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EMBLR: A High-Performance Optimal Routing Approach for D2D Communications in Large-scale IoT 5G Network

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Abstract: Coping with the skyrocketing needs for massive amounts of data for the future Fifth Generation (5G) network, Device-to-Device (D2D) communications technology will provide seamless connectivity, high data rates, extended network coverage, and spectral efficiency. The D2D communications are a prevalent emerging technology to achieve the vision of symmetry in the Internet of Things (IoT) services. However, energy resource constraints, network stability, traffic congestion, and link failure of the devices are the crucial impediments to establish an optimal route in the D2D communications based IoT 5G network. These obstacles induced packet drop, rapid energy depletion, higher end-to-end delay, and unfairness across the network, leading to significant route and network performance degradation. Therefore, in this paper, an energy, mobility, queue length, and link quality-aware routing (EMBLR) approach is proposed to overcome the challenges and boost network performance. Moreover, a multicriteria decision making (MCDM) technique is utilized for the selection of the intermediate device in an optimal route. Extensive simulation has been conducted and proven that the proposed routing approach significantly enhances network performance. Overall, results have been carried out in Quality of Service (QoS) performance metrics and compared with other well-known routing approaches.

Keywords: D2D communications; IoT; 5G network; routing; backpressure; EMBLR

1. Introduction

From a luxury to a necessity, the internet has revolutionized communication and has been a keen interest in industries and academic research. With the world nowadays at the end of our fingertips, the intellectualization of machines, vehicles, homes, factories, and embedded systems, in parallel with the Internet of Things (IoT), has simplified and enhanced the control of routine tasks [1–3]. The IoT act as a sophisticated multidisciplinary channel that carries an immense weight of information. Large amounts of data are transmitted and received daily to carry out orders and to provide information.

Nevertheless, the current telecommunication technologies could not cope with the exponential insistence of the emerging digital era. Higher data throughput, lower latency, and less device energy consumption are needed to cater to the augmenting demand of the internet, which complies with the Fifth Generation (5G) network [4–6]. The 5G network provides a more robust, dexterous system and a more reliable technology for data transmission. Despite all the offered advantages, the 5G

network has limited network coverage, which is one of the main concerns before deploying the network infrastructure. The 5G network infrastructure is using a millimeter-wave frequency range that does not travel far, which jeopardizes the consistency of the network coverage [7–9]. Although the 5G network carries a higher data rate, it has a smaller coverage profile. To propagate the waves in densely populated areas such as in a megalopolis, more subsidiary repeaters will be needed to conserve stable data speeds. Thus, to efficiently deploy a 5G network, a more extensive network of antenna and base stations infrastructure is required to provide stable coverage and signal. The expenses incurred in building the antenna network and base stations is not likely cost-effective.

Furthermore, for the remote and sub-urban areas, it is not practical and convenient for the network infrastructure to be set-up. In the case of natural disaster, total connectivity is removed for the survivors due to damage to the base station's infrastructure; hence, it is impractical for the cellular base station to be constructed during a short time frame. In these situations, Device-to-Device (D2D) communications technology offered the best solution to increase signal proximity [10,11]. As the name implies, in D2D communications technology, numerous devices are connected with each other to create an ad-hoc wireless network. D2D communications technology opens up a new avenue that overrides the orthodox way of the cellular network (that all the communications must go through the base stations) by offering an option to work with an absence of cellular network infrastructure [12–14]. The main features of D2D communications technology are shown in Figure 1.

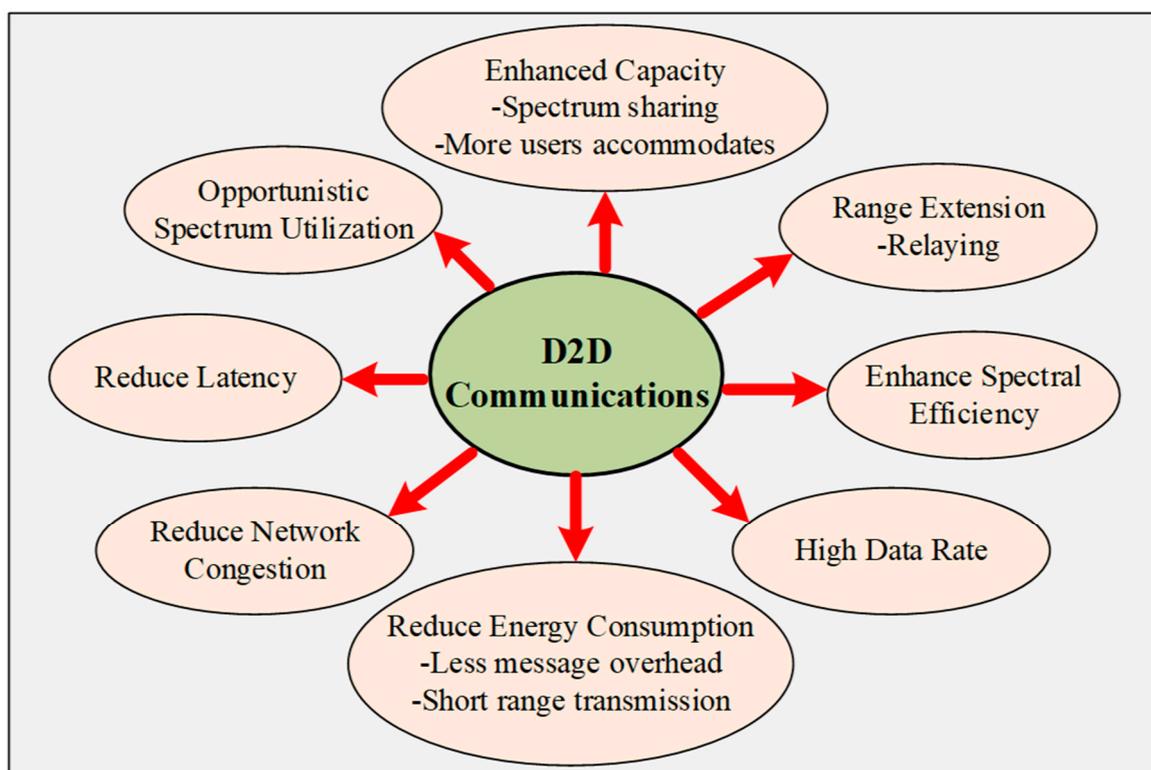


Figure 1. Features of the Device-to-Device (D2D) communication technology.

The D2D communications technology is one of the key components of 5G network infrastructure, developed by the researchers to enhance the data transmission efficiency [15,16]. With D2D technology, the devices can communicate with each other, with or without the core network, and alleviates the amount of data being sent to the base stations. By reusing cellular resources, D2D technology offered a prominent advantage that can boost spectral efficiency, fairness, delay, and network throughput performances [17,18]. Despite its notable advantages, several key challenges have been identified by the researchers to deploy reliable D2D communications technology in 5G network infrastructure,

including resource management, selection of transmission band, and routing path [19]. An example of a D2D communications scenario in 5G IoT networks is depicted in Figure 2.

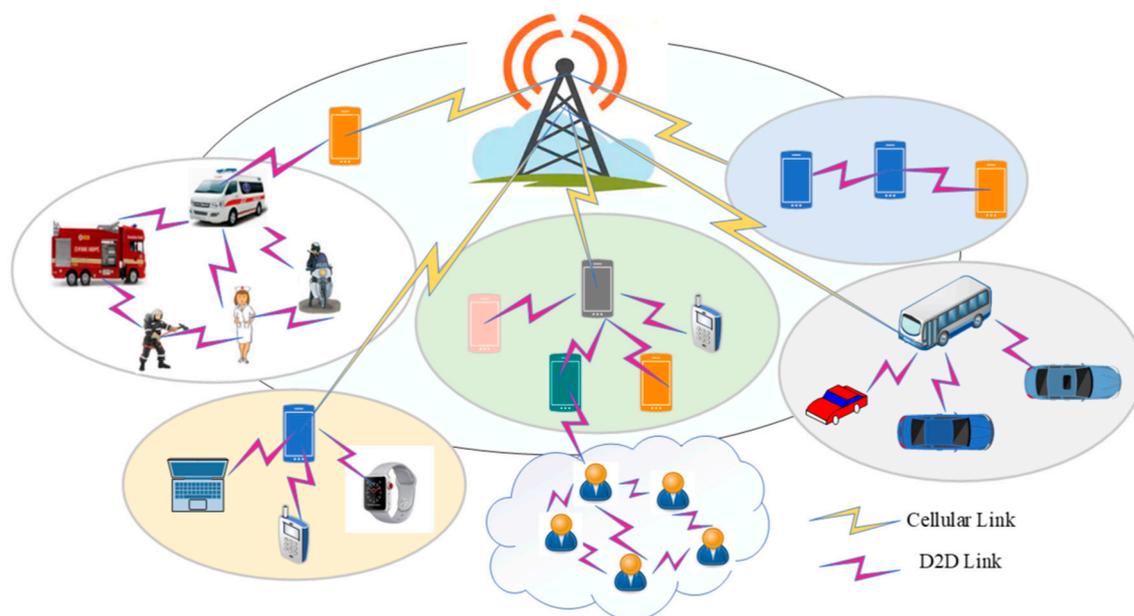


Figure 2. An example of a D2D communications scenario in 5G IoT networks.

However, this paper focuses on the routing path selection to facilitate an optimal route for the efficient transmission of data packets. Routing path selection is the crucial factor to underpin the overall Quality of Service (QoS) network performance, with wrong routing decisions, the QoS can be worse than the orthodox cellular network [20]. Orthodox cellular networking does not need to consider the device mobility, mobile users' equipment, and dynamic network topology. Due to this, in D2D technology, energy constraints, network stability, link failure, and traffic congestion factors need to be addressed when deciding an optimal routing [21]. These factors are briefly discussed in the following section.

In D2D communications, every device has a limited battery capacity. Hence, once the device battery is drained, it will shorten the establish route lifetime among the devices, which extensively impacts the overall network performances. Since the device keeps moving in the network, the network topology is dynamically changing, causing intermittent interconnectivity between the devices. Furthermore, due to the number of devices continually fluctuating unpredictably (coming in and exiting the network), it leads to the deterioration of network QoS performances [22–25]. Moving on to the traffic congestion factor, when the network devices transmit their data packets to a single device, there is a chance that data packet traffic congestion occurs at that particular device. Therefore, data packets need to wait until the queue is empty on the device that induces delay during data transmission between the source and destination devices. This results in the escalation of the network capacity, which attenuates the overall network coverage. Turning now to the last factor, links failure. In normal circumstances, the mobile devices in the network are changing their position frequently, and it causes the chance of link failure for an intermediate device in the established route. Hence, the source device again needs to reselect an alternate route based on the updated network topology information, which affects the packet drop in the established route.

1.1. Related Works

This section presents a review of recent literature on routing protocol for wireless networks, which focuses on energy constraints, network stability, traffic congestion, and link failure among mobile devices. Optimized Link-State Routing (OLSR) is one of the most prominent routing protocols

that provide loop-free paths for the wireless network and its applications [26]. Since its inception, it has been modified and improved over time by numerous scholars. One of its implementation, known as MP-OLSRv2 [27], focuses on discovering multiple paths between source and destination devices in order to utilize the available links and enhance the performance of the routing protocol. In another work carried out in [28], incoming data packets have been prioritized to each device such that the user's QoS requirements are met. On the other hand, QoS-based OLSR (QOLSR) utilizes the shortest-widest path algorithm to estimate the loop-free paths and improves the network performance by reducing the interferences among device-disjointed paths. The obtained results are supported by a comparison of single-path routing with multi-path routing schemes, however, multi-path routing schemes performed better than single-path QOLSR. In the article [29], the authors presented a header processing mechanism to reduce the control packets overhead information attached to each packet. The proposed mechanism ensured that the devices process the header more rapidly while consuming less energy in packets processing, which consequently saves energy for the whole network to be utilized later. This technique will not only save energy and processing time but also reduces the load on the network links since there are less data to be carried and improves the capacity of the individual link. The obtained simulation data indicated a significant improvement in the packet delivery ratio, while the authors further justified that the proposed algorithm performs better when the network is highly dynamic with frequent changes in the device position.

In another study, an Energy-aware Multi-path Routing Protocol (EMRP) is presented in [30], where the device battery's residual energy information is exchanged within neighbor devices along with routing information. Hence, when the devices select the best paths, they will consider the residual energy of all the devices as well, which are present in the selected path(s). Also, devices provide update information to the neighbor devices regarding their queue length size, which determines the data packet load on a specific device. Thus, devices with a higher queue length size would consume their residual power more rapidly in comparison to devices with a low or minimal queue length size. In addition, devices with a larger queue length size cannot efficiently be part of new routes, as it will initiate the dropping of data packets once its queue is filled up. Therefore, combining queue length size and residual battery power to the routing metric will ensure that routing and traffic load is evenly divided among the network devices and no device will have a large queue length size. The relationship between energy consumed by the network and data packet collision in the medium or channel is presented in [31]. One of the significant causes of energy loss is by the data packets that are initially transmitted by the source device but never reached their destination due to channel impairments. The data packets that are either lost or delayed are required to be retransmitted by the source node; hence, energy is wasted on those data packets that are initially sent. The data packet loss is mainly due to a collision in the medium. Therefore, a collision sensitive routing protocol, Energy Efficient, and Collision-Aware (EECA) routing algorithm is proposed as an energy-efficient collision conscious multi-path routing for wireless sensor networks. The authors have targeted a specific type of data packets that are broadcasted in the network in order to propagate routing information across the network. In traditional multi-path routing networks, routes are calculated by broadcasting the Route Request packets (RREQ) to the neighbor devices, which led to massive energy loss. The proposed protocol minimizes the collision by disjointed multi-path routing and only selects two paths for the broadcasting of this information, i.e., RREQ to those two devices which consequently saves energy. Devices are able to save up the residual battery energy according to the proposed algorithm, and is compared to the Ad-hoc On-demand Distance Vector (AODV) routing protocol.

The authors in [32] employed an ant colony-based meta-heuristic and swarm intelligence to optimize the routing protocol for energy efficiency in wireless networks. This proposed protocol could self-configure in order to adapt to alterations in the network, including topological and geographical changes, as it is based on real ant behavior in which ants wander randomly in a small geographical region. Rather than sending its current residual battery status to other devices, it takes into account the required battery power to deliver a single packet along the path and decides the optimization

routing protocol based on the computed information. In the article [33], the authors introduced an Energy-Efficient Cloud-Assisted Routing Mechanism (EECRM) for Cloud Assisted-Mobile Ad-hoc Networks (CA-MANETs). The authors exploited the Bellman–Ford algorithm for quick path recovery and detection processes in order to discover the alternate paths when the link failure occurs between the devices. Service schedule, information update, and information notice functions have been applied to maintain connections in the CA-MANETs. The proposed routing protocol achieved efficient energy consumption, extended network coverage, and the ability to prolong the lifetime of CA-MANETs. To address the challenges of traffic load variations and energy availability conditions, the authors in [34] proposed an effective Energy-Harvesting-Aware Routing Algorithm (EHARA) for heterogeneity of the IoT networks. The EHARA protocol selects the optimal path based on harvested energy, consumed energy, and the residual energy cost metric functions of the intermediate device for data transmission toward the destination device. The proposed protocol improved energy efficiency and prolonged the device and network lifetime for mobile distributed IoT networks.

Another work has been carried out in [35], where the authors proposed the mechanisms for D2D communication session setup and management involving procedures in the Long-Term evolution Advanced cellular network (LTE-A) System Architecture Evolution (SAE) that control and limit the interference to the primary cellular network. In this paper, the authors have studied the additional changes required for the SAE procedures and functions to facilitate the D2D communication session setup. Both the uplink and downlink period of time division duplex operation of the LTE-A cellular network issues are addressed due to their different natures in multiple access interference and power control. The results show that the overall throughput of the network is increased with limited interference for the primary cellular network by allowing the D2D communication to underlay cellular networks. Meanwhile, the authors in [36] have proposed a game-theoretic framework in order to determine an efficient solution for the problem of uplink transmission power control and interference mitigation in D2D communication enabled cellular network. The proposed framework has utilized the control intelligence and decision-making process for the realization of mobile user self-optimization functionalities. An iterative distributed heuristic algorithm is exploited to determine the Nash equilibrium point for the non-cooperative power control game. The simulation results provide spectrum efficiency, utilization of white interference management zones, and better power control between the cellular and the D2D communications.

Meanwhile, in the article [37], the authors provide and analyze an overview of the study in the energy efficiency challenges with useful resource allocation and its potential applications toward the 5G broadband wireless access networks. It formulates an optimization problem to minimize the energy consumption with the auction-based offloading system, where the energy cost of both computing and data transmission tasks are taken into consideration. Besides, hybrid resource allocation approaches are studied to improve energy efficiency performance in potential 5G wireless networks. Another work carried out in [38]; in which the authors have considered the fair resource blocks allocation issue in a D2D communication overlay enabled cellular network. The authors exploited a blocking queuing model to enhance the effectiveness of resource block allocation for different users. The proposed work escalates the user's communication establishment possibilities which either utilize the D2D communication or the conventional cellular network, which co-exist with traditional users that can be only established by conventional cellular communication. Multi-objective and Markov decision process optimizations are formulated to address the resource blocks allocation issues. The results show that the proposed work balances and minimizes the probability of resource blocks unavailability for the different types of users in the network.

In the article [39], the authors introduced a Spectrum based Energy-Efficient multi-hop multi-channel routing protocol in IoT mesh network (SpEED-IoT) based on D2D communications. The spectrum sensors gain radio environment map (REM) information through the spatiotemporal spectrum usage. The REM is utilized for the selection of the best route based on channel condition and transmission power for each hop in the route. The SpEED-IoT takes advantage of a selective flooding

mechanism to mitigate the route request packets overhead and minimize the energy consumption of the IoT devices. The proposed protocol increased throughput performance of the network without compromising fairness and is spectrum agnostic. In [40], the authors proposed a Lightweight On-demand Ad hoc Distance-vector Routing protocol-next Generation for mobile IoT networks (LOADng-IoT-Mob). The proposed routing protocol introduced a new short periodical control message harnessing mechanism that permits the network devices to track the change in the position of the devices and maintains the availability of the neighbor's device without significantly increasing the message overhead. As a result, these devices select the best path and avoid forwarding data packets toward the broken route (due to the movement of the devices) according to received signal strength, which increases network reliability and QoS performances. The LOADng-IoT-Mob routing approach has improved delay, control packets overhead, and energy efficiency in the mobile IoT network. Another study in [20], the authors have investigated a rank-based trust model routing protocol that aims to maximize the Trusted Connectivity Probability (T-CP) for multi-hop D2D communications over 5G IoT applications. The authors have suggested that when the base stations are randomly distributed, they provide the shortest path based on connectivity probability metric between D2D transmitter and receiver. In contrast, when the base stations are fixed, the optimal route selection depends upon the position of the base stations, which provide a useful understanding of the development of D2D communications for 5G IoT applications.

Whereas in [27], the authors proposed a Multi-Path OLSR version 2 (MP-OLSRv2) to discover multiple disjoint paths for wireless networks. The MP-OLSRv2 exploits the multi-path Dijkstra's shortest path algorithm to explore multiple disjoint routes from a source to a destination device based on the network topological information. The proposed approach avoids the disjoint routes if a single link failure occurred and transmits the data packets in a parallel manner to aggregate network throughput. The MP-OLSRv2 approach enhances the overall network throughput and data delivery reliability in a dynamic and high-loaded network by avoiding link failure relay devices in the optimal route. Whereas, in the article [41], the authors proposed hybrid multi-path energy and QoS based on OLSRv2 (MEQSA-OLSRv2) routing approach in IoT networks to maintain energy consumption and QoS performance. The device rank metric concept is utilized for the selection of the best route based on a multicriteria (energy and QoS) value to estimate the link cost assessment function during the multi-path route computation. The proposed approach forwards the data packets to the multiple disjoint routes according to the link cost assessment function. The energy-efficient multipoint relays (MPRs) selection mechanism is employed to mitigate the topological flooding packets in the network and prolong the MPRs' lifetime. Consequently, the MEQSA-OLSRv2 routing approach is able to boost the QoS performance metric even in a heavy traffic load and high-mobility network scenarios.

Based on the literature, up to the present moment, most of the research has only focused on the combination of two- or three-parameter metrics of the intermediate devices (two or three combinations of metrics, i.e., mobility, energy consumption, link quality, or device queue length size) for route computation. As per the author's best knowledge, there are no such studies that merge all the parameter metrics in one single route computation for IoT 5G network based on D2D communications. Thus, this paper integrates all the parameter metrics in one single metric for the route computation process with the Backpressure algorithm to evaluate the network QoS performances. The energy, mobility, queue length, and link quality-aware routing (EMBLR) approach utilized the functionalities of the well-known existing routing approaches and modified with the combination of device parameter metrics, i.e., mobility, energy consumption, link quality, and queue length size of the devices for the route selection procedure. Besides, the multicriteria decision making (MCDM) decision mechanism is employed for the selection of the best route among the multiple routes. The conceptual structure, framework, implementation feature, and methodology adopted for the proposed EMBLR routing approach is depicted in Figure 3. The framework elaborates on the structural elements of the proposed EMBLR routing approach and their incorporation to accomplish the research objective.

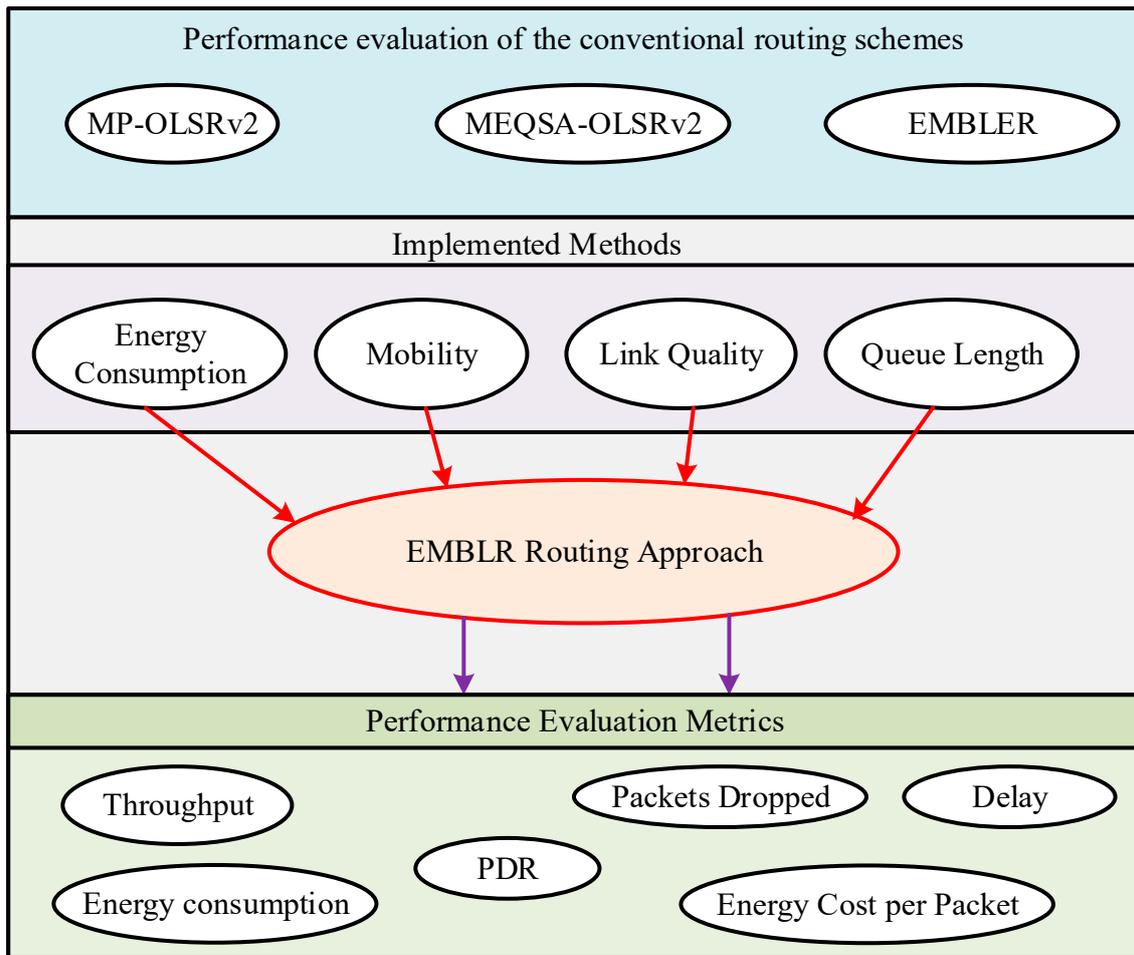


Figure 3. Basic structure and framework of the proposed energy, mobility, queue length, and link quality-aware routing (EMBLR) routing scheme.

The routing protocols in wireless networks are highly dependent on the established communication channel links. Adjusting the resource allocation within the network can change the channel capacity of an individual link that influences the routing of data packets and alters the overall network performance. The proposed framework utilizes the link quality among the users with the Backpressure algorithm in order to schedule the routing of data packets and allocates the efficient resources to the users which improve network QoS performances. The findings presented in the study can be potentially used in the optimization formulations for various wireless communication technologies and useful for designing the efficient routing approach in the next-generation wireless communication networks. Moreover, the proposed EMBLR routing scheme provides high network QoS performance even in heavy traffic load and high-mobility scenarios. The following section describes the system model of the proposed EMBLR routing approach for D2D communication over the IoT 5G network.

1.2. Contribution

Conforming to the challenges mentioned above; energy constraints, network stability, traffic congestion, and link failure of the device play an essential determinant to establish an optimal route and it has to be addressed accordingly to enhance the overall network performance. The challenges can be demonstrated through the application of an effective routing decision technique. However, the other well-known existing routing approaches have been focusing on only two or three metrics factors of the devices (two or three combinations of metrics, i.e., device mobility, energy consumption, link quality, or queue length size) for route computation. As per the author's best knowledge, this

study is the first to integrate all the parameter metrics in one single metric for the route computation process by using a Backpressure algorithm to evaluate the performance of the D2D communications in a large-scale IoT 5G network. Therefore, this paper proposes a multicriteria-aware optimal EMBLR routing approach to enhance the D2D communications in a large-scale IoT 5G networks. Furthermore, the proposed EMBLR routing approach does not introduce extra control overhead packets in the network, as a consequence, it decreases the complexity of the route computation algorithm. Thus, simplicity and applicability are the vital features of the proposed EMBLR routing approach for reliable data transmission as compared to the other well-known existing routing approaches. The contributions of the paper can be summed up as follows:

- (i) The proposed EMBLR routing approach utilizes the functionalities (hybrid and Dijkstra algorithm multi-path concept of routing) of the well-known existing routing approaches and modifies accordingly for the full combination of device parameter metrics, i.e., mobility, energy consumption, link quality, and queue length size of the devices for the route selection procedure.
- (ii) We evaluate the energy consumption, mobility, queue length size, and link quality of the intermediate devices between source and destination devices for the topology sensing and route discovery process.
- (iii) We apply the MCDM multicriteria decision mechanism for the selection of an optimal route among the multiple routes, which provides weight to the intermediate devices based on the estimated value.
- (iv) We study the QoS performance metrics of the proposed EMBLR routing approach and compare it with the well-known existing routing approaches under various device speeds for the D2D communications in large-scale IoT 5G networks.

The rest of the paper is organized as follows. Section 2 describes the system model of the proposed framework, followed by results and discussion obtained through extensive simulation in Section 3. Finally, the conclusion and future research of the proposed work are presented in Section 4.

2. System Model

A directed graph $G(D, L)$ can model the D2D communications in a large-scale IoT 5G network, where D is the set of devices that are randomly placed in the network and L represents all feasible connection sets of the directed point-to-point wireless links. Here, $l(x, y) \in L$ defines the available connection link between two devices $x \in D$ and $y \in D$. Table 1 illustrates the main notations and descriptions that have been adopted in the paper.

Data packets transmission is scheduled when the two devices in the communication link with each other. In contrast, when the devices are not in communication range with each other, the source device selects the relay/intermediate devices in the route for transmitting data packets towards the destination devices. The selection of the relay devices in the optimal path is based on their estimated parameter value, such as energy consumption, mobility, link quality, and queue length size. Therefore, the proposed EMBLR routing scheme utilizes the relay device estimated parameters value for finding the optimal path in order to enhance the overall network performance. The energy consumption, mobility, link quality, and queue length size estimation parameter values of the device are discussed in the following section.

Table 1. Summary of notations.

Symbol	Description
D and L	Set of devices and all feasible connection sets of links
$l(x, y) \in L$	Link between two devices $x \in D$ and $y \in D$.
λ and d_0	Signal transmission distance and threshold value
k	Number of data packets transmitted
$E_{Tx-elec}$ and $E_{Rx-elec}$	Energy consumed per bit by Tx and Rx circuits
ε_{f_s} and ε_{amp}	Power amplification factor of the radio models
RE_{max} and RE	Maximum and residual energy of the devices
$DR_{(x,y)}^c$ and $M_{(x,y)}^c(t)$	Drain rate and mobility of relay device c in the path (x, y)
$pos_c^T(t)$ and $pos_c^T(t - t_0)$	Current and initial positions of the devices c in trace time T
$\theta_c^T(t)$ and $\theta_c^T(t - t_0)$	Current and initial directional angle of device c in trace time T
$n(T)$	Number of time samples taken during trace time T
p_f and p_r	Forward and reverse delivery ratio
$D_{(x,y)}$ and $w_{(x,y)}^c(t)$	Distance of link (x, y) and Backpressure weight on link (x, y)
S_p and $\mu_{(x,y)}$	Packets size and rate of packets transmission
w_i and $\Gamma_{S(t)}$	Window size of probe packets and set of data rate transmission
$Num(t_{i-1}, t_i)$	Number of probe packets received at current and previous time window
w/τ	Number of probe packets sent before the data transmission
$Q_n^c(t)$	Number of data packets flow from device c are backlogged at device n at time t
$E[Q(t)]$	Expected average queue length of the network at a time t .
$\alpha_n^c(t)$	Number of exogenous flow c packets generated at the device n

2.1. Device Energy Consumption Estimation

The battery (with its limited lifetime) is the only source of energy for the devices to operate in the D2D communication for data transmission. The device performs a vital operation such as receiving data packets from the neighboring devices and forwarding data packets toward the destination devices. For this, devices consumed an excessive amount of energy that leads to an energy depletion problem; thereby affecting the routing and network performance. Hence, the energy consumption of the intermediate device plays a significant role in the selection of an optimal route between source and destination devices. The device energy consumption is estimated with the utilization of the energy consumption model for wireless communication [42,43]. Device energy consumption mainly occurred during the transmission and receiving states of data packets for data transmission. This paper exploits the free space model (λ^2 power loss) and multi-path fading model (λ^4 power loss) to calculate the signal transmission distance between the transmitter (Tx) and receiver (Rx) device. Here λ defines the distance between the Tx and Rx . The free space model is utilized when the distance between Tx and Rx is lower than the threshold value (d_0). In contrast, the multi-path fading model is utilized when the distance between Tx and Rx is higher than d_0 . Furthermore, the transmission circuit and power amplification losses also consumed energy during the operation time of the circuit. Therefore, when the k number of data packets are transmitted in the network, the energy consumption of the devices can be calculated as follows:

$$E_{Tx}(k, \lambda) = \begin{cases} kE_{Tx-elec} + k\varepsilon_{f_s}\lambda^2 & \lambda < d_0 \\ kE_{Tx-elec} + k\varepsilon_{amp}\lambda^4 & \lambda > d_0 \end{cases} \quad (1)$$

$$E_{Rx}(k) = kE_{Rx-elec}, \quad (2)$$

where $E_{Tx-elec}$ and $E_{Rx-elec}$ are defined as the energy consumed per bit by Tx and Rx circuits. Also, ε_{fs} and ε_{amp} are the power amplification factors of the free space and multi-path radio models, respectively. Whereas, the threshold value (d_0) is estimated via $d_0 = \sqrt{\varepsilon_{fs} / \varepsilon_{amp}}$. Equations (1) and (2) calculate the energy consumption of the device for k number of data packets transmission. The proposed routing scheme also utilizes maximum energy (RE_{max}) and residual energy (RE) of the intermediate device for the selection of the optimal path. The RE_{max} and RE values are estimated by exploiting the linear battery model [44]. Thus, the rank of intermediate devices c based on drain rate $DR_{(x,y)}^c$ for the selection of optimal route between the source and destination devices can be calculated as follows:

$$DR_{(x,y)}^c = \frac{RE_c(k)}{RE_{max}(k) \times \{E_{Tx}^c(k, \lambda) + E_{Rx}^c(k)\}} \quad (3)$$

2.2. Mobility of Devices Estimation

Devices move randomly in the network; unpredictably change the network topology and affect the routing performance. Thus, the mobility of the device needs to be considered for the selection of the optimal route. For this, the well-known Random Way Point (RWP) mobility model is utilized to predict the mobility pattern of the devices [45]. The RWP model estimates the device mobility based on the position, directional angle, and trace time of the devices. The mobility $[M_{(x,y)}^c(t)]$ of the intermediate device c can be calculated as below:

$$M_{(x,y)}^c(t) = \frac{\sum_T \sqrt{\{pos_c^T(t) - pos_c^T(t-t_0)\}^2 + \{\theta_c^T(t) - \theta_c^T(t-t_0)\}^2}}{\sum_c n(T)} \quad (4)$$

where T refers to the total tracing time of the devices. $pos_c^T(t)$ and $pos_c^T(t-t_0)$ refers to the current and initial positions of the devices c in trace time T , respectively. Moreover, $\theta_c^T(t)$ and $\theta_c^T(t-t_0)$ are defined as the current and initial directional angle of the mobile device c in trace time T , respectively. Besides, $n(T)$ refers to the number of time samples taken during the trace time T . Therefore, the device mobility value, estimated based on the RWP mobility model, enhances the route robustness while maintaining the stability of the established route.

2.3. Link Quality of Devices Estimation

Links failure among the devices is the most common issue due to the limited battery lifetime of the devices, and it severely affects the data packet losses and network stability. In order to maintain reliable data packet delivery and network stability optimization, it is essential to rapidly and accurately detect the links' failure in the network. Therefore, the link quality of the intermediate device plays a significant role in the selection of the optimal path, which minimizes the data packet losses in the network. Consequently, this study exploits the concept of Expected Transmission Count (ETX) on the link, which is the number of transmissions and retransmissions required for the successful transmission of data packets to the destination device over the link [46]. Probe packets are sent to the link before data transmission, which does not include the data information. Therefore, the ETX value of the link is computed according to the forward delivery ratio p_f and reverse delivery ratio p_r through the probe packets, such as: $1/(p_f \times p_r)$. The link quality is estimated with ETX metric value, provides better performance in the light traffic networks. However, when the network condition is highly loaded, the ETX metric induces flooding of RREQ packets in the network for finding the optimal route. Therefore, to mitigate the flooding effect of RREQ packets in the network, this study presents the concept of High load-ETX (HETX) [47]. The HETX is the extended version of the ETX metric, which utilizes the current and previous time window rather than only the current time window (ETX). The time window

employed in this study is ten times the probe packets. The window time is scaled into the discrete window time scale having equal size $[t_{i-1}, t_i]$. The HETX value of the link is computed as below:

$$HETX = \frac{D_{(x,y)}}{p_f(t_i) \times p_r(t_i)} \frac{S_p}{\mu_{(x,y)}}, t \in [t_i, t_{i+1}] \quad (5)$$

where $D_{(x,y)}$ is denoted as the distance from the source to destination devices. S_p and $\mu_{(x,y)}$ are defined as the packets size and rate of data packets transmission, respectively. All the network devices periodically broadcast probe packets for a window w_i at an interval of τ seconds to evaluate the forward delivery ratio $p_f(t_i)$ and reverse delivery ratio $p_r(t_i)$. Every probe packet includes the number of probe packets and previous window information w_{i-1} , which is received from the neighboring devices. Hence, the forward and reverse delivery ratios $r(t_i) = \text{Num}(t_{i-1}, t_i) / (w/\tau)$ are estimated with the use of the information contained in the probe packets. Here $\text{Num}(t_{i-1}, t_i)$ refers to the number of probe packets received at the current and previous time window. The w/τ refers to the number of probe packets sent before the data transmission. The link quality among the device is calculated with the HETX metric which reduces the flooding of RREQ packets in the network and thereby minimizes the chance of link failure and improves the overall network QoS performances.

2.4. Queue Length of Devices Estimation

Queue length size of the device refers to the number of backlogged data packets that are stored at the device. A larger queue length size on the intermediate device induces data transmission delay in the network. The number of data packets in the queue is a metric that reflects the data traffic load of the mobile devices. The queue length size of the devices is evaluated by using the Backpressure algorithms [48]. Backpressure is referred to as the throughput optimal scheduling algorithm in the highly dynamic network, which forwards the data packets based on the traffic congestion information of the devices. In a queuing network, packets are removed from the device queue once it delivered or added to the next device queue. Next, when the packets received at the destination device, the packets will be removed from the queue of all devices. Let $Q_n^c(t)$ denotes the number of data packets flow from the device $c \in D$ are backlogged at the device $n \in D$ at the time t . Therefore, the backlogged packets on an intermediate device c of the link (x, y) are defined as $Q_{(x,y)}^c(t) = Q_x^c(t) - Q_y^c(t)$. All the devices in the network maintained backlogged packets information locally through the information packets exchanged with each other. A weight assigned to the link (x, y) over flow c at the time t is estimated as below:

$$w_{(x,y)}^c(t) = \max[Q_{(x,y)}^c(t), 0] \quad (6)$$

The $w_{(x,y)}^c(t)$ denotes the Backpressure weight on the link (x, y) , which is the maximum weight assigned to the link (x, y) at the time slot t , i.e., $W_{(x,y)}(t) = \max_{c \in N} w_{(x,y)}^c(t)$. The packets are scheduled for flow c only when the device c attains the maximum weight on the activated link [49]. In this way, the maximum weight on the link (x, y) can be defined as below:

$$\max \sum_{x \in N} \sum_{y \in N} \mu_{(x,y)}(t) W_{(x,y)}(t), \quad (7)$$

$$\text{s.t. } \mu_{(x,y)}(t) \in \Gamma_S(t)$$

The equations given above illustrates the maximization of the weighted network throughput by choosing transmission rates. The links scheduled is based on the primacy of order, i.e., the highest prioritized link would be the first to be scheduled. Based on the stability theory, the linear optimization by Equation (7) is made with the queuing network toward stability, thereby, achieved the maximum network throughput performance in the IoT 5G network based on D2D communications [49].

Moreover, the maximum network throughput is attained in a queuing network if all the traffic arrival rates and all individual queues of devices are strongly stable. As a result, the channel capacity of the stable network with memoryless channels is achieved, equivalent to the Shannon channel capacity [50]. Therefore, the maximum throughput can be attained in the queuing network to maintain the network stability with maximum data packets arrival rates that can be derived as follows:

$$\limsup_{T \rightarrow \infty} \frac{1}{T} \sum_{t=0}^{T-1} E[Q(t)] < \infty \quad (8)$$

The $E[Q(t)]$ refers to the expected average queue length of the network at a time t . The network backlog update at each time slot t is obtained by transmission rate matrix $\mu_{(x,y)}(t)$, and it denotes the rate offered for flow c on the link (x,y) during the slot t . Thus, the Backpressure schedule algorithm based on the system queuing process dynamics is satisfied.

$$Q_n^c(t+1) \leq \max[Q_n^c(t) - \sum_b \mu_{(n,y)}^c(t), 0] + \alpha_n^c(t) + \sum_a \mu_{(x,n)}^c(t) \quad (9)$$

The equation (Equation (9)) above expresses inequality due to an actual number of packets from neighbors device arrives at the device m during the slot t is less than $\mu_{(x,n)}^c(t)$ if the neighbor's device has few or no packets to transmit. The notation $\alpha_n^c(t)$ refers to the number of exogenous flow c packets generated at the device n . Therefore, the EMBLR routing scheme aims to maximize throughput in the IoT 5G network based on D2D communications with minimizing the backlog queue length size between $Q_n^c(t+1)$ and $Q_n^c(t)$.

2.5. Multiple Criteria Decision-Making (MCDM) Technique

The MCDM decision metric is applied to access the link cost function of all the multiple routes and choose the best route based on the estimated parameter value of the relay devices. The MCDM metric aggregates all the parameter value (energy consumption, mobility, queue length size, and link quality of the relay devices) into the one single metric and provides weight to the devices based on the estimated parameter value. The parameter's value is estimated and monitored periodically during the route discovery and topology sensing stage, which is comprised of link sensing, neighbors, and topology discovery by broadcasting the topological packets to the neighbor's devices. The MCDM metric value is estimated locally at every device and broadcasts to their neighbors' devices into a single metric value by the individual device sending multiple metrics in order to mitigate the control overhead packets in the network. The MCDM metric of relay devices c in the routes is calculated as follows:

$$MCDM = \left\{ W_{RE} \times EC_{(m,n)}^c(t) + W_{mob} \times Mob_{(m,n)}^c(t) + W_{LQ} \times LQ_{(m,n)}^c(t) + W_{QL} \times QL_{(m,n)}^c(t) \right\} \quad (10)$$

where W_{RE} , W_{mob} , W_{LQ} , and W_{QL} are weight assigned according to the estimated parameters value and ranging from "0" to "1". The device which has a high MCDM metric value has a higher chance of selection in the optimal route. Whereas, the device which has below threshold MCDM metric value is avoided in the route selection procedure. Therefore, the MCDM metric used these parameters value to make a decision to establish an optimal path between the sources and the destination device. The flow chart for the optimal route selection procedure of the proposed EMBLR routing scheme is shown in Figure 4.

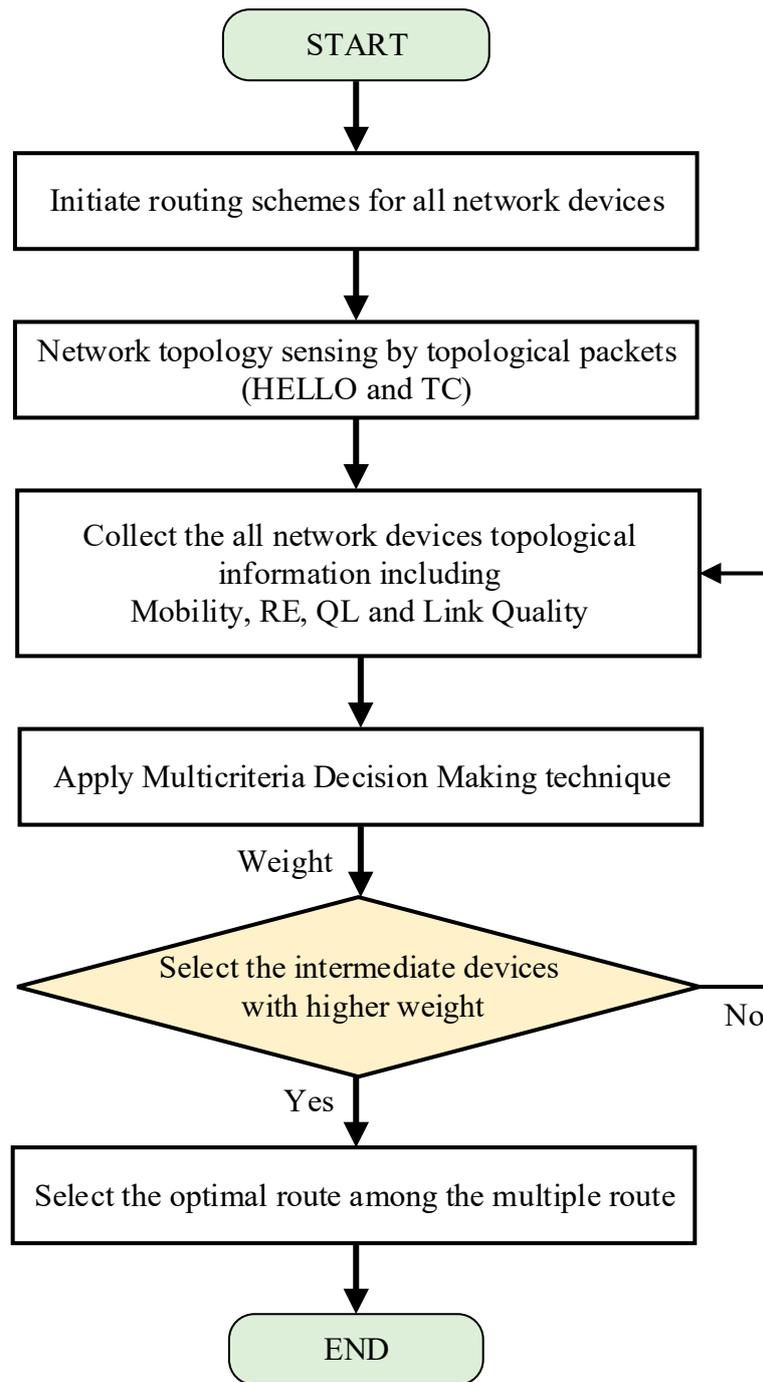


Figure 4. Flow chart of optimal route selection with EMBLR routing scheme.

2.6. Simulation Setup

MATLAB 2018a simulator was employed to execute extensive simulations that assess the performance of the routing approaches with various device speed scenarios [51,52]. In this simulation, the scenarios used randomly distributed 49 devices in an area of 500×500 m. The mobile device moves in the network according to the RWP mobility model with the speed from 10 to 60 m/s. Constant Bit Rate (CBR) is set to 20 packets per second that correspond to each source and destination devices flow that generates universal datagram protocol packets by 512 bytes size at the source device. The radio transmission distance is set at 270 m. The 802.11b radio data link layer and channel capacity are set to 11 Mbps. The simulation run time is assigned to 200 s and each simulation cycle is repeated 200 times

to get the value of the average results. The 2.4 GHz wireless channel frequency is set for the simulation. The other parameters value are presented in Table 2 as follows:

Table 2. Simulation parameters value.

Simulation Parameters	Value
Routing protocols	EMBLR, MEQSA-OLSRv2, and MP-OLSRv2
Number of devices	49
Traffic type	CBR (20 Packets/s)
Battery capacity	3600 mAh
Generic energy model	$P_{Transmission} = 1300$ mW and $P_{Receive} = 900$ mW
Battery model	Linear battery model
Transmission range	270 m
Mobility model	RWP model with Min 10 m/s, Max 60 m/s
Simulation area	500 m × 500 m
Application packet size	512 bytes
Transport protocol	Universal datagram protocol
Wireless channel frequency	2.4 GHz
Pathloss model	Two ray ground
Power amplification factors	$\epsilon_{fs} = 10$ pJ/bit/m ² , and $\epsilon_{amp} = 0.0013$ pJ/bit/m ²
Channel capacity	11 Mbps

2.7. Performance Evaluation Criteria

The extensive simulation aims to assess and validate the effectiveness of the proposed EMBLR routing approach and critically analyzed with the subsequent QoS performance metrics:

- (i) *Throughput*: It is referred to as the total number of bytes that are successfully delivered to the destination device in the definite time duration [41] and can be computed as follows (in Kbps):

$$Throughput = \frac{Total\ number\ of\ bytes\ successfully\ delivered \times 8}{Simulation\ Time} \quad (11)$$

- (ii) *End-to-End Delay (EED)*: This metric indicates the total average time taken by the data packets transmission throughout the simulation time, which includes the propagation, queuing, buffering, and retransmission delays [34]. The EED can be computed as follows:

$$EED = \frac{1}{N_r} \sum_{c \in D} Delay(c) \quad (12)$$

where N_r is the total number of data packets successfully delivered at the destination device. $Delay(c)$ includes all the delay when the data packets transmitted between the source and destination devices.

- (iii) *Packet Delivery Ratio (PDR)*: This metric refers to the ratio between the total number of data packets successfully delivered at the destination device and the total number of data packets sent from the source device [41]. The PDR value can describe the reliability of the routing scheme. It can be calculated as follows:

$$PDR = \frac{N_r}{N_s} \times 100 \quad (13)$$

where N_s and N_r are the total number of data packets sent from the source device and successfully delivered at the destination device, respectively.

- (iv) *Packet Drop*. This metric is the total number of packets dropped throughout the data transmission in the network [34] and can be calculated as follows:

$$Packets\ Drop = N_s - N_r \quad (14)$$

- (v) *Energy Consumption*: This is the average energy consumption of all network devices throughout the network simulation time [33]. It depends upon the state of the device, such as transmitting, receiving, and an ideal state. Energy consumption of the devices can be calculated as follows:

$$\text{Energy Consumption} = \frac{1}{D} \sum_{c \in D} E_{Total}(c) \quad (15)$$

where $E_{Total}(c)$ is the total energy consumed by all network devices and D is the total number of network devices.

- (vi) *Energy Cost*: The ratio of the total energy consumed by all network devices over the total number of the data packets received at the destination device [41]. Energy cost can be calculated as follows:

$$\text{Energy Cost} = \frac{\text{Total energy consumed by all devices}}{\text{Total number of Packet Recieved}} \quad (16)$$

- (vii) *Convergence Time*: Convergence occurs in the network due to frequent network topology changes; meanwhile, the intermediate devices independently run routing algorithms and recalculate parameter values. The intermediate devices update the routing information and build a new routing table based on the parameter's information. It is calculated based on the time required before all of the intermediate devices can reach a consensus regarding the updated network topology.

3. Results and Discussions

The results obtained from the extensive simulation for the proposed EMBLR, well-known existing MEQSA-OLSRv2, and MP-OLSRv2 routing approaches with various device speed are presented in this section. The routing protocol's results are expressed in the performance metrics as mentioned above. In summary, this section presents a critical analysis of the obtained simulation results.

3.1. Throughput Comparison

Figure 5 depicts the throughput comparison of the EMBLR, MP-OLSRv2, and MEQSA-OLSRv2 routing approaches. It can be observed that the results achieved through the proposed EMBLR approach are higher than the existing approaches in terms of network throughput. Both MP-OLSRv2 and MEQSA-OLSRv2 routing approaches exclude the link quality metric of the intermediate devices in the selection of the optimal route. Whereas the EMBLR routing scheme exploits the HETX value through the probe packets before data transmission, which minimizes the chance of link failure and enhances the network throughput. Moreover, the EMBLR routing scheme utilizes the Backpressure algorithm which forwards the packets toward the low congested device. Therefore, it balances the load among the devices that lead to the maximization of the network throughput. When the speed of devices increases from 10 to 60 m/s, the network throughput decreases. The EMBLR decreases from 58.45 to 49.64 kbps, the MEQSA-OLSRv2 decreases from 54.56 to 46.22 kbps, and the MP-OLSRv2 also decrease from 53.12 to 43.56 kbps. The EMBLR routing protocol has a higher throughput performance than both MEQSA-OLSRv2 and MP-OLSRv2 in all of the different device speeds.

3.2. End-to-End Delay Comparison

The EMBLR routing scheme performs much better in EED as compared with other routing approaches, as shown in Figure 6. The EED includes the propagation delay between the source and the destination device, together with queuing delay for every intermediate device. The other two routing schemes forward the data packets through the long and congested route, which induces more EED. On the other hand, the EMBLR exploits the Backpressure algorithm with the queue length size of the intermediate device. It diverts the data packets flow from a high to a low congested device that

leads to network load balance, and thereby minimizes the data transmission time between source and destination devices. Furthermore, the EMBLR selects the highly-reliable path, which keeps the route stable and reduces EED for data transmission by exploiting the HETX metric. Overall, it can be observed that EMBLR reduces the EED by approximately 18.78% and 12.83% as compared with the MP-OLSRv2 and MEQSA-OLSRv2 routing approaches, respectively, at 60 m/s device speed.

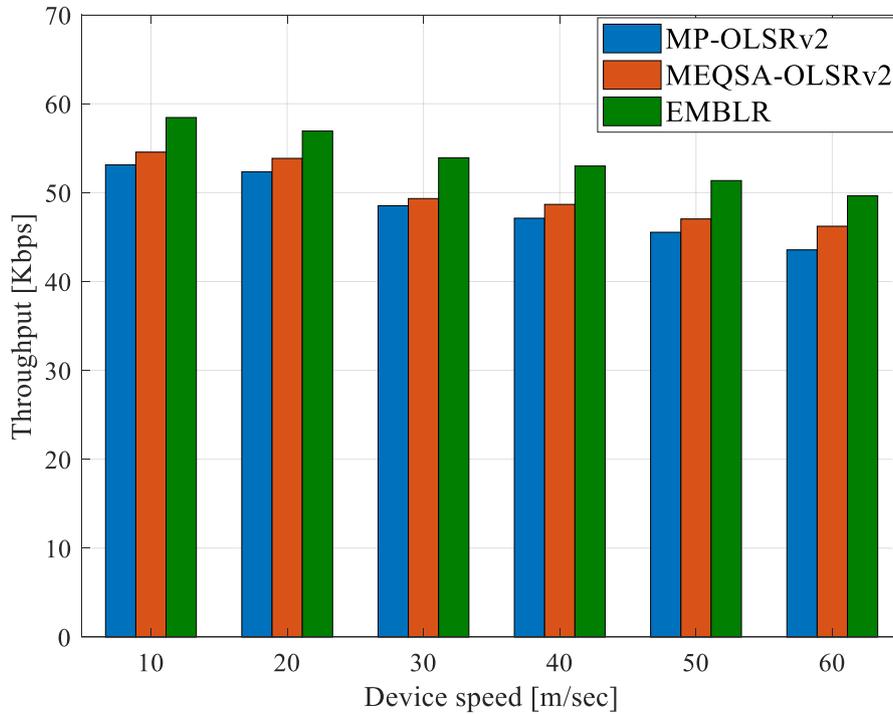


Figure 5. Throughput vs. various device speeds.

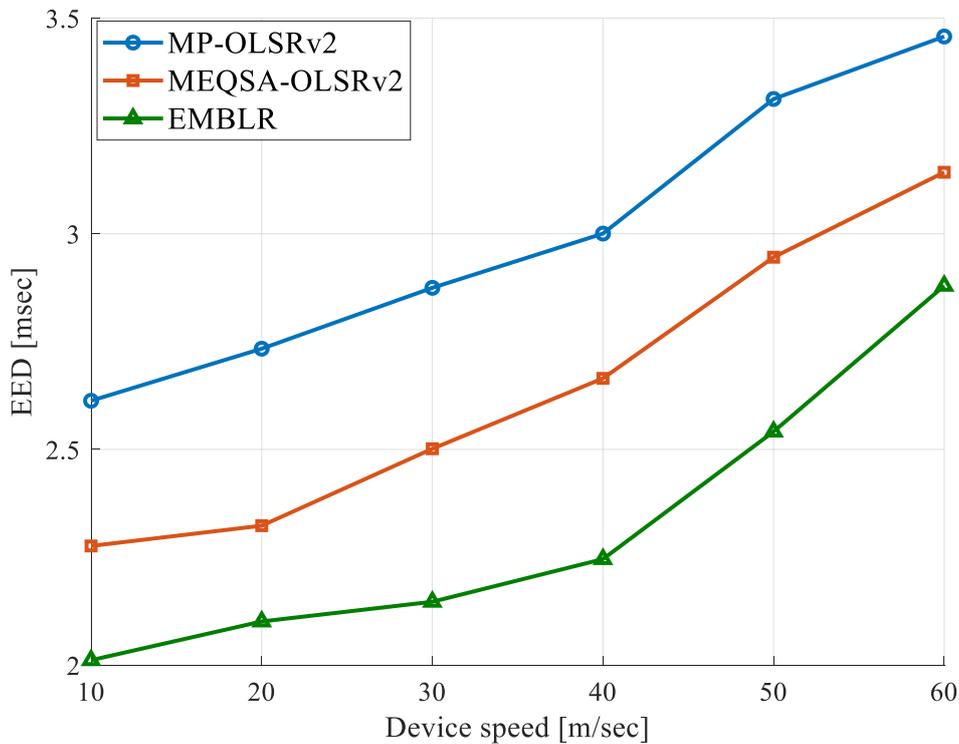


Figure 6. End-to-end delay vs. various device speeds.

3.3. Packet Delivery Ratio Comparison

The EMBLR routing scheme exploits the HETX metric that decreases the number of intermediate devices in the optimal path selection, which minimizes the number of dropped packets during data transmission. In addition, the HETX metric decreases the number of trials for data retransmission and reduces link failure probability resulting from the dynamic nature of networks, thereby keeping a higher packet delivery ratio compared to the other multi-path routing schemes. Besides, the EMBLR routing scheme considers the rate of data transmission and queue length size of the intermediate devices during data transmission, which minimized the congestion level at the device. Therefore, it forwards the data packets towards the device with a smaller queue length size and a higher rate of data transmission, which reduces the chance of packets dropped in the network. For high-speed device scenarios, it can be seen from Figure 7 that the EMBLR routing approach attains better PDR performance compared with the other routing approaches. Consecutively, the improvement percentages with an average of all device speed are approximately 33.67% and 23.84% as compared with the MP-OLSRv2 and MEQSA-OLSRv2 routing approaches, respectively.

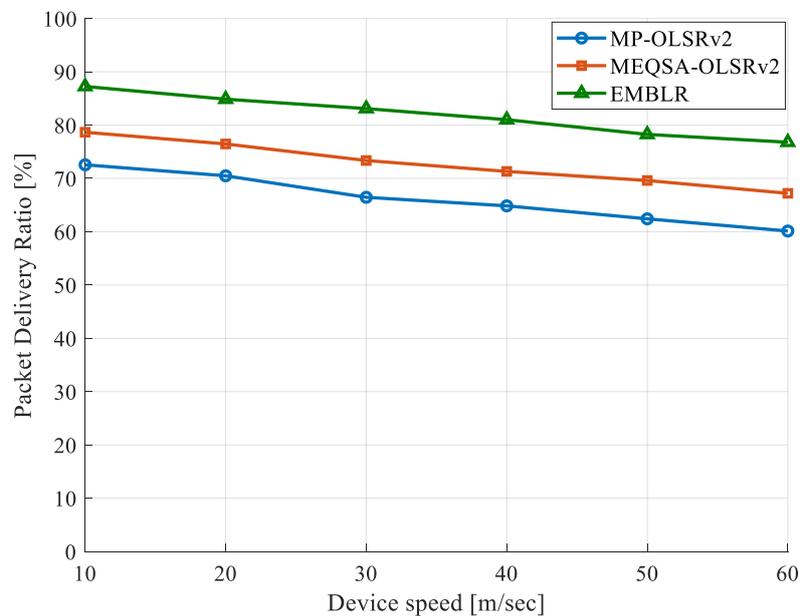


Figure 7. Packet delivery ratio vs. various devices speed.

3.4. Packets Drop Comparison

Figure 8 illustrates the packets drop of the EMBLR, MP-OLSRv2, and MEQSA-OLSRv2 routing approaches with different speeds of network devices. It can be observed that the EMBLR routing approach outperforms the other routing approaches. The MP-OLSRv2 and MEQSA-OLSRv2 routing approaches exclude the channel condition awareness for data transmission; due to this, there is a collision of the data packets at the MAC layer. Whereas the EMBLR utilizes the HETX metric before the data transmission to the link that minimizes the collision of the data packets, as well as the dropped packets. As the devices' speed elevates, the number of data packets dropped in the network also elevates. The MP-OLSRv2 packet drop (27.43%), and MEQSA-OLSRv2 packet drop (14.15%) is higher than the EMBLR routing approach at the highest 60 m/s device speed.

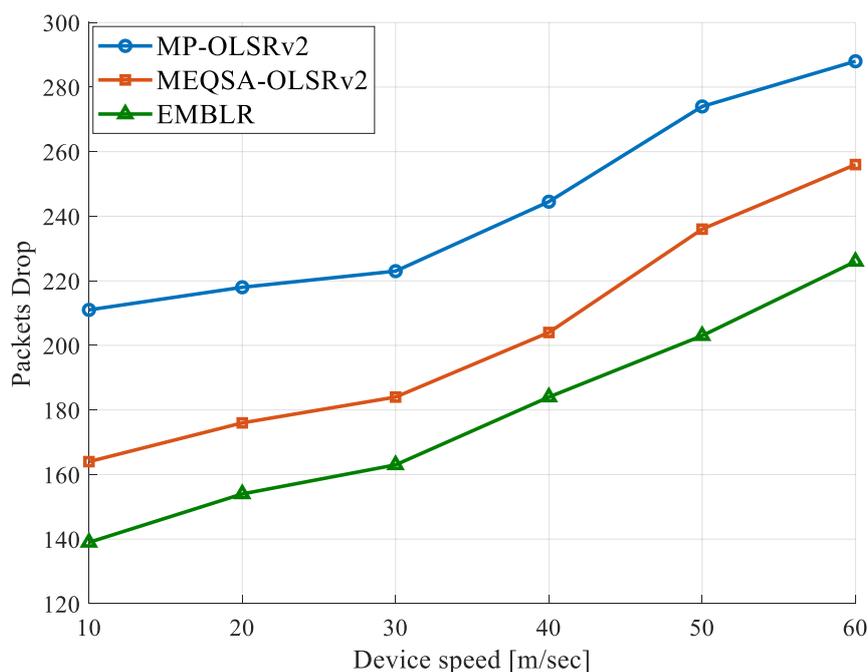


Figure 8. Packet drop vs. various devices speed.

3.5. Energy Consumption Comparison

Figure 9 presents a comparison of device energy consumption of the routing approaches during network operation time. The result shows that EMBLR is superior to the other routing approaches due to the simultaneous consideration of intermediate devices estimated parameters value during multiple path computation process. The EMBLR routing approach selects the intermediate devices based on the low HETX metric through probe packets. In the EMBLR, the link quality is estimated by using the HETX metric that can mitigate the flooding impact of RREQs packets in the network. Therefore, the HETX metric decreases the chance of frequent route failures that lead to the mitigation of the network load as well as device energy consumption in the route selection process. When the device speed increases from (10, 20, 30, 40, 50, and 60), the device energy consumption also increases. The EMBLR increases from 53.454 to 56.124 mAh, MEQSA-OLSRv2 increases from 54.541 to 58.465 mAh, and MP-OLSRv2 increases from 56.145 to 59.648 mAh. It can be seen that the EMBLR routing approach has less energy consumption as compared to the MEQSA-OLSRv2 and MP-OLSRv2 routing approaches.

3.6. Energy Cost Comparison

Figure 10 illustrates the result of energy cost per packet based on the routing approaches for various speeds of the network devices. The proposed routing approach attains the lowest energy cost owing to exploitations of the HETX metric, which reduces packets flooding in the network. Therefore, a smaller number of RREQ packets induces in the network as a result of the minimization of the device energy cost. Frequent movement of intermediate devices in the network causes the variation of the device's energy levels while increasing mobility. The EMBLR routing approach also selects devices with better link quality and lower speed to decrease energy consumption and packet loss ratio; this awareness is excluded in the other routing protocols. The EMBLR routing approach recorded the lowest energy cost, followed by both MEQSA-OLSRv2 and MP-OLSRv2. Energy cost attained by MP-OLSRv2 is 20.45% and 19.22%, while the MEQSA-OLSRv2 is 11.56% and 9.56% higher than the EMBLR routing approach when the device speed varies from 10 to 60 m/s, respectively.

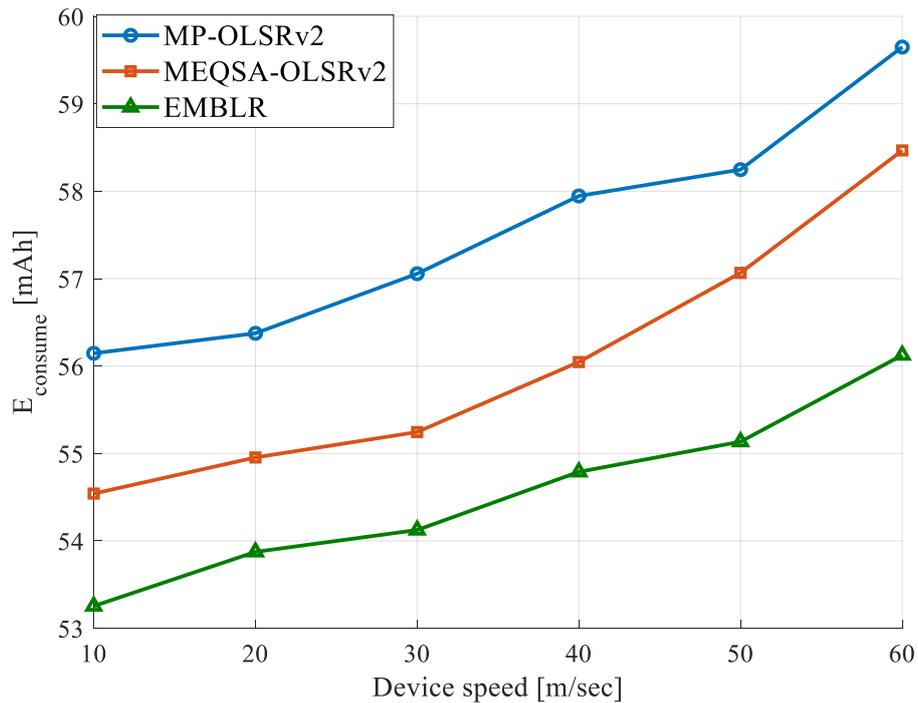


Figure 9. Energy consumption vs. various devices speed.

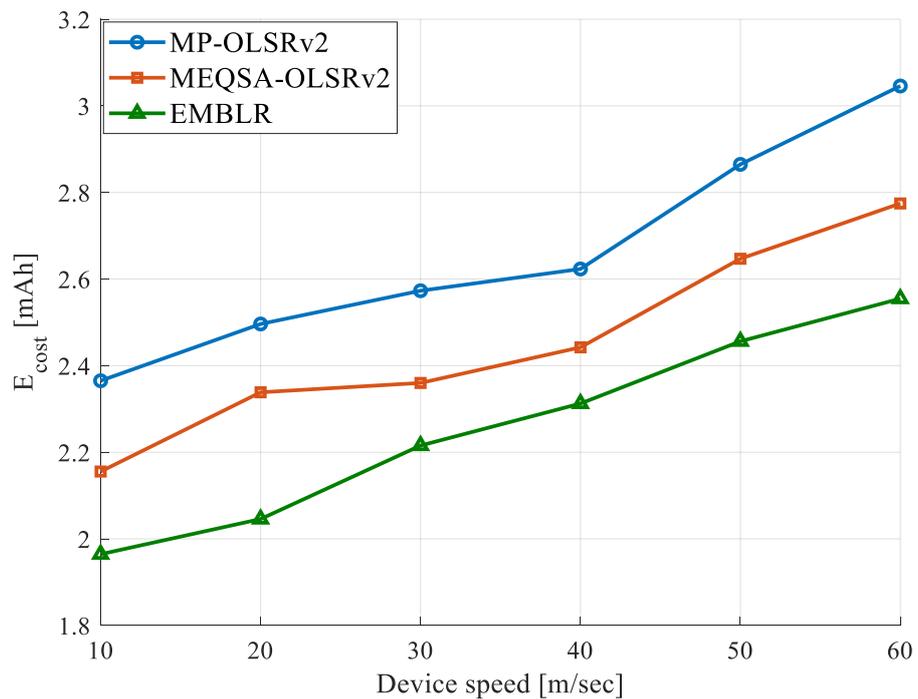


Figure 10. Energy cost vs. various devices speed.

3.7. Convergence Time Comparison

Figure 11 shows that the proposed EMBLR routing approach provides a significantly lower convergence time in all device speed scenarios as compared with the MP-OLSRv2 and MEQSA-OLSRv2 routing approaches. The EMBLR routing approach prohibits data flows in the congested and longer paths that minimize the data packets transmission time between the source and destination devices, which leads to low convergence time. Moreover, the proposed EMBLR routing approach exploits the

HETX metric value with the use of the information contained in the probe packets in order to reduce the chance of link failure among the devices. Therefore, the EMBLR routing approach instantaneously updates the routing table information with any changes occurring in the network that minimizes the network convergence time. Overall, Figure 11 shows that the proposed EMBLR routing approach achieves around 20.72% and 12.43% lower convergence time when compared with the MP-OLSRv2 and MEQSA-OLSRv2 routing approaches respectively, at device speed 30 m/s.

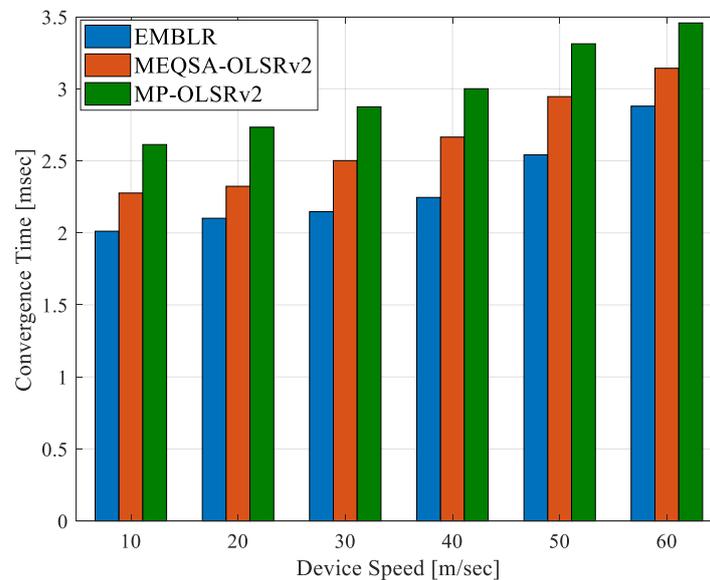


Figure 11. Convergence time vs. various devices speed.

4. Conclusions

In this paper, a new routing approach is presented by using device multicriteria in the optimal route selection between the source and destination devices for 5G IoT networks based on D2D communications. The proposed routing scheme has overcome the challenges of energy constraints, network stability, traffic congestion, and link failure of the intermediate device for the selection of an optimal route. Therefore, to address these challenges, the proposed routing approach exploited energy consumption, mobility, queue length, and the link quality of the intermediate devices in the optimal route selection mechanism. Moreover, the MCDM technique is employed for the selection of intermediate devices in the optimal path, which provides weight to the intermediate devices according to its estimated values. Extensive simulations were conducted with various device speed, and the results have been illustrated in network QoS performance metrics. Based on the simulation results, it shows that the proposed EMBLR routing approach attains significant performance as compared to the other well-known existing routing approaches. Overall, the proposed EMBLR routing approach significantly improves EED (18.78% and 12.83%), PDR (33.67%, and 23.84%), and energy costs (20.45% and 11.56%) approximately, as compared to the MP-OLSRv2 and MEQSA-OLSRv2 routing approaches, respectively. The proposed framework is highly beneficial for society, such as in the case of a natural disaster, where the communication for survivors can be established with additional deployment of drone-based emergency management systems. In the future, with the help of the resource allocation method, the higher system data rate can be achieved, along with the security aspects. D2D communication is one of the key technologies in the 5G network, and further research in the heterogeneous network domain is imperative. Besides, as the D2D link shares the same spectrum resources with cellular links and mobile devices, it causes interference among the spectrum-sharing links, thus decreasing the overall network performance. Better spectrum utilization such as cognitive radio, coordinated multi-point joint transmissions can be used to enhance the overall network performance.

Author Contributions: V.T. conceived and designed the experiments; V.T. and M.N.H. performed the simulation and results; V.T., M.N.H. and K.D. analyzed the data; K.D., T.F.B.T.M.N.I., and I.S.A. contributed Materials/reagents/analysis tools; V.T. wrote the paper. All authors have read and agree to the published version of the manuscript.

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