An Improved RPL Objective Function for Load Balancing Using Swarm Intelligence Algorithm in IoT Network

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Abstract : The Internet of Things (IoT) consists of a group of smart devices that rely on energy-efficient and congestion-aware routing to extend the lifetime of resource-constrained networks in 6LoWPAN. This paper proposes a novel load-aware objective function by using an Artificial Bee Colony based parent selection algorithm that optimizes routing in 6LoWPAN by dynamically considering energy levels, queue occupancy, and channel level congestion. The proposed method compared with existing methods.

IndexTerms – **Internet of Things, Objective Functions, Routing.**

I. INTRODUCTION

The IoT is a framework that enables various advanced technologies to allow objects to collect, process, and communicate through the Internet without human intervention [1]. IoT devices are wireless and self-operating, increasing radially to accomplish application needs; a standard setup of IoT network is essential, and for that reason, IETF (Internet Engineering Task Force) introduced standardized IPV6 over low power and lossy Wireless Personal Area Network (6LoWPN) with RPL (routing protocol for reliable data transmission) to provide a connection between low power wireless device to the Internet using RPL border gateways [2].

In 6LoWPAN networks, congestion can occur at two levels: node-level congestion and channel-level congestion. These two types of congestion help determine the overall congestion situation in an IoT network. To control packet loss, existing congestion control mechanisms are classified into network-traffic-based, node-resource-based, and hybrid approaches. Traffic-based congestion control regulates the data transmission rate to prevent excessive packet flow and reduce congestion [3]. The RPL objective function (OF) plays a prominent role in data transmission over 6LoWPAN. There are two native OF available for RPL are OF0 [4], MRHOF [5,6]. Bothe are single metric based route selection. However, its single metric-based route selection makes it inefficient for congestion control and energy efficiency.

Developing such an objective function remains a challenge in 6LoWPAN. This motivates us to propose a congestion control strategy that considers congestion awareness while selecting the parent node by applying swarm intelligent optimization algorithm.

II. LITERATURE REVIEW

This section presents the literature work on congestion aware objective function to achieve energy efficiency in RPL over 6LoWPAN. There are many paper published to enhance the RPL objective functions, those paper advantages and limitation are discussed as follows.

Sabrina Mokrani et al. [6] suggested a new objective function parameter energy-ETX along with LSTM predicting inertia-weight-based PSO with Online Gradient-descent utilized to optimize both the parent selection process and Trickle-timer adjustment. It controls the frequent parent change operation. The proposed work was validated using a Cooja simulator, and a comparison was made with previous protocols regarding packet delivery, energy efficiency, convergence time, delay, and control overhead. The proposed work outperforms the existing protocols.

Ali Kadhum Idrees et al. [7] suggested an energy-aware load-balancing RPL based on fitness value calculated for both downward and upward routing processes. The proposed work reduces the DIO packet generation, which proves energy efficiency and reduces the control overhead in the 6LoWPAN network. The simulation was done to compare the suggested work with the existing work; the results proved that suggested idea achieves a more extended network lifetime. The proposed work depends on the single metric-based route selection; it would not consider the composite metrics to select the route.

Aastha Maheshwari et al. [8] presented a novel OF using the adaptive fuzzy-multi-criteria method to select the best parent to balance the load in the congested network to increase the data forwarding capacity. The suggested approach mitigates the network congestion dynamically. The simulation outcome prove that the work achieves less delay, minimum energy consumption, and packet overflow and maximizes the network throughput compared to existing works.

Kala Venugopal et al. [9] proposed Congestion-energy-efficient RPL, it is a multipath extension of RPL designed to improve load balancing and congestion management in LLN. The evaluation was performed in Contiki Cooja, which provides the proposed CEA-

OF a lower power consumption, end-to-end delay and queue loss ratio, and improved network lifetime. The approach lacks network mobility and stability support, which may affect its effectiveness in dynamic IoT environments.

III. PROPOSED LOAD-AWARE METHODOLOGY

This section contains the network model, proposed congestion-aware Objective function (ACO-RPL), rousing metrics and parent selection process are explained in detail.

The major objectives of the proposed work are:

1) Congestion-aware energy-efficient objective function (ACO-RPL) by considering both node level and channel level congestion.
2) Optimal node parent selection process based on artificial bee colony optimization algorithm.
3) Dynamic adjustment of beacons value for energy efficiency.

The RPL network layer protocol is designed for data transmission over Low-Power and Lossy Networks (LLNs). There are two basic objective functions defined for RPL by the Internet Engineering Task Force (IETF): Objective Function Zero (OF0) and Minimum Rank with Hysteresis Objective Function (MRHOF). These OFs is a basic version of RPL, as it determines the best parent node to select in the Destination-Oriented Directed Acyclic Graph (DODAG).

ICMP (Internet Control Message Protocol):

The control messages play a major role in network formation, maintenance, and optimization. The RPL ICMP messages used in RPL include DODAG Information Object (DIO), which disseminates routing information and constructs the topology. DIS-(DODAG Information Solicitation), used by nodes to request DIO messages when joining the network or seeking updated routes.
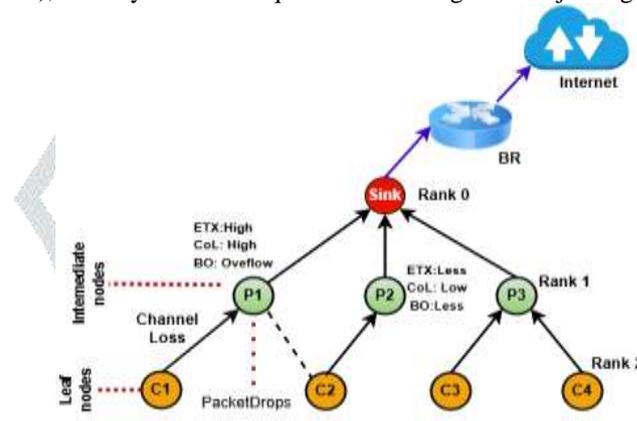

Fig. 1: Proposed Parent Selection Process.

In the LLN, nodes create a tree-structured topology. For any source node to communicate with the sink, they must exchange ICMPv6 control messages to establish this tree. The proposed 6LoWPAN architecture, depicted in the Fig. 1, consists of eight nodes: C1, C2, C3, and C4 are leaf nodes, while P1, P2, and P3 act as parent nodes. Additionally, there is one sink and a border router that connects to the Internet.

Algorithm 1: ABC-RPL for best parent selection

Input: Set of Parent list
Output: best parent node
// Initialize the network parameters
 Initialize nodes and neighbors
Define parameters: max_iterations, colony_size, w1, w2, w3,w4
Step 1: Initialize population (neighbor nodes)
For each node Ni **do**
  Get neighbor list P = {P1, P2, ..., Pm}
  Compute initial fitness F(Pj) for each parent Pj using: Eq.4.
End
// **Step 2:** Employed Bees Phase
For each node Ni **do**
  For each neighbor **Pj**:
    Compute new candidate solution by modifying current solution
Evaluate new fitness F_new(Pj)
    If F_new(Pj) > F(Pj):
      Update parent selection to Pj
    End
End

// **Step 3:** Onlooker Bees Phase
For each node Ni **do**
  Compute probability of selecting a parent:
  Prob(Pj) = F(Pj) / sum(F(Pk) for all k)
  Select a parent Pj based on Prob(Pj)
End

// Step 4: Scout Bees Phase
For each node Ni **do**
   If fitness of current parent degrades (e.g., high congestion, low energy):
      Explore new parents by re-evaluating F(Pj)
If no good parent is found, switch to alternative path
End
//Step 5: Update the RPL DODAG
For each node Ni **do**
   Set best parent based on fitness values
   Update routing table and forward packets accordingly
End
End

The ABC-RPL algorithm shown in Algorithm 1. enhances parent selection in RPL-based IoT networks using Artificial Bee Colony (ABC) optimization to improve energy efficiency, link reliability, and congestion control.

IV. SIMULATION AND PERFORMANCE RESULTS

The proposed work is evaluated under simulation environment using Cooja simulator. The detailed simulation setup is presented in Table I. The performance evaluation metrics are used in simulation and discuss the obtained results with previous protocols LEA-RPL[161], standard MRHOF[4] and ACOF[28].

Fig.2 shows that the packet delivery rate of the proposed work outperforms the existing approaches. MRHOF, LEA-RPL, and ACOF. In the proposed work, the parent node with buffer space is selected, and less channel congestion is considered along with the node's energy. However, LEA-RPL does not consider congestion. It only concentrates on the ETX value and delay parameter. In this case, the parent node with buffer overflow may also selected as the parent that gives an unreliable link. MRHOF also consumes more packet loss during transmission due to its single metric-based parent selection. On the other hand, the ACOF generates more control packets, which creates congestion and increased packet loss.
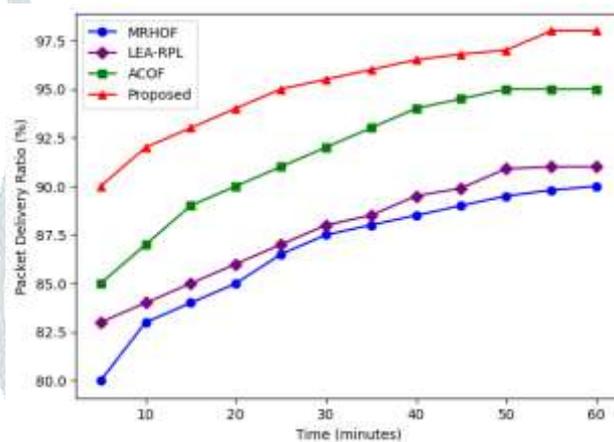

Fig. 2: Packet Delivery Ratio.

Fig.3 illustrates energy consumption over time, showing that as the simulation progresses, the energy levels of the nodes begin to decline. The proposed method's energy consumption is lower than that of existing approaches because it addresses congestion at the node level by selecting non-congested nodes with high energy reserves.
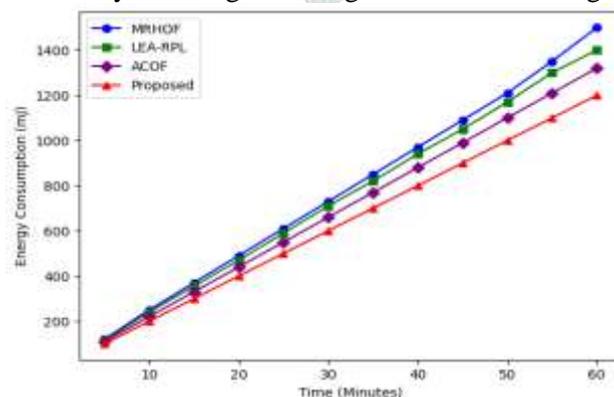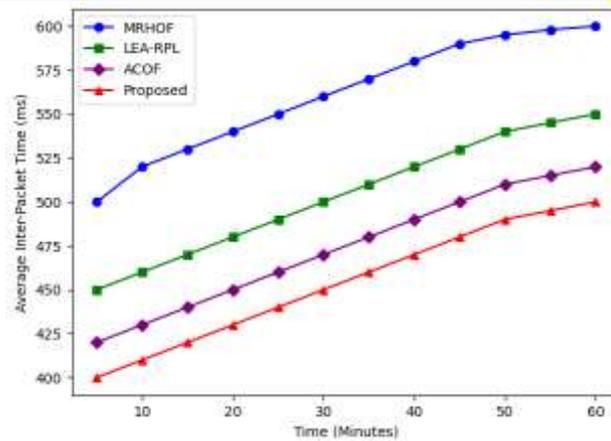

Fig.3. Energy Consumption.

Fig.4 Average inter-packet time.

Fig. 9 shows the proposed work reduces the average inter-packet time by around 5% of internal packet time due to efficient congestion control OF for selecting parent nodes. MRHOF generates huge control messages that increase the inter-packet time, and LEA-RPL also has a high inter-packet time between packets.

V . CONCLUSION AND FUTURE ENHANCEMENT

This work introduces a novel congestion-aware energy-efficient objective function for selecting the optimal parent node using an artificial bee colony (ABC) algorithm. The function considers both channel-level and node-level congestion parameters when ranking the nodes. The goal is to establish an energy-efficient and reliable path for IoT applications. Future work could focus on adaptive parameter tuning, which allowing for dynamic parameter adjustments of weights based on network pattern conditions. Additionally, integrating reinforcement learning could facilitate self-learning in parent selection, improving adaptability in highly dynamic IoT environments.

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