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A Hybrid Routing Protocol to Support Mobility in LLNs

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Abstract - *The development of devices and communication technologies has led to the concept of the Internet of Things (IoT), aiming to connect everything to the Internet to facilitate communication and interaction between people and smart devices. However, smart devices often face limitations in power and memory. The IEEE 802.15.4 standard has low power consumption and bandwidth limitations, is well-suited for smart devices, and relies on the Routing Protocol for Low Power and Lossy Networks (RPL). Nonetheless, RPL lacks support for mobile nodes, posing challenges in achieving mobility without casuing overhead in low-power and lossy networks. This paper proposes HRP protocol which uses hybrid routing as an alternative to proactive routing in RPL. By using hybrid routing, updates in the routing table are reduced when nodes move, resulting in fewer control packets, so reduced overhead. A performance evaluation of HRP shows it is superior to the proposed protocols in previous studies. The proposed approach improved efficiency by minimizing updates and overhead, thus addressing the challenge of supporting mobile nodes in low-power and lossy networks. This research contributes to supporting mobile nodes without affecting the network performance.*

Key Words: **Proactive, Reactive, Hybrid, IoT, LLN, RPL.**

1.INTRODUCTION

The Internet of Things (IoT) enables ubiquitous connectivity for smart devices, allowing them to connect to the Internet at any time and location [1]. Smart devices, characterized by low power and limited processing and memory capabilities, form a self-organizing network without the need for infrastructure, with nodes acting as routers. Smart devices utilize the IEEE 802.15.4 standard [2] and the Routing Protocol for Low Power and Lossy Networks (RPL) [3]. However, RPL lacks support for mobile nodes, leading to increased overhead due to the transmission of additional control packets in the network.

So much research improved RPL to support moil nodes. Our paper proposes a lightweight hybrid routing protocol. Unlike reactive routing, the hybrid protocol minimizes the number of control packets and reduces the frequency of routing table updates compared to proactive routing. This approach is well-suited for devices with limited resources.

1.1 Routing Protocol for Low Power and Lossy Networks [3]:

The RPL routing protocol, developed by the Routing Over Low-Power and Lossy Networks (ROLL) group, is specified in RFC 6550. In RPL, a root node acts as a gateway to the Internet, enabling communication among devices in the network. The topology is organized as a Directed Acyclic Graph (DAG) with the root node. The root node periodically sends DODAG Information Object (DIO) messages to invite neighboring nodes to connect with the root node. Each node that receives the DIO message and desires communication with the root node responds by sending a Destination Advertisement Object (DAO) message. This process continues until all nodes in the network are connected, as illustrated in Figure 1.

To manage the timers for DIO messages and minimize overhead in the networks, so RPL uses the Trickle algorithm. The Trickle algorithm adjusts the transmission rate of control messages based on network stability. When an unstable state is detected, the transmission rate increases to spread the updates. Conversely, when the network stabilizes, the transmission rate decreases,reducing unnecessary overhead[4].

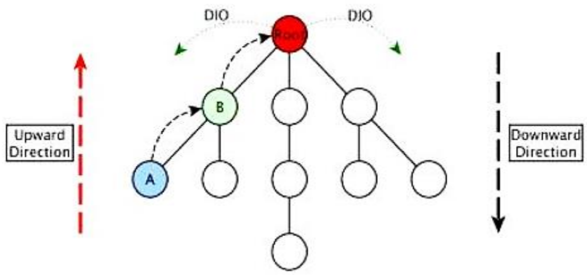

Fig -1: Example of using RPL in network

The parent node is selected using Objective Function (OF0) that depends on hop count. OF is developed to MRHOF (The Minimum Rank with Hysteresis Objective Function) [5], which the parent node is selected based on the value of the Expected Transmission Count (ETX) that determines the quality of the link.

1.2 Routing types

There are three types of routing protocols: proactive, reactive, and hybrid. Proactive protocols maintain up-to-date routing information in tables and scatter update messages across the network. Reactive protocols generate routes when necessary, using a path discovery method in which control messages are flooded across the network. Hybrid protocols combine proactive and reactive routing, which split the topology into zones and use a proactive protocol intra-zone routing since these protocols maintain an up-to-date view of the topology of the zone, which results in no initial delay when communicating with nodes within the zone, and a reactive protocol performs inter-zone routing. [6]

RPL is a proactive routing protocol primarily designed for static devices rather than mobile ones. Proactive routing with mobile nodes induces overhead and power consumption, making it unsuitable for battery-powered devices to update the routing table during node mobility. On the other hand, using a reactive routing protocol is also not the right choice because it depends on making nodes send periodic control messages, which increases overhead and power consumption. So this paper depends on hybrid routing.

2. Related work

P2P-RPL protocol (RFC 6997) [7] uses a route discovery mechanism where a P2P Route Discovery Object (P2P-RDO) message is broadcasted, and then intermediate or target nodes respond with a P2P Discovery Reply Object (P2P-DRO) message. However, a drawback of P2P-RPL is the network flooding of control messages during the route discovery phase, leading to increased consumption.

Fotouhi proposed the MRPL protocol [8], which integrates RPL with smart hopping using beacons. The MRPL protocol consists of two phases: route discovery and data transmission. During the route discovery phase, a mobile node broadcasts multiple DIS messages. The receiving nodes calculate the Average Received Signal Strength Indicator (ARSSI) and include this value in a DIO message. The mobile node selects its parent node based on the DIO message with the highest ARSSI.

Gara [9] suggests an adaptive timer algorithm to regulate the transmission of DIO and DIS messages sent by mobile nodes. This algorithm computes the remaining distance (d) for a node to leave the radio range of its parent node by subtracting the parent node's radio range from the distance between the two nodes. As (d) becomes shorter, the node discovers to find a new parent node. The proposed algorithm utilizes ETX and RSSI values to determine the best parent node.

In [10], the EMAEER protocol is proposed, which divides the network into non-overlapping regions based on the Euclidean distance to the reference node (containing GPS). Each time a node wants to transmit data, it constructs a network tree with itself as the root. However, this approach increased power consumption and overhead since all nodes participate in the route discovery phase. EMAEER supports mobile nodes but experiences performance degradation as the number of mobile nodes increases.

Sanshi [11] modified the RPL protocol using fuzzy logic with parameters (residual power, expected transfer count (ETX), RSSI, and mobility timer). FL-RPL incorporates the mobility timer parameter, which estimates the time a node will remain within radio range based on location information obtained from RSSI. However, this method is not accurate due to obstacles and interference. Mobile nodes are treated as leaf nodes and cannot participate in the routing process, which is not suitable when the network has more mobile nodes than static ones.

Safaei [12] proposed the ARMOR protocol, introducing a new parameter called Time-to-Reside (TTR) to select the best parent node that will remain within radio range for the longest time. TTR is calculated based on a node's speed and position and is included in the DIO message. The research also proposed a new timer to increase the rate of sending DIO messages by static nodes, enabling them to introduce themselves and be selected as parent nodes by mobile nodes. The mobile nodes did not modify their timer, but this is not suitable for its neighbor nodes to be aware of their current speed in case it changes.

MobiRPL [13] utilizes RSSI and hop count to classify nodes into three categories. Nodes with RSSI above a specific threshold are considered white area nodes and are preferred over others. Nodes with lower RSSI are categorized as gray area nodes. Black area nodes are not connected to the network and are not selected as parent nodes until they reconnect to the network.

V-RPL [14] is a proactive routing protocol that uses multiple criteria for parent node selection, including RSSI, node rank, link quality, and remaining energy. Additionally, it modifies the timer algorithm based on the speed of neighboring nodes. When the speed of neighboring nodes increases, the timer period decreases. The node calculates its speed by measuring the interval time between two successive DIO packets and includes this information in the DIO message sent to neighboring nodes. As a result of the research, the packet delivery ratio reached less than 70% when half of the nodes were mobile in the network.

The research [15] introduced a new objective function called rpl-TotEg-Neighbors, which takes into account the node's energy, the number of neighbor nodes, and the expected transmission count (ETX). When selecting the parent node, the energy value is given the highest weight, followed by the number of neighboring nodes and ETX. Comparative evaluations were conducted with the objective function (of0, MRHOF) using various movement patterns. The results showed the superiority of the proposed objective function, but it increased energy consumption.

The related work led to increased delay and overhead in the network. So was the need for a protocol that supports mobility. This research proposed using hybrid routing, which aims to strike a balance between mobility support and network efficiency.

3. Hybrid Routing Protocol (HRP)

HRP divides the network into regions by informing the network about subtrees. Within each subtree, proactive routing is utilized, allowing nodes to establish and maintain routes. On the other hand, between different subtrees, reactive routing is employed. When a route is required between subtrees, nodes initiate a reactive routing process to establish the necessary path. This mixed approach aims to achieve efficient routing while considering the mobility of nodes within the network.

3.1 Proposed control message

The HRP control messages consist of an ICMPV6 [16] header followed by a message body. To support hybrid routing mechanism in HRP protocol, various control messages are proposed for network construction and maintenance. They are:

- **Neighbor Information Solicitation (NIS)**

The NIS message is used to solicit a tree of Information from another node in order to establish a connection with it. The structure of the NIS frame consists of 4 bytes unused, so MUST be initialized to zero by the sender and MUST be ignored by the receiver. The structure of NIS is shown in Figure (2).

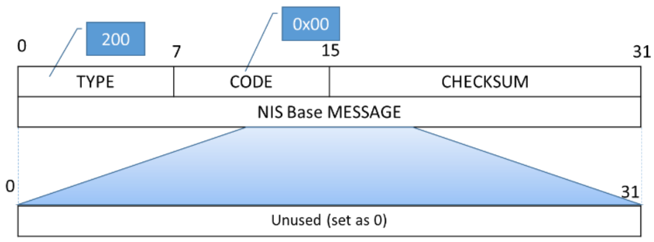

Fig -2: The structure of NIS

- **Neighbor Information Object (NIO):**

The node sends the proposed control message (NIO) to inform itself with the following information:

- Height_sub_tree: A byte that stores the distance between the node and the subroot of the subtree to which it belongs.

- Hop_count: a byte that stores the number of hops between a node and the root of the main tree.

- Mobility_Level: a byte that stores a value that determines the mobility level of the node, whether it is static or moving.

- Flags: A byte where only two bits are utilized, while the remaining bits must be initialized to zero by the sender and ignored by the receiver. The two bits within the Flags field are as follows:

Energy Type flag: This flag should be set to 1 if the node is connected to an electrical power source. Otherwise, it is assigned a value of 0, indicating that the node relies on battery power.

Warning Battery flag: This flag should be set to 1 when the node's power level reaches a critically low state and requires recharging.

The structure of NIO is shown in Figure (3). The node that receives the NIO control message has to decide if wants to connect with it as a parent node, depending on context-aware method [17] using the parameters value that gets them from the NIO packet.

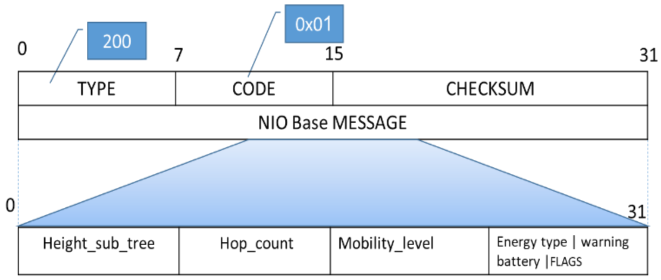

Fig -3: The structure of NIO

- **Neighbor Advertisement Object (NAO)**

The node that receives the NIO control message and decides to connect with it as the parent node sends the corresponding control message called NAO. The structure of the NAO frame consists of the following fields:

- Flags: a byte of which only one bit is used for the sub_root flag that indicates whether the node is a sub-root, and the rest of the bits must be assigned a value of zero.

- Unassigned bits of the NAO Base are reserved. They MUST be set to zero on transmission and MUST be ignored on reception

- Options: This specification does not define any options. So they are set to zero on transmission and MUST be ignored on reception

The structure of NAO is shown in Figure (4)

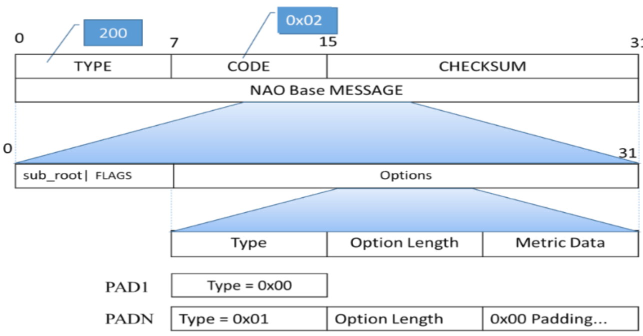

Fig -4: The structure of NAO

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3.2 Building the network:

The network is comprised of multiple sub-trees, each having a sub-root. Proactive routing is employed within each sub-tree, while reactive routing is utilized to establish communication between different sub-trees.

The network formation begins with the root node sending a control message called Neighbor Information Object (NIO). This message carries essential information that enables a node to discover the network and acquire its configuration parameters. Neighboring nodes respond to the NIO message by sending a proposed control message known as Neighbor Advertisement Object (NAO) if it is suitable to connect with it as a parent nods. Each connected node in the network will propagate the NIO message to inform itself and update its knowledge about the network.

Once a child node selects a parent node based on the information received in the NIO message, it calculates its height within the subtree to which it belongs.

If the network is in its initial stage and the Height_sub_tree value is 3 hops, the node is considered a sub-root if it is static. If the next node is static, it will be a sub-root. However, if the node is mobile, so when a new node connects to a network that has a Height_sub_tree of 5 hops, it is considered a sub-root regardless of its mobility level. Subsequently, the node sends an NAO message to its chosen parent node to confirm communication and indicate whether it is acting as a sub-root.

3.3 Routing table

The sub-root node plays a crucial role in the hybrid network by storing routing information for all nodes within its subtree, as well as the route information for downward sub-root nodes. Each node within the network maintains the necessary downward routes within its respective subtree. When a node or sub-root node receives a Neighbor Advertisement Object (NAO) message from another sub-root node, it stores the route information for that node and forwards the message to its parent node.

In a hybrid network, the advantage lies in the reduced number of routing table updates required when mobile nodes move, in comparison to proactive routing. Instead of updating routing information for every node in the network, the updates are localized to the sub-root nodes. Consequently, the need for extensive updates throughout the entire network is minimized.

Figure 5 illustrates an example network utilizing the Hybrid Routing Protocol (HRP) for network construction, where the orange nodes represent sub-root nodes, and each rectangle represents a tree. This network structure allows for efficient routing and filling of routing tables.

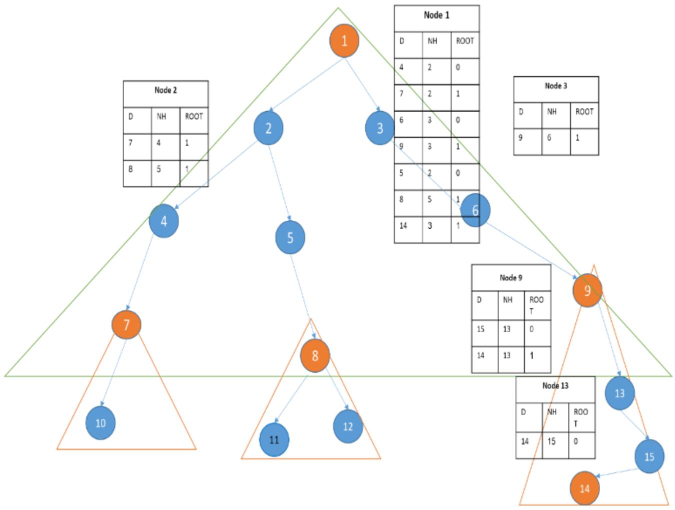

Fig -5: Example of network using HRP

4. Repair the network:

We have proposed rules to maintain the network when a node experiences a problem or moves out of its parent node's range. Here are the rules:

- If a sub-root node experiences an issue, its child node will search for a new parent node.
- If a node joins a subtree, it will calculate its distance from the root. If its height exceeds 6, it identifies itself as a sub-root node.
- If the tree height decreases, then there is no change. However, if the tree height becomes less than 2, then we cancel the sub_root attribute of the node.
- If the tree height increases, then the node that calculates its distance from the sub-root of the tree will be given the root attribute if the value becomes more than 6.

5. Evaluating the performance of the HRP protocol

To evaluate the performance of the Hybrid Routing Protocol (HRP), we utilized Contiki's IoT simulator called Cooja [18], which supports various IoT platforms such as Zolertia One (Z1), Sky mote, and Wismote.

In order to evaluate the performance of HRP, we compare it with many paper:

1) MobiRPL: Adaptive, robust, and RSSI-based mobile routing in low power and lossy networks [13]

The research relied on several scenarios cooja1, cooja2, and cooja3. The comparison with the standard RPL protocol showed its superiority over it.

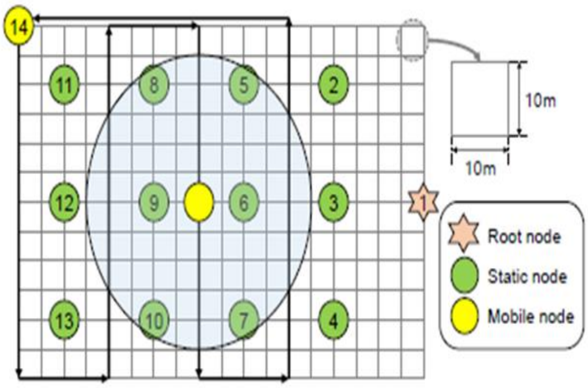

Fig -6: Cooja1 scenario

Figure (6) shows the Cooja1 scenario with 12 static nodes, a mobile node, and a root. All the nodes have the same transmission range (50 m), and one example is indicated by a large light blue circle.

The network contains:

- 12 static nodes (nodes with ID 2 to 13). The distance between them is 40 meters.
- one mobile node, which is the node with ID 14 that moves at a speed of 1 m/s.
- One root is the node with ID 1.

One data packet is sent every 30 seconds. MobiRPL evaluated the performance with different speeds. The results were as follows:

Packet delivery ratio of mobile node:

Chart (1), We note that the result is close between MobiRPL and HRP because the network contains only one mobile node at low speeds, so the difference between the performance of the two protocols will not appear clearly.

PDR decreased when speed increased. When the node speed increases to (5 m/s), HRP records a higher PDR than MobiRPL because it helps to organize the network by subtrees, reducing collisions.

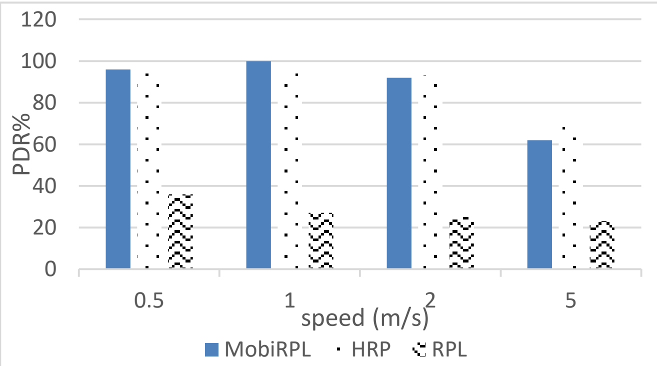

Chart -1: PDR versus the speed of the mobile

Figure (7) shows the Cooja2 scenario, with one root node and six static nodes, where the small circles indicate the coverage area of the static nodes and the number of different mobile nodes up to 18 nodes moving at a speed of m/s (0.5 - 2.0) within the area covered by the large circle. One data packet is sent every 60 seconds. The performance was evaluated with different numbers of mobile nodes.

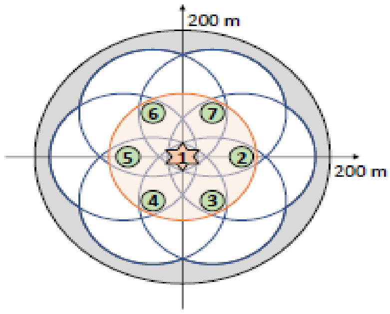

Fig -7: Simulation (Cooja-2)

Packet delivery rate for mobile nodes:

The PDR to mobile nodes using the MobiRPL protocol Chart (2) ranges from 80 to 85 when the number of nodes increases. Using the proposed HRP protocol, the PDR ranges between 85 and 90. The positive impact of mobile nodes is that they participate in packet forwarding.

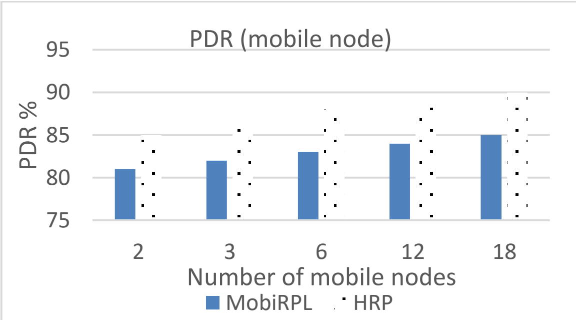

Chart -2: PDR versus number of mobile nodes

The average duty cycle of mobile nodes is high in the MobiRPL protocol Chart (3) due to the mobile nodes' routing and forwarding overheads. MobiRPL relies on a mechanism to verify communication between nodes by sending n DIS messages to be responded to with DIO messages. Thus, nodes are still on most of the time to send control messages, which affects the duty cycle of static nodes, as shown in Chart (4). But HRP is less resource-intensive as it employs hybrid routing, which means that there are fewer updates of the routing table if mobile nodes move. which lower the number of control packets, so less duty cycle.

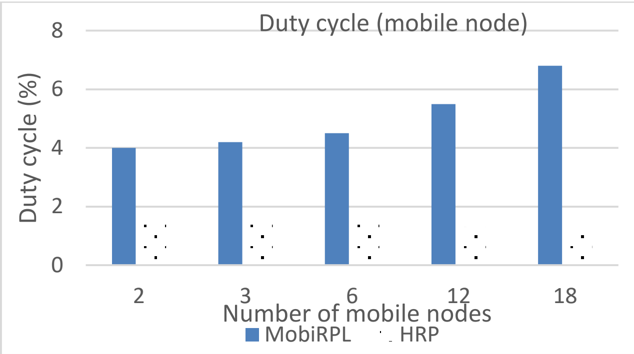

Chart -3: Duty cycle versus number of mobile nodes

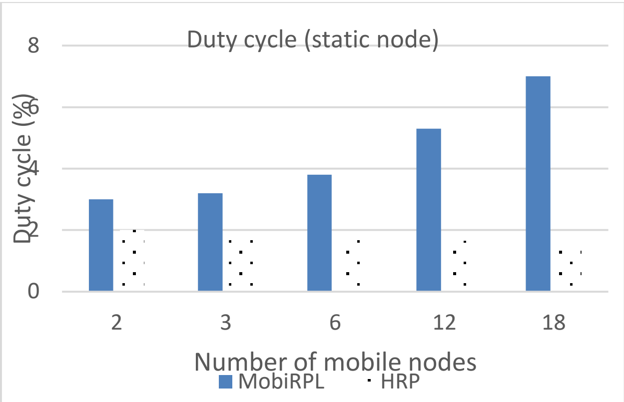

Chart -4: Duty cycle versus number of static nodes

Figure (8) shows the Cooja3 scenario. The simulation topology has a radius of 250 meters with 18 mobile nodes.

The analysis of different simulation topologies aims to assess the effect of network size on the performance and connectivity of the MobiRPL protocol. The MobiRPL protocol is analyzed using two different simulation topologies: Cooja-2 with a radius of 200 meters and Cooja-3 with a radius of 250 meters. The wider area covered by Cooja-3 may result in some nodes being unable to establish a connection with the root node when a node is located at a point empty of another node because the area is wide and the relatively small number of nodes available.

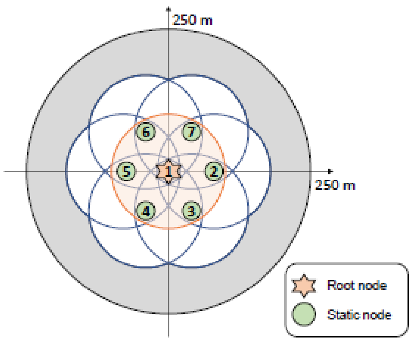

Fig -8: Simulation (Cooja-3)

Packet delivery rate: with a wider network area, the PDR decreases, so less transmission, which reduces the duty cycle because it is calculated from radio listen and radio transmit, which is shown in Chart (5), Chart (6), and the Chart (7).

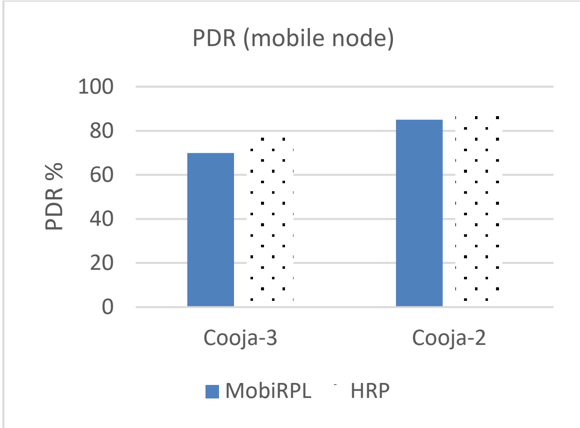

Chart -5: PDR in Cooja-2 vs Cooja-3 (mobile node)

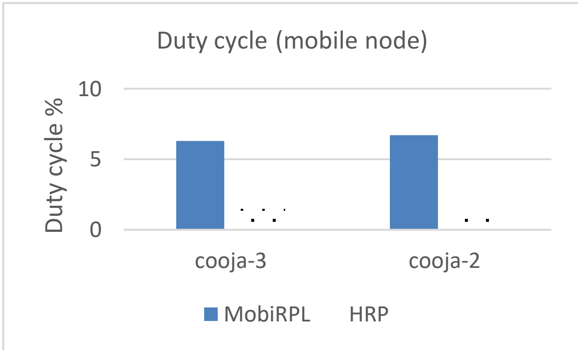

Chart -6: Duty cycle in Cooja-2 vs Cooja-3 (mobile node)

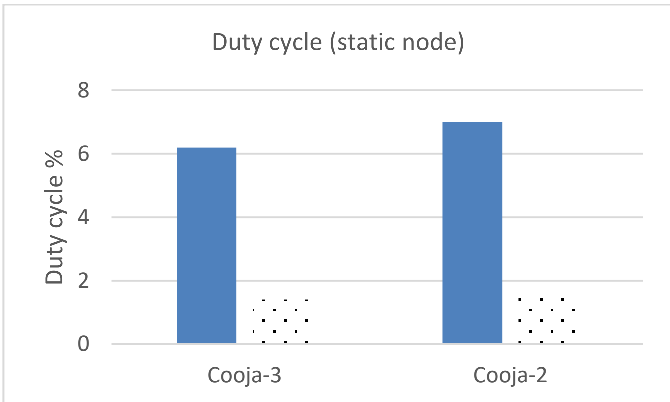

Chart -7: Duty cycle in Cooja-2 vs Cooja-3 (static node)

2) V-RPL: An effective routing algorithm for low power and lossy networks using multi-criteria decision-making techniques (2022) [14]

This research implements scenario A (half of the nodes are mobile) and scenario B (all nodes are

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mobile). The Simulation time is 3000 seconds. With a network area of 300 * 300 m. Whereas in Scenario A, the node speed is (1-2) m/s. The effect of node speed was analyzed in the presence of 20 mobile nodes, and another scenario has 40 nodes that are half mobile.

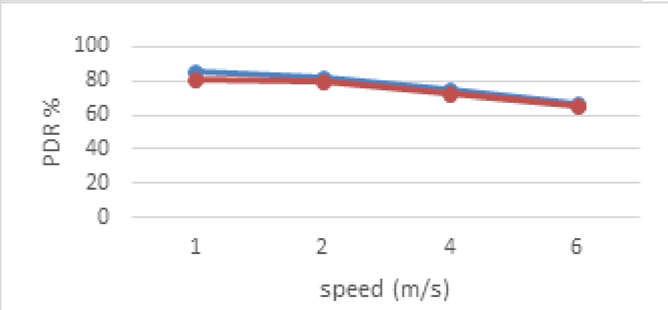

Chart -8: PDR versus average velocity of mobile nodes (*N* = 20).

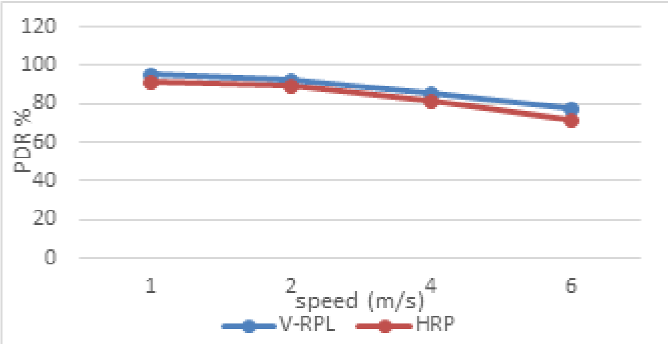

Chart -9: PDR versus average velocity of mobile nodes (*N* = 40).

To study the effect of increasing the number of mobile nodes in the network on performance, we compare Chart (8) (the case of 20 mobile nodes) and Chart (9) (the case of 40 mobile nodes). We notice that the packet delivery ratio decreases as the number of mobile nodes in the network increases due to collisions. The network is more stable if there are static nodes, so there is no need to change the parent node every time the node moves.

The packet delivery ratio of the proposed HRP protocol was close to the V-RPL protocol because the V-RPL protocol relied on decreasing the interval value of DIO control messages, which helps maintain network stability and reduce disconnection between nodes, but this increases the overhead.

We also note that it increased delay and power consumption. Chart (10), which shows the value of the delay with the simulation time, whereas the time increases, the delay increases, and the HRP proposed protocol helped reduce the delay. Chart (11) shows that the proposed protocol consumed less energy even if all nodes were mobile.

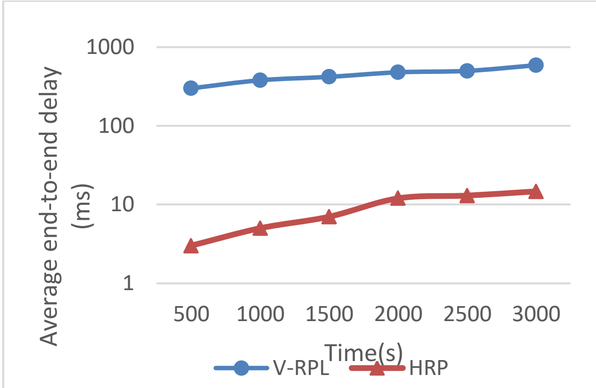

Chart -10: PDR versus simulation time (*N* = 20).

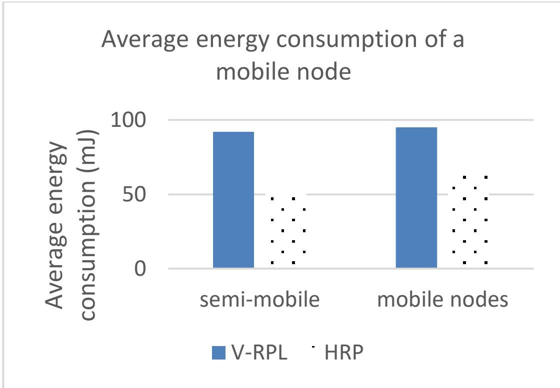

Chart -11: Average energy consumption vs the rate of mobile node

3) ARMOR: A Reliable and Mobility-aware RPL for Mobile Internet of Things Infrastructures (2021) [12]

The area simulation is 10,000 m2, the number of nodes (20,40), half of which are mobile nodes with speeds of 0.5-1.5 m/s according to mobility models (Manhattan, Random Movement Model). The simulation time is 3600s.

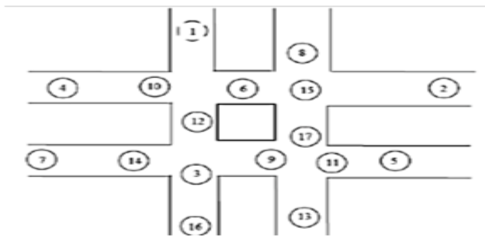

Fig -9: Manhattan mobility mode

Manhattan mobility model: It is a model of movement within the city. The nodes move according to horizontal and vertical streets according to the map of the area, Figure (9). [19]

HRP's proposed protocol outperformed the ARMOR protocol in both mobility models due to its ability to increase the stability of the network and select the most suitable parent node. ARMOR relied on RSSI value to calculate the speed of the nodes and select the parent node, but RSSI value is affected by obstacles, so it is not always correct.

HRP gives a greater packet delivery rate with the random waypoint model(RWP), so HRP is more suitable for RWP than the Manhattan model. We also notice by comparing Chart (12) and Chart (13) that when increasing the number of nodes in the network, the packet delivery ratio increases because the network area is wide, so increasing the number of nodes will help them to connect with the network.

The increase in the packet delivery ratio means the network is stable, so less power consumption, as shown in Chart (14), and less overhead on the network, as in Chart (15).

Chart -12: Packet delivery rate vs mobility model (n=20)

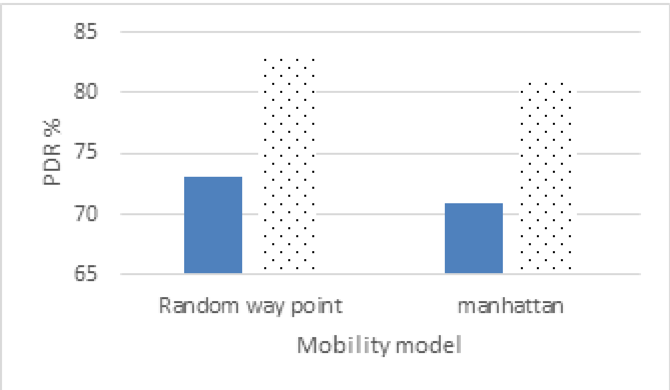

Chart -13: Packet delivery rate vs mobility model (n=40)

Power consumption increases with the number of nodes due to the increase in sending control messages to build and repair the network and to choose the most appropriate parent node. Chart (16) shows that control packets cause an increase in overhead, so our goal with HRP's proposed protocol was not to increase the rate of sending control packets. However, the ARMOR protocol relied on modifying the timer to increase sending control packets, so overhead increased significantly. By comparing Chart (16) and Chart (17) increasing the number of nodes in the network will increase the rate of sending control packets.

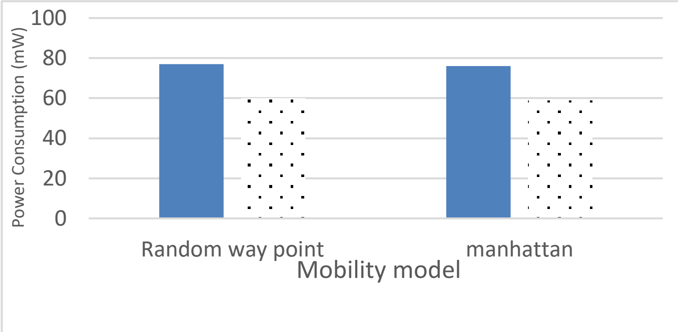

Chart -14: Power consumption vs mobility model (n=20)

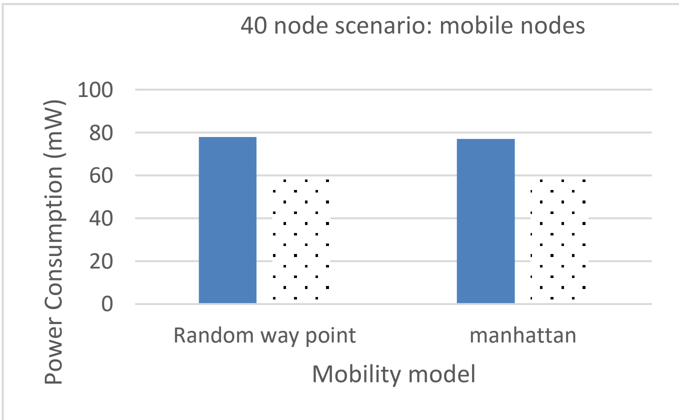

Chart -15: Power consumption vs mobility model (n=40)

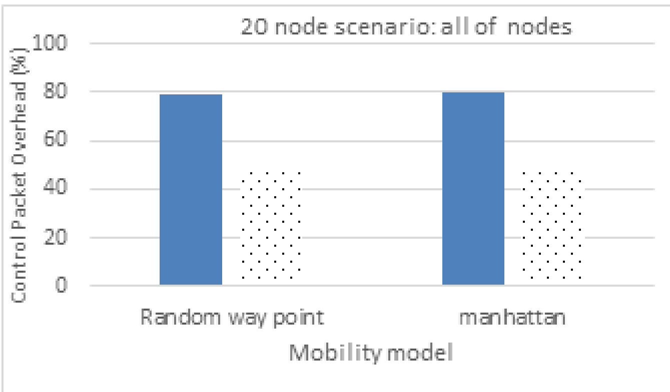

Chart -16: control packets overhead vs mobility model (n=20)

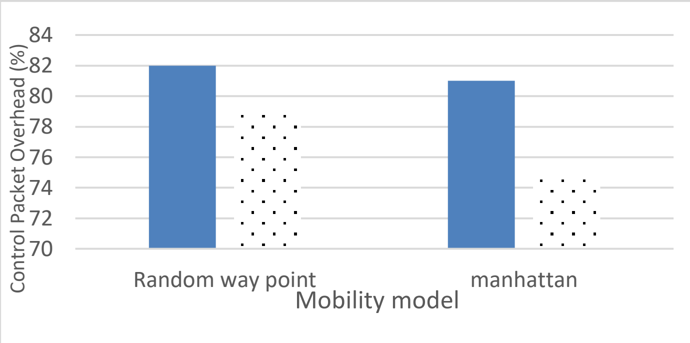

Chart -17: control packets overhead vs mobility model (n=40)

4) A New Objective Function for RPL Based on Combined Metrics in Mobile IoT (2023) [15]

In this research, a new objective function rpl-TotEg-Neighbors was proposed that depends on the energy of the nodes, the number of neighboring nodes, and the value of the expected transmission count (ETX). The node rank is calculated according to a function described as follows:

Rank(N) = Rank(PN) + ETX (N, PN) + α × NEIGHBORS (PN) + β × 1 / AverageEnergy × ENERGY (PN)

Where:

Rank (N) is the Rank of the node, Rank (PN) is the Rank of the parent node

ETX (N, PN) is the value from node N to its parent node PN

NEIGHBORS(PN) is the number of neighbors of the parent node (PN)

α is the coefficient, which is the weight of NEIGHBORS(PN). It's fixed to 2.

β is the weight of ENERGY (PN). It's fixed to 3.

Average Energy: Average energy of nodes.

ENERGY(PN): Total Energy consumed by the parent node PN,

The simulation area network is 10,000 m2 and the number of mobile nodes (15, 25, 35, 45). The simulation duration was 600s. The results of this study were compared with the proposed HRP protocol according to several mobility models (random waypoint - RPGM):

- Random waypoint model

In this model moves randomly in speed and position, Figure (10).[19] By applying the random waypoint model, the results were as follows:

Packet delivery ratio: The HRP proposed protocol increases the average received packets, and this is due to the use of many parameters to select the parent node according to the state of the node and the state of the parent node, so choose the more suitable node to be a parent. Chart (18) shows that the rate of received packets decreases because of collisions when more nodes are in the network.

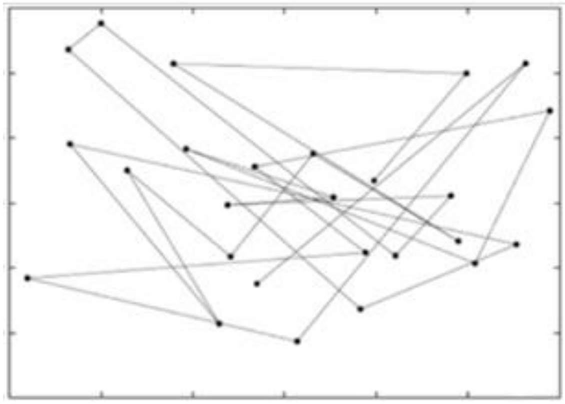

Fig -10: Random waypoint mobility mode

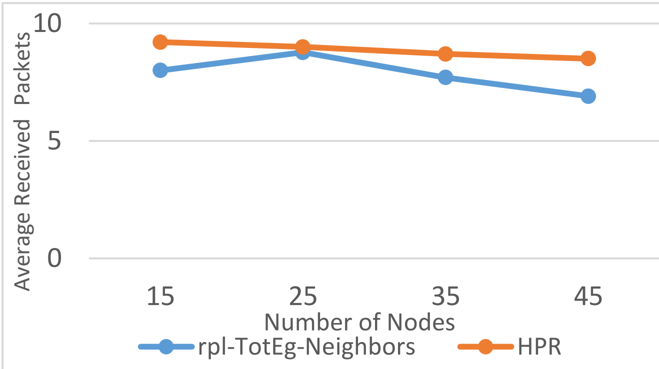

Chart -18: Average received packets vs number of nodes(RWP)

The value of the ETX indicates the quality of the link. HRP selects the more suitable parent node so the quality of the links is better as shown in Chart (19). Chart (20) shows that the number of control packets in HRP is decreased compared to rpl-TotEg-Neighbors-RPL. HRP makes the network more stable, so it decreases the sending of the control packets, which means less power consumption, Chart (21).

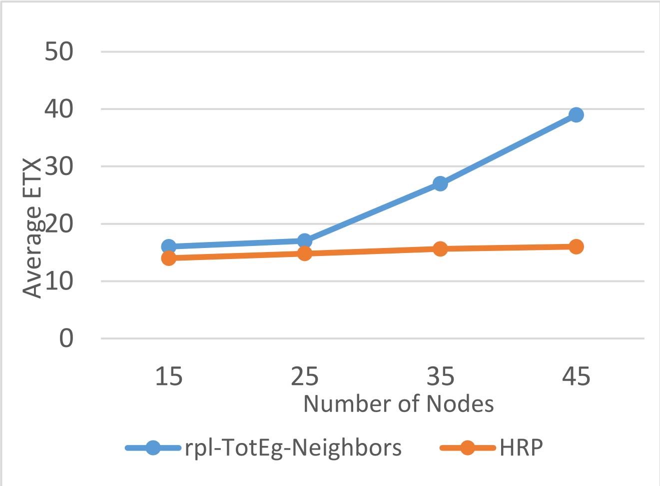

Chart -19: Average ETX vs number of nodes (RWP)

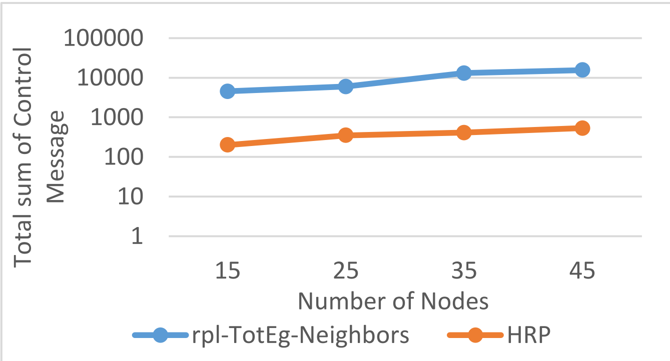

Chart -20: Total sum of Control Message vs number of nodes (RWP)

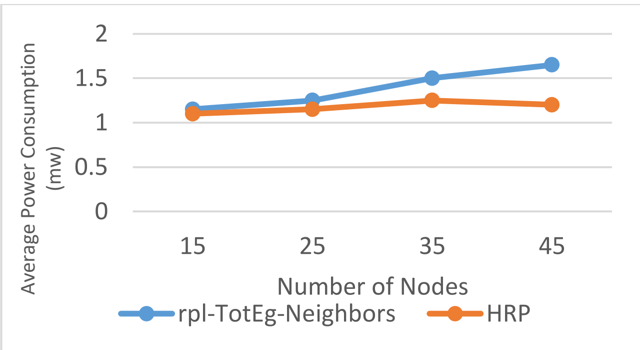

Chart -21: Average Power Consumption vs number of nodes (RWP)

- Reference Point Group Mobility Model (RPGM):

In this model, all nodes work as a group and move as a single entity to achieve different tasks. Each group has a group leader. RGPM is used for several applications, such as a battlefield situation. Figure (11).[19] By applying the RPGM mobility model, we obtained results shown in Chart (22-25). By comparing these results with the random way point, we notice that the performance of the proposed HRP protocol is better in the RPGM model due to the node that uses HRP protocol which are in the same sub-tree and in the same group in RPGM, there will be no changes in the network topology when they move, which further reduces the need to update the routing table.

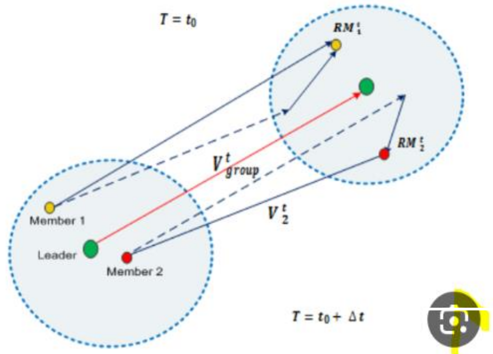

Fig -11: RPGM mobility mode

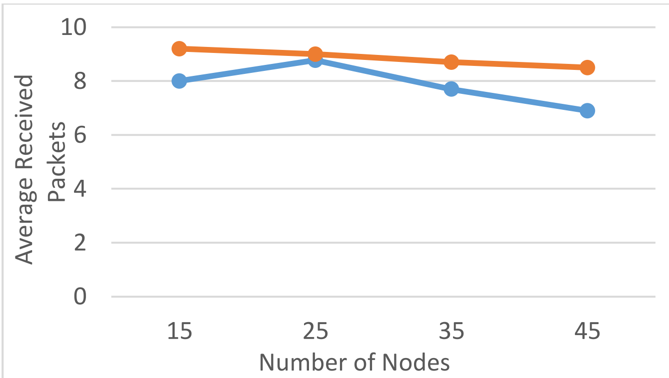

Chart -22: Average received packets vs number of nodes (RPGM)

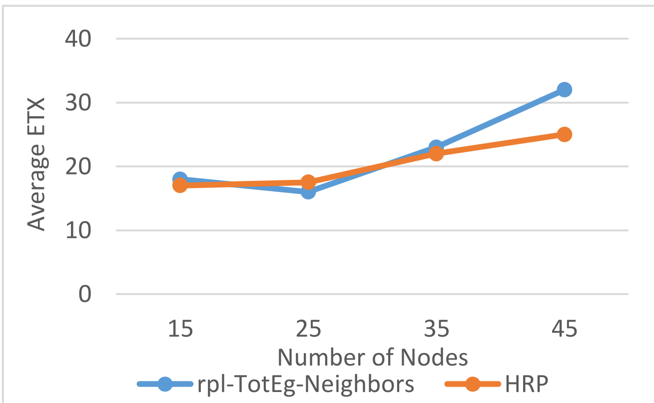

Chart -23: Average ETX vs number of nodes (RPGM)

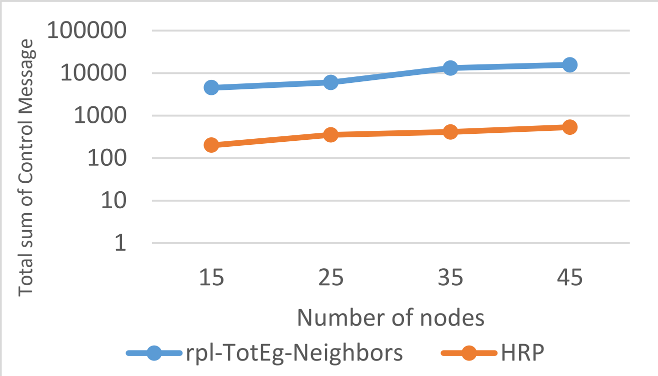

Chart -24: Total sum of Control Message vs number of nodes (RPGM)

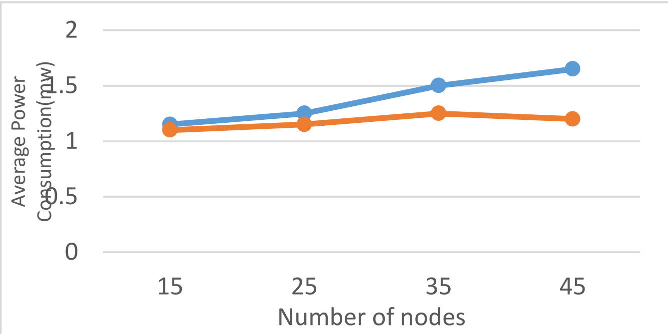

Chart -25: Average Power Consumption vs number of nodes (RPGM)

3. CONCLUSIONS

This paper introduces HRP, a hybrid routing protocol designed to support mobile nodes. It proposed control messages to establish and maintenance network connectivity as nodes move. Through a comparative analysis of HRP with previous studies, it showed better and superior performance by effectively reducing energy consumption, delay, and overhead.

REFERENCES

[1] M. Saare and S. Lashari, "Review of routing protocol for low power and lossy network in the internet of things," Indonesian Journal of Electrical Engineering and Computer Science, vol. 32, no. 2, pp. 865-876, 2023.

[2] A. Ott, "Wireless Networking with IEEE 802.15.4 and 6LoWPAN," in Embedded Linux Conference, Europe, 2012.

[3] P. Thuber and B. Brandt, "RFC 6550: IPv6 Routing Protocol for Low-Power and Lossy Networks," Internet Engineering Task Force (IETF) Request For Comments, 2008.

[4] S. Shahzad, R. Rashid and T. Muhammad , "Importance of Trickle Algorithm in IoT," in IEEE 2019 2nd International Conference on Communication, Computing and Digital systems (C-CODE), Islamabad, Pakistan, 2019.

[5] O. Gnawali, "RFC 6719: The Minimum Rank with Hysteresis Objective Function," Internet Engineering Task Force (IETF), 2012.

[6] T. Leenas, "Comparison of Proactive, Reactive, and Hybrid Routing Protocols in Mobile Ad Hoc Networks", Conference: 2021 10th International Conference on Information and Automation for Sustainability (ICIAfS), 2021.

[7] M. Goyal and E. Baccelli , "RFC 6997:Reactive Discovery of Point-to-Point Routes in Low-Power and Lossy Network," IETF, 2013.

[8] H. Fotouhi and D. Moreira, "mRPL: Boosting mobility in the Internet of Things," Ad Hoc Networks, Elsevier, 2015.

[9] F. Gara, L. B. Saad, E. B. Hamida and B. T. a. R. B. Ayed, "An adaptive timer for RPL to handle mobility in wireless sensor networks," in International Wireless Communications and Mobile Computing Conference (IWCMC), Paphos, 2016

[10] J. V. Sharma P., "EMAEER: Enhanced Mobility Aware Energy Efficient Routing Protocol for Internet of Things," in Conference on Information and Communication Technology, Jabalpur, India, 2018

[11] S. Sanshi and J. CD, "Fuzzy optimized routing metric with mobility support for RPL," *IET Communications*, 2019.

[12] B. Mohammadsalehi, A. Safaei and B. Monazzah, "ARMOR: A Reliable and Mobility-Aware RPL for Mobile Internet of Things Infrastructures," IEEE Internet of Things Journal, vol. 9, no. 2, pp. 1503-1516, 2020.

[13] H. Kim and S. Bahk, "MobiRPL: Adaptive, robust, and RSSI-based mobile routing in low power and lossy networks," Journal of Communications and Networks, 2022.

[14] F. Fazli and M. Mansubbassiri, "V-RPL: An effective routing algorithm for low power and lossy networks using multi-criteria decision-making techniques," Ad Hoc Networks, 2022.

[15] H. Echoukairi, M. El Ghmary and O. Ali, "A New Objective Function for RPL Based on Combined Metrics in Mobile IoT," Journal of Communications, vol. 18, no. 5, pp. 301-309, 2023.

[16] A. Conta, "Internet Control Message Protocol (ICMPv6) for the Internet Protocol Version 6 (IPv6) Specification RFC4443," Network Working Group, 2006.

[17] A. Althalji, S. Khawatmi and B. A. Kassab, "A context-aware algorithm for parent selection in LLNs," *Research Journal of Aleppo University*, vol. 183, 2023

[18] a. IoT Networking Research Group, "Cooja Simulator Manual Version 1.0," Edinburgh Napier University, 2016.

[19] C. Bettstetter, "Mobility modeling in wireless networks," *ACM SIGMOBILE Mobile Computing and Communications*, vol. 5, no. 3, 2001