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Comprehensive Approach in Studying the Behaviour of Contiki RPL Protocol in Diverse Data Transmission Ranges

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Abstract—Internet of Things (IoT) is a collection of interconnected wireless objects. These objects are smart objects which are communication and auto computing devices. All these devices are uniquely identifiable and addressable and able to send data to other objects. With rapid growth of wireless and electronic objects, IoT brings the new dimension to the world to communicate. The Routing Protocol for Low Power and Lossy Networks (RPL) is the standard routing protocol of Network layer for Internet of Things (IoT). This paper presents the concepts of RPL routing protocol and its working mechanisms. Also, this paper provides the simulation results of RPL protocol using Cooja Simulator.

Keywords—DAO, DIO,DIS,OF and Rank

I. INTRODUCTION

The Internet of things (IoT) is invariably applicable in all fields such as agriculture, education, automobile industries etc. due to its characteristics and architecture. Internet of Things (IoT) [2][3][19] establishes the connection among any smart devices at any time at any place as shown in Fig.1. IoT offers various services to the world and changes it as smart world in terms of smart agriculture, smart home, smart traffic system etc. In IoT, many challenges and issues exist.

Routing is one of the major research areas in IoT due to various reasons such as Communication medium is wireless, smart devices are battery operated devices , devices are with different configurations, devices are sometimes mobile. A Routing protocol [4][5][6][21]should consider all these and establish as well as maintain the route among devices. RPL is a distance vector and standard routing protocol for Internet of Things (IoT). Because, IoT can set up the network using low power and less configured smart devices.

As per the above discussion, Routing process in IoT [20][21] is a research avenue for research community and designing a routing protocol for IoT is a challenging one. An efficient routing protocol should find and establish the shortest route to destination. Routing is the process to find the route and switch the packets over the route to destination. In addition, routing protocol should possess the characteristics such as Adaptability, Efficiency, Security, low Power consumption and distribute the load equally.

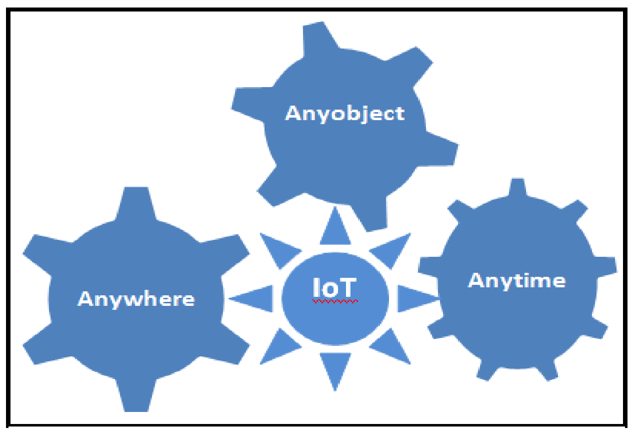

Fig. 1- Internet of Things (IoT)

This paper is organized as follows. Section 2 presents RPL protocol and RPL Protocol messages. Section 3 presents Performance Metrics and Section 4 presents simulation Environment and Section 5 shows the simulation results of the RPL protocol and Section 6 concludes this paper.

II. ROUTING PROTOCOL FOR LOW POWER AND LOSSY NETWORKS (RPL)

In IoT, many routing protocols are existing and this paper discussed the Routing protocol for Low power and lossy networks (RPL). RPL [2][7][8][12] is IPv6 routing protocol for low power and lossy networks designed by IETF [19]for low power and lossy network (ROLL). RPL is a distance vector routing protocol because IoT devices are low power computing devices. RPL establishes the directed acyclic graph (DAG) to all nodes in the network and sends packets. The nodes in the network can select the parent based on different metrics such as rank, residual energy etc. RPL ensures nodes in the graph to use the objective function[13] to select the parent.

A. RPL protocol Control Messages

RPL Control Message consists of an ICMPv6 header and message body. Message body has a message base and options as shown in Fig. 2 and its Fields in Table 1. RPL[14][16] message addresses are restricted to link addresses except DAO/DAO-ACK (Destination Advertisement Object-Acknowledgement) [1]messages. In general, source address is a link-local address as well as destination address is either multicast address or link-local unicast addresses. DAO messages[1]use global or local unicast address for both source and destination in Non-Storing mode.

0	1	2	3
Type	Code	Checksum	
Base			
Option(s)			

Fig. 2 RPL Control Message

Field	Meaning
Type (8 bits)	Type of Message
Version Number (8 bits)	Assign by DODAG Root
DODAGPreference (Prf.) (3 bits)	Helps and assigns the preferences

Table 1- RPL Control Message

B. DODAG Information Object (DIO) Message:

DIO Message [1] allows a node to select a best parent from available parents, send its information to other nodes to become a member and to discover a RPL instance. DIO has information about Rank, Objective Functions. Fig.3 and Table 2 shows DIO message and its Fields.

C. Destination Advertisement Object (DAO):

Node propagates DAO message in upward direction towards destination. In storing mode, DAO message [1] is in unicast manner to select parents. Otherwise, node sends

0				1	2	3
RPLInstance ID				Version Number	Rank	
G	O	MOP	Prf	DTSN	Flags	Resv.
DODAGID						
Option(s)						

Fig. 3 DIO Structure

Field	Meaning
RPLInstanceID (8 bits)	Assigned by DODAG Root
Version Number (8 bits)	Assigned by DODAG Root
DODAGPreference (Prf.) (3 bits)	Helps and assigns the preferences
Grounded (G)	1-DODAG is grounded otherwise grounded
Mode of Operation (MOP)	Nodes are as either Router or leaves
Rank (16 bits)	Rank of the node
Destination Advertisement Trigger Sequence Number (DTSN) (8bits)	Maintains Downward routes
Flags (8 bits)	Sender set zero and receiver ignore it
Resv. (8 bits)	Sender set zero and receiver ignore it
DODAGID(128 bit)	Assigns by DODAG root to identify a DODAG

Table 2- DIO Structure's Fields

in unicast manner towards DODAG root in non storing mode. DAO sends its rank to other nodes in the network. i.e. distances from sink. Fig.4 shows DAO message and its Fields are in Table 3.

0	1			2	3
RPLInstance ID	K	D	Flags	Resv.	DAOSequence
DODAGID*					
Option(s)					

Fig. 4 DAO Structure

Field	Meaning
RPLInstanceID (8 bits)	Topology Instance ID with DODAG from DIO
K (1 bit)	Recipient is expected to send a DAO-ACK back
D (1bit)	Local RPLInstanceID is used
Flags(6 bits)	Sender Initialises zero and receiver ignores it
Resv.(8 bits)	Sender Initialises zero and receiver ignores it
DAOSequence(8 bits)	Node increments a value at each unique DAO message and echoed in the DAO-ACK message
DODAGID(128 bits)	Associates with 'D' bit to rep. Local RPLInstanceID and absent when global RPLInstanceID

Table 3-DAO Structure's Fields

D. DODAG Information Solicitation Message (DIS):

Fig.5 and Table 4 shows DIS message [1] and its Fields. Node sends DIS message to solicit a DODAG Information Object in the graph.

0	1	2
Flags	Resv.	Option(s)

Fig. 5 DIS Structure

Field	Meaning
Flags(8bits)	Sender Initialises zero and receiver ignores it
Resv.(8 bits)	Sender Initialises zero and receiver ignores it
Options(16 bits)	0x00 -Pad1, 0x01 -PadN, 0x07 –Solicit Information

Table 4-DIS Structure's Fields

E. Destination Advertisement Object Message (DAO-ACK):

DAO Recipient sends the DAO-ACK message to respond to DAO message to DAO parent or DODAG root in unicast manner. Fig.6 shows DAO-ACK message and its fields in Table 5.

0		1	2	3
RPLInstance ID	D	Resv.	DAOSequence	Status
DODAGID*				
Option(s)				

Fig. 6 DAO-ACK Structure

Field	Meaning
RPLInstanceID (8bits)	Topology Instance ID with DODAG from DIO
D(1 bit)	1- local RPLInstanceID is used
Resv.(7 bits)	Reserved for flags
DAOSequence(8bits)	Node increments a value at each unique DAO msg., and echoed in the DAO-ACK message. It Correlates a DAO msg.
Status(8bits)	Indicates either accepted or rejected 0:Unqualified acceptance; 1-127: Not an outright rejection;127-255:Rejection
DODAGID(128 bits)	Associates with 'D' bit to rep. Local RPLInstcceID and absend when global RPLInstanceID

Table 5-DAO-ACK Structure's Fields

F. DODAG Construction Modes:

Upward Direction:

RPL protocol establishes the route upwards towards DODAG roots using Objective Function (OF) [1] . RPL nodes use DODAG Information Object (DIO) messages to construct and maintain the DODAG. u

Downward Direction:

RPL nodes establish route using Destination Advertisement Object (DAO) messages in two modes. There are two types of downward traffics such as Storing (full stateful) or Non-Storing (fully source routed). In storing mode, the packet propagates in downward direction towards destination by common ancestor node. In non-storing mode, the packet travels towards DODAG root.

G. Objective Function (OF):

An Objective Function helps nodes to make decision in order to select best parent based on metrics helps such as node residual energy, rank. RPL nodes use this function to optimize routes within a RPL Instance. Objective Function is identified by an Objective Code Point (OCP) within the DIO Configuration option. It is used to calculate the Rank of the nodes in DAG and also helps node to prioritize parent.

III. PERFORMANCE METRICS

A. Packet Delivery Ratio (PDR)

Packet delivery ratio is defined as the total number of data packets received at destination node to total number of data packets sent by source node during the simulation time. An efficient routing protocol should achieve maximum packet delivery ratio.

B. End-to-End delay

End-to-End delay is the time that a packet consumes time to travel from source to destination in the network. End-to-End delay includes all delays such as waiting at buffer queue, propagation time etc. An efficient routing protocol should consume minimum end-to-end delay to deliver a packet at destination.

C. Routing Load

Routing Load includes all control messages used to establish the route and deliver the packets at destination. In RPL protocol, control messages are DIO, DAO, DIS, DIO-ACK. An Efficient Routing protocol produces minimum routing load to achieve the high Packet delivery ratio.

IV. SIMULATION ENVIRONMENT

This paper analyzed the performance of the RPL Routing Protocol using CONTIKI Simulator i.e. COOJA [10][22][23]. Contiki is an Open Source Operating system exclusively designed for low power and memory constrained devices. Also, this operating system supports Internet of Things (IoT). Contiki is designed to run on low power microcontrollers.

Cooja is a simulator of Contiki's operating sytem and Cooja is used to create simulation environment for wireless networks in general, sensor networks in particular. This simulator helps to set up wireless environment with number of motes range from large to small. Also, it supports low power personal area networks with devices. This paper explains the behavior of RPL Protocol [17][18][20]in different data transmission ranges using Cooja simulator.

The simulation Environment was setup with a size of 100x100 square meter area with a single sender node. The simulation setup was conducted to observe the behavior of RPL protocol in different data transmission ranges. Simulation was conducted by varying number of motes as 20,40,60,80,100 and the simulation for 300 seconds with motes setup as Linear Positioning. The parameters for simulation are illustrated in Table 6.

The simulation was conducted by using RPL Protocol network using OF0 and MRHOF by setting the experiments under different motes.

Parameter	Value
Radio medium	Unit Disk Graph Medium
Routing Protocol	RPL
Tx Range	20,40,60,80,100m
Int. Range	100m
Topology	Linear Position
Simulation Time	300 seconds
Simulation Area	1000 sq. meter
Objective Function	OF0, MRHOF
Number of Motes	50

Table 6. Simulation Parameters

V. SIMULATION RESULTS

Fig. 7 and Fig. 8 represent simulation setup for 20 nodes and are distributed in Linear Positioning in Unicast and Broadcast data transportation types.

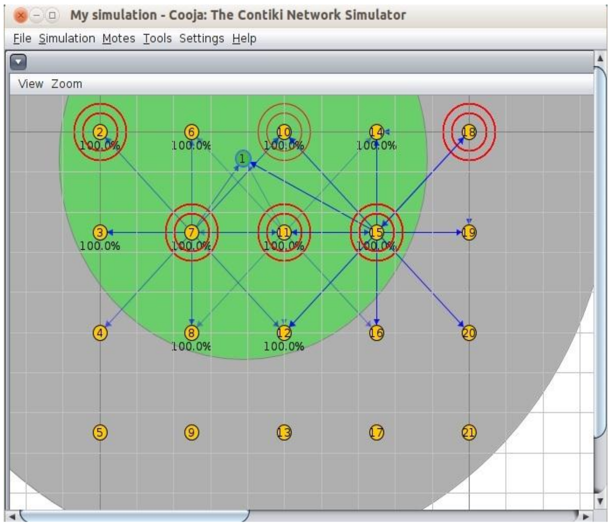

Fig.7 Linear Position of 20 Nodes-Unicast Data Transmission

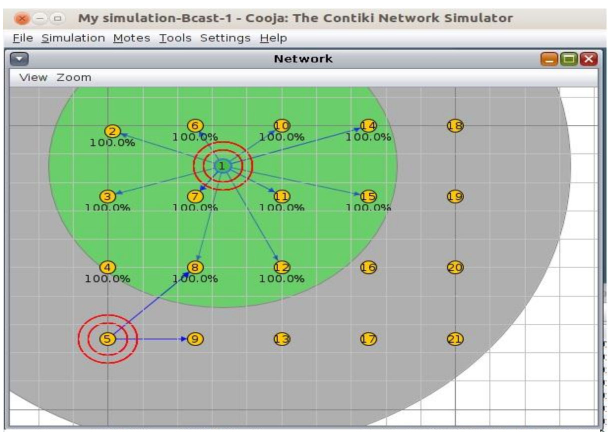

Fig.8 Linear Position of 20 Nodes-Broadcast Data Transmission

Fig.9 and Fig.10 show the Mote output and Radio messages with Energy Model.

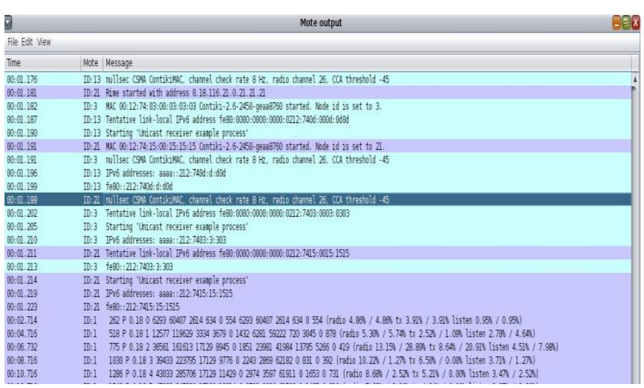

Fig.9 Mote Output Window

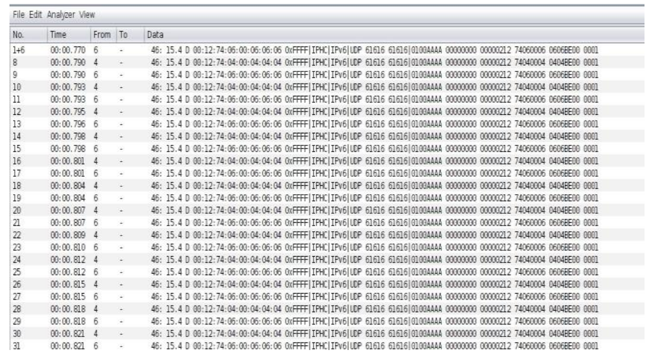

Fig.10 Radio Message

Fig. 11, Fig.12 and Fig. 13 represent simulation setup for 50 nodes are distributed in Linear Positioning under different data transmission ranges [31].

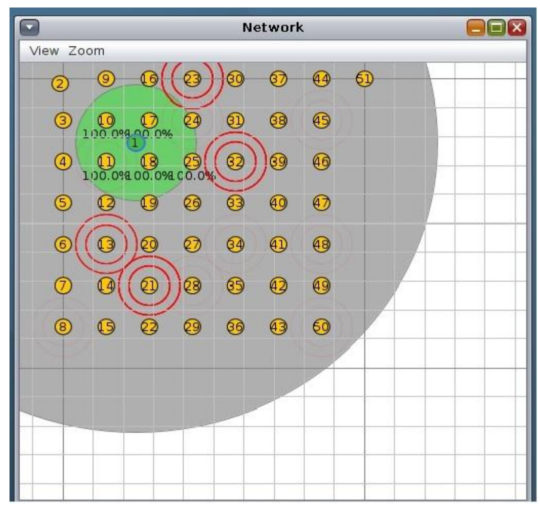

Fig.11 Broadcast Transmission_50 Nodes Tx=20

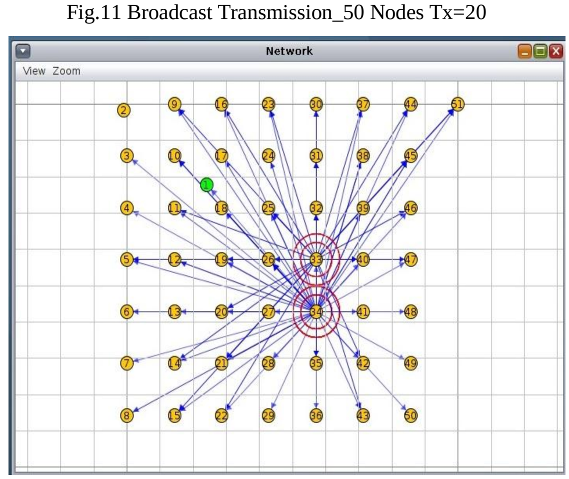

Fig.12 Broadcast Transmission_50 Nodes Tx=80

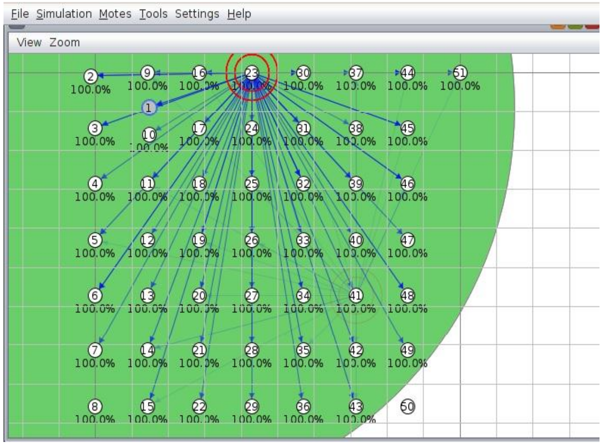

Fig.13 Broadcast Transmission_50 Nodes Tx=100

Fig.14 shows the DIO messages exchanged among the motes during the simulation time. More messages are exchanged at minimum transmission range.

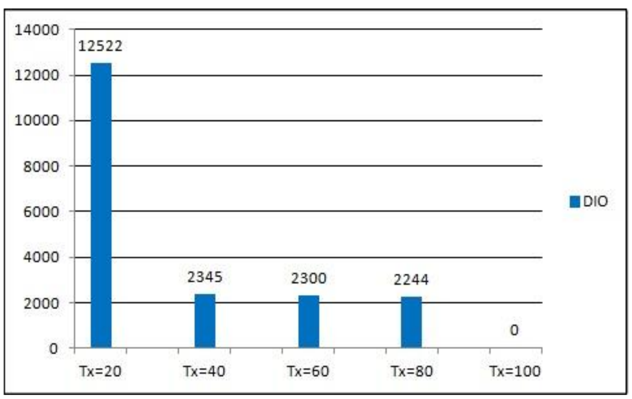

Fig.14 DIO Messages for diff. Transmission Ranges

Fig.15 and Fig.16 show the DIO and DIS messages exchanged among the motes during the simulation time. More messages are exchanged at minimum transmission range compared to maximum transmission ranges. As per Fig.16, DIS messages are only for Transmission range is 20m.

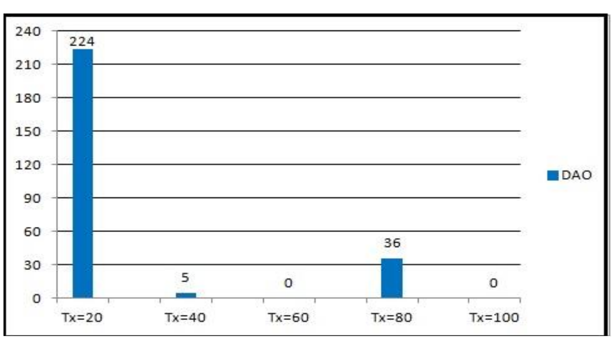

Fig.15 DAO Messages for diff. Transmission Ranges

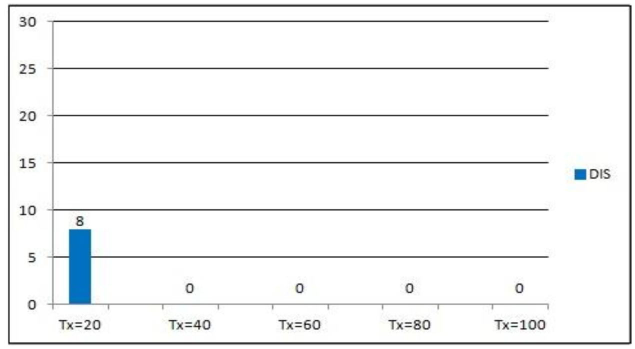

Fig.16 DIS Messages for diff. Transmission Ranges

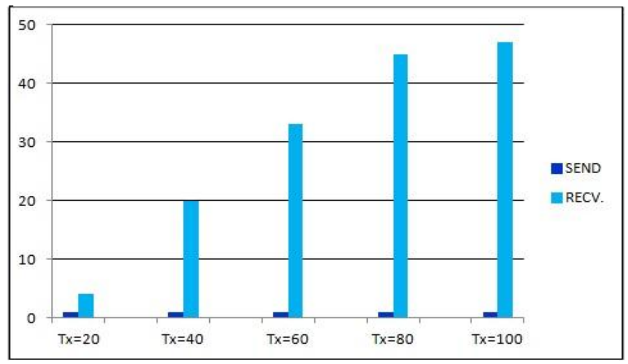

Fig.17 Number of Motes for diff. Transmission Ranges

Fig.17 shows number of motes which can exchange data during the simulation time. As per fig.17, the no. of motes are higher when transmission range is high. Fig.17 shows that number of motes is increased when transmission range is increased. Fig.18 shows the results of RPL protocol for average End-to-End delay metric by varying transmission range. It is observed that RPL protocol took minimum delay to transfer a packet from the source to the destination when transmission range is higher and vice versa.

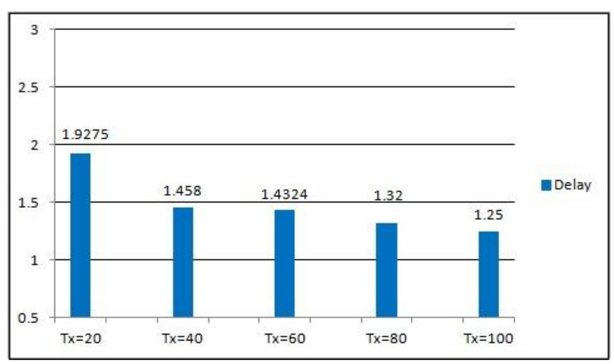

Fig.18 Avg. End-to-End delay for diff. Transmission Ranges

VI. CONCLUSION

Internet of Things (IoT) is a next generation networks and able to setup the wireless network of smart devices. The salient feature of Internet of Things sets up the network irrespective of time, place and devices. This paper briefly explains the applications of IoT and qualities of an efficient Routing Protocol. A detail discussion of RPL Routing Protocol and its messages are discussed in this paper. Also, this paper presents complete data structure of all messages of RPL during DODAG construction and data transmission is explained. This paper shows the behavior of RPL protocol in different data transmission ranges.

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