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A STUDY ON PROTOCOL STACK IN 6LOWPAN MODEL

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ABSTRACT

Due to recent advances of heterogeneous network and the emergence of Internet of Things (IoT), wireless personal area networks including wireless sensor networks are assumed to be part of the huge heterogeneous network. This calls for a smooth integration between the higher network layer protocols Internet Protocol version 6 (IPv6) and the lower media access control (MAC) layer protocol IEEE 802.15.4. IEEE 802.15.4 is a standard that specifies the physical layer and MAC layer for Wireless Personal Area Network (WPAN). This standard is suited for Low-Rate Wireless Personal Area Networks (LR-WPANs), a constrained network of tiny, low power, low rate, small size memory with low computation and communication capabilities. However, IPv6 is forming the backbone of the desired heterogeneous network. Direct integration between IPv6 and IEEE 802.15.4 lower network layers is not possible. Hence, latest technology development is the transmission of IPv6 packets over Low-power Wireless Personal Area Networks (6LoWPAN). This has enforced some modification to the existing protocol stack and introduced the 6LoWPAN protocol stack. The 6LoWPAN protocol stack involves 802.15.4 physical (PHY) and Medium Access Control (MAC) layer, 6LoWPAN adaptation layer, network layer, transport layer and application layer with specific 6LoWPAN application. This review paper describes all layers in 6LoWPAN protocol stack including its routing protocols, namely the Route-over and Mesh-under. These routing schemes are applied in 6LoWPAN adaptation layer and network layer.

Keywords: *6lowpan, Protocol Stack, Adaptation Layer, MAC, PHY*

1. INTRODUCTION

Sensor node is the emergence of new technologies is a small, low-power, low-cost and multifunctional devices. These tiny devices are capable of sensing, computation (signal processing) and wireless communication capabilities. In some applications, these sensors can be mobile. Mobility issues have been discussed in [1]. Collaboration between the sensor nodes is capable of producing powerful wireless networking systems known as Wireless Sensor Nodes. However, the use of Internet Protocol (IP) in these networks has embarked on the development of Internet Protocol version 6 (IPv6) over Low power Wireless Personal Area Networks (6LoWPAN). 6LoWPAN defines that layering of IPv6 over low-power, low bandwidth, low-cost and small network by IEEE 802.15.4 standard. There are many main issues related to 6LoWPAN, including the IP connectivity, topologies, limited packet size, limited configuration and management, service and security discovery [2].

Basically, 6LoWPAN protocol stack are comprises of 802.15.4 physical (PHY) and medium access control (MAC) layer, adaptation layer, network layer, transport layer and application layer. Now days, many research on these layers have been made and analyze. 802.15.4 PHY and MAC are exactly similar to ZigBee protocol standard. In this paper, review of protocol stacks in 6LoWPAN is identified and some routing protocols are involved.

There have been a few developments on routing protocols for 6LoWPAN and it can be categorized into two routing schemes: Route-over and Mesh-under. Some protocols for mesh-under are described as below. The 6LoWPAN Ad-Hoc On-Demand Distance Vector Routing protocol (LOAD) has been proposed in [4]. LOAD is a simplifies routing protocol based on Ad hoc On-Demand Distance Vector (AODV) for 6LoWPAN. This routing protocol is a single path routing protocol. It enables multi-hop routing between IEEE 802.15.4 devices to establish and maintain routing routes in 6LoWPAN.

Besides that, Dynamic MANET On-demand for 6LoWPAN Routing (DYMO-low) [5] is another

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6LoWPAN routing protocol that based on Dynamic MANET On-demand (DYMO). DYMO-low positioning is underneath of IP layering in creating a mesh network topology of IEEE 802.15.4 devices. It use single wireless interface underneath and unbeknownst to IP. The significant feature in DYMO-low is it can support either 16-bit link layer short address or IEEE 64-bit extended address (EUI-64).

On the other hand, considering low power, low memory, low bandwidth and small packet size of the 6LoWPAN devices, the on-demand multi-hop routing with routing table and EUI-64 identifier may limit the scalability. Hierarchical Routing for 6LoWPAN (HiLow) is employed in 6LoWPAN because of the capability of the dynamic assignment of 16-bit short addresses [6]. Extensively, it reduces the overhead of maintaining routing tables and support larger scalability.

2. 6LoWPAN OVERVIEW

6LoWPAN is an abbreviation of IPv6 over Low Power Wireless Area Networks. The specification of 6LoWPAN involves the transmission of IPv6 over IEEE 802.15.4 network. The original idea is that the Internet Protocol can be applied to the tiny and lightweight devices [3]. Figure 1 shows 6LoWPAN position in the network hierarchy. A wireless personal area network (WPAN) is types of wireless networking. It is a network for interconnecting devices around specific workspace where the connections are wireless. Network layer addressing scheme can be categorized into, the fourth and sixth revisions in the development of the Internet Protocol (IP), IPv4 and IPv6 respectively. Since the futuristic IPv6 protocol was created to supersede and replace IPv4, in conjunction with the revolution of heterogeneous network and internet of things, 6LoWPAN came to life avoiding creation of unborn 4LoWPAN protocol.

The main difference between 6LoWPAN and OSI protocol stacks is the emergence of adaptation layer. This layer is assumed to perform fragmentation/reassembly, header compression and mesh addressing which will be addressed later in this paper.

2.1 IPv4 and IPv6

IPv6 known as Internet Protocol version 6 designed through an operation by transferring data in small packets that are independently routed across networks as specified by international communications protocol. The exhaustion of IPv4 address as predicted by the Address Lifetime Expectation (ALE) working group would occur between 2005 and 2011 [12]. Since, IPv4 defines a 32 bit address is meant that, there are 2^32 (4 294 967 296) unique address available. However, most of the addresses are already occupied and the Internet is simply running out of IPs. Then, IPv6 is developed based on experience of developing IPv4. It is designed to handle the growth rate of the Internet [13]. There are a few advantages of IPv6 over IPv4 that can be highlighted in table 1.

2.2 IEEE 802.15.4

IEEE 802.15.4 is a standard that specifies the physical (PHY) layer and media access control (MAC) layer for smallest devices in wireless personal area network. The characters and its description of IEEE 802.15.4 standard are listed below [11]:

- Low bandwidth specifies the difference data rates of 250 kbps, 40 kbps, and 20 kbps for each defined physical layers 2.4 GHz, 915 MHz and 868 MHz.
- Low power specifies that some or all devices are battery operated.
- Low cost specifies that these devices collaborating with sensors which adopt low processing capabilities and low memory usage.
- Distance covered from the range of 10 m to 100 m, typically it is in small room, small area of specific location.
- Devices involved are the Full Function Device (FFD) and Reduced Function Device (RFD). FFD will act as a coordinator and router. The coordinator will form networks and route packets, the router will routes packet. RFD is the end device which will act as a sensor and used to be sleep mode.
- Two types of modes involved by MAC layer are beacon enabled and non-beacon modes [11].

With this, the IETF working group insinuating IPv6 over low rate, low power, low cost which adopt physical layer and MAC layer of IEEE 802.15.4 standard. Figure 2 shows the architecture of a device in accordance with the IEEE 802.15.4 standard and has the characteristics of low power, low memory usage and low cost. Transmission of data packets by a RFD or a low power processing in sensor nodes to outside 6LowPAN will be forwarded through FFD. The FFD will act as a router in 6LowPAN and forward the data to the gateway of 6LowPAN. Gateway of 6LowPAN that connects with IPv6 domain will forward data packets to the receiver's devices using IP address [3].

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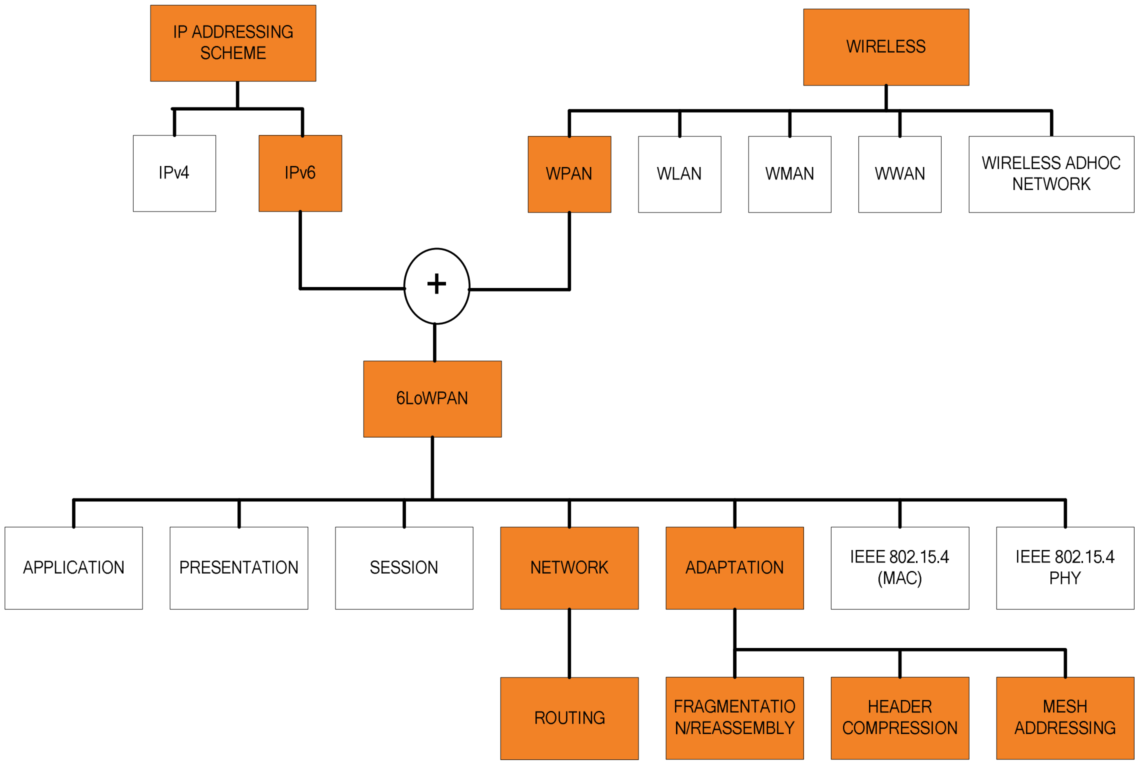

Figure 1. 6LoWPAN in networking

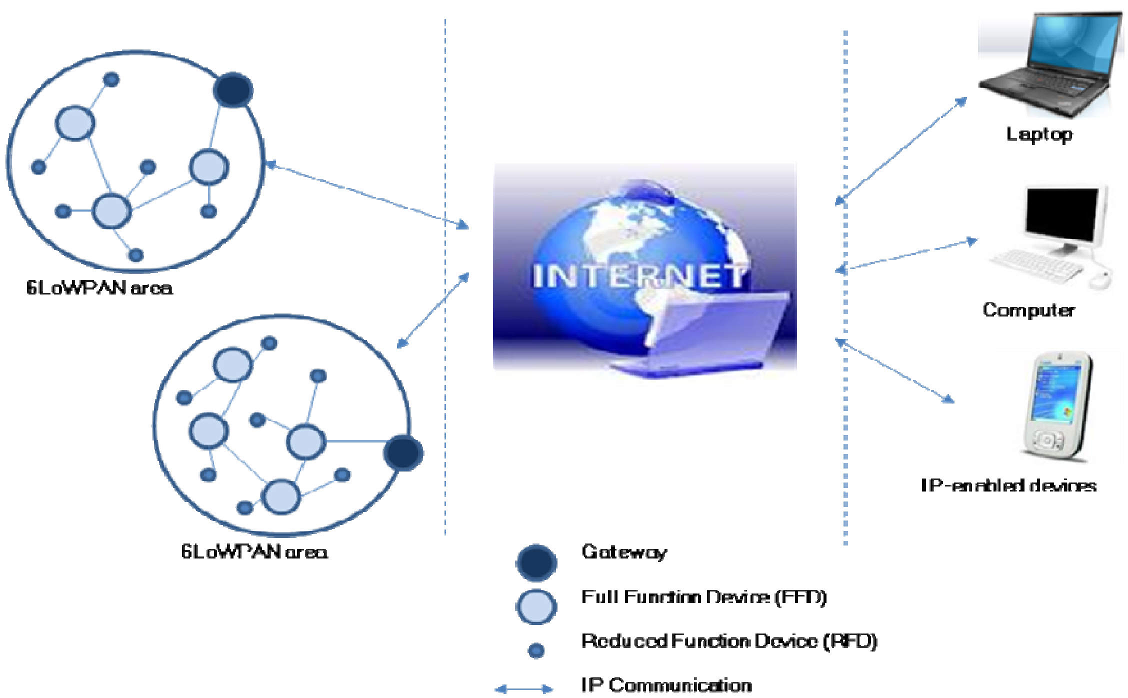

Figure 2. 6LoWPAN overview

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Table 1. Comparisons of IPv6 and IPv4 based on main features[14]

	IPv4	IPv6	IPv6 Advantages
Address Space	2^{32} address space	2^{128} address space	More address space
Routing (packet fragmentation)	End station and routers	End station	Faster routing
Mobility	Need agent & used MIPv4	No agent & used MIPv6	Faster handover
Quality of Services	High latency & differentiated services	Low latency & Use traffic classes & flow labels	Enhanced support
Security	Site-to-site secure communications	End-to-end secure communications	More secure
Auto Configuration of Hosts	Need configuration	Plug-and-play	Faster configuration
Checksum in header	Included	No checksum	Faster routing
Header includes options	Required	Moved to IPv6 extension headers	Faster routing
Fragmentation	Routers & source node	Source node	Faster routing
IP configuration	Manually or DHCP	Auto-configuration or DHCP	Speed up connection
IPSec support	Optional	Required	Better security
Unicast, multicast and broadcast	Use all	Uses unicast, multicast and anycast	Less packet traffic
Address Resolution Protocol (ARP)	Use to resolve an IPv4 address	Replaced by neighbor Discovery	Less packet traffic

Figure 3a. and 3b. explain the differences of the OSI Layer Model and the reference model of 6LoWPAN protocol stack. It adopts IEEE 802.15.4 standard PHY and MAC layers which are specified in [3]. 6LoWPAN Model consists of application layer, presentation layer, session layer, transport layer, network layer, IEEE 802.15.4 MAC layer and IEEE 802.15.4 PHY layer. This paper will address all layers in 6LoWPAN. However, the main idea is to emphasis the network layer and adaptation as it is the main framework of 6LoWPAN.

3 6LOWPAN STACK LAYERS

6LoWPAN stack layers consist of PHY layer, MAC layer, adaptation layer, network layer, transport layer and application layer. Basically, it employs how the IEEE 802.15.4 devices to communicate with each other over a wireless channel.

3.1 6LoWPAN Physical Layer

The 6LoWPAN PHY layer provides two services: the PHY data service and the PHY management service interfacing to the physical layer management entity (PLME) service access point (SAP) known as the PLME-SAP [8].

The PHY data services ultimately provides transmission and reception of data packets between MAC and PHY across the physical radio channel, as well as the PHY management service interface, which offers access to every layer management function and maintains a database of information on related personal area networks. It is based on IEEE 802.15.4 with data rate of 250 kbps and operates at frequency of 2400 – 2483.5 MHz. Figure 4 shows the PHY layer protocol data unit of IEEE 802.15.4 is compliant with a maximum payload of 127 bytes.

The PHY is prefixed prefixed by a Synchronization Header (SHR) fields encompasses the Preamble Sequence and Start of Frame Delimiter fields, and a PHY Header (PHR) encompasses of Frame Length/Reserved. The SHR condone the receiver to achieve symbol synchronization. As a result, the SHR, PHR, and PHY payload form PHY packet.

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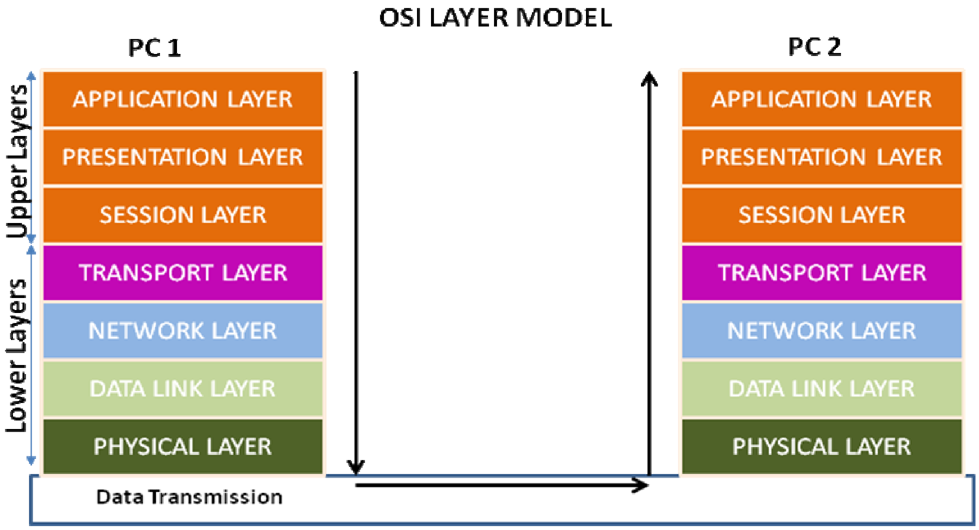

Figure 3a. OSI layer model

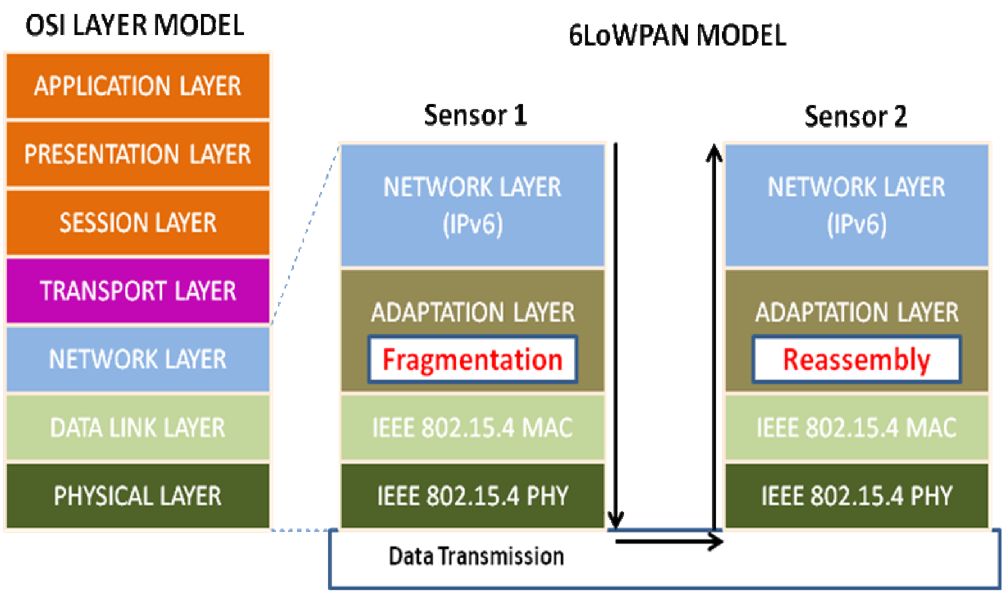

Figure 3b. Comparison of 6LoWPAN layer model and OSI layer model

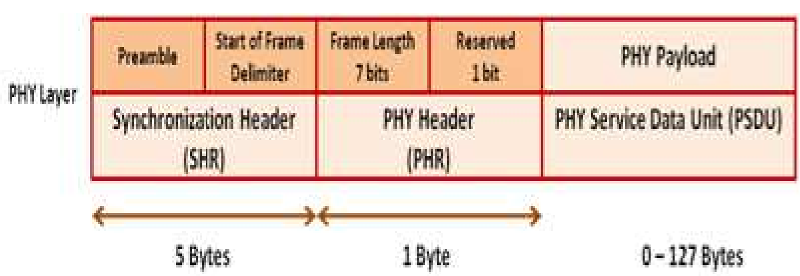

Figure 4. IEEE 802.15.4 PHY Packet Structure

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3.2 6LoWPAN Data Link Layer

The 6LoWPAN Data Link Layer, which is the MAC sub-layer, provides two services: the MAC data service and the MAC management service interfacing to the MAC sub-layer management entity (MLME) service access point (SAP) (MLMESAP). The MAC data service is to let the transmission and receiving of MAC protocol data units (MPDU) across the PHY data service. In IEEE 802.15.4 standard defined 4 frame structures for MAC layer: data frame, beacon frame, acknowledgement frame and MAC command frame.

Basically, MAC data frame is used for data transferring, MAC beacon frame is generated by coordinator for synchronization, MAC command frame is used by MAC management entity and MAC acknowledgement frame will acknowledge successful reception of the frame. Figure 5 explain the general MAC frame format.

Figure 5 shows MAC Header (MHR) has frame control, sequence number and address information fields. The addressing field contains source and destination of PAN and its address. The information of IPv6 is allocated in the payload which is the MAC service data unit (MSDU). Then, the MFR has Frame Check Sequence (FCS). The MHR, MSDU and MFR form the general MAC frame format.

3.3 6LoWPAN Adaptation Layer

The 6LoWPAN format delineate on IPv6 communication is carried in 802.15.4 frames and specifies the adaptation layer's key elements. 6LoWPAN has three primary elements:

- Fragmentation and Reassembly

IPv6 packet size over IEEE 802.15.4 is 1280 bytes [7]. However, the packet size is larger than IEEE 802.15.4 frame. In this condition, IPv6 packet size unable to be encapsulated in one IEEE 802.15.4 frame. 802.15.4 protocol data units have variety of sizes. It depends on the overhead occurred [8]. Maximum Transmission Unit (MTU) for IEEE 802.15.4 is 127 bytes. This frame has 25 bytes, header, footer and addressing, overheads. In addition, security header imposed by Link Layer adds 21 bytes overhead when AES-CCM-128 is used. As a result, the remaining for payload is 81 bytes as shown in figure 6a and 6b.

Due to this matter, one IPv6 that need to be transmitted over IEEE 802.15.4 frame has to be divided to more than 16 fragments. Hence, adaptation layer should handle these fragmentation and reassembly process.

- Header Compression

IEEE 802.15.4 defines four types of frames: beacon frames, MAC command frames, acknowledgement frames, and data frames [7]. Figure 7 shows IPv6 packets must be carried on data frames. After the packet is fragmented and transmitted over IEEE 802.15.4 frames, each fragment carries a part of the original IPv6 packets. The IEEE 802.15.4 frame which has a maximum packet size of 128 bytes; instead IPv6 header size is 40 bytes, User Datagram Protocol (UDP) and Internet Control Message Protocol (ICMP) header sizes are both 4 bytes, fragmentation header add another 5 bytes overhead. Without compression, 802.15.4 is not possible to transmit any payload effectively.

- Routing

There are a number of existing routing protocols in 6LoWPAN like: 6LoWPAN Ad-hoc On-Demand Distance Vector (LOAD), Multipath based 6LoWPAN Ad-hoc On-Demand Distance Vector (MLOAD), Dynamic MANET On-Demand for 6LoWPAN Routing (DYMO-Low), Hierarchical Routing (Hi-Low), Extended Hi-Low and Sink Ad-hoc On-Demand Distance Vector Routing (S-AODV).

3.4 6LoWPAN Network Layer

The 6LoWPAN network layer provides the internetworking capability to sensor nodes. The main considerations of this layer are addressing, mapping and routing protocols. As described earlier, mesh-under routing decision occurs in 6LoWPAN adaptation layer. On the other hand, route-over routing decision occurs in 6LoWPAN network layer.

Figure 8 shows routing decision layer for both mesh-under and route-over routing protocols. The main differences of routing issues in route-over and mesh-under schemes are in packet/fragment forwarding process rather than route establishment phase. In route-over scheme, each link layer hop is an IP hop and each node acts as IP router. The packet is forwarded hop by hop from source to destination between these links. The packet's payload is encapsulated in IP header.

Later, IP packet is fragmented and the fragments are sent to the next hop based on routing table information. If the adaptation layer in the next hop received all the fragments successfully, then it

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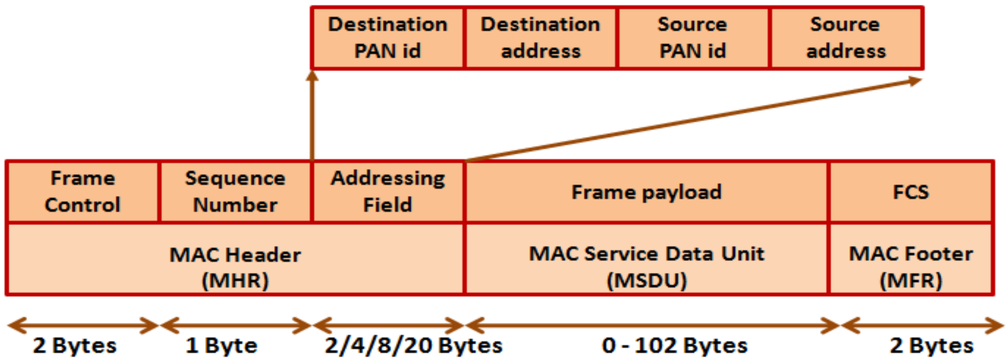

Figure 5.General MAC frame format

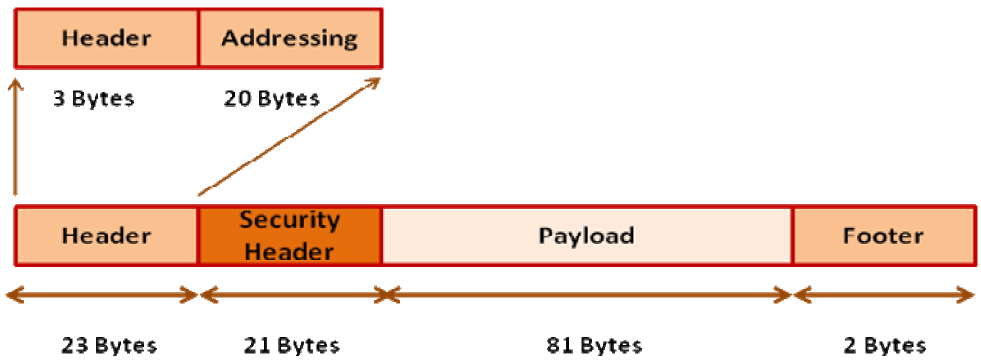

Figure 6a. IEEE 802.15.4 frame format

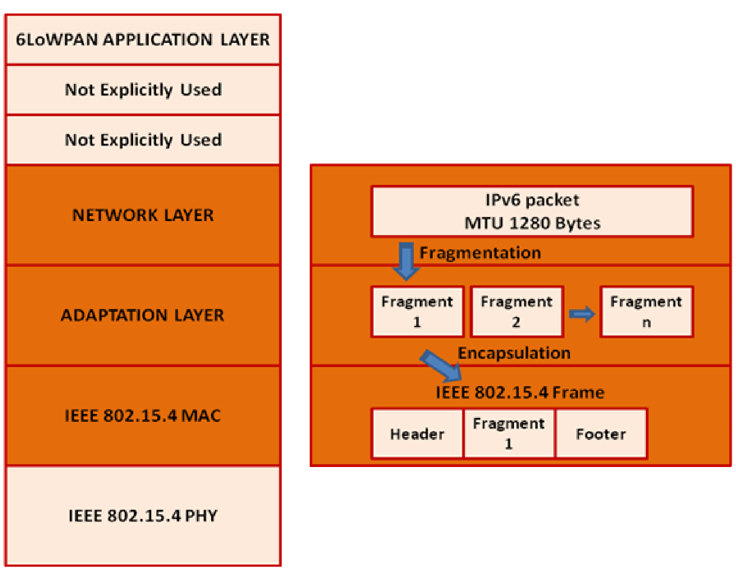

Figure 6b. IEEE 802.15.4 frame format

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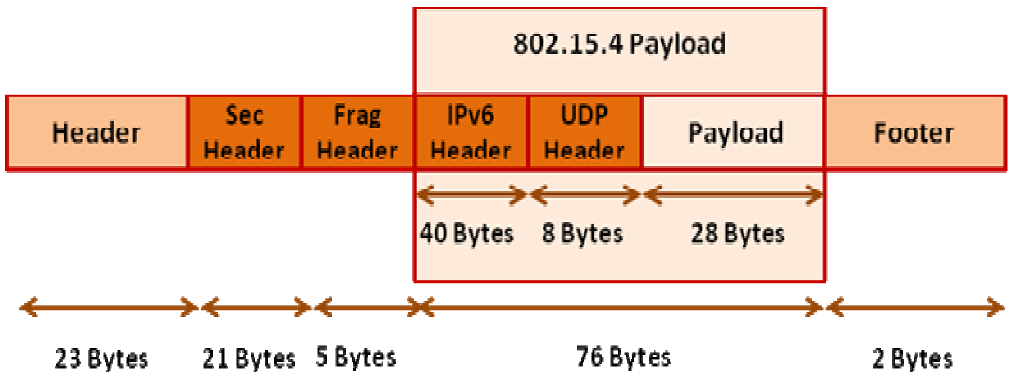

Figure 7. IEEE 802.15.4 frame format

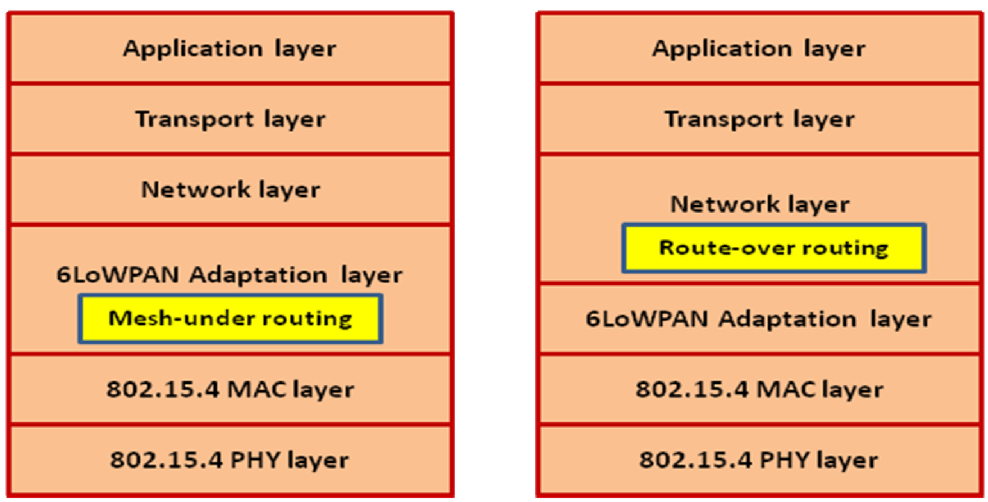

Figure 8. Routing decision layer

creates an IP packet from fragments and sends it up to the network layer. After that, the network layer sends the packet to the upper layer (transport layer), if the packet is destined for it. Otherwise, it forwards the packet to the next hop according to the routing table information. However, if there are some fragments missing, all fragments are retransmitted to one hop distance.

3.5 6LoWPAN Transport Layer

Similar to the transport layer in OSI model, 6LoWPAN transport layer is responsible for process-to-process delivery. It delivers data segment to the appropriate application process on the host computers. In this layer, there are two types of transport protocols; User Datagram Protocol (UDP) and Transmission Control Protocol (TCP). At the source side, either TCP or UDP connections is established based on the application. Hence, either TCP or UDP processes is created. The data from application layer is organized in either UDP or TCP segments and attached to created process (TCP or UDP processes). At the destination side, after the UDP or TCP segments is received from the network layer, the transport layer processes the segment probably based on the protocol used and send it up to the application layer. However, the most common protocol applied with 6LoWPAN is the UDP [10]. In aspect of performance, efficiency and complexity, TCP is not preferably used with 6LoWPAN.

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3.6 6LoWPAN Application Layer

The 6LoWPAN application layer uses a socket interface for a specific application. From figure 9 below, each 6LoWPAN application opens a socket which is then used to receive or send packets. Each socket is associated with a protocol, TCP or UDP, and source and/or destination ports [9].

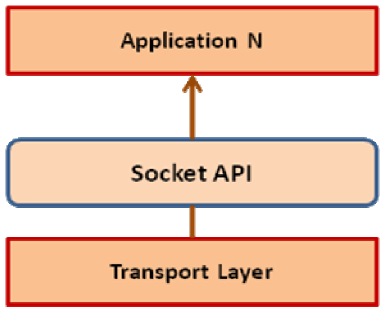

Figure 9. 6LoWPAN application uses a socket interface for a specific application

4 CONCLUSIONS

This paper describes the emergence of 6LoWPAN due to heterogeneous network. We have reviewed the 6LoWPAN, integration between higher network layer protocol of IPv6 and lower MAC layer protocol of IEEE 802.15.4. Hence, it enforces some modification in the existing protocol stack and introduce 6LoWPAN protocol stack. Moreover, some comparisons between IPv4 and IPv6 have been made and reviewed. Besides that, two routing scheme was identified: Route-over and Mesh-under and these schemes are applied in 6LoWPAN adaptation layer and network layer.

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