Interoperability of LoWPANs Based on the IEEE802.15.4 Standard through IPV6

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Abstract

The role and the increasing demand for wireless communications industry in recent years has increase the design of standards and the development of technologies which are appropriate to LoWPAN networks. The industry and researchers has now spread beyond the office and home to include new environments such as factories, hospitals, smart metering, and agriculture. This trend of deploying LoWPAN and their connectivity to the Internet is in line with the achievement of the concept of Internet of Things.

The aim of this paper is to present two major LoWPAN technology, namely the Zigbee and 6LoWPAN, to describe theirs protocols and architectures, and to explore the possibility of interconnecting the 6LoWPAN and Zigbee through IPv6 in order to make them interoperable and seamless for the end user, so it gives an idea about the Internet of Things over IPv6.

Keywords: *IEEE 802.15.4, LoWPAN, 6LoWPAN, ZigBee, Internet of Things, Gateway.*

1. Introduction

The Institute of Electrical and Electronics Engineers or IEEE is an international non-profit, professional organization for the advancement of technology related to electricity. It has the most members of any technical professional organization in the world. The IEEE Standards Association has a portfolio of more than 900 active standards and more than 400 standards in development [1].

This includes the prominent IEEE 802 standards for wireless networking. The IEEE 802 standard is dedicated for Local Area Networks (LAN) and Metropolitan Area Networks (MAN) carrying variable-size packets. The services and protocols specified in IEEE 802 map to the lower two layers (Data Link and Physical) of the seven-layer OSI networking reference model. In fact, IEEE 802 splits the OSI Data Link Layer into two sub-layers named Logical Link Control (LLC) and Media Access Control (MAC) [2], so that the layers can be listed like this:

- Data link layer
  - LLC Sublayer
  - MAC Sublayer
- Physical layer

The most widely used IEEE 802 standards are the Ethernet family (802.3), Token Ring (802.5), Wireless LAN (802.11), Wireless PAN (802.15) and WiMAX also called Broadband Wireless Access (802.16).

Researchers and industrials are focused to carry IPv6 over the IEEE 802.15.4 standard for low-rate wireless personal area networks (LR-WPAN) in order to deploy wireless sensor networks and embedded systems, and in order to achieve the Internet of Things over IPv6.

Therefore this paper is focused on the technologies over IEEE 802.15.4. First, we will present the IEEE 802.15.4 standard, then we will introduce the two majors LoWPAN technologies based on this standard: the Zigbee and the 6LoWPAN, theirs protocol stack and architectures. Also, we will describe the challenges/approaches for interconnecting Zigbee and 6LowPAN networks. Finally, we will introduce the concept for interconnection LoWPAN networks over IPv6 in the context of designing a world of Internet of Things.

2. IEEE 802.15.4 standard

The IEEE 802.15.4 LR-WPAN task group is charged with developing a standard for Low-Rate Wireless Personal Area Networks (LR-WPANs). It is still a new technology as the IEEE Standards board has approved IEEE 802.15.4 draft 18 on May 12, 2003.

Generally speaking, the applications that IEEE 802.15.4 addresses are characterized by their requirements for low power consumption and low cost of deployment.

The mains properties of IEEE 802.15.4 are described in the following table 1:

Property	**Range**
Raw data rate	868 MHz: 20 kb/s; 915 MHz: 40 kb/s; 2.4 GHz: 250 kb/s
Range	10 - 20 meters
Channels	868MHz: 1 channel; 915 MHz: 10 channels; 2.4 Ghz: 16 channels
Frequency band	Two PHYs: 868 MHz/915 MHz and 2.4 GHz
Addressing	Short 16-bit or 64-bit IEEE
Channel access	CSMA-CA and slotted CSMA-CA
Temperature	Industrial temperature range -40 to +85 C

Table 1: **Summary of main properties [3]**

Other main characters of IEEE802.15.4 standard are listed below [4]:

- Low power: Small batteries for months or even years.
- Low cost: Usually using the low-end embedded device of limited hardware resource
- Multiple types Device: Full Function Device (FFD) and Reduced Function Device (RFD)
- Multiple modes: Two transmission modes are defined by MAC layer:

LR-WPAN based on IEEE802.15.4 differs from others wireless technologies standards (WLAN and WPAN) as described on table 2:

	WLAN (802.11)	**Bluetooth-based WPAN (802.15.1)**	**Low-rate WPAN (802.15.4)**
Range	~100 m	~10 - 100 m	~10 m
Data throughput	~2 - 11 Mbs	~1 Mbs	~0.25 Mbs
Power consumption	Medium	Low	Ultra low
Size	Larger	Smaller	Smallest
Cost/complexity	>6	1	0.2

Table 2: A comparison of LR-WPAN with other wireless technologies [5]

2.1 LR-WPAN Architecture

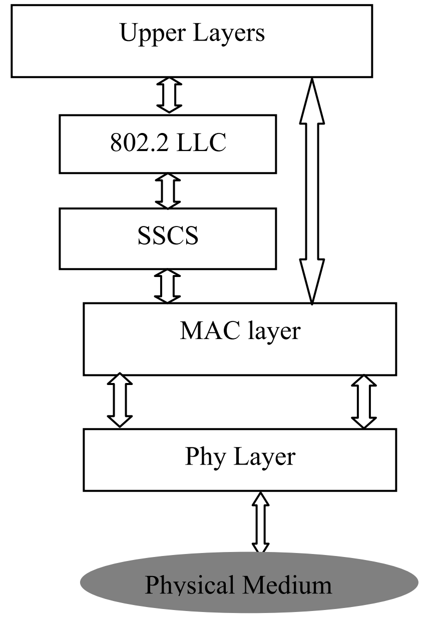

Figure 1: LR-WPAN Device Architecture [6]

Figure 1 shows an LR-WPAN device. The device comprises a PHY, which contains the radio frequency (RF) transceiver along with its low-level control mechanism, and a MAC sublayer that provides access to the physical channel for all types of transfer. The upper layers consists of a network layer, which provides network configuration, manipulation, and message routing, and application layer, which provides the intended function of a device. An IEEE 802.2 logical link control (LLC) can access the MAC sublayer through the service specific convergence sublayer (SSCS).

The IEEE 802.15.4 physical layer specification:

The PHY provides two services: the PHY data service and PHY management service interfacing to the physical layer management entity (PLME). The PHY data service enables the transmission and reception of PHY protocol data units (PPDU) across the physical radio channel. The feature of the PHY are managing the physical RF transceiver and performing channel selection and energy and signal management functions. It operates on one of three possible unlicensed frequency bands: 868.0-868.6 MHz, 902-928 MHz and 2400-2483.5 [6].

The IEEE 802.15.4 MAC layer specification:

The MAC sublayer handles all access to the physical radio channel and is responsible for the following tasks [6]:

- Generating network beacons if the device is a coordinator
- Synchronizing to network beacons
- Supporting PAN association and disassociation

- Supporting device security
- Employing the CSMA-CA mechanism for channel access
- Handling and maintaining the GTS mechanism
- Providing a reliable link between two peer MAC entities

The MAC sublayer provides an interface between the SSCS and the PHY. The MAC sublayer conceptually includes a management entity called the MLME. This entity provides the service interfaces through which layer management functions may be invoked. The MAC sublayer provides two services, accessed through two Service Access Point SAPs:

- The MAC data service, accessed through the MAC common part sublayer (MCPS) data SAP (MCPS-SAP), and
- The MAC management service, accessed through the MLME-SAP.

2.2 Network topologies of IEEE802.15.4

IEEE 802.15.4 defines four types of frames: beacon frames, MAC command frames, acknowledgement frames, and data frames. IPv6 packets must be carried on data frames. Data frames may optionally request that they be acknowledged. The standard uses the star and mesh topology as below [6]:

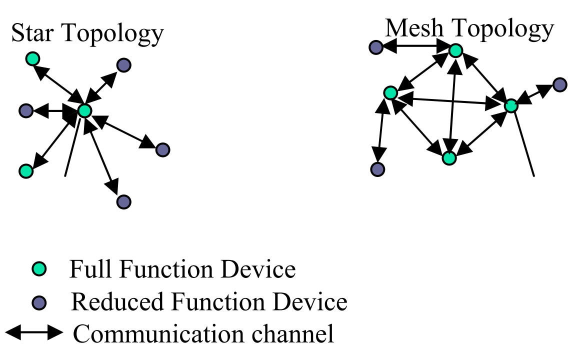

Figure 2: Network topology for IEEE802.15.4

IEEE 802.15.4 carries information on radio transceivers- roughly the same band as Wi-Fi but using about 1% of the power. Because this point limits transmission range, collections of devices must work together to route information hop by hop over longer distances and around obstacles. The standard defines two types of network node.

- The first one is the full-function device (FFD). It can serve as the coordinator of a personal area network just as it may function as a common node.
- On the other hand there are reduced-function devices (RFD). These are meant to be extremely simple devices with very modest resource and communication requirements.

3. Mains standards based on IEEE802.15.4: Zigbee and IPv6 over IEEE802.15.4

Overview

This concept of interoperability already requires communication between IPv6 over LR-WPAN (6LoWPAN) and other technologies based on the IEEE802 .15.4. We chose to study the interconnection between 6LoWPAN and the Zigbee technology since it is the most advanced in terms of standardization, research, deployment and solutions.

3.1 ZigBee/ IEEE802.15.4

ZigBee, its specification and promotion, is a product of the ZigBee Alliance. The Alliance is an association of companies working together to ensure the success of this open global standard. ZigBee is built on top of the IEEE 802.15.4 standard. ZigBee provides routing and multi-hop functions to the packet-based radio protocol. Solutions adopting the ZigBee standard will be embedded in consumer electronics, home and building automation, industrial controls, PC peripherals, medical sensor applications, toys, and games.

3.1.1 Stack architecture

The ZigBee stack architecture is made up of a set of blocks called layers. Each layer performs a specific set of services for the layer above. A data entity provides a data transmission service and a management entity provides all other services.
The IEEE 802.15.4-2003 standard defines the two lower layers: the physical (PHY) layer and the medium access control (MAC) sub-layer. The ZigBee Alliance builds on this foundation by providing the network (NWK) layer and the framework for the application layer [7]. The application layer framework consists of the application support sub-layer (APS) and the ZigBee device objects (ZDO).

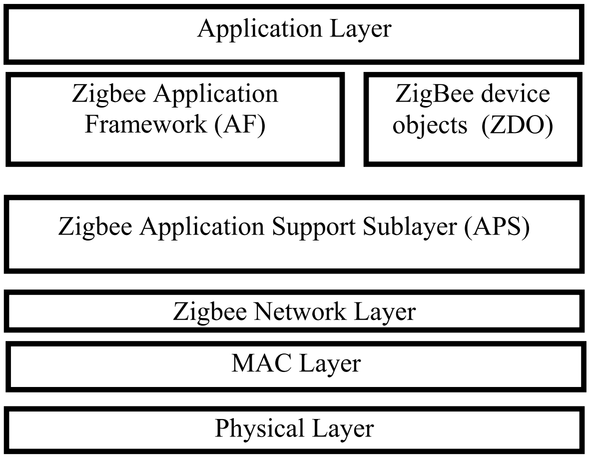

Figure 3: ZigBee Stack Architecture [7]

- Network NWK layer:

The network layer ensures the proper operation of the underlying MAC layer and provides an interface to the application layer. The network layer supports star, tree and mesh topologies.

- ZigBee device objects (ZDO):

The ZigBee device objects (ZDO), represent a base class of functionality that provides an interface between the application objects, the device profile, and the APS. The ZDO is responsible for the following:

- Initializing the application support sub-layer (APS), the network layer (NWK), and the Security Service Provider.
- Assembling configuration information from the end applications to determine and implement discovery, security management, network management, and binding management.

- Zigbee Application Support Sublayer (APS)

The application support sub-layer provides the interface between the network layer and the application layer through a general set of services for use by both the ZigBee device object (ZDO) and the manufacturer-defined application objects.

- Application framework:

The application framework in ZigBee is the environment in which application objects are hosted on ZigBee devices. Up to 240 distinct application objects can be defined, each identified by an endpoint address from 1 to 240.

3.2 IPv6 over Low-Rate WPAN

3.2.1 Mains challenges of IPv6 over Low-Rate WPAN

Initially, IP was not discussed when the researchers examined the design of communication protocol for LoWPANs. Researchers thought that IP is too heavy weight and too expensive to use for these applications. The most important challenges/issues for developing a protocol that supports IPv6 over LowPANs are as follows:

- Frame size

802.15.4 Protocol data units have different sizes depending on how much overhead is present [2]. Starting from a maximum physical layer packet size of 127 octets (aMaxPHYPacketSize) and a maximum frame overhead of 25 (aMaxFrameOverhead), the resultant maximum frame size at the media access control layer is 102 octets. Link-layer security imposes further overhead, which in the maximum case (21 octets of overhead in the AES-CCM-128 case, versus 9 and 13 for AES-CCM-32 and AES-CCM-64, respectively) leaves only 81 octets available [9]. Furthermore, since the IPv6 header is 40 octets long, this leaves only 41 octets for upper-layer protocols, like UDP. The latter uses 8 octets in the header which leaves only 33 octets for application data.

-Fragmentation

Fragmentation is necessary because IP packets are very large compared to IEEE802.15.4 maximum frame size, in fact, IPv6 requires that all links support 1280 byte packets.
As mentioned above, the protocol data units may be as small as 81 bytes. This is obviously far below the minimum IPv6 packet size of 1280 octets, and in keeping with the IPv6 specification [10], a fragmentation and reassembly adaptation layer must be provided at the layer below IP.

- Header compression

The small frame size leaves 33 octets for data over UDP and 21 octets for data over TCP data over UDP and 21 octets for data over TCP.

- LoWPANs design constraints

IPv6 should be adapted to the characteristics of LowPANs devices; these characteristics impose the following constraints:

- Low power constraint: Typically, some or all devices are battery operated
- Resources and energy saving constraint: In fact, RFDs may not have enough processing, RAM, or storage for a 1280 byte packet.

- Sleeping status constraint: In many environments, devices connected to a LoWPAN may sleep for long periods of time in order to conserve energy, and are unable to communicate during these sleep periods.

Furthermore, a large number of devices are expected to be deployed, this constraint poses the need for a large address, well met by IPv6 capacity addressing.

- LowPANs addressing constraints

IEEE 802.15.4 defines several addressing modes: it allows the use of either IEEE 64-bit extended addresses or 16-bit addresses unique within the PAN [5]. Stateless auto configuration (as compared to stateful) is attractive for IP over LoWPANs, because it reduces the configuration overhead on the hosts. There is a need for a method to generate an "interface identifier" from the EUI-64 [EUI64] assigned to the IEEE 802.15.4 device [9].

- Application and higher layer

As header compression becomes more prevalent, overall performance will depend even more on efficiency of application protocols. Heavyweight protocols based on XML such as SOAP may not be suitable for LoWPANs. As such, more compact encodings (and perhaps protocols) may become necessary. The goal here is to specify or suggest modifications to existing protocols so that they are suitable for LoWPANs.

- Mesh Routing Protocol

A routing protocol to support a multi-hop mesh network is necessary. There is much published work on ad-hoc multi hop routing for devices. Some examples include. Also, these protocols are designed to use IP-based addresses that have large overheads. For example, the Ad hoc On-Demand Distance Vector (AODV) [RFC3561] routing protocol uses 48 octets for a route request based on IPv6 addressing. Given the packet-size constraints, transmitting this packet without fragmentation and reassembly may be difficult. Thus, care should be taken when using existing routing protocols (or designing new ones) so that the routing packets fit within a single IEEE 802.15.4 frame [9].

- Security constraint:

Security threats at different layers must be clearly understood and documented. Bootstrapping of devices into a secure network could also be considered given the location, limited display, high density, and ad-hoc deployment of devices [9].

Since the idea that the protocol IP could and should be applied to even the smallest of devices and all important challenges was listed, a work group named 6LoWPAN (IPv6 over Low-rate WPAN) was formally established by IETF to institute LR-WPAN standard based on IPv6. The next section discusses the 6LoWPAN protocol.

3.2.2 6loWPAN

6LowPAN IETF working group works on the research of IPv6 protocol suite based on IEEE802.15.4 standard. Its appearance impelled the development of LR-WPAN. 6LowPAN technology bottom layer adopts PHY and MAC layer standards of IEEE802.15.4, and 6LowPAN chooses IPv6 as the networking technology, its objective market mainly is wireless sensor networks WSNs.

6LoWPAN protocol Stack:

In order to achieve the seamless connection of MAC layer and network layer, 6LowPAN WG suggested that adding an adaptation layer between MAC layer and network layer to perform the header compression, fragmentation, and reassembly and mesh route forwarding. The adaptation layer is needed to overcome all the issues described in the section above. The 6LoWPAN protocol stack model is as below [6]:

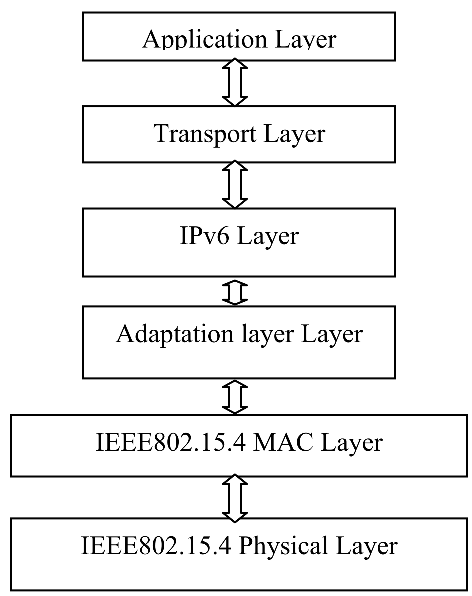

Figure 4: 6LowPAN Protocol Stack

The RFC 4944 [11] gives many definitions and solutions to deal with all challenges about transmission of IPv6 Packets over IEEE 802.15.4 Networks as described above. A frame format, formation of IPv6 link-local addresses and statelessly autoconfigured addresses on top of IEEE 802.15.4 networks as well as mechanisms for header compression required to make IPv6 practical on IEEE802.15.4 networks are defined.

4. Interconnection between IPv6 users and LoWPANs: Zigbee and 6LoWPAN

Among the goals of 6LoWPAN protocol is the culmination of a solution for the interconnection of low-power devices, especially the WSN networks to the Internet through IPv6. In what follows, we will present what has been proposed as communication architecture with IPv6 by the ZigBee Alliance and 6LoWPAN.

4.1 6LoWPAN / IPv6 communication architecture

Standard 6LoWPAN architecture consists of several entities. Figure 5 illustrates the typical 6LoWPAN architecture in which 6LoWPAN gateway is a primary source for outside the network IPv6 clients to communicate with 6LoWPAN sensor nodes. Whereas it also shows web server, which retrieves sensor data from the 6LoWPAN gateway and publishes on the Internet [12].

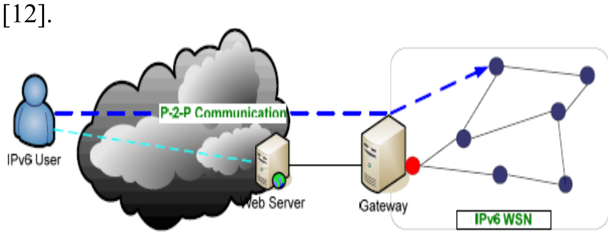

Figure 5: 6LoWPAN typical architecture

The 6LoWPAN gateway is responsible for the conversion made between IPv6 users and 6LoWPAN devices (WSN devices). The conversion is made at the IPv6 layer. The 6LoWPAN gateway is as follow [13]:

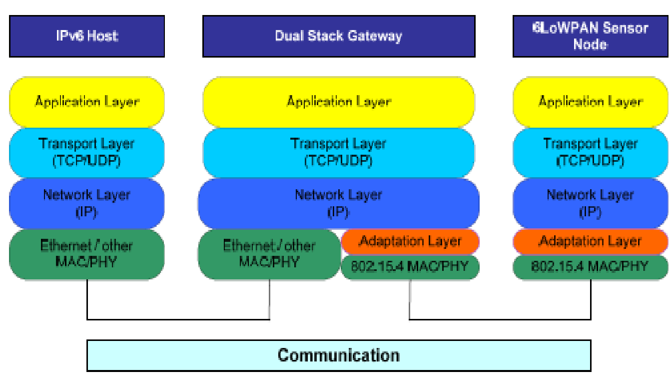

Figure 6: 6LoWPAN gateway structure

4.2 ZigBee / IPv6 communication architecture

To unlock the full potential of sensor networks a method of communication with Industrial LANs and the Internet is needed. It is also a strategic value to allow a wireless network the ability to use a wired line to help performance or to connect networks that are out of range. The ZigBee Alliance has taken into account these considerations and has defined gateway stack for interconnecting IPv6 with Zigbee networks.

ZigBee Gateway

A ZigBee Gateway is intended to provide an interface between ZigBee and IP devices through an abstracted interface on the IP side. The IP device is isolated from the ZigBee protocol by that interface. The ZigBee Gateway translates both addresses and commands between ZigBee and IP. The IP stack is terminated at the Gateway as is the ZigBee Stack. The Gateway provides translation between the respective stacks [14].

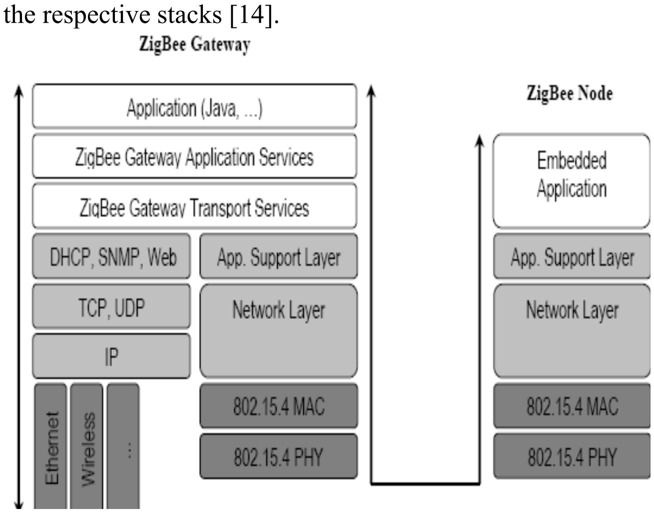

Figure 7: Stack diagram of ZigBee gateway [15]

Zigbee Bridge

It's noteworthy to notice that ZigBee alliance was also defined a bridge called Zigbee Bridge or Zigbee Extension Device (ZED). Zigbee Gateways provide a fuller featured connectivity and allow a greater diversity of devices and applications to connect to the ZigBee network. Zigbee Bridges are much simpler than Gateways and hence would be a lower cost to the user but serve a smaller application space [14].

A ZigBee ZED extends the ZigBee network over an IP based network. Since the specific PHY and MAC layers are not pertinent as long as the network layer is IP based, the ZED will work over Ethernet or WiFi types of devices. The ZigBee network layer is continuous among the ZigBee devices by overlaying it on the IP network's transport layer. The ZED makes the IP connectivity transparent to the ZigBee devices.

In an alternative configuration, a ZED may be used to communicate with IP devices that are executing the ZigBee stack and communicate through a ZigBee network layer. In this usage scenario, the IP device behaves like an extension of the ZigBee network. Standardization of these devices will permit multiple vendors to interoperate and provide a superior solution to ZigBee users [14].

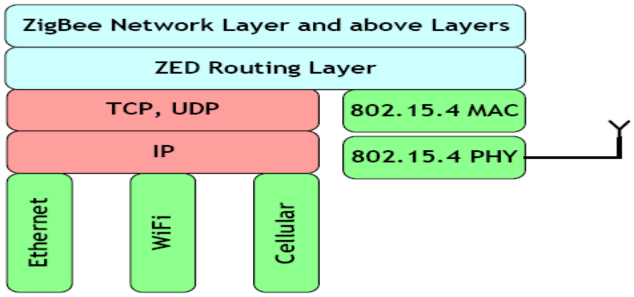

Figure 8: Stack diagram of ZED [14]

Internetworking between Zigbee/802.15.4 and IPv6/802.3 networks

Wang R, Chang R and Chao h [16] has designed a novel overlay mechanism for the internetworking between Zigbee/IEEE802.15.4 and IPv6/802.3. This novel gateway can easily be extended to all kind of IPv6 networks such as IPv6/802.11, IPv6/UMTS, etc. In this design, each ZigBee devices is assigned with a Global Unicast IPv6 address so that every IPv6 node can communicate with it directly. On the other hand, each IPv6 node who wants to communicate with the ZigBee devices is also assigned with a ZigBee short address. From the viewpoint of a ZigBee node, every IPv6 host is like another ZigBee node because it has a ZigBee address for communication. Besides, from the viewpoint of an IPv6 host, every ZigBee nodes is like another IPv6 host because it has an IPv6 address. The gateways will handle all the transformation. All the other ZigBee nodes and IPv6 hosts can keep unchanged. The design is quite useful for connecting the two kinds of networks.

5. Interconnecting between IPv6, 6LoWPAN and Zigbee

6LoWPAN and ZigBee are two standards for LoWPAN networks. The ZigBee standard is already being deployed in several environments and it is still improved and maintained by the ZigBee Alliance. Similarly, the 6LoWPAN is already adopted by the wireless network vendors like Arch Rock and Sensinode. Generally the 6LoWPAN is designed for wireless sensors network WSN. WSN is one of the Emerging technologies which will have impact on our daily life in near future. Current Trends Have directed the use of wireless sensor network for various purposes. The applications of using this technology are endless from agriculture to health to military monitoring purposes. The deployment of IP based wireless sensor network is a next step to integrate this technology with the Internet and a device for global connectivity. In order to take a real benefit from all LoWPANs and to interconnect them to the internet, we should define an architecture for interoperability of 6LoWPAN and Zigbee over IPv6.

5.1 6LoWPAN and Zigbee Interoperability Considerations

The 6LoWPAN and ZigBee have different protocol stacks despite the fact that they rely on the same physical and MAC layers of IEEE892.15.4 standard. Zigbee has its own layers of routing and application independently of the IPv6, while 6LoWPAN is based on IPv6 with an adaptation layer. Their interoperability is not feasible, given the following constraints [17]:

- Header compressions cannot be applied to Zigbee nodes;
- Some features of 802.15.4 MAC have been modified by 6LoWPAN for a more efficient usage, like association/disassociation, beacon and beaconless mode and many others.
- The three types of devices that Zigbee defines are unknown to 6LoWPAN.
- 6LoWPAN is composed of the traditional TCP/IP stack architecture, thus IPv6 stack is the transport layer beneath. In case of ZigBee, IPv6 will be one of the profiles of ZigBee.
- Different security algorithm between Zigbee and 6LoWPAN

5.2 A proposal gateway between IPv6, 6LoWPAN and Zigbee

Md. Sakhawat Hossen and other researchers on [17] propose a model of gateway connecting 6LoWPAN and Zigbee through IPv6. Their idea takes place from the IP-NET solution developed by Helicomm Inc., a wireless solutions company with a strong market presence in Asia. The IP-NET use a dual stack approach in which both the 6LoWPAN and Zigbee stack coexist on the same 802.15.4 MAC as shown in figure 9.

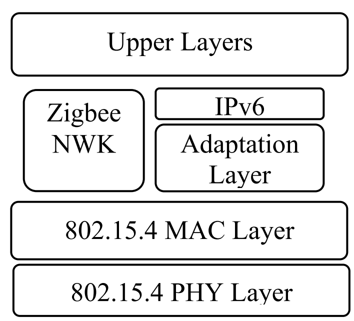

Figure 9: Dual Stack, coexistence of 6LoWPAN and Zigbee

The proposal architecture gateway between IPv6, 6LowPAN and Zigbee as proposed by [17] is as below:

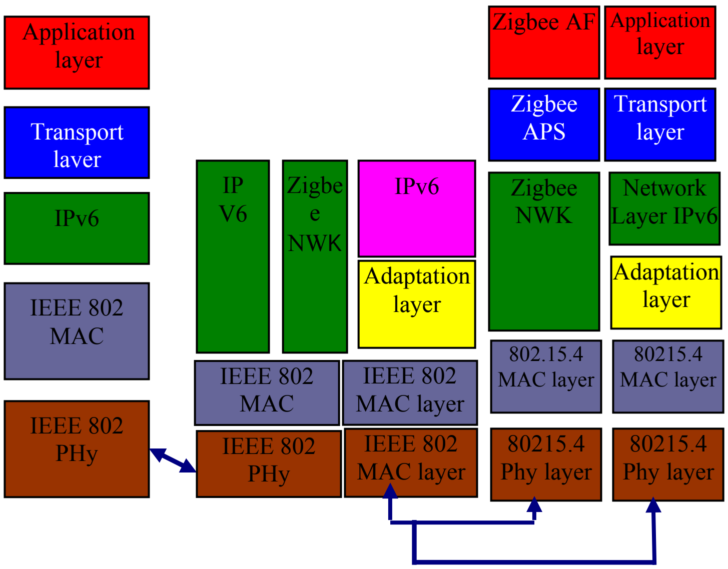

Figure 10: Proposal gateway between IPv6, 6LoWPAN and Zigbee

6. Conclusion

In this paper, we have studied the Zigbee and 6LoWPAN which are the major technologies for LoWPANs networks. We also describe the possible architectures for interconnecting Zigbee and 6LoWPAN with IPv6 and the issues faced to release this interconnecting. Finally we presented the conceptual architecture for connecting IPv6, 6LoWPAN and Zigbee. The real deployment for an interconnecting architecture between IPv6, 6LoWPAN and Zigbee will be essential to connect LoWPANs to Internet in the perspective of the internet of Things (IoT). The massive deployment of WSN networks and their connection to the Internet will probably be a path to the IoT. This will be achieved through a homogeneous and interoperable interconnection solution for LoWPANs. This subject still needs studies and searches and more implication from industrials vendors. Also, searches must take in consideration the other WSN technologies (HART wireless, ISA100, etc) [18] for the conception of a global interconnecting solution through IPv6.

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