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Problem Analysis of RPL Overhead in 6LOWPAN using 5w1h Model

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***Abstract:** Smart Home (SH) is one of the Internet of Thing (IoT) ecosystem that is experiencing rapid growth, especially in communication and application technologies. However, most applications of SH are embedded devices that are categorized as low power, less memory usage, and limited cost. Therefore, the IPv6 Low Power Area Network (6LoWPAN) is introduced by Internet Engineering Task Force (IETF) in order to fulfill the connectivity requirement of embedded devices. However, the 6LoWPAN standard is restricted to 250 kbps and the frame length is limited to 127 bytes, whereas the packet size over IPv6 is 1280 bytes. Because of this glaring discrepancy, routing becomes the main issues in 6LoWPAN network capability. There is a number of existing routing protocols for 6LoWPAN, and among them RPL is effective in terms of latency and throughput, but the overhead is considerably high when implemented in a large-scale network. Therefore, this study focusses on analysing the causes of RPL overhead in the 6LoWPAN network. For that, this document analysis employed the 5W1H (What, Where, When, Why, Who and How) model in investigating and describing the causes of RPL overhead in 6LoWPAN. The results of this model show four (4) critical parameters needed to be addressed in solving the RPL overhead problem: i) network topology change, ii) limitation of 6LoWPAN, iii) Node failure in the large network and iv) additional transmission information. Furthermore, the future goal of this study is to come up with a novel 6LoWPAN routing protocol algorithm that would be used as high-level technical recommendations for IoT SH ecosystem communication.*

***Keywords** : 6LoWPAN, RPL overhead, 5W1H, Internet of Thing, Smart Home*

I. INTRODUCTION

Nowadays, the development of the Internet of Thing (IoT) application is experiencing a tremendous growth in various fields, especially in Smart Home (SH) [1]. The aim of SH is to improve the quality of life to the people at home [2]. SH provides the environment that facilitates the interaction between the user and the things at home, like home appliances, in which SH maintains a connection with every kind of object, at any given time and anywhere [3]. For example, the SH is designed to improve the safety and security at the house, where all the devices such as smoke detector, human sensor, and CCTV-can be controlled and accessed via the IoT network. However, the rapid development of IoT devices had presented a challenging issue in enabling and maintaining interoperability among the heterogeneous devices and systems [4]. This later would greatly affect the performance of network connectivity between IoT devices when they are to be deployed in large-scale[5]. There are many types of wireless technologies for the IoT environment. For long-range connectivity, there are two technologies that are rapidly developing and available for: SigFox and Cellula; while for short-range connectivity, there are several technologies for consideration, for instance 6LoWPAN, ZigBee, RFID, and Z-Waze. However, this paper would be focussing in detail about the 6LoWPAN network that invariably meets the requirements of IoT devices communication [6]. Most of these devices are embedded devices from a variety of differing vendors, networks, and technologies [7]. Presently, the embedded device is categorised as low power (powered by battery), limited memory usage, tiny size and low cost to be connected to the Internet [8]. The basic architecture for SH using the 6LoWPAN network is shown in Fig. 1 [9].

6LoWPAN is an Internet Protocol (IP) based communications technology in Wireless Sensor Network (WSN) that allows a huge number of embedded devices to be connected via Internet directly (end-to-end communication) and requires no gateway translation [10], in which it could mitigate the huge number of IPv6 address space required for its deployment. However, the limitations of 6LoWPAN network such as its comparatively small frame size (127 bytes compared to IPv6 frame size about 1280 bytes), limited data rates (250 Kbps), limited range (200m), limited battery power (less than 2 years) have inadvertently increased the complexities and challenges in designing the routing algorithm[10], [11].

Thus, the said shortcomings would inevitably degrade the performance of QoS in terms of network lifetime, latency, and throughput for 6LoWPAN network [3], [5]. Therefore, in supporting the 6LoWPAN routing algorithm requirement, the IETF had proposed two types of route-over routing Working Group (WG), which are: i) Routing Over Low power and Lossy (ROLL); and ii) Mobile Ad hoc Networks (MANET). ROLL WG formulates a new protocol for embedded device namely Routing Protocol for Low power lossy network (RPL). Meanwhile, MANET WG presents three (3) standard protocol that support 6LoWPAN routing algorithm such as Ad Hoc On-Demand Distance Vector Routing (AODV), Dynamic MANET On-demand (DYMO), On-Demand Distance Vector (LOAD). Fig. 2 shows the 6LoWPAN'srouting protocols taxonomy [16].

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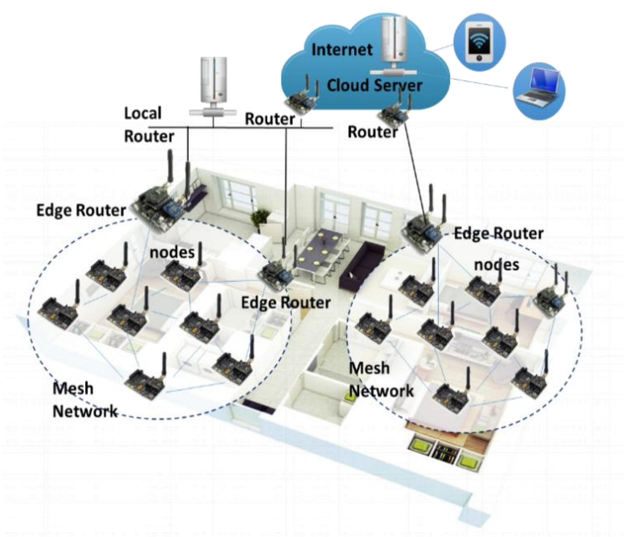


Figure 1: Basic 6LoWPAN architecture for SH [9]

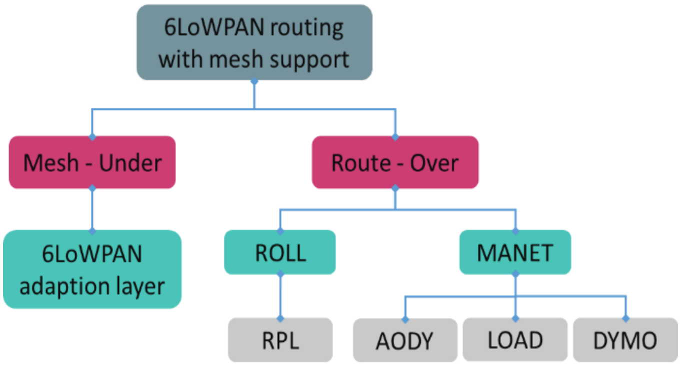


Figure 2: 6LoWPAN Routing Protocol Taxonomy [16]

According to [17], the RPL is expected to be a standard protocol for 6LoWPAN network in IoT environment, like home automation. Supporting the evidence from previous study [12] [14], the RPL routing protocol is effective than MANET in terms of delay and throughput, however its overhead is very high. Nevertheless, based on this result, the RPL protocol is not able to achieve the efficiency performance of Quality of Service (QoS) [18][17]. Therefore, this study focusses in pointing out the causes of RPL routing overhead in the 6LoWPAN network. The result would be used to develop a new routing protocol for enhanced RPL that would provide a more efficient way in communicating with devices, in which later it would improve the QoS of the 6LoWPAN's network performance.

II. AIM AND SCOPE

The aim of this paper is to investigate the causes of RPL overhead in 6LoWPAN by employing the document analysis approach and provide detailed explanation by utilising the 5W 1H model.

III. METHODOLOGY

In order to achieve the objective, the document analysis approach was used. It identified the causes of RPL protocol in 6LoWPAN through previous studies and theories. The selection of studies was based on the number of citations and whether the document has been published in Scopus journal. The collected data were analyzed by using meta-analysis method to get the number of study about the RPL protocol overhead. According to Lee et al. [19], meta-analysis is a method that could create the aggregate of other individual's research result based on several findings that would have some relations between them. Based on this analysis, the infographic in Fig. 5 presented the problem analysis that causes RPL overhead in 6LoWPAN protocol. Then, the explanation according to the 5W (What, Where, When, Why, Who) and 1H (How) model is used in describing and analysing which of the critical parameter needs to be addressed in solving the RPL overhead problem in the 6LoWPAN network.

IV. 5W 1H MODEL

The essence of 5W1H lies in its ability in analysing problems systematically and comprehensively [20] in investigating the specific issue that needs to be solved. It can be used to find the solution in designing a new technique or approach in improving the capability of the existing system. As stated in [21], the 3 steps in implementing the 5W1H model are as follow:

- Analysing the problem in 6 aspects (refer Table 1)
- Formulating the question (refer Figure 3)
- Discussing the question to find the solution (Refer to Section V)

According to [22], the questions that need to be formulated are dependent on the problems found during the implementation of the study. Therefore, it would be reasonable to answer these questions when analysing the problem. Table 1 presents the meaning and policy of 5W1H [21] used in this study as a guideline for researcher to formulate the question to be answered in order to analyse the causes of RPL routing in 6LoWPAN.

Table 1: The Meaning and Policy of 5W1H Model

5W 1 H	Explanation	Policy
What?	Description of the task, the activity, the problem	Analysis
Who?	Determine the stakeholders involved, the people responsible or affected.	manipulator
When	Determine the time when the situation took, takes or will take place.	Time
Where	Describe the place or location involved.	Place
Why	Describe the motivation, or the objective, or the justification or reason behind a selected method of study.	Principle
How	Determine the way to proceed, the steps and method employed.	Solution

Table 2: Findings of RPL Control Overhead Technique Studies in 6LoWPAN

Reff.	Method	OS and Simulator	Approach
[29]	E	NS3	Proposed eN Route (NR) to improve RPL in term of latency and overhead
[30]	S	NS2	Proposed a resource aware routing protocol (RAM-RPL) for heterogeneous wireless networks containing nodes with different resources and capabilities.
[31]	S	Contiki OS & Cooja	Proposed Trickle-based link- quality estimation to provide an accurate link quality estimation with minimal modifications to the existing RPL.
[32]	S	Contiki OS & Cooja	Proposed multi-path RPL (M-RPL) to provide temporary multiple paths during congestion over a path
[33]	SE	TinyOS 2.1 &TOSSIM	Proposed Routing-layer Node Failure Detector (RNFD) to handle link failures relatively by tracking node failures
[34]	SE	Contiki OS & Cooja	Proposed Secure and Efficient Flooding (SEF) to reduce the amount of data transmitted that will causes of overhead.
[35]	SE	Contiki OS & Cooja	Proposed a set of techniques to improve the routing scheme: TRUST + ETX + Second Chance that expected will minimize the number of transmitted packets (#TX).
[36]	SE	Contiki OS 2.5 & Cooja	Proposed solution to the local repair based on a link reversal algorithm (RPL+LR).

* E – Experiment S - Simulation SE – Simulation Experiment

V. ANALYSIS AND RESULT

Fig.4 shows a total of eight previous studies that were focussing on RPL control overhead technique in 6LoWPAN and details of the selected studies are presented in Table 2. The results obtained from the document analysis of RPL Overhead studies in 6LoWPAN are illustrated in Fig. 5. Finally, the detail analysis in using the 5W1H model that was formulated in Section III previously is described in the following subsections.

A. *What is Routing Overhead (RO)?*

RO is the number of routing packets required to transfer bit per packet frame from source to destination[23]. Routing algorithm generates small-sized routing packets, such as HELLO, RREQ, RREP and RERR packets that are used for checking whether the neighbouring node is active or not.

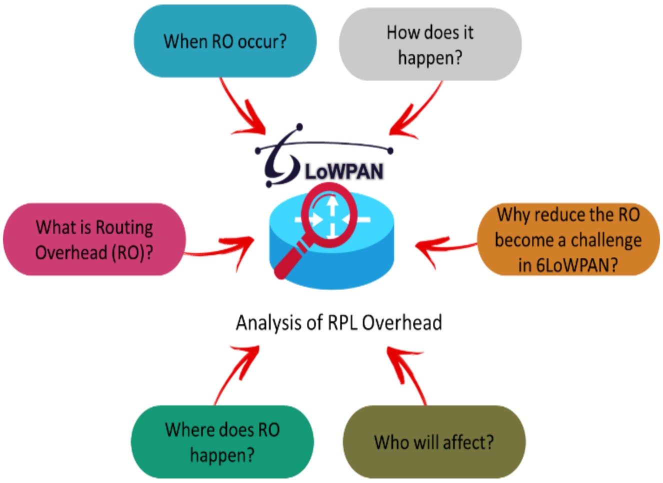


Figure: 3: The Formulated Question

B. *When RO occur?*

Routing packet is considered to be the overhead in the network or the routing overhead when both the routing and data packets have to be shared in the same network bandwidth for most of the time.

C. *Where does RO happen?*

6LoWPAN network.

D. *Why does reducing the RO becomes a challenge in 6LoWPAN?*

The fragmentation of the frames should minimize the RO. However, the limitation of 6LoWPAN length frame has made it compulsory to be compressed to 127 bytes instead of the larger 1280 bytes over the IPv6.

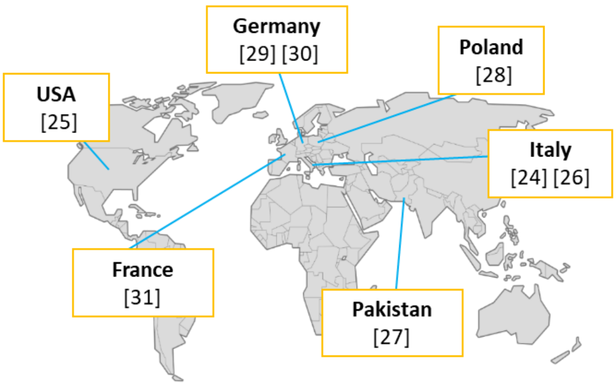
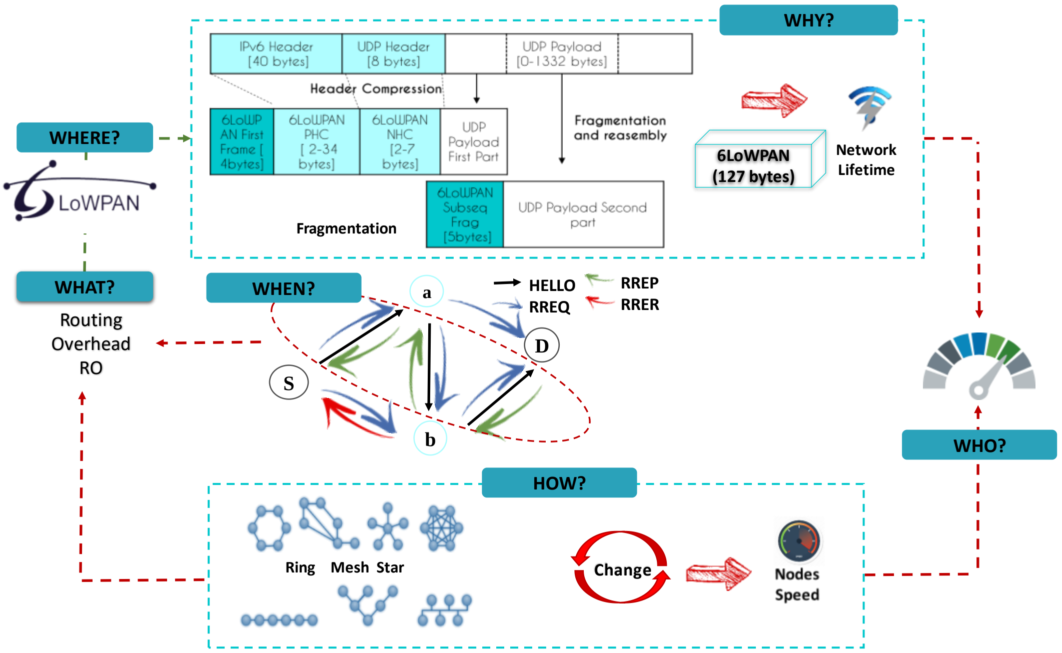


Figure 4: The Number of Studies of RPL Control Overhead Technique in 6LoWPAN



E. *Who would be affected?*

RO significantly affects the performance of 6LoWPAN routing protocol, hence it would impact the performance of the QoS as well.

F. *How does it happen?*

In paper [24], the authors defined the RPL overhead is increasing when the number of nodes is high. This is happening because the nodes are further from the Destination Oriented Directed Acyclic Graphs (DODAGs) root, which resulted in it becomes a root by itself before joining one of the existing graphs. In this case, the nodes are possibly more than one node who had self-nominated itself as a root contemporary. As a result, these nodes received more than one HELLO packets from different Edge Routers (ER) when connectivity is achieved, and through this scenario the occurrence of routing overhead had been realised. The results that were exhibited in this paper showed that RPL overhead was increasing linearly with the node's speed movement. The authors in [25] pointed out that the difference in resources and capabilities of the node performance in different routing function is the cause of the RPL overhead. As [26] pointed out, RPL routing could be high because of the limitation of 6LoWPAN [10] frame size in large networks. The fragmentation and reassembly mechanisms and compression techniques used in an adaption layer could drain the limited amount of power available to each node. This condition would cause the nodes to fail. The RPL utilised different types of control message to build routes either from node to root (upward routes) or from root to the node (downward routes) as shown in Figure 6.

However, RPL features do not support mixed modes of operation (MOP) for all routers in a network. In fact, the routing overhead is increased when the nodes might discover a new route and send more control message. Furthermore, RPL drops more data packets due to buffer overflow[27]. In contrast, the RPL routing in 6LoWPAN network needs to increase its throughput to minimize the routing overhead. Reference to [28] revealed that a standard RPL approach does not define a specific solution for handling node failures. When the nodes crashed, the routing overhead would be increased, in which it would cause the router to try repeatedly to forward nodes over the dead link to the root. In this case, the nodes would reply the HELLO message to the ER by sending the un-Acknowledged Message (ACK) to select another preferred parent. As a consequence, the demand for energy would be increasing in response to the ACK retransmission, and also because the less efficient root is chosen. As a result, the network lifetime is decreased.

Both [29] and [30] have expressed a similar view in their report that RPL does not detect the non-reliable links that are causing the information gap in the delivery rate of the route, from which the overhead transpired into the network. Consequently, the energy consumption of RPL would be high, notwithstanding the fact that in a 6LoWPAN network the battery power is limited, hence constricting the capability of the RPL even further. Furthermore, the study in [31] has drawn attention to the fact that RPL overhead is increased when the network topology changes. This is because of the trickle timer [32] used generated many DIOs in order to maintain the route consistency. In a nutshell, the RPL routing overhead increased according to the changes in the network topology, and also when the possibility of an additional information transmission is higher. In addition, the RPL overhead significantly increased when the speed movement of node increased. When the nodes are moving, there is a corresponding increase of routing overhead, and this overhead is affected by the speed of the movement.

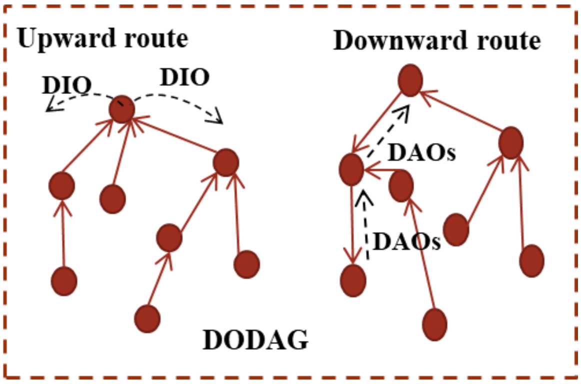


Figure 6: RPL Control Message Route

VI. DISCUSSION

The RPL generates several routing messages, such as (DODAG Information Object (DIO), DODAG Information Solicitation (DIS), User Datagram Protocol (UDP), and CLR) and maintains a DODAG as a default route to allow a node to send a packet to any destination in the network. The last nodes will rebroadcast the last DIO sent by root, and thus, the number of bytes are transmitted adequately over the Internet. However, if the nodes do not have the next hop for the destination, the root sends the RREQ message over the DODAG to find the route, and this will significantly reduce the number of RREQs issued in the network. The usage trickle timer helps RPL to reduce the overhead at the cost of an increased time to wait and forward DIOs. However, when the topology changes, the trickle timer resets the DIO interval to respond, and it generates many DIOs and does not handle the routing destination crash failures. Due to this condition, the overhead of RPL routing is increased and at the same time it would reduce the number of bytes transmitted.

Concisely, in optimising the network performance, the routing overhead must be reduced, while at the same time the nodes speed must be increased. However, the size of the control packet frame should not be crossed with 6LoWPAN's standard frame size. This is because it would make designing the routing protocol more challenging, as the standard frame size for 6LoWPAN is compressed to 22/33 octets with a packet size of 127 bytes. In addition, the reduction of routing overhead would significantly reduce the power consumption transmission of packet frame that would affect the network lifetime. Conversely, the 6LoWPAN network lifetime could be increased, and at the same time the power consumption of the embedded device could also be lowered. In a nutshell, there are four (4) major challenges that need to be taken into account in designing the extended RPL routing protocol in 6LoWPAN for IoT ecosystem, which are:

1. Network topology change
2. Limitation of 6lowpan
3. Node failure in the large network
4. Additional information transmission

VII. CONCLUSION AND FUTURE WORK

In this paper, the review was done in analysing the cause of RPL overhead in a 6LoWPAN network by using the 5W1H model. Based on the report, the existing technique was still considered unable in achieving the efficient performance of QoS in 6LoWPAN network. Therefore, this study focusses on finding out the causes of RPL overhead that would need to be addressed in enhancing the RPL protocol. For future study, the future researcher would need to investigate and find the effective solution for the additional information transmission when network topology changes and node failure in large scale networks in order to adapt when designing RPL algorithm to improve the QoS performance of 6LoWPAN.

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