# ENHANCING IOT COMMUNICATION AND NETWORK LIFE IN SOFTWARE-DEFINED NETWORKING- CONTROLLED EMBEDDED NETWORKS WITH COOPERATIVE ROUTING

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***Abstract:***

*Strong communication protocols and effective network management approaches are needed to ensure scalability, reliability and energy savings in the ever-growing field of Internet of Things (IoT) applications. This research could significantly improve the efficiency of video streaming in IoT ecosystems, which is important for many reasons, particularly for smart cities, autonomous vehicles and remote monitoring systems. Minimising packet loss in video transmission, coping with fluctuating network topologies caused by mobile devices, and maximising the lifetime of embedded network devices are all difficulties that are being addressed. The Internet of Things-based Efficient Mobility Video Streaming (IoT-EMVS) method is an innovative framework that optimises video streaming in IoT networks by addressing energy consumption, bandwidth allocation and mobility issues. IoT-EMVS uses cooperative routing protocols to allow devices to work together to improve data pathways, manage network resources, and guarantee a smooth handover as they move. This results in fewer delays, better video quality and a longer network life. Among the many potential uses of IoT EMVS are interactive multimedia services in IoT-enabled environments, real-time mobile health monitoring and other similar fields. Compared to conventional forms of IoT connectivity, IoT-EMVS shows considerable gains in power savings, packet delivery ratio, and overall quality of service, as shown in a thorough simulation research. energy consumption, bandwidth allotment, and mobility issues. This*

## 1 Introduction

SDN embedded networks can lead to many issues that hinder the application of standard procedures for enhancing IoT connectivity and sustainability. Most of these techniques are based on established protocols that are rather rigid towards the evolving trends in the IoT [1]. Static routing leads to more delays and drains out more energy and available resources in the embedded systems, where such resources are limited. Conventional methods are also found to be inadequate to scale the IoT networks because they are unable to cope with the ever-changing data flow rates and device density [2]. For this reason, there might be network congestion and bottlenecks that could adversely affect performance. Because IoT devices are weak, so no guarantee existing methods will protect these networks [3]. They do not address all participants in the communication network for optimal routing of messages, a factor leading to inefficient message routing and poor durability of networks

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[4]. However, this routing flexibility is constrained in SDN as resource planning and routing parameters are more rigid to individual networks [5]. However, as these systems have been demonstrated to be critical for the efficient communication in the developing IoT ecosystems, routing systems need to become flexible, cooperative and secure and optimally utilize SDN in embedded networks to tackle these issues [6]. Cooperative routing raises several issues in improving the IoT connection and network lifespan in embedded SDN networks with the use of paths or segmenting them [7]. However, these are not permanent attachments, and these devices may be brought in or taken away in the shortest of time. More flexible routing methods need to be implemented in view of this [8].

The current cooperative routing paradigms or algorithms are unable to support dynamic changes in the topology, leading to delays and loss of information [9]. Our model utilizes adaptive cooperative routing protocols that dynamically adjust to topology changes, such as device mobility or network congestion. Unlike existing solutions that rely on static routing, our framework employs machine learning algorithms to predict and adjust routing paths based on real-time data traffic and device conditions, ensuring continuous network stability and performance even under fluctuating conditions. IoT devices differ in terms of the aforementioned parameters and people's unwillingness to accept uniformity of routing protocols [10]. There is the aspect of the network's security, which is critical, especially for privacy and genuineness of information, when cooperating routing systems are employed, they need to be protected. Network routing, besides performance and energy effectiveness, and cyber attack risk, all raise human resources metrics complexity in IoT devices, which are progressively used as launching pads for cyber-attacks [11]. When it comes to SDN systems, there will be a question of how scalable they are when the number of devices increases. Resource management for better systems performance optimization involves checking how fast a large amount of data traffic can be handled with the software-defined networking controller [12]. It's important to consider that developing cooperative routing solutions aimed to minimize energy spending while supporting the appropriate communication level will prolong the functioning period of the device [13]. New energy-saving, secure, and SDN-based systems that enhance the IoT connectivity paradigm shift are emerging.

The use of cooperative routing in SDN-managed embedded networks can be used effectively to enhance Internet of Things connectivity and the lifespan of the network. Adaptive routing protocols can be employed to broadly transition the borderline control meshed networks in terms of their circumstances. Management of machine learning algorithms is fundamentally energy efficient and reduces time latency, and routing decisions, including processes of authentication and encryption, are less vulnerable to invasion [14]. Using SDN's centralised control allows for effective resource management and real-time monitoring. This enables diverse devices integrate seamlessly, extending network lifespan and improving IoT reliability. This study addresses the gap in flexible, cooperative, and secure routing solutions for dynamic IoT environments by leveraging SDN, energy-efficient adaptive protocols, and machine learning to optimize resource management and network longevity.

### *1.1 Problem Definition*

SDN-controlled embedded networks using cooperative routing to improve IoT connectivity and network life encounter many challenges. There are many of these, one of which is the optimisation of energy usage to increase the lifespan of embedded network components. Other instances include optimising energy efficiency, minimising packet loss during video streaming, and correcting IoT device mobility-related network topologies. In dynamic environments, traditional routing methods often fail to manage resource and bandwidth usage efficiently. Addressing challenges with real-time monitoring systems, driverless vehicles, smart cities, and other applications requires novel ways, such as the Internet of Things, Employee Monitoring, and Security building design.

i) Reducing packet loss and improving video quality in IoT environments should motivate the development of the IoT-EMVS framework.
ii) Cooperative routing techniques are suggested for proper bandwidth allocation and resource management in dynamic topologies.
iii) Implementing energy-efficient solutions is crucial for Internet of Things applications to ensure embedded network devices last as long as possible without power outages.

Limitation

One potential limitation is the complexity of real-time data processing required for adaptive routing. The model's reliance on machine learning for decision-making may lead to higher computational overhead, particularly in resource-constrained devices. Furthermore, integrating SDN with existing IoT infrastructures may present compatibility challenges. These issues could be mitigated through careful system design and edge computing solutions to distribute processing tasks. The research paper's structure has been set out in this section, which includes the following: Cooperative routing in software-defined networking-controlled embedded networks is the focus of Section II of this paper, which aims to improve Internet of Things (IoT) communication and network life. Section III of this dissertation presents an in-depth analysis of IoT-based Efficient Mobility Video Streaming (IoT-EMVS). An exhaustive examination, a comparison to prior approaches, and an examination of the consequences are presented in Section IV. The results are thoroughly examined in Section V.

## 2 Literature Review

These protocols enhance resource utilisation, improve security, and eliminate Internet of Things issues like void holes and malicious behaviour. The energy harvested and cooperative-enabled efficient routing protocol (EHCRP) that was introduced by Khan, M. D. and colleagues [15] improves multi-hop routing in Internet of Things wireless body area networks (IoT-WBANs), hence increasing network lifetime and throughput while simultaneously decreasing end-to-end delay in comparison to the methods that are currently in use. The traffic-splitting technique (T-SA) that was proposed by Al-Shammari, H. Q., et al. [16] improves the robustness of Internet of Things (IoT) services by optimising resource embedding, delivering power savings of up to 35%, and reducing average traffic delay by 37% through energy-efficient node selection. Along with assuring consistency and collaboration in Internet of Things networks, the Metric-based RPL Trustworthiness Scheme (MRTS) that was presented by Djedjig et al. [17] improves RPL security by evaluating trust, hence enhancing packet delivery, energy efficiency, and throughput. Outperforming numerous current protocols in key performance measures, the three-layer cluster-based routing protocol (C-RP) that was proposed by Ilyas et al. [18] improves Internet of Things (IoT) sensor networks by enhancing network lifetime, throughput, and routing efficiency while limiting malicious activities.

The energy-aware zone-based routing technique (E-AZRT) proposed by S. Iqbal [19] improves the throughput, packet delivery ratio, and lifetime of the networks in Internet of Things environments. This technique employs game theory for node cooperation as well as energy efficiency. To mitigate the void hole problem more efficiently, Draz, U., et al. [20] proposed the Energy Efficient Layer-by-Layer Watchman-based Collision Free Routing (ELW-CFR) approach, which is proactive. This scheme increases the Packet Delivery Ratio and reduces the End-to-End delay within the area of the Internet of Things. The work of Majid, M [21] proposed the use of clustering in wireless sensor networks is further enhanced by the development of the weight-based LEACH protocol (LEACH-W). This approach increases network lifetime, throughput, and energy efficiency factors through balanced cluster and adaptive multi-hop routing. Internet of Things (IoT) is a wireless network's emerging platform for communicating with sensors, smart devices, and controllers [22]. This connects devices online for communication. Due to massive sectors, ioT devices and SDN controllers have energy limits in inappropriate routing schemes. In health care, patient monitoring data uses more energy, reducing network connection lifespan and causing data loss during IoT device collection. Software-defined networks regulate embedded communication to preserve energy usage and extend energy-efficient network lifespan. Flexible software-defined networking (SDN) is being utilized in various areas. It may be crucial to the Internet of Things. Decoupling the control plane from the data plane lets the controller oversee the whole network. SDN routes wireless sensor networks (WSNs) [23]. Some SDN controller algorithms determine the routing route, but none can optimize it. Reinforcement learning (RL) helps choose the optimum routing. In this post, we optimize SDWSN routing using RL. A reward function that covers all energy efficiency and network QoS criteria is suggested. The agent receives the incentive and acts accordingly, while the SDWSN controller optimizes the routing route based on experience. The Internet of Things (IoT) connects devices, sensors, and systems to the Internet for real-time monitoring, control, and automation in smart cities, healthcare, transportation, homes, and grids. The vast amount of data created by IoT devices and the constraints of conventional cloud-based systems have caused latency, privacy, and bandwidth issues [24]. IoT devices' fast expansion and heterogeneity have caused difficulties in network administration, interoperability, security, and scalability. Researchers suggested SDN-EC-IoT, which combines Edge Computing for the Internet of Things (EC-IoT) with Software Defined Internet of Things (SDIoT), to solve such issues.

*Table 1. Simulation Related Works.*

| Protocol/Technique | Advantages | Limitations |
|---|---|---|
| **EHCRP (Energy Harvested and Cooperative-Enabled Routing Protocol)** (Khan et al., [15]) | - Increases network lifetime and throughput. - Reduces end-to-end delay in IoT-WBANs. | - Primarily focused on multi-hop routing in IoT-WBANs, may not generalize to all IoT applications. |
| **T-SA (Traffic-Splitting Technique)** (Al-Shammari et al., [16]) | - Improves IoT service robustness. - Saves up to 35% of power and reduces traffic delay by 37%. | - Focuses mainly on energy-efficient node selection, may not address other critical performance metrics. |
| **MRTS (Metric-based RPL Trustworthiness Scheme)** (Djedjig et al., [17]) | - Enhances security and trustworthiness in RPL networks. - Improves packet delivery, energy efficiency, and throughput. | - May add complexity in terms of trust management, affecting scalability. |
| **C-RP (Cluster-based Routing Protocol)** (Ilyas et al., [18]) | - Enhances network lifetime, throughput, and routing efficiency. - Reduces malicious activities. | - The clustering mechanism may lead to high overhead in dynamic environments. |
| **E-AZRT (Energy-Aware Zone-Based Routing Technique)** (Iqbal, [19]) | - Improves throughput, packet delivery ratio, and network lifetime. - Uses game theory for energy efficiency and node cooperation. | - Game theory-based approaches can be computationally expensive and unsuitable for resource-constrained devices. |
| **ELW-CFR (Energy Efficient Layer-by-Layer Watchman-based Collision-Free Routing)** (Draz et al., [20]) | - Increases Packet Delivery Ratio and reduces end-to-end delay. - Proactively mitigates void hole problems. | - May not be optimal for networks with highly dynamic and unpredictable environments. |
| **LEACH-W (Weight-based LEACH Protocol)** (Majid, [21]) | - Increases network lifetime, throughput, and energy efficiency through balanced clustering and adaptive multi-hop routing. | - May struggle with scalability in large, highly dynamic networks. |
| **SDN for IoT** [22] | - Enables centralized control and energy-efficient communication. - Optimizes network performance by decoupling control and data planes. | - May introduce latency in decision-making due to centralized control. |
| **SDWSN Optimization with RL (Reinforcement Learning)** [23] | - Optimizes routing for energy efficiency and network QoS. - Uses past experience for decision-making. | - Requires significant training and may introduce delays during the learning phase. |
| **SDN-EC-IoT (SDN with Edge Computing)** (SDN-EC-IoT) [24] | - Solves issues of latency, privacy, and bandwidth. - Combines SDN and edge computing to improve scalability, security, and network management. | - Complex integration between SDN and edge computing may lead to implementation challenges and overhead. |

The framework of the Internet of Things i.e. IoT-EMVS is due to its effectiveness in conserving energy, low latency, and scalability. But improving communication technologies, the IoT-EMVS architecture is superior to the conventional methods. While there has been research on cooperative routing within SDN for IoT networks, this paper brings forward some unique contributions. Unlike previous works that have concentrated primarily to static or limited routing protocols, our approach introduces adaptive cooperative routing, which dynamically adjusts to changes in network topologies, device densities, and real-time data traffic. We also incorporate AI-driven resource management and energy-efficient mechanisms for optimizing routing decisions to reduce latency and extend the network's lifespan. Moreover, we address security concerns in cooperative routing by using advanced encryption and authentication protocols that ensure data integrity and privacy. These developments make our approach distinct from other methods, making it more flexible, scalable, and secure for IoT networks.

## 3 Proposed Method

Widespread adoption of the IoT is also bringing about a number of challenges associated with video streaming in IoT environments, including overuse of energy, packet loss, and delays. Efficient video streaming underlies many IoT applications such as smart cities, self-driving cars and tele-operations. To avoid all these challenges, this paper proposes a design for an Internet of Things – Enhanced Mobile Video Streaming. IoT-EMVS aims at ameliorating video quality and primary data paths whilst enabling seamless device hand-off during mobility by integration of SDN and cooperative routing protocols. It enhances energy efficiency, reduces the network, improves packet loss reduction, and increases the lifetime of embedded devices. In addition to this constructing the system helps to use cloud and edge computing solving the problem of static routing; allowing dynamic routing and management of the resources in real time. The system is very effective for real-time use in an IoT environment where it is proven through extensive simulations that the proposed framework achieves significant improvement in the delivery ratio of the packets and user experience.

### *3.1 Optimized Video Streaming Performance*

In this case, the IoT-EMVS framework solves latency constraints and packet loss, enhancing the efficiency of video streaming in IoT applications. The framework uses cooperative routing protocols to improve video quality and guarantee reliable streaming in applications such as smart cities and remote monitoring systems. The framework being applied in smart cities, industrial IoT networks, and healthcare systems. IoT devices are highly mobile in these scenarios, and network traffic fluctuates. Our framework can handle these dynamic conditions by maintaining low latency, ensuring secure communication, and optimizing energy consumption, resulting in extended device lifespan and efficient network performance.

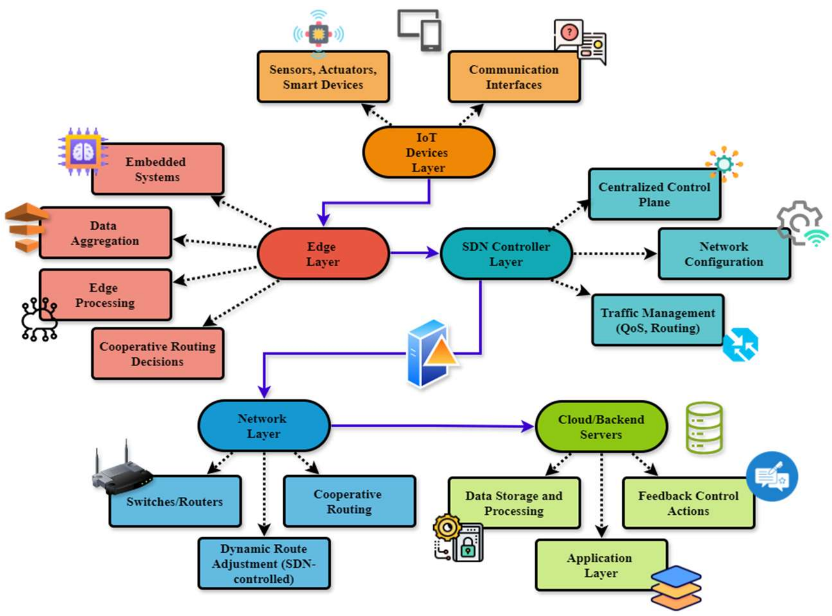


*Figure 1. SDN-IoT Architecture with Edge and Cloud Integration.*

Combining the IoT with SDN in a layered architecture improves data processing and network management, as shown in Figure 1. The IoT Devices Layer enables the connectivity of sensors, actuators, and smart devices through embedded systems and interfaces. After receiving transmissions from these devices, the data is processed and stored at the Edge Layer. This layer also makes cooperative routing decisions to optimize network traffic. The SDN Controller Layer ensures quality of service and effective routing by controlling traffic and network parameters via a centralised control plane. At the Network Layer, switches and routers utilising SDN protocols provide dynamic routing. The Application Layer, tasked with user interface interaction, derives its information from the highly parallel Backend Servers. This method improves the effectiveness of Internet of Things deployments by integrating edge computing with SDN for dynamic routing. This facilitates scalable, real-time network management.

$$m_2 \sim \frac{2 * R_q}{xy} * Er\big(F_2 * M(n - vf)\big) + z_{p-2}^r \tag{1}$$

The equation 1 considers factors such as packet delivery ratio ($m_2$ ), energy efficiency ($\frac{2*R_q}{xy}$), and node mobility ($Er$), which enhance network stability $F_2 * M$, reduce video transmission latency $n - vf$, and prolong the lifespan of components $z_{p-2}^r$. The energy and resource gains brought forth by IoT-EMVS compared to older systems may be quantified in this equation.

$$\partial q - E\_2\, m + vtanp = z\_2 * \partial \forall (y, z\hat{}2 - Qr) \tag{2}$$

This is the equation 2 that describes the connection between energy consumption ($E_2 m$), packet delivery in mobile contexts, and mobility ($vtanp$). When optimising video quality $y, z^2 - Qr$ and minimising latency $\partial \forall$, it takes into consideration the impact of changing network topologies and data rates $z_2$. This equation exemplifies the stabilisation of transmission of videos in IoT networks achieved by managing device mobility and cooperative routing.

$$v\_2\ (\forall k\_(r - p) * Z(Rv\hat{}2\ (Qw(r - f)))) = \ 〚rw〛\ \hat{}(z - yr) \tag{3}$$

In the IoT-EMVS approach, the bandwidth ($\forall k_{r-p}$), video data rate ($Z$), and routing efficiency $v_2$ are all described by the equation 3. It simulates the effect of network circumstances $Rv^2$ on cooperative routing $Qw(r - f)$, which enhances video streaming $rw^{z-yr}$ by minimising packet. This equation 3 helps put a number on the performance benefits in terms of both information throughput and total network lifetime.

$$k\_j\ (v - e\hat{}')= 3q(J - p\_2\, r) + \ 〚Rz〛\ \hat{}(m - n\_w\ ) \tag{4}$$

Inside the IoT-EMVS approach $J - p_2 r$, the equation 4 balances energy consumption ($v - e'$), node velocity ($k_j$), and packet transmission ($3q$). The approach enhances performance by dynamically modifying energy usage $Rz$ and routing parameters $m - n_w$ to optimise video streaming. For it to keep video quality good across different situations in IoT networks, this equation 4 highlights the trade-off between conservation of energy and packet delivery.

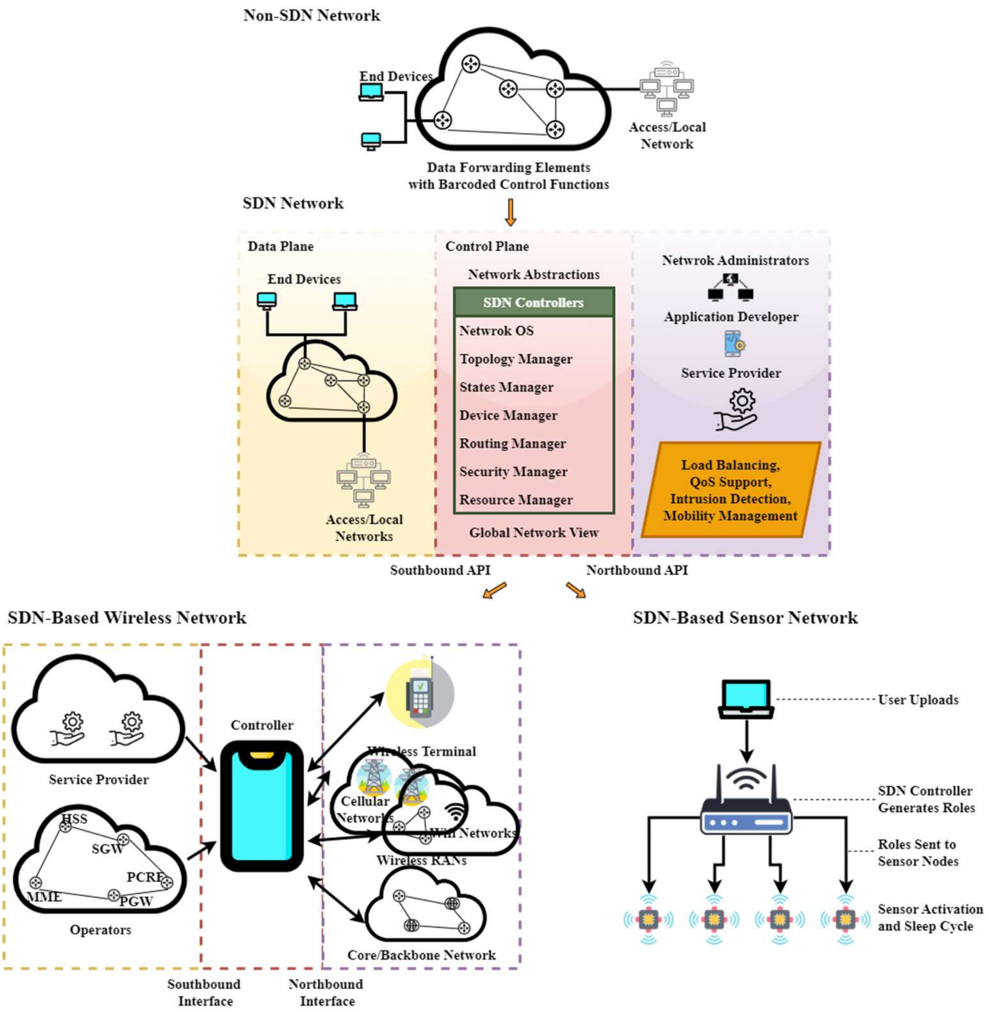


*Figure 2. IoT-EMVS Architecture for Efficient Video Streaming and Mobility Management.*

Figure 2 shows the architecture in action. Data, control, and management planes are the main parts of the architecture. The Efficient Mobility Video Streaming (IoT-EMVS) architecture is built to optimise video streaming in IoT ecosystems. Sensors and actuators, integral to the IoT, transmit data inside local networks on the data plane. The control plane facilitates communication between networks and SDN controllers, which oversee critical functions such as routing, security, topology, and resource allocation using abstractions. The control plane provides an overhead view of the network, allowing for simpler real-time resource and network management. Network administrators, application developers, and service providers control critical functions such as mobility management, intrusion detection, load balancing, and quality of service support on the management plane. Cooperative routing protocols are essential for applications such as smart cities, driverless cars, and real-time health monitoring to provide effective device handoffs during movement. These solutions optimise bandwidth and reduce packet loss and improve the network's durability.

$$\partial\_r * m(y,up) - w\_2 \rightarrow Yt * ( \llbracket eq \rrbracket \hat{}2 - Rz) \qquad (5)$$

Energy efficiency $w_2$ and transmission of packets $Yt$ are affected by the variable's mobility $(\partial_r)$ and network load $(m(y,up))$. As devices move, it optimises network management by showing the trade-offs between video quality $eq^2$and routing stability $-Rz$ . By adjusting to changing loads and mobility, IoT-EMVS maintains constant video performance while reducing energy consumption, as seen in this equation 5.

$$p\_((y,zw)) * w\_2 (W - e\hat{}r ) = M(y,fh) * Rn\hat{}2 \qquad (6)$$

The relationship between network efficiency $p_{(y,zw)}$, mobility $w_2$, and routing weight $W - e^r$ is represented by the equation 6. It simulates the process by balancing energy needs, network load $Rn^2$, and mobility impacts $(M(y, fh))$. This demonstrates increasing data throughput and energy conservation in ever-changing IoT settings.

$$\partial_{v-m} = N_e\left(\forall_r + Mq\left(n^{r-f}\right)\right) * Rq(m^{n-st}) \quad (7)$$

Both network efficiency $(N_e)$ and packet routing $(\partial_{v-m})$ are affected by the equation 7 in v and m, which are units of mobility $Rq$. Changes in network topology $\left(n^{r-f}\right))$ and traffic load $(\forall_r + Mq)$ are used to alter routing $m^{n-st}$ and distribution of resources in this strategy. This equation helps IoT-EMVS optimise video quality and minimise delays by constantly controlling mobility and network circumstances.

$$\forall_m * E(v^2 + R) = \forall_{d-2}(y, z) * Wq_{n-r}(mk) \quad (8)$$

Optimizing energy consumption $\forall_m$, velocity $(v^2 + R)$, and routing efficiency $E$ in respect to network circumstances $\forall_{d-2}$ and load $y, z$ is shown by the equation 8. Efficiency in video streaming is ensured by adjusting $mk$ to real-time network fluctuations $Wq_{n-r}$, which improves overall system performance. This is achieved by capturing controls energy and bandwidth as devices move and topologies change.

### *3.2 Energy Efficiency and Network Longevity*

The proposed method addresses energy-efficient approaches to address the energy consumption challenge in IoT devices. The proposed IoT-EMVS framework extends the operational lifetime of embedded networked appliances. It enhances the utilization of their available bandwidth by applying cooperative routing approaches, creating optimal network infrastructure. As a result, it fosters the advancement of network sustainability that has been brought about by obviating the problem of frequent replacement of devices and therefore lowering general running costs. Incorporate robust security measures, including advanced encryption, authentication protocols, and secure routing techniques, to ensure the cooperative routing approach does not introduce new vulnerabilities. The model is designed to avoid overburdening the network by optimizing energy usage and routing decisions, thus minimizing inefficiencies. Additionally, we conduct extensive testing to assess security and performance under various conditions.

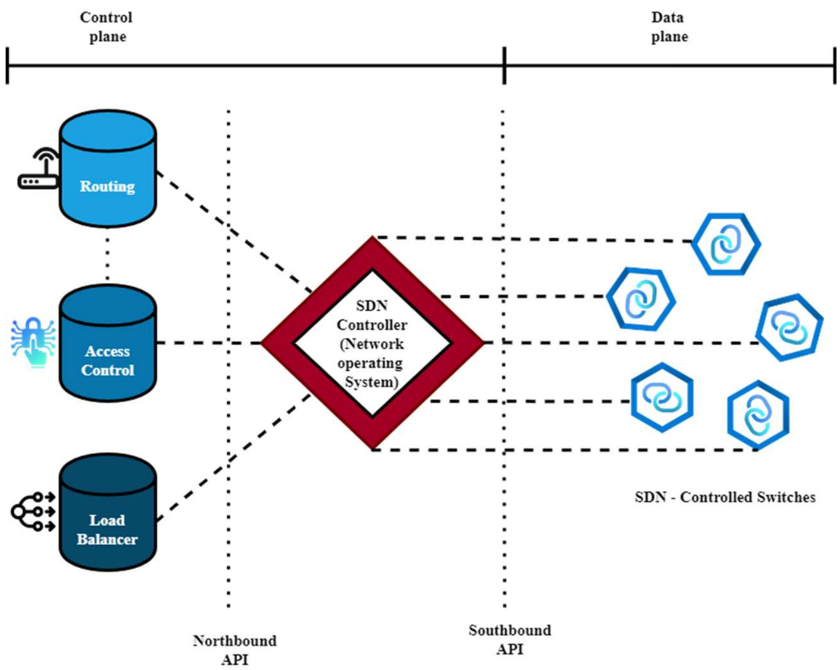


*Figure 3. SDN-Based Network Management for Efficient IoT Video Streaming.*

The Figure 3 depicts the architecture meant for managing the Internet of Things ecosystems based on SDN. The architecture addresses the concerns of effective video streaming services. The SDN controller manages core services like routing, access, and load balancing of the networks. These features prove to be useful in the context of Internet of Things. This is total water transport for the information to its consumer without elevating the power demand during delivery and with negligible chances on packet loss. Access of specific network routing, devices, and bandwidth is from the SDN controller. Such management of networks is made progressive for scalability, mobility and congestion reasons. Cooperative routing allows the IoT nodes to communicate with one another. It reduces the latency in the transmission of information and video. Because of its efficiency in energy consumption, high quality of video streaming and general dependability, this structure has found use in designs such as smart city and remote monitoring system applications.

$$v''(m-n') - u + rq(z') = X_a(c-pk) + Y^{2-e} \tag{9}$$

The model predicts the impact on network stability of node mobility $v''$, routing quality $u + rq(z')$, and energy consumption $X_a$. Optimise energy usage $Y^{2-e}$ and preserve video streaming quality, it explains IoT-EMVS dynamically balances routing modifications $c - pk$ and mobility. Equation 9 shows approach boosts system performance in real-time Internet of Things settings.

$$\forall\_2\ (\varphi - \omega\tau) + (\rho\sigma(\pi - \mu)) = G\_R\ (l\text{^}' - mn\text{^}'') \tag{10}$$

Equation 10 $\rho\sigma$, where $\forall_2(\varphi - \omega\tau)$represent bandwidth, latency $\pi - \mu$, and load $G_R$, respectively. It shows IoT-EMVS optimizes video streaming by balancing these elements, making dynamic adjustments to routing and mobility $l' - mn''$to preserve energy efficiency. This equation demonstrates how well the strategy works in enhancing video quality and lowering latency under changeable settings.

$$D\_0 = 1 + [\![er]\!]\text{^}(m-n)\left[M_{(b-g)}\right] * Q\_v\left(K^{\text{^}'} - vb\right) \tag{11}$$

This is the equation 11 that describes the relationship between network circumstances, mobility $1 + er^{m-n}$, and resource allocation $D_0$. To improve data transmission $k' - vb$, the approach adapts to variations in velocity $M_{b-g}$ and optimises quality ($Q_v$), which improves video streaming. Improving initial delivery rate success while controlling energy is the method's aim, as seen by this equation.

$$\mathrm{z\_2 = Y\text{^}'\ (m - er\text{^}'') + F(d\text{^}2\ (l - p)) * Wn} \tag{12}$$

By modelling $Wn$ the efficiency of video streaming $z_2$ according to mobility $m - er''$, energy consumption $Y'$, and resource distribution $d^2(l-p)$, the equation 12 is shown to correspond $F$ with the IoT-EMVS technique. For effective data distribution and consistent excellent video streaming in IoT settings, this equation highlights the need of dynamic modifications.

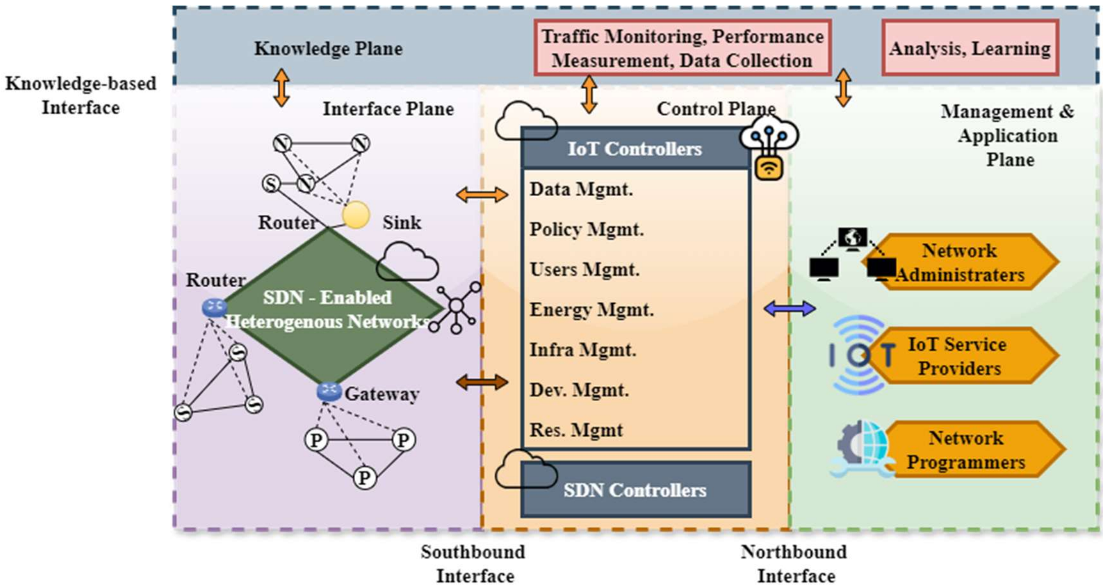


*Figure 4. SDN-Enabled Heterogeneous Network for Efficient IoT Mobility and Video Streaming.*

Figure 4 displays an example of an SDN-enabled heterogeneous network design ideal for IoT video streaming ecosystems. Knowledge, Interface, Control, and Management and Application are the four tiers that comprise the system. In the Interface Plane, there are the sinks, gateways, and routers that let mobile and stationary devices to talk to each other. The Control Plane is responsible for maintaining network stability and optimising resources by managing data, regulations, users, and energy, reporting to the IoT and SDN controllers. The Management & Application Plane architecture is used by programmers, network administrators, and IoT service providers to monitor IoT devices, analyse traffic, and assess performance. The IoT-EMVS framework increases video quality, energy economy, and decreases packet loss in IoT applications by optimising resources, regulating mobility, and supporting seamless communication. This setup is following their guidelines.

$$T_2 (v - er') = \sigma_2 (\rho - \pi) * (\mu(\vartheta - \delta r)) \quad (13)$$

Network factors such as load ($\sigma_2$ ) and routing efficiency $T_2(v - er')$are modelled against the relationship between transmission time ( $\rho - \pi$ ), node velocity $\mu(\vartheta - \delta r)$, and energy consumption in the IoT-EMVS technique. Delivering high-quality video in ever-changing IoT contexts requires energy conservation and network performance, as this equation 13 demonstrates.

$$Y_1 = Mz * (Ev_2 + Yp' (w' - gm'')) \quad (14)$$

A function of the distribution of resources $Y_1$, energy efficiency $Mz$, and modifications for mobility $w' - gm''$ and routing $Ev_2$ is the overall performance $Yp'$. To improve data transmission in IoT networks, this equation 14 highlights the need to balance resource utilization with mobility impacts.

$$[mn]_2 - jk([er]' - bz) = v' - \sin(R_z([2p]_v - w'')) \quad (15)$$

The model that represents the relationship $2p_v - w''$ between many variables $er' - bz$, including network stability ($mn_2$), energy consumption $jk$, routing efficiency ($v'$), mobility ($R$), and resource allocation ($\sin\left(R_z(2p_v - w'')\right)$). Reliable transfer of information in IoT contexts is ensured by optimizing routing and managing energy consumption, as shown by equation 15.

### *3.3 Evaluation of the proposed method using mathematical equation*

This paper shows that compared to the old ways of connecting devices to the internet, IoT-EMVS greatly improves the service quality. By boosting the robustness of IoT-enabled settings, the framework proves through extensive simulations that it improves both the packet delivery ratio and the user experience. This makes it suitable for real-time applications like mobile health monitoring and interactive multimedia services.

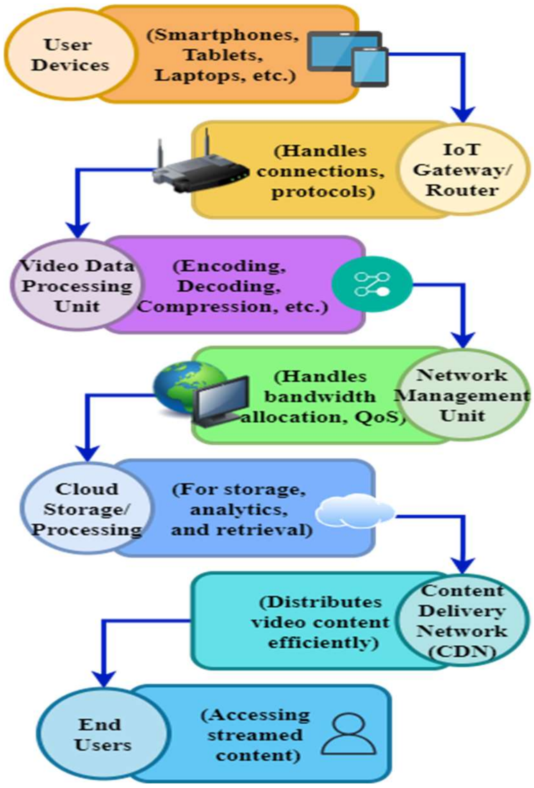


*Figure 5. IoT-Enabled Video Streaming Architecture with Cloud and CDN Integration.*

Figure 5 shows an IoT-based design that optimises video streaming across several network levels to back up the IoT-EMVS framework. User Devices, including smartphones and tablets, initiate the process by transmitting data through Internet of Things Gateways/Routers, which manage connections and protocols. The Video Data Processing Unit handles the data processing, encoding, decoding, and compression to make sure it is sent efficiently. The role of the Network Management Unit is to control distribution of bandwidth and QoS to help balance the load on the network. Content delivery network (CDN) uses the cloud for the efficient storage, processing, and streaming of videos to the viewers. This structure is demanded in smart cities, real-time surveillance, and autonomous applications. Such an architecture is designed to resolve existing difficulties like high energy cost, delays, and high packet loss rate in an IoT ecosystem. It enhances the reliability, robustness and the clarity of the network. The IoT-EMVS described in the current work utilizes resource management and data path optimization technologies to enhance the video streaming in IoT systems. The SDN-based architectural framework adheres to SDN controllers for maximum utilization of the available resources and low-latency services by controlling routing, security, and capacity provisioning, as well as effective data delivery. Mobile and stationary routing procedures enhance video quality by lowering the number of lost packets and enhancing the operational life of the networked devices. The architecture also employs the use of cloud storage and CDNs to allow for easier distribution of video contents to help optimize resource utilization. NAT-EMVS addresses energy efficient problems which results to a novel network architecture which is also green and more scalable. Comprehensive simulations also demonstrate that the framework records better packet delivery ratios, energy efficiency and overall service quality than current connectivity models adapted in the context of IoT. This makes it suitable for applications using awareness and real-time information, such as smart cities, m-health systems, and interactive multimedia applications.

$$|(|g(Y, z)|)| = D(1 - u|v| * Q - 2k) * M(y \equiv \forall) \tag{16}$$

The equation 16 is related to the IoT-EMVS approach since it models the effect of energy consumption $||g(Y,z)||=$, quality of service $D$, and the distribution of resources $1-u|v|$ on network efficiency $Q-2k$ and overall performance $M(y\equiv\forall)$ . Careful monitoring of network settings is crucial for ensuring high-quality communication of data in dynamic IoT contexts, as shown by this equation 16 on network lifetime extension analysis.

$$z_p v' = \{3Q(y,p)\} + E_{(v(k-2v))}^{z'} - M(y' - \forall\partial) \quad (17)$$

Several characteristics of the network $M(y'-\forall\partial)$, such as packet delivery $z_p v'$, node velocity $E_{v(k-2v)}^{z'}$, and energy consumption $3Q(y,p)$, are included in the equation 17. Reliable transfer of data and high-quality service in unpredictable IoT contexts are ensured as shown by this equation for latency analysis.

$$R_{(m-n)} = E'(\partial_\forall - nk) + \sigma\delta(\beta - \alpha r) \quad (18)$$

To improve data delivery $\partial_\forall - nk$ and keep service quality high in ever-changing IoT environments $\sigma\delta$, adaptive resource management is crucial $\beta-\alpha r$. This equation is related to the IoT-EMVS method and models the relationship between routing efficiency ($R_{m-n}$). This equation 18 energy consumption, and network parameters are affected by load and routing adjustments.

$$-\forall\partial = R(\omega - \varphi\tau) + \rho\pi(\vartheta - pk) - E(\theta) \quad (19)$$

To optimize video streaming regardless $(\theta\delta+m)$ of changes in mobility and bandwidth, the equation 19 connects routing performance $-\forall\partial$, load $R(\omega-\varphi\tau)$, and energy usage $\rho\pi(\vartheta-pk)$. Reliable transmission of information in ever-changing IoT contexts relies on this equation's emphasis on the vital balance between energy management on scalability analysis.

$$A_{(b-m)} \geq jk(n^2 - Wq) * E(m' - fr) \quad (20)$$

A network performance threshold, denoted as $A_{b-m}$, is defined by the $E$ that arises from the interplay of routing efficiency $jk$, load $n^2-Wq$, and energy consumption $m'-fr$. To keep data transmission quality good in ever-changing IoT contexts this disparity is highlighted in video quality and bandwidth utilization analysis in equation 20. The proposed IoT-EMVS architecture improves the performance of video streaming in IoT systems by managing resources and optimising data paths. To provide effective data transfer with minimum latency, the framework uses SDN controllers to govern key network operations including routing, security, and capacity allocation. Cooperative routing methods ensure that mobile and stationary devices collaborate to increase video quality, decrease packet loss, and increase embedded network device lifetime. The design incorporates cloud storage and Content Delivery Networks (CDN) to help distribute video content to enable effective resource consumption further. The IoT-EMVS framework considers issues with energy consumption, leading to a network architecture that is both sustainable and easier to scale. Extensive simulations show that the framework outperforms conventional IoT connectivity models regarding packet delivery ratios, energy efficiency, and overall service quality. This makes it an excellent fit for real-time applications like smart cities, interactive multimedia services, and mobile health monitoring.

## 4 Results and Discussion

SDN-controlled embedded networks are optimised for Internet of Things connection, network endurance, and scale using cooperative routing protocols. Operational efficiency depends on energy, latency, scalability, and bandwidth. Due to rising IoT devices and changeable environments. We strive to increase IoT ecosystems' network durability, latency, energy efficiency, scalability, and video quality.

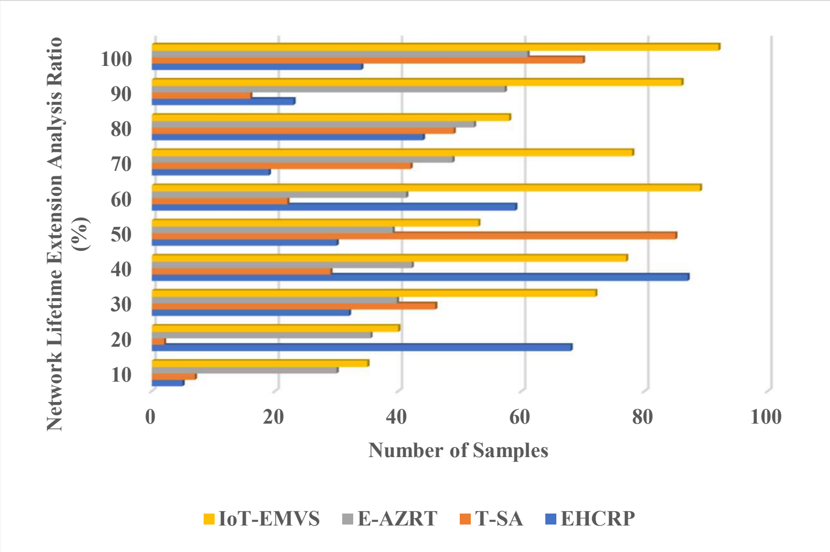


*Figure 6. Network Lifetime Extension Analysis.*

In the above Figure 6, for embedded networks controlled by SDN that use cooperative routing to improve IoT connectivity and network longevity, lifespan extension research is essential. Due to the growing number of IoT applications, especially in dynamic environments, operational efficiency must be maintained. The present research aims to determine the most important factors energy consumption, resource allocation, and efficient routing algorithms that affect network lifetime. Devices can coordinate data path optimisation via cooperative routing protocols, reducing power consumption and network failures. Real-time network changes are possible with adaptive algorithms, this is crucial for mobile device and dynamic topology control. Prioritising energy-efficient communication protocols extends embedded device battery life, making them more valuable produces 92.9% using equation 16. Simulations show how these innovative techniques can greatly extend the lifetime of a network, ensuring the reliability and responsiveness of Internet of Things applications. This analysis emphasises the relevance of eco-friendly practices in IoT networks and how innovative frameworks like the IoT-EMVS might advance communication technology.

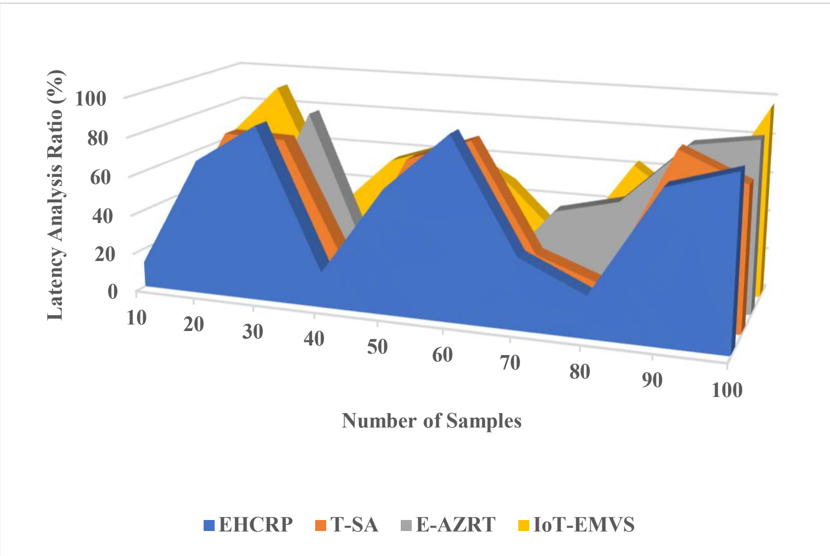


*Figure 7. Latency Analysis.*

Latency analysis is essential for SDN-managed embedded networks using cooperative routing to improve IoT connection and network life. IoT environments, especially real-time applications like remote monitoring and video streaming, need minimal latency to assure data transmission and user satisfaction. In the above figure 7, several latency factors are examined in this investigation, including routing protocol efficiency, network design modifications, and device mobility. Cooperative routing technologies allow devices to change data paths dynamically. This accelerates network packet delivery. Adaptive algorithms provide real-time network-state assessments; this capacity is needed to repair device mobility-induced oscillations. The simulation findings show that effective routing systems reduce latency, improving communication quality. SDN infrastructures optimise bandwidth usage and resource distribution, reducing latency. This analysis contains two primary points. It highlights how difficult it is to reduce latency in complicated IoT networks produces 97.5% using equation 17. It shows how novel frameworks like IoT-EMVS may help, increasing performance and usability in many applications.

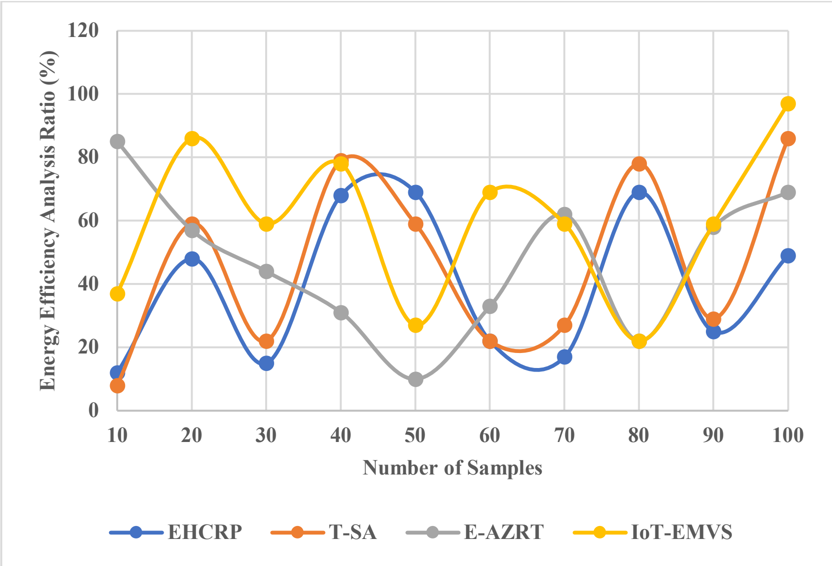


*Figure 8. Energy Efficiency Analysis.*

Energy efficiency analysis is crucial to boosting IoT connection and network functionality in SDN-controlled embedded networks with cooperative routing. Due to their limited battery capacity, Internet of Things devices must be optimised for energy management to work properly. In the above Figure 8, this research aims to reduce energy utilisation without compromising communication rates. By allowing devices to share data, cooperative routing protocols improve routing patterns and energy use, and adaptive algorithms enable dynamic resource allocation based on network conditions, optimising energy utilisation. The purpose of this study is to reduce energy without sacrificing performance. These opportunities can be found in gearbox power, routing overhead, and stationary states. The modelling results suggest that these novel techniques could boost energy efficiency, extending device life. Further, energy-efficient communication solutions help IoT ecosystems establish sustainable behaviours, which increases their ability to handle complicated applications produces 97.6% using equation 18. For this energy efficiency analysis, IoT-EMVS are crucial. In IoT contexts, these frameworks will improve communication, resource management, and embedded lifespans of networks.

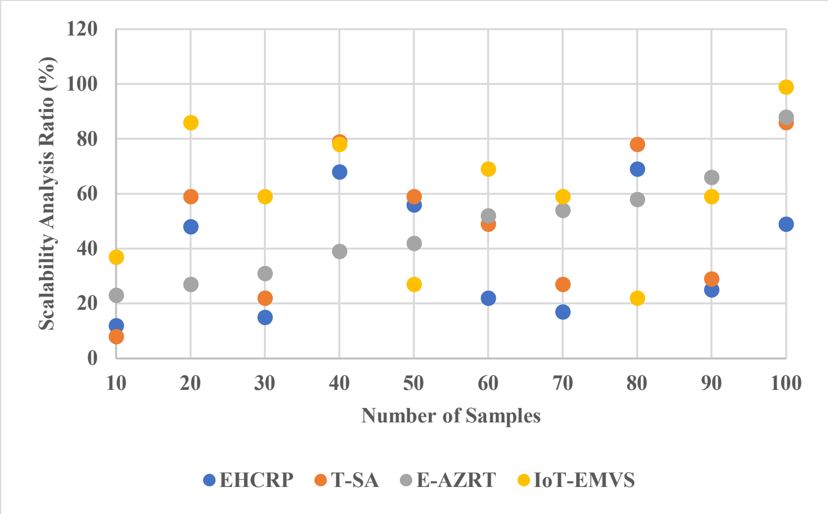


*Figure 9. Scalability Analysis.*

SDN-controlled cooperatively routed embedded networks need scalability research to improve IoT connectivity and network durability. A network's capacity to accommodate this expansion without compromising speed is becoming increasingly important as the number of IoT devices grows tremendously. In the above figure 9, the present research explores the issues of increasing IoT networks: routing, data traffic control, and resource distribution. To effectively handle the increased load, devices can use cooperative routing protocols to optimise data pathways and share routing information. SDN enables centralised control, consequently network settings and resource allocation can be adjusted in real time based on resource utilisation. The analysis aims to find efficient ways to maintain performance as the network increases produces 99.7% using equation 19. The comparison of packet delivery ratios, latency, and throughput across different device densities is the way to arrive at these aforementioned solutions. The simulation shows that these solutions considerably improve scalability, which is essential for IoT systems to manage large-scale deployments' complexity while preserving efficiency and dependability.

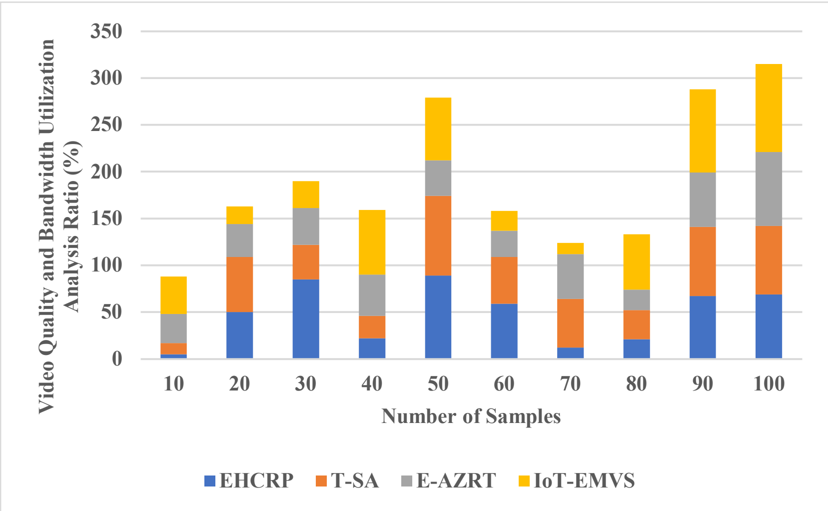


*Figure 10. Video Quality and Bandwidth Utilization Analysis.*

Measuring video quality and bandwidth utilisation is necessary to improve connection for the IoT, as well as to enhance the longevity of networks that SDN manages and to make use of cooperative routing. Since video streaming is becoming more frequent in Internet of Things applications, bandwidth optimisation and high-quality video are essential for user enjoyment and resource management. In the above figure 10, the present research investigates how cooperative routing algorithms improve data transmission efficiency and video quality. Allowing devices to exchange routing details and make course changes as needed reduces network congestion and optimises bandwidth usage. In addition, adaptive bitrate streaming can modify video quality in real time based on bandwidth. This ensures flawless viewing independent of network changes. Better bandwidth management produces higher-quality video with fewer buffering occurrences, making users more satisfied, according to simulations. Bandwidth use additionally improves embedded equipment life by eliminating unnecessary power consumption. The IoT-EMVS framework is needed to improve video quality and bandwidth management, according to this research produces 94.8% using equation 20. A more effective and dependable ecosystem for the Internet of Things will be developed as a result of this, which is absolutely necessary for the purpose of satisfying the requirements of modern applications in Table 2.

*Table 2. Comparison table.*

| **Analysis** | **Key Focus** | Arc time, min | Heat input, J/mm | Electrical energy consumption, kWh |
|---|---|---|---|---|
| **Network Lifetime Extension** | Extending the lifetime of SDN-controlled embedded networks using cooperative routing for IoT. | Energy consumption, resource allocation, efficient routing algorithms, and real-time network adaptability. | Network lifetime extended by optimizing data paths and reducing power consumption. | 92.9% using equation 16 |
| **Latency Analysis** | Reducing latency for SDN-managed networks, especially for real-time IoT applications like video streaming. | Routing protocol efficiency, network design changes, and device mobility. | Reduced latency and improved communication quality. | 97.5% using equation 17 |
| **Energy Efficiency Analysis** | Enhancing energy efficiency in SDN-controlled embedded networks to support IoT devices with limited battery. | Transmission power, routing overhead, and dynamic resource allocation via adaptive algorithms. | Increased energy efficiency, longer device life. | 97.6% using equation 18 |
| **Scalability Analysis** | Ensuring IoT networks can scale without compromising performance. | Routing, data traffic control, real-time resource distribution, and device density management. | Improved scalability, better performance with higher device densities. | 99.7% using equation 19 |
| **Video Quality and Bandwidth** | Optimizing bandwidth for high-quality video streaming in IoT networks. | Cooperative routing, adaptive bitrate streaming, and real-time bandwidth management. | Higher video quality, reduced buffering, and optimized bandwidth utilization. | 94.8% using equation 20 |

According to the paper, cooperative routing protocols and adaptive algorithms greatly increase network lifespan, reduce latency, and improve energy economy in embedded software-defined networking networks. Data transmission and video quality improve with bandwidth scalability and efficiency from effective routing systems.

## 5 Conclusion

With the implementation of its IoT-EMVS architecture, embedded networks that are governed by SDN have at recently found a solution to the issues that have been affecting communication and network lifespan. Video streaming in IoT ecosystems improves with IoT-EMVS. Critical challenges including energy usage, changing network topologies, and packet loss during video transmission are managed well. Cooperative routing systems increase device collaboration and optimise data flow and resource management. These improvements are essential for dynamic communication, by lowering latency and improving video quality, the framework's mobile handoff improves user experience. Its wide range of applications makes IoT-EMVS valuable and could impact many industries. It benefits smart cities, driverless vehicles, and real-time mobile health monitoring. Compared to traditional IoT connecting approaches, the architecture saves electricity, improves packet delivery ratios, and improves service quality. In addition to laying the groundwork for future developments in video streaming over the IoT, this study emphasises the significance of dependable communication protocols and tactics for the management of social networks. IoT-EMVS could help create IoT applications by focussing on dependability, scalability, and energy conservation.

## References


[1] K. Saeed, W. Khalil, S. Ahmed, I. Ahmad, and M.N.K Khattak, "SEECR: Secure energy efficient and cooperative routing protocol for underwater wireless sensor networks," *IEEE Access*, vol. 8, pp. 107419-107433, 2020, doi: 10.1109/ACCESS.2020.3000863.

[2] K.S. Bhandari, and G.H. Cho, "An energy-efficient routing approach for cloud-assisted green industrial IoT networks," *Sustainability*, vol. 12, no.18, pp. 7358, 2020, doi: 10.3390/su12187358.

[3] M. Z. Hussain, and Z. M. Hanapi, "Efficient secure routing mechanisms for the low-powered IoT network: A literature review," *Electronics*, vol. 12, no.3, pp. 482, 2023, doi: 10.3390/electronics12030482.

[4] M. Shafiq, H. Ashraf, A. Ullah, M. Masud, M. Azeem, N.Z. Jhanjhi, and M. Humayun, "Robust cluster-based routing protocol for iot-assisted smart devices in WSN," *Computers, Materials & Continua,* vol. 67, no. 3, pp. 3505-3521, 2021, doi: 10.32604/cmc.2021.015533

[5] L. Kaur, and R. Kaur, "A survey on energy efficient routing techniques in WSNs focusing IoT applications and enhancing fog computing paradigm," *Global transitions proceedings*, vol. *2*, no. 2, pp. 520-529, 2021, doi: 10.1016/j.gltp.2021.08.001.

[6] A. Al Hayajneh, M.Z.A. Bhuiyan, and I. McAndrew, "A novel security protocol for wireless sensor networks with cooperative communication," *Computers*, vol. 9, no. 1, pp. 4, 2020, doi: 10.3390/computers9010004.

[7] F. Jibreel, E. Tuyishimire, and M.I. Daabo, "An enhanced heterogeneous gateway-based energy-aware multi-hop routing protocol for wireless sensor networks," *Information*, vol. 13, no. 4, pp. 166, 2022, doi: 10.3390/info13040166.

[8] Z. Wang, H. Ding, B. Li, L. Bao and Z. Yang, "An Energy Efficient Routing Protocol Based on Improved Artificial Bee Colony Algorithm for Wireless Sensor Networks," in IEEE Access, vol. 8, pp. 133577-133596, 2020, doi: 10.1109/ACCESS.2020.3010313.

[9] H. Gul, G. Ullah, M. Khan, and Y. Khan, "EERBCR: Energy-efficient regional based cooperative routing protocol for underwater sensor networks with sink mobility," *Journal of Ambient Intelligence and Humanized Computing*, pp. 1-13, 2023, doi: 10.1007/s12652-020-02781-7.

[10] S.K. Gupta, and S. Singh, "Survey on energy efficient dynamic sink optimum routing for wireless sensor network and communication technologies," *International Journal of Communication Systems*, vol. 35, no. 11, pp. e5194, 2022, doi: 10.1002/dac.5194.

[11] P.K. Devulapalli, P.S. Pokkunuri, and S. B. Maganti, "Energy efficient multi-hop cooperative transmission protocol for large scale mobile ad hoc networks," *Wireless Personal Communications*, vol. 121, no. 4, pp. 3309-3328, 2021, doi: 10.1007/s11277-021-08878-2.

[12] K.A. Darabkh, O.M. Amro, R.T. Al-Zubi, and H.B. Salameh, "Yet efficient routing protocols for half-and full-duplex cognitive radio Ad-Hoc Networks over IoT environment," *Journal of Network and Computer Applications*, vol.173, pp. 102836, 2021, doi: 10.1016/j.jnca.2020.102836.

[13] M. U. Younus, M. K. Khan and A. R. Bhatti, "Improving the Software-Defined Wireless Sensor Networks Routing Performance Using Reinforcement Learning," in IEEE Internet of Things Journal, vol. 9, no. 5, pp. 3495-3508, 1 March1, 2022, doi: 10.1109/JIOT.2021.3102130.

[14] T. Safdar Malik, K.R. Malik, A. Afzal, M. Ibrar, L. Wang, H. Song, and N. Shah, "RL-IoT: Reinforcement Learning-Based Routing Approach for Cognitive Radio-Enabled IoT Communications," *In IEEE Internet of Things Journal,* vol. 10, no. 2, pp. 1836-1847, 2023, doi: 10.1109/JIOT.2022.3210703.

[15] M.D. Khan, Z. Ullah, A. Ahmad, B. Hayat, A. Almogren, K.H. Kim, and M. Ali, "Energy harvested and cooperative enabled efficient routing protocol (EHCRP) for IoT-WBAN," *Sensors*, vol. 20, no. 21, pp. 6267, 2020, doi: 10.3390/s20216267.

[16] H. Q. Al-Shammari, A. Q. Lawey, T. E. H. El-Gorashi and J. M. H. Elmirghani, "Resilient Service Embedding in IoT Networks," *In IEEE Access*, vol. 8, pp. 123571-123584, 2020, doi: 10.1109/ACCESS.2020.3005936.

[17] N. Djedjig, D. Tandjaoui, F. Medjek, and I. Romdhani, “Trust-aware and cooperative routing protocol for IoT security,” *Journal of Information Security and Applications*, vol. 52, pp. 102467, 2020, doi: 10.1016/j.jisa.2020.102467.

[18] M. Ilyas, Z. Ullah, F.A. Khan, M.H. Chaudary, M.S.A. Malik, Z. Zaheer, and H.U.R. Durrani, “Trust-based energy-efficient routing protocol for Internet of things–based sensor networks,” *International Journal of Distributed Sensor Networks*, vol. *16*, no. 10, 1550147720964358, 2020, doi: 10.1177/1550147720964358.

[19] S. Iqbal, K.N. Qureshi, N. Kanwal, and G. Jeon, “Collaborative energy efficient zone-based routing protocol for multihop internet of things,” *Transactions on Emerging Telecommunications Technologies*, vol. 33, no. 2, pp. e3885, 2022, doi: 10.1002/ett.3885.

[20] U. Draz, A. Ali, M. Bilal T. Ali, M.A. Iftikhar, A. Jolfaei, and D.Y.U. Suh, "Energy Efficient Proactive Routing Scheme for Enabling Reliable Communication in Underwater Internet of Things," in IEEE Transactions on Network Science and Engineering, vol. 8, no. 4, pp. 2934-2945, 2021, doi: 10.1109/TNSE.2021.3109421.

[21] C. R. K. J, V. K. D, M. A. B, B. D, and M. A. Majid, "Energy-Efficient Adaptive Clustering and Routing Protocol for Expanding the Life Cycle of the IoT-based Wireless Sensor Network," *2022 6th International Conference on Computing Methodologies and Communication (ICCMC),*2022, pp. 328-336, doi: 10.1109/ICCMC53470.2022.9753809.

[22] Dhandapani, A., Venkateswari, P., Sivakumar, T., Ramesh, C., & Vanitha, P. (2022). Cooperative self-scheduling routing protocol based IOT communication for improving life time duty cycled energy efficient protocol in SDN controlled embedded network. Measurement: Sensors, 24, 100475.

[23] Younus, M. U., Khan, M. K., & Bhatti, A. R. (2021). Improving the software-defined wireless sensor networks routing performance using reinforcement learning. IEEE Internet of Things Journal, 9(5), 3495-3508.

[24] Kamarudin, I.E., Ameedeen, M. A., Ab Razak, M. F., & Zabidi, A. (2023). Integrating Edge Computing and Software Defined Networking in Internet of Things: A Systematic Review. Iraqi Journal for Computer Science and Mathematics, 4(4), 121-150