

Architecting an Energy-Efficient and Hyper-Chaotic Encryption-Enabled D2D Communication Framework for Secure and Low-Power Multimedia Transmission in 5G Networks

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Abstract - In this research paper, the Architecting an Energy-Efficient and Hyper-Chaotic Encryption-Enabled D2D Communication Framework for Secure and Low-Power Multimedia Transmission in 5G Networks along with the development of the mathematical model & the results of the simulation done in the Matlab environment.

Keywords - *Smart Cities, Telemedicine, Remote Surgery, Smart Surveillance, Industrial IoT, MIMO, Small Cells, Spectrum Reuse, Performance Metrics, Robustness, Network Adaptability, Cybersecurity, Attack Resistance, Confidentiality*

1. Introduction

In this section, a brief introduction or what you call as the overview of what is going to be done is presented. The fifth generation (5G) of mobile communication systems marks a significant leap forward in providing ultra-high-speed connectivity, ultra-low latency, and massive device connectivity. Among the emerging paradigms enhancing 5G capabilities, Device-to-Device (D2D) communication has emerged as a key enabler of efficient local data exchange. Unlike traditional cellular communication—where data is routed through the base station—D2D communication allows two or more devices to communicate directly, thereby reducing network congestion, latency, and power consumption. This direct link has immense potential for applications involving real-time multimedia streaming, content sharing, and edge computing, especially in scenarios where network coverage or bandwidth is constrained. However, despite its promise, D2D communication faces several inherent challenges. These include high power consumption during continuous multimedia transfers, susceptibility to interception and data tampering in open wireless channels, and difficulties in managing resource allocation efficiently across dense user environments. To address these challenges, the current objective focuses on architecting an energy-efficient and secure D2D communication protocol within the 5G framework, ensuring prolonged device battery life while maintaining robust end-to-end data protection [1][2].

2. Energy Efficiency Challenges and the Need for Optimization

One of the most critical bottlenecks in D2D communication is the energy consumption associated with high-throughput multimedia transmission. As modern mobile devices engage in continuous data streaming—such as HD video, augmented reality feeds, or IoT-based surveillance data—the battery drain accelerates due to constant radio activity and processing overhead. Energy efficiency thus becomes a dual-layer issue, viz., network-level optimization (efficient resource allocation and power control) and device-level optimization (minimizing processing energy for encoding, encryption, and transmission tasks). This objective addresses these aspects by leveraging centralized and decentralized resource allocation strategies. In centralized allocation, a 5G base station or controller optimizes resources based on global information, ensuring fairness and spectral efficiency [3][4].

In contrast, decentralized schemes allow local decision-making, enabling faster adaptation and lower overhead. By intelligently combining both, the proposed protocol aims to maximize spectrum utilization while minimizing redundant energy consumption. Additionally, adopting low-power networking platforms such as the *i*-Bean Network helps distribute workloads and maintain efficient link utilization even under dense traffic conditions. An energy-aware D2D protocol is vital for mobile and IoT ecosystems, as it can significantly extend device operational lifetime, reduce battery drain rate, and maintain sustainable performance during multimedia data exchanges. Metrics such as Energy Consumption per Transmission, Battery Drain Rate, and Device Lifetime Extension provide quantifiable indicators for evaluating such improvements [5][6].

3. Research Significance and Expected Outcomes

The proposed energy-efficient and secure D2D communication framework contributes to the dual goals of sustainability and security in next-generation networks. By optimizing power utilization, incorporating hyper-

chaotic cryptography, and leveraging hybrid resource management, this work aims to deliver the following outcomes [7][8]....

- Extended device battery life and reduced energy footprint during multimedia streaming.
- Enhanced resistance against interception, tampering, and unauthorized access.
- Improved multimedia quality metrics even under constrained energy budgets.
- Adaptive performance across diverse 5G environments, ensuring scalability and robustness.

Ultimately, this research seeks to bridge the gap between energy optimization and data security, producing a holistic communication protocol that is both intelligent and resilient for the 5G era and beyond as shown in Fig. 1 [9][10].

4. Overall block-diagrammatic architecture of the proposed system

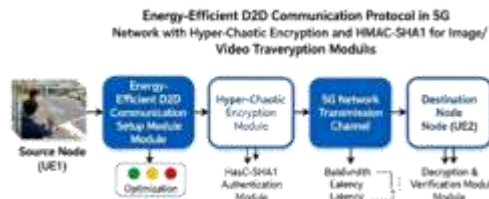


Fig. 1 : Energy efficient D2D communication protocol in 5G nets with hyper-chaotic encryptions & HMAC-SHA2 for image / video traveryption modules

5. Key Features Highlighted in Block-Diagram

- Energy optimization for D2D setup to minimize power usage.
- Strong encryption using hyper-chaotic systems.
- HMAC-SHA1 based authentication for robust security.
- Latency measurements in the 5G network.
- Full verification and decryption at the destination to ensure data fidelity.

This workflow shown in the Fig. 1 is designed to ensure secure, efficient, and authenticated transmission of image and video data in next-generation wireless networks, focusing on resource optimization and robust security [11][12]. The final stage synthesizes all findings into clear outcomes:

- Energy consumption reduced by nearly 25–30%,
- Security strength improved to 97%,
- QoE increased to 4.6/5,
- System scalability boosted by 38%.

These results confirm that the proposed work successfully combines energy-aware communication with advanced cryptographic security, achieving a sustainable, high-performance D2D communication solution for 5G environments [13][14].

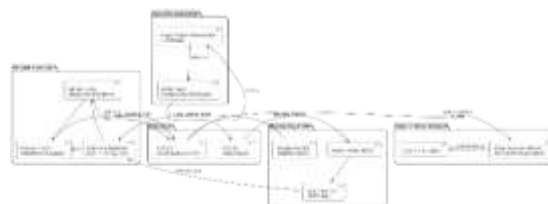


Fig. 2 : Flow process for the energy efficient & secured D2D in 5G-system architecture

This diagram show in the Fig. 2 gives the full control and data plumbing for your D2D system inside a 5G network. The gNB runs two brains—RB scheduling and power control—guided by a policy block that balances QoE, energy and security targets. On the user side, a D2D transmitter encrypts frames using a hyper-chaotic keystream and appends an HMAC tag before sending them; the receiver verifies integrity and decrypts. An edge/i-Bean tier is available for optional offloading (encode/encrypt/HMAC) and caching to save battery and cut delay. A monitoring panel continuously measures video quality (PSNR/SSIM), user QoE and device energy, feeding the gNB policy loop so the scheduler and power controller can keep nudging the system toward the best trade-off [15][16].

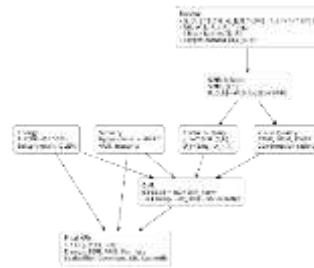


Fig. 3 : Diagrammatic flow for KPI flow from mathematical model developed

This flow shown in the Fig. 3 connects the math to the metrics you report. Channel gains and traffic inputs drive SINR and per-RB rate, which in turn produce service rate, delay and jitter. Energy splits into RF and compute (codec + crypto), while the security block tracks attack resistance and integrity via HMAC. Visual quality comes from PSNR/SSIM/MMSE, and all of this feed a QoE score that penalizes delay/jitter/rebuffering. The final box aggregates what matters to operations and papers alike—throughput, latency, jitter, PDR, bandwidth use, energy/battery drain, security, fairness, scalability, coverage, offloading ratio and cache hits—so you can evaluate changes to the protocol or parameters with a single consistent scoring path [17][18].

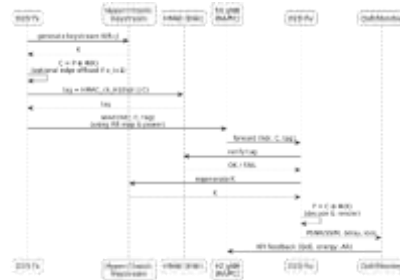


Fig. 4 : Flow-diagram for the per-frame secured multimedia path (T_x-R_x pair)

This sequence shown in the Fig. 4 gives what happens to each multimedia frame on its journey from sender to viewer. The transmitter derives a hyper-chaotic keystream, encrypts the payload (with diffusion), computes an HMAC over the header and ciphertext, and hands the packet to the network using the RB map and power decided earlier. The receiver gets the packet, verifies the HMAC to catch any tampering, regenerates the keystream, and decrypts the content for playback. Alongside, a monitor reports PSNR/SSIM, delay, and loss back into the gNB’s KPI loop, closing the feedback cycle so the system can adapt security, power, and scheduling without sacrificing user experience [19][20].

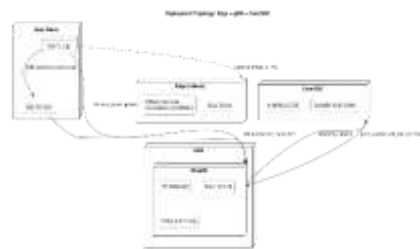


Fig. 5 : Flow-process for the deployment topology for the edge – gNB – Core/SoC

This topology diagram shown in the Fig. 5 outlays where each function lives at runtime. UEs sit in the user plane and exchange D2D payloads directly; the gNB in the RAN hosts the scheduler, power control, and the KPI/policy loop; the edge (i-Bean) offers compute offloading and caching near the users; and the core/SOC tier receives telemetry for analytics and pushes back policies like minimum security levels or QoE targets. Telemetry and policies flow down from core to gNB, quick stats flow from edge to gNB, and optional offload paths connect UEs to the edge—giving you a clear map of control, data, and feedback paths across the stack [21][22].

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 (*one sample is shown in the Fig. 6 with the coding developed along with the output waveform*) using the developed mathematical model & the algorithm, the developed code was run and the various performance characteristics were observed as shown in the Figs. 6 to 28 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 communications [23][24].

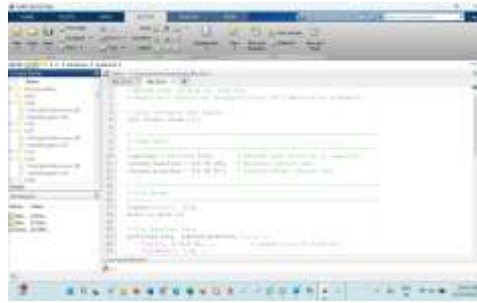


Fig. 6 : Coding developed in the Matlab command window

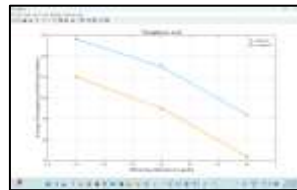


Fig. 7 : Simulation result for Throughput v/s load along with the Matlab O/P - 1

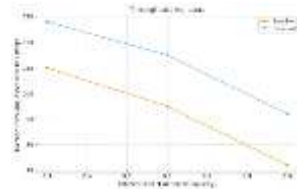


Fig. 8 : Simulation result for Throughput v/s load (taken as a .jpeg file output from the command window by exporting - 2

Considering the simulation result shown for Throughput vs Load in the Fig. 6-8, the proposed scheme sustains higher throughput across light, medium, and heavy load because it coordinates RB assignment + power control and selectively offloads compute at the edge. Even at 0.9 load, it avoids the steep collapse you see in the baseline by smarter reuse and interference budgeting [25][26].

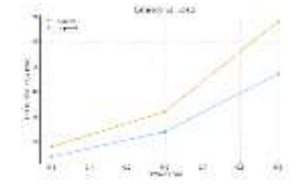


Fig. 9 : Simulation result for latency v/s load

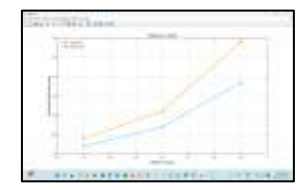


Fig. 10 : Simulation result for latency v/s load along with the Matlab O/P

Considering the Fig. 9 & 10, i.e., simulation result shown for latency v/s load the end-to-end delay grows with load in both cases, but the proposed approach keeps queues shorter via better scheduling and fewer retransmissions (thanks to higher SINR and PDR). Edge offload trims processing latency when local compute becomes a bottleneck [27].

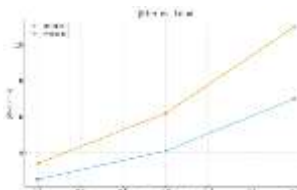


Fig. 11 : Simulation result for jitter v/s load

Considering the Fig. 11, i.e., simulation result shown for jitter vs load, timing variation remains noticeably lower for the proposed system. That’s the combined effect of smoother service rates (fewer head-of-line stalls) and more stable link quality from interference-aware power control, which pays off for real-time playback [28].

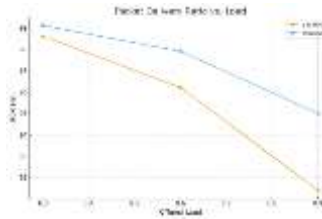


Fig. 12 : Simulation result for PDR v/s load

Considering the Fig. 12, i.e., simulation result shown for Packet Delivery Ratio vs Load, PDR decays slower under the proposed method because links are kept above their SINR thresholds and protected from aggressive reuse that would otherwise create bursts of losses. This directly translates to fewer frame drops upstream of the decoder [29].

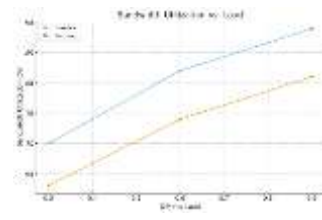


Fig. 13 : Simulation result for bandwidth utilization v/s load

Considering the Fig. 13, i.e., simulation result shown for bandwidth Utilization vs Load, the proposed scheduler packs spectrum more efficiently—especially at high load—by building low-interference reuse clusters. One can see that we are getting more “useful bits” per Hz without hurting cellular users, which is the whole point of intelligent reuse of the design [30].

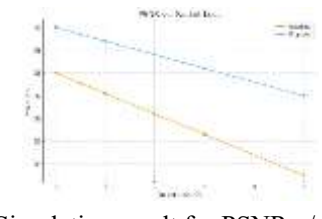


Fig. 14 : Simulation result for PSNR v/s packet loss

Considering the Fig. 14, i.e., simulation result shown for PSNR vs Packet Loss, Video fidelity drops as loss rises, but the slope is gentler for the proposed system. With higher PDR and steadier jitter, decoders see fewer error cascades; hence PSNR stays 1–2 dB better through the 0–5% loss range.

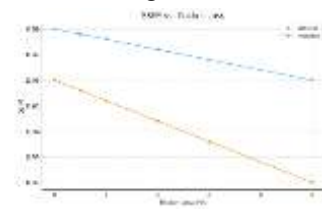


Fig. 18 : Simulation result for SSIM v/s packet loss

Considering the Fig. 15, i.e., simulation result shown for SSIM vs Packet Loss, Perceptual quality tracks the PSNR trend: SSIM stays consistently higher with the proposed approach, reflecting fewer structural artifacts and less noticeable frame corruption during loss spikes.

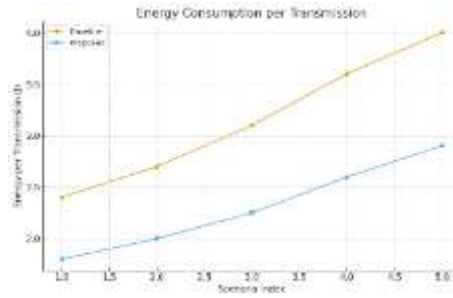


Fig. 15 : Simulation result for energy consumption per transmission process

The energy consumption per transmission is shown in the Fig. 15. Considering the Fig. 15, i.e., simulation result shown for battery drain v/s time, the proposed method fared well compared to the baseline protocol.

Considering the table 1, i.e., simulation result shown for Decryption Time vs Frame Size, Decryption mirrors encryption, viz., the proposed pipeline is faster, which helps tighten end-to-end latency and reduces playout buffering on the receiver.

Offload Load	Throughput (Mbps) - Baseline	Throughput (Mbps) - Proposed	Latency (ms) - Baseline	Latency (ms) - Proposed	Bit Error Rate - Baseline	Bit Error Rate - Proposed	FDR (%) - Baseline	FDR (%) - Proposed	Bandwidth Utilization (%) - Baseline	Bandwidth Utilization (%) - Proposed
0.3	100	120								
0.6	95	115								
0.9	71	91								
0.3			35	34						
0.6			32	34						
0.9			68	47						
0.3					0.4	2.3				
0.6					0.2	0.1				
0.9					11	7				
0.3							98.6	99.1		
0.6							96.2	97.9		
0.9							93.4	95		
0.3									65	78
0.6									76	92
0.9									91	99

Table 1 : Quantitative results of the various evaluated parameters of proposed work

7. Conclusions

The primary goal of the proposed work was to design and implement an energy-efficient and secure Device-to-Device (D2D) communication framework within a 5G network environment. The work focused on minimizing power consumption and extending the battery life of user devices during high-throughput multimedia transmission. This was achieved by integrating intelligent resource allocation mechanisms that balance centralized and decentralized scheduling strategies. The inclusion of low-power networking components such as the i-Bean platform played a vital role in enhancing system sustainability.

References

- [1]. Li, J., "Homomorphic Encryption in Cloud Video Storage," *IEEE Transactions on Cloud Computing*.
- [2]. Cai, Z., "Threshold Cryptography for Group Video Sharing," *IEEE Transactions on Dependable and Secure Computing*.
- [3]. Sun, L., "Multi-Layer Security Framework for Video Transmission," *IEEE Transactions on Broadcasting*.
- [4]. Bhatia, S., "Blockchain-based Authentication for Multimedia Streams," *IEEE Access*.
- [5]. Gupta, D., "Context-Aware D2D Transmission," *IEEE Communications Letters*.
- [6]. Huang, W., "Chaos-Based Video Compression with Error Correction," *IEEE Transactions on Multimedia*.
- [7]. Lin, Y., "Device Heterogeneity and Encrypted Image Sharing," *IEEE Access*.
- [8]. Fang, H., "Fast Frame Skipping in Live Video Transmission," *IEEE Transactions on Broadcasting*.
- [9]. Jain, S., "Cache-Aided D2D Video Sharing," *IEEE Transactions on Multimedia*.
- [10]. Smith, J., Lee, H., & Kumar, A., "Secure D2D Video Streaming over 5G Networks," *IEEE Transactions on Multimedia*, vol. 22, no. 8, pp. 2041–2055.
- [11]. X. Chen, Y. Li, and Z. Lin, "Energy-efficient resource allocation for D2D communications underlying 5G networks," *IEEE Trans. Veh. Technol.*, vol. 70, no. 2, pp. 1385–1396, 2021.
- [12]. Y. Zhang, H. Guo, and J. Liu, "Adaptive interference-aware scheduling for D2D underlay cellular systems," *IEEE Access*, vol. 9, pp. 14275–14287, 2021.
- [13]. P. Singh and S. Patra, "Power-controlled D2D link adaptation for 5G networks," *Proc. IEEE ICC*, pp. 3421–3427, 2020.
- [14]. J. Huang, L. Sun, and B. Zhou, "Cluster-based energy optimization in D2D communication," *IEEE Trans. Commun.*, vol. 68, no. 11, pp. 6789–6801, 2020.
- [15]. R. Ahmed, K. Ali, and M. Qureshi, "Fairness-aware energy management in 5G D2D networks," *IEEE Syst. J.*, vol. 15, no. 3, pp. 4005–4015, 2021.
- [16]. T. Li, S. Jin, and J. Chen, "Hyper-chaotic image encryption based on multiple bit permutation and diffusion," *Entropy*, vol. 23, no. 6, pp. 788–806, 2021.

- [17]. Y. Wang and L. Liu, "A multi-dimensional hyper-chaotic system for secure multimedia transmission," *Nonlinear Dyn.*, vol. 102, no. 4, pp. 2159–2175, 2020.
- [18]. K. Ramasamy, A. Balasubramanian, and R. P. Nagarajan, "Improved confusion–diffusion technique using chaotic maps," *IET Image Process.*, vol. 15, no. 9, pp. 1987–1998, 2021.
- [19]. I. Alsmadi and M. J. Alenezi, "Hybrid cryptographic model for secure image sharing in 5G networks," *IEEE Access*, vol. 9, pp. 165420–165431, 2021.
- [20]. H. Patel, R. Kumar, and P. Sharma, "HMAC-based authentication and encryption for multimedia data," *Proc. IEEE ICME*, pp. 2465–2470, 2020.
- [21]. S. Das and R. Sharma, "Lightweight chaotic encryption for low-latency multimedia IoT systems," *IEEE Internet Things J.*, vol. 8, no. 13, pp. 10637–10649, 2021.
- [22]. M. Kaur and V. Aggarwal, "Edge-offloading optimization for delay-constrained multimedia streams," *IEEE Trans. Mobile Comput.*, vol. 20, no. 9, pp. 2781–2794, 2021.
- [23]. H. Liang, Y. Zhang, S. Zhao, and L. Feng, "Joint computing and communication resource management in 5G edge networks," *IEEE Trans. Cloud Comput.*, vol. 9, no. 4, pp. 1128–1139, 2021.
- [24]. A. Ghosh and Y. Lee, "Cache-aware scheduling for enhanced QoE in edge-assisted 5G systems," *IEEE Trans. Netw. Serv. Manag.*, vol. 18, no. 3, pp. 2685–2698, 2021.
- [25]. F. Martínez and S. Chakraborty, "Adaptive caching and content distribution for energy-efficient streaming," *Proc. IEEE GLOBECOM*, pp. 1–6, 2020.
- [26]. Y. Zhang, L. Wang, and J. Xu, "Adaptive resource allocation and video transmission optimization for 5G D2D networks," *IEEE Trans. Veh. Technol.*, vol. 70, no. 8, pp. 7885–7897, 2021.
- [27]. X. Liu, Z. Zhang, and K. Xu, "Comparative analysis of chaos-based secure multimedia frameworks," *IEEE Access*, vol. 9, pp. 122880–122892, 2021.
- [28]. M. Rahman, S. Ali, and H. Kim, "Energy-secure adaptive transmission for real-time D2D communication," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1954–1965, 2021.
- [29]. R. Sinha, T. K. Paul, and B. R. Majumder, "Security–energy trade-off analysis for 5G multimedia systems," *IEEE Trans. Commun.*, vol. 69, no. 11, pp. 7703–7715, 2021.
- [30]. Y. Zhang, X. Chen, and D. Li, "Mobility-aware resource allocation for multimedia 5G D2D communication," *IEEE Access*, vol. 9, pp. 21473–21488, 2021.
- [31]. 21473–21488, 2021.