Performance Analysis of Objective Function MRHOF and OF0 in Routing Protocol RPL IPV6 Over Low Power Wireless Personal Area Networks (6LoWPAN)

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***Abstract*— 6LoWPAN is one of the implementations of WSN that using IPv6 as sensor addressing. 6LoWPAN is categorized in the new technology and still being developed. This causes issues about the networks performance to create the communication path and collecting data. Routing Protocol for Low-power-loosy (RPL) is a routing protocol used in 6LoWPAN. In RPL, there are two kind of objective functions development. Objective function is path selection mechanism when formation of the networks. This research is focus on performance analysis in two objective functions RPL that are Minimum Rank with Hysteresis Objective Function (MRHOF) and Objective Function Zero (OFO). This research observed using COOJA as a WSN simulator. The parameter that observed in this research are: networks convergence time, power consumption, ETX, hop, Packet Delivery Ratio (PDR), latency, PDR in mobility node. Based on the simulation we concluded that MRHOF give better performance than OF0 in terms of network quality. The implementation of MRHOF is suitable for use in sensor network that require data delivery in the reliable network. While OF0 is suitable for use in sensor network that require fast formation network link and low power consumption.**

Keywords—6LoWPAN, performance, objective function RPL, MRHOF, OF0

I. INTRODUCTION

6LowPAN technology is a future development in tech that combine Internet of Things paradigm or Wireless Sensor Network with IPv6 [1]. We can't avoid that IPv6 addressing is absolutely must be used in this era where personal device ratio increasing. 6LoWPAN technology or abbreviation of IPv6 Over Low Power Area Network is the implementation of node sensor that comunicate as Wireless Sensor Network (WSN) using IPv6 identifier with low power consumption. One of the implementation of 6LoWPAN is home automation system.

Routing Protocol fo Low-power-loosy (RPL) is a routing protocol for 6LoWPAN. RPL support the characteristics as routing protocl with low bandwidth, lossy and low power consumption [2]. RPL routing protocol suitable with 6LoWPAN networks that focus on network formation and data exchange in lossy network and low power consumption.

Objective function (OF) is a process that affect to performance of routing protocol. Objective function is a path selection mechanism towards root node by selecting the parent node [3]. There are different path selection mechanism between objective function based on the metric they use. MRHOF is objective function that use minimum ETX (Expected Transmission Count) as path to the root. While OF0 use minimum hop as path to the root. Therefore, further research is needed to analyze the impact of different implementation of objective function with RPL in network operation.

Performance analysis of objective function RPL in 6LoWPAN technology will be done with simulation in COOJA simulator that support the 6LoWPAN mechanism. The method used is a common method commonly used to compare routing protocols. In this research the method slightly altered to test the objective function performance. The node position organized in various type to observe the performance and characteristics both objective function RPL in network formation and data delivery. The parameter determined and compared between this two objective functions.

II. RELATED WORKS AND NETWORK PARAMETERS

A. Related Works

RPL in type of high dense network (narrow distance between node) worked well [4]. RPL still transmitted data for maintenance the network (overhead) besides the main data from sensor in dense condition. In this research stated that further research needed to observe the stability and efficiency objective function in RPL [4]. In research related to the control network indicates that the RPL had a good control for the overhead of data [5]. But in this research didn't discuss specifically about the objective function they used.

Next problem that observed was the type of sensor network with RPL protocol [6]. This research showed that the node position in DODAG (Destination-Oriented Directed Acyclic Graph) will affect to the network formation time. Related to the DAG root, power consumtion between node with long distance or with high number of hop to reach DAG root will increase [7].

Research related to the objective function performed on two types of networks, there are grid and random [8]. In this research, node placed in unsymmetrical distance in grid network scenario. Even sink node placed in inconsistent distance with another node surrounding in grid network scenario. This research didn't observe latency and mobility node scenario.

B. 6LoWPAN Technology and Network Parameter

1) RPL: is a routing protocol designed to be implemented in device with limited processing capabilities, limited memory, and limited energy [9]. Link between node in RPL formed with lossy and low data rate characteristics. There are characteristics in RPL traffic communication between sensor are point to point, point to multipoint, and multipoint to point. 6LoWPAN use low bandwidth of 250 kbps follow the 802.15.4 IEEE standard.

2) Objective Function: is a selection path mechanism when choosing parent node by node underneath to form DODAG [10]. Objective function works using routing metric as a reference and calculate it with some algorithm to form link in DODAG. Fundamentally, it can be said that objective function will optimize the routing metric that is used to form link between sensor. So, objective function will organize the path selection to get the best path.

3) Minimum Rank with Hysteresis Objective Function (MRHOF): is an objective function that use minimum value of Expected Transmission Count (ETX) on parent node selection [10]. ETX is an expected number of transmission that required for it to be received without error at its destination [11]. ETX calculation showed in equation 1. Df value obtained from the probability calculation of received packet at neighbour node. While Dr value obtained from the probability calculation of acknowledgement (ACK) packet at receiver. ETX value can be either a discrete value or not an integer [11].

$$ETX = \frac{1}{Df\ x\ Dr} \qquad (1)$$

Df = forward delivery ratio
Dr = reverse delivery ratio

4) Objective Function Zero (OF0): is an objective function that use minimum value of hop to reach root node. Each node will calculate rank based on the hop value to the root node. The fewer number of jumps will get higher priority link to be selected by OF0. Rank value on child node is always higher than the parent node. Increment calculation in hop based algorithm is different calculations from ETX based. The increment value in hop based algorithm rising constantly. In COOJA simulator each link addition will increase the hop value.

5) The Convergence Time: is amount of time it takes from the beginning when root node sends a first control message until entire node listed in the routing table at root node [12]. Another indication the timer stop is when entire node connected to the DODAG. Each node with RPL implements full routing function during the simulation.

6) Power Consumption: is amount of power used in each node. In power measurement there are four types: Low Power Mode (LPM), CPU power, radio listen, and radio transmit. Power consumption is a total of all calculation off all type above [6]. LPM is a power consumption parameter that indicates the power used when in sleep condition. CPU power is a power parameter that indicates the level of node processing. While radio listen and transmit is parameter related with node communication (transmit and receive) [12].

7) Packet Delivery Ratio (PDR): is a ratio between amount of received packet in receiver with amount packet transmitted. PDR value obtained by dividing the total number of packet received at the receiver and total packet sent by the sender. This metric indicates the network reliability level [13]. PDR value is correlated inversely with the ETX value. The higher the value of the PDR, the ETX value will be far below 1 [11].

8) Latency: is a parameter to measure time delay during packet sent at UDP layer until its received in receiver [14]. Latency is calculated by subtracting the time when packet arrive in receiver and time when packet sent. Average of end to end latency is the average of latency time that used to transmit data from sender to the root node of some process during the interval. The calculation of average end to end latency can use the formula in equation 2 below. RecvT is time when packet arrived at receiver and sendT is time when packet sent from sender. The total delay of all process divided with the number of process to get the average end to end latency.

$$Average\ Latency = \frac{\Sigma\ (recvT - sendT)}{no\ of\ process} \qquad (2)$$

9) COOJA: is a sensor network simulator that support 6LoWPAN technology. This simulator runs on the CONTIKI operating system. Inside this simulator there were many scenario and open source code. We can change the code and the parameter and simulates using COOJA. This simulator widely used for 6LoWPAN simulation because the simulator development controled by many developers and distributed as open source.

III. Research Methodology

There are seven parameters observed in this research related to DODAG convergence time, average power consumption, average ETX, average hop, Packet Delivery Ratio (PDR) in static node, average latency, and PDR in mobile node. In this research the 6LoWPAN network simulated under COOJA with CONTIKI 2.7 operating system to analyze the parameter value.

A. Measurement of DODAG Convergence Time

DODAG formed when the entire node is connected and can reach the root node. DODAG can be monitored through Sensor Map features in Sensor Data Collect COOJA. The number of nodes used were 25, 49, and 81. The reason to choose that number is an attempt to maintain the range of sink node remain symmetric in grid network scenario. The same amount of node implemented in random network scenario.

Grid and random network topology used in this research is shown in Fig.1. There is no difference between senders. All senders have the same characteristics. The colour different is just to distinguish the amount of node. This topology is used when measuring DODAG convergence time, average power consumption and average ETX and average hop measurement. Node transmission range is 20 meters with 50 meters of interference range. Tx and Rx value is 100%.

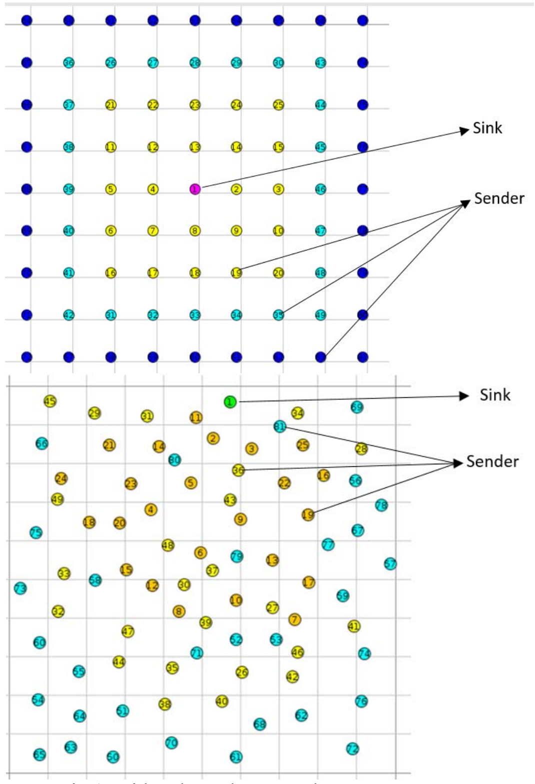

Fig.1 Grid and Random Topology

B. Measurement of Average Power Consumption

Average power consumption is a parameter related to the average energy used in each node. This parameter was observed with the same of simulation design as the DODAG convergence observation design. The difference is in the type of observed parameter. The parameter measured was CPU_Power. CPU_Power is energy used relating to the node processing level. Average power consumption observed through Sensor Data Collect.

C. Measurement of Average ETX and Hop

ETX and hop measurement process is almost the same as DODAG time convergence measurement and power consumption measurement. The difference is in the process data retrieval. The data obtained twice each simulation. First data obtained when DODAG formed and second obtained after 5 minutes of time simulation. Next step was increase the node number and repeated the simulation again to observed the different amount of node used. Average ETX and hop measurement observed using Sensor Data Collect.

D. Measurement of Static Node Packet Delivery Ratio

To perform this measurement first thing to do was configure the tools and plugin in simulator. There was only random network topology used in in this observation without increasing the number of nodes. Due to a high number of combinations, network type was not changed. There were 25 nodes used in this measurement. There was no different amount of node performed because the parameter observed relating to the network reliability. Therefore, the variable changed in packet reception ratio and data rate.

Packet reception ratio simulated in various ratio. Packet reception ratio used were 25%, 50%, 75%, and 100%. While transmission ratio (Tx) remained in 100%. The data rate used in this measurement were 10 packets/minute, 30 packets/minute, 50 packets/minutes and 70 packets/minute. This data rate value implemented to the entire sender nodes (24 sender nodes). Transmission and interference range configured at 50 meters. The same value used to eliminate the interference area. So the interference controlled by the Tx value. The topology used to observe the PDR is shown in Fig.2.

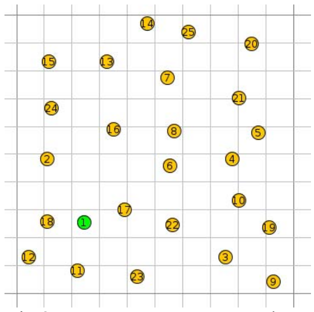

Fig.2 PDR Measurement Topology

E. Measurement of Average Time Latency

Time latency measurement process was similar with PDR measurement without packet reception ratio changes and different analyse method. Average time latency observed in the data rate variation. Both objective function compared in this various data rate value. Both transmission and reception ratio were 100%. Latency calculated based on the difference time between transmission and reception at sink node. Average calculated from entire latency in each data rate. Simulations were performed in 5 minutes of simulation time.

F. Measurement of Mobile Node Packet Delivery Ratio

There are two scenario observed in mobility node measurement. First scenario was a simple movement with one sink node and one sender node. Sink node in static condition. While sender move away from the sink. Sender moved linearly away from the sink node with a speed of 1m/s. Range configured with 70 meters and 60 meters. The interference range was 100 meters. This is to observe the characteristic when the node is out of range.

In this second test used simple topology with 10 nodes (1 sink node and 9 sender nodes) as shown in the Fig.3. The PDR compared between node in static condition and in mobile condition (2 sender nodes moves in the network). The movement of the node was determined at the beginning of simulation. Node with ID 7 and 10 were move along the track as shown in Fig.3. The simulation held in 5 minutes of simulation time. Transmission and interference range configured at 20 meters in this scenario.

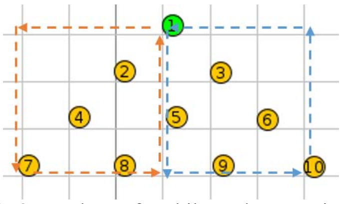

Fig.3 Topology of Mobile Node Scenario

G. Code Used in Simulation

There were four codes used in this simulation. The codes are part of the CONTIKI operating system contributor. This code distributed as open source code. We used this code and modify some parameter to observed through simulation. Udp-sink.c and udp-sender.c were used at DODAG convergence time, average ETX, average hop and average power consumption measurement. While udp-server.c and udp-client.c were used at PDR static node, PDR mobile node and average latency measurement.

IV. RESULT

A. Measurement of DODAG Convergence Time

In this observation shown that OF create DODAG faster than MRHOF in grid and random network. The measurement result is shown in Fig.4 and Fig.5. Convergence time pattern in grid network had a similar pattern between objective function. But in random network, there are various pattern.

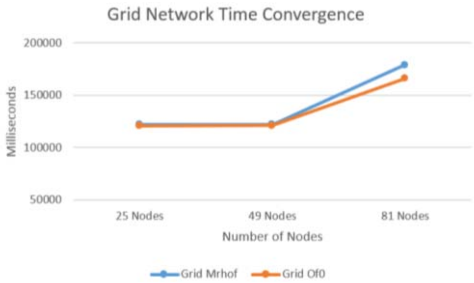

Fig.4 Grid Network Time Convergence Graph

MRHOF time convergence increased significantly at 45 nodes. While in OF0, there was no significant increase at the same amount of nodes. There was significant increase at 81 nodes when OF0 used. The pattern differences may be caused by node position. Grid had a similar pattern characteristic than random network.

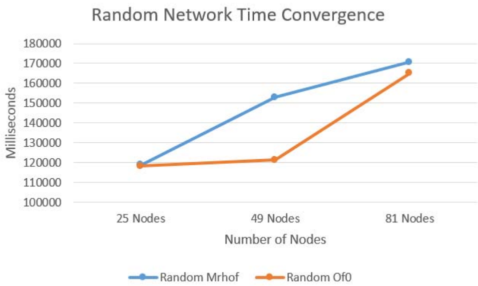

Fig.5 Random Network Time Convergence Graph

MRHOF took longer DODAG convergence time may be caused by the process of the objective function is a bit more complicated than OF0. We observed the rpl-mrhof.c and rpl-of0.c code in /contiki/core/net/rpl directory to find the different mechanism between both objective function. The ETX metric in MRHOF had a different value between link. While hop value in OF0 increased constantly with the constant value between link. The ETX calculation may cause the convergence time of MRHOF longer than OF0.

B. Measurement of Average Power Consumption

The graph result of average power consumption measurement is shown in Fig.6 and Fig.7. MRHOF consumed more power than OF0. This is still related with MRHOF method complexity. Thus during the DODAG formation will require a higher power than OF0. This is correlated with the parameter observed that is CPU_Power. This parameter related with node processing level. The calculation of ETX metric required more complex process than hop metric.

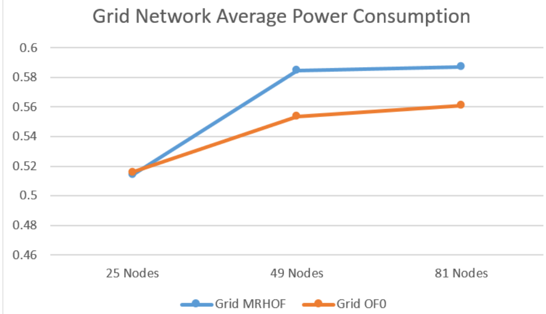

Fig.6 Grid Network Average Power Consumption Graph

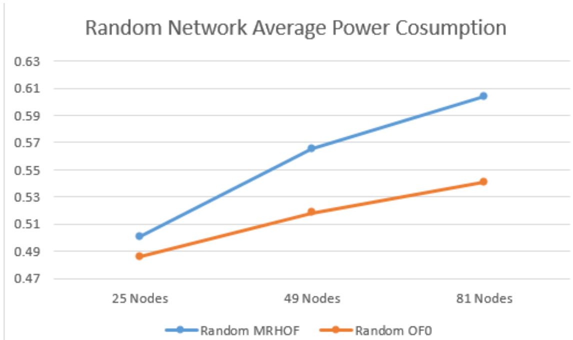

Fig.7 Random Network Average Power Consumption

C. Measurement of Average ETX and Hop

In this ETX measurement obtained the difference characteristic between MRHOF and OF0. There was a change in average value of ETX when implement MRHOF during the DODAG formed until 5 minutes of simulation. While in OF0 there was no change until 5 minutes of simulation. Average ETX in MRHOF decreased during the simulation time. In grid network ETX value decreased 13.9% and in random network decreased 16.5%. This change is due to the MRHOF mechanism to update the ETX metric. In mrhof.c code there was a function to update ETX and power metric. This function called update_metric_container. While there was only reset metric container code in the update_metric_continer in rpl-of0.c code. Therefore, there was no ETX change in OF0. The comparison average ETX between MRHOF and OF0 is shown in Fig.8.

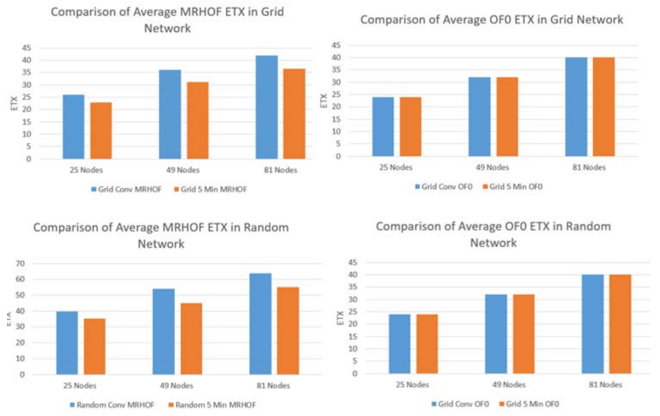

Fig.8 Average ETX Comparison Between MRHOF and OF0

Average hop measurement result is shown in Fig.9. There was a change in MRHOF average hop especially in random network topology. While in OF0 there wasn't a change of average hop in random and grid. This is still related with update_metric_container function. In OF0 there was no change because no update mechanism for hop metric inside the update_metric_container function.

There was a change of average hop that varies to the 3 types amount of nodes in random topology. Average hop increased 0.03125 in 25 nodes and decreased 0.0125 in 81 nodes. While in 49 nodes there was no change of average hop. This average hop change caused by the update mechanism inside MRHOF to find the best path based minimum ETX.

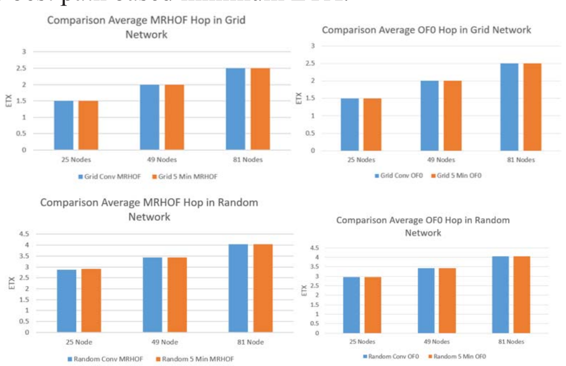

Fig.9 Average Hop Comparison Between MRHOF and OF0

The implication of this mechanism could change the number of hops. It can be increased, decreased or not change the hop value. When the minimum ETX required more hops, it will increase the hop value and vice versa. If the change occur with same number of hops it will not change the average hop.

D. Measurement of Static Node Packet Delivery Ratio

The measurement of static node PDR result is shown in Fig.10. It shown that MRHOF had higher PDR than OF0. When data rate at 10 packets/minute observed that small domination PDR value between both objective function. At low data rate there was small difference and no domination. But when data rate at 30,50, and 70 packets/minute, the PDR of MRHOF value were higher than the PDR of OF0. The most significant difference was 0.5559 when data rate at 30 packets/minute. MRHOF took effect optimally when data rate at 30 packets/minute than the others data rate in this research. The difference value at data rate 30 packets/minute approached twice the difference at each 50 and 70 packets/minute data rate. There was some feedback to CONTIKI developers because the PDR value in Rx 100% performed worst from several Rx lower. This is quite strange result. Higher reception ratio will get higher PDR value.

The highest PDR difference based reception ratio was at 100% reception ratio. In this ratio the PDR difference was 0.4561. While on the other ratios observed smaller than Rx 100%. This indicates that MRHOF create more reliable network than OF0. The network quality is getting better (reliable) when PDR value approach 1.

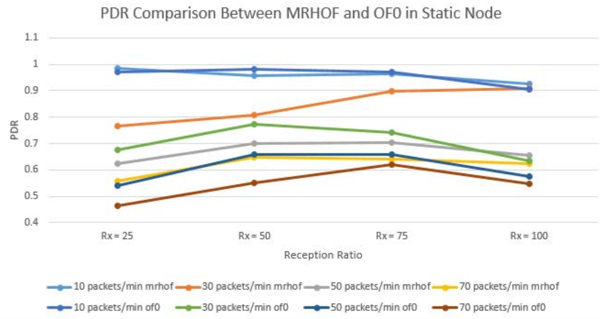

Fig.10 PDR Comparison Between MRHOF and OF0 in Static Node

E. Measurement of Average Time Latency

The measurement of average time latency result is shown in Fig.11. The MRHOF latency was lower than the OF0. The significant differences were 00:00.763 with 30 packets/minute data rate and 00:00.402 with 70 packets/minute data rate. There was a different pattern between both objective function.

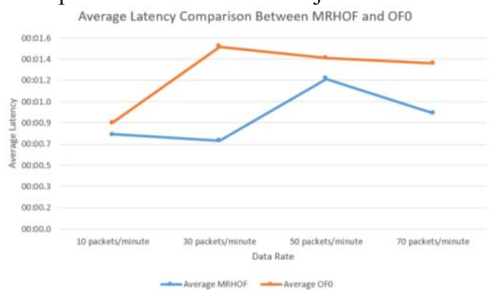

Fig.11 Average Time Latency Comparison Between MRHOF and OF0

The OF0 increased the time latency significantly at 30 packets/minute with margin 00:00.615. While MRHOF increased significantly at 50 packets/minute with margin 00:00.504. Further research is required to observe the pattern with data rate higher than 70 packets/minute.

Inside processing core in CONTIKI 2.7 there was a bug when observed the time through mote output in COOJA simulator. There were three columns in mote output. They were time, ID node and mote message. This bug caused error value in time output. Error occurred because time when packet received was earlier than when packet transmitted. The error value was 4-6%.

This error value was not included in average time latency calculation.

F. Measurement of Mobile Node Packet Delivery Ratio

In the first scenario, there was no difference either when node inside sink range or not. This is because only two node used in this scenario (one sink and one sender). This indicates that objective function doesn't influence on network which only has one link. Objective function will influence the network performance when there are other options of nodes to switch the link with another.

The result of measurement the second scenario is shown in Fig.12. There was no domination based the graph between both objective function. MRHOF had lower difference when data rate at 30 packets/minute and 50 packets/minute. While MRHOF dominated the difference with data rate at 10 packets/minute. But the significant difference occurred when data rate at 70 packets/minute where MRHOF more affected to the movement of nodes. This is indicated with the high difference PDR value of MRHOF than the OF0.

There was no pattern in the graph to analyse the trends. However, the average of the PDR difference each objective function was 0.137625 for MRHOF and 0.131175 for OF0. From the average result can be said that MRHOF had higher difference than OF0 with a difference of 0.00645. This indicates that MRHOF more influenced with node movement than OF0 based PDR parameter measurement.

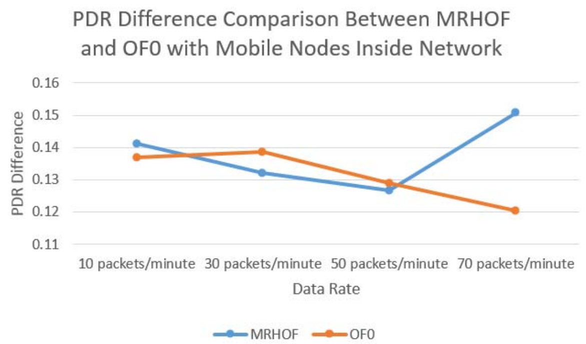

Fig.12 PDR Difference Comparison Between MRHOF and OF0 with Mobile Nodes Inside Network

V. Conclusion and Future Work

From the simulation, we conclude that MRHOF gives better performance than OF0 in the aspect of network reliability while OF0 has faster in network convergence and consume less power than MRHOF during the DODAG convergence time interval. OF0 suitable for use in network with mobile node scenario and network with limit power. This is because OF0 can maintain the PDR value in mobile node scenario. MRHOF suitable for use in network that requires reliable network.

For the CONTIKI developer, there was error in CONTIKI 2.7 core related to the time in mote output. Some transmission process receive packet in time before it sent. This process created error around 4-6%. Future work needed to observe the pattern to analyse trend in higher data rate and number of nodes.

References

[1] A. Musa, D. Lee, I. Paramitha, K. Ramli and D. Choi, "Constructing Energy Aware Home Automation within the IPv6-USN Architecture," *International Journal of Smart Home*, pp. Vol. 8 Issue 5, p63, 2014.

[2] Cisco, "Routing Protocol for LLN (RPL) Configuration Guide, Cisco IOS Release 15M&T," *Cisco Support White Paper*, 2015.

[3] T. Zhang and X. Li, "Evaluating and Analyzing the Performance of RPL in Contiki," in *Proceedings of the first international workshop on Mobile sensing, computing and communication*, Philadelphia, 2014.

[4] K. Heurtefeux, H. Menouar and N. AbuAli, "Experimental Evaluation of a Routing Protocol for WSNs: RPL robustness under study," in *Wireless and Mobile Computing, Networking and Communications (WiMob), 2013 IEEE 9th International Conference*, Lyon, 2013.

[5] J. Tripathi, J. C. d. Oliveira and J. P. Vasseur, "A performance evaluation study of RPL: Routing Protocol for Low power and Lossy Networks," in *Information Sciences and Systems (CISS), 2010 44th Annual Conference on*, Princeton, NJ, 2010.

[6] O. Gaddour, A. Koubâa, S. Chaudhry, M. Tezeghdanti, R. Chaari and M. Abid, "Simulation and Performance Evaluation of DAG Construction with RPL.," in *Third International Conference on Communications and Networking*, Hammamet, 2012.

[7] N. Khelifi, W. Kammoun and H. Youssef, "Efficiency of the RPL repair mechanisms for Low Power and Lossy Networks," in *2014 International Wireless Communications and Mobile Computing Conference (IWCMC)*, Nicosia, 2014.

[8] M. Qasem, H. Altawssi, M. B. Yassien and A. Al-Dubai, "Performance Evaluation of RPL Objective Functions," in *Computer and Information Technology; Ubiquitous Computing and Communications; Dependable, Autonomic and Secure Computing; Pervasive Intelligence and Computing (CIT/IUCC/DASC/PICOM), 2015 IEEE International Conference on*, Liverpool, 2015.

[9] T. Winter, A. Brandt, P. Thubert, J. Hui, R. Kelsey, P. Levis, K. Pister, R. Struik, J. Vasseur and R. Alexander, "RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks," in *Internet Engineering Task Force (IETF)*, 2012.

[10] J. Ko, J. Eriksson, N. Tsiftes, S. Dawson-Haggerty, A. Terzis, A. Dunkels and D. Culler, "ContikiRPL and TinyRPL: Happy Together," *ACM 978-1-4503-0512-9/11/04*, 2011.

[11] H. Lamaazi, N. Benamar, M. I. Imaduddin and A. J. Jara, "Performance Assessment of the Routing Protocol for Low Power and Lossy Networks," in *2015 International Conference on*, Marrakech, 2015.

[12] N. T. Long, N. D. Caro, W. Colitti, A. Touhafi and K. Steenhaut, "Comparative Performance Study of RPL in Wireless Sensor Networks," in *2012 IEEE 19th Symposium*, Eindhoven, 2012.

[13] M. Banh, H. Mac, N. Nguyen and K.-H. Phung, "Performance evaluation of multiple RPL routing tree instances for Internet of Things applications," in *Advanced Technologies for Communications (ATC), 2015 International Conference on*, Ho Chi Minh City, 2015.

[14] M. Vučinić, B. Tourancheau and A. Duda, "Performance comparison of the RPL and LOADng routing protocols in a Home Automation scenario," in *Wireless Communications and Networking Conference (WCNC), 2013 IEEE*, Shanghai, 2013.