Analysis of RPL Power Consumption in 6LoWPAN Ecosystem using COOJA Simulator

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Abstract— The vision behind the IoT comprises of embedded devices (ED), which also called as intelligent objects, characterized by low power, limited memory capacity, small size and less cost to be connected to the Internet by using Wireless Sensor Network (WSN). Thus, Internet Engineering Task Force (IETF) introduced IPv6 Low Power Area Network (6LoWPAN) as a standard network for ED. Nevertheless, communication between ED with 6LoWPAN network demands special design considerations for instance simple, compressible, and suits for most applications protocol needs. Among the protocol of 6LoWPAN network, RPL is the best protocol but the Power Consumption (PC) of RPL is high when it implements in large network. Therefore, this paper presents the analysis of RPL PC in four parameters (CPU power, listen power, LPM power and transmit power) in 6LoWPAN ecosystem using COOJA simulator. The result shows the total of PC is increase with the increasing of number of nodes and transmission range (TR).

Index Terms—Internet of Thing; 6LoWPAN; Embedded Devices:

I. Introduction

Nowadays, Internet Protocol version 6 (IPv6) is a next-generation IP, which developed due exhausted of IPv4 [1]. For a long time, the IPv6 provide 2^{128} bit IP unique address space that will offer to connect a large number of devices with Internet [2]. Enabling the concept of the Internet of Thing (IoT) as an illustration in Fig. 1, the expected devices connected to the Internet using IP address increase over 50 billion devices by 2020 [3] and it makes possible by using IPv6 addressing space.

The IoT concept is basically connecting any objects, peoples, and things to the internet that provided with a unique identifier and ability to transfer data and communicate over a network. However, the performance of network connectivity between IoT devices become more challenging. This is because the technology evolution in the development of IoT applications (intelligent devices) could be embedded and categorized to low power battery, low memory, small size and less cost [4]. Therefore, to facilitate this connection, IPv6 Low Power Area Network (6LoWPAN) is defined by Internet Engineering Task Force (IETF) that enable the embedded device to connect to the Internet over IEEE 802.15.4 in the frequency range 2.4 GHz.

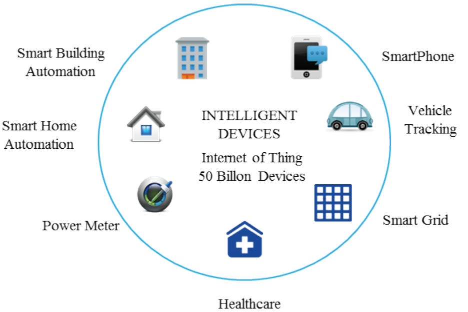

Fig. 1: Internet of Thing Applications [5]

6LoWPAN is a wireless embedded internet [5] that integrates IPv6 with Wireless Sensor Networks (WSN) [6] using IEEE 802.15.4 link network. Also, this network allows the embedded devices which are mainly sensor nodes to connect and exchange information directly with other devices on the Internet. There are many wireless technologies such as ZigBee®, Bluetooth, and HART. However, most existing wireless technologies require stateful and complex application gateway to connect IP-based network [7]. For this condition its used huge amount of energy [8] and is not scalable for large network connectivity especially for embedded devices. On the other hand, in 6LoWPAN the connecting between IP-based embedded devices with other IP networks is direct (end to end) and require no gateway gateways translation [5]. Thus, the energy used for connectivity is saved and for this purpose, 6LoWPAN protocol becomes an essential part of the IoT development application[8].

As a consequence, Routing Protocol for Low Power and Lossy Network (RPL)[9] is designed by IETF to optimization the performance of Low power and Lossy Network (LLN) such as minimum power consumption, maximum throughput and minimize delay. Moreover, RPL is a powerful technique for 6LoWPAN network compare existing protocol (Ad Hoc On-Demand Distance Vector Routing (AODV) and Dynamic Manet on demand (DYMO)) in term of throughput and delay[10]. However, RPL routing overhead is high up to 75% when its run-in large network. Due to this matter, the power consumption usage of node are increase [11] and at the same time affect the network performance. In addition, the use of a simulator is a good thing to carry out testing on RPL protocol performance in real scenarios[12]. Therefore, we are addressing the parameter measured for RPL power consumption in COOJA simulator and we did the experiments to investigate and analysis the 6LoWPAN performance in different transmission range and the number of nodes. Thus, proposed the effect of power consumption usage in 6LoWPAN ecosystem.

The remainder of this paper is organized as follows: first, the introduction this paper and the author gives related works on RPL power consumption performance analysis in multiple scenario in Section 2, then a brief of the architecture of 6LoWPAN ecosystem and issues in current IoT systems are presented in Section 3. The simulation environment is explained in Section 4. Then, Section 5 show the performance evaluation of RPL power consumption and finally, our conclusion is in Section 6.

II. Related Work

Table 1 present the analysis the effect of RPL performance indicator in multiple scenario of 6LoWPAN network. From the analysis power consumption used in 6LoWPAN network is increased significantly with all scenarios (network topology change, number of nodes, packet rate). Consequently, power consumption has been reduced by introducing Multipath-RPL [13] and Backpressure RPL for High-throughput and Mobile IoTs (BRPL) [14] and Congestion-Aware RPL for 6LoWPAN Networks (CA-OF) but the average of delay is high because the nodes spend many time in sleep mode for all protocol. This because the limitation of 6LoWPAN frame length for each data transmission highly complicated to implement in real scenario [5]. In addition, 6LoWPAN frame length for each data transmission limited to 127 bytes compare 1280 bytes over IPv6. Therefore, this study focusses on the power usage for each parameter such as CPU power, Listen Power, LPM Power and Transmit Power in 6LoWPAN architecture to investigate which parameter contributes to increased power consumption.

TABLE 1
ANALYSIS OF POWER CONSUMPTION IN MULTIPLE SCENARIO

References	Result and Analysis
[14]	The value of power consumption in topology grid RX=100% and RX=60% have same behavior whereas power consumption is increased due the fact that the sink represents a bottleneck. However, for packet delivery rate (PDR), and delay RX=60% is better than RX=100%.
[15]	Three limitation of RPL in LLN: low throughput, low adaptability in dynamic network and lack support for node mobility.
[16]	RPL transmission energy consumption per successfully delivery packet is high than compared protocol in both network (network 1 consist 12 intermediate nodes and 6 leaf nodes and Network 2 consist 24 intermediate nodes and 10 leaf nodes). RPL energy consumption is lost due to buffer overflow on the path without successful delivery because the buffer occupancy has not been considered.
[13]	RPL has higher packet drop ratio resulting in wastage of energy on unsuccessful transmissions.

III. 6LoWPAN Architecture For IoT

This section explains the design of a 6LoWPAN architecture that minimize power consumption to support the embedded application of IoT. Based on previous studies, there are three (3) types of architectures for a 6LoWPAN network that suitable for IoT application, which are Simple LoWPANs, Extended LoWPANs and Ad Hoc LoWPANs [5]. Detailed architectures are presented in Fig. 2, 3 and 4 respectively.

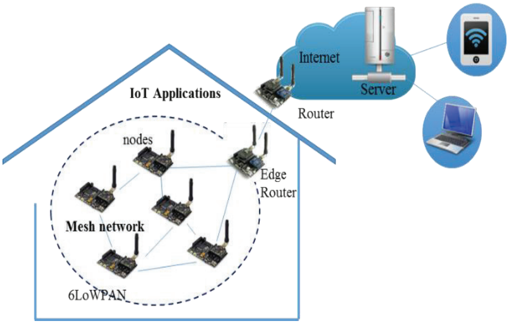

Fig. 2: Simple LoWPANs [8][5][17]

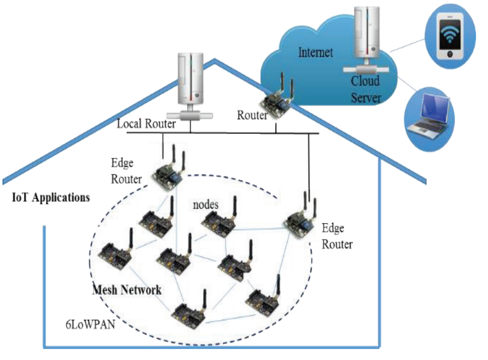

Fig. 3. Extended LoWPAN [5][18][17]

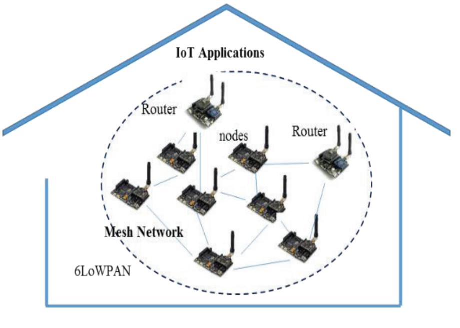

Fig.4. Ad Hoc LoWPAN [5][18]

Based on the architectures, LoWPAN referred to the collection of 6LoWPAN nodes that share the first 64 bits of an IPv6 address (IPv6 prefix). On the other hand, all nodes remain the same as IPv6 prefix. These intelligent nodes can act as both host or router and the mesh topology used for the throughput where nodes are free to move between LoWPAN and edge router. Based on previous studies the application of mesh topology in 6LoWPAN protocol are defined the communication stack and routing protocol become very stable and able to react quickly[19]. Due to this result, the power consumption used can be reduced (minimize) and it becomes the advantage to 6LoWPAN network for IoT ecosystem. For 6LoWPAN, the power consumption is depending on the type of battery used. For example, according to [8] 2.3 years can be considered to be a very long for AA batteries to maintain the connectivity.

In Simple LoWPANs architectures (Fig. 2), LoWPAN connected with another IP Network through only one LoWPAN edge router and share backbone link to connect to the internet. Besides that, the function of edge router is to connect 6LoWPAN with another IP network. At the same time, the edge router is handling the 6LoWPAN compression and Neighbor Discovery (ND) for 6LoWPAN nodes. As mention in [8] the power consumption using simple LoWPANs architecture remain low when the intelligent objects are idle, and increases to the data rate in both host and router mode. While the extended LoWPANs (Fig. 3) were designed based on backbone link with encompasses the LoWPAN multiple edge routers for interconnecting them [19]. Even the same channel of the multiple edge router in LoWPANs can overlap each other. That means, the IPv6 address nodes will change when moving from one LoWPAN to another LoWPAN. Thus, for IoT ecosystem, a network deployment may also choose to use multiple edge router. Therefore, this architecture compatible for large infrastructure example smart building, smart grid, industrial automation and so on. Besides that, the Ad Hoc LoWPANs (Fig. 4) was designed to operate without infrastructure and no Internet connection [19]. Due to the architecture design, it is suitable for IoT appliances such as asset management system.

However, communication between any embedded device (IoT appliances) with 6LoWPAN network needs special design consideration as it is simple, compressible, and suits most applications protocol needs. Therefore, 6LoWPAN embedded internet system is usually designed based on the purpose of IoT deployment, for example, a facility management network, home automation and so on to minimize power consumption usage. In order to investigate the power consumption usage for each architecture, RPL protocol is implementing in real 6LoWPAN network using simulator software. For this study, the testing only focusses on simple LoWPAN to measure and analysis the power consumption usage of RPL protocol.

IV. Simulation Environment

This section presents in detail explanation about COOJA Simulation, Simulation setup and Measurement Parameter in COOJA simulation.

A. COOJA Simulator

The RPL protocol is implemented in Contiki OS [20], [21] and execute simulation in COOJA simulator [22] by the creation of a simulation framework, which is modified from the existing set up [23], [24] as present in Table 2. The simulation results evaluate for different transmission range and the number of nodes. As mentioned in [12], the number of nodes and Transmission Range (TR) are highly effect the power consumption.

TABLE 2
System Parameter for Simulation Environment

OS and Simulator:	Contiki (version 3.0) and Cooja
Protocol	RPL
PHY and MAC	IEEE 802.15.4 and CSMA
Radio Medium	Unit Disk Graph Medium (UDGM)
Transport Layer	UDP
Transmission range	50m & 100m
Mote Type	T mote Sky
Simulation time	300 second
Tx and Rx ration	100%
Root waiting Times	5ms
Number of nodes	10, 20, 30, 40 (including root)

B. Simulation Setup

In introduction to start the simulation, once the instant Contiki OS and COOJA is already install and ready to use as shown in Fig. 5. The following steps are used to open initial Cooja interface in Fig. 6.

1. Click on terminal icon and the command **cd contiki/tools/cooja** is written then enter
2. Next, **ant run** is typed then enter.

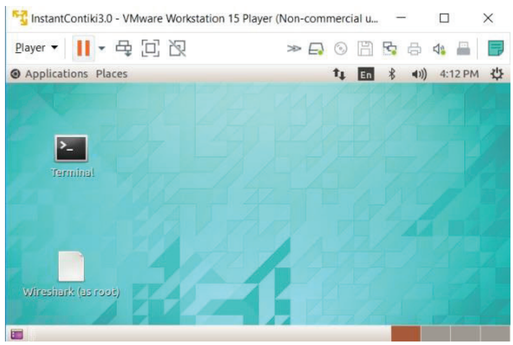

Fig.5. Contiki 3.0 Interface

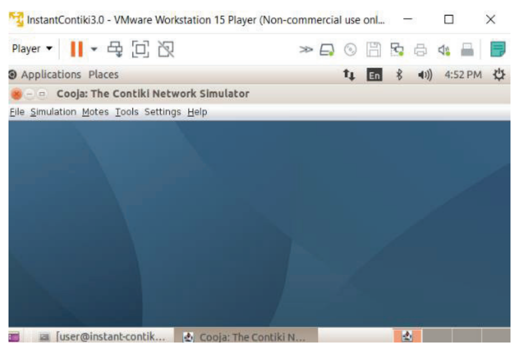

Fig.6. COOJA Simulator Interface

Next, create new simulation by click on File menu and dialog box are appear as present in Fig. 7. The setting of simulation parameter is followed to Table 2. In this case the network topology shall involve two types of node there are single sink nodes and sender node. A single node was created with the RPL firmware path selected is **/ home / user / Contiki / examples / ipv6 / rpl-collect / udp-sink.c.** While to create a sender node the selected the firmware path is **/home / user/ Contiki / examples / ipv6 / rpl-collect / udp-sender.c.** Finally, 8 experiments were setup based on two different transmission range (50m and 100m) with four different number of nodes (10, 20, 30, 40) as presented in Fig 8a-8h)

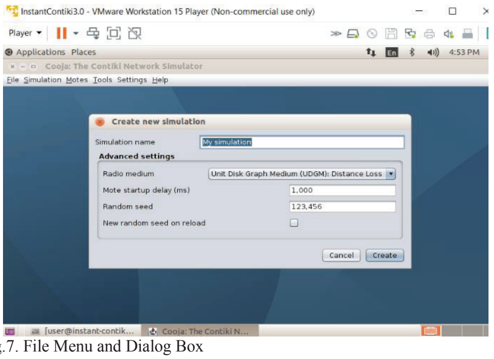

Fig.7. File Menu and Dialog Box

C. *Measurement*

There are four types of parameters used to monitor the power consumption used for each node in COOJA simulator through plug in of Powertrace : i. CPU Power, ii. Low Power Mode (LPM) Power iii. Transmit Power and iv. Listen Power. From the datasheet of Powertrace output, the total Power Consumption (PC) can calculate with the following formula as :

$$PC = \frac{Energest\_Value \ x \ Current \ x \ Voltage}{RTIMER_{SECOND}} \qquad (1)$$

Where as,

- RTIMER_SECOND - is the value of the number of ticks per second for rtime (the typical value of this constant is 32768).
- Energest_Value is the number of ticks the radio has been in four condition mode as follow
  - ✓ Transmit mode (Energest_Type_Transmit),
  - ✓ Listen mode (Energest_Type_Listen),
  - ✓ Active mode (Energest_Type_CPU),
  - ✓ Idle mode (Energest_Type_LPM),
- Current is current consumption in each mode in mA (obtain the value from the datasheet of the nodes). For this simulation the current used in each mode as following
  - ✓ Transmit mode = 17.4 mA
  - ✓ Listen mode = 18.8 mA
  - ✓ Active mode = 0.33 mA
  - ✓ Idle mode = 0.0011 mA
- Voltage of the system powered from a pair of AA batteries (1.5v x 2 = 3V).

Therefore, the energy of each parameter can calculate with the following formula :

$$CPU \ Power = \frac{Energes\_Type\_CPU \ x \ 0.33 \ mA \ x \ 3V}{32768} \qquad (2)$$

$$LPM \ Power = \frac{Energes\_Type\_LPM \ x \ 0.0011 \ mA \ x \ 3V}{32768} \qquad (3)$$

$$Transmit \ Power = \frac{Energes\_Type\_Transmit \ x \ 17.4 \ mA \ x \ 3V}{32768} \qquad (4)$$

$$Listen \ Power = \frac{Energes\_Type\_Listen \ x \ 18.8 \ mA \ x \ 3V}{32768} \qquad (5)$$

V. PERFORMANCE EVALUATION

The performance analysis of power consumption usage for 50 m and 100 m TR are presented in Fig 9 and Fig 10. The result shown the value of CPU power, listen power and transmit power is significantly increase with the number of sender nodes in all TR. As opposed to LPM power, the value is decrease when the numbers of sender nodes are increased.

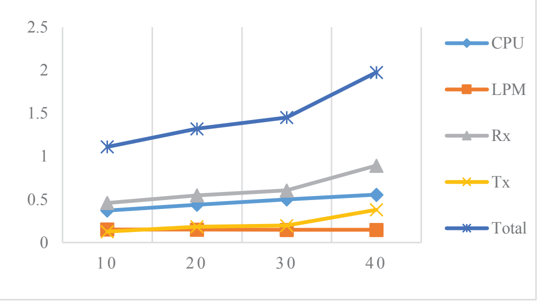

Fig. 9. Power Consumption Usage in 50 m Transmissions Range

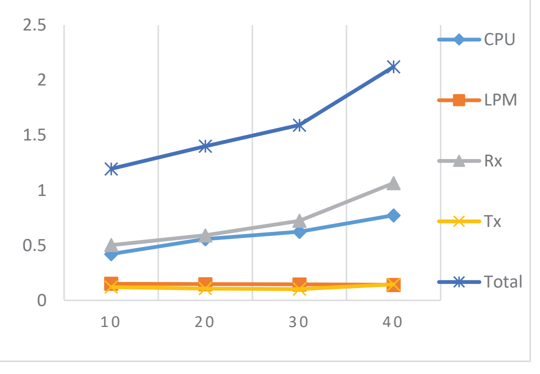

Fig. 10. Power Consumption Usage in 100 m Transmissions Range

The detail comparison between the two TR (50 m and 100 m) for each parameter are shown in Fig 11-14. The result of this study shows that the value of CPU power and Listen power are increased when the number of nodes is increased. Also, the value CPU power and Listen between 50 m TR and 100 m TR is increased significantly. However, it is

Fig.8a. 50m TR with 10 Nodes Scenario

Fig.8b. 100m TR with 10 Nodes Scenario

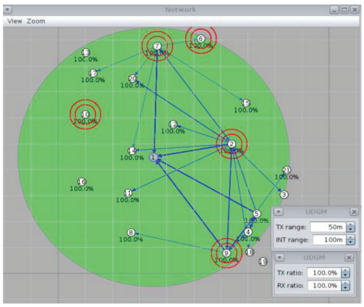

Fig.8c. 50m TR with 20 Nodes Scenario

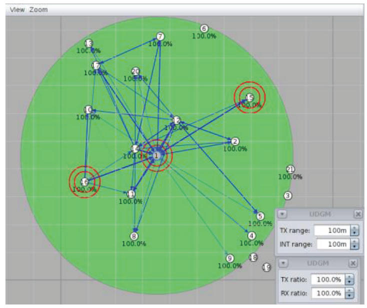

Fig.8d. 100m TR with 20 Nodes Scenario

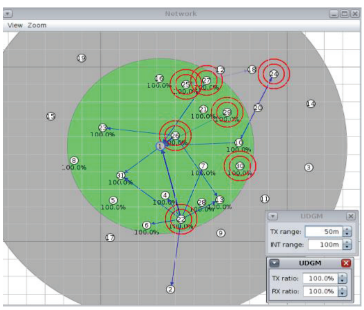

Fig.8e. 50m TR with 30 Nodes Scenario

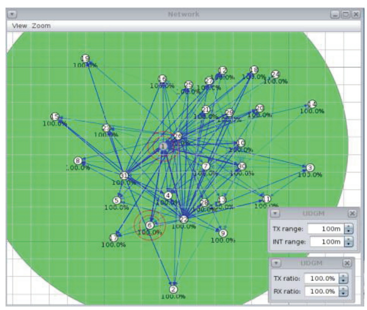

Fig.8f. 100m TR with 30 Nodes Scenario

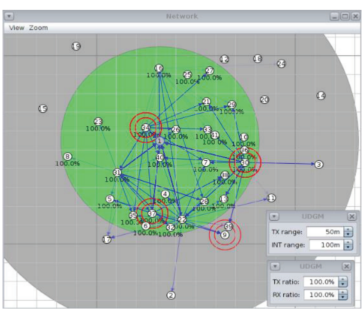

Fig.8g. 50m TR with 40 Nodes Scenario

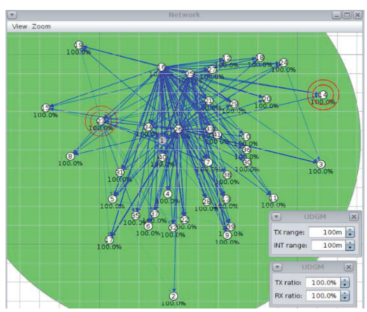

Fig.8h. 100m TR with 40 Nodes Scenario

interesting to note that the value transmits power and LPM Power for 50 TR is less than 100m TR.

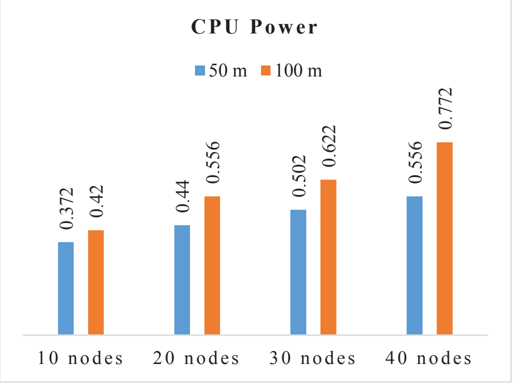

Fig.11. Comparison of CPU Power Between 50m and 100m TR

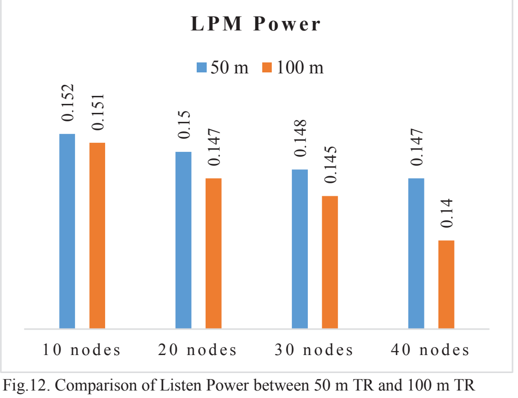

Fig.12. Comparison of Listen Power between 50 m TR and 100 m TR

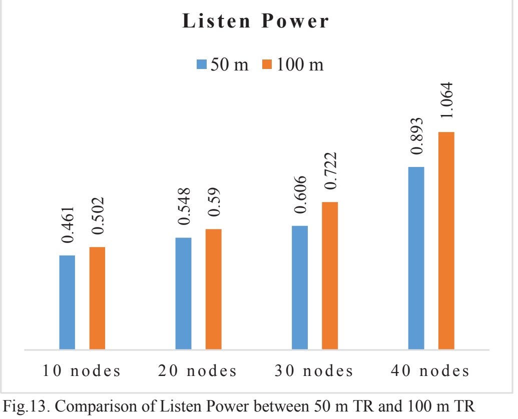

Fig.13. Comparison of Listen Power between 50 m TR and 100 m TR

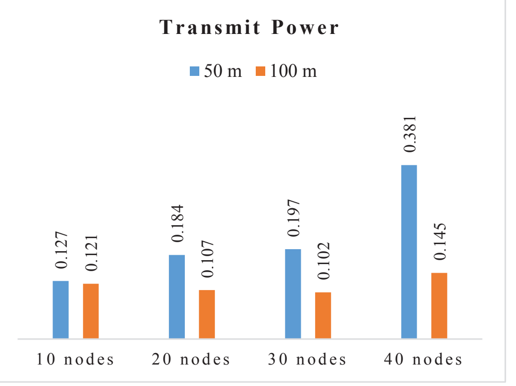

Fig.14. Comparison of Transmit Power Between 50 m TR and 100 m TR

VI. Conclusion

By using a 6LoWPAN based approach, the system could be easily deployed in a building using the low-power IEEE 802.15.4 wireless network, while at the same time connect into the building's existing IT infrastructure to the use of standard Internet protocols. However, the designing of 6LoWPAN network highlights some challenging issues such as operation with short range, low bit rate, low power, low memory usage and low cost. There are some studies on 6LoWPAN protocol for IoT deployment and the result is 6LoWPAN becomes priority network for IP based communication for embedded devices. The result of this study shows the power consumption of nodes are increasing significantly with the number of nodes and TR. However, these results were limited number of nodes is only 40 nodes and suitable for simple LoWPAN architecture. Further research should be done to investigate for large scale network Remarkable advances in enabling technologies for IoT allows the practical implementations of diverse services and applications. Still, there are many open research issues because wireless embedded devices require a high-performance protocol for efficient Internet connectivity.

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