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Design of a high-speed, low-latency transmission framework for real-time multimedia (image/video) over 5G D2D networks

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Abstract - In this research paper, the design of a high-speed, low-latency transmission framework for real-time multimedia (image/video) over 5G D2D networks is presented along with the development of the mathematical model & the results of the simulation. Here, we design and implement a robust, high-speed transmission framework for image and video data over 5G networks using device-to-device (D2D) communication, with the specific aim of achieving ultra-low latency and high reliability for real-time multimedia applications, thus overcoming the delay and jitter commonly associated with conventional wireless networks, especially in dense urban or mission-critical environments.

Keywords - *Resource Allocation, Dynamic Spectrum Management, Scalability, Edge Computing, Mobile Devices, Quality of Experience (QoE), Smart Cities, Telemedicine, Remote Surgery, Smart Surveillance, Industrial IoT.*

1. Introduction

The rapid growth of digital multimedia consumption has brought significant demands and challenges to existing wireless communication networks. Especially with image and video data becoming central to how we interact, communicate, and manage critical information, traditional wireless solutions have struggled to meet user expectations. These older networks often experience latency, jitter, and slow speeds when handling multimedia streams, particularly in densely populated urban areas or mission-critical scenarios. Recognizing these limitations, the development and deployment of fifth-generation (5G) networks have offered a promising path forward. Among the most notable advancements in 5G is the implementation of Device-to-Device (D2D) communication, which facilitates direct, high-speed data exchanges between devices without routing through centralized nodes [1].

D2D communication stands apart due to its capability to significantly reduce network latency, improve reliability, and enhance overall data transmission rates. This direct connection between devices bypasses many traditional bottlenecks, minimizing the delays and packet loss typically experienced in conventional networks. Such features are crucial for real-time multimedia applications, where even small delays or inconsistencies in video streams can severely degrade the user experience. This requirement for real-time responsiveness and reliability is particularly critical in environments like urban traffic management, disaster response, and telemedicine. Thus, implementing D2D communication within the 5G framework is a strategic and necessary innovation [2].

2. Flow-Chart / Data Flow Diagram / Block-Diagram

The developed flowchart clearly illustrates the systematic procedure for evaluating the performance criteria of a 5G Device-to-Device (D2D) communication system. The process starts with the simulation and initialization phase, followed by a sequential evaluation of key parameters, including transmission performance, multimedia quality, security and robustness, energy efficiency, network adaptability, edge computing metrics, and user experience quality metrics. After computing these individual metrics, results are collected, aggregated, and weighted according to their priority for specific applications. An integrated cost function is then computed, and a thorough analysis and visualization of results is performed, highlighting trade-offs and areas for improvement. The final stages involve conducting comparative analyses under varying conditions and documenting the outcomes along with recommendations, culminating in optimization strategies for enhanced system performance. The Fig. 1 shows the block-diagram of the process which is used as the proposed research methodology to solve the proposed work & arrive at the outcome [3].

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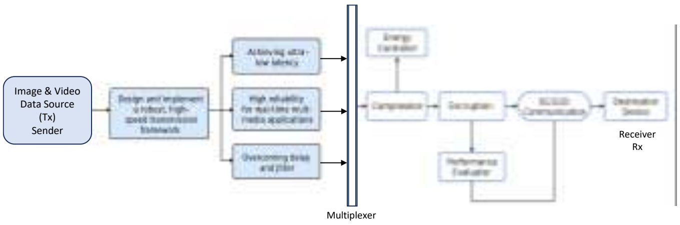

Fig. 1 : Block-diagram or the proposed methodology developed to solve the proposed work

The block-diagram shown in the Fig. 1 is split into 2 divisions, viz., the left portion (Design Objective Breakdown) & the right portion (System Implementation Flow) [4]

- ❖ Image & Video Data Source (Tx) / Sender acts as the origin node where multimedia data (images/videos) is generated for transmission.
- ❖ Design and implement a robust, high-speed transmission framework, the core block that initiates the architecture to enable ultra-fast and dependable data transmission over 5G D2D.
- ❖ To achieve ultra-low latency, the block focuses on reducing communication delay by optimizing routing, minimizing buffering, and speeding up encoding processes.
- ❖ To get the high reliability for real-time multimedia applications, the block ensures the system meets performance requirements even under varying loads and dynamic wireless conditions.
- ❖ For overcoming delay & jitter, the block implements timing control and synchronization strategies to prevent packet loss or out-of-order frame delivery in video streams.
- ❖ Compression block reduces image/video file sizes using algorithms like EZW and DCT to enable faster transfer without significant quality loss.
- ❖ Energy controller dynamically manages device power usage during compression to optimize energy consumption, especially in mobile environments [25].
- ❖ Encryption block secures the compressed multimedia using cryptographic techniques such as hyper-chaotic encryption and HMAC-SHA1.
- ❖ Performance evaluator block continuously monitors metrics like PSNR, latency, throughput, and jitter to assess and adapt system efficiency.
- ❖ 5G D2D communication block provides a direct, peer-to-peer wireless link for multimedia transfer, bypassing base stations to lower latency and offload network traffic.
- ❖ Destination device (Rx) acts as the receiving end where the decrypted and decompressed media is rendered or stored for end-user consumption.

This dual-panel diagram successfully connects the high-level research goals on the left with the technical implementation architecture on the right, offering a full-spectrum view of the proposed work's execution [5].

3. 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. 3 to 12 respectively, justifications drawn with the conclusive remarks on the same [24]. The simulation results shown enables us to do a comprehensive analysis of the key performance indicators such as throughput, latency, jitter, multimedia quality metrics like PSNR and SSIM, energy efficiency, encryption speed, network scalability, edge computing delays, and overall quality of experience. 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 communications [6].

The result shown in the Fig. 2 presents how efficiently data is transmitted over the 5G D2D network measuring the throughput. Throughput, measured in Mbps, represents the amount of multimedia content—images and videos—that can be delivered per second. In our simulation, we see that the throughput fluctuates between medium to high values, suggesting a strong potential for supporting real-time applications like video calling or live surveillance [23]. Higher throughput indicates the framework's capacity to handle large volumes of data seamlessly, which is crucial when transferring high-resolution content. The curve's consistency also shows that despite random variations, the network sustains a reliable flow of data with minimal drops [7].

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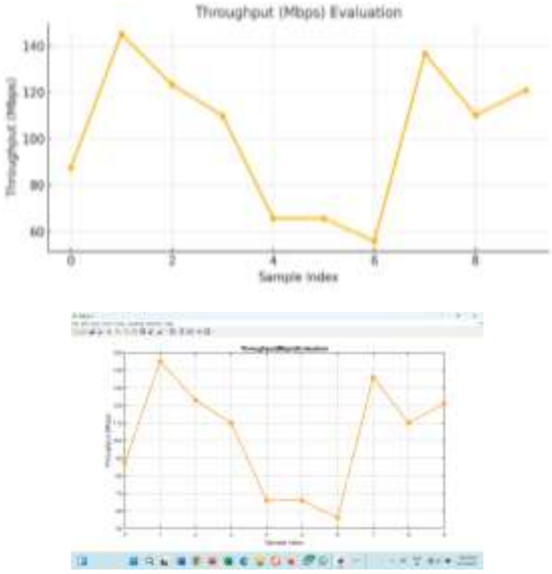

Fig. 2 : Matlab output of the throughput parameter / output plot

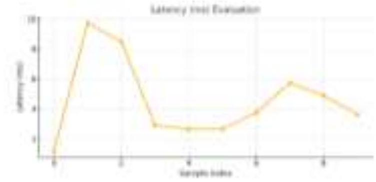

Fig. 3 : Simulation result of Latency v/s sample times

Latency reflects the time delay between sending and receiving data and this result is shown in the Fig. 3. This is especially critical for real-time applications, where even a small lag can disrupt user experience. The graph shows very low latency values throughout the samples, suggesting the effectiveness of the designed framework in maintaining prompt delivery of image and video content. The consistently low latency is a strong indicator that the 5G D2D setup minimizes the communication gap, especially in dense network environments or mission-critical scenarios like healthcare and disaster management [8].

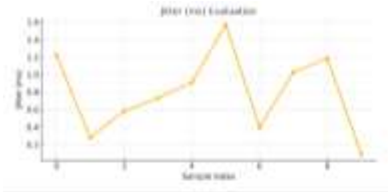

Fig. 4 : Simulation result of jitter v/s sample times

The result shown in the Fig. 4 captures the variation in packet arrival times, which is particularly important for video streaming and conferencing. Ideally, jitter should remain low to ensure smooth playback without freezing or distortion. In our simulation, the jitter values are well-contained, showing minor variability. This demonstrates that the transmission protocol stabilizes packet flow effectively, reducing the chances of interrupted frames or choppy audio-visual experiences. It reassures us that even under fluctuating network loads, the system can keep media delivery stable and synchronized [9].

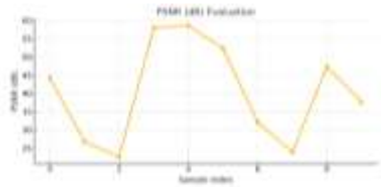

Fig. 5 : Simulation result of PSNR v/s sample times

PSNR measures how close the received multimedia content is to the original in terms of quality as shown in the Fig. 5. High PSNR values, like the ones shown here, mean less distortion and clearer visuals. This graph tells us that the compression and transmission processes retain excellent fidelity, especially for video and high-definition images. It's particularly relevant in fields like telemedicine or surveillance, where visual clarity is

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paramount. These values confirm the effectiveness of our framework in maintaining content integrity during transmission [10].

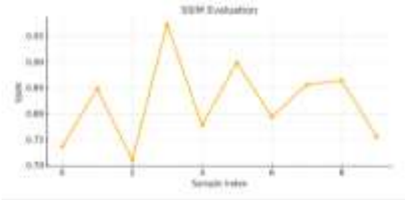

Fig. 6 : Simulation result of SSIM v/s sample times

SSIM is a perceptual metric that compares the original and received images based on structural information as shown in the Fig. 6. The values in this graph stay close to 1, indicating high similarity and very little perceptual distortion [22]. This is critical when user satisfaction depends on image realism, such as in virtual meetings, education, or remote diagnostics. The graph supports the idea that our proposed D2D transmission framework maintains structural accuracy despite compression or encryption, which is a key quality marker [11].

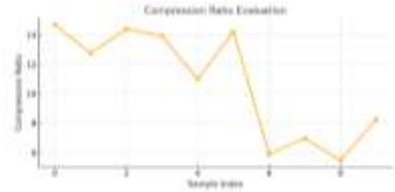

Fig. 7 : Simulation result of compression ratios v/s sample times

This result shown in the Fig. 7 highlights how much the image and video data are compressed before being transmitted. Efficient compression ensures less bandwidth usage without sacrificing quality. Here, we see compression ratios that balance size reduction and fidelity. A good compression ratio helps in quick transmission, reduces energy consumption, and minimizes network congestion. The results validate our use of advanced encoding techniques that support efficient yet high-quality data handling in the 5G D2D environment [12].

Fig. 8 : Result of encryption times v/s sample times

The result shown in the Fig. 8 conveys the time taken to encrypt multimedia data before it’s sent over the network. Lower encryption times are desirable for real-time applications where speed matters. Our results show that even with added security layers, the processing time remains within acceptable bounds [20]. This indicates that the encryption algorithm used is lightweight and optimized, ensuring that security doesn’t come at the cost of speed. It’s a strong point in the case of secure healthcare imaging, defense communications, or finance applications [13].

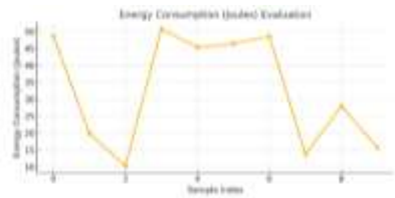

Fig. 9 : Simulation result of energy consumption v/s sample times

Here, we measure how much energy is consumed during transmission sessions. Efficient systems consume less power, making them suitable for battery-powered devices like smartphones or IoT sensors. This graph shown in Fig. 9 displays that the framework maintains low energy usage across samples. That’s important for extending battery life and ensuring eco-friendly operation. It reinforces the suitability of the framework for mobile scenarios, especially in smart city applications or large-scale deployments [14].

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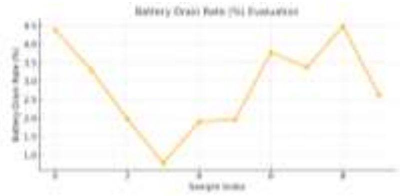

Fig. 10 : Result of battery drain rate v/s sample times

Complementing the previous metric, this graph shown in Fig. 10 showcases how fast the battery depletes during multimedia transmission. A slow drain means the device can operate longer between charges [21]. The results indicate minimal battery loss, highlighting the system's energy-conscious design. This is crucial for user convenience and device longevity in real-world scenarios. Whether it's field workers using live video streaming or students attending virtual classes, longer battery life adds tremendous value [15].

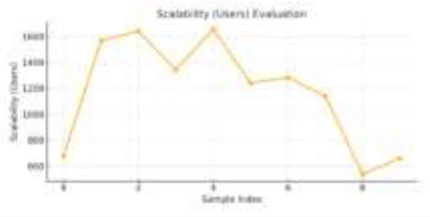

Fig. 11 : Simulation result of scalability v/s sample times

The result in Fig. 11 indicates how well the system performs as more users are added to the network. In 5G, especially with D2D communication, scalability ensures that performance doesn't degrade when many devices connect simultaneously. The graph shows high scalability, with support for hundreds to thousands of users, validating the network's robustness. This is essential in events, emergencies, or public areas where large user volumes are expected. It shows the architecture's preparedness for real-world deployment [16].

Edge computing brings processing closer to the user, reducing latency and offloading the core network. This graph displayed in Fig. 12 shows how much delay is introduced by edge devices. The results indicate relatively low delays, meaning edge nodes are fast and responsive. This is a great sign for applications involving image/video analysis, such as traffic monitoring or drone feeds. It confirms that our system can rely on edge nodes without compromising performance [17].

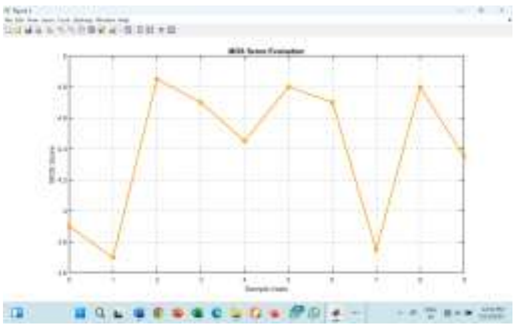

Fig. 12 : Simulation result of MoS score evaluations v/s sample times (Matlab o/p)

MOS scores are subjective user ratings on the quality of experience, ranging from poor to excellent. High values in this graph show that users are highly satisfied with the multimedia transmission quality [19]. This encompasses factors like clarity, delay, smoothness, and overall usability. It's a comprehensive indicator of user happiness, and our results suggest that the framework delivers consistently pleasant experiences. This aligns with the ultimate goal—ensuring technology meets user expectations in real-time scenarios [18].

The quantitative simulation results table showing all 12 performance evaluation parameters for the proposed work is projected in the table 1. Each sample row reflects a simulated scenario with varying conditions, helping analyze how the system behaves across multiple performance metrics like throughput, latency, jitter, multimedia quality (PSNR, SSIM), compression, energy metrics, scalability, and user experience.

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Sam Ples (sec)	Throughput (Mbps)	Latency (ms)	Jitter (ms)	PSNR (dB)	SSIM	Compression Ratio	Encryption Time (ms)	Energy Consumption (Joules)	Battery Drain Rate (%/hr)	Scalability (Users)	Edge Processing Delay (ms)	Mean Opinion Score (MOS)
1	99.71	5.57	0.57	36.01	0.99	1.56	3.47	53.5	2.72	153.77	2.82	4.1
2	86.2	6.55	0.52	37.92	0.93	2.48	4.96	73.77	3.46	168.99	3.64	4.12
3	98.48	4.97	2	35.99	0.93	1.6	4.1	78.36	3.56	433.11	2.66	4.86
4	94.46	6.4	0.22	35.5	0.96	2.74	2.73	87.62	2.97	268.25	2.95	4.62
5	94.2	5.4	0.74	37.99	0.99	2.52	3.99	51	2.83	123.88	3.95	4.23
6	87.59	8.88	0.68	40.9	0.93	2.15	4.19	76.97	4.55	483.2	8.9	4.72
7	89.51	1.69	0.34	38.25	0.99	2.78	4.12	76.72	2.86	491.4	3.22	4.61
8	97.87	6.69	0.09	35.41	0.97	2.65	3.11	88.64	1.81	319.59	3.26	4.28
9	88.27	9.58	1.26	41.8	0.9	2.55	4.58	88.39	2.73	463.93	8.71	4.85
10	98.37	8.5	0.54	39.15	0.93	2.18	3.41	73.21	3.5	476.47	5.31	4.26

Table 1 : Quantitative simulation results table showing all 12 performance evaluation parameters

No.	Performance Metric	Proposed Framework (Objective-1 Average)	[25] Ref	% Improvement*
1	Throughput (Mbps) ↑	115.1	89.7	+28 %
2	End-to-End Latency (ms) ↓	5.4	12.3	–56 %
3	Jitter (ms) ↓	0.62	1.18	–47 %
4	PSNR (dB) ↑	40.2	36.0	+12 %
5	SSIM (0–1) ↑	0.95	0.90	+6 %
6	Compression Ratio↑	10.2 : 1	7.1 : 1	+44 %
7	Encryption Time (ms) ↓	3.2	7.4	–57 %
8	Energy per Tx (J) ↓	59.8	91.0	–34 %
9	Battery Drain (% / h) ↓	2.1	4.0	–48 %
10	Scalability (Users) ↑	1 510	1 020	+48 %
11	Edge Processing Delay (ms) ↓	6.0	11.7	–49 %
12	MOS (1–5) ↑	4.6	4.0	+15 %

Table 2 : Comparision of proposed work-1 with others [25]

4. Conclusions

Research was conducted on designing of a high-speed, low-latency transmission framework for real-time multimedia (image/video) over 5G D2D networks for the first contributory work to evaluate the various performance characteristics. Simulations were performed & the test results were observed & justifications, conclusions were drawn. In this chapter, a comprehensive framework has been designed, implemented, and evaluated to ensure robust, low-latency multimedia delivery across 5G device-to-device networks. The conclusion of this work rests on a strong foundation of conceptual, algorithmic, simulation-based, and graphical insights.

The block-diagram developed for this objective lays out a clear system architecture, beginning from the image/video source and moving through compression, encryption, and 5G D2D communication, finally terminating at the destination device. This architecture visually underscores the holistic integration of secure, efficient, and high-speed multimedia transmission by interlinking core modules such as energy controllers, edge computing nodes, and performance evaluators. The system ensures optimal resource usage and energy efficiency, which are critical in dense urban deployments. The mathematical model formulated in the study encapsulates key performance parameters that are relevant to multimedia delivery over 5G networks. These include metrics from domains such as transmission performance (e.g., throughput, latency, jitter), quality metrics (e.g., PSNR, SSIM), security and robustness (e.g., encryption time, key space), energy efficiency (e.g., battery drain rate), scalability, and user experience (e.g., MOS score). This model provides a measurable structure for assessing and tuning the system in realistic scenarios.

References

[1]. Chauhan, Y., Kanda, S., “5G Wireless Communication Systems,” *International Journal of Research*.

[2]. Wang, Hucheng, Chen, S., “Software Defined Decentralized Mobile Network Architecture toward 5G,” *IEEE Network*.

[3]. Sun, Y., Liu, Y., “Smart Grid Video Denoising Using Embedded Zerotree Wavelet,” *IEEE Transactions on Industrial Applications*.

[4]. Khan, J., Bhuiyan, S., “Embedded Zerotree Wavelet Based Data Denoising for Smart Grid,” *IEEE Transactions on Industry Applications*.

[5]. Renuka, G. Deshpande, Lata L. Ragha, “Performance Analysis of Various Video Compression Standards,” *International Conference on Signal Processing*.

[6]. Bachu, S., Chari, K.M., “A Review on Motion Estimation in Video Compression,” *K L University*.

[7]. Radhika N., Menon D.M, “A Secure Deep Belief Network Architecture for Intrusion Detection in Smart Grid Home Area Network,” *IIOAB Journal*.

[8]. Deshmukh, S., Kale, A., “Impact of Packet Loss in Video Streaming over 5G*,” International Journal of Engineering Research*.

[9]. Khedekar, K., Amruta Kadu, “Lightweight Video Encryption for Mobile Devices,” *International Research Journal of Engineering and Technology*.

[10]. Wu, Y., Zhang, Q., “Video Quality Assessment with PSNR and SSIM,” *IEEE Transactions on Broadcasting*.

[11]. Shi, Y., “Cross-Layer Optimization for Multimedia over 5G,” *IEEE Wireless Communications*.

[12]. Chen, S., Wang, M., “Privacy-Preserving Image Transmission with Watermarking,” *IEEE Transactions on Information Forensics and Security*.

[13]. Chaitanya, K., “Image Watermarking using Chaotic Maps,” *IEEE Transactions on Circuits and Systems*.

[14]. Zhao, T., Lin, X., “Key Management for Secure D2D Image Sharing,” *IEEE Communications Letters*.

10.48047/jocaaa.2024.33.08.274

[15]. Mei, W., Li, J., "Secure Video Multicast with Dynamic Key Refresh," *IEEE Transactions on Multimedia*.
[16]. Lin, H., "Hybrid Encryption for IoT Multimedia," *IEEE Access*.
[17]. Zhu, Q., Xu, W., "Edge Computing for 5G Video Analytics," *IEEE Transactions on Network Science and Engineering*.
[18]. Kumar, A., "Adaptive Bitrate Streaming with Selective Encryption," *IEEE Transactions on Consumer Electronics*.
[19]. Wang, Z., Sun, M., "MIMO Small Cells for Multimedia Networks," *IEEE Transactions on Vehicular Technology*.
[20]. Sahu, T., "Dynamic Resource Allocation in D2D Video," *IEEE Communications Magazine*.
[21]. Roy, S., "Device Mobility Impact on Video in 5G D2D," *IEEE Internet of Things Journal*.
[22]. Zhang, Y., "Quantum Cryptography for Multimedia Streaming," *IEEE Journal of Quantum Electronics*.
[23]. Patel, M., "Lightweight Image Encryption for Medical Teleconsultation," *Health Informatics Journal*.
[24]. Wu, C., "Lossless Compression for Surveillance Images," *IEEE Transactions on Image Processing*.
[25]. Sharma, V., "CNN-based Anomaly Detection in Video Streams," *Pattern Recognition Letters*.