On Power Consumption in IPv6 Over Low Power Wireless Personal Area Network (6LoWPAN)

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ABSTRAC

Energy consumption in Wireless Sensor Network (WSN) is one very critical factor in its operation because of being battery powered and the need to operate continuously over a long period of time. WSN nodes are generally miniaturized that make them light and mobile and non intrusive, but this leads to have a smaller space to carry bulky power sources. 6LoWPAN protocol, a version of WSN that can run IPv6 protocol, have a large address space in order to give unique addresses to individual objects connected to the Internet. The majority of these objects does not have access to permanent energy sources while they have to do sensing, pre-processing, and participate in routing process, including self-configuration without human intervention. There are many factors that influence energy consumption in WSN and 6LoWPAN in particular, a few examples being on the architecture or protocol layers. In this paper, we discuss some critical factors that influence energy consumption pattern. First, the parameters that are dependent on 6LoWPAN's architecture, structure and relation with other network technology standards are introduced. This is followed by a discussion on the protocol layering and other algorithms that serve as the technical foundations for energy saving.

KEYWORDS

IPv6, IoT, 6LoWPAN, Energy Consumption, Gateway, Neighbor Discovery,WSN

1. INTRODUCTION

Over the past two decades or so communication networks have experienced tremendous growth and expansion all over the world. The explosive growth of many types of mobile devices such as smart phones and laptop computers, has fueled the demand for more bandwidth with varying quality of service (QoS), pervasive connectivity and at affordable costs. These mobile devices are generally very powerful in themselves with ever more innovative user interfaces, better information security and privacy, capability for higher end-to-end data transfer rate, streaming or interactive communications, and many other features [1]. The mobile wireless network can be classified into three types: sensor networks, ad-hoc networks and cellular networks. These three groups can encompass a wide array of application areas such as vehicular networks, mobile peer-to-peer, WiFi hot-spots, sensor networks, pervasive systems, ad-hoc mesh networks and cellular data services such as 3G, LTE and WiMAX. In this paper we survey the relationship between energy consumption in 6LoWPAN nodes, such as protocol layering and its mechanisms which is a subject of interest in [2].

This paper is organized as follows; a discussion on 6LoWPAN architecture is first given in section 3. Then the link between 6LoWPAN architecture and power consumption is reviewed in section 4. Finally in section 5 and 6, the 6LoWPAN mechanisms for power consumption reduction and other recent works are evaluated.

2. BACKGROUND

Most electronic appliances depend on energy to function while most energy resources are not permanent nor cheap. Energy consumption in mobile nodes should be managed wisely by way of reducing its usage and harvesting more from the environment. Energy consumption in mobile devices and nodes should be optimized by using economical algorithms and developing current methods. Advances in the field of electronics and communications have pushed the frontier of technology very rapidly. One of the innovative ideas introduced recently is the concept of Internet of Things (IoT). IoT covers and traces every object (also known as thing) as nodes such as PC laptops, smart phones, even living things like wild life and pets, and people especially those who need care giving remotely, and other usual objects such as cars, factory products, and other merchandise. However, IoT is faced with two serious questions; the exhaustion of addresses of current IPv4, and the type of network which is suitable for low powered devices.

On the first question, by 2015 it is expected that there will be billions of devices or wireless nodes on the Internet. This range of nodes will certainly outnumber wired PCs used for Internet applications. Therefore, IPv6 (128-bits) has been developed with an address space that can cover $2^{128} = 3.4 * 10^{38}$ (nodes) [2], which means that it is enough to provide unique addresses for every single thing in this planet. In addition, with hierarchical addressing, it makes the routing clear and easier [1].

On the second question, in the future, applications will be based on sensors and mobile devices will integrate objects, people and events. These nodes which generate information as well as perform data computing on the Internet, will lead to a very different set of communication requirements. 6LoWPAN which was designed for networks of low powered devices, can solve these two problems in one go since it uses IPv6 addressing space and is designed for low powered nodes. However, even though, IPv6 has ample address space and resolves the issue of lower power networking, but the problem is not over yet. Because of the duration of communication and connectivity between low powered nodes and network, this issue remains for small nodes that do not have access to a power supply for some period of time such as those that are used to track animals in their natural habitat or for merchandise under shipment. This sensor node perpetually consumes energy for maintaining the connectivity and exchanging data with the Base Station (BS) as well as performing self-detection and self-organization automatically. Although energy consumption is considered in all aspects of 6LoWPAN technology, but it is more specific in the mobile nodes (MNs).

3. 6LoWPAN ARCHITECTURE

In this section, the 6LoWPAN structure and adaptation layer is explained, and then the relationship between 6LoWPAN parameters and energy saving is considered. From Fig.1, three models of LoWPAN architecture is suggested: (i) Simple LoWPAN, with an edge router, (ii) Extended LoWPAN with more than one edge router, (iii) Ad-hoc LoWPAN, with no infrastructure [3].

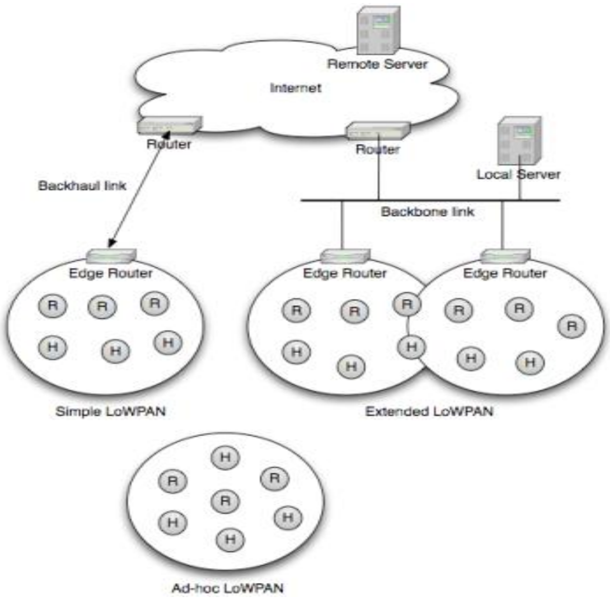

Figure 1. LoWPAN Architectures

Fig. 2 shows the 6LoWPAN architecture with fixed and mobile nodes. There are 6LoWPAN devices such as sensor nodes, a PAN coordinator, and a Gateway (GW). The connection between 6LoWPAN routers and the Internet is provided by the GW, which serves as a Foreign Agent (FA) for visiting nodes and a Home Agent (HA) for its MNs. In fact, the GW performs more functions such as fragmentation or reassembly of the IPv6 and 6LoWPAN, compressing the Internet or incoming packets and decompressing the outgoing or 6LoWPAN packets that are exchanged between 6LoWPAN routers and the Internet. The GW table saves information about the entire 6LoWPAN nodes in its PAN such as Mobile Routers (MRs) with 16-bit addresses [4]. The PAN coordinator is a master of a PAN showing the starting formation of the 6LoWPAN network. There are two types of 6LoWPAN sensor nodes; those that are mobile and those that are static. The connection between a router function and MNs to the other nodes is created by fixed nodes. The sensor node which is able to move independently in a 6LoWPAN area is named referred to as mobile node [5]. A partner node is a static node that saves the information of MNs in its table for supporting the mobility management which are located nearby itself. The static node is responsible for pre-configuration as well as giving support to the MN as an access point. One of popular movement detection algorithms to detect the movement of nodes is signal strength indicator, sending of hello packets periodically, and estimating the presence of the link quality [6].

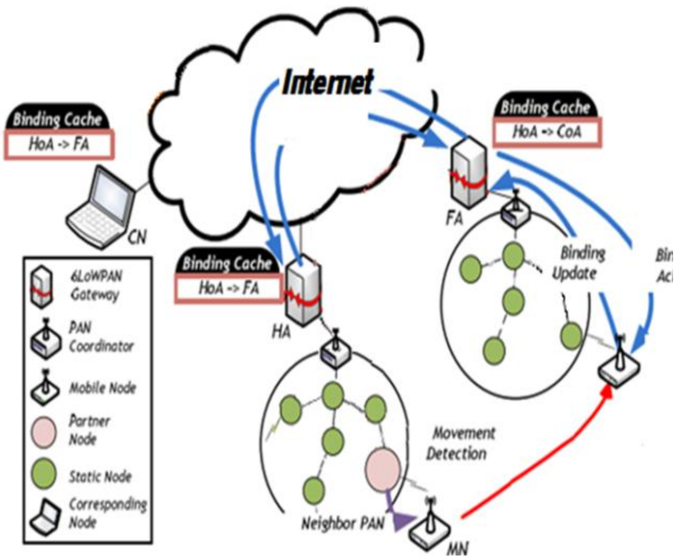

Figure 2. 6LoWPAN Mobility Structure

4. THE LINK BETWEEN 6LoWPAN ARCHITECTURE AND POWER CONSUMPTION

There are different software and hardware techniques for energy saving. In hardware devices, the two general methods which are used for power consumption reduction and improving energy efficiency are power management and renewable energy [2]. In software the best solution is increasing and optimizing the transition speeds and levels of sleep-mode. Although, energy saving is considered when designing the hardware and other new technologies to reduce power consumption, but these efforts are not sufficient. Because of this, software and hardware techniques are combined together. Indeed software parts manage hardware devices, and software algorithms could be upgraded regularly since software methods are more flexible than hardware. Furthermore, the software solution is an option to implement new ideas and upgrade current power consumption methods.

Fig. 3 illustrates the interval of sleep-mode and wake up-mode; the sleep-mode is one of the general solution to reduce power consumption, when most parts of the device is turned off (idle) and just a few parts should be turned on to restart the system for communication. In listening techniques, the receiver should check the scheduling methods or lengthen transmissions periodically, which consist of the synchronization time between nodes [7]. For example, IoT or Machine to Machine (M2M) applications reside in battery operated devices and are short-lived. A sensor node or device is usually put in sleep-mode, and when it needs to exchange data it will transit to wake up-mode [8]. In the following subsection, we will introduce a more effective 6LoWPAN device and protocol layer such as GW and adaptation layers.

4.1 The 6LoWPAN Gateway

The GW as an edge router is busier compared to other nodes because it is responsible for more tasks and interface between different standard networks that have to communicate with each other. The duty of a 6LoWPAN GW is to establish a connection between 6LoWPAN and the Internet. Additionally, it has a close relationship with IEEE 802.15.4. Although 6LoWPAN supports IPv6 network, it is distinctly different from IEEE 802.15.4 networks terms of architectures and protocol layering [4]. These distinctions increase the processing time of the adaptation layer in GW and the total energy consumed, owing to its function as the interface between these networks. These GW or edge router tasks increase its energy consumption under the following situations: (i) when the 6LoWPAN GW plays the role of a default Internet GW or as an interface router between the 6LoWPAN area and the Internet. (ii) It coordinates routing, node mobility, network mobility mechanisms. (iii) It translates IPv4 to IPv6 and vice versa. (iv) It manages the addressing and must save

PAN information such as the list of all nodes and mobile routers. In other words, to establish a connection between 6LoWPAN and other networks, the GW or edge router requires a full suite of IPv6 protocol stack or IPv4/IPv6 dual stack, neighbor discovery (ND) mechanism, a 6LoWPAN wireless interface, and 6LoWPAN adaptation [2].

4.2 The 6LoWPAN Adaptation Layer

Fig. 4 demonstrates the adaptation layer of 6LoWPAN which is located between Medium Access Control (MAC) layers and the network layer to exchange the IPv6 packets in IEEE 802.15.4 links [3]. This layer manages the addressing under mesh topology for packet delivery, header compression, decompression, fragmentation, and reassembly [2]. Handling previous mechanisms take the adaptation layer time for processing. Because of its position in 6LoWPAN, edge router is very busy and engaged with more processes. Because of the extra tasks given to a 6LoWPAN G/2 in order to improve power consumption, we should consider the adaptation layer and its mechanisms more than the other layers in 6LoWPAN.

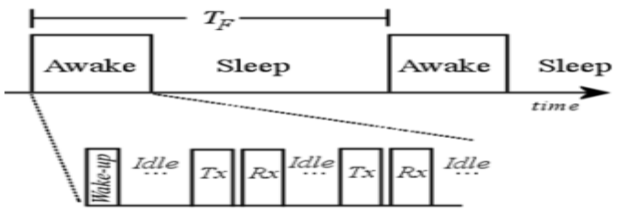

Figure 3. Sleep mode and Wake-up mode

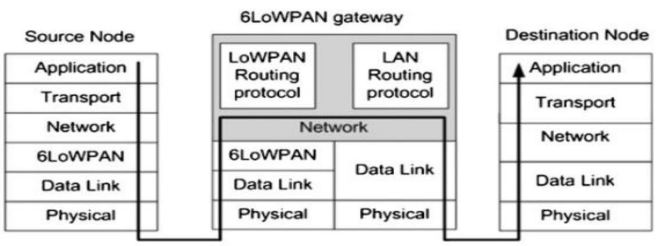

Figure 4. Protocol stack of 6LoWPAN node and Gateway

5. EVALUATION 6LoWPAN MECHANISMS FOR POWER CONSUMPTION REDUCTION

As has been highlighted before 6LoWPAN is one type of technology with a new adaptation layer which are proposed for small sensor nodes in low power and energy saving conditions. It enables IPv6 over very constrained links with limited frame size and bandwidth, wireless mesh topologies and sleep-modes, and no native multicast support. In this section, after discussing 6LoWPAN mechanisms, we survey its mechanisms in the best and worst conditions to show its challenges. We also show the summary of our results in Table 1.

5.1. Fragmentation/Reassembly

The performance of large IPv6 packets over low-power wireless mesh networks is bound to be poor. So, if a packet is lost or corrupted, the whole packet needs to be retransmitted which reduces goodput and increases delay [2]. 6LoWPAN defines a header encoding scheme to support packet fragmentation mechanism end-to-end, and does not run on intermediate IPv6 routers. It happens when the IPv6 datagram exceeds a single frame size and does not fit in a single 6LoWPAN frame, and growth in link bandwidth. Hence, IPv6 hosts should detect PMTU, or send IPv6 packets no larger than the minimum transfer unit size of 1280 octets [9]. Fragmentation does not include end-to-end recovery of lost fragments, expecting that link-layer acknowledgments will provide sufficient delivery success rates. [10].

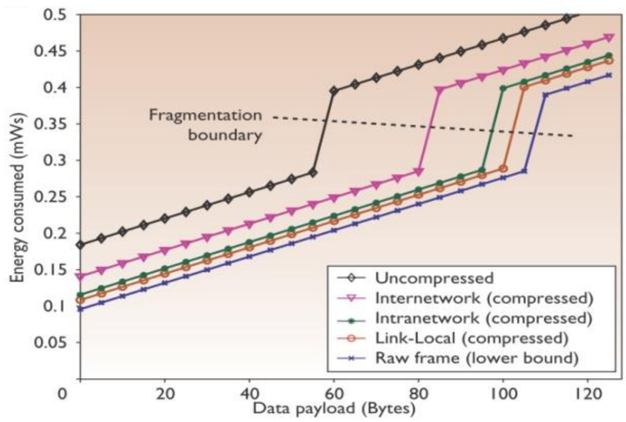

Figure 5. The energy cost for transmitting IPv6/6LoWPAN packets on the CC2420 radio.

From Fig. 5, in the best situation, when a 6LoWPAN node transfers a small IPv6 datagram in a single IEEE 802.15.4 hop, fragmentation of headers or mesh addressing are not required [7]. The fragmentation header is omitted in small datagrams because the entire payload is just carried by a single frame. In the

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worst situation, when it produces more fragments for large packets, it wastes the fragmentation process time as well as increases the energy consumption. In the case where it sends large packets without fragmentation, if a packet is lost, it consumes energy to retransmit the whole packet.

5.2. Compression/Decompression

Header compression in 6LoWPN serves to reduce transmission overhead, therefore this section will discuss more on this aspect. Reducing packet header size decreases packet overhead and improves battery lifetime and hence improves energy saving in WSNs significantly [11]. For example, if part of the header field changes only rarely within a flow and communication, it can be eliminated. For fully compressed, the mesh header will be removed when 6LoWPAN frames are transferred in a single radio hop because the destination and source address of the link-layer header are uniform [12]. The header of UDP is decreased to 4 bytes. The upper bits of the source and destination ports are compressed and payload length is elided when the header transfers a predefined value [7]. The IPv6 header (40-Bytes) is compressed to 3-bytes including the dispatch header by the 6LoWPAN protocol scheme [4]. It compresses or elides some fields in the IPv6 Header Compression (HC1) when the following situations happen:

First, 6LoWPAN compresses the following: (i) the network prefix of both source and destination if the link-local prefix is known, (ii) flow label and traffic class when their values are both zero, (iii) the next header field whenever the packet uses TCP, UDP, or ICMPv6. Secondly, 6LoWPAN can exploit some information from the cross-layer redundancy, so it elides the following fields: (i) the 64-bit interface identifier (IID): the destination and source addresses can exploit from other headers such as mesh addressing header or the link-layer address of the 802.15.4, (ii) payload length: it can exploit from other fields such as IEEE 802.15.4 frame or fragmentation header of 6LoWPAN, (iii) version field: 6LoWPAN elides version when it has communications via IPv6 [7].

In the best case, the full header compression is 7 bytes (2bytes for HC1, 4bytes UDP header, 1byte dispatch). In the worst case, when 6LoWPAN communicates with IP nodes in other PAN areas using multicast the packets may transfer the total IPv6 address [4].

5.3. Routing Mechanisms

The communication capabilities and memory limitation of each node constrains the routing situation and these restrictions create problems for protocols that rely on complete link-state information [13]. From Fig. 6, it can be observed that there are two serious architectural issues in 6LoWPAN. First, how link-level factors detect the routing mechanism and secondly, which LoWPAN datagram forwarding layer can support the routing process. 6LoWPAN can support routing in two layers the link-layer or the network-layer. As a result, there are two different routing mechanisms; route over and mesh under. The mesh under mechanism performs at the link-layer to emulate a single broadcast domain whereas the route over mechanism uses IP routing to keep accessibility between nodes within a subnet. Also the routing protocol manages the forwarding table [10].

In the best case, when 6LoWPAN frames are transferred in a single radio hop, the source and destination addresses are similar to those in the link-layer header, and the mesh header will be removed [13].

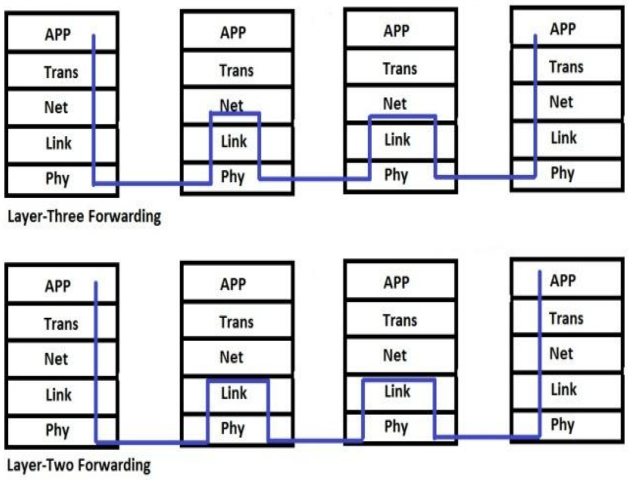

Figure 6. Mesh-Under vs. Route-Over Forwarding.

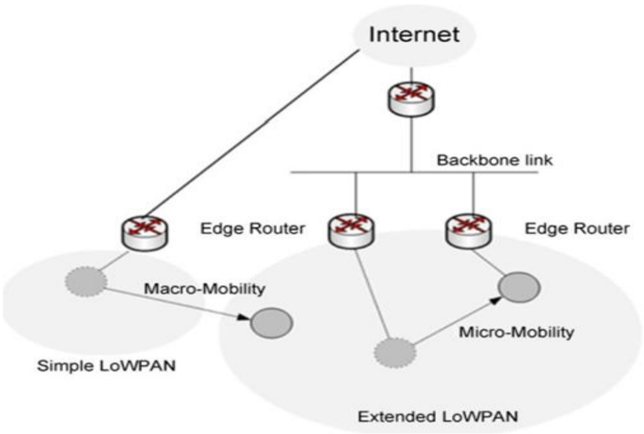

Figure 7. 6LoWPAN Macro and Micro-Mobility

5.4. Mobility

From sensor networks point of view, movement occurs in 6LoWPAN when an MN or a PAN tries to leave its link and connect to a new 6LoWPAN area as shown in Fig. 7. 6LoWPAN should do self-configuration and self-detection automatically. This process starts by binding message exchange through neighbor discovery, and establishing a bi-directional tunnel that connects home agent (HA) and the mobile router (MR). As a result, the overhead of the binding process incurs the highest power consumption in 6LoPWAN areas [4].

Mobility is categorized as either micro-mobility or macro-mobility and involves two processes roaming and handover [2]. Roaming is moving from the previous 6LoWPAN area to a new PAN and handover is defined by changing the current point of attachment and data flows. Micro-mobility or Intra-PAN mobility is when the MR node of 6LoWPAN leaves the current position and moves within the same PAN or 6LoWPAN area. The MR compares the previous PAN ID with the current PAN ID until detection through the beacon message, and depending on whether it is in a new PAN ID or otherwise it will not do any movement or it moves to a new PAN. If the PAN ID is not new then it is still in the previous PAN area and does not do any movement, else it moves to a new PAN. The list of all the 6LoWPAN MRs or nodes inside a PAN with 16-bit addresses is stored by GW as GW table [4]. On the other hand macro-mobility or Inter-PAN is the mobility between network domains where there would be an address change.

In the best case, BU and BA messages are compressed as parts of the mobility process between MRs and 6LoWPAN GWs, optimizing the energy consumption [4]. The energy consumption is decreased by using the pre-configuration solution in NEMO for Network Mobility (Inter-MARIO technique) before the mobility process [5]. The worst case happens in macro-mobility for a PAN, because the duration for pre-configuration and installation is longer and influences more interface nodes for configuration.

5.5. Neighbor Discovery (ND)

In order to support communication among neighboring IPv6 nodes, IPv6 ND protocol is provided. It is a set of messages and mechanisms that supports the discovery of neighboring routers and address prefixes discovery, determining each other's link-layer addresses, discovering each other's presence, discovering parameter, and maintaining reachability information to active neighbors [14]. In other words, if ND is supported by hosts, it discovers address prefixes, neighboring routers addresses, and parameters of configuration, while if ND is applied by routers, it determines on-link prefixes, host configuration parameters, advertise their presence, and detects the best next-hop address to transfer packets for hosts. Finally, if ND mechanism is applied by nodes, it resolves the link-layer address of a neighboring node to which an IPv6 packet is being forwarded. It detects when the link-layer address of a neighboring node is different, and determines whether a neighbor node is still accessible [15].

Hosts receive useful network informations such as prefixes and default hops limit, etc. Besides listening to Router Advertisements (RA), nodes also perform Duplicate Address Detection (DAD) when designating a unique IPv6 address to an interface. All ND communications occur within the link-local scope. In address resolution, a node must find link-layer's address for the neighboring node before it can send unicast IP messages. To resolve this problem, IPv6 ND sends a link-local multicast query and processes the report from the target neighbor via a neighbor table rather than a cache.

Table 1. Comparing the power consumption in each mechanism

Mechanism		How does it increase Power Consumption? Best Case (Low Energy Consumption)	Worst Case (High Energy Consumption)
Packet MTU	Fragmentation Reassembly	- Sending small datagrams over a single hop. - Sending small datagrams less than MTU.	- When the large packet is lost and retransmitted. - Fragmentation for large packets is time consuming.
Header	Compression Decompression	- Fully header compression (total 7bytes).	- When IPv6 header is 40 bytes. - When using the whole IP address for source and destination and communicating with the outside of 6LoWPAN.
Routing	Mesh Under	- The existing routing in 6LoWPAN [16].	- Depend on more routing parameters and mechanisms. - When it uses hello message, have higher delay [16]
	Router Over		
Mobility	Micro	- Compressing the header of BU and BA message. - Doing pre-configuration before mobility process.	- Macro-mobility for a PAN with uncompressed BU and BA message.
	Macro		
	PAN Mobility		
	Handover		
ND	Address Resolution	- When send packet directly without caching. - Use neighbor table in address resolution.	- Use cache in address resolution.
	NUD		
	DAD		
	Router Discovery		

The link-layer address mappings for next-hop neighbors to whom a node may communicate with are always resident in the memory. An explicit query mechanism is not required since there is no possibility of a cache miss [10].

In the best case, while on-link determination and address resolution proceeds, 6LoWPAN nodes do not need to store per-neighbor state or cache packets when a packet directly sends to a router or the destination (if it is link-local) [10].

6. RECENT WORKS

Recently, there are a few papers which have proposed schemes to reduce power consumption in 6LoWPAN through routing and mobility mechanisms. In [10], the 6LoWPAN group developed a new compression format for stateless and stateful headers by using two way compact stateless headers: first, the redundant information across the transport, network, and link layers will be removed; second, defining compact forms of common values by assuming these values for header fields. They also progress towards the header compression format for stateful arbitrary IPv6 address prefixes and this is effective for two reasons because, prefix information is common to all nodes and not specific to individual flows. The first reason is that, the same subnet ID is shared by nodes within the sensor network's subnet and secondly, many applications involve on-link determination of all nodes communicating with a single common destination (e.g. data collection traffic).

Recently, [17] proposed a cluster tree scheme for routing in 6LoWPAN. This scheme minimizes the total number of cluster heads in cluster-tree architecture by launching the cluster generation algorithm. Hence, the total number of nodes in a cluster tree is reduced and the total routing cost decreases. The proposed scheme keeps the cluster-tree topology stable. The analytical data illustrates that the performance of this scheme is better than Least Cluster Change Lowest-ID algorithm (LCCLID) and Root-based Lowest-ID (RLID) algorithm [17].

7. CONCLUSION

From this brief discourse it is anticipated that 6LoWPAN will become more popular in the future. This is primarily because its vast address space that is able to individually identify all objects that are going to be connected to the Internet. Nevertheless, power consumption is a 6LoWPAN serious issue, therefore mechanisms need to be sought in order to optimize on this resource. One approach is to increase the idle time in 6LoWPAN so that the process time decreases and hence conserve on its power consumption. This mechanism should be applied particularly to busy devices in the network. One example of a busy device is the edge routers; it is a very complex device to design and manage since they perform significant functional and semantic translations, as well as being responsible for many jobs. Furthermore, the 6LoWPAN adaptation layer of edge router handles more mechanisms and also the mobility processes are more complex. In this paper, we suggest the appropriate device, protocol layer and mechanisms for reducing power consumption.

For future works, we shall focus on the gateway, adaptation layer and the two most used mechanisms such as routing and mobility.

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