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RESEARCH ARTICLE

Enhanced Objective Function ETX Metric in Routing Protocol for Low-Power and Lossy Networks (RPL)

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Abstract – An Internet of Things (IoT) is a technique capable of real-time object connections on the Internet and accessing them anywhere at any time. The low-power wireless network is the primary component for Internet of Things applications. In this scenario, the major processes of the wireless sensor network (WSN) applications are considered routing, deploying low-power nodes, load balancing, and controlling remotely. The Internet Engineering Task Force (IETF) is systematized to enable communication over Low-Power and Lossy Networks (LLNs) using Internet Protocol Version 6 (IPv6) routing. The Routing Over Low-power and Lossy Networks (ROLL) working group has determined a new routing protocol for LLNs named Routing Protocol for Low-Power and Lossy Networks (RPL). Moreover, two Objective Functions (OF) are designed for implementing the routing technique that applies the metrics. In the network routing process, hop count is a core metric in Objective Function Zero (OF0), and expected transmission count (ETX) is a metric in Minimum Rank Hysteresis Objective Function (MRHOF). However, the network becomes high-density, and nodes are increased. Adapting the existing objective function single metric generates long hops and bottlenecks affecting network performance. To solve the stated problem, the objective function requires optimized enhanced metrics. This paper aims to provide an optimization path selection in RPL by implementing a new routing objective function metric. It is called Variance Expected Transmission Count (VETX), in which the optimized best route is computed by the method of modified variance calculated in ETX values. This implementation is simulated using the Cooja simulator, and the obtained result of the enhanced ETX metric (VETX) ensures an average of 2.6% outperformance in OF0 and MRHOF in the subjects of packet delivery ratio, latency, energy consumption, overhead, and goodput.

Index Terms – IoT, WSN, RPL, Objective Functions, Routing metric, VETX.

1. INTRODUCTION

Smart technology development dimensions a greater number of objects or things are connected to the Internet. This growth indicates development and research requirements in the IoT and the LLNs since the WSN has high responsibility in the IoT network for data collection like environmental monitoring, smart health care, and smart city applications. Daily IoT applications the need is growing; not only are we mentioned here [1], they have introduced a new technology called GARNUS (Garden Binus) at low cost and have proven to increase the productivity of ornamental plants by accessing the website. IoT applications have various components; hence this application development has high challenges for optimum utilization of IoT application resources with constrained energy, routing, and memory. The ROLL working group developed the most common routing protocol for IoT development in the name of RPL, and the routing technique is accomplished by using two objective functions. These functions are not an algorithm, optimized path obtained by metrics. An OF0 uses the hop count as the metric, and MRHOF is the other end objective function, which uses the ETX as a core metric.

In the last decade, research, experiment, and IoT application development of WSN focused on IPv6 routing for low-level power consumption with minimized packet loss rates [2]. The different scenarios of the IETF community aimed constrained requirements of low energy consumption and Quality of Service (QoS) then defined in IPv6 routing on Low-power Wireless Personal Area Network (6LowPAN), which allows integration of IEEE 802.15.4 standard and named as Routing Protocol for Low power and Lossy Networks (RPL) [3].

RPL supports standard routing protocol for IPv6-based Low-power and Lossy networks (LLNs), such as WSN and routing technique presented by the ROLL working group. RPL operates in IEEE 802.15.4 Physical layer and Data Link layer in a dynamic routing of extensible and flexible manner and computes each path distance by the method of distance-vector routing[4]. In today's LLNs network communications, there is a high need for various information rapid accesses offered by the Internet and sensor devices for connecting the real-world

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environment with link-state quality. However, many improvement fields in this network are still in research[5]. As a result of constrained components, this network routing is a challenge in LLNs. The global standardized group and researchers are focusing on designing a high-quality routing protocol for the IPv6 dimension to support the LLNs. The RPL protocol is flexible and allows the interconnection of heterogeneous object communication with constrained memory, energy, and other network resources. The existing standardized implementation used a routing metric, thus not emphasizing the reliability of links [6].

Compared to other networks, IoT devices are smart but still possess more improvements required in routing protocols. Specifically, in the RPL protocol, optimum utilization of constrained resources is the biggest gap in route formation, energy consummation, extending the transmission speed, interconnection nodes, avoiding bottleneck issues, etc. The lossy and unstable links help with low-level data rates in WSN. The filling of this gap will lead to extending the RPL protocol to the next level. There is more scope we have to optimize the constrained resources in RPL.

1.1. Contribution

We found that the existing RPL system reduced the network performance by using standard metrics in objective functions. A single metric and best path selection result in bottleneck issues. VETX was implemented to allow RPL to test the network performance without affecting the existing standardized routing design and evaluated the improvements with network parameters in the Cooja simulator. This contribution reveals that the average 2.6% result obtained on a small conversion ETX will greatly help IoT applications. It is noteworthy that our proposal in this is beyond any standard definition.

In the reset of the sections follows: in 2 defines the RPL protocol overview, section 3 narrates related work contributions, in section 4, our contribution of proposal VETX has discussed with the example scenario, and section 5 explains the obtained results from simulation and results from the comparison of OF0, MRHOF, and VETX with five parameters and in section 6 VETX concludes the VETX result performance and future direction of our proposal.

2. RPL PROTOCOL OVERVIEW

The LLNs have limited specifications of low data rate and packet loss to connect to the Internet. The RPL addresses these specifications in IPv6 routing and is based on distance vector routing protocol with the following types: node sink (receiver) and issuer (sender). The Destination-Oriented-Acyclic-Graph (DODAG) technique builds a tree topology for the network operation, and the following four major control messages are responsible for establishing and performing the network operations. Figure 1 illustrates the DODAG Information Object (DIO) operations.

(i) DIO: DODAG Information Object – Comprises routing information such as root node information and objective function, and the root node sends DIO messages to all other network nodes.

(ii) DIS: DODAG Information Solicitation – probe the node information, and neighbor nodes receive the routing information sent by the node.

(iii) DAO: Destination Advertisement Object – contains destination information, and each node sends the message to the root.

(iv) DAO-ACK: DAO- Acknowledgement- Yes or no response acknowledge by the root or parent to its child.

2.1. General Principles of Objective Function

In RPL, the network tree topology formation, the DODAG root or parent node sends a DIO to every node in the network topology. All the respective node sends DAO messages to the root or parent of DODAG for acknowledgment with relevant information. RPL has a bidirectional link and enables uplink and downlink traffic, supports different patterns of networks like Point-to-Point (P2P), Multipoint-to-Point (M2P), and Point-to-Multipoint (P2M).

The constructed network node contains Low-power and lossy-network Border routers (LBR), routers, and hosts. While forming the RPL network, it defines a logical network topology following tree methodology with root (border router) and edges (host) for transmitting the data in the up and down traffic flow of the network.

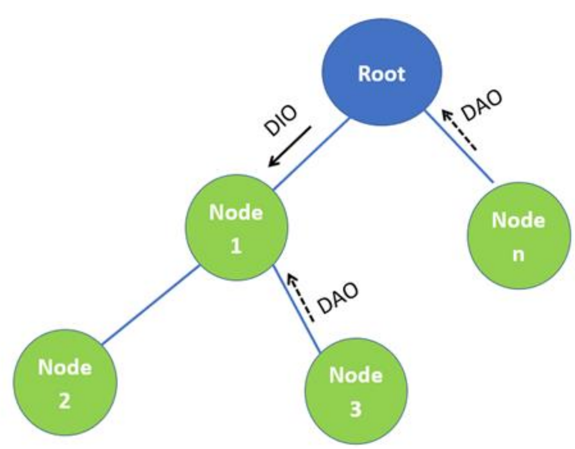

Figure 1 DIO Format

An objective of OFs defined to select an optimized path and network topology formation, selection of parent and candidate path, and estimate the rank position of a node within an RPL-instance based on OF metrics such as topology-based and

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link-based. The ROLL team defined two objective functions and named OF0 and MRHOF objective functions using the single metric for the optimal route towards the destination. The first objective function, OF0, is based on the number of hops as the metric for selecting the best parent, and the second MRHOF uses the ETX metric to select the optimal route in the network topology[7]. The choice of metrics and constraints are selected in OFs having high responsibility and reflection in defining the network parent node selection and routing. The decided metrics are computed path cost and authority on the optimized path.

The metric is classified as node-based and link-based; the metric is considered with physical constraints like the node's remaining energy (RE) and maximum lifetime (MLT) of the node. The link-based metrics are directly involved in the quality of the network; hence these metrics like ETX, Expected Transmission Time (ETT), Received Signal Strength Indications (RSSI), Packet Loss Rate (PLR), and Link Latency (LL).

3. RELATED WORK

The goal of designing the routing protocols must be the nature of the network applications and the demand of network architecture. In wireless sensor network protocol design must be highly considerable on constraints of resources to achieve the communication among nodes and designing the routing protocols in wireless communication the routing metrics in routing protocols are makes a high impact on communication protocols. The path calculation method and packet transmission mechanisms are the main components of the wireless network. These two operations must focus on the valid lightest path among the source and destination nodes, either hop-by-hop or source node schemes. In this fact, the arbitrary selection of metrics and combination metrics in routing protocols will lead to failure to find the optimal path in wireless networks [8].

In the standardized objective functions, either OF0 or MRHOF used a single metric to select the route to provide Quality of Service (QoS) assurances for static and mobile infrastructures is highly challenging in RPL. The routing metrics specification in RPL does not recommend any metrics and open choice for implementations with adequate LLN requirements. However, these metric selections cannot fulfill the QoS based on the various real-time IoT applications[9].

For successful packet delivery, the number of transmissions of a node (ETX) is calculation follows Eq. (1):

$$\mathrm{ETX} = \frac{1}{\mathrm{df \times dr}} \quad (1)$$

The Df and Dr are probability measures the packet forward to the neighbor node and acknowledgment successfully received by the neighbor node[10]. The concept of avoiding the long hop route and single hop forwarding problem, the new metric in RPL was introduced under the Per Hop ETX (PER HOP-ETX). In this concern, the best routing path is calculated using metric ETX average values between each node from source to destination [2]. However, the standardized ETX and previously mentioned proposals focus on the best parent selection in the LLN networks and improving the QoS in LLN.

Wireless Mesh Network (WMN) evaluates an important time metric for extending the coverage area in multi-hop technology. Both proactive and reactive conditions Weighted-Cumulative Expected-Transmission Time (WCETT) implemented with the Annealing algorithm to achieve maximizing network link capacity by WCETTs in the linear programming model. The goal of this implementation was to minimize the end-to-end latency between two nodes and avoid the loss of information by selecting a high-throughput path[11].

To enhance the energy consumption, transmission of data packets, and higher reliability in fixed and mobile nodes proposed in KP-RPL[12] with link quality metric of average ETX. The mobile to anchors link metric is selected for ETX computation based on the Kalman filter with blocklist. Anchor nodes are error-free; the locations are static or mobile, and the confidence regions are estimated by Kalman filtering. The unreliable mobile nodes are discarded and considered as a blocklist then the best routing decisions are performed by end-to-end ETX computation.

The normal routing metric of RPL is an inefficient route selection results and leads to more energy depletion and high traffic and packet loss ratio in the density network. The composite routing metric work proposed with Load and Battery Discharge Index (BDI) LE-RPL. This proposal has combined more than one metric-based objective function focused on data traffic in multipoint-to-point communication, loop-freeness, and bottleneck selection issues. Achieved an improved network lifetime by efficiently using the energy in LLN and fulfilling the optimal Packet Delivery Ratio (PDR)[13].

Instead of using the standard metric in the RPL network uses the remaining energy of the nodes as the main routing metric concept proposed in[14]. To estimate node battery Residual Energy (RE) for selecting the next hop at runtime using a well-known battery theoretical model for increasing the network lifetime and node battery energy maintaining the same energy for improving the network lifetime.

The metrics are liable to enrich the network performance execution in LLN/IoT and select the optimal path. At this juncture, an Energy-Efficient and Path Reliability Aware-Objective Function (ERAOF) for IoT applications proposed [15] the reliable energy-efficient and data communication/transmission. The proposed ERAOF is that

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node's energy and link quality metrics provide improved network performance, increased PDR, and efficient power consumption in small dense IoT Network resources.

The two parameters from the network layer and MAC layer concepts are proposed [15] in hybrid nodes to determine the best path, manage multiple interfaces, and improve reliability using the retransmission scheme. In this proposal, they provided parent-oriented solutions and interface-oriented solutions. The best quality link is decided in the MAC layer, and the RPL objective function selects the next forwarding node from the network layer. The Link Quality Level (LQL) Expected Transmission Time (ETT) metric values were used to compute the rank.

To provide continuous connectivity by way of additional control message and timer is utilized to detect the mobile nodes by improving the RPL protocol proposed in [16] with additional metrics such as ETX, RSSI, and Energy. This method has four steps; the parent node monitors the average received signal strength indicator (ARSSI), and the parent node finds any mobility nodes. The parent node designates a new route; the mobile nodes update the routing information in the last step. This work compared with previous mRPL[17] regarding energy efficiency.

In the case of path failures in RPL topology In LLNs, a novel objective function based on QoS and congestion-aware (QCOF) has been proposed[18]. The proposed method significantly improves from the standard RPL regarding the constrained feasible path, energy, packet priority, and congestion metrics. The QCOF sends packets based on predetermined (constraints) priorities, and subject to path failure, the candidate nodes request a new DODAG root to choose the feasible path. The new DODAG is formed according to node availability scenario and node positions.

The network interface average power metric (NIAP) is a new routing metric presented in [19]; the rapid battery exhaustion is mainly considered and calculated as an average of power utilization of the network interface to avoid energy-based bottleneck problems. It enables equal path selection and avoids path selection with collision probability. NIAP is used as the power metric that aids in selecting dependable RPL path more quickly than normal ETX, contributed to the network load balancing, extending the lifetime and attaining the network lifetime 24%, average delay reduced up to 13%.

Among the number of nodes, the parent selection process and construction of an unbalanced topology network addressed and proposed the new method in[20]. This proposed method uses numerous routing metrics to determine the rank and ensure reliability in Advanced Metering Infrastructure (AMI). Construct the balanced routing topology with Residual Buffer (RB) size, Child Count (CC) metric, and ETX to understand the link quality. However, the comparison result is done with standard RPL and OF-FL obtained, which turns the high packet deliver ratio.

The OFs routing metric selections are open according to the application requirement to select the best paths. Paper [21] proposes the trickle time short-listen problem overcome by the single and combination of various metrics with each other are used to escalate the objective function performance of RPL. In forest monitoring applications, the residual energy with ETX (i.e., energy + ETX = EE) and enhanced timer are the metrics to accomplish an energy consumption presented. The hypothesis scenario proved the improved PDR and latency delay result compared to default ETX.

In multi-hop low-power wireless networks, the distribution mechanism controls transmission power, and routing topology formation was implemented and named Power Controlled RPL (PC-RPL)[22]. The PC-RPL presents an improved end-to-end packet delivery ratio in high traffic with a test-bed among 49 nodes. To avoid the hidden terminal risk issue and load balance by constructing novel local rules. The parent node selection metrics are RSSI thresholds, RSSI reference values and hop distance, and ETX from the default RPL protocol.

Generally, the RPL parent selection is the responsibility of the child and rank based. The mutual concept introduced in Enhanced RPL (EN-RPL)[23] formed the mutual understanding decision technique between parent and child node. The child nodes prevent the selection of congested parent nodes from the network topology. Furthermore, introduces the new objective function for enriching routing along with new metrics Composite Efficient Routing (CER). The metrics of the link quality, delay, queue utilization, lifetime of a node, and bottleneck issued nodes are accountable for optimal parent selection.

The Laplacian energy-based stable path selection concept presented in L-RPL [24] enriches the existing RPL using the neighbourhood node information to improve the route selection and reduce the control overhead. The major goal of this proposal is to find an alternative solution to ETX-based path selection and avoid link failures on the high-density network. The candidate path selection computation considers the drop energy metric using the Laplacian in standard RPL-OF. The 2-walks link metric method produces high and low measured values for selecting the upward candidate parent selection, or the regular ETX is a metric for selecting the candidate path.

The link quality and current node energy metrics are combined as Weighted Combined Metric (WCM-OF) and Non-Weighted Combined Metrics (NWCM-OF) in the objective function to achieve network reliability and energy consumption presented in[25]. The computed new metric adds to the sender node on its own and sends the DIO messages to

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the nearest node; then, path selection depends on the lowest sum of new combined metrics. This proposal increases the network reliability, extends the network lifetime, and reduces the parent selection for a solid routing.

A new additive combined metric is recommended and named Delay-Aware RPL (DA-RPL) to enhance the RPL to attain link reliability and low latency in the smart-meter network[26]. In this proposal, the following metrics ETX, delay, and energy relative weights are assigned to α,β, and γ. These three metric values compute the coefficients, and the result of best weight is utilized for DODAG topology construction. The candidate path is selected between high-reliability nodes with lower energy and delay. All of the article comments we mentioned above confirm that we are in a position to take the RPL protocol to the next level and increase its potential. It shows that the dominant metrics used by the RPL objective function will help us significantly if we achieve this. We made variations on its ETX metrics and added a significant level of performance improvement in network parameters. Optimization is applied to enhance the performance of any kind of network [27] – [34]. Table 1 Summarizes the Proposals' Carried Out Related Works Objectives and Performance Achievements with Metrics.

Table 1 Summary of Related Works

Proposal	Computed Metric (s)	Proposed Objectives	Achieved Performance
PER-HOP ETX [2]	Minimum Hop count and ETX metrics	The best routing path is the calculation	Low latency, high PDR, and low energy consumption
WCETT[11]	WCETT	Extend the network coverage area	Minimize the end-to-end delay. Avoid the loss of information by selecting a high-throughput path
KP-RPL [12]	Average – ETX	Static and mobile node robust and reliable routing	Extended the lifetime of both anchor and mobile nodes.
LE-RPL [13]	Composite – metric	Improvement in the network Performance	High Packet Delivery Ratio
RE-RPL [14]	Residual Energy	Nodes remaining energy for the next-hop selection	Improve the network lifetime.
ERAOF[15]	ETX and energy	Data transmission with energy efficiency and reliability	Improvement in the network performance and increase the packet deliver ratio
Hybrid Objective Function [16]	LQL and ETT	Manage multiple interfaces nodes and retransmission scheme	Hybrid network in RPL
A new method for improving RPL to support mobility[17]	ETX, RSSI, and Energy	Mobility node detection reduces the energy and network overheads	An efficient algorithm for energy efficiency and easy to implement
QCOF [18]	Constrained node position, real-time constraints, packet priority, congestion metrics.	Choose the feasible path in the case of a path failure. Constrained level	According to packet priorities, significant improvement achieves the highest packets delivery ratio, Consumed low energy.
NIAP [19]	Average Energy	Selecting reliable paths and avoiding rapid depletion of battery energy at bottleneck nodes	Improved the network lifetime and reduced end-to-end delay

Resource-oriented topology (AMI) [20]	RB, CC, and ETX	Efficient parent selection strategy and away from the overburdened parent.	Improved PDR, lower latency, and higher throughput
OF using variant routing metrics for IoT applications [21]	ETX, Content, and Energy	According to the requirement of the application	Energy consumption and hypothetical improvement in packet delivery ratio, latency.
PC-RPL[22]	The transmission power and routing parent are adjusted based on the combined link and queue loss.	lightweight distribution, adaptive routing, and power control	Improved performance in end-to-end and PDR in high traffic.
EN-RPL[23]	Link quality, queue, the lifetime of nodes, delay, and number of bottleneck nodes	Optimized parent selection	Derived stability, reliability, and energy efficiency in network
LRPL[24]	Laplace in energy drop and ETX	Alternative to ETX and avoid the node failure states	Minimized the control packets and delayed packet reception end.
WCM-OF and NWCM-OF[25]	link quality and energy metrics	Additive metrics of link quality ETX and energy	Reduced the parent selection and provide more stability on routing.
DA-RPL [26]	Delay, energy, and ETX	To ensure link reliability and low latency	Performance increased in end-to-end delay by avoiding retransmissions and energy consumption.

4. PROPOSED METHODOLOGY

The ETX metric is the wireless link for data transmission in LLN to attain high quality. However, the number of hops is the most considered metric for data transmission in low-density networks (few nodes in the network). The method of route selection, the summation of ETX minimum value, and the minimum hop count metric is a good solution for selecting the best route in low network density, and also thus, the selected route minimum sum of ETX has the risk of the number of hops. The problem identified while the network density increases, the existing method's evidence suggests that the best path has long hops to reach the destination. Moreover, the long hops will generate the bottleneck for the entire network topology and affect the network performance.

The VETX is implemented to avoid the above-stated problem by using the modified variance. The implementation is achieved by combining two metrics, least hop-count, and ETX, where the best and optimum route is calculated in the modified variance of each ETX value between nodes.

The following Figure 2 shows that there are two possibilities to reach from source to destination. The summation of ETX values between each node in a path is used to select the optimal route. However, the hops count of a path is more relevant than the transmission quality at the selection time.

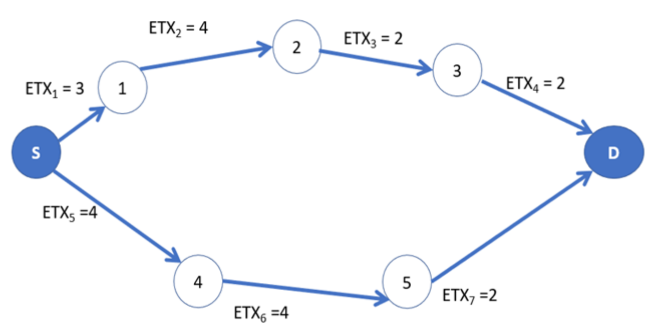

Figure 2 Sample ETX and Hops Count

According to the standard MRHOF, path selection is calculated using the ETX metric followed by Eq. (2).

Where,

$$ETX_{SDi} = ETX_i + ETX_{i+1} + ETX_{i+2} .. + ETX_n \quad (2)$$

Therefore, in our example the, route 1 (S-1-2-3-D)

ETXSD1= ETX1 + ETX2 + ETX3 + ETX4

= 3 + 4 + 2 + 2

= 11

then route 2 (S-4-3-D)

ETXSD2 = ETX5 + ETX6 + ETX7

= 4 + 4 + 2

= 10

Hence, ETXSD1 > ETXSD2

Route 2 is the best path from source to destination. While the ETX value is large, it can form the bottleneck; therefore most cases, the standardized path selection does not provide the best path. The ETX averages are calculated and compared to the paths for best path selection in[2], and the best path selection result follows Eq. (3).

$$\text{P-ETX}_{\text{SDi}} = \frac{\sum_{i-1}^{n} ETX_i}{n} \quad (3)$$

route 1

$$\text{P- ETX}_{\text{SD1}} = \frac{\text{ETX1 + ETX2 + ETX3+ ETX4}}{4}$$

$$= \frac{11}{4} = 2.75$$

route 2

$$\text{P- ETX}_{\text{SD2}} = \frac{\text{ETX5 + ETX6 + ETX7}}{3}$$

$$= \frac{10}{3} = 3.33$$

The presented network model result is

route 1 P- ETX_{SD1} = 2.75 and

route 2 P- ETX_{SD2} = 3.33

If two candidate paths occurred in this model, follow the Gaussian distribution for producing the statistical principle to find the best path in the objective function. Moreover, in this proposed model, the average calculation does not fulfill the dense network models to avoid long hops. P-ETX average values are very close between more paths in the network; in this case, there is the possibility of some packet loss and energy consumption, which brings us to find a new solution with long hops.

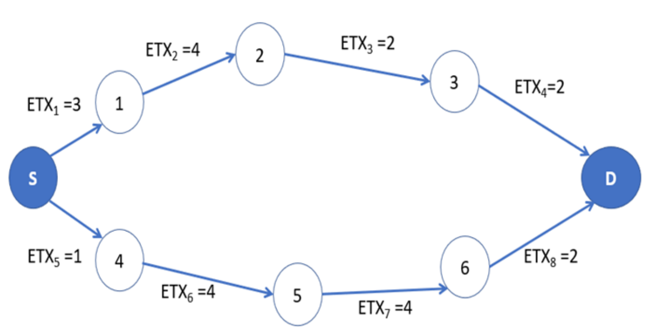

Figure 3 Example of the Average Calculation Model

In the following Figure 3, network model route:1 (S-1-2-3-D) and route:2 (S-4-5-6-D) represent both routes with are same value in the standardized objective function attempted by using the hop-count or ETX summation. Unfortunately, both metrics hop-count and the average of ETX also equal value.

Route: 1 is

$$\sum(\text{R1} - \text{ETX}) = 3 + 4 + 2 + 2 = 11$$

Route: 2 is

$$\sum(\text{R2} - \text{ETX}) = 1 + 4 + 4 + 2 = 11$$

The average ETX of route 1 or route 2 is

$\text{Avg(R1-ETX)} = \frac{11}{4} = 2.75$

$\text{Avg(R2-ETX)} = \frac{11}{4} = 2.75$

Therefore, this model problem is solved using the modified variance in our VETX proposal followed by Eq. (4).

$$\frac{\sum_{i=1}^{N} x^2}{N} - \mu^2 \quad (4)$$

Where,

The total number of nodes n and μ is the average of ETX in the route

n= 4

$\mu = \text{Avg}(R_i\text{-ETX}) = 2.75$

Applied in route 1,

$$\text{Route 1} = \frac{3^2 + 4^2 + 2^2 + 2^2}{4} - 2.75^2$$

$$= \frac{33}{4} - 2.75^2$$

$$= 8.25 - 2.75^2$$

$$\text{R1} = 0.69$$

Applied in route 2,

$$\text{Route 2} = \frac{1^2 + 4^2 + 4^2 + 2^2}{4} - 2.75^2$$

$$= \frac{37}{4} - 2.75^2$$

$$= 9.25 - 2.75^2$$

$$\text{R2} = 1.69$$

Hence,

VETX (R1) = 0.69

VETX (R2) = 1.69

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The VETX (R2) route has a higher value in modified variance; therefore, the VETX (R1) is stable and no longer hop. Figure 4 shows the different steps that perform the VETX(R) selection. Algorithm 1 presents the pseudocode scheme for selecting an optimized path for the generalized VETX operation algorithm.

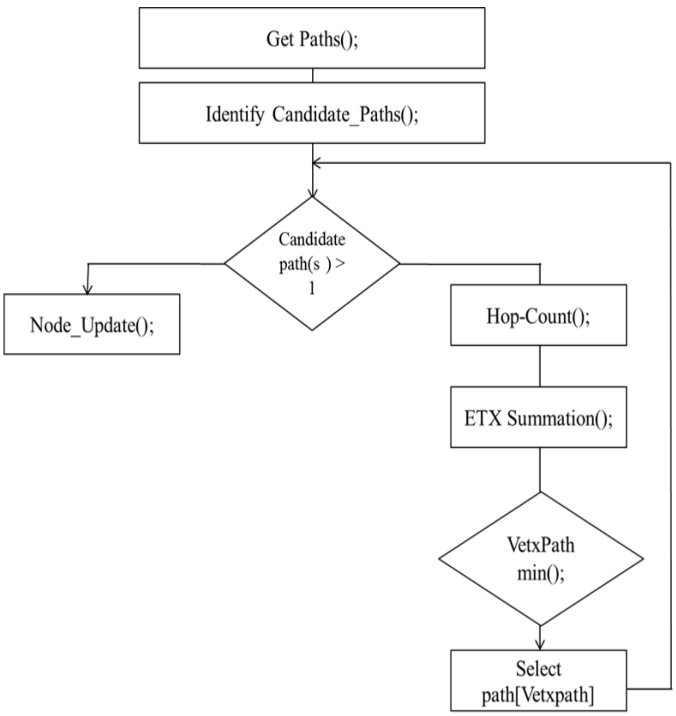

Figure 4 Flowchart of VETX Path Selection

1: Begin

2: Set ETX values in nodes

3: Send Pa_Request DAO to parent

4: Node_Update();

i = Nearest_Root(Cp);

5: paths = Get_Paths(i, Cp, NULL);

While paths = NOT NULL do

path = paths[i];

mean = Mean(path);

VetxSum = pow(sum(ETX),2);

Vetx[i] =pow(VetxSum/path – mean,2);

End While

VetxPath = pos_Min(Vetx);

Return Preference(paths[Vetxpath]);

6: End

7: Get_Paths(i,Cp, paths)

8: path = path+i;

9: Cp = Cp- i;

if Cp = NOT NULL then

Parent = Select_Parent(i,Cp)

While Parent = NOT NULL do

i = Min_ETX(Parent);

Get_Paths(i,C,paths);

Parent = Parent – i;

End While

End If

Return (paths);

10: End

Algorithm 1 Pseudocode of VETX

Algorithm 1 illustrates the proposed method. VETX computation pseudocode in steps from 5 to 6. if the get_path() is not equal to null as stated in Eq (4), which calculates the VETX and returns the preferred path for data transmission. The step from 7 to 10 procedures collects the list of available routes with the parent node and returns the paths.

5. SIMULATION AND RESULT

Table 2 VETX Simulation Setup in Cooja

Simulation Parameters Name	Values
Network Area	1000 meters
Number of nodes	20,40, 60, 80,100
Tx range	100 m
Simulation time	45 min
Topology	Random
Radio environment	UDGM
Tx ratio / Rx ratio	100%
Mote	Tmote sky
Number of packets	200
Objective Function	OF0, MRHOF and VETX

The implementation of the VETX proposal is simulated and computed in the Contiki OS-2.7 Cooja simulator; the open-source Contiki is a lightweight operating system and highly

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flexible in hardware and software for wireless and IoT networks. The VETX simulation setup is presented in Table 2, and we set the network square area as 1000 meters, a single sink node, and the RPL is designed with OF0, MRHOF, and VETX. The proposed simulation model performed 45 minutes for the respective setup. We used the different sizes of dense network sizes like 20, 40, 60, 80, and 100 for analyzing the performance metrics.

To evaluate the PDR, Latency performance, and node energy consumption on the different network dense experimental setups named Network Dense I to Network Dense V. In Network Dense I to Network Dense V of 20, 40, 60, 80, and 100 nodes simulations were implemented with the same configuration is presented in Figure 5, a, b, c,d, and e.

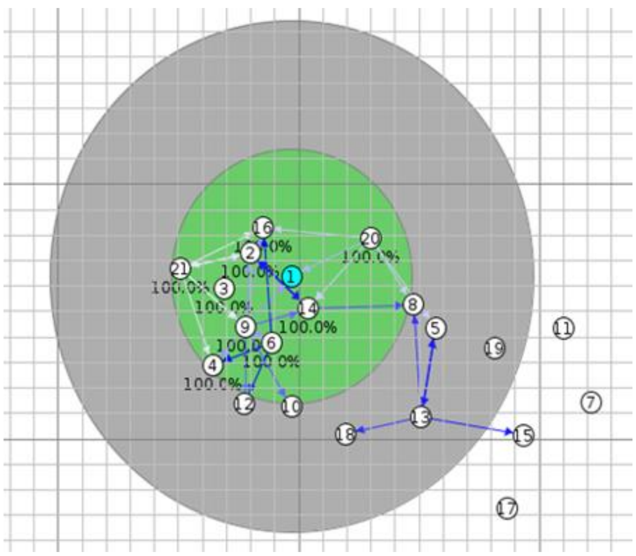

Figure 5. a) Network Dense I: 20 Nodes

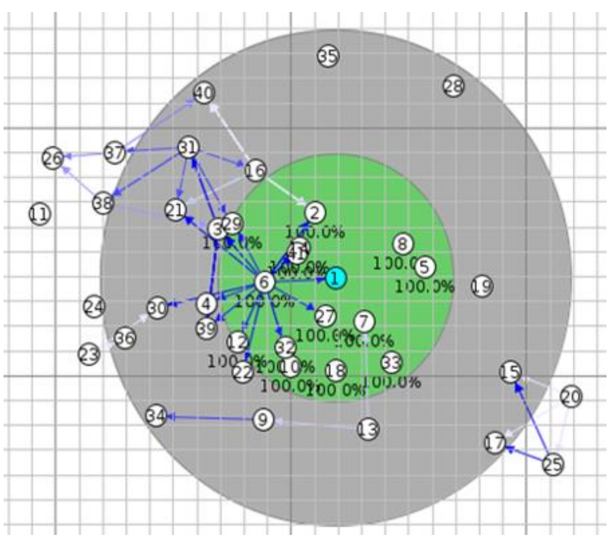

Figure 5. b) Network Dense II: 40 Nodes

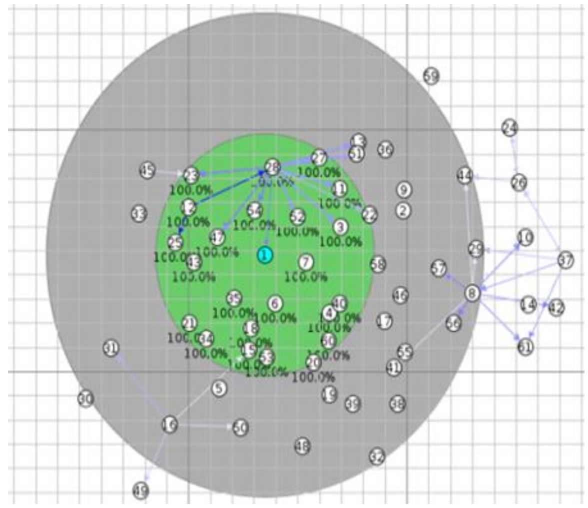

Figure 5 .c) Network Dense III: 60 Nodes

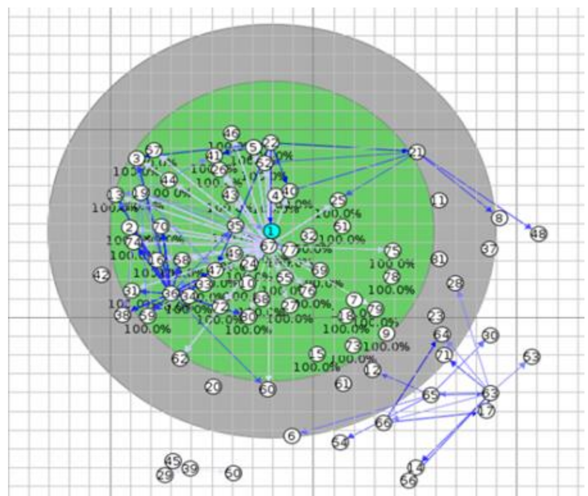

Figure 5. d) Network Dense IV: 80 Nodes

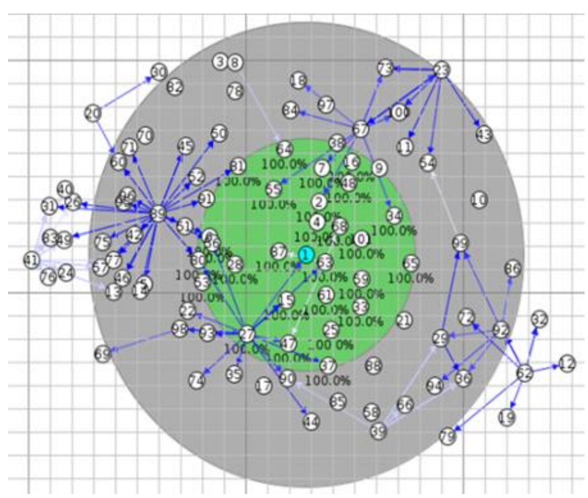

Figure 5. E) Network Dense V: 100 Nodes

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5.1. Result and Discussion

This section validates and analyses the OF0, MRHOF, and VETX on the Network as mentioned above, Dense I to Network Dense V. We identified energy consumption, constrained resources, and routing efforts in LLNs protocols, with the majority of existing works aiming to route and consume energy indirectly. However, more traditional IoT applications constrained resources as well. The proposed VETX is compared with standardized OF0 and MRHOF, and it achieves better results and overcomes the bottleneck issues of the previous objective function path selection technique.

5.1.1. Packet Delivery Ratio

The packet delivery ratio is determined by PDR = (Total_Packets_ Received / Total_ Packets Sent) X 100 and compared objective functions; Figure 6 shows there are no dominations in small network size, but when the node density increases, it clearly shows the proposed VETX performance is 2% better than standard OF0 and MRHOF.

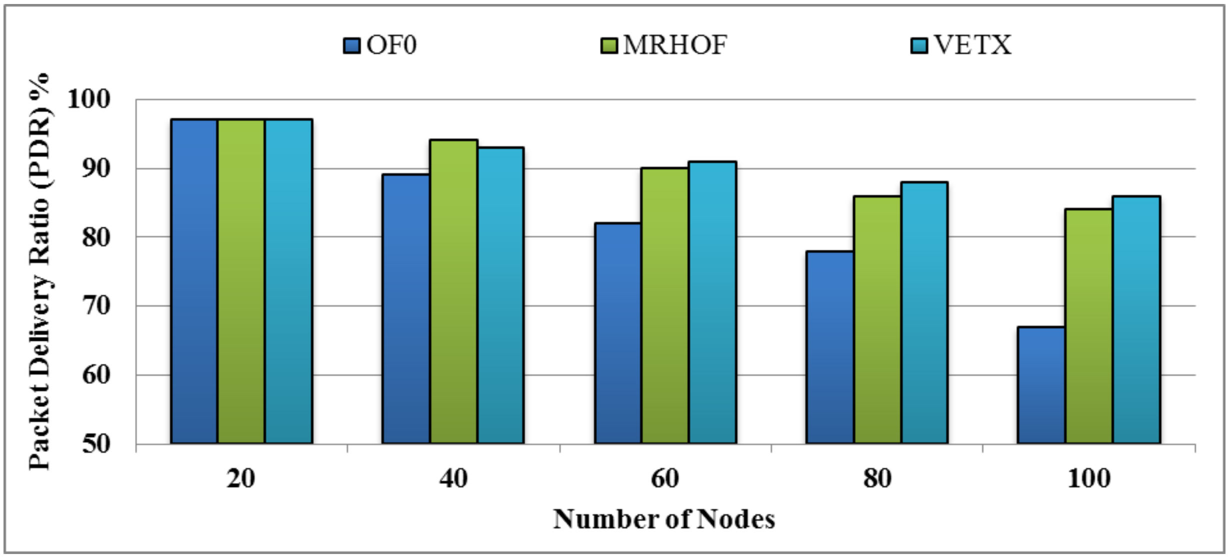

Figure 6 Packet Delivery Ratio

5.1.2. Latency

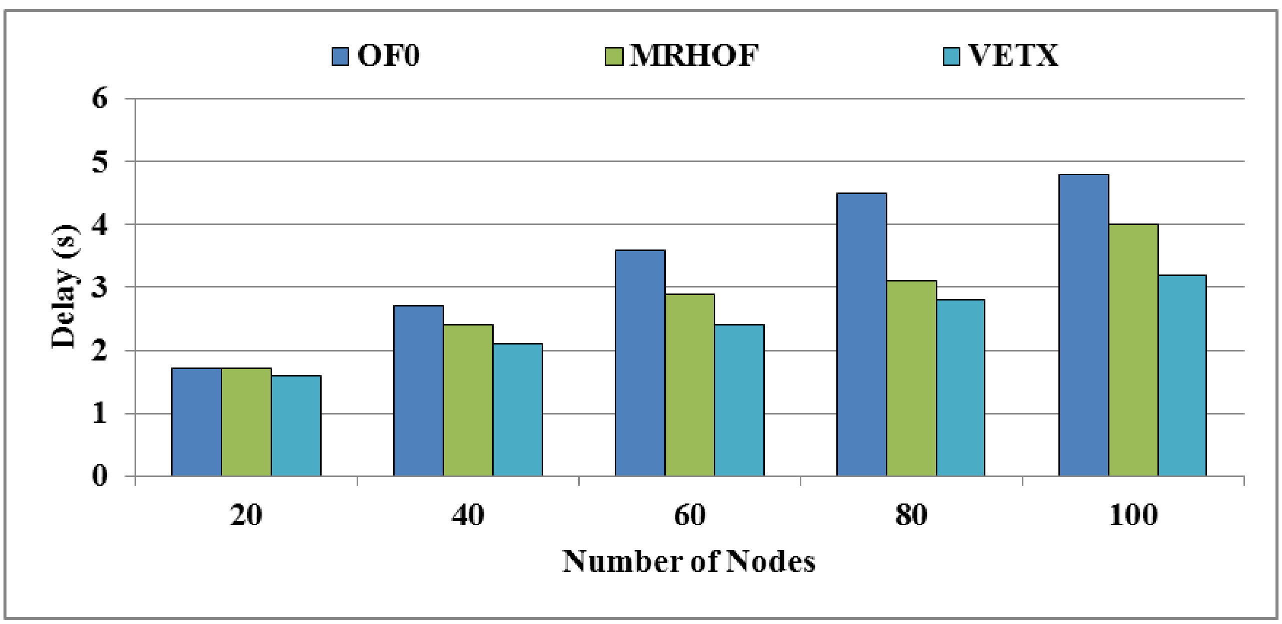

Figure 7 Latency

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The latency refers to the time it takes for a packet to arrive at its destination, and it is calculated using latency = Time_Packet_Arrive – Time_Packet_Sent. Our proposed method achieved an optimized time of delay. The latency result difference is depicted in Figure 7; comparing OF0 and MRHOF, the MRHOF latency is better than OF0. Both objective functions significantly result in a 3% delay of the PDR between source and destination in the different network sizes. While compared to OF0, MRHOF and VETX methods result in a less delay time. The proposed VETX metric is to avoid bottleneck issues in the path selection process.

5.1.3. Energy Consumption

Energy parameter utilization in each node observation is noteworthy to extend the network lifetime. The VETX proposed method comparison is mentioned in Figure 8; the proposed VETX needs complex calculation; therefore, up to 40 nodes, dense consumes more energy. In contrast, if the network density is more than 60 nodes reduces the energy consumption by up to 4% of existing objective functions. Already we made this evident through PDR by path selection.

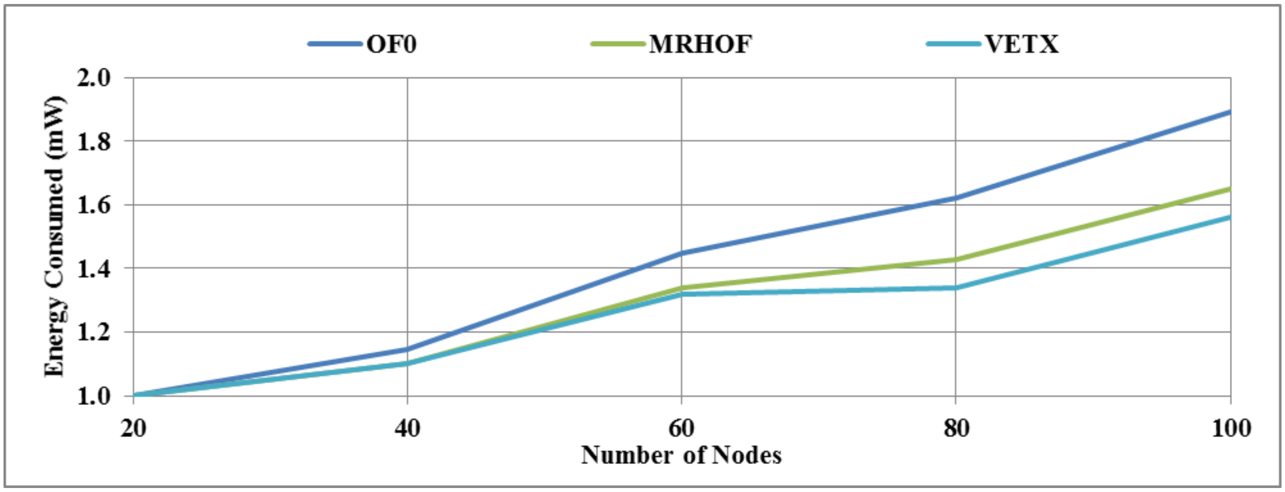

Figure 8 Energy Consumption

5.1.4. Control Traffic Overhead

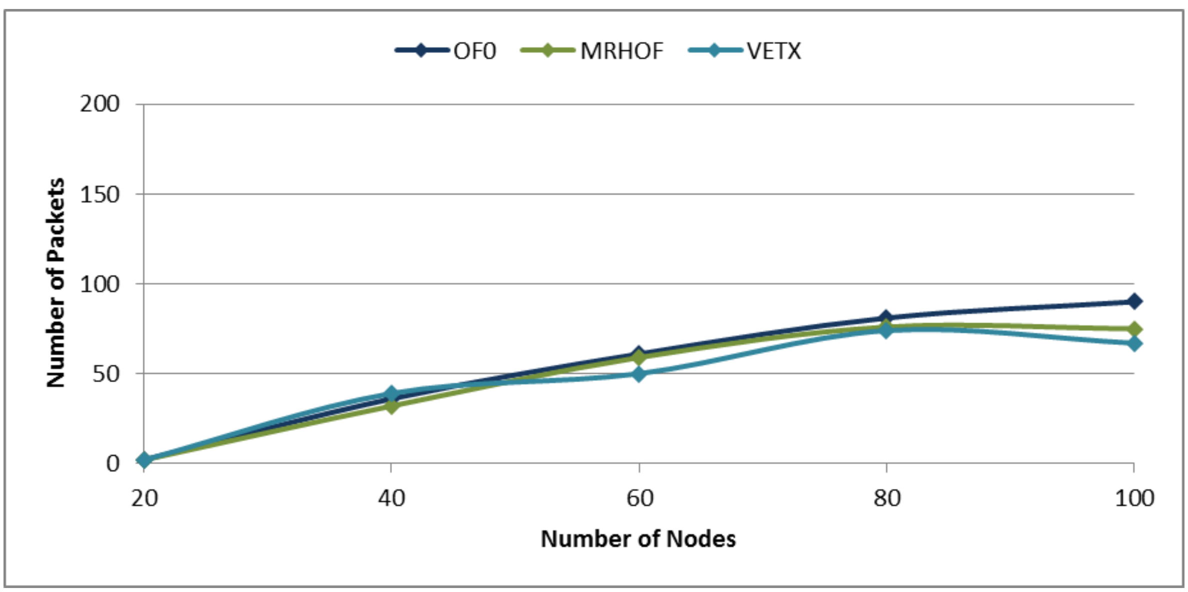

Figure 9 Control Traffic Overhead

When the RPL protocol employs OF0 and MRHOF to find the route to the destination, it provides the DIO, DAO, and DIS control messages. The high dense network experienced a high overhead to construct the DODAG routes, which

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propagates the routing between nodes. We identified that the DIO control message is the dominant message between all nodes. The increased control message overhead affects the network performance and churns in routing. This situation delay becomes increases and consumes more energy. Figure 9 illustrates a comparison among OF0, MRHOF, and VETX in the least network dense (20-40) control message overhead is similar in 45 minutes simulation. On the other end, if network density >60 affects the network stability and mitigates collision between packets up to 5% in OF0 and MRHOF, the 2.2% control traffic overhead incurs outperformance in VETX.

5.1.5. Goodput

The goodput avoids duplicate transmissions and controls messages measured at the parent. All senders' packets are configured periodically. The OF0 and MRHOF results are unstable and have high data retransmission due to periodic route changes to reach the destination over the control messages (DIS, DIO, and DAO) and poor link quality. It implies the unstable route will affect the packet transmission parameters. Frequently, the high control traffic allows grantees to reconstruct routes and retransmissions, affecting data delivery and network performance. The VETX identifies the optimum route and prevents frequent changes in the routing path with a highly stable ETX connection.

Moreover, it avoids high-level retransmission and data loss. The goodput analysis is in Figure 10. As on the simulation setup (200 packets), the dense 20 comparison result shows that MRHOF is excellent but results from 80 and 100 nodes of dense VETX. VETX achieves a better result of 3.4 percent in the configured 200 packets.

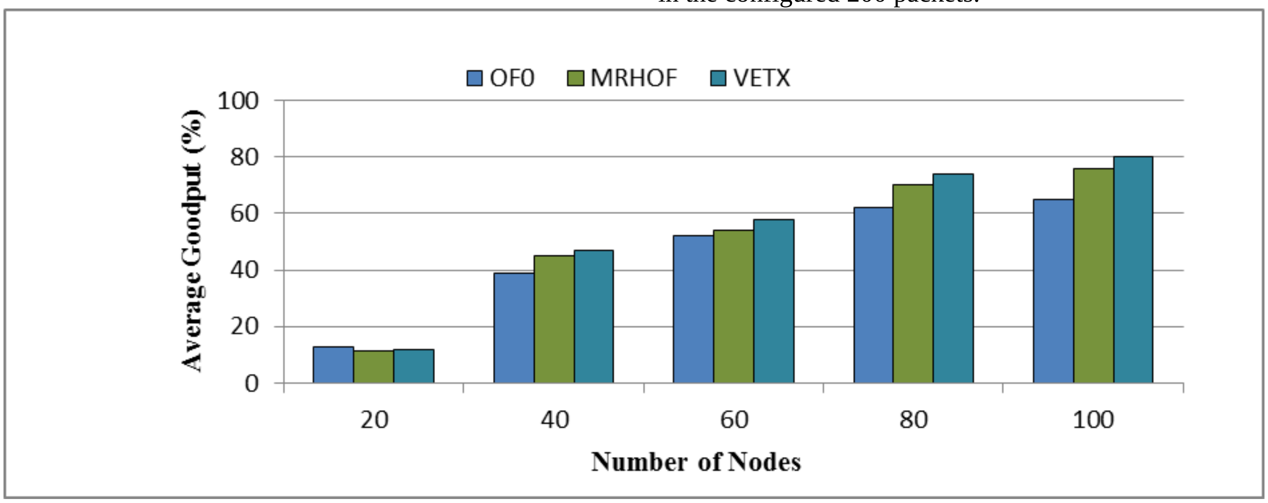

Figure 10 Goodput

6. CONCLUSION

In this work, the new VETX objective function metric was proposed in the RPL protocol. It shows that VETX is more efficient in QoS in LLNs routing with many nodes. The design of the LLNs protocol is more important because LLNs are the backbone of the IoT, and billions of devices are connected to implementing the smart objects. In RPL, all routing optimization improvements are reliable utilization of IoT devices, our proposed model attempt of VETX is successfully implemented, and the obtained result shows a qualitative and quantitative performance than the existing OFs. In this work, three network scale measures of pack delivery ratio, latency, and energy consumption are outperformance in the proposed method in RPL. This proposed method attempts only one metric to avoid the candidate path bottleneck problem in RPL. The proposed effort used only three network components and a single metric, resulting in an average improvement of only 2.6%. To further improve performance in the coming future direction, we would like to extend our work will be incorporated more types of link-based metrics such as Expected Transmission Time (ETT), Link Quality-Level (LQL), Received Signal Strength Indication (RSSI), and node-based metric of Remaining Energy (RE) and Maximum Life Time (MLT). We will also consider designing of new routing protocol for LLNs/IoT.

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