

Energy Efficient Resource Management in Multimedia IoT Networks

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Abstract

This literature review examines energy efficiency and load balancing in software-defined multimedia IoT. It compares published approaches to routing, allocation, encryption, event distribution, smart irrigation, video traffic reduction and intrusion detection. The review preserves the supplied study comparison and identifies requirements for evaluating an integrated system. It concludes that energy, delay, multimedia quality, workload distribution and security overhead should be assessed together.

Introduction

The Internet of Things (IoT) connects devices, sensors and applications through communication networks. Its applications include home security, environmental monitoring, intelligent transportation and healthcare. Sensors support the collection of detailed data, while resource management coordinates sensing, processing and communication without consuming unnecessary resources [1]. The central challenge is to allocate these resources efficiently as the number and diversity of connected devices increase.

Multimedia applications add substantial communication and processing demands to this environment. Video conferencing, entertainment, video-on-demand services and gaming generate continuous or bursty traffic, often with real-time delivery requirements [2]. Cameras and other multimedia sensors also produce data whose volume and timing differ from those of simple scalar measurements. The Internet of Multimedia Things (IoMT) extends IoT capabilities to the acquisition, transmission and use of multimedia content [3]. Here, IoMT refers to multimedia things; the separate use of the same abbreviation for medical things is not the focus of this review.

Software-defined IoMT integrates software-defined networking (SDN) with IoT and multimedia technologies. Separating network control from forwarding can support coordinated resource allocation, but the resulting system must still balance energy consumption, workload distribution and service quality [8]. Energy-efficient and load-balanced resource management therefore remains a central design problem.

Energy efficiency describes the ability to perform required tasks while limiting energy consumption. This is particularly relevant to resource-intensive multimedia applications and battery-powered devices. Communication choices, cluster-based routing and optimization objectives can influence energy use, network lifetime and overall performance [5]. Research on [energy-efficient wireless sensor routing](#) provides a related perspective on selecting routes under constrained energy budgets, although its setting differs from a complete multimedia IoT deployment.

Resource management allocates processing power, memory, storage and network bandwidth to competing tasks. Real-time applications require allocations that meet deadlines while limiting scheduling overhead and energy consumption [6]. Load balancing distributes work across available resources to reduce congestion and avoid persistent overload at individual nodes [7]. Related work on [energy-aware cloud task scheduling](#) illustrates the connection between allocation decisions and energy objectives in a different computing environment.

Energy efficiency and load balancing offer complementary benefits. Lower energy consumption can extend operational life, while balanced workloads can reduce bottlenecks and improve the consistency of multimedia delivery. Dynamic allocation may also help a network respond to failures and traffic surges. These properties matter in applications that depend on timely multimedia information, including transportation and emergency response. Better utilization may reduce operating costs, but the benefits depend on the implementation and workload [8].

Related wireless access research includes Q-learning approaches to coexistence between LTE and other users of unlicensed spectrum. Such methods address channel access and efficiency, while fairness and throughput remain important evaluation criteria [9]. Device-to-device communication can reduce reliance on the cellular core and improve spectrum utilization, but interference, power control, radio-resource allocation and quality of experience require careful coordination [10]. These access-layer issues interact with, rather than replace, network-wide resource management.

Multimedia networking also raises questions about medium access, addressing, neighbour discovery, routing, cross-layer quality-of-service coordination and security. The literature identifies these as continuing challenges for IoMT [11]. Related nanoscale multimedia concepts introduce additional communication constraints; their results should not be assumed to transfer directly to conventional sensor networks.

This review examines published approaches relevant to energy-efficient and load-balanced software-defined multimedia IoT. It brings together the supplied studies on encryption, routing, semantic event distribution, smart irrigation, load balancing, video traffic reduction and intrusion detection. The purpose is to compare their contributions and limitations and identify requirements for an integrated design. The review does not report a newly implemented SD-IoMT system or a new experimental evaluation.

Literature Review

In 2021, Gupta et al. [12] proposed lightweight image encryption using a logistic-tent map and the crossover operator of a genetic algorithm. Their approach combines a one-dimensional chaotic map with crossover operations to generate a session key for each image and improve confusion and diffusion during encryption. The study evaluates resistance to statistical attacks through histogram analysis, correlation and entropy, as well as differential attacks through the unified average changing intensity (UACI) and number of pixel change rate (NPCR). Secret-key sensitivity is another component of the evaluation. This work addresses the security cost of protecting images on constrained multimedia devices.

In 2020, Bouzebiba and Lehsaini [13] introduced FreeBW-RPL, an objective function for the Routing Protocol for Low-Power and Lossy Networks. The method uses an estimate of available bandwidth to support route selection for multimedia traffic. Its quality-of-service objective is to select paths with sufficient free bandwidth rather than relying exclusively on conventional routing criteria. Simulations in COOJA compare throughput, end-to-end delay, packet delivery and energy consumption with conventional protocols. The study reports improved performance in the simulated conditions. Its routing focus complements work on [mobility management in RPL IoT networks](#), where changing connectivity creates further demands on route maintenance.

In 2022, Choi and Yu [14] proposed image encryption based on compressed sensing and scrambling. Sparse measurement matrices support encryption, while a modified linear-feedback shift register generates the required nonzero values. Additional scramblers operate after compressed-sensing encryption to increase diffusion. The reported numerical evaluation considers reconstruction, histogram behaviour, entropy, correlation and plaintext sensitivity. The approach aims to preserve reliable compressed-sensing decryption while improving statistical security. Its implications for resource management depend on the processing and communication costs of the full encryption and reconstruction pipeline.

In 2022, Zaarour et al. [15] presented OpenPubSub, a semantic publish/subscribe system that combines rendezvous routing and gossiping over an organized peer-to-peer structure. It uses a high-dimensional semantic vector space rather than only conventional logical key regions. The work includes space partitioning, a bootstrapped semantic distributed hash table, approximate semantic retrieval and node grouping around shared interests. The supplied comparison reports up to 54% recall and a 44% reduction in message cost for rendezvous routing, against an estimated event-matching upper-bound recall of 56.7%. The hybrid strategy reports up to 43.8% recall and a 59% reduction in messaging overhead. These figures illustrate a trade-off between retrieval coverage and communication cost.

In 2020, Wang et al. [16] studied energy-efficient and load-balanced clustering and routing for wireless sensor networks using a chaotic genetic algorithm. The work is relevant to the distribution of

communication workloads and energy consumption across sensor nodes. Clustering and routing decisions should be considered together because repeatedly using the same relays can concentrate resource demands. The comparison in this review treats the cited study as an optimization-based clustering and routing approach; it does not attribute a separate reinforcement-learning protocol to that reference.

In 2019, AlZu'bi et al. [17] investigated the use of multimedia IoT in smart agriculture. Their irrigation system combines environmental sensors, multimedia observations, machine-learning techniques and image processing. Sensors inside and outside the prototype provide information about plant conditions, while image analysis contributes another perspective on irrigation requirements. The supplied study description reports a hardware implementation and MATLAB-based analysis. Its value to this review lies in showing how an application can combine several data sources, although the sensing, processing and communication requirements must all be included in resource planning. The comparison table retains the reported precision and recall values.

In 2023, Datiri and Li [18] examined a hybrid load-balancing approach for resource optimization in IoT. Their decentralized strategy combines clustering and edge-computing concepts with round-robin allocation, resource-based decisions and particle swarm optimization. The resulting PSOR2B approach considers both resource allocation and scheduling. The study evaluates performance through five simulation test scenarios and compares the approach with ant-colony optimization, a centralized optimization strategy, LEACH and C-LBCA. The reported advantage is specific to those comparisons and scenarios; it does not establish superiority for every multimedia workload or deployment.

In 2019, Shifa et al. [19] proposed a lightweight selective cipher for H.264 video. The EXPer method encrypts selected syntax elements from the entropy-coding stage, rather than treating the entire encoded stream as an undifferentiated input. The encryption space ratio provides a diagnostic relationship between encoding complexity and the amount of encryption performed. The study compares confidentiality, computational expense and bitrate effects with other encryption approaches. The reported results support selective protection as a candidate for constrained multimedia devices, while the selection of protected elements remains an important security consideration.

In 2020, Tanseer et al. [20] investigated real-time, content-based communication load reduction for multimedia IoT. The method examines motion between adjacent frames to decide whether to transmit motion information or omit redundant frame data. It aims to reduce traffic, energy use and latency while preserving useful video information. Encryption is also included for security and privacy. The study compares the approach with related methods using video-quality measures and quality-of-service indicators. Its contribution is relevant to resource management because reducing unnecessary data at the source can lower demands on every subsequent network stage.

In 2023, Alshahrani et al. [21] proposed an intrusion-detection framework for industrial IoT using SDN and machine learning. An SDN controller analyzes traffic-flow information, manages switch rules and

monitors network behaviour. The evaluation includes support vector machine and decision-tree classifiers, with a reported attack-detection accuracy of 99.7%. The result is an outcome of the cited study rather than a new experiment in this review. Security monitoring also consumes resources, so its placement and overhead should be considered alongside routing and multimedia delivery. Related [deep-learning intrusion detection in cloud environments](#) offers another example of traffic classification, with different deployment assumptions.

Comparative Assessment and Problem Statement

The following table preserves the supplied comparison of the reviewed techniques, benefits, drawbacks and reported observations. These observations come from different studies and evaluation settings. They should not be interpreted as a single benchmark or used to rank unrelated methods directly. A dash indicates that the supplied comparison did not provide a numerical observation.

Author [Citation]	Technique	Advantages	Drawbacks	Observations
In 2021, Gupta et al. [12]	1-D chaotic map (logistic-tent map) and a genetic algorithm operator (crossover),	Resistance to Cryptanalytic Attacks, enhancement of the security of the encryption Lightweight	Computational Overhead, Complexity	Key space = 2^{80} NPCR=99.63
In 2020, Bouzebiba et al. [13]	FreeBW-RPL Protocol, QoS Routing Challenge	Improved Performance, QoS for Multimedia, Simulator-Based Testing	Complexity	-
In 2022, Choi et al. [14]	Compressed Sensing (CS), Scrambling Mechanism	Reliable CS Decryption, Statistical Security, Plaintext Sensitivity	Potential Complexity	Number of Pixel Change Rate (NPCR) = 99.6094% Unified Average Changing Intensity (UACI) =33.4635%

In 2022, Zaarour et al. [15]	Rendezvous Routing, Gossiping, Semantic Vector Space, Space Partitioning	Improved Recall, Reduced Messaging Overhead, Context-Aware Routing	Complexity, Recall Trade-off	Recall = 43.8%, decreasing messaging overhead by 59%
In 2020, Wang et al. [16]	Chaotic genetic algorithm, Clustering and routing	Energy Efficiency, QoS Improvement, Comparison with Traditional Protocols	Complexity	-
In 2019, AlZu'bi et al. [17]	Machine Learning Techniques, Data mining techniques, such as classification and prediction, Smart Irrigation,	Automatic and Unsupervised, Multi-Factor Consideration, Quality Improvement, Wireless and IoT Integration	Complexity, Cost	precision 0.96 recall 0.8
In 2023, Datiri et al. [18]	Hybrid Algorithms (round-robin), particle swarm optimization	Resource Optimization, Decentralized Topology, Hybrid Algorithm, Security	Complexity	-
In 2019, Shifa et al. [19]	EXPer (Extended Permutation with Exclusive OR)	Confidentiality, Lightweight, Negligible Overhead	Selective Encryption Limitation	Entropy =5.1265 Peak Signal-to-Noise Ratio (PSNR) (dB) = 7.9325 Structural Similarity Index (SSIM) = 0.183

In 2020, Tanseer et al. [20]	Video Content- Based Solution, Data Encryption	Load Reduction, Energy Conservation, Reduced Latency, Improved Bit Rates	Complexity, Quality Trade-offs	For all types of video datasets load reduction is 2.76%.
In 2023, Alshahrani et al. [21]	SDN-based framework, Machine Learning	High Accuracy, Adaptive Network Control, Centralized Management	Complex Implementation, Computational resource requirements	accuracy 99.7%.

Implications for an Integrated Design

The reviewed studies address different parts of the multimedia IoT pipeline. Encryption protects content, routing distributes traffic, load balancing coordinates work, and content-aware processing reduces the volume of transmitted data. An integrated SD-IoMT design must account for their interactions. For example, additional encryption or classification can increase processing demands even when it improves security, while a route with greater available bandwidth may place a different burden on relay batteries.

The resulting problem is to coordinate energy use, workload distribution, delay, multimedia quality and security under finite device and network resources. A useful evaluation would state the topology, workload, energy model, controller placement, comparison methods and quality requirements explicitly. It would then measure both the benefits of coordination and its overhead. The supplied literature supports these evaluation requirements but does not provide a completed implementation or a shared experimental dataset for testing them here.

Conclusion

Energy-efficient and load-balanced resource management in multimedia IoT requires coordination across sensing, computation, communication and protection of data. The reviewed work offers complementary approaches: bandwidth-aware routing, optimization-based allocation, selective encryption, semantic event delivery, application-aware sensing, video load reduction and SDN-based intrusion detection. Their reported results demonstrate different aspects of the design space, rather than a directly comparable set of outcomes.

Software-defined control provides a framework for coordinating these decisions, but an effective solution must account for control overhead, device limitations and application-specific service requirements. Future implementation work should test the combined system under clearly described

workloads and report energy consumption, delay, delivery quality, load distribution and security overhead together. This review establishes the literature-based problem and comparison; it makes no claim of a newly validated resource-management algorithm.

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