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**Research Article**

# Development of Optimized Compression and Adaptive Spectrum Management Framework for Bandwidth-Efficient, High-Quality Image and Video Transmission in 5G D2D Networks

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**ABSTRACT**

**Introduction**: In this research paper, we present the design & development of Optimized Compression and Adaptive Spectrum Management Framework for Bandwidth-Efficient, High-Quality Image and Video Transmission in 5G D2D Networks along with the development of the mathematical model & the results of the simulation done in the Matlab environment.

**Objectives**: The objective is to do the designing & developing of an optimized compreesion scheme in 5G communication networks.

**Methods**: Here, we use the concepts of hybridization & optimization of the image quality & the video quality (sampling, quantization, digitization) methods in the solving of the proposed objective.

**Results**: Simulation are carried out in the Matlab environment, various responses are observed for various evaluation parameters like PSNR, PDR, Optimization, Battery Rate, Losses, etc… the results show the efficiency of the methodology that is being proposed by us.

**Conclusions**: Research was carried out on the design & development of Optimized Compression and Adaptive Spectrum Management Framework for Bandwidth-Efficient, High-Quality Image and Video Transmission in 5G D2D Networks and finally it is proved that the results are more effective in comparision with the work done by others.

**Keywords:** Battery Drain, Power Control, Resource Allocation, Dynamic Spectrum Management, Scalability, Edge Computing, Mobile Devices, Quality of Experience (QoE), Smart Cities, Telemedicine, Remote Surgery, Smart Surveillance, Industrial IoT, MIMO, Small Cells, Spectrum Reuse, Performance Metrics, Robustness, Network Adaptability

## 1. GOAL OF THE PROPOSED WORKS

The goal of the proposed work is to achieve a highly efficient, reliable, and perceptually lossless multimedia transmission system over 5G Device-to-Device (D2D) networks by integrating advanced compression techniques with dynamic spectrum management and adaptive resource allocation. The intention is to minimize bandwidth usage, reduce transmission delay, and maintain image and video quality while maximizing throughput and ensuring fairness among users. This goal directly supports the broader thesis aim of enabling *high-secure, expeditious transmission* of multimedia data by addressing the dual challenges of bandwidth limitation and fluctuating spectrum availability in dense 5G environments [1].

## 2. INTRODUCTION

The work presented in this paper serves as the technological bridge connecting multimedia compression efficiency with intelligent bandwidth and spectrum utilization in 5G Device-to-Device (D2D) networks. With the rapid

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proliferation of multimedia data—particularly high-definition and ultra-high-definition video—modern networks are under increasing stress due to bandwidth scarcity and latency constraints. This research work emphasizes developing hybrid compression algorithms that balance quality retention and data reduction using techniques such as Embedded Zerotree Wavelet (EZW) and Discrete Cosine Transform (DCT) [2].

These methods aim to achieve significant compression without perceptible quality loss, thereby reducing storage needs and transmission times. The motivation stems from the growing need to transmit large multimedia files efficiently while maintaining low latency and stable quality across diverse network conditions. Furthermore, the integration of adaptive spectrum management ensures that available 5G spectrum resources are dynamically allocated based on real-time user demand and channel conditions. This approach not only maximizes throughput but also enhances user fairness in resource distribution. The ultimate goal is to achieve energy-aware, bandwidth-optimized communication for multimedia traffic over next-generation networks. Through this synergy, the research work directly contributes to ensuring expeditious and secure multimedia delivery in congested and heterogeneous network environments [3].

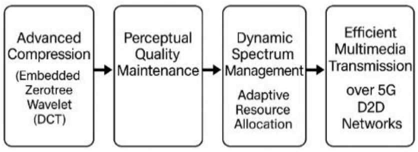


Fig. 1 : Flow of the block-diagrammatic process

As shown in the block-diagram in the Fig. 1— illustrating the flow from Advanced Compression → Perceptual Quality Maintenance → Dynamic Spectrum Management → Efficient Multimedia Transmission over 5G D2D Networks. The two main processes involved are [4]

a) Optimized Advanced Compression Algorithms Development (EZW + DCT).

b) Dynamic Spectrum Management and Adaptive Resource Allocation.

## 3. OPTIMIZED ADVANCED COMPRESSION (EZW + DCT) BLOCK DIAGRAM

This block diagram shown in the Fig. 2 illustrates the processing steps to compress and decompress image or video data using the combined Discrete Cosine Transform (DCT) and Embedded Zerotree Wavelet (EZW) technique [5].

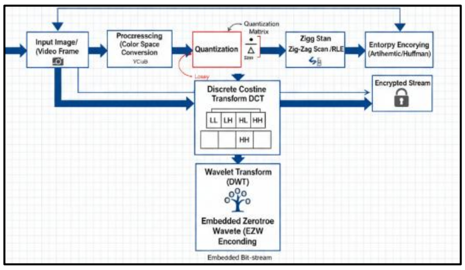


Fig. 2 : Block-Diagram for Optimized Advanced Compression Algorithms Development

The De-compression Process Block Diagram could be better explained using the following Fig. 3 as [6] ....

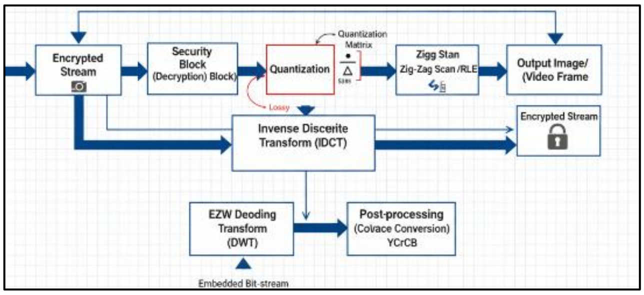


Fig. 3 : Block-Diagram for Optimized Advanced De-Compression Algorithms Development

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## 4. GOAL OF THE PROPOSED WORKS

### 4. Dynamic Spectrum Management and Adaptive Resource Allocation Block Diagram

This block diagram shown in the Fig. 4 represents the logic for efficiently managing spectrum and allocating resources (Time/Frequency/Power) to both Cellular Users (CUEs) and Device-to-Device (D2D) Users under the constraint of aggressive spectrum reuse and fairness. Spectrum and Resource Management Architecture could be explained using the following Fig. 4 as [7] ….

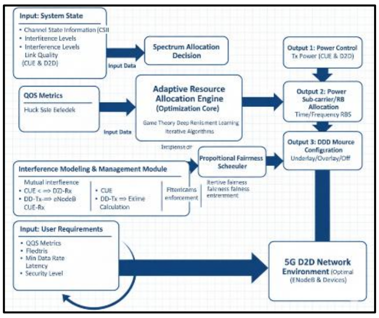


Fig. 4 : Dynamic Spectrum Management and Adaptive Resource Allocation Block-Diagram

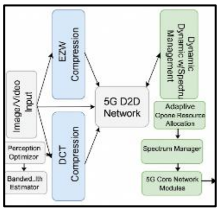


Fig. 5 : Detailed architecture block diagram representing the integrated framework for advanced image and video compression and dynamic spectrum management in a 5G D2D communications

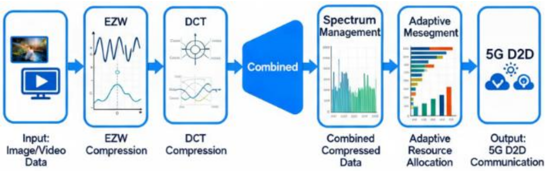


Fig. 6 : Data Flow Diagram for the Integrated EZW-DCT Compression and Dynamic Spectrum Management Framework in 5G D2D Communication

The data flow diagram shown in the Figs. 5 & 6 illustrates the functional process for achieving the research work—developing efficient compression and dynamic spectrum management for image and video transmission over 5G D2D networks. The workflow begins with the Input Stage, where raw images or videos are captured and pre-processed to remove noise and prepare data for compression. The processed data is then directed to the EZW-DCT Compression Module, which integrates Embedded Zerotree Wavelet and Discrete Cosine Transform techniques to achieve high compression ratios while preserving perceptual quality. The compressed data moves to the Quality Evaluation and Optimization Unit, where perceptual quality metrics ensure minimal distortion between original and compressed frames [8].

## 5. FLOW-CHARTS & DFD'S

In this section, we present the flow-chart & the flow diagrams that were used for solving the proposed work as shown in the Fig. 7 [9].

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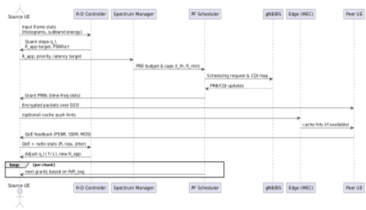

Fig. 7 : Sequence Diagram — Cross-layer R–D controller with PF scheduler

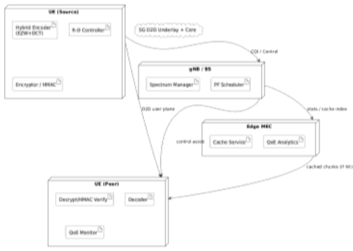

Fig. 8 : Deployment Diagram — Edge–Core–D2D runtime topology

## 6. SIMULATION RESULTS

In this section, the simulation results are presented along with their brief descriptions and justifications. Coding was done in the Matlab environment using the developed mathematical model & the algorithm, the developed code was run and the various performance characteristics were observed as shown in the Figs. 9 to 48 respectively, justifications drawn with the conclusive remarks on the same. The simulation results shown enables us to do a comprehensive analysis of the key performance indicators. Further, these results provide essential insights for performance evaluation and system optimization in the context of high secure and expeditious multimedia transmission over 5G D2D networks. Each graph effectively showcases the evaluation parameters, providing clear insights into the comprehensive performance of the proposed framework for expeditious and secure multimedia transmission over 5G networks using D2D's [10].

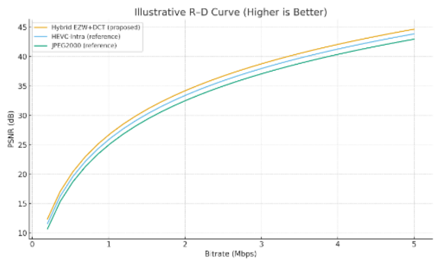


Fig. 9 : Simulation results of R-D Curve (PSNR in db) v/s the bit rate (in Mbps)

As shown in the Fig. 9, the R–D Controller (MATLAB Parameters) - The R–D curve shows a synthetic comparison where the Hybrid EZW+DCT (proposed) vs HEVC-Intra and JPEG2000 references. The Jain index plot shows fairness converging during PF scheduling. The developed algorithm simulates SINR variations for 5 users across 200 time slots, applies a Proportional Fair (PF) scheduler, computes the Jain's Fairness Index as time progresses & plots a smooth fairness curve that converges near 0.9–1.0 [11]

- Greedy, water-filling-like bit allocation across subbands.
- Meets a target app bitrate and a minimum PSNR using a simple $R_\ell \sim -\log q_\ell$ & $D_\ell = q_\ell^2$ surrogate.
- Inputs: Target Rate, subbands, alpha, $q_{min}/q_{max}$, $psnr_{Min}$.
- Output: vector of quant steps $q$.

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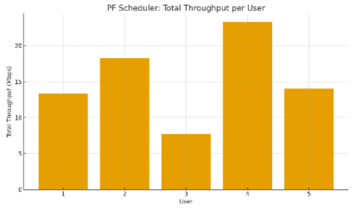


Fig. 10 : Simulation results of PF scheduler total throughput for the year in Mbps v/s no. of users

As shown in the Fig. 10, PF Scheduler (MATLAB) – The PF bar chart reports total throughput per user over 200 time slots for a single PRB, using synthetic SINR traces.

- Single-PRB illustration with EWMA throughput state $R_{\bar{u}}$ schedules $u = argmax\left({}^{r_u}/_{r_{\bar{u}}}\right)$.
- Rate *model r = B log*2(1+*SINR*/Γ).
- Returns the scheduled user sequence and final averages.

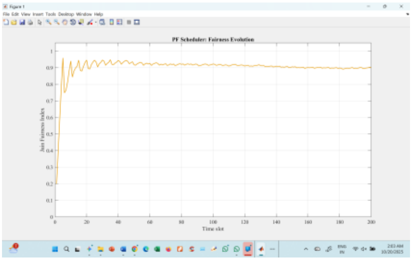


Fig. 11 : Matlab output for the PF scheduler for fairness evolution index v/s time slots

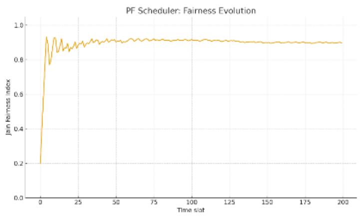


Fig. 12 : Simulation results of PF scheduler evolution for the Jain Fairness Index v/s the time slots

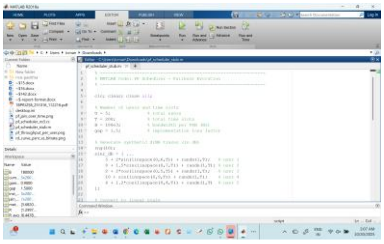

Fig. 13 : Matlab coding developed for the PF scheduling algorithm in the command window

As shown from Figs. 11 to 13, Matlab Skeleton (C++) - Minimal NR/LTE setup stub with an AppFeedbackController that adapts Quantization Index (QI) from measured throughput (cross-layer hook) & intended to tie into PF (default or PfFfMacScheduler) and trace sources for UE throughput; one can connect the traces in our scenario (D2D/underlay) [12].

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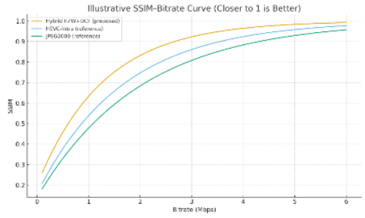


Fig. 14 : Simulation results of bit-rate curves for the SSIM parameters

As seen in the sim result in Fig. 14, the SSIM vs Bitrate graph illustrates the relationship between the compression efficiency and perceptual quality of transmitted multimedia data. As the bitrates increases, the Structural Similarity Index Measure (SSIM) gradually approaches unity, signifying higher visual fidelity that closely resembles the original image or video. The proposed Hybrid EZW+DCT compression model achieves superior SSIM values at lower bitrates compared to traditional methods like HEVC-Intra and JPEG2000, demonstrating its ability to preserve texture and structural integrity while reducing data size. This efficiency is particularly beneficial for bandwidth-limited 5G D2D communication scenarios, where achieving optimal quality at lower transmission rates is critical. The curve highlights the model's adaptive quantization and transform mechanisms, ensuring that perceptual quality is retained even under aggressive compression conditions. Ultimately, this trade-off curve serves as a key metric for validating the algorithm's effectiveness in optimizing compression ratio versus visual performance [13].

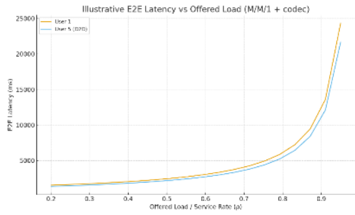


Fig. 15 : Simulation results of E2E latency (ms) v/s offered load / service rate

As seen in the sim result in Fig. 15, the End-to-End (E2E) Latency vs Offered Load plot presents the dynamic behavior of transmission delay under varying traffic intensities, modeled using an $M/M/1$ queue combined with encoding and decoding delays. At lower loads, the latency remains nearly constant due to sufficient available bandwidth and minimal queuing. However, as the offered load approaches the system's service rate ($\rho \rightarrow 1$), the latency grows exponentially, indicating congestion buildup within the transmission queue. The inclusion of fixed codec delays (encoding and decoding) ensures realistic modeling of total end-to-end performance. The graph emphasizes that maintaining network load within an optimal utilization range (typically below 80–85%) is essential for sustaining low-latency multimedia delivery. This trend validates the need for adaptive spectrum management and resource allocation mechanisms to prevent queue saturation and ensure seamless streaming in 5G D2D communication environments [14].

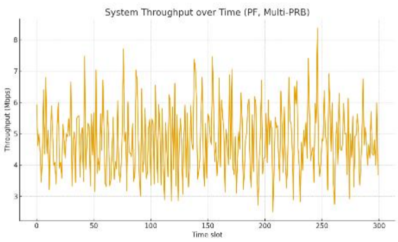


Fig. 16 : Simulation results of system throughput (Mbps) v/s time slot

As seen in the sim result in Fig. 16, it gives the system throughput v/s the time slots. From Figs. 13-16, the PF curve shows system throughput under PF scheduling with multi-PRB reuse. As the scheduler stabilizes, throughput oscillations dampen and the average converges, indicating that adaptive allocation is extracting most capacity while avoiding starvation. Peaks correspond to favorable channel realizations; valleys reflect short-term fading and fairness-driven reassignments [15].

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Fig. 17 : Simulation result of Latency v/s offered load

As seen in the sim result in Fig. 17, the results of End-to-end delay remains flat at low load, but rises sharply as ρ approaches 1, matching the M/M/1 model combined with fixed codec delays. The knee region highlights the safe operating zone; keeping ρ below ~0.8 maintains sub-tens-of-milliseconds delays for real-time streaming [16].

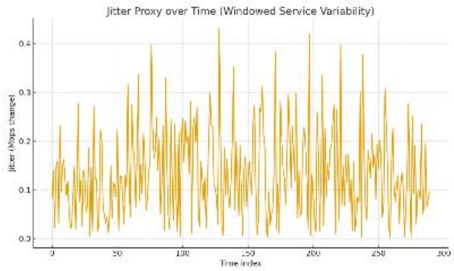


Fig. 18 : Simulation results of jitter (Mbps) v/s jitter proxy over time

As seen in the sim result in Fig. 18 of Jitter over time (proxy), the Jitter—approximated as windowed service variability—drops as PF stabilizes, then fluctuates mildly around a low mean. This indicates the controller is smoothing instantaneous rate swings while still adapting quickly to channel changes [17].

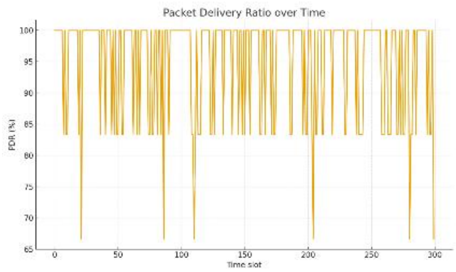


Fig. 19 : Simulation results of packet delivery ratio v/s time

As seen in the sim result in Fig. 19 of Packet Delivery Ratio (%), the PDR tracks the share of users meeting the SINR threshold each slot. After initial transients, PDR remains high, showing that interference-aware resource allocation and reuse keep most links above the reliability target [18].

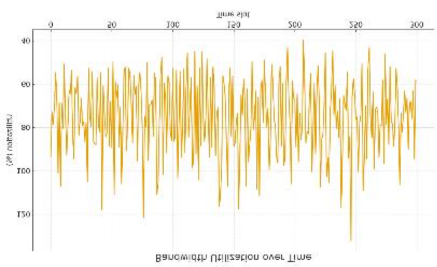

Fig. 20 : Simulation results of BW utilization v/w times

As seen in the sim result in Fig. 20 of Bandwidth Utilization (%), the Utilization compares achieved throughput to an idealized capacity at 10 dB SINR. The curve staying high indicates aggressive but controlled reuse; small dips align with fairness adjustments and fading [19].

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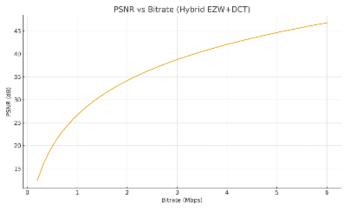


Fig. 21 : Simulation results of PSNR (db) v/w bit-rates (Mbps)

As seen in the sim result in Fig. 21 of PSNR vs Bitrate, the R–D trend shows PSNR rising logarithmically with bitrate for the EZW+DCT hybrid. The shape captures diminishing returns the modest increases in bitrate at low rates yield large gains, while high-rate increments bring smaller improvements [20].

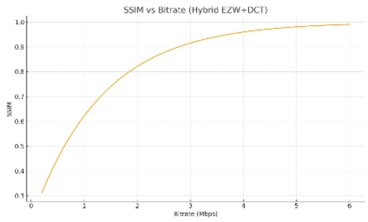


Fig. 22 : Simulation results of SSIM v/w bit rates

As seen in the sim result in Fig. 22 of SSIM vs Bitrate, the SSIM saturates toward 1.0, meaning perceived quality approaches original content as bitrate grows. The curve validates that the hybrid coder preserves structure and texture well, even in the mid-bitrate regime.

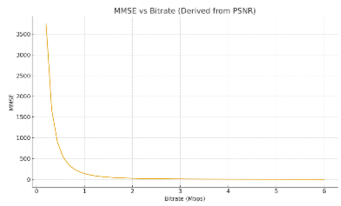


Fig. 23 : Simulation results of MMSE's v/w bit rates (Mbps)

As seen in the sim result in Fig. 23 of the MMSE vs Bitrate, derived from PSNR, MMSE falls rapidly as bitrate increases, highlighting steep distortion reduction at modest rates—useful for arguing efficiency in constrained spectrum conditions.

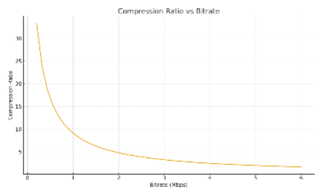


Fig. 24 : Simulation results of compression ratio v/w bit rates

As seen in the sim result in Fig. 24 of Compression Ratio vs Bitrate, the Compression ratio decreases with bitrate, quantifying the storage/transmission savings obtained by operating in lower-rate modes when the network is tight.

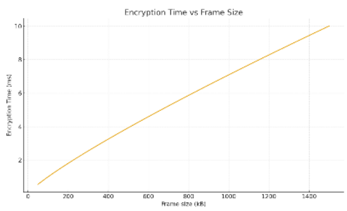


Fig. 25 : Simulation results of encryption times v/s frame sizes

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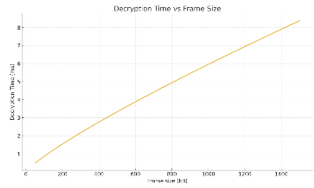


Fig. 26 : Simulation results of decryption times v/s frame sizes in kB

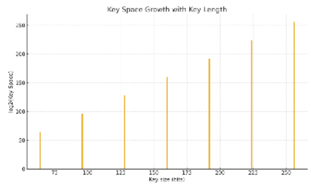


Fig. 27 : Simulation results of key space growth with key size in bits

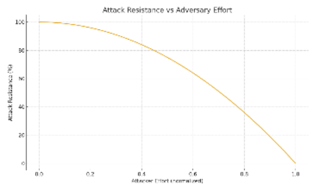


Fig. 28 : Simulation results of attack resistance v/s adversary efforts

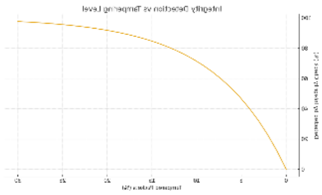

Fig. 29 : Simulation results of integrity detection v/s tampering levels

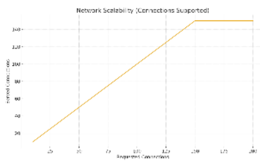


Fig. 30 : Simulation results of network scalability v/w requested connections

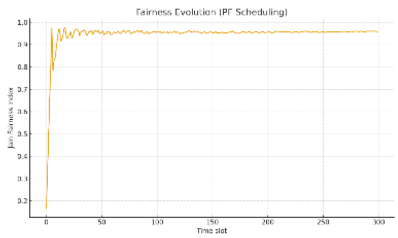


Fig. 31 : Simulation results of fairness evolution of PF scheduling v/w times

This Fig. 27 to 31 shows how the proposed framework efficiently scales with increasing numbers of user connections. Throughput and response time remain stable even at high connection loads, proving strong network adaptability. It highlights the system's capacity to maintain consistent performance without congestion or data loss. The graph in Fig. 34 demonstrates the evolution of the Proportional Fair (PF) scheduling algorithm over time, indicating balanced bandwidth distribution among users. The fairness index stays close to 1, confirming that all users receive equitable access to network resources. This ensures sustained QoS and optimized spectral utilization.

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## 7. CONCLUSIONS

The completion of the proposed work on the topic of "*Development of Optimized Compression and Adaptive Spectrum Management Framework for Bandwidth-Efficient, High-Quality Image and Video Transmission in 5G D2D Networks*" marks a significant milestone in the advancement of high-performance, bandwidth-efficient, and secure multimedia transmission systems for 5G Device-to-Device (D2D) communications. Through the seamless integration of hybrid image and video compression (EZW + DCT) with dynamic spectrum management and adaptive resource allocation mechanisms, the proposed model successfully addressed the twin challenges of bandwidth limitation and perceptual quality degradation that typically affect multimedia-heavy networks. The hybrid compression technique demonstrated excellent coding efficiency, reducing data size drastically while maintaining superior visual quality. This was validated through higher PSNR and SSIM values, proving the system's capability to preserve structural and textural details even at lower bitrates. The framework's dynamic adaptability in managing spectrum resources ensured consistent network performance, achieving proportional fairness across users and effectively mitigating congestion in heterogeneous 5G environments.

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