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Energy Efficient Green Routing Protocol for Internet of Multimedia Things

Sheeraz A. Alvi, Ghalib A. Shah, Waqar Mahmood
Al-Khawarizmi Institute of Computer Science, UET, Lahore 54000, Pakistan
Email contact: {sheeraz.akhtar, ghalib, director}@kics.edu.pk

***Abstract*—Internet of Things (IoT) envisions the notion of ubiquitous connectivity of ‘everything’. However, the current research and development activities have been restricted to scalar sensor data based IoT systems, thus leaving a gap to benefit from services and application enabled by ‘multimedia things’ or Internet of Multimedia Things (IoMT). Moreover, a crucial issue for Information and Communication Technology (ICT) community is the steer increase in CO_2 emissions, which mandates green communication to reduce energy consumption and carbon footprint emissions. Recently, IETF ROLL working group standardized an IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL) for resource constrained devices. RPL builds a tree-like network topology based on some network metric optimization using RPL Objective Functions. Previous RPL implementations for scalar sensor data communication are not feasible for IoMT, since multimedia traffic pose distinct network requirements. The goal of this paper is to design an enhanced version of RPL for IoMT in which the sensed information is essentially provided by the multimedia devices. Our proposed RPL implementation minimizes carbon footprint emissions and energy consumption, along with the incorporation of application specific Quality of Service requirements. To evaluate the performance of the proposed scheme a simulation study is carried out in Cooja simulator for Contiki-OS, which suggests significant gains in terms of energy efficiency and delay.**

***Index Terms*—Internet of Things, Multimedia sensors, Contiki, Green communication, Energy efficiency, RPL.**

I. INTRODUCTION

Internet of Things (IoT) is defined as the global network of uniquely identifiable and addressable ‘smart things’ which possess the capability to interact and communicate with other ‘smart things’ with or without direct human intervention [1]. IoT has the potential to enable enormous number of applications and services which can significantly influence our lives and the way we interact with things [2]. Concurrently, there have been huge growth in online multimedia traffic, due to the eminent interest in development and usage of multimedia based applications, services and solutions, i.e. video conferencing, telepresence, online-gaming, etc. However, the current research and development activities have been restricted to scalar sensor data based IoT systems and overlooked the challenges of provisioning multimedia devices over IoT. Thereby, leaving a gap to benefit from services and application based on the multimedia information essentially provided by the Internet of Multimedia Things (IoMT).

Thanks to Micro Electro Mechanical Systems (MEMS) and Complementary Metal Oxide Semiconductor (CMOS) technologies, IoMT devices are envisioned to be tiny and low-cost, possessing a low-power transceiver, a microprocessor, a battery and a sensor. Consequently, they are expected to be deployed in huge numbers [3]. Smart multimedia things operate in wireless medium with instable links, frequent packet drop, and high bit-error-rate, that is referred as the Low-power and Lossy Networks (LLNs). Moreover, the acquired multimedia data, i.e. audio, video, and audio+video, possess distinct characteristics as compared to the scaler sensed data and impose stringent Quality of Service (QoS) requirements in terms of network bandwidth, delay, jitter, etc [4].

IoT systems are built on LLNs mandating a lightweight energy efficient routing protocol. Therefore, IETF Routing Over Low-power and Lossy networks (ROLL) working group has recently standardized Routing Protocol for Low Power and Lossy Networks (RPL) [5], which is a proactive distance vector routing protocol for LLNs. RPL forms a tree like network topology by maintaining a directed acyclic graph (DAG). In RPL each sensor node chooses a preferred parent towards the root node based on specific routing policies. RPL uses multiple routing metrics and constraints while optimizing an objective function to select the best path. The standard provides the choice to select appropriate objective functions as per the application requirements, which makes RPL highly adaptive and dynamic. However, so far no optimizations have been made for RPL to support multimedia communication.

Environmental awareness in society regarding the carbon dioxide (CO_2) emissions and its effects, has aspired the Information and Communication Technology (ICT) community to ensure low-power and greener operation of communication systems in order to minimize carbon footprint emissions [6], [7]. For this reason, the research community has specifically focused on minimizing CO_2 emission and energy dissipation in next-generation wireless networks, i.e. IoT or IoMT, to enable green communication. Moreover, the multimedia traffic is bulky in nature and operating on high transmission rates. Thereby, the CO_2 emissions are significantly higher in multimedia networks or IoMT. In heterogeneous wireless networks like IoMT, the devices are equipped with different energy sources i.e. lithium batteries, solar cells, piezoelectric energy, etc. Therefore, green communication can be enabled by adopting routes with nodes equipped with green energy source in order to minimize carbon footprint emissions.

Energy efficiency of RPL have been addressed in multiple prior studies in order to optimize RPL for IoT systems based on scalar sensed data. However, to the best of our

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knowledge no RPL implementation is designed in prior studies that incorporates the QoS requirements for multimedia communication over IoMT. Similarly, green communication has attracted lot of attention and motivated researchers to reduce CO_2 emissions, yet there is no RPL implementation to enable green communication. Therefore, in this paper we design an energy efficient green routing protocol (Green-RPL) for IoMT. The proposed Green-RPL routing protocol is an enhanced version of RPL in which a node chooses a preferred parent by considering a set of network metrics such as the delay constraint, battery consumption of potential parent nodes, type of energy sources along the route towards the root node, etc. In this way, the proposed Green-RPL routing protocol minimizes network carbon footprint emissions and energy consumption, while assuring application specific QoS.

The rest of the paper is organized as follows. Section II, presents an overview of RPL and Contiki-OS. Related work is presented in Section III. Section IV, presents the proposed RPL implementation design and its performance analysis is done in Section V. Finally, Section VI concludes the paper.

II. PRELIMINARIES

A. Overview of RPL routing protocol

RPL create a Destination Oriented Directed Acyclic Graph (DODAG) to maintain network topology. DODAG contains multi-hop paths from leaf nodes towards the root node [5]. Thus, leaf nodes choose a preferred parent considering an objective function which is minimized or maximized as per application requirements based on some routing metrics (e.g. ETX, OF0, Node-Energy, etc) representing quantitative path cost. To avoid loops in the route a rank 0 is assigned to root node and the rank increases towards the leaf nodes such that every child has higher rank than its parents.

RPL uses three ICMPv6 packets for routing signalling while creating and maintaining the routing table. (i) DODAG Information Object (DIO) messages are used to form, maintain and discover DODAGs. (ii) DODAG Information Solicitations (DIS) is used to explicitly solicit DIO message from neighbor nodes. (iii) DODAG Destination Advertisement Object (DAO) messages are sent form leaf nodes towards the root to support downward traffic. DODAG uses DODAGSequenceNumber to indicate freshness of the information. The creation and maintenance of network topology requires exchange of control packets. DIO packet pose the most significant overhead which can be controlled with a trickle timer. The smallest interval between two DIOs is equal to DIO-Minimum-Interval which keeps on increasing (doubling) until it reaches the maximum value determined by DIO-Interval-Doublings.

B. Contiki-OS, ContikiRPL, Cooja-Simulator

Contiki is a wireless sensor network operating system (OS) with IPv6 protocol stack, specifically designed for constrained devices with limited processing and memory resources [8]. Contiki-OS is vastly used by the research community for simulation and real-implementation of IoT systems. It supports multiple MAC layer protocols, i.e. CSMA, NullMAC, as well as a radio duty cycling driver, ContikiMAC, to save energy consumption by the transceiver. Contiki-OS also implements a RFC-complaint prototype for RPL, ContikiRPL, which is segregated into multiple modules providing functionalities like RPL control packet creation and interpretation, tricker timer handling, route selection policy and its maintenance, and objective functions implementations.

Cooja simulator is designed to simulate wireless networks in which sensors operate on Contiki-OS. The simulator is implemented in Java but allows sensor node software to be written in C language. In Cooja all the interactions with the simulated nodes are performed via plugins like Simulation Visualizer, Timeline, and Radio logger. It stores the simulation in an xml file with extension 'csc' (Cooja simulation configuration). This file contains information about the simulation environment, plugins, nodes and their positions, random seed, etc.

III. RELATED WORK

IoMT systems are based on LLNs mandating an efficient multi-hop routing protocol to exchange multimedia content among resource constrained multimedia devices. RPL requires low memory resources and its signalling overhead can be tuned using trickle timer. Moreover, IETF ROLL working group did not restrict any parameter settings and routing metrics [5], thus the route selection policy (objective function) can be adapted as per the application and network requirements, which makes it highly flexible and suitable for IoMT systems. Consequently, a number of studies have been carried out to optimize the performance of RPL in various network scenarios.

Energy efficient operation of a routing protocol greatly rely on the choice of paths being selected as well as the overhead posed by the control traffic that is used to find and maintain routes. RPL uses trickle timer to control the number of control packets being sent by each node [9]. When a RPL network is initiated the control traffic overhead is relatively higher, however it decreases once the network routes are stabilized [10]. In [11], authors reported that in a network of 20 nodes operating under a packet error rate of 1%, the control traffic overhead oscillates around the 25%. Similarly, in [11] authors reported that the control overhead increases up to 75% for 100 network nodes. This overhead needs to be reduced to save energy by calibrating the RPL parameters.

Existing network metrics supported by RPL are OF0 and ETX. The OF0 metric find the shortest path towards the root node. Nonetheless, it ignores the channel quality which may result in higher energy consumption. Whereas, ETX metric estimate the number of transmissions required to successfully deliver a packet. ETX metric ignores the traffic load balancing and battery level at the parent nodes which may result in smaller network lifetime. It is reported in [12] that only using energy metric in the objective function may result in high packet loss ratio. Similarly, in [12] authors claim that ETX metric results in uneven energy distribution and energy metric decreases packet delivery ratio. Thereby, a linear weighting function is proposed to control the weighting function of both the energy metric and link quality metric, in order to enhance network lifetime and packet delivery ratio. In [13] a duty cycle aware routing scheme is proposed in which instead of unicast packet transmissions, the packets are forward to all potential receivers and the node that wake up earliest forwards the packet. Thereby, packet delay and energy consumption are significantly reduced along with the radio duty cycle.

Another RPL enhancement is proposed in [14], which uses multiple metrics for a node, i.e. amount of energy utilized and factors influencing the battery consumption. In addition, only those nodes are selected as parents which support particular sensed data traffic. The proposed protocol is reported to save significant amount of energy without compromising on the throughput. Similarly, in [15] the energy metric is used to find the cost effective path and then transmit power is decreased using probing technique to save additional energy. Authors in [16] also designed an energy based metric for RPL named Expected Life Time (ELT) metric, which chooses best parent by evaluating ELT for parent node and itself considering traffic load, residual energy, link quality and load ratio.

Multiple prior studies [11], [17]–[19] evaluated the performance of RPL in various scenarios and configurations, by tweaking its parameters i.e. DIO interval, Rank increase parameter, objective functions, etc, which play a vital role in its convergence time, control traffic overhead, and energy consumption. However, these studies are limited to scalar sensed data network applications and no previous work has considered RPL for multimedia communication over IoMT. Similarly, to the best of our knowledge their have been no consideration given whatsoever about the carbon footprint emissions in a RPL-based IoT system. Also, the heterogenous network devices, in terms of their energy sources, are not considered before in a IoT scenario. Therefore, design of an energy efficient green routing protocol which support application specific QoS is still an open issue.

IV. GREEN-RPL DESIGN

The smart things in IoT systems are envisioned to be deployed in huge numbers that is why there cost and size is kept to a minimum. In addition, these resource constrained devices are supposed to operate in extremely low-power mode in the LLNs so that the network lifetime could be prolonged. In typical IoT scenarios the scalar sensed data is periodic in nature, therefore energy efficient operation is guaranteed by employing a very low radio duty-cycle as low as 1% i.e. the radio is kept ON for only 1% of the total time. Moreover, with help of routing data over less energy consuming paths, a significant amount of energy can be saved. However, in an IoMT scenario the smart low-power devices exchange multimedia data which is bulky in nature and requires higher bandwidth. Thus, packet transmission take place more frequently and the radios are kept in the ON state for longer durations, which results in higher energy consumption and higher carbon footprints emission. Consequently, the energy efficiency and green communication operation is more critical for smart multimedia things in IoMT based systems in order to prolong the network lifetime.

It is noteworthy to mention here that by network lifetime we mean the time when first node drain all of its battery energy. In prior studies many efforts have been made to prolong network lifetime in IoT scenario. However, the multimedia communication over IoT or IoMT along with its prospective requirements and challenges have been overlooked in previous studies on RPL routing protocol. Although lot of work is done on green communication for various wireless networking technologies, yet enabling green communication over RPL-based IoT systems is not given any consideration.

In this paper, a novel RPL implementation is presented in which the carbon footprints emission is minimized provided that the application delay requirement and energy efficiency is guaranteed. To ensure sufficient QoS for specific multimedia application the delay constraint is pre-determined. For example, the delay bound for a Voice over IP (VoIP) application is typically 120 msec, while for video application per packet delay bound varies with the video frame resolution, transmission rate, variable packet sizes, etc, yet transmitter must ensure that in 1 sec at least 25 frames are successfully delivered to the receiver node. Similarly, the energy efficiency is ensured by considering the quality of the intermediate links towards the root node, the energy already consumed by the possible preferred parent node, and by evaluating the potential of the parent node to support traffic requirements for yet another child node. To evaluate a parent node as per these constraints and requirements, an optimization model for the proposed Green-RPL routing protocol is designed in the following part of this section. Among all the parent nodes of a specific sensor node, the solutions of the optimization problem gives the preferred parent.

Consider the wireless link between node α and node β is denoted by (α, β). In practical wireless networks the wireless link quality (Bit Error Rate) is time varying, thus the packet transmissions are affected by the wireless channel conditions. Various methods have been proposed in the literature to estimate the link quality, such as Received Signal Strength Indicator (RSSI), Link Quality Indication (LQI), Signal to Noise Ratio (SNR). The RFC-compliant RPL routing protocol implementation in Contiki-OS provides ETX metric to estimate the link quality which measures the expected number of transmissions required to successfully deliver a packet over a specific link. Let the estimated link quality metric between node α and node β is denoted by $\ell(\alpha, \beta)$.

We define the neighboring nodes of a node α as the nodes which are in the transmission range of node α, i.e. node α can transmit packets towards them. Let the set of neighbor nodes of node α is represented by $\delta(\alpha) = \{\delta_1,\delta_2,...\}$. Since, signal power distributions are not uniform, thus it is possible that node α can listen to some node β, however node β may not listen to node α. So, we define another set of nodes, which are able to transmit packets to node α and represent it as $\vartheta(\alpha)$. Also, consider the rank of node α is denoted by $\phi(\alpha)$. As per the specifications provided by the IETF ROLL working group for RPL implementation, a node can be a parent node ρ for a node c, if it conform the following conditions:

$$\rho \in \delta(c) \tag{1}$$

$$c \in \delta(\rho) \tag{2}$$

$$\phi(\rho) < \phi(c) \tag{3}$$

Let the set of parent nodes of a node c is denoted by $\xi(c) = \{\rho_1, \rho_2, ...\}$. Thereby, the nodes in set $\xi(c)$ send DIO messages to node c who then choose one of these parent nodes as a preferred parent as per the objective function. In our proposed Green-RPL routing protocol the preferred parent is chosen as per the solution of the optimization problem given below:

$$\min. \quad \Gamma(\rho) \tag{4}$$

$$s.t. \quad \rho \in \xi(c) \tag{5}$$

$$\Lambda(\rho) < \mu^d \tag{6}$$

$$\Omega(\rho) < \mu^\ell \tag{7}$$

$$\Psi(\rho) > \mu^b \tag{8}$$

$$\Upsilon(\rho) > \mu^i \tag{9}$$

Here $\Gamma(\rho)$, $\Lambda(\rho)$, $\Omega(\rho)$, $\Psi(\rho)$, and $\Upsilon(\rho)$ represent the cumulative path carbon footprints, cumulative path delay, cumulative path link energy, battery status, and idle time for the parent node (ρ), respectively. In this optimization problem, the objective is to minimize the cumulative carbon footprint emissions on all the links along the path from parent node ρ towards the root node. Therein, if when multiple parent nodes fulfill the given constraints then the node offering the most greener path will be selected as the preferred parent. The heterogeneous smart devices in a IoMT network can be equipped with distinct energy source, thus emitting disparate amount of carbon footprints. Let the carbon footprints emitted by a link ℓ within the path from parent node ρ to root node is denoted by $cf(\ell)$, then $\Gamma(\rho)$ can be given as;

$$\Gamma(\rho) = \sum_{\ell \to 1}^{L} cf(\ell) \tag{10}$$

here L is the total number of links in the path. Moreover, the parent node ρ needs to fulfill some other constraints to enable application specific QoS and longer network lifetime. The first constraint is very basic that is the potential preferred parent node ρ should belong to set of parents of node c i.e. both ρ and c are neighbors of each other and rank of node ρ should be less than the rank of node c. The second constraint specifies the application QoS in terms of the delay bound that is the cumulative path delay for a data packet should not increase a predefined delay threshold μ^d. In LLNs a packet may experience different wireless channel conditions, thus undergo distinct packet delays per link. Thereby, if the delay induced by a link ℓ is denoted by $d(\ell)$, then the cumulative delay of the path can be given as

$$\Lambda(\rho) = \sum_{\ell \to 1}^{L} d(\ell). \tag{11}$$

Energy consumption of a node significantly depends upon the link quality of the path selected for packet routing. For example, if a path with poor link quality is selected then the probability of successful delivery of packet in single transmission attempt will be very low, which may result in several retransmissions before packet gets delivered to the destination, consuming significant amount of energy. Therefore, an important metric to consider while selecting a route is to evaluate the energy cost as per the quality of links along the path which can be given as

$$\Omega(\rho) = \bar{D} \sum_{\ell \to 1}^{L} \frac{ETX(\ell) \times P_t(\ell)}{\lambda(\ell)}. \tag{12}$$

Here $\bar{D}$ is the data packet size, while the $P_t(\ell)$ and $\lambda(\ell)$ is the transmit power and data rate of link ℓ, respectively. $ETX(\ell) = (\ell - \tau)\left(1 + \frac{1}{\tau}\right)$ is the expected number of transmissions required to successfully deliver the packet over link ℓ and τ is the probability of successful packet transmission.

The battery status of the parent node ρ is also a critical metric, since it can influence the network lifetime and traffic load on a particular node. Consider a scenario in which a single parent node is selected by multiple child nodes as a preferred parent for traffic forwarding, in this case the parent node will quickly drain its energy resources and network lifetime will be reduced. Similarly, selecting a parent node with low remaining energy will also result in route instability as the route will be required to change in a short time when the parent node battery dies. Therefore, we propose that the child node c only select a parent node ρ as the preferred parent if its available energy resources (battery level) is higher than a pre-defined threshold μ^b. If the maximum battery energy capacity and battery energy already utilized is given by E_c and E_u, respectively, then the battery status can be given as

$$\Psi(\rho) = \frac{E_c(\rho) - E_u(\rho)}{E_c(\rho)}. \tag{13}$$

Lastly, the $\Upsilon(\rho)$ constraint represents the amount of time the parent node ρ keeps its radio ON, yet no activity (transmission or reception) is done during this period. It is essential to know if a node has enough idle time to support a child node. For example, in a LLN the nodes operating on very low radio duty cycles can only support a limited number of child nodes within their radio ON period. For this reason, a parent node ρ should only be selected as a preferred node if its idle time is enough for supporting another child node, i.e.

$$\Upsilon(\rho) > \frac{t_{tx}(\rho) + t_{rx}(\rho)}{c\_n(\rho)}. \tag{14}$$

Here $t_{tx}(\rho)$ and $t_{rx}(\rho)$ represents the time parent node ρ spends in transmission and reception mode, respectively. While $c\_n(\rho)$ denotes the number of child nodes already supported by parent node ρ. This concludes our Green-RPL routing protocol design, which considers various constraints while selecting a parent node as a preferred parent, so that an energy efficient operation along with the minimization of carbon footprints emission can be guaranteed.

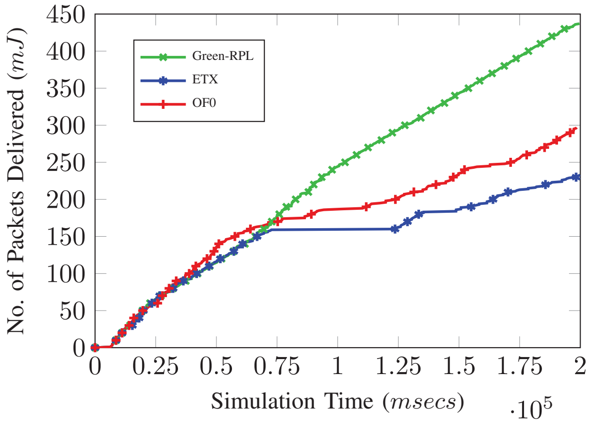

Fig. 1: Number of packets delivered to the root node.

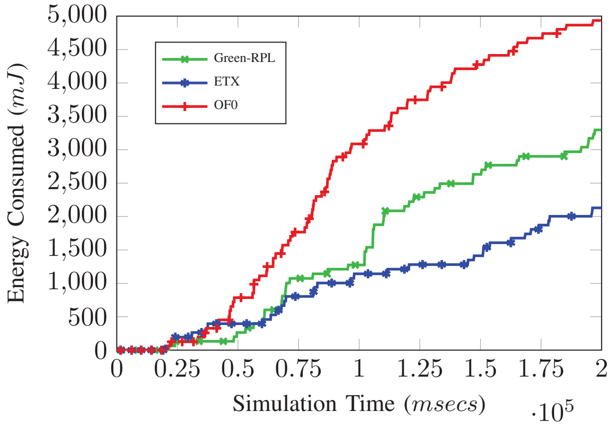

Fig. 2: Cumulative amount of energy consumed with time.

V. PERFORMANCE EVALUATION

The proposed Green-RPL routing protocol is implemented in Contiki-OS v2.7 and its performance is evaluated by carrying out a simulation study in Cooja simulator. Moreover, its performance is compared with existing objective functions i.e. OF0 and ETX. These objective functions select preferred parent to route traffic towards the root node by considering number of intermediate hops and the number of transmissions required to deliver the packet to the root node, respectively. The simulated network scenario consist of 20 TMote Sky nodes transmitting multimedia traffic towards the root node via multi-hop links. The multimedia content specifically video content generate frames of different size at irregular intervals, thus packet generation rate is kept variable.

The network nodes are randomly distributed in an area of 200x200 meters experiencing a lossy channel model Unit Disk Graph Medium (UDGM)-distance-loss with a 2% packet loss. ContikiMAC is used as a radio duty cycling driver. As suggested in [18] DIO-Minimum-Interval, DIO-Interval-Doublings, and Radio-Duty-Cycling intervals are set to 12, 16, and 16, respectively. Half of the sender nodes are supposed to be equipped with greener energy sources (e.g. solar) and the other half have carbon emitting energy source. For comparison the network topology is kept same for all three cases, i.e. Green-RPL, OF0, ETX. The network simulation is run for 1 hour. Note that Contiki-OS provides IEEE 802.15.4 at the link layer which is proposed for the IoT communication stack. Thus, maximum packet size and data rate are restricted to 128 bytes and 250 kbps, respectively, with a packet generation rate of 25 pkts/sec. Certainly, the limited packet size and data rate of IEEE 802.15.4 questions its feasibility for multimedia communication. Yet the scope of this paper is restricted only to the performance of routing protocol and the parent selection mechanism in low-power and lossy multimedia networks. Thus these MAC layer issues are not relevant and the proposed Green-RPL mechanism can be adopted for any underlying MAC layer technology.

First, we compute the number of packets transmitted by nodes in each RPL implementation scenario. The total number of packets successfully delivered to the root node in a 20 node network is shown in Fig. 1. Network is simulated for 1 hour, however to present the results clearly we restrict the time window to a smaller duration. Our proposed Green-RPL algorithm provides a significant improvement in number of successful packet transmissions, as shown in Fig. 1. In ETX and OF0 objective function some nodes on key locations/positions are selected as preferred parent by multiple nodes, resulting a higher congestion on the forwarding nodes. However, in our scheme preferred parent is selected only if it can support the traffic of another node. Thereby, a significantly high delivery rate is achieved in our proposed scheme.

To calculate energy Contiki-OS provides the timing information about different states of a node i.e. transmit, listen, etc. We computed energy as per TMote Sky specifications, voltage of 3.6 V and current values 21 mA, 23 mA, 0.21 mA, 1.2 mA, 2.4 mA, drawn in the transmit, listen, low-power-mode, idle, CPU states, respectively. The cumulative energy consumed by all the network nodes is shown in Fig. 2. Note that even though the energy consumption in our Green-RPL is higher than ETX, yet the number of packets transmitted in the same time by Green-RPL are significantly higher, see Fig. 1, thus energy consumption is higher. However, its energy efficiency can be observed by the per packet energy consumption which is 7.545 mJ for Green-RPL, 9.18 mJ for ETX, and 16.73 mJ for OF0. This shows that the proposed Green-RPL algorithm is eminently energy efficient as compared to ETX and OF0 objective functions.

Contiki-OS does not support heterogeneous energy source models. Thus, CO_2 emissions need to be inferred in a logical manner.We assume that the network contains equal number of possessing green or non-green energy source emitting no or some CO_2 footprints, respectively. The green nodes are randomly deployed in the network and identified by their IP addresses. We simulated multiple network scenarios with different network densities/topologies and observed the number of packets transmitted+forwarded by green nodes, in order to infer CO_2 emissions. Fig. 3 shows the normalized number of packets (ratio) sent by the green nodes in each case, which

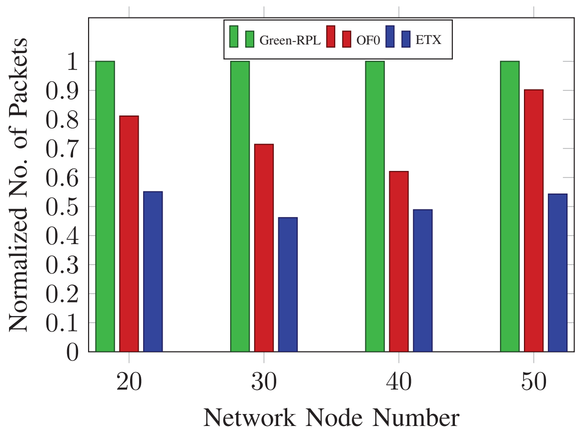

Fig. 3: Normalized number of packets sent+forwarded by nodes possessing green energy source.

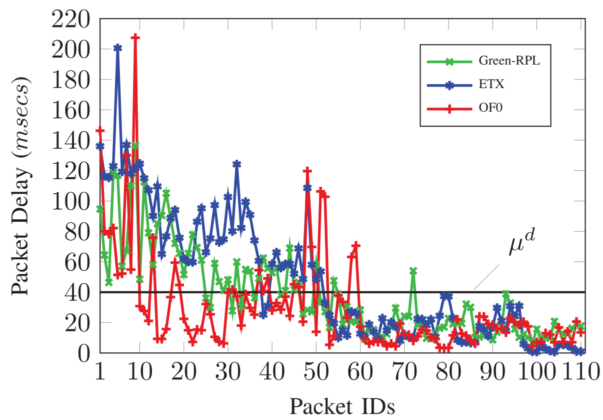

Fig. 4: Per packet delay to get it delivered to the root node.

confirms that in each network scenario our proposed Green-RPL utilizes green nodes the most. Because, in ETX and OF0 the energy source of a node is not considered while selecting the preferred parent that may result in high CO_2 emissions.

Finally, the per packet delay experienced by a packet is evaluated. Again a network of 20 nodes is simulated and the delay of individual packets sent by sender nodes towards the root nodes is computed. As shown in the Fig. 4, at the start of the network when network topology is not formed completely the delays are higher. However, as the complete RPL-DODAG is created optimal paths are selected based on the objective function in use and the delays get reduced. The simulation is run for 1 hour, yet to clear observation only limited time duration is presented. The average per packet delay in our proposed Green-RPL, ETX, and OF0, are 20.4 msecs, 47 msecs, and 26.2 msecs, respectively.

VI. CONCLUSION

The current research and development activities for IoT systems have overlooked the incorporation of 'multimedia things'. Similarly, there have been no consideration of green communication or carbon footprints reduction using the RPL routing protocol. For this reason, in this paper an enhanced version of RPL for IoMT is proposed, Green-RPL, in which the sensed information is essentially provided by the smart 'multimedia devices'. The proposed Green-RPL routing protocol minimizes carbon footprints emission and energy consumption, and supports application specific QoS requirements by considering various constraints while selecting routes towards the root node. To evaluate the performance of the proposed scheme a simulation study is carried out in Cooja simulator for Contiki-OS, which suggests promising results and performance gains as compared to prior RPL implementations.

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