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A Multi-Constraints Routing Scheme for MANET-assisted IoT in Smart Cities

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Abstract

The fifth-generation mobile network (5G) provides extreme throughput and extremely low latency, which enables the Internet of Things (IoT) era and a series of smart IoT ecosystems. The widespread equipping of Device-to-Device (D2D) modules for vehiculars allows transmitting directly between devices without relying on central devices such as access points or base stations. This is the foundation for the shaping of mobile ad hoc communications, so-called MANETs. The combination of MANETs and IoT technology has led to the development of MANET-assisted IoT applications, which offer unprecedented capabilities. However, due to the mobility of network nodes, routing is one of the main challenges in these networks. To address this problem, we propose a multi-constraints routing schema to enhance the performance of MANET-assisted IoT systems. Our simulation experiments show that the proposed solution significantly outperforms traditional routing solutions in terms of performance such as latency, packet delivery ratio, and throughput.

Keywords: Performance, Energy, Multi-Constraints, Routing Protocol, MANET-assisted IoT

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1. Introduction

In recent years, the rapid proliferation of IoT applications across various domains has ushered in the Internet of Things (IoT) era [1-2]. The IoT represents a convergence of smart devices, applications, infrastructure, platforms, solutions, and human interactions enabled by the underlying Internet infrastructure [3]. A key communication technology that shapes the IoT is Device-to-Device (D2D) communication, which allows direct communication between IoT devices without relying on pre-existing infrastructure such as base stations or access points [4-5]. The interconnected arrangement of IoT devices through D2D communication forms the basis of Mobile Ad hoc Networks (MANETs) [6-7]. By combining MANETs with IoT technology, MANET-assisted IoT architectures are created, offering unprecedented capabilities [8-10]. An illustrative example of a Clustering-based MANET-IoT Applications is depicted in Fig. 1.

While this integration brings numerous advantages and flexible communication capabilities, it also presents challenges related to performance, security, Quality of Service (QoS), and energy consumption [11-12]. Extensive research has shown that routing plays a crucial role in addressing these challenges [13-14]. The mobile nature of wireless nodes in MANETs results in frequent link disconnections, necessitating frequent routing and retransmissions [15]. These issues collectively lead to suboptimal performance, increased power consumption, and compromised quality of service.

The presented findings emphasize the pressing need for efficient routing protocols in MANET-assisted IoT architectures. While some conventional hop-based routing schemes like AODV and DSR have been proposed for MANETs, studies have demonstrated their limitations

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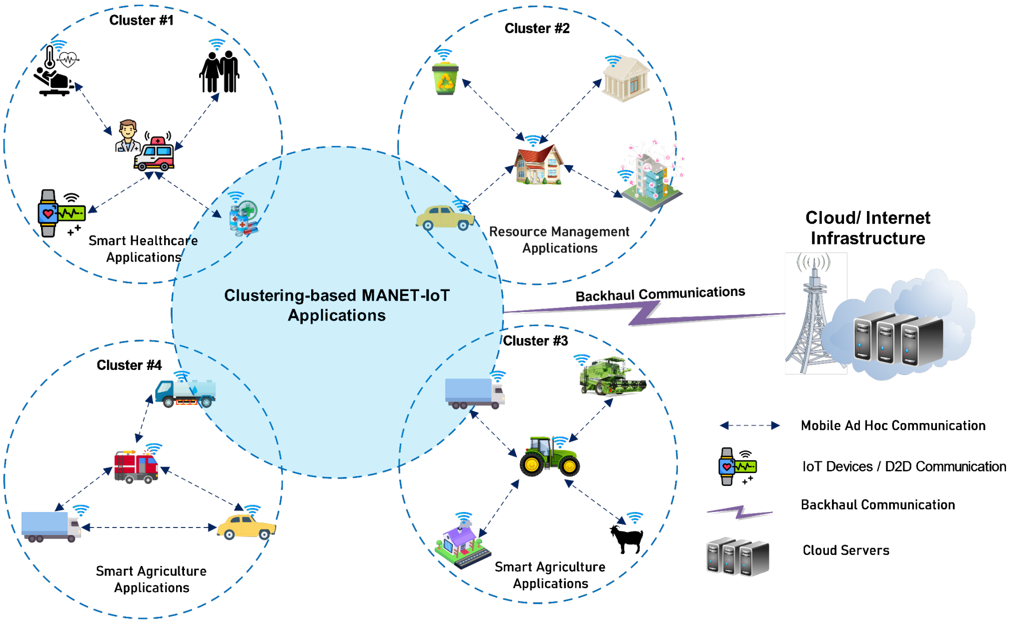

Figure 1. An illustration of Clustering-based MANET-IoT Applications.

when relying solely on hop count as a routing parameter [16-17].

It is evident that an optimal route must fulfill various constraints, including distance, bandwidth, delay, power consumption, and node capacity [18-20]. However, incorporating multiple routing parameters simultaneously can lead to NP-complete complexity issues [21-22]. One potential solution is to aggregate individual routing parameters into a comprehensive parameter using a routing cost function, as introduced in previous research [23-24].

In MANET-assisted IoT systems, performance is influenced by factors such as system size, communication environment, and interaction models. Wireless nodes collaborate in routing and forwarding packets towards their destinations through neighboring nodes [25]. Consequently, dynamic decision-making regarding the next hops for data transmission takes place, considering link conditions and the chosen routing scheme. Routing schemes thus play a pivotal role in enhancing overall system performance.

To address these challenges, we propose a novel multi-constraints routing scheme that improves upon the AODV routing scheme by integrating hop count and throughput bottleneck into the cost function. Through simulations, our proposed algorithm demonstrates enhanced performance and reduced latency compared to existing routing algorithms. The rest of the paper is organized as follows. Section 2 provides the related works. Section 3 describes our routing scheme. Section 4 presents the efficiency of the proposed scheme and Section 5 is the conclusion.

2. Related Works

The performance challenge remains a significant hurdle in mobile communication systems [26-27]. The dynamic nature of wireless nodes results in frequent changes in the network structure, leading to significant degradation in network performance due to re-transmissions and re-routing. In recent years, researchers have proposed various advanced routing schemes to enhance system performance in MANETs, employing different approaches and achieving positive outcomes. We summarize some notable results as follows.

Kumari et al. (2022) [28] introduced an optimal routing scheme that leverages the advantages of the ant colony optimization (ACO) and particle swarm optimization (PSO) algorithms. These routing schemes are integrated into the AODV routing protocol to enhance its effectiveness. Simulation results demonstrate that the proposed solution significantly improves performance metrics such as delay, throughput, and overhead compared to existing routing schemes.

Sharma et al. (2023) [29] developed an efficient weight-based clustering algorithm tailored for military-MANETs. Particularly in electronic warfare scenarios, real-time and dynamic communication between autonomous robots and unmanned military vehicles (UMVs) play a crucial role. To address this, the authors tackle the vehicle clustering problem by selecting a cluster head (CH) based on two weighted factors: real-time average speed and node degree. Simulation experiments using SUMO and NETSIM show that the proposed solution outperforms traditional AODV and DSR routing protocols, achieving significant performance improvements.

Al-Zahrani et al. (2020) [30] proposed an advanced routing model aimed at enhancing performance in multi-hop ad hoc networks. They improved the search set values and intervals of traditional routing schemes to optimize overall performance. Additionally, they integrated flooding algorithms into various routing protocols to consider energy consumption and system performance. Simulation results demonstrate that the proposed routing models significantly outperform existing models in terms of energy efficiency and performance in multi-hop ad hoc networks.

Manogaran et al. (2021) [31] introduced a novel AI-based routing model designed for drone-assisted vehicular networks in urban environments. Their approach involves seamless vehicle handover based on classification learning techniques and utilizes a decisive data dissemination model (D3M) to mitigate handoff failures. Simulation results highlight that the proposed model exhibits remarkable improvements in latency, data rate, backlog, and failure rates compared to traditional routing models.

In the context of ad hoc vehicular networks in smart cities, *Safavat et al.* (2021) [32] employed a heuristics-based approach and proposed an ant colony optimization-based routing scheme to enhance privacy and security. They specifically addressed privacy and security concerns in intelligent transportation systems within the 5G framework. By integrating the ECC (elliptic curve cryptography) technique into the ACO-AODV routing protocol, they achieved communication security in IoV (Internet of Vehicles) networks. Simulation results demonstrate that the proposed solution excels in terms of malicious vehicle detection, secure communication, and routing compared to existing schemes.

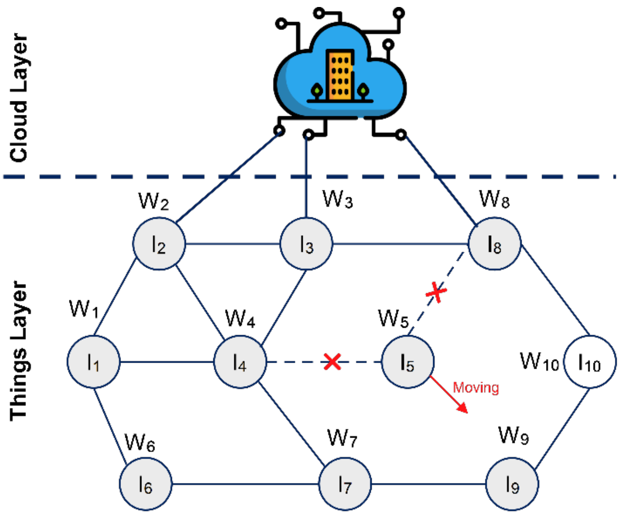

Figure 2. A graph model of a MANETs- IoT structure

These surveyed findings emphasize the significant roles and contributions of MANETs in shaping the future of the Internet of Things era. Moreover, they highlight that routing issues represent major challenges in mobile ad hoc network environments. In dynamic smart cities, the integration of MANETs and IoT systems forms novel MANET-assisted IoT architectures that enable the development of unprecedented capabilities and capacities.

Integrating MANETs into diverse IoT systems for multimedia applications requires the development of intelligent and flexible QoS-aware routing schemes. In the upcoming section, we present our proposed QoS-aware multi-constraints routing scheme. The intricate calculations and methodology are elaborated in Section 3.

3. MCR Routing Scheme

In this section, we introduce our proposed routing scheme, called the Multi-Constraints Routing (MCR) scheme, which incorporates multiple metrics such as distance and bottleneck throughput. The main objective of this routing scheme is to ensure QoS guarantees and enhance the overall performance of MANET-assisted IoT systems. We provide a detailed description of the proposed routing scheme in the following subsections.

3.1 System Model

To illustrate the fundamental principles and structure of the proposed routing scheme, we introduce a model for MANET-assisted IoT systems, as depicted in Fig. 2. In this model, each IoT node is assigned a weight that represents its capabilities, such as remaining battery capacity, hardware platform, and queue length. Based on this system model, we establish the interconnection architecture, denoted as $G = (V, E)$, where $V = \{I_1, I_2, \cdots, I_n\}$ represents the set of IoT devices, and E represents the set of links. An edge (I_i, I_j) exists between two devices I_i and I_j if they have a direct connection.

To address the performance challenges faced by MANET-assisted IoT systems, we define the interconnection architecture using a node-weighted graph. Each IoT device I_i is represented as a pair (I_i, W_i), where W_i denotes the bottleneck throughput of I_i. The IoT devices can establish direct connections with other devices or communicate indirectly through local devices in-network.

3.2 Operation Principle

The proposed scheme operates based on the principles of the AODV protocol, specifically its smallest hops number-based routing scheme, which has been previously introduced for mobile ad hoc networks by the IETF (Internet Engineering Task Force) [33]. Our MCR scheme follows a reactive approach, wherein an IoT device initiates the route discovery procedure to find an optimal route to the destination node that satisfies the given constraints.

To initiate the route discovery procedure, the source node broadcasts route request (RREQ) packets with a modified header, including {*MinThroughput, AODV RREQ Header*}. These RREQ packets are propagated through intermediate nodes until they reach the destination node. In the traditional AODV routing scheme, each intermediate node simply increments the hop count of the route by one unit. However, in our approach, in addition to this step, intermediate nodes also trigger the bottleneck throughput discovery procedure. This procedure aims to determine the bottleneck throughput of the route and is further illustrated in detail in Fig. 3. The primary task of this procedure is to compare and store the throughput of the route.

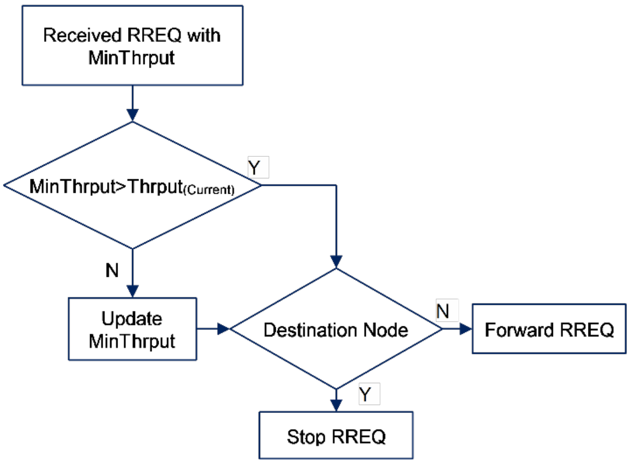

Figure 3. Bottleneck Throughput Discovery Procedure

Upon receiving the RREQ packet, the destination node will send a unicast RREP (Route Reply) packet to the source node, with the modified header {*MinThroughput, AODV RREP Header*}. Similar to the AODV routing scheme, our scheme includes route maintenance procedures that utilize RRER (Route Error) packets. Once this procedure is completed, the source node obtains valid paths, as depicted in Fig. 4.

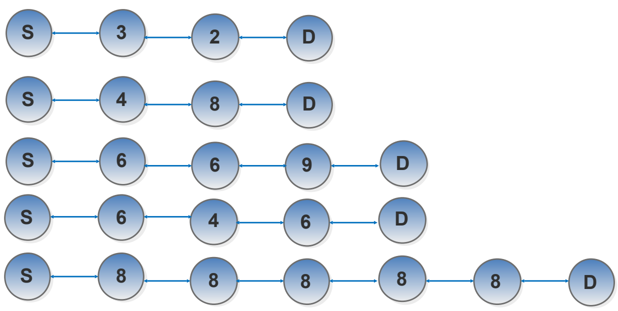

Figure 4. The set of paths between a pair (S, D) after the discovery phase

3.3 Path Selection Multi-Constraints

The right-after destination node collects a set of positive paths through the path identifies procedure, for the purpose of optimization, these paths need to satisfy specify two constraints, as follows:

1) The hops number of these positive paths must be within $[Hopmin, Hopmax]$. The routes with the hops number exceeding this range will be removed.

$$Hops\_Number = [Hopmin, Hopmax] \tag{1}$$

where $Hopmin$ is the hops number of the shortest path of a pair (S, D). For purpose of reducing the number of considered paths to optimize the system, the MRS defines $Hopmax = Hopmin + k$ (k is a natural number). In this research, we install $k = 1$.

2) In paths that satisfy the first *hops number* condition, to determine paths that meet QoS requirements, the destination node needs to identify the candidate path with maximal throughput and no overload, as follows:

Denoted $Throughput_{(i)}$ be the bottleneck throughput of path i received via the $MinThroughput$ field of the RREP packet.

Denoted n and $ThroughputSet$ are the numbers of paths and cost set of the candidate paths, respectively. We have:

$$ThroughputSet = \begin{bmatrix} Throughput_{(1)} \\ Throughput_{(2)} \\ \vdots \\ Throughput_{(n-1)} \\ Throughput_{(n)} \end{bmatrix} \tag{2}$$

$$Optimalpath = Max(ThroughputSet) \tag{3}$$

The optimal path is identified by Equation (3). We summarize the path selection algorithm in Algorithm 1.

Algorithm 1: MCR algorithm

$path\_set = candidate(S, D)$
$minhop = min(path\_set)$
$maxhop = minhop + 1$
$constraint1 = \emptyset$
for $i = 1$ *to* $maxsizeof(path\_set)$ **do**
  if $numhop(path\_set(i)) \le maxhop$ **then**
    $constraint1 \leftarrow path(i)$
  endif
end for
$cost = 0$
$thput = 100$
for $t = 1$ *to* $sizeof(constraint1)$ **do**
  $thput = minthroughput(constraint1(t))$
  if $cost < thput$ **then**
    $cost = thput$
    $optimizepath = constraint1(t)$

Algorithm 1: MCR algorithm

```
        end if
    end for
    return(cost, optimizepath)
```

Assuming that, there exist five paths between a pair of source nodes (S) and the destination node (D), each link of a pair of nodes has the throughput as shown in Fig. 4, $Hopmin = 3$ and $Hopmax = 4$. With the information obtained, using the cost Equation (1), the $PathID$ #5 will be removed and according to Equation (3), the MCR scheme will select $PathID$ #4 with the highest throughput value $MCR = 6$, as presented in Table I.

TABLE I: METHOD OF CALCULATING THE COST OF THE ROUTE

PathID	*Hops*	MinThroughput	*MCR*
1	3	2	2
2	3	4	4
3	4	5	5
4	4	6	6
5	5	8	*Discarded*

The results have demonstrated that, by accounting for distance and bottleneck through of routes, our proposed solution provides QoS-aware, and stable, balancing paths. Moreover, in our opinion, this scheme has also improved overall effectiveness and energy consumption.

4. Results and Analysis

To evaluate the efficacy of our proposed solution, we integrate the routing scheme into the AODV protocol, resulting in the MRS_AODV protocol. We then proceed to compare the performance of MCR_AODV with that of the traditional AODV [33] and DSR [34] protocols. We conduct simulations using the network simulator tool (NS2) [35], version 2.34, the network traffics are changed by considering the number of end-to-end connections.

4.1 Performance Parameters

For the purpose of effectiveness comparison of the CRM_AODV and other routing schemes, we have defined performance parameters, specify as follows.

1) $Packet\ Delivery\ Ratio\ (PDR)$: defined as the ratio of the number of successfully received packets to the destination nodes (P_d) and the number of delivered packets of the source nodes P_s.

$$PDR = (P_d/P_s) \times 100\% \qquad (4)$$

2) $Average\ End-to-End\ Delay\ (Delay)$: defined as the period taken for packets to be transmitted across the network from source to destination.

$$\text{Delay}_{\text{avg}} = \frac{\sum_{i=1}^{n}(t_r - t_s)}{P_r} \qquad (5)$$

3) $Throughput$: shows the transmission capacity of the network, which is determined by multiplying the number of transmitted packets and the packet size per time unit.

$$\text{Throughput} = \frac{P_r \times \text{KT}}{T} \qquad (6)$$

TABLE II: SIMULATION PARAMETERS

Parameter	Value
Simulation Area	2000×2000 (m)
Simulation Time	300 (s)
Number Nodes	200
MAC Layer	802.11b
Propagation Model	Two-Ray Ground
Auto Rate Fallback (ARF)	-85dBm
Transport Layer	UDP
Size of Packets	512 (byte)
Transmission Range	100 (m)
Mobile Node Speed	2 (m/s)
$Hopmax$	$Hopmin + 1$
Mobility Model	Random Waypoint
Routing Schemes	MCR, AODV, DSR

4.2 Simulation Parameters

We have set up simulation scenarios with parameters that are described as follows. The system consists of 200 ad hoc mobile IoT nodes, the mobility speed of these nodes is set up at 2 m/s, and using model random waypoint in a square area: 2000×2000 (m). Because our main goal is considering this algorithm in an urban context, hence, we install a low mobility speed. The speed 2m/s or 7.2 km/h is equivalent to the bike speed or popular mobilities of humans in urban. We have also installed the size of packets as 512 bytes, simulation time of all scenarios is 300 seconds. For the purpose of network traffic simulation, we have set up the number of end-to-end connections as a constant bit rate (CBR). The number of end-to-end connections measured at $[50, 10, \cdots, 50]$. Some other simulation parameters are listed in Table II.

4.3 Result Analysis

Fig. 5 illustrates the effectiveness of our proposed solution, *MCR_AODV*, in comparison to other routing schemes, using the packet delivery ratio (PDR) as the evaluation criterion. The simulation results demonstrate that when the number of end-to-end connections is low, the packet delivery ratio (PDR) achieved by all routing schemes is relatively high and equivalent. However, as the network traffic increases with a higher number of end-to-end connections, the PDR of the protocols decreases. This decrease is caused to the growing conflicts and collisions among packets, leading to re-routings, re-transmissions and overloading of network nodes.

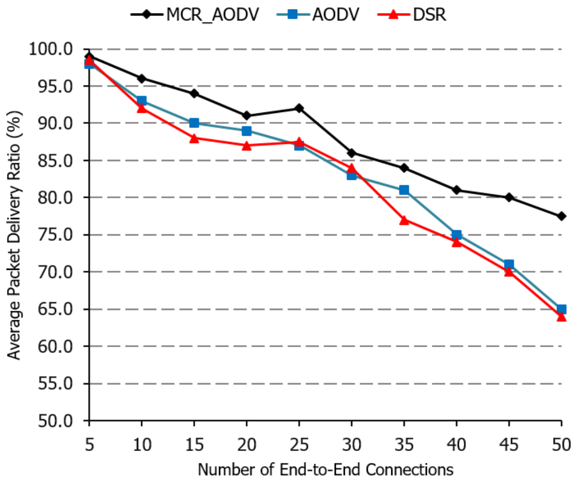

Figure 5. Packet Delivery Ratio & Network Traffic

As a consequence, the PDR of routing schemes such as AODV and DSR, which rely on the smallest hops number, significantly decreases. In contrast, our proposed routing scheme achieves a loading balance by considering multiple candidate paths with the highest throughput. This approach effectively reduces collisions and conflicts among packets within the network. Consequently, the PDR of the MCR scheme shows remarkable improvement compared to other routing schemes.

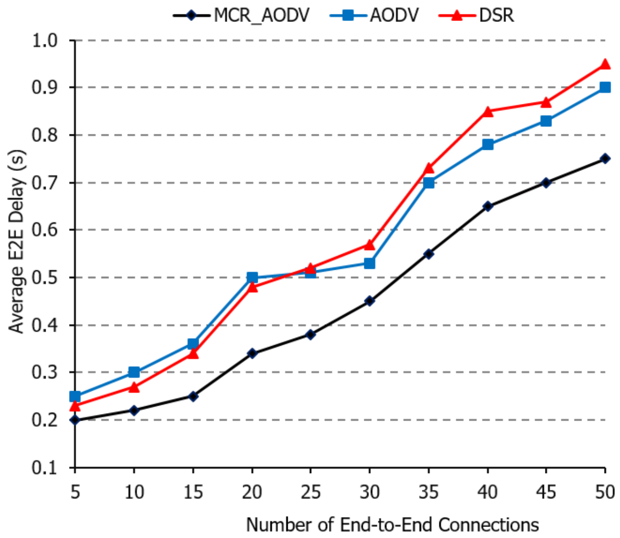

Figure 6. End-to-End Delay & Network Traffic

Fig. 6 illustrates the effectiveness of the *MCR_AODV* routing scheme compared to traditional routing schemes in terms of average end-to-end delay. When the low network traffic, the number of end-to-end connections is under 25 pairs, the delay of AODV has an uptrend higher than the DSR. However, when the increase in network traffic, the dynamic source-based routing mechanism of DSR reveals some limitations, hence the delay of DSR has an uptrend compared to the AODV. These results have been shown detailed by the $Perkins\ et\ al.$ in [36]. The simulation results demonstrate that when the number of end-to-end connections increases, the delay of all routing schemes also increases. However, due to its flexible path selection mechanism, the MCR_AODV routing scheme considers both the number of hops and throughput in its cost function. Consequently, the system selects paths with the highest throughput among the candidate paths that have the optimal number of hops. This balancing load allocation leads to a significant improvement in the delay of the proposed solution, achieving approximately a 10% compared to other routing schemes.

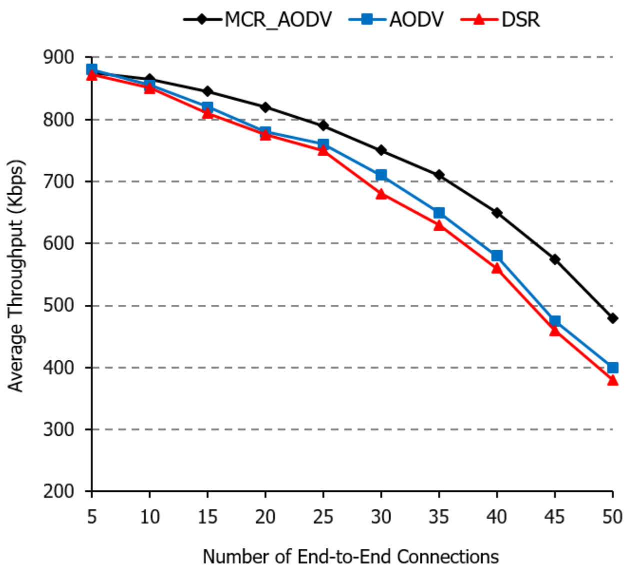

Figure 7. Throughput & Network Traffic

Fig. 7 illustrates the effectiveness of the *MCR_AODV* routing scheme compared to other routing schemes in terms of average throughput. The simulation results demonstrate that as the number of end-to-end connections increases, the throughput of the routing schemes shows a consistent decline. Specifically, the throughput of the smallest hops number-based routing schemes experiences a significant reduction under high network traffic conditions. In contrast, the proposed routing scheme not only selects paths with the highest throughput, as commonly seen in QoS-aware routing schemes, but also considers the constraint of hops number (*hopmin+1*). This suitable path selection mechanism enables the proposed scheme to identify paths that satisfy both distance constraints and have the highest throughput. Consequently, the proposed scheme improves performance in terms of packet delivery ratio, delay, and throughput when compared to traditional approaches.

Although the aspects of energy consumption haven't been evaluated, however, in our opinion, the achieved results in terms of performance such as packet delivery ratio, delay, and throughput through the proposed algorithm will improve the energy efficiency of the whole system.

5. Conclusion

The rapid development of 5th generation mobile networks has ushered in the IoT era, enabling diverse applications to cater to human needs. MANET-assisted IoT architectures, facilitated by smart mobile devices equipped with D2D communication modules, have emerged to provide highly convenient and flexible communication capabilities across various domains. However, this architecture faces challenges, particularly in enhancing system performance to support multimedia applications. To address this challenge, we have proposed an advanced QoS-aware routing scheme that prioritizes paths with the highest throughput instead of solely relying on the smallest hops number, as seen in traditional approaches. Additionally, we have incorporated a constraint on the hops number of the selected paths ($hopmin + 1$) to further improve overall system performance. These enhancements enable the system to choose an optimal path that maximizes throughput while considering factors such as delay and energy consumption.

Looking ahead, we believe that the integration of artificial intelligence into the network edge [37] will play a crucial role. Context-awareness capabilities [38] and energy efficiency optimization [39-40] of smart IoT nodes will enhance the operating effectiveness of MANET-assisted IoT networks. These aspects will be the subject of future research, as they hold topical and compelling implications for MANET-assisted IoT systems.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

We conducted the research together; V.K. Quy proposed models and performed simulations; V.K. Quy, N. M. Quy, N. T. Ban & V-H Nguyen analyzed the data; We wrote the paper together; V. K. Quy & V-H Nguyen proofread this paper. All authors had approved the final version.

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