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A Survey on Load Balancing Schemes in RPL based Internet of Things

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***Abstract*—**Internet of Things technology is a collection of sensors and actuators which gathers data from physical environment that can be stored and processed to generate actuating information. Physical environment data such as temperature, pressure, humidity, pollution and any valuable parameters related to human body, machine, etc. have great value for automation, fault detection and timely remedy. Thus, IoT networks have given rise to Smart Cities, Smart Health, Smart Transport Logistics, Smart Production and Supply chain management, Smart Home and many more. For IoT deployments, ROLL-WG has standardized Routing Protocol for Low Power and Lossy Networks (RPL) for urban environment (RFC 5548), home automation (RFC 5826), industrial control (RFC 5673) and building automation (RFC 5867). RPL is a destination vector protocol for low power devices which is designed to address the needs of constrained IoT environment. In RPL, nodes organize themselves by forming a Destination Oriented Directed Acyclic Graph (DODAG) rooted towards the sink. RPL uses Objective Functions (ETX & Hop Count) to optimize path selection. Many newObjective Functions for IoT applications are suggested by researchers for path optimization. In most cases, RPL is efficient in providing fast network convergence. However, path optimization and network performance are affected by Load Balancing problem. In this article, we survey existing load balancing schemes in RPL based Internet of Things. We also list out load balancing metrics and challenges in RPL with reference to load imbalance.

***Keywords*—** Internet of Things, RPL, Load Balancing schemes, Load Balancing Metrics

I. INTRODUCTION

Low power and lossy networks (LLNs) are providing innovative applications such as smart building, habitat monitoring, smart city [1] and industrial automation. Routing in LLNs environment is challenging since LLNs are composed of large number of nodes which are resource constrained: memory, processing power and energy. Lossy wireless communication environment make network topology unstable, load imbalanced DAG construction and eventually result in imbalanced routing and poor performance.

In 2014, the IETF ROLL working group standardized routing requirements for four application scenario: home automation (RFC 5826), Industrial control (RFC 5673), urban environment (RFC 5548) and building automation (RFC 5867) [2]. RPL is a distance vector routing protocol, in which nodes construct a destination oriented acyclic graph (DODAG) by exchanging distance vectors and root with a controller. To achieve load balanced routing and data collection, the RPL allows a node to have multiple parents in the DODAG structure with one preferred parent for data forwarding. Performance evaluation of RPL by researchers suggests fast network setup and good scalability. However, RPL may suffer from load imbalance as shown by [3] and [4] and frequent parent change which have adverse impact on the performance of network. RPL uses objective function (OF) for guiding nodes to select parents and construct DODAG topology. Several routing metrics such as hop count and ETX are specified [5]. However, load balancing metrics are missing.

Load Balancing in RPL is a challenging task. Wireless communication resources are valuable in LLNs in which nodes are constrained with short range capabilities. High control traffic overhead associated with route discovery and maintenance can drain resources quickly. Therefore, load balanced parent selection and routing in RPL based IoT is the need of the hour.

The rest of this paper is organized as follows. Section II presents over view of Routing Protocol for Low Power and Lossy Networks (RPL). Section III describes the load balancing problems in RPL based IoT. Section IV gives detailed survey of existing load balancing schemes in RPL. Section V suggests Load Balancing performance metrics.

In section VI, we conclude the survey paper with future works.

II. ROUTING PROTOCOL FOR LOW POWER AND LOSSY NETWORKS

IPv6 Routing Protocol for Low Power and Lossy networks (RPL) is a route over distance vector routing protocol for networks in constrained conditions such as limited power and bandwidth. It is standardized by IETF to meet challenges in low power and lossy network environment (LLN). RPL uses multi-hop routing method to deliver data from leaf node to the sink. In this section, we provide a brief overview of RPL protocol with emphasis on load balancing problem. RPL topology construction is explained in figure 1.

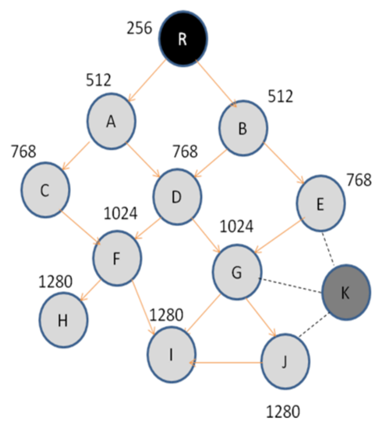

Figure 1: RPL topology construction

A. *RPL Overview*

In general, an RPL based network consists of three types of nodes: root node, connecting to another network as a gateway or border router (R); router, forwarding topology information and data packets to their neighbours (A,B,C,….G); leaf node (k), 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 (256, 512,…, 1280). 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][6].

Rank(N) = Rank(PN) + RankIncrease (1)
RankIncrease = Step * MinHopRankIncrease (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. *Routing Metrics and Objective Functions in RPL*

Nodes in RPL are arranged forming DODAG construction. The node rank in a DODAG suggests the position of the node from the root and in the RPL network. Node rank is calculated based on some routing metric such as hop count, expected transmission count, latency, etc. Path Selection from sender node to the sink node is based on these routing metrics. Routing metrics in RPL can have one or additive in number. However, additive values need to be of the same type like high or low. For example, rank will be calculated based on low additives like low on ETX, hop count and latency. Hence RPL uses Objective functions (OF) to and path selection. In a way Objective function in RPL is a path optimizations technique. Since LLN is basically resource constrained network, routing optimization or OF is important parameter for network performance. Newer OFs can be designed to meet the various application needs of LLN environment. Thus adaptive of flexible OF in RPL makes routing in RPL advantageous than fixed routing parameters used in traditional IP based networks.

C. *Load Balanicng Problem in RPL*

RPL is designed with several robust features such as quick configuration, low delay, loop free topology and self-healing [2]. Other network parameters such as packet delivery ratio, control traffic overhead, power consumption differ depending on density of the network and other application parameters. In all cases, load imbalance is considered as a weakness in this protocol and more specifically RPL is dealing with non-uniform distribution of in large-scale LLNs, which may lead to unequal data traffic distribution. In DODAG construction new nodes select preferred parent based on the rank property of the parent. It is observed that large batch of leaf nodes select the same parent node and avoid other parent nodes. This phenomenon in RPL is called thundering herd. In RPL based multi hop network, parent nodes also act as forwarding nodes. So, the parent nodes are faced with fast depletion of resources than non parent nodes. This problem is severe if the overloaded node is a first hop node to the root. These problems are identified as bottleneck [3] and hotspot [4]. All of these problems create load imbalance at the node, DAG and DODAG levels. Load imbalance in RPL results in poor network performance, early node death, partition of the network and finally unreliable. Therefore, load balancing problems in RPL need urgent solutions to improve stability and efficiency.

III. LOAD BALANCING PROBLEMS IN RPL

The load balancing problems in RPL is shown in figure 2. Leaf nodes (C, D and E) would select preferred parentA1 and B according to the parent rank. In this case the preferred parents A and B have the same rank. But node A has more children than node B. Many nodes are waiting to join the DODAG. The unbalanced parent selection approach in RPL will result in parents A and B have unequal number of child nodes resulting in Load Imbalance. In such an unbalanced scenario, if one parent fails due to load balancing problems like bottle neck, thundering herd, energy hole, it will result in many child nodes attached to that parent disconnected from network until they go through the global repair mechanism. This problem occurs in RPL due to the unequal distribution of child nodes to preferred parents.

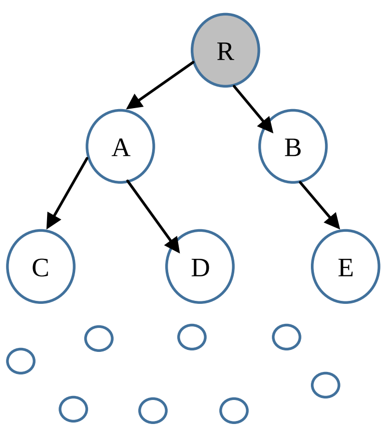

Figure 2: Load Balancing problem

A. Hot Spot Problem

When the parent node or forwarding node is faced with network congestion due to load imbalance characteristics. The parent or forwarding node utilizes its own and system resources to manage the network traffic. As a result, fast depletion of node and system resources occur. This problem is called Hot Spot problem.

B. Bottleneck Problem

Bottle neck problem happen to one nodes that are one hop distance from the root or sink. These nodes are busy all the time either sending their own data to the sink or forwarding data from other nodes in the network. Since all nodes in the network go through these nodes, their resources are in danger. More network load or congested can deplete their resources much faster than their capacity. At such times, early node death can happen. In bottle neck, the nodes and links attached to these nodes disconnect from the DODAG and at the next interval re join the network through existing parent node.

C. Thundering Herd Problem

As explained in figure 1, When a node (K) joins the RPL-based network, the transmission path may be better than other nodes because the Default_Rank_Increase is 3*256, calculated by equation (1) with the following default values specified in [RFC 6552]:
DEFAULT_MIN_HOP_RANK_INCREASE =256
DEFAULT_STEP_OF_RANK: 3

Suppose the RANK of another parent in figure 1is much lower than 3*256 and meets the requirement of parent switching; it may trigger a switch of numerous nodes from their original parent node to a new parent. Once a new node joins a network with a small RANK default value, it may suddenly attract numerous sub-nodes, impacting on the stability of the network This phenomenon is called “Thundering Herd”.

D. Increased Load on Nodes and Network

Load imbalance problems in RPL network results in many new nodes choosing the same parents for forwarding data or to send communication messages. Thus the forwarding nodes or parent nodes will have more network load and this load increases as the node is closer to the root. Hence the increased load of the parent nodes have the risk of energy hole and early death which can affect the network in a hard way.

E. Instability of the Network

The selection of the parent node in the RPL-based network directly influences the networking balance, and particularly, a poor balance causes the frequent switches of parent nodes. During the switching process, the delayed communication directly affects the stability of the entire network, so networking balance is an important indicator of the stability of mesh network.

F. Poor Packet Delivery Ratio

Packet Delivery is an important issue in RPL based LLNs. The network suffers from resource constraints and lossy nature of links will hinder the proper delivery of data packets. If the parent nodes or the forwarding nodes fail to deliver data or retransmit data packets frequently due to load balancing problems

IV. Load Balancing Schemes in RPL

RPL based Internet of Things is gaining attention from researchers and industry personnel. As the IoT deployments in smart city, smart agriculture, automotive, smart home, etc. get popularity, newer IoT designs and solutions to RPL problems are explored. In most cases, RPL based solutions focus on themes like Routing Optimization, Energy Efficiency, Resource management and context aware network. Load balancing schemes in RPL is an important research area that need attention. In this section, we illustrate a detailed survey on available load balancing schemes in RPL. These proposals address load balancing challenges like bottle neck, hot spot, thundering herd, increased network load, poor network performance and instability. The survey is shown in table 1. In [7], 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 [8] 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 [9], 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 [10], 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 [11] the authors propose three multipath schemes based on RPL: Energy Load Balancing (ELB), Fast Local Repair (FLR) and their combination (ELB-FLR).

In [12] 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 [9], the authors design energy balancing routing protocol that maximizes the life time of the most constrained nodes.

They proposed expected life time metric that suggests residual time of a node and hence detect energy-bottleneck nodes and to spread the traffic load uniformly among all nodes.

In [13], the authors suggested neighbourhood metric that would suggest quality of neighbouring nodes along with current forwarding route. Current forwarding is compared with neighbouring nodes for ETX. Hence improved load balancing is obtained.

In [14], the authors suggested Heuristic Load distribution algorithm (HeLD) which achieves a balanced traffic load and improved life time when throughput is high. This is based on braided multipath RPL extension technique.

In [15], the authors proposed proper selection of cluster head with reduced communication distance that improves network life time.

In [16], the authors suggested opportunistic routing algorithm to select neighbouring nodes to improve energy consumption and network life time. They introduced a sleepy algorithm called PSS algorithm for sensor nodes integrating with opportunistic routing protocol.

In [17], the authors exploited expected life time metric by denoting the residual time of the nodes to detect energy bottleneck nodes and to spread the traffic load uniformly among all nodes. This improved network life time and routing reliability.

In [18], the authors found that unbalanced load distribution has more chances to occur in small intervals (Imin sized intervals). So they designed Opt-Trickle that gives similar chance to all competing nodes to transmit an update.

In [19], the authors designed extension of RPL namely Opportunistic Routing RPL (ORPL-LB) where nodes continuously adapt their wake-up interval in order to adjust their availability and attain a deployment specific target duty cycle. Thus it results in better balanced load across the nodes.

In [20], the authors suggested stability metric based routing protocol (sRPL) for reliable routing and data collection in LLN. They introduced a new routing metric called stability Index (SI) which exploits stability characteristics of nodes to select more stable routes.

In [21], the authors proposed routing metric called TXPFI that captures expected number of frame transmission needed for the successful delivery of data in the presence of malicious nodes and lossy links. It takes in to account the nodes that do not cooperate in packet forwarding operation

Table 1: Survey of Load Balancing Schemes in RPL based Internet of Things

No	Author and Year of Publication	H S	BN	TH	RL	PNL	P D R	Technique Used
1	Declan T. Delaney et el., 2013[13]				x	x		Neighbourhood Metrics
2	O. Iova et el., 2015[12]					x		Multi parent routing
3	R. Jadhav et el., 2017[4]			x				Child node count metric
4	H.-S. Kim et el., 2016 [10]						x	Queue utilization
5	X. Liu et el., [9]		x			x		Balanced work load distribution
6	M. Michel et el., 2015[19]				x			Adaptation of wake up interval to attain deployment specific target duty cycle
7	M. N. Moghadam et el., 2014[14]					x	x	Heuristic load distribution
8	Tarcisio Bruno Oliveira et el., 2016[22]				x	x		Load Balancing OF by using traffic profile of nodes and ETX of links.
9	S. Surendran et el., 2015[15]					x		Smart Cluster Head Selection
10	M.Qasem A et el., 2017[3]		x		x			Load Balancing Objective Function
11	S. K. Baji Baba et el., 2016[16]					x		Sleep Scheduling Algorithm
12	Shivkumar S et el., 2016[23]				x			Load Sensitive Data Gathering
13	Pratyay Kuila et el., 2012[24]				x	x	x	Energy Efficient Load Balancing Clustering
14	Badis Djamaa et el., 2015[18]					x		Opt-Trickle for balanced load distribution
15	Yang, X. et el, 2015[20]					x		Stability metric based routing
16	Panagiotis Karkazis et el., 2014[21]				x	x		Minimize the Transmission count by avoiding nodes and links that do not cooperate in packet forwarding operation
17	A. Sebastian et el., 2018[25]						x	Multi sink for improved network life time
18	A. Sebastian et el., 2018[26]				x		x	Bandwidth Allocation based Load Balancing
19	Onna Iova et el, 2015[12]					x		

HS=Hot Spot (Energy Depletion); BN=Bottleneck Problem; TH=Thundering Herd Problem; RL=Reduced Load ; PNL=Prolonged Network Life Time ; PDR=Packet Delivery Ratio

In [22], the authors proposed a new objective function based on MHROF. The new OF uses both the traffic profile of the nodes and the ETX of the links in order to solve imbalance problem. The proposal is called A LoAd BAlancing Model for RPL (ALABAMO). It improves the network life time.

In [23], the authors developed a handoff optimization and dynamic link quality estimation based forwarding route selection algorithms for single mobile sink based data gathering. It shows improved load sensitive network performance.

In [24], the authors proposed energy efficient load balancing clustering (EELBC) algorithm that addresses energy efficiency as well as load balancing. EELBC algorithm builds a min-heap cluster heads (CHs) on the number of sensor nodes allotted to CHs.

In [25], the authors proposed multi sink for improved network life time. Multi sink technique allows more node to participate in the network which reduces the number of hop thus resulting in improved life time. In [26], the authors suggested Bandwidth Allocation based RPL Load Balancing (BA-LBRPL). They considered network resource like bandwidth for parent selection.

V. LOAD BALANCING PERFORMANCE METRICS

RPL based Internet of Things have performance metrics such as convergence time, power consumption, control traffic overhead, packet delivery ratio, latency and metrics related to Quality od Service (QoS). However, RPL lacks standard performance metrics to evaluate load balancing problems in RPL. Performance metrics in RPL is largely application specific. The node and link metrics and/or constraints are utilized for parent and path selection depending on the application scenario. Hence, there is a need to discuss performance metrics to evaluate RPL based

IoT for Load Balancing scenario. In this section, we list the important load balancing metrics.

A. Network Efficiency

Network efficiency in RPL based IoT can be evaluated by Convergence Time, Control Traffic Overhead, Power Consumption and Packet Delivery Ratio. For any scenario, these standard metrics come handly to evaluate RPL based IoT network. Therefore, load balancing schemes in RPL also need to satisfy metrics for network efficiency.

B. Load Balancing Parameters

Performance metrics proper to load balancing are identified as prolonged network life time, reduced/distributed load across the network, node death, bottleneck, hotspot and thundering herd. Many of these parameters create load imbalance in RPL based IoT network and hence ways of evaluating them will be very important.

C. Network Stability

Network stability is yet another important parameter to evaluate load balancing in RPL. In load imbalance scenario, frequent parent switching is observed. Parent switching will create reorganizing of the RPL network frequently. This results in huge control traffic overhead and more energy consumption. This also affect the stability of the network.

VI. COLCLUSION AND FUTURE WORKS

The aim of this survey on Load Balancing schemes in RPL is to bring out the latest developments and research proposals to response to problems related to load balancing. The existing methods suggest load balancing objective function, child count metric, new trickle timer, multi parent selection, etc. However, all these attempts provide partial load balancing to RPL based IoT network. There are more issues that need to be addressed before RPL can have become load balanced IoT network. Designing load balancing metrics in a big challenge. Load balancing at DODAG and Multi DODAG level is also a big challenge. Efficient utilization of network resources like bandwidth, data reporting or event rate for load balancing schemes is another area of research. Load balancing optimization using machine learning or nature inspired algorithm are other challenges for the future work.

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