JCSE International Journal of Computer Sciences and Engineering Open Access
Review Paper Volume-6, Special Issue-2, March 2018 E-ISSN: 2347-2693

Bandwidth Allocation based Load Balancing for RPL (BA-LBRPL)

A. Sebastian[1], S. Sivagurunathan[2*]

[1]Dept. Of Computer Science and Applications, Gandhigram Rural Institute, Dindigul, India
[2*]Dept. Of Computer Science and Applications, Gandhigram Rural Institute, Dindigul, India

Corresponding Author: s.sivagurunathan@ruraluniv.ac.in , Tel.: +91-9486376381

Available online at: www.ijcseonline.org

***Abstract*— ** The RPL routing protocol published in RFC 6550 was designed for efficient and reliable data collection in low power and lossy networks. It constructs a Destination Oriented Direction Acyclic Graph (DODAG) for data forwarding. However, due to the load imbalance the parent nodes face heavier workload, bottle neck and hot spot problems. Such load imbalance will result in the parent nodes quickly exhausting their energy, and shorten the overall network lifetime. There are attempts to load balance the RPL network using LB-OF algorithm and Child Node Count (CNC) object. Load balance using LB-OF and CNC provides load balance of the DODAG but fails in terms of load balancing network resources, i.e., bandwidth. In this paper, we propose Bandwidth Allocation based load balancing algorithm in RPL named (BA-LBRPL). BA-LBRPL removes the deficiency faced in LB-OF and CNC and enhances resource load balancing in low power and lossy environments. Thus, BA-LBRPL is efficient theoretically in thwarting bottleneck, fast energy depletion of parents and improve life of the network

Keywords— *Internet of Things, RPL, Load Balancing, Bandwidth Allocation*

I. INTRODUCTION

The Internet of Things (IoT) are comprised of several sensing devices that communicate and enable different applications, such as smart building [1], habitat monitoring, smart city [2] and industrial automation. In general, IoT networks are resource constrained: memory, processing power and energy. Considering these limited capabilities, the routing protocols need to be well designed, since protocols impact the use of node's resources and energy consumption. In 2012, the IETF ROLL working group published the RFC 6550, which specifies a Routing Protocol for Low Power and Lossy Networks (RPL) [3]. RPL is standardized IPv6-compliant routing protocol for Low power and Lossy Networks (LLNs). It is a distance vector protocol that establishes Destination Oriented Directed Acyclic Graphs (DODAGs) based on links and/or node metrics. Different Objective Functions (OF) can be designed in order to achieve specific optimization criteria and satisfy the requirements of a particular application.

In RPL, route optimization and parent selection is crucial. Even though selecting the parent with best link quality is a local optimum choice, it may cause a load balancing problem. In scenarios where nodes distribution and traffic pattern are heterogeneous, the work load imbalance becomes critical. Nodes that are close to the root and that have many children with good-quality links will receive and forward a large number of packets which may quickly deplete their battery life.

To tackle the above issues, load balancing using Load Balanced Objective Function (LB-OF) algorithm, Child Node Count (CNC) object, Load balanced RPL LB-(RPL), ALABAMO, multi parent selection, etc are proposed. Although methods proposed in the literatures provide partial load balance, they fail to provide load balance of resources such as bandwidth. This paper attempts to provide RPL load balancing based on bandwidth allocation.

This paper is organized as follows. Section 2 provides related literature review. Section 3 states the background and problem statement. In Section 4, our proposed method bandwidth allocation based load balancing for RPL is described in Section 5 concludes the paper with future scope.

I. RELATED WORK

RPL load balancing is very important for LLN since its application scenarios have numerous nodes with high node density. Many authors have suggested solutions to load balance the RPL that would improve stability of the network, extended network life time and improved network performance. In [4], the authors suggested queue utilization (QU-RPL). QU-RPL is designed for each node to select its parent node considering the queue utilization of its neighbour nodes as well as their hop distances to an LLN border router (LBR). QU-RPL is effective in lowering queue losses and increasing the packet delivery ratio compared to the standard RPL.

In [5] the authors propose, Minimum Degree RPL (MD-RPL) which builds a minimum degree spanning tree to enable load balancing in RPL. MD-RPL modifies the original tree formed by RPL to decrease its degree.

In [6], the authors proposed a load balanced routing protocol based on the RPL protocol (LB-RPL) to achieve balanced workload distribution in the network. LB-RPL detects workload imbalance in a distributed and non-intrusive fashion. It also optimizes the data forwarding path by jointly considering both workload distribution and link-layer communication qualities.

In [7], the authors designed an energy-balancing routing protocol that maximizes the lifetime of the most constraint nodes. They proposed the Expected Lifetime metric, denoting the residual time of a node (time until the node will run out of energy). They also designed mechanism to detect energy-bottleneck nodes and to spread the traffic load uniformly among them.

In [8] the authors propose three multipath schemes based on RPL: Energy Load Balancing (ELB), Fast Local Repair (FLR) and their combination (ELB-FLR).

In [9] the authors address the imbalance of traffic load among gateways. The load balancing between gateways is suggested to reduce the traffic congestion thereby enlarging the network capacity. They proposed dynamic and distributed load balancing scheme to achieve a global load fairness motivated by water flow behaviour named Multi-gateway Load Balancing Scheme for Equilibrium (MLEq).

In [10] the authors suggest optimization of parent node selection using Child Node Count. CNC of preferred parent is considered for Rank calculation and parent selection.

All of the methods suggested above provide partial load balance to RPL. However, the bandwidth allocation can create overload the parent which will face route congestion and bottle neck problems. So our proposed method intends to load balance RPL based on bandwidth allocation.

II. Background and Problem Statement

Routing protocol for Low power and lossy network (RPL) is designed for resource constrained networks. RPL based network is comprised of thousand of nodes with limited resources and high packet loss. It is an adaptable routing protocol that dissociates packet processing and forwarding from the routing optimization. An OF describes how nodes should convert one or more metrics and/or constraints into a rank. A rank represents the node's distance to the Directed Acyclic Graph (DAG) root. DAG is used to construct or reconstruct RPL topology for effective communication. The constrained resource of nodes and RPL network can have poor performance due to load imbalance. When new nodes join the preferred parent, many nodes rush to join the preferred parent with low rank. As a result some parents are overloaded and others left with more resources. Hence load balancing problem in RPL is addressed in this paper. We present below short description of the background and problem statement of load balancing in RPL.

A. RPL Overview and Parent Selection

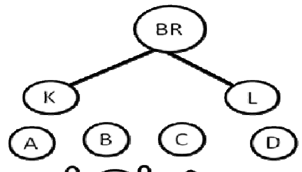
In general, an RPL-based network consists of three types of nodes: root node, connecting to another network as a gateway or border router (BR); router, forwarding topology information and data packets to their neighbors; leaf node, only joining a DODAG as an end member. The construction of a DODAG starts at the root node, through the routers, down to the leaf nodes. The root node broadcasts to its sub nodes the DODAG information Object (DIO) messages that contain RANK information. Once receiving DIO messages, a child node can decide whether to join this DODAG or not based on the calculated rank according to the equations (1) and (2) [RFC 6719]. [11]

$$\text{Rank}(N) = \text{Rank}(PN) + \text{RankIncrease} \quad (1)$$
$$\text{RankIncrease} = \text{Step} * \text{MinHopRankIncrease} \quad (2)$$

Where Step represents a scalar value and MinHopRankIncrease represents the minimum RPL parameter. If the node decides to join, then it adds the DIO sender to the candidate parent list. Next, the preferred parent, i.e. the next hop to the root, will be chosen based on the rank from this list to receive all traffic from the child node. Then, it computes its own rank with a monotonical increase according to the selected OF. After that, the node propagates its own DIO with all updated information to all its neighbors including the preferred parent. This process is repeated till a path from leaf node to the root is constructed in the form of Destination Oriented Directed cyclic Graph (DODAG). Hence RPL is a proactive distance vector routing protocol designed for LLNs [RFC 6550].

B. CNC based Parent selection and LB-OF

In the RPL-based mesh network, due to the lack of balance algorithm, a large batch of nodes select the same parent node and leave others empty or act as a just forwarding node. A higher rate of transmission will result in a sharp increment in RANK, which triggers all child nodes to re-select and switch their parent node. This way frequent switching of parent nodes greatly decrements the network efficiency, unstable topology and deplete constrained resources. Therefore there was an urgent need to develop a mechanism to select optimised parent node in a load balanced way using Child Node Count (CNC) object.



CNC based optimised parent selection is shown in figure 1. As depicted the RANK of parents K and L are supposed to be equal but parent K by chance dominates in the n

Figure 1: Load Balance RPL (LB-

n they share the common coverage. It is a waste of resource that parent L is left empty while many new nodes become child of node 1. When the network achieves a relative balance a new node will create imbalance. If the new node is situated in the vicinity of root node will create serious imbalance of network. The authors suggested CNC based parent selection [10]. CNC field gives the number of child node of preferred parent. Using a combined metrics of ETX and CNC, parent selection is carried out. Using CNC object as constraint load balancing is achieved.

In Load Balanced Objective Function (LB-OF), data traffic is balanced by taking in to account the number of children for each preferred parent. When the leaf node receives DIO from parent node, it updates its own rank and broadcasts updated DIO to neighbouring nodes including the preferred parent. In normal RPL, the preferred parent discards the DIO messages received from leaf node. But in LB-OF, the preferred parent records the DIO information details and when the parent address of leaf node matches the preferred parent address, it increments the child count. In DODAG construction process, new leaf nodes will avoid parents with more node count and thus avoid bottle nech and load imbalance in future [12].

C. Child Count based Load Balancing in RPL(Ch-LBRPL)

Load balancing using CNC and LB-OF achieves some load balancing in the RPL network but in the long run it still creates imbalance. The authors introduced novel method to identify the common nodes between the preferred parents 1 and 2. This scenario is explained in figure 2. In the figure, a DODAG has 2 Sub-DAGs with parents 1 and 2. Parent 1 has 2 existing child nodes and parent 2 has 1 existing child node. 5 new nodes fall in the communication range between parent 1 and parent 2. In traditional case, the new nodes will accept DIO from the preferred parent and join the parent with low RANK property. In such case, the children selecting parent is not balanced. The low RANK parent will have more child nodes than the other parent. So they devised a method by which the new child nodes are distributed to parents in such a way that both parents have same number of nodes. The parent 1 and parent 2 report the nodes in their radio environment to the root node (BR) and the BR makes the load balancing decision about the number of child node each parent should acknowledge. This way any number of new nodes will be shared between preferred parents equally. In this case,

Load Imbalance = Total number of nodes – existing nodes in parent (1)-existing nodes in parent (2) (3)

Total node in DODAG=Existing nodes of parent (1) and parent (2) + Load Imbalance Nodes (4)

Equation 3 and 4 are used to balance the nodes among the parent 1 and parent 2.

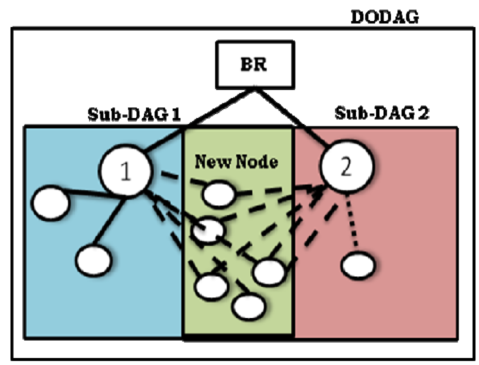


Figure 2: Load Balance using child count

III. BANDWIDTH ALLOCATION BASED LOAD BALANCING RPL (BA-LBRPL)

The optimization and performance is at risk due problems such as bottle neck, hot spot and thunder herd. The utmost result of all theme problems is RPL Load imbalance. Load imbalance in RPL can reduce the battery life time of critical nodes in network infrastructure and also deplete the network life time. The proposed methods such as CNC, LB-OF and Ch-LBRPL, even if the leaf nodes are distributed equally to preferred parents, the RPL will face load balance problem due to constraints in network resource like bandwidth. This problem is depicted in figure 3.

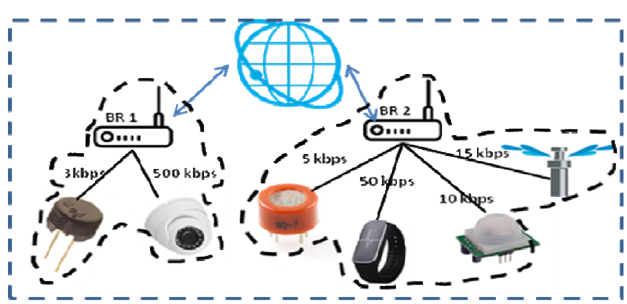


Figure 3: Overview of Bandwidth Load Imbalance

A. Problem Definition

Figure 3 shows bandwidth allocation based load imbalance in RPL. Let the RPL based mesh network consist of 2 Border Routers BR1 & BR1 connected to the Internet. This network topology consists of 2 sub-DAGs with n number of devices under each sub-DAG. Both sub-DAGs form one Destination Oriented Directed Acyclic Graph (DODAG) with 2^m devices, i.e., (2^m=2^n+2^n). The Border (BR) is the root of Sub-DAGs. DODAG will have proper load balancing if bandwidth (BW) is equally shared between the BR1 and BR2 or between sub-DAGs. But in actuality this does not take place. As shown in figure 3, BR1 has 2 devices and BR2 has 4 devices. However, the bandwidth use of BR1 is 503 kbps (500+3).

On the contrary, BR2 uses 80kbps (5+50+10+15). At any time interval, BR1 will have more utilization of bandwidth and BR2 utilization of bandwidth will be low. If we load balance the BR1 and BR2 based on child count then the number of devices at BR1 will increase and BR2 will decrease. In such a case, the bandwidth utilization of BR1 will increase further and utilization of BR2 bandwidth will be further reduced. This will eventually lead BR1 to bottle neck problem. Hence, network resources like bandwidth also need to be balanced between Border Routers (BR) for stable RPL network and improved life expectancy of the network.

Load balanced best parent selection algorithm (Bandwidth)
Require: Neighbor nodes, Child nodes, Available bandwidth, and Routing metrics
Output: Load balanced DODAG
Min_Load←(load capacity - Current load) ÷ Required Load $_i$
mp_i ← Calculate path metric (p_i)
mp_j ← Calculate path metric (p_j)
PP_i ← Preferred parent of node (i)
PP_i_capacity ← Total Bandwidth of PP_i
$_{CN}$ ← Set of child Nodes
If DODAG root = null;
Construct new DODAG()
if (DODAG == null)
RANK = newRANK
Step ← Routing cost + Min_rank Increase
Rank← Parent rank + step
Parent[i] ← min_rank_parent
if(Current preferred parent rank > New available parent) then
if(mp_i< mp_i+ Min_Load) AND (mp_i> mp_j– Min_Load) then
If (SentPktp$_i$> SentPktp$_j$) AN D (WorkloadRatio < M axWorkloadRatio) then
For i=1to n where n is the number of neighbour nodes
Expected Count-BR = Child of BR(i)+Child of BR(j)+LIM-BR
If (Expected Count_BR is odd) then
Expected Count of BR(i)= $\frac{Expected\ Count_{BR}+1}{2}$
AND
Expected Count of BR(j)= $\frac{Expected\ Count_{BR}-1}{2}$
Else
If Expected Count of BR is even then
Expected Count of BR(i) = $\frac{Expected\ Count_{BR}}{2}$
AND
Expected Count of BR(j) = $\frac{Expected\ Count_{BR}}{2}$
return p_j
else
If (SentPktp$_j$> SentPktp$_i$) AN D (Workloadratio< MaxWorkloadRatio) then
return p_i
return current preferred parent
If mp_i < mp_j then
If (Workload Ratio < MaxWorkloadRatio) AND (ET X Ratio > MaxETX Ratio) then
return p_j
return p_i
else
If (Workload Ratio < MaxWorkload Ratio) AN D (ETXratio> MaxETXRatio)
then
return p_i
return p_j
end

This problem is shown in Figure 4. The RPL network has two parents p1 and p2. Parent 1 has 5 devices and parent 2 has 3 devices. According to load balancing using child count, child count p1 should use more bandwidth and p2 less bandwidth. But the bandwidth indicator suggests that p2 is facing bottle neck than p1. Therefore, bandwidth allocation based load balancing need to be tackled for efficient performance of RPL in terms of load balancing.

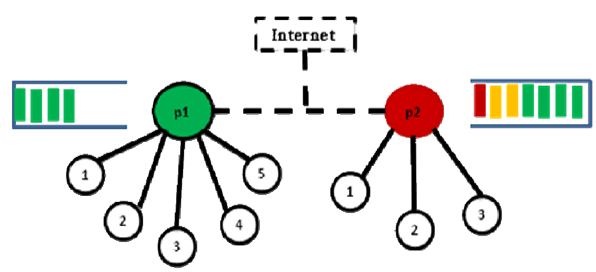


Figure 4: Bottle neck due to bandwidth imbalance

B. Bandwidth Allocation based Load Balancing Algorithm

To overcome the load balancing problem using child count method in RPL, we propose bandwidth allocation based load balancing algorithm. Bandwidth allocation based algorithm works on the following steps.

Step 1: The Root node sends DIO message, initiating DODAG construction using node metric.

Step 2: The DODAG optimization is carried out using routing Metric, i.e., Bandwidth

Step 3: The Bandwidth capacity of the parent node and the total bandwidth utilized by child nodes are calculated

Step 4: The DODAG Load is shared between the parents with their common children. The available bandwidth and available common child information are sent to the Load Balancing Parent (LBP)

Step 5: LBP receives the available Load and Expected Load

Step 6: LBP equally shared between the preferred parents.

STEP 7: IF THE LOAD SHARING PARENT IS ODD THEN THE LOAD IS SHARED BY SUM OF REQUIRED LOAD BY ADDING THE ROUND OFF VALUE WITH THE FRACTION OF TOTAL AVAILABLE RESOURCE. IF THE LOAD SHARING PARENT IS EVEN THEN THE LOAD IS SHARED BY THE FRACTION OF TOTAL AVAILABLE

II. V CONCLUSION AND FUTURE WORK

In wireless networking scenario such as Low power and lossy networks (LLN) and especially RPL based internet of things networks load imbalance creates bottleneck, fast depletion of energy in parent devices, decrease network life expectancy and inefficient network performance. Load balancing initiatives such as LB-OF, child count, etc offer partial load balance and improvement is desired. In such a scenario, we propose bandwidth allocation based load balancing for RPL networks. The proposed load balancing algorithm is theoretically efficient to solve narrated load balancing problem. And in future, full testing model and simulation studies need to be done to validate our proposed method.

REFERENCE

[1] Z. Sheng, S. Yang, Y. Yu, A. Vasilakos, J. McCann, and K. Leung, "*A survey on the ietf protocol suite for the internet of things: Standards, challenges, and opportunities*", IEEE Wirel. Commun., vol. 20, no. 6, pp. 91–98, 2013.

[2] S. Sivagurunathan et al (2016), "*Connectivity Framework for smart Devices*"(ed) by Zaigham Mahmood, Computer and Communications Network, Springer, 307-331, 2016

[3] T. Winter, P. Thubert, A. R. Corporation, and R. Kelsey, "RPL: Routing Protocol for Low Power and Lossy Networks," pp. 1–157.

[4] H.-S. Kim, H. Kim, J. Paek, and S. Bahk, "Load Balancing under Heavy Traffic in RPL Routing Protocol for Low Power and Lossy Networks," *IEEE Trans. Mob. Comput.*, vol. 1233, no. c, pp. 1–1, 2016.

[5] Marwa Mamdough et al, "*RPL Load balancing via minimum degree spanning tree*", IEEE transaction, 2016

[6] X. Liu, J. Guo, G. Bhatti, P. Orlik, and K. Parsons, "Load Balanced Routing for Low Power and Lossy Networks."

[7] O. Iova, F. Theoleyre, and T. Noel, "Exploiting multiple parents in RPL to improve both the network lifetime and its stability," *IEEE Int. Conf. Commun.*, vol. 2015–Septe, pp. 610–616, 2015.

[8] Quan Le, Thu Ngo-Quynh, Thomas Magedanz et al, "*RPL based multipath Routing protocols doe Internet of Things*", IEEE Xplore, 2014

[9] Minkeun Ha, Kiwoong Kwon, Daeyoung Kim, Peng-Yong Kong, *"Dynamic and Distributed Load Balancing Scheme in Multi-gateway based 6LoWPAN"*, IEEE International Conference on Green Computing, 2015

[10] B. G. Mamoun Qasem, Ahmed Al-Dubai, Imed Romdhani, "*Load Balancing Objective Function in RPL*," . Internet Draft, February, pp. 1–10, 2017.

[11] O Gnawali, P Levis, "*The Minimum Rank with Hysteresis Objective Functione*", RFC, pp. 1–13, 2012.

[12] J Hou, R Jadhav, Z Luo, "*Optimization of Parent node delection in RPL based Networks*", Internet Draft, pp.1-11, 2017

Authors Profile

A. Sebastian is a research scholar in the department of Computer science and applications at Gandhigram Rural Institute. His research areas include Internet of Things, smart cities and Network security. He obtained his Graduation degree from St. Joseph's, college, Tiruchirapalli and Post Graduation from Loyola College, Chennai.

Dr. S. Sivagurunathan is Assistant Professor in the Department of Computer Science and Applications at Gandhigram Rural Insttute, Gndhigram. His specializations are Mobile Ad Hoc Networks, Internet of Things and Cloud Computing. He has 19 years of teaching experience and 8 years of research experience. He has guided one phd and presently guiding 3 research students. He has many research publications and book chapters in leading international journals under his credit.