Multi-Layer Cluster Based Energy Aware Routing Protocol for Internet of Things

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Abstract: *We propose a multi-layer cluster based energy aware routing protocol for Low Power and Lossy Networks, which divides the network area into equal length rings. The intra-ring clustering process divides a ring into equal sized clusters and inter-cluster routing applies the fuzzy logic to select the best route for data transfer. It increases the network lifetime and packet delivery ratio by 18-22% and 5-8%, respectively.*

Keywords: *Internet of things, low power and lossy networks, IPv6 routing protocol for low power and lossy networks, cluster head, cluster member.*

1. Introduction

Internet of Things (IoT) is an emerging research area in Information and Communication Technology (ICT). IoT provides various solutions to the problems in different domains [1]. It is a collection of sensor-enabled physical objects connected to the Internet, which exchanges data between them without human involvement. Its applications are vital in the smart home, smart grid, smart city, smart agriculture, building automation, etc., [6, 16].

The Low power and Lossy Network (LLN) contain highly resource-constrained wireless devices, which have low processing capacity and transmission rate [17]. IEEE 802.16 is quite lossy compared to IEEE 802.11 [21]. IPv6 Routing Protocol for Low power and lossy networks (RPL) is the standardised routing protocol for LLN by IETF [22]. It is a distance vector and source routing protocol designed explicitly for LLN. It follows the Destination-Oriented Directed Acyclic Graph (DODAG) like tree topology. The DODAG root is connected directly to the Internet. It generates RPL instances, each RPL instance may contain more than one DODAG, uniquely identified by DODAGID. The source node transfers the data to the destination or receiver node via DODAG root. Upward routing indicates the edge directed towards

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the DODAG root and downward route indicates the edge direction far away from the DODAG root [3].

Although RPL fulfils the requirements of LLN, we require a lot improvement in RPL to prolong the network lifespan and to provide the Quality of Service (QoS). Network data traffic, load imbalance problem in an uneven parent selection process, multi-sink and multi-instance problem in mobility scenario, interoperability issues in vast Internet hosts, link failure and local repair in parent unreachable situation, fault tolerance and security mechanism are the major challenges in RPL [4].

The major contribution of this paper is to address the problem of multipoint-to-point (MP2P) data traffic, to extend the network lifetime. In this paper, we propose a Multi-layer Cluster based Energy Aware Routing Protocol (MCEA-RPL) for LLN. In MCEA-RPL, the network area is divided into rings of equal width, using the finest ring width for the network space. In the intra-ring clustering process, it forms equal-sized clusters in a ring. In inter-cluster routing, the parent selection process applies the fuzzy logic over the routing metric Expected Transmission count (ETX) and Residual Energy (RER), to select the optimal parent node, for transferring the data efficiently.

The paper is organized as follows: Section 2 describes the related work. Section 3 represents the MCEA-RPL protocol. Section 4 discusses the result and discussions. Section 5 is the conclusion and future work of this paper.

2. Related work

In this section, we discuss the cluster based RPL, ring topology based cluster routing model and fuzzy logic based clustering protocol in WSN.

T a n [20] proposed the cluster based RPL protocol to prolong the network lifetime in LLN. It splits the network area into layers and each layer is considered as a cluster. Each cluster selects the CH node based on the remaining energy. All the Cluster Members (CM) forward the data to Cluster Head (CH). The CH node aggregates and forwards the data to DODAG root. Z h a n g et al. [24] proposed an energy Efficient Heterogeneous Ring Clustering protocol (E2HRC) to extend the network lifetime of WSN. It forms rings of equal area in the network space and it selects the CH node rotationally. The CM sends the data packets to the CH node. The CH node aggregates and forwards the data packets to parent CH. Likewise, the data is forwarded to DODAG root. Z a n g et al. [25] proposed an Improved RPL (IRPL) for WSN. It divides the network area into equal size of rings. It selects the CH based on Clustering Probability Model (CPM). The CH node aggregates and forwards the data packets to the parent CH node in the DODAG. Y i j u n et al. [23] proposed a Sink Oriented Layered Clustering (SLOC) protocol for WSN. The SLOC protocol divides the network space into rings of equal width. It performs intra-ring clustering and inter-cluster routing process to transfer the data from participant node to DODAG root.

Z h a o, I v a n and P e t e r [26] proposed a region based routing protocol (ER-RPL). It improves the energy efficiency and packet delivery ratio in LLN. It

divides the network space into several regions. It sets the reference node randomly in each region and it establishes the point-to-point best route in the region. Finally, it aggregates data from the whole region and transfers the data to the DODAG root. Z h a o, P e t e r and H e n r y [27] proposed a hybrid cluster parent routing protocol (HECRPL). It enhances the reliability of the nodes and increases the energy efficiency by Cluster Parent Selection (CPS), overhearing coordination mechanism to avoid the duplicate data, loss recovery scheme for the lost data packet and refined the transmission power.

J u n g, J o n g-Y o n g and H w a-Y o u n g [7] proposed a fuzzy based energy efficient cluster routing protocol (FEMCHRP) for WSN. It selects the CH node based on the routing metrics, battery level, data frequency and node density to transfer the data. R a n a et al. [14] proposed a multiple cluster head selection routing protocols for WSN. The Cluster Members (CM) forward the data to the CH node. The Cluster Head Leader (CHL) node collects the data from the CH node and it forwards the data to the Base Station (BS). N a y a k and A n u r a g [11] proposed a fuzzy cluster routing protocol, to prolong the network lifetime in WSN. It follows the LEACH behaviour, to select the CH node. It maintains two levels of nodes between the source node and the sink node namely, SuperCluster Head (SCH) and Cluster Head (CH). The fuzzy descriptor is applied to the CH node and it elects the SCH node among the CH node for transferring the data to the mobile sink.

G a d d o u r, A n i s and M o h a m e d [4] proposed fuzzy-based Objective Functions (OF-FL), which take into account the routing metrics, ETX, delay, hop count and Link Quality Level (LQL), to provide the QoS in LLN. A l j a r r a h [2] proposed a multi fuzzy logic model based objective function (ML-FL) for LLN. It considers the node metrics (node energy, ETX and neighbours in connectivity), channel metrics (channel capacity, RERQ and channel bandwidth) and link oriented metrics (link stability, hop count and mobility), to extend the network lifetime. K a m g u e u et al. [8] proposed a fuzzy logic based RPL protocol for LLN. It applies the fuzzy logic over the routing metrics, delay, ETX and energy, to transfer the data efficiently.

3. System model

3.1. Network model

The network area contains N number of sensor nodes, which are deployed statically and distributed uniformly. It has one sink or DODAG root, which is located in the center of the network area. All the nodes are deployed in a circular area of radius R and have the same initial energy [19].

Fig. 1 shows that the network area is divided into rings of equal width, by computing the finest ring width r for the network area. In the intra-ring clustering process, it forms clusters and selects the Cluster Head (CH). In inter-cluster routing, the CH selects the optimum parent CH node in the upward layer, considering the routing metrics namely, ETX and RER.
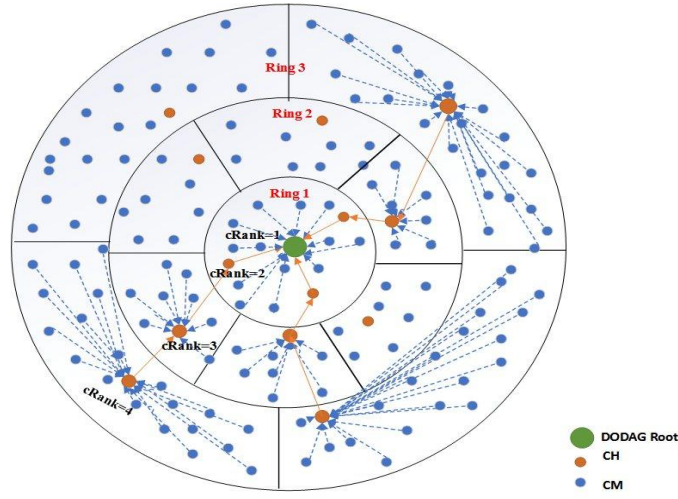
Fig. 1. Ring and cluster formation

3.2. Energy model

Energy model considers the factors, namely sensing, transmission, reception and aggregation for the energy consumption. The energy consumed for sensing, transmitting, receiving and aggregating one bit of data packet is represented as e_s, e_t, e_r and e_a, respectively. The energy consumed for transmission of one bit over a distance of (dist) is computed as

(1)
$$e_t(\text{dist}) = \varepsilon_1 + \varepsilon_2 \times \text{dist}^{\alpha},$$

where ε_1 is electronic transmission energy consumption, α is decay exponent and ε_2 is the amplifier energy. It is considered the variable transmission power level and it follows the simplified radio channel model.

4. The MCEA-RPL protocol design

The MCEA-RPL protocol is designed to enhance the network lifetime in LLN. It consists of three phases, namely, ring creation, intra ring clustering process and the intercluster routing process. Initially, it creates the virtual rings and the sensor nodes are distributed randomly in the network area. The ring width is fixed based on the energy consumption of nodes and the network area. The intra-ring clustering process performs two operations, namely cluster formation and CH selection. The cluster formation is based on the energy consumption of nodes in each ring. The cluster is of smaller size closer to the sink node and its size increases gradually as it gets far away from the sink node. The inter-cluster routing applies the fuzzy logic over ETX and RER to select the best CH parent node, for data transfer from participant node to DODAG root.

4.1. Network ring creation

The network area is divided into rings of equal width [23]. The number of rings Q created in the network area with radius R, of ring width r, is given by

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$$(2) \qquad\qquad Q = \frac{R}{r}.$$

The sensor nodes are uniformly distributed and the number of sensor nodes present in each ring n_q, is

$$(3) \qquad\qquad n_q = \frac{(2q-1)r^2}{R^2} \times N,$$

where $q = 1, 2, ..., Q$.

The innermost ring is considered as a single cluster. It directly forwards its data to the sink. Moreover, some of the nodes acts as cluster heads, which receive and forward the data packet from the downward layer nodes to the sink.

The energy consumption of the cluster member $E_{1,CM}$, in the innermost ring q_1 is

$$(4) \qquad\qquad E_{1,CM} = e_s + e_t \times \text{dist},$$

where e_s, e_t represents the energy consumption for data sensing and transmission, respectively.

The energy consumption of the cluster head $E_{1,CH}$, in the innermost ring q_1 is

$$(5) \qquad\qquad E_{1,CH} = (e_s + e_t \times \text{dist}) + \frac{\sum_{q=2}^{Q} \rho n_q}{j_q} (e_r + (e_t \times \text{dist})),$$

where dist indicates distance between sensor node in the innermost ring and the sink node, which is calculated by

$$(6) \qquad\qquad \text{dist} = \int_{\theta=0}^{2\Pi} \int_{b=0}^{r} b\lambda_1 b \partial b \partial \theta = \frac{2}{3}r,$$

where b denotes the area of the ring and θ denotes the angle of the ring.

The CH role is supposed to be rotated equally in the inner most ring. If a node acts as a cluster head CH in a particular round, it will not act as CH node for the next $\frac{n_1}{j_1} - 1$ rounds. The general aggregation model is applied in the downward layers [11]. The total energy consumption E_1 in the innermost ring is computed by

$$(7) \qquad E_1 = \frac{\left(\frac{n_1}{j_1} - 1\right) \times E_{1,CM} + E_{1,CH}}{\left(\frac{n_1}{j_1} - 1\right)} = e_s + (e_t \times \text{dist}) + \frac{\sum_{q=2}^{Q} \rho n_q}{j_q} (e_r + (e_t \times \text{dist})) =$$

$$= e_s + \varepsilon_1 + \varepsilon_2 \times \left(\frac{2}{3}r\right)^{\alpha} + \rho \times \frac{R^2 - r^2}{r^2} \times [e_r + \varepsilon_1 + \varepsilon_2 \times \left(\frac{2}{3}r\right)^{\alpha},$$

where ε_1, ε_2, r represents the electronic energy consumption, amplifier energy and ring width, respectively.

To simplify the average energy consumption E_1 of the inner most rings, we differentiate the (7) with respect to r and we construct the Quadratic equation, represented as

(8)
$$\frac{\partial E_1}{\partial r} = 0 \Rightarrow Xr^{\alpha+2} + Yr^{\alpha} + Z = 0,$$

where X, Y and Z are obtained by:

(9)
$$X = \left(\frac{2}{3}\right)^{\alpha} \times \varepsilon_2 \times \alpha \times (1-\rho),$$

(10)
$$Y = \left(\frac{2}{3}\right)^{\alpha} \times \varepsilon_2 \times \rho \times R^2 (\alpha - 2),$$

(11)
$$Z = 2 \times \rho \times R^2 \times (e_r + \varepsilon_1),$$

where α, ρ represents exponent decay and aggregation ratio, respectively. Finally, the ring width r is computed as follows:

(12)
$$r = \left(\frac{Z}{X}\right)^4 = \left(\frac{\rho \times (e_r + \varepsilon_1)}{\left(\frac{2}{3}\right)^2 \times \varepsilon_2 \times (1-\rho)}\right)^{\frac{1}{4}} \times \sqrt{R} = 4.12\sqrt{R}.$$

The lifetime of a node is calculated as E_{init}/E_1 rounds, where E_{init} represents the initial energy of a node. We decide the number of cluster heads j_1 in the innermost ring depends on the application requirement.

We compute the number of cluster head in the q-th ring j_q, where q=2, 3, ..., Q, such that it balances the energy consumption in each ring [23]. The energy consumption for aggregating and transmitting a data packet by a cluster head in the q-th ring $E_{q,\text{CH}}$, is given by

(13)
$$E_{q,\text{CH}} = e_s + e_r \left(\frac{n_q}{j_q} - 1\right) + \left(e_a \times \frac{n_q}{j_q}\right) + \left(\frac{\rho n_q}{j_q} \times e_t \times \text{dist}_{q,q-1}\right) +$$
$$+ \left(\frac{\sum_{i=q+1}^{Q} \rho n_i}{j_q} \times [e_r + e_t \times \text{dist}_{q,q-1}]\right),$$

where n_q, j_q represent the numbers of sensor nodes in q-th ring and number of CH in q-th ring, respectively. The $\text{dist}_{q,q-1}$ indicates the distance between sensor nodes in q-th ring and $(q-1)$-th ring and is given by

(14)
$$\text{dist}_{q,q-1} = \varepsilon \times (\text{dist}_{q,1} - \text{dist}_{q-1,1}), \quad \varepsilon \geq 1,$$

where ε is a constant and $\text{dist}_{q,q-1}$ indicates the distance between the sensor node in q-th ring and the sink node. Thus, it fine-tunes the number of CH nodes in the inner most ring and it tries to balance the energy consumptions in all the rings.

4.2. Intra-ring clustering

The intra-ring clustering has two sub-processes namely, cluster formation and cluster head selection.

4.2.1. Cluster formation

The number of CH in each ring is decided by the energy consumption in the innermost ring, i.e., $E_{q,\text{CH}} = E_{1,\text{CH}}$ where $q=2, 3, ..., Q$. In our simulation, we consider the number of nodes $N = 150$, overall network region $W = 150$ m, ring width $r = 50$, number of ring $Q = \frac{W}{r} = \frac{150}{50} = 3$ and $\alpha = 2$. The number of nodes in each ring n_q are 15, 50 and 85, respectively. The number of sensor nodes in the innermost ring n_1 is 15. Initially, we pick the number of CH in the innermost ring j_1, varying from 7, 5, 4, 3, 2 based on 1/2 to 1/6 of n_1 nodes. To balance the energy consumption of each ring, the MCEA-RPL forms the number of clusters in the rings nearby the sink and less number of clusters in the rings far away from the sink. The number of CH node j_n is based on the energy consumption of each ring. It optimizes the number of CH in q_1 and it maintains the same energy consumption of sensor nodes in each ring. Finally, we obtain the optimal number of CH's are 3, 6 and 4, respectively for the ring q_1, q_2 and q_3.

The area of each ring A_q is calculated from the network area and represented by

$$(15) \qquad A_q = \Pi(q \times r)^2 - \Pi((q-1) \times r)^2,$$

where $q = 1, 2, ..., Q$. The average area of cluster or cluster size cs_q is calculated from the area of rings and it is given by

$$(16) \qquad \text{cs}_q = \frac{A_q}{j_q}, \quad q = 1, 2, ..., Q,$$

where A_q, j_q represent the area and the number of CH in q-th ring.

4.2.2. Cluster head selection

The cluster head selection has two phases, namely, setup phase and steady phase. During the setup phase, the node selects the CH stochastically in the cluster. This approach gives the equal chance to all nodes to act as a CH and maintains equal residual energy among the nodes within a cluster. Each node in the cluster generates the random number between 0 and 1. The node with the largest threshold value is selected as the cluster head, for that time period called round:

$$(17) \qquad T(n) = \begin{cases} \dfrac{1}{n_{q,j}} \times (\text{round}\,/\,n_{q,j}) & \forall n \in G, \\ 0 & \forall n \notin G, \end{cases}$$

where $n_{q,j}$ is the total number of nodes in q-th ring of j-th cluster and G is the set of nodes that do not act as a cluster head in last $\dfrac{1}{n_{q,j}}$ rounds.

Algorithm 1: Intra-Ring Clustering Algorithm
1: **Input:**
2: Number of ring Q, Area of ring A_q, Number of nodes in each ring N_q
3: **Output:**
4: Number of CH in each ring j_q

//Cluster Formation
5:   Compute the number of CH node in the innermost ring
6:   Calculate the area of each ring A_q
7:   Calculate the number of distributed in each ring n_q

$$n_q = \frac{(2q-1)r^2}{W} \times N \quad \text{, where } q=1, 2,\ldots, Q-1$$

8:   Compute number of CH node j_q in each ring q
9:   Calculate the average area of cluster size (cs_q)

10:     $cs_q = \sqrt{\frac{A_q}{\pi j_q}}$, $q=1, 2, \ldots, Q$

Cluster Head Selection
// Setup phase
11:   Calculate Probability value T for each round

12:    $T(n) = \begin{cases} \dfrac{1}{n_{q_i}} \times (\text{round}/n_{q_i}) & \forall \text{Node\_id} \in G, \\ 0 & \forall \text{Node\_id} \notin G \end{cases}$

13: **For** each node n **do**
13:    **If** $T(n) < 1$ **then**
14:      Node_state= cluster member
15:    **Else**
16:      Node_state=Cluster Head
17:    **End if**
18: **End for**
   // Steady phase
19:   DIOC_control_messages (CH to entire CM)
20:   DAOC_control_messages (CM's to CH)
21:   CH-ACK_control_messages (CH to CM)
22:   CH collects the data using TDMA schedule
23:   CH forwards the data to another CH using CDMA schedule

In steady phase, CH node multicasts the control message DODAG Information Object for Cluster (DIOC) to the entire CM. The CM replies with the control message DODAG Advertisement Object for Cluster (DAOC) to CH node. The CH node sends the Cluster Head ACKnowledgement (CH-ACK) message to the entire CM. The CM sends data to the CH node using the TDMA schedule. The CH node applies the data aggregation ($\rho = 0.2$), to aggregate data from CM. The CH node forwards the data to the parent node or DODAG root using the CDMA time schedule.

4.3. Inter cluster routing

Inter cluster routing maintains the DODAG topology, to select the best parent node for data transfer. It implements the route establishment process of cluster based RPL [20]. The CH node broadcast the DIOC control messages to all CM inside the cluster. The CM node sends the DAOC control messages to CH node within the trickle time. Finally, the CH node sends the CH-ACK messages to the cluster members and

updates the node information in the routing table. During the routing process, it maintains the CH node information in two states namely, original optimal parent and suboptimal parent. The suboptimal parent collects and aggregates the data from the cluster members. The parent node passes its information to the participant node in the option field (DAG metric container) of the DIOC control message. We apply the fuzzy logic on the routing metrics ETX and RER, to select the optimal parent node, for data transfer. The Suboptimal node selects the best original parent among the preferred original parent node using cRank. The suboptimal parent forwards the aggregated data to the parent CH node or optimal parent node. The original optimal parent gathers the data packets from suboptimal parent and it forwards the data packet to DODAG root or parent CH node without data aggregation.

4.3.1. Fuzzy inference system

Fuzzy inference system (FIS) is a type of input and output mapping system applying fuzzy logic. In FIS, the major important components are fuzzification, inference engine and defuzzification [10, 12].

- Fuzzification

Fuzzification is a process of converting the crisp value into fuzzy set value. In MCEA-RPL, RER and ETX are the input variables to the fuzzy inference system.

Linguistic variable: The Linguistic variable belongs to the fuzzy set and its values are words or sentences rather than numbers. In MCEA-RPL, the first fuzzy input variable RER contains three linguistic variables namely, low, medium and high. The second fuzzy input variable ETX contains three linguistic variables namely, short, average and long. Moreover, the output variable quality of CH parent node contains five linguistic variables namely, awful, bad, good, very good and excellent.

Membership Function: Membership functions are used to evaluate the linguistic variable. Fig. 2-4 shows that the membership functions of input and output fuzzy variable. Here, we have chosen the trapezoidal and triangle membership function for selecting the best CH node. The membership function value is a universe of discourse and its ranges between 0 and 1.

The triangle membership function generation representation is given by

$$(18) \qquad \mu_{A_1}(y) = \begin{cases} 0, & z \leq d_1, \\ \dfrac{z - d_1}{e_1 - d_1}, & d_1 \leq z \leq e_1, \\ \dfrac{f_1 - z}{f_1 - e_1}, & e_1 \leq z \leq f_1, \\ 0, & f_1 \leq z. \end{cases}$$

The trapezoidal membership function generation representation is given

$$(19) \qquad \mu_{A_2}(y) = \begin{cases} 0, & z \le d_2, \\ \dfrac{z - d_2}{e_2 - d_2}, & e_2 \le z \le f_2, \\ 1, & e_2 \le z \le f_2, \\ \dfrac{f_1 - z}{f_1 - e_1}, & f_2 \le z \le g_2, \\ 0, & g_2 \le z. \end{cases}$$

The membership function of the first fuzzy input variable RER is represented in Fig. 2 [9]. The variable low and high are resented using the trapezoidal shape of the membership and the variable medium is represented using triangle shape membership function.
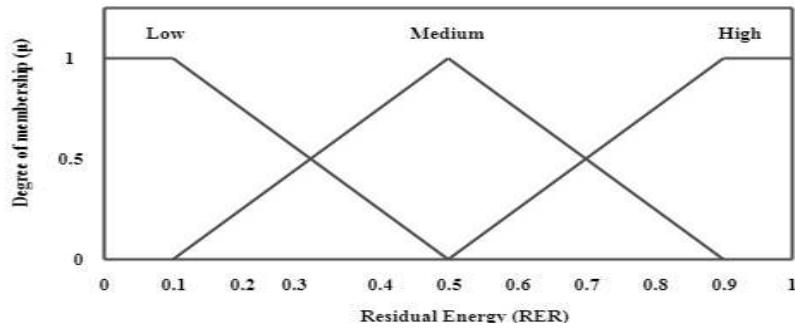

Fig. 2. Membership function of residual energy

The membership function of second fuzzy input variable ETX is described in Fig. 3 [22]. The linguistic variables short and long are represented using the trapezoidal shape of the membership and the variable average is represented using triangle shape of the membership function.
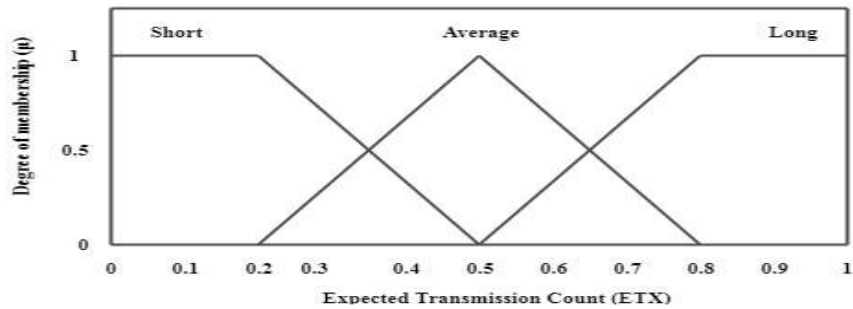

Fig. 3. Membership function of expected transmission count

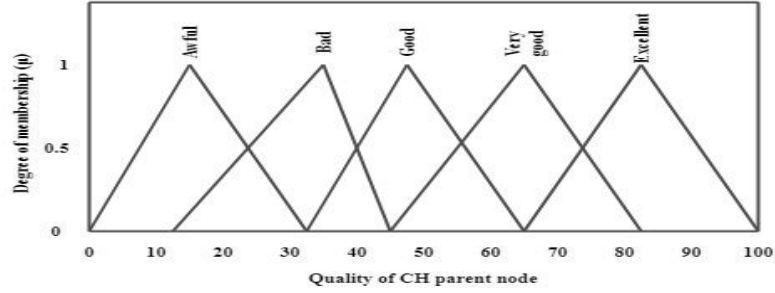The membership function of output fuzzy variable quality of CH node is represented in Fig. 4 [9].

Fig. 4. Membership function of the quality of CH parent node

- Fuzzy inference rule

In MCEA-RPL, we use the routing metrics ETX and RER, to select the best route, for transferring the data from source to DODAG root following the upward routing. The fuzzy rule contains 2 input controllers and 3 membership functions which are represented as 3^2=9 rules. The fuzzy rules are given in Table 1.The quality of parent CH node ranges between 0 and 100. The fuzzy rules are described using "if-then" rules and it is evaluated by the Mamdani model [13]. It varies based on the application requirements.

Table 1. Fuzzy rules

No	RER	ETX	Quality of CH node
1	low	short	good
2	low	average	bad
3	low	long	awful
4	medium	short	very good
5	medium	average	good
6	medium	long	bad
7	high	short	excellent
8	high	average	very good
9	high	long	good

- Defuzzification: It is a process of getting the crisp value from fuzzy set value. In MCEA-RPL, we have used the Center Of Area (COA) method for the defuzzification process [15]. The center of area is given by

$$(20) \qquad \text{COA}(z) = \frac{\int \mu_A(z)y\,dz}{\int \mu_A(z)\,dz},$$

where $\mu_A(z)$ is the aggregated output membership function for different input variables, COA(z) is defuzzified fuzzy output variable.

4.3.2. cRank calculation process

The cRank represents the number of CH nodes between DODAG root and suboptimal parent node. The rank increase value is calculated from step value and min_hop_rank_increase_value. The default value of min hop rank increase is 256 [20]. The step_value is calculated from defuzzified value of routing metrics RER and ETX. The suboptimal parent rank cRank (N) is given by:

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(21) $c\text{Rank}(N) = c\text{Rank}(PN) + \text{Rank\_increase},$
(22) $\text{Rank\_increase} = \text{step\_value} + \text{Min\_Hop\_Rank\_Increase}.$

The inter-cluster routing algorithm is represented, for transferring the data from the downward layer to DODAG root and it is given in below.

Algorithm 2. Inter Cluster Routing Algorithm
1: **Input:**
2:    Node N, DODAG root, CH_Node_ParentID, CH_NodeID,
      Best_CHParentRank=∞, Min_Hop_RankIncrease=256,
      RER and ETX;
3: **Output:**
4:    CH_Preferred_ParentNode (N)
5: **for** CH_Preferred_ParentNode $\in$ CH_Parent_List **do**
6:    fuzzy input variables: RER and ETX
7:    Construct the linguistic variable and membership function for
      fuzzy input variables.
      // Fuzzification process
8:    fuzzy_set_value=fuzzification (RER, ETX)
      // fuzzy rule base
9:    fuzzy_set_value compare with fuzzy rule base
10: Convert the fuzzy_set_value into crisp set using centre of Area
      Defuzzification Method
      $$\text{step\_value} = \frac{\int \mu_A(z) z \, dz}{\int \mu_A(z) \, dz}$$
      // cRank Calculation
11: Rank (CH_node (N)) ←Rank (CH_Preferred_ParentNode (N)) +
      Rank_increase;
12: Rank increase ← step_value + Min_Hop_Rank_Increase;
13: **if** CH_BestParent_Rank>=CH_Preferred_ParentNode_Rank (N) **then**
14:    CH BestParent_Rank ← CH_Preferred_ParentNode_Rank (N);
15:   **End if**
16: **End**
17: **While** CH_Preferred_ParentNode_Rank (P) ==CH_BestParent_Rank **do**
18:    CH_Node_ParentID=CH_Preferred_Parent_NodeID;
19: **End**

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5. Result and discussions

5.1. Simulation setting and parameters

The objective of the simulation is to show, how the MCEA-RPL protocol is better than RPL and IRPL. The COOJA simulator is used to conduct the simulation [18]. We use sky mote in our simulation. 150 RPL routers and 1 DODAG root are taken for simulation. The overall network radius is 150 m. The simulation is conducted in two scenarios, **a**. Transmitting one packet per minute and **b**. Transmitting six packets

per minute. We set the DIOC time interval as (12 ms * the number of CM). The simulation parameter details are given in Table-2.

Table 2. Simulation setting and parameters

Parameter	Value
Operating system	Contiki 2.7
Routing protocol	RPL
Node type	Sky mote
Radio environment	Unit Disk Graph Medium (UDGM)
Simulation hour	1 h
MAC layer	ContikiMAC/6LowPAN
Network over all radius	150 m
Number of nodes	150 RPL Router + 1 DODAG root
Transmission range	100 m
Data packet timer	60 s
RPL parameter	MinHopRankIncrease=256
e_s (data sensing energy)	5 nJ per 1 bit
e_r (rx receiving energy rate)	50 nJ per 1 bit
e_a (data aggregation energy)	5 nJ per 1 bit per 1 signal
ε (data approximation ratio)	1.1
ε_1 (tx transmission energy rate)	50 nJ per 1bit
E_2 (tx amplifier energy rate)	100 (pJ.bit)/m^2
CH changes	1000 bits per 1 round
α (energy decay exponent)	2
Initial energy (E_{init})	2 J
ρ (data aggregation rate)	0.2

5.2. Performance evaluation results

We simulate and compare the performance of MCEA-RPL with RPL and IRPL in the above mentioned scenario.

5.2.1. Average packet loss ratio

The poor route selection and increased number of hops between source and destination lead to increased packet loss. We simulate with the packet rate of one and six packets per minute. It shows the packet loss increases as the network size increases.
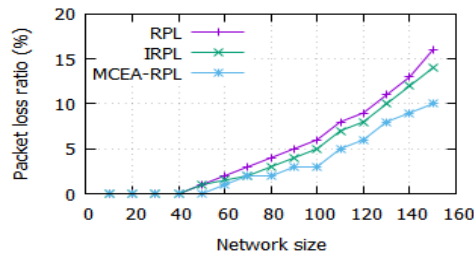

Fig. 5. Packet loss ratio vs. network size

Fig. 5 shows that packet loss rate on transfer of one packet per minute. It is observed that the packet loss ratio is lesser in MCEA-RPL compared to IRPL and RPL. In MCEA-RPL, as most of the nodes are located in the coverage area of

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neighbour layer and the application of fuzzy logic over the routing metrics ETX and RER, for route selection, results in lower packet loss rate. Fig. 6 shows the packet loss rate on the transfer of six packets per minute. It is noted that the packet loss increases, as the data transfer rate increases. It is observed that the packet loss rate is lesser in MCEA-RPL compared to IRPL and RPL.
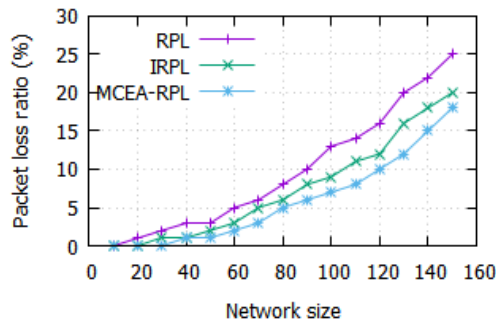

Fig. 6. Packet loss ratio vs. Network size

5.2.2. Number of parent changes

The number of parent change indicates the network stability. The stable networks have less number of topology changes during the data transmission. The simulation is done for one hour. Fig. 7 shows that the average parent change values of MCEA-RPL, IRPL and RPL. The parent change values of MCEA-RPL, IRPL and RPL are 0.15, 0.18 and 0.28, respectively. It is observed that MCEA-RPL forms the stable network, resulting in an extended network lifetime, compared to IRPL and RPL.
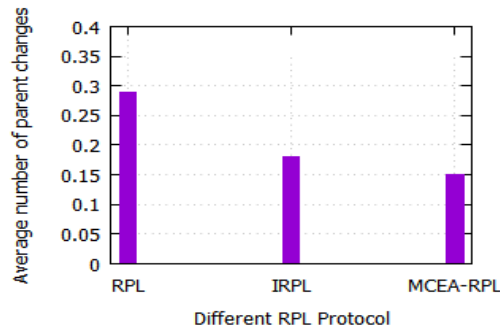

Fig. 7. Number of parent changes

5.2.3. Average end-to-end delay

Fig. 8 shows that average end-to-end delay (latency) of RPL, IRPL and MCEA-RPL. The average delay of MCEA-RPL, IRPL and RPL are 0.8 ms, 1.1 ms and 1.3 ms, respectively. It is noted that the average end-to-end delay is below 1.3 s for 6 hops. MCEA- RPL has lower delay compared to RPL and IRPL, due to reduced node failures and route breakages during data transfer. It is achieved by selecting the optimal parent for forwarding the data to the sink.
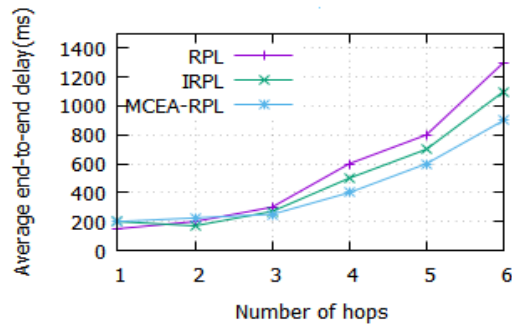
Fig. 8. Average end-to-end delay vs. number of hops in the network

5.2.4. Average packet loss ratio due to node failure

We simulate with the packet rate of one and six packets per minute. Fig. 9 shows that the packet loss rate due to node failure with the packet rate of one packet per minute. We calculate the packet loss ratio for the amount of failure nodes ranging from 0 to 60. The average packet loss ratio of MCEA-RPL, IRPL and RPL are 20%, 23% and 30%, respectively for the failed node size is 60. It shows that packet loss rate increases, as the number of failure node increases. MCEA-RPL can find the alternate original optimal parent quickly, which results in reduced packet loss compared to IRPL and RPL.
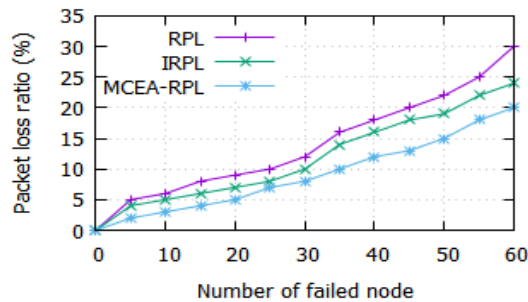

Fig. 9. Average packet loss ratio vs. number of failed nodes

Fig. 10 shows the packet loss rate due to node failure with the packet rate of six packets per minute. We observed that the packet loss ratio of MCEA-RPL, IRPL and RPL are 28%, 32% and 40%, respectively for the failed node size is 60.
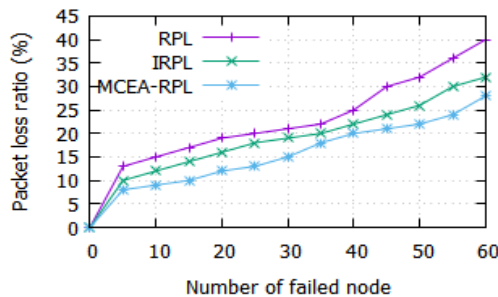

Fig. 10. Average packet loss ratio vs. number of failed nodes

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5.2.5. Average power consumption of network nodes

Fig. 11 shows the power consumption of nodes with the packet rate of one packet per minute. It is observed that the amount of power consumption increases, as the number of node increases in the network. It is noted that MCEA-RPL consumes less energy than IRPL and RPL, as its CH node transmits the aggregated data packets to the sink node through the optimal parent. The average power consumptions of MCEA-RPL, IRPL and RPL are 5.2 mW, 6.5 mW and 7 mW, respectively for the network size of 150 m.
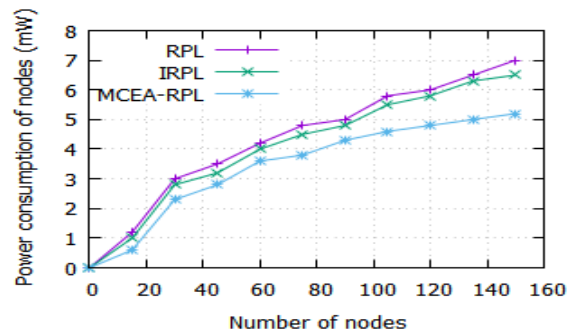

Fig. 11. Average power consumption vs. number of nodes

Fig. 12 shows the power consumption of nodes with the packet rate of six packets per minutes. The packet drop increases, as the amount of transfer rate increases in the network. The average power consumptions of MCEA-RPL, IRPL and RPL are 7 mW, 8.8 mW and 9 mW, respectively for the network size of 150 m.
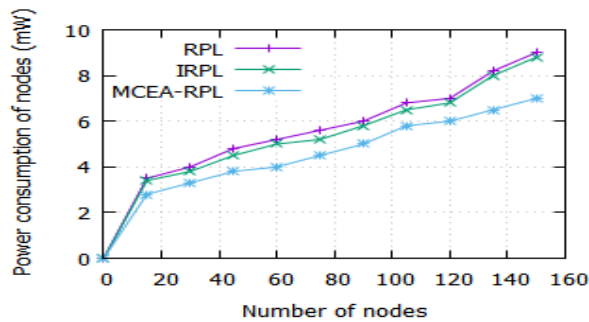

Fig. 12. Average power consumption vs. number of nodes

6. Conclusion

In this paper, we proposed a Multi-layer Cluster based Energy Aware Routing Protocol (MCEA-RPL) for LLN. It divides the network area into rings of equal width. It forms intra ring cluster to balance the energy consumption over the ring. The inter cluster routing selects the best optimal parent, by applying the fuzzy logic over the routing metrics ETX and RER. It reduces the path breakages due to early energy depletion on the nodes nearby the sink. The simulation result shows that MCEA-RPL

has extended the network lifetime and increased the packet delivery ratio considerably.

As part of future work, MCEA-RPL is planned to introduce mobility in the network scenario and also to deploy it in the real-time environment.

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