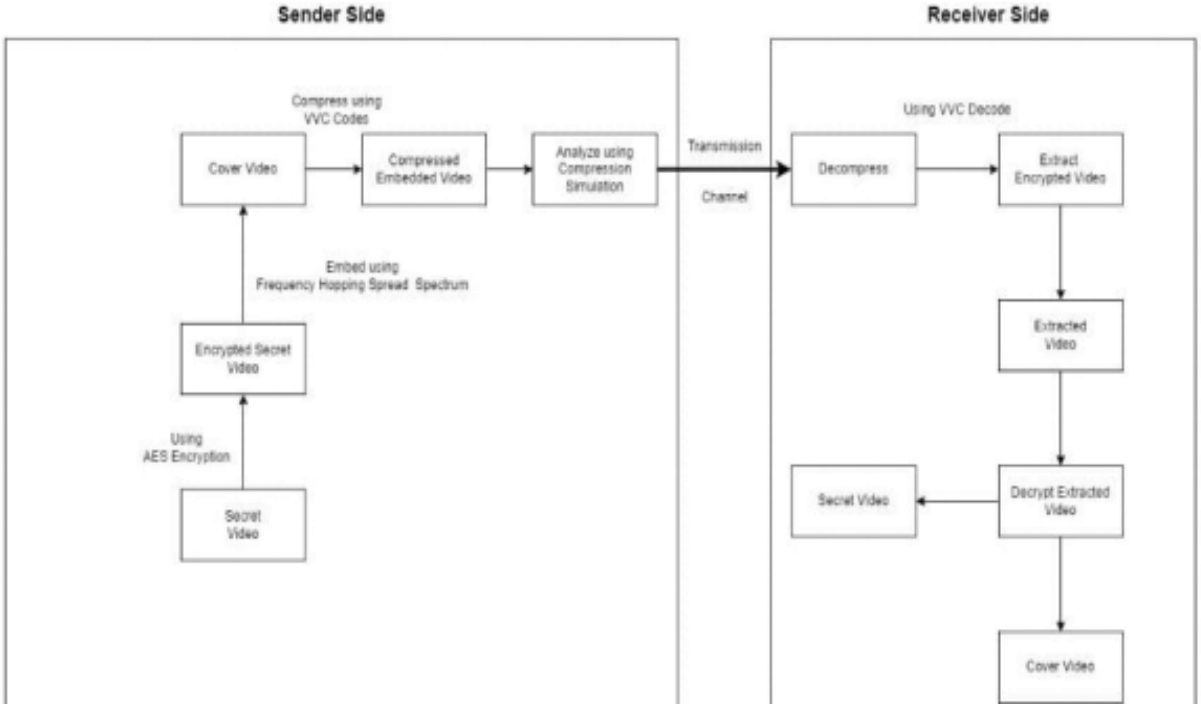

Figure 3: BLOCK DIAGRAM

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IV. VVC COMPRESSION TECHNIQUE

The proposed video steganography framework depends on the progressive Flexible Video Coding (VVC) strategy, which addresses a critical headway past its ancestors, including High Proficiency Video Coding (HEVC) [9]. VVC stands apart as the encapsulation of video pressure norms, integrating progressed encoding apparatuses and complex coding designs to accomplish wonderful pressure proportions while protecting perceptual video quality [11]. Its incorporation into the proposed framework serves not exclusively to improve data transmission use yet in addition as an establishment for implanting and removing disguised data inside the compacted video transfers. At its quintessence,

VVC utilizes a crossover coding approach, consistently coordinating conventional prescient coding and change coding strategies to take advantage of spatial and transient redundancies in video groupings [8]. Intra-outline coding depends on effective block forecast strategies, including intra expectation modes and refined change methods, guaranteeing insignificant overt repetitiveness inside individual edges [12]. The between outline coding use movement pay and refined forecast structures, further lessening transient redundancies across continuous casings [10]. This perplexing coding worldview brings about profoundly packed video portrayals that act as an optimal transporter for hid data.

The predominance of the VVC pressure method lies in its capacity to accomplish astounding pressure proficiency without compromising visual quality, settling on it an optimal decision for steganographic applications where keeping up with the trustworthiness of the cover media is principal [7]. The work of cutting edge devices, for example, quadtree-based block apportioning, versatile circle sifting, and effective entropy coding adds to the general adequacy of VVC in addressing video happy with uncommon constancy [6]. Besides, the fuse of in-circle sifting systems upgrades the evacuation of lingering redundancies, guaranteeing that the compacted video transfer fills in as a powerful and unnoticeable transporter for the implanted data.

In the domain of video steganography, the usage of VVC presents the two difficulties and open doors. Thought should be given to pressure initiated curios and the perceptual effect of installed information to accomplish impalpability. VVC's pressure strength, combined with its versatile quantization plans, gives an establishment to hiding data inside the packed space without essentially corrupting video quality [4]. Furthermore, the progressive design of VVC-coded bitstreams works with particular implanting inside unambiguous layers or locales of interest, empowering a flexible and versatile steganographic structure [5].

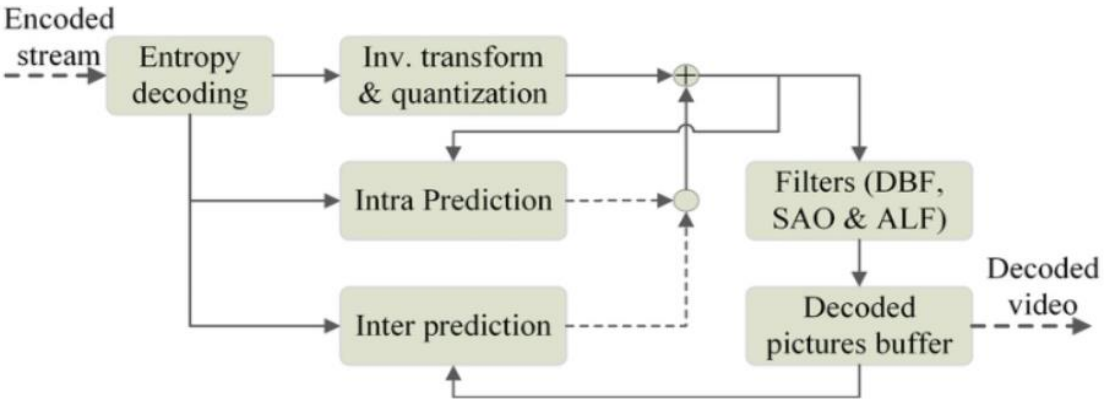

Figure 4: VVC BLOCK DIAGRAM

The consolidation of the VVC pressure strategy into the proposed video steganography framework addresses a change in perspective in utilizing cutting edge video coding principles for secure and proficient mixed media correspondence [3]. The high level pressure capacities of VVC, joined with its versatility and flexibility, position it as a key empowering influence for covering data inside compacted video transfers while keeping an elevated degree of perceptual quality [2]. This cooperative energy between cutting edge pressure strategies and steganographic philosophies opens new boondocks in secure media correspondence and data stowing away.

The previously mentioned fuse of the VVC to proposed Video Steganography model gives a proficient and smooth Steganography strategy that opens another presented approach which opens additional opportunities for data concealing in basic organization.

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V. SYNERGISTIC INTEGRATION OF AES, FHSS, AND VVC IN VIDEO STEGANOGRAPHY

Every one of the central matters of the examination work are written in this segment. Guarantee that the theoretical and the end shouldn't be the same. Chart and tables shouldn't use in that frame of mind of cryptographic sturdy High level Encryption Standard (AES) [1], Recurrence Jumping Spread Range (FHSS) [2], and the state of the art Flexible Video Coding (VVC) [3] inside the proposed video steganography structure lays out a complex mixture of techniques. This combination guarantees vigorous security and vague data installation. AES fills in as the fundamental layer, giving a protected balance to defending the secrecy and respectability of implanted data [4]. Working through key development and replacement stage network layers, AES utilizes productive encryption adjusts [10], making a considerable cryptographic safeguard against unapproved admittance to hid information.

Complementing AES, FHSS presents dynamic recurrence tweak, improving the framework's obstruction against capture and antagonistic assaults [6]. FHSS quickly switches transmission frequencies inside a predefined range, making it innately versatile to narrowband obstruction and snoopping endeavors. Represented by a pseudo-irregular recurrence jumping design produced by a safe key, the FHSS calculation presents an extra layer of cryptographic intricacy [9]. This intricacy sustains the framework's versatility against recurrence explicit assaults and unapproved signal investigation.

Pair with cryptographic protections, VVC improves the steganographic interaction by giving an effective and subtle transporter for encoded and recurrence bounced information [12]. VVC's high level pressure capacities empower the production of exceptionally reduced and outwardly dedicated portrayals of video content [11]. Its progressive bitstream association works with particular installing inside unambiguous layers or districts of the video, considering a flexible and versatile steganographic structure [5]. The pressure flexibility of VVC, combined with its versatile quantization plans, guarantees that disguised data stays indistinct inside the compacted video transfer [8].

The organization of AES [1], FHSS [2], and VVC [3] inside the video steganography worldview presents an imposing safeguard top to bottom procedure, where cryptographic vigor, recurrence variety, and pressure productivity unite to make a solid and secretive correspondence channel. This synergistic coordination presents a multifaceted security design, guaranteeing that regardless of whether one layer is compromised, the others keep on defending the respectability and classification of implanted data.

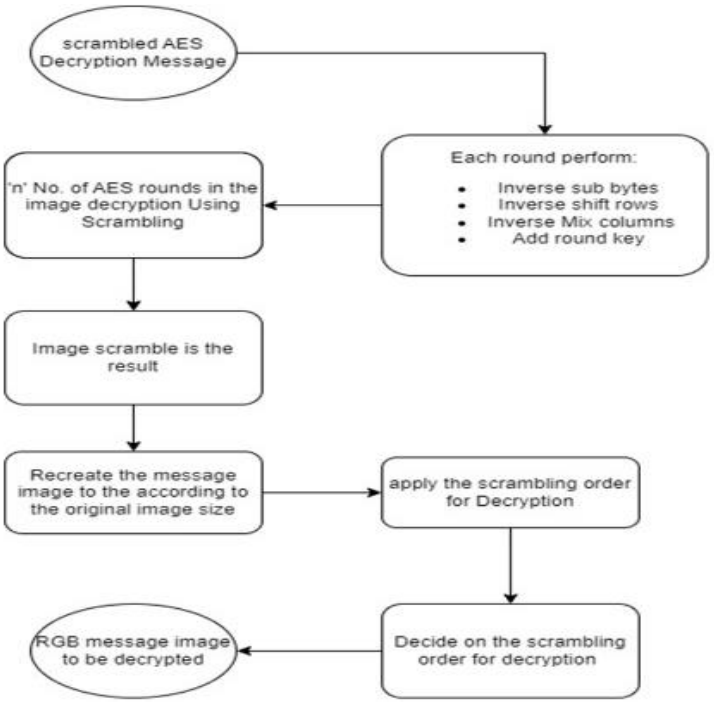

Figure 5: DECRYPTION PROCESS

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In outline, the synergistic blend of AES [1], FHSS [2], and VVC [3] in video steganography is a finished way to deal with managing secure and sensitive information embedding. The blend of cryptographic strength, repeat nimbleness, and tension adequacy reinforces the system against malevolent dangers while likewise working on the adaptability and assortment of the steganographic structure. This blend of state of the art improvements lays out a perspective for secure correspondence in which mystery, versatility, and imperceptibility join to make a powerful and current video steganography structure.

VI. EXPERIMENTAL SETUP AND SIMULATION PARAMETERS

The Validation of the proposed video steganography system, which incorporates AES, FHSS, and VVC, depends on the fastidious plan of the exploratory arrangement and reenactment boundaries. This coordinated reenactment climate guarantees controlled and reproducible testing situations, with cryptographic modules, for example, the AES encryption calculation [1] and FHSS recurrence jumping instrument [7], executed inside a protected territory to imitate true encryption processes. The computational framework, including elite execution processors and particular equipment gas pedals, works with the execution of computationally escalated cryptographic activities while sticking to standards of algorithmic loyalty and effectiveness [12].

Standardized video datasets, enveloping different substance types and goals, are utilized in the reenactment to copy sensible media situations [13]. The decision of these datasets lines up with standards of far reaching testing, empowering the assessment of the proposed system across shifting substance intricacies and goals. The recreation boundaries cover different encryption key lengths, regulation plans for FHSS, and pressure settings for VVC, giving a nuanced investigation of the structure's exhibition under assorted setups [9]. Recreation situations envelop controlled antagonistic circumstances, including channel disabilities, clamor, and shifting degrees of pressure antiquities, to survey the strength of the steganographic framework against reasonable difficulties. Throughput measurements, dormancy estimations, and spot blunder rates are fastidiously caught and examined to evaluate the effect of the proposed system on video quality and information installing proficiency [10]. The reenactment suite is intended for broad trial and error, guaranteeing factual importance and dependability in the appraisal of the steganographic structure's exhibition.

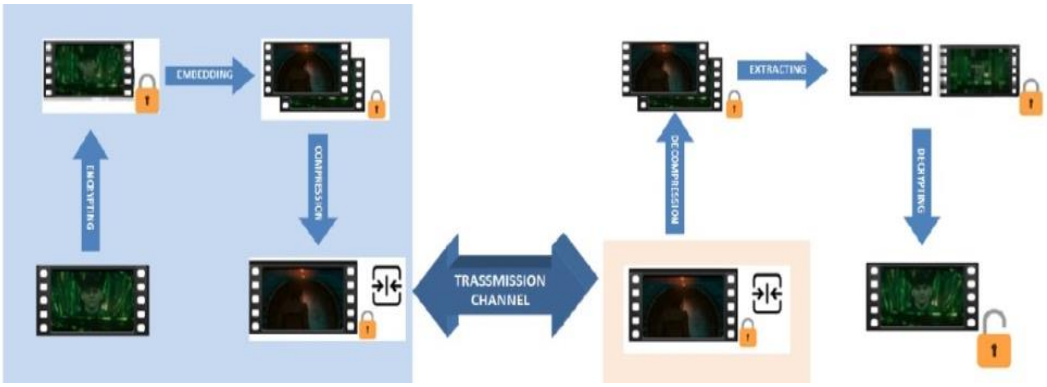

Figure 6: PROPOSED METHOD

Moreover, the recreation boundaries consolidate ecological factors, for example, signal engendering models, obstruction sources, and dynamic channel conditions, which reflect the intricacies of true correspondence circumstances. This expansive reenactment philosophy is lined up with the ideas of framework strength testing, permitting the structure to show viability over a great many functional situations. The blend of these mechanical perspectives frames the reason for an intensive and useful assessment, permitting sensible ends to be reached with respect to the capacities and limits of the proposed video steganography design.

In conclusion, the experimental setup and simulation parameters embody the scientific rigor essential for substantiating the claims and performance of the proposed video steganography framework. The orchestrated integration of cryptographic modules, standardized datasets, diverse simulation scenarios, and comprehensive metrics collectively contributes to a holistic evaluation, facilitating a nuanced understanding of the framework's behavior under varying conditions. This meticulous approach ensures the reliability and generalizability of the experimental outcomes, paving the way for informed decisions and advancements in the realm of secure and stealthy multimedia communication

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VII. PERFORMANCE EVALUATION AND SECURITY ANALYSIS

The robustness and efficacy of the integrated AES, FHSS, and VVC framework in video steganography are pivotal aspects evaluated through performance metrics aligned with established standards and cryptographic principles. The computational efficiency of the AES encryption module, adhering to NIST guidelines [1], serves as a benchmark, with metrics like throughput, latency, and processing overhead examined across various simulation scenarios. Concurrently, the FHSS frequency-hopping method undergoes detailed analysis, evaluating its impact on communication reliability, spectrum utilization, and resistance against interference, with metrics such as bit error rates and spectral efficiency scrutinized under dynamic channel conditions [7].

Security analysis encompasses a thorough examination of the cryptographic resilience of the entire framework, subjected to rigorous testing against known cryptographic attacks, including differential and linear cryptanalysis. The VVC compression technique's efficiency is intricately evaluated in terms of compression ratios, distortion metrics, and computational complexity, with a focus on achieving a delicate balance between high compression ratios and perceptual video quality under diverse compression settings.

The comprehensive evaluation extends to cover the steganographic framework's robustness against various attacks, including statistical analysis, watermarking detection, and visual quality assessment. Performance metrics such as Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSI), and perceptual hashing techniques contribute to an informed assessment of the proposed framework's viability in real-world applications. This multifaceted evaluation serves as a cornerstone for advancing the state-of-the-art in secure multimedia communication.

VIII. CHALLENGES AND FUTURE DIRECTIONS

The exploration of video steganography, leveraging the triad of AES, FHSS, and VVC, confronts multifaceted challenges across cryptographic intricacies, communication protocols, and multimedia compression. A pivotal challenge lies in the constant adaptation to evolving adversarial techniques, demanding ongoing refinement of encryption methods to thwart sophisticated attacks [6]. Adapting AES scrambling methods to resist quantum threats becomes paramount, necessitating research at the confluence of lattice-based cryptography and quantum-resistant primitives [4]. Moreover, the FHSS embedding method encounters challenges in dynamic communication environments, where rapid channel variations may compromise synchronization and reliable reception of steganographic data [2]. Addressing these challenges mandates a delicate balance between communication reliability and the imperceptibility of the embedded data, posing a nuanced problem in protocol design.

The integration of the VVC compression technique introduces its unique set of challenges, particularly in reconciling high compression ratios with the preservation of steganographic data integrity. Achieving a delicate equilibrium between efficient compression and secure data embedding becomes an intricate task, requiring advanced algorithms for adaptive compression based on the specific requirements of the steganographic payload [10]. Moreover, as VVC operates in the context of multimedia compression, there is a need for an in-depth examination of how different types of media, such as images and videos, impact the steganographic process and its resilience against detection [9].

Looking toward the future, the evolution of video steganography demands a comprehensive exploration of novel cryptographic primitives, beyond AES, capable of withstanding quantum computing advancements [5]. The FHSS method calls for innovations in dynamic spectrum allocation algorithms to enhance communication reliability amidst dynamic channel conditions [3]. Additionally, the symbiotic integration of steganography with emerging technologies, such as blockchain, offers intriguing possibilities for enhancing data integrity and secure communication [8]. The exploration of hybrid encryption schemes that amalgamate lattice-based cryptography, post-quantum primitives, and classical encryption methods may pave the way for heightened security in video steganography [1].

Future directions in VVC compression techniques involve delving into adaptive compression methodologies, leveraging machine learning algorithms to dynamically adjust compression settings based on the characteristics of the steganographic payload [7]. The exploration of explainable AI in the steganographic context becomes pertinent to comprehend the trade-offs between compression efficiency, data embedding

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security, and perceptual video quality. Furthermore, the steganographic framework's resilience against advanced machine learning-based steganalysis techniques necessitates ongoing research to fortify its defensive capabilities [11].

In conclusion, the challenges and future directions in video steganography underscore the intricate interplay of cryptographic resilience, communication robustness, and multimedia compression. The continuous evolution of adversarial techniques necessitates perpetual innovation, while the integration of emerging technologies and advanced encryption schemes charts the course for the future of secure multimedia communication.

IX. REAL-WORLD APPLICATIONS AND USE CASES

Real-world applications and use cases of video steganography extend across various domains, showcasing its versatility and practical significance in contemporary scenarios.

A. Secure Communication in Sensitive Environments

Video steganography finds application in secure communication within sensitive environments such as military and intelligence operations. Concealing critical information within video streams adds an extra layer of protection against interception, ensuring confidential communication.

B. Digital Watermarking for Copyright Protection

Video steganography is employed in the embedding of digital watermarks within multimedia content for copyright protection. By imperceptibly altering certain elements in the video, creators can embed ownership information, aiding in the identification and protection of intellectual property.

C. Covert Data Transmission in Law Enforcement

Law enforcement agencies utilize video steganography for covert data transmission during surveillance operations. Embedding information within video streams enables discreet communication and information exchange without attracting unwanted attention.

D. Medical Image Security and Privacy

In the healthcare sector, video steganography plays a role in securing medical images and videos. Patient data, diagnostic information, and sensitive medical records can be hidden within medical multimedia, ensuring privacy and compliance with healthcare regulations.

E. Digital Forensics and Anti-Piracy Measures

Video steganography serves as a tool in digital forensics, where investigators embed tracking information or hidden markers within videos to trace their origin and usage. This application aids in combating video piracy and unauthorized distribution.

F. Secure Video Conferencing and Telemedicine:

With the rise of remote communication, video steganography is applied in securing video conferences and telemedicine sessions. Embedding encryption keys or participant authentication data within video streams ensures the integrity and confidentiality of sensitive discussions and medical consultations

G. Cultural Heritage Preservation

Video steganography finds utility in cultural heritage preservation, where historical information, annotations, or metadata can be embedded within video recordings of artifacts, preserving valuable context and knowledge for future generations.

H. Journalism and Whistleblower Protection

In the realm of journalism, video steganography can be used to protect the identity of whistleblowers or sources by embedding information discreetly within video content. This adds an extra layer of security to investigative reporting.

I. Educational Content Protection

Video steganography is employed to protect educational content, such as online courses and tutorials. Watermarking or embedding identifiers within videos helps in tracking and preventing unauthorized distribution or use of educational materials.

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J. Authentication and Access Control

Video steganography serves as a tool for authentication and access control systems. In scenarios such as secure facility access, biometric information or access credentials can be embedded within video streams to enhance security measures

X. CONCLUSION

In conclusion, the multidimensional domain of video steganography, entwined with the intricate amalgamation of cryptographic resilience, communication robustness, and multimedia compression efficiency through AES scrambling, FHSS embedding, and VVC compression techniques, charts a compelling trajectory. The cryptographic robustness intrinsic to AES, rooted in lattice-based cryptography, establishes a foundational layer for safeguarding steganographic data against adversarial threats and presents avenues for further enhancement through the exploration of post-quantum cryptographic primitives [4] [10]. The FHSS embedding method, while encountering challenges in dynamic communication environments, emerges as a pivotal element in secure data transmission by dynamically adapting to channel conditions, ensuring reliable and covert communication [2]. Complementing these cryptographic and communication aspects, the VVC compression technique orchestrates a delicate balance between high compression ratios and secure data embedding, necessitating continual refinement [8].

As we cast our gaze into the future of video steganography, the challenges posed by evolving adversarial techniques propel a continuous exploration of novel cryptographic primitives beyond conventional AES, pushing the boundaries of resilience against quantum computing advancements [7] [10]. The symbiotic integration of steganography with emergent technologies, such as blockchain, introduces intriguing prospects for enhancing data integrity and secure communication [11]. This fusion of cryptographic robustness with technological innovation propels video steganography into the realm of heightened security, albeit with the ongoing imperative to fortify its defenses against emerging threats [6] [9].

Furthermore, the trajectory of VVC compression techniques unfolds towards adaptive methodologies, leveraging machine learning algorithms to dynamically optimize compression settings based on steganographic payload characteristics [12]. This convergence of explainable AI within the steganographic framework offers insights into the delicate trade-offs between compression efficiency, data embedding security, and perceptual video quality. The future landscape of video steganography also demands a nuanced exploration of the framework's resilience against sophisticated machine learning-based steganalysis techniques, driving ongoing research to fortify its defensive capabilities [9] [11].

In the tapestry of challenges and future directions, video steganography stands as a dynamic crucible, where cryptographic resilience, communication robustness, and multimedia compression converge. As we traverse the landscape marked by quantum-resistant cryptography, dynamic communication environments, and adaptive compression methodologies, video steganography emerges not only as a safeguard for secure data transmission but as a frontier for continual innovation and exploration in the realms of privacy-preserving communication and multimedia processing.

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