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IP communication optimization for 6LoWPAN-Based Wireless Sensor Networks

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Abstract: The emergence of 6LoWPAN makes it possible that Wireless Sensor Networks access to the Internet. However, the cost of IP communication between 6LoWPAN wireless sensor node and external internet node is still relatively high. This paper proposed a new addressing configuration and compression scheme in 6LoWPAN network called IPHC-NAT, which largely reduced the proportion of the IP header in 6LoWPAN packet, designed and constructed a bidirectional data transmission gateway to connect 6LoWPAN wireless sensor node with IPv6 client. The experimental results show the feasibility of the design of IPHC-NAT and the data transmission efficiency has significantly been improved compared to the original 6LoWPAN network. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: 6LoWPAN, Wireless Sensor Networks, IPHC, NAT, gateway.

1. Introduction

Wireless sensor networks is widely used in health, smart home, industrial control, environmental monitoring and forecasting, military and other fields, and it has a very broad application prospect [1]. However, the concept of wireless sensor networks has been proposed for many years and has been researched for long time, WSN have not been applied as widely as the personal computer and the Internet. Recently, with the rapid development of Internet of Things application, a large number of sensor nodes need access to the Internet to communicate with the Internet node. In the case of that the current IPv4 addresses has been exhausted, people will hope on next generation Internet protocol IPv6.

In order to meet the need of low-power and lightweight protocols of sensor nodes, recent years, the researchers have done much deep research on the combination of WSN and IPv6, and have achieved some important results. November 2004, the Internet Engineering Task Force (IETF) established 6LoWPAN [2] Working Group to develop IPv6-based low-speed wireless personal area network standard with IEEE 802.15.4 as the underlying protocol standard. October 2008, SISCO, ATMEL and SICS jointly released uIPv6 [3], which is the smallest open-source IPv6 protocol stack for Contiki and other embedded operating systems, offering the interoperability between 802.15.4 and IPv6. All these simplified protocol of IPv6-based wireless sensor network [4] have significantly reduced the threshold that wireless sensor network access to IP network. However, the transmission of sensor data between the wireless network and the Internet still need a relatively high IP communication cost.

In 6LoWPAN-based wireless sensor networks, the MTU of underlying IEEE 802.15.4 link is only 127 bytes. In the worst situation, it only has 81 bytes for the data load after removing the MAC header and MAC security header. However, a complete IPv6 header requires 40 bytes in network layer, with IPv6 source address and destination address occupying 16 bytes respectively. In order to improve the efficiency of data transmission and network resource utilization, IP header needs to be compressed effectively. 6LoWPAN_HC1 header compression which is described by document [5] highly optimized the local address compression in unicast link. The improvement program IPHC defined by document [6] achieved the effective compression of the global IPv6 addresses and multicast addresses. Then, the part of HC1 header compression will be discarded, supporting header compression techniques IPHC. But the context-sharing address compression used by IPHC made the system overhead and software complexity increasing. On the basis of these two 6LoWPAN header compression scheme, document [7] respectively designed the simple and flexible solutions IIPHC1 and relatively complex IIPHC2 programs for the link-local and global addresses, and using stateless compression for all the global address, which reduce the complexity of the header compression to some extent. Considering 6LoWPAN header compression is mainly for the address compression, IIPHC and IPHC compression are still have problems of low address compression efficiency and high design complexity, which further lead to low data transmission efficiency and short life of the sensor node. In view of the above situation, on the basis of header compression technology IPHC, this paper introduced NAT/PAT: (1) the part of IPv6 header removing the source and destination addresses still use IPHC to compress; (2) IPv6 address field uniformly use the 16-bit short address to identify to reduce system overhead caused by address compression, and transfer more work to 6LoWPAN gateway which rely on the power supply. In the sensor networks, the network address identified by a 16-bit short address. Then the NAT gateway makes the conversion of internal network address and outside network address.

This paper first presented a new 6LoWPAN-based wireless sensor network address configuration, compression and conversion program IPHC-NAT, allowing the internal wireless sensor nodes to use a 16-bit short address as link-local address for packet data transmission. Then add NAT mechanism on 6LoWPAN gateway to achieve the mapping of IEEE 64-bit extended node address and 16-bit short node address. Combining global routing prefix issued by upper router, sensor node own a global address, and achieve bi-directional data transfer with IPv6 users.

The paper is organized as follows: Section 2 describes related work on 6LoWPAN-Based wireless sensor networks; Section 3 presents 6LoWPAN network address configuration, compression and conversion program IPHC-NAT, and gives the bidirectional data transfer process between WSN nodes and internal IPv6 users; Section 4 discusses the implementation of 6LoWPAN gateway and analyzes experimental data; Section 5 of this paper summarizes the research and propose the future research directions.

2. Related Work

2.1. The Network Topology of 6LoWPAN

The interconnection of Wireless sensor networks and the Internet mainly includes three elements: the 6LoWPAN-based WSN; 6LoWPAN gateway; IPv6 users, as it is shown in Fig. 1.

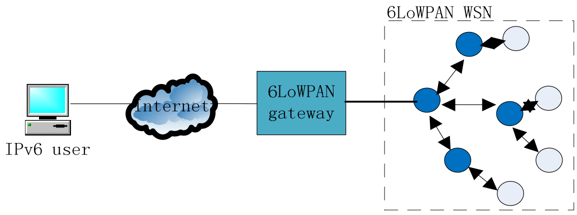

Fig. 1. The connection of IPv6 user and WSN.

1) All the nodes in 6LoWPAN-based WSN support 6LoWPAN protocol, realizing the IPv6 data transmission by fragmentation and compression mechanisms of 6LoWPAN.

2) 6LoWPAN gateway is an important component integrating wireless sensor network into the IPv6 network. Its main tasks include compressing and decompressing IPv6/6LoWPAN header, as well as making fragmentation for a large packet and reassembling. The above tasks are done through 6LoWPAN adaptation layer, as shown in Fig. 2.

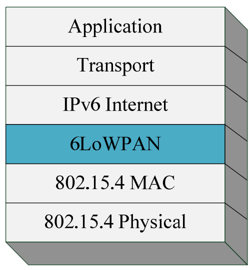

Fig. 2. The 6LoWPAN protocol stack.

3) IPv6 users can directly establish communication of end to end with 6LoWPAN-based WSN internal nodes, controlling the state of the node and accessing the data collected by the nodes. Our program in this paper also supports that the internal WSN node actively connect to external IPv6 users, which is quite important in some scenarios.

2.2. Address Auto-configuration

Each node in IEEE 802.15.4 network has a 64-bit address that can uniquely represent this device. But in 802.15.4, the size of the packet is limited and 64 bits long address is impractical, so nodes are allowed to use 16-bit short address. This short address is assigned by the PAN coordinator, and is only valid in the PAN. You can select any one of the nodes including short and long address to send packets.

The IPv6 address of 6LoWPAN sensor node consists of two parts: the 64 global routing prefix obtained from the upper router and 64-bit interface ID created locally. Interface ID can be obtained by EUI-64 which is converted by the 48-bit MAC address. In IEEE 802.15.4, all devices have the EUI-64 address, and 16-bit short address is also allowed to be used. When using a short address, a 48-bit pseudo-address can be acquired by the following algorithm:

•The first 16 bits correspond to the PAN ID;

•The next 16 bits are all zero;

•The remaining 16 bits correspond to the short address. Then this 48-bit address can be used following the "IPv6 over Ethernet" address packaging technology [8].

2.3. 6LoWPAN Header Compression

The idea of 6LoWPAN header compression is that the IP address is exported from the link-layer address, in order to avoid unnecessary duplication information, as well as IPv6 header omit some common values [9]. In addition, shared context technology (for example, a common 6LoWPAN network prefix) can be used to compress IPv6 global address.

HC1 and IPHC are two 6LoWPAN header compression techniques. HC1 compression is valid for unicast link-local address, but very limited for the global address and multicast addresses. IPHC is an effective compression technique for the global IPv6 addresses. The Fig. 3 below shows the basic coding IPHC format.

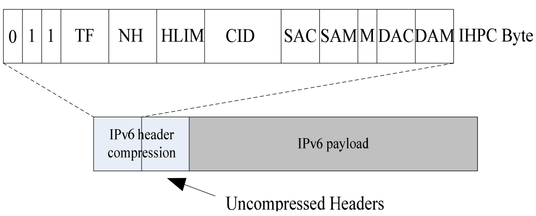

Fig. 3. The coding of IPHC.

IPv6 address compression of IPHC does not apply to the low-power network equipment in WSN. The reasons are mainly as follows: (1) IPHC compression increases the software complexity and system overhead; (2) IP address will be calculated by the link-layer address if it is not included in this context. But, during a packet transmission, network layer address is immutable, the link-layer address will change. So deriving IP address from the link-layer address will undoubtedly increase the complexity of the algorithm design.

2.4. NAT / PAT Technology

Network Address Translation (network address translation, NAT) can be used to map the private address and the global address. This technique allows a site using a set of private addresses for internal communications, and using another group (at least one) of global Internet address communicating with others. PAT is a form of dynamic NAT, using different TCP / UDP port numbers to map multiple IP addresses to a single IP address. On the PAT, it can make each computer converted to the same public IP address in a private network, with assigning different source port numbers. Sometimes the NAT / PAT are referred to as NAT.

In order to reduce IP communication cost for 6LoWPAN network, the paper uses the idea of NAT: 6LoWPAN gateway provides a 16 bits port ID for each connection between the sensor node and the Internet nodes. In 6LoWPAN internal network, data transmission between 6LoWPAN gateway and node via 16 bits port ID and 16 bits short address, making more space to the data of application layer, while the bottom nodes do not have to make a complex address compression operations, reducing node energy consumption and prolonging the lifetime of 6LoWPAN networks.

3. IPHC-NAT Program

IEEE 802.15.4 defines two addressing modes, which are IEEE 64-bit extended address and 16-bit PAN (Personal Area Network) separate address. To reduce the IP communication cost in sensor network and avoid address conflict, we introduce the NAT mechanism to 6LoWPAN gateway, using 16 bits short address to identify the network layer address, completing the conversion between 16-bit short address and 64-bit extended address after the data packet reach the 6LoWPAN gateway, and forming their own global unicast addresses by combining global routing prefix, then exchange data with IPv6 users.

3.1. IPHC-NAT Program

For the issue of 6LoWPAN header compression, the purpose is to reduce the communication overhead of IP header in data transmission. This paper introduces NAT ideas on the basis of IPHC and proposes a new 6LoWPAN network address configuration compression conversion program, called IPHC-NAT. The program use IPHC to compress 6LoWPAN header beside the address field, Source and destination address are identified by 16-bit short address in 6LoWPAN networks inside. When 6LoWPAN network nodes communicate with the external network, internal address will be replaced by the global address at the gateway.

Specifically , when the internal WSN node communicate with the IPv6 user, the gateway assigns a 16-bit port ID for each end to end communication, and decomposes data communication into the communication between the internal node and the WSN gateways and the communication between IPv6 users and a gateway. When a packet data from the internal nodes sent to WSN gateway, the source address is 16 bits PAN address of the node, while destination address is 16 bits port ID assigned by gateway. In the same way, when the packet data from the WSN gateway sent to internal nodes, the source address is 16 bits port ID assigned by gateway, the destination address is the 16 bits PAN independent address of the node.

We identify the source and destination addresses field base on the improved 6LoWPAN header compression technique IPHC, as shown in Fig. 4.

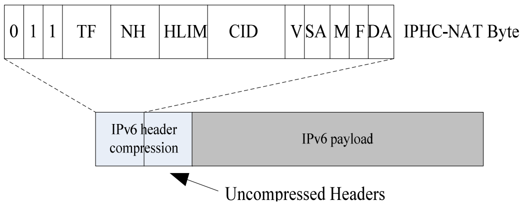

Fig. 4. The coding of IPHC-NAT.

The meaning of addressing type identifiers is as the following:

V = 00, indicates the source address SA is a 16 PAN separate address;

V = 11, indicates the source address SA is 16 bits port ID assigned by NAT gateway and the packet is sent by gateway;

V = 01, indicates the source address SA is a 64-bit extended address;

V = 10, indicates the source address SA is a 128 bits full IPv6 address;

F = 00, indicates the destination address DA is a 16 bits PAN separate address;

F = 11, indicates the destination address DA is a 16 bits port ID by assigned NAT gateway and the packet need to be sent to gateway;

F = 01, indicates the destination address DA is a 64-bit extended address;

F = 10, indicates the destination address DA is a 128 bit full IPv6 address.

3.2. Bidirectional Data Transfer

Scene I, WSN node actively connected to IPv6 users:

1) A WSN internal node actively connects to IPV6 user. Connection request firstly was send to the gateway.

2) Gateway check the mapping table of 16-bit PAN separate addresses and the 64-bit extended address, as shown in Table 1, and combine the global unicast routing prefixes to form a global unicast address.

Table 1. Address mapping.

Short address	MAC	Global IPv6
1234	0212:4b00:0108:bb2c	2001::0212:4b00:0108:bb2c
…	…	…

3) Gateway binds a 16-bit port ID for this end to end communication, and records it in the NAT port table, as shown in Table 2.

Table 2. NAT port table.

SA	DA	Port ID
2001::0212:4b00:0108:bb2c	2002::0215:2000:0002:2145	4567
…	…	…

4) When the packet data returns from the IPv6 user, the gateway make the destination address of the data packet 16-bit internal PAN separate address of the node, while the source address is set to corresponding 16-bit port ID, and set the addressing type identifier V to 11, F to 00, send the packet to WSN internal nodes.

5) WSN internal nodes set source address of the data packet to 16-bit PAN separate address, while the destination address of this packet is set to Corresponding 16-bit port ID, and set the address type identifier V to 00, F to 11, send the packet to the gateway and then send it to IPv6 users through the gateway. At this point, the packet data communication is established, as shown in Fig. 5.

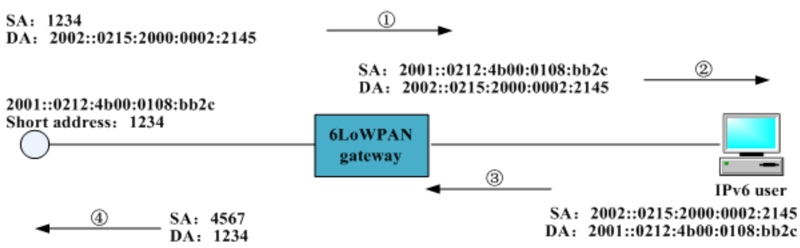

Fig. 5. WSN internal node actively connects to IPv6 user.

Scene II, IPv6 users actively visit WSN node:

1) The request of IPv6 user is sent to the gateway;

2) Gateway get the 64-bit extended address of the target node from the destination address of the packet data, and get the 16-bit PAN separate address of target node through checking the address mapping table;

3) Gateway binds a 16-bit port ID for this end to end communication, and records it in the NAT port table;

4) Gateway set the 16-bit PAN separate address of the target node as the destination address of packet data, while the source address is set to Corresponding 16-bit port ID, and the address type identifier V is set to 11, F is set to 00, send the packet to the target node;

5) The source address of the packet data is set to 16-bit PAN separate address by the inside node, while the destination address of this packet data is set to the corresponding 16-bit port ID, and the address type identifier V is set to 00, F is set to 11, then the packet is sent to the gateway, and is sent to IPv6 users through the gateway. At this point, the packet data communication is established, as shown in Fig. 6.

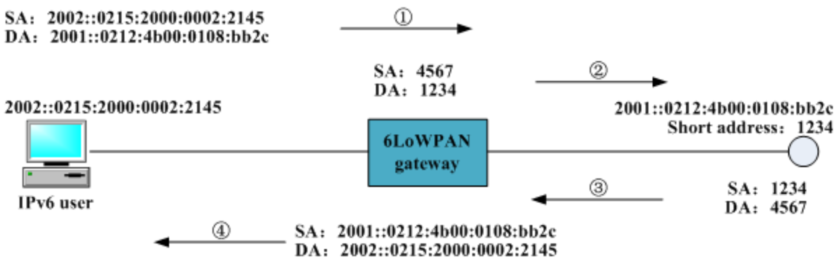

Fig. 6. IPv6 actively access WSN internal node.

4. Implementation and Testing

In the design of 6LoWPAN-based wireless sensor network, TI's CC2530 is chosen as the core component of the sensor node, using Contiki operating system as the software platform [10]. Underlying communication protocol follows the IEEE 802.15.4 standard. The functions of 6LoWPAN adaptation layer and IPv6 communication protocol stack are provided by the Contiki operating system. A border router program is deployed on a node which transports the data from the gateway to the WSN via radio and collects internal data through the serial port and uploads them to the gateway. 6LoWPAN gateway requires two network interfaces: one is a virtual TUN network port based on SLIP protocol, responsible for data exchange between the gateway and WSN border routing nodes; the other is Ethernet port to connect the gateway to the external IPv6 network. Gateway running the Linux operating system, realizing the NAT mechanism proposed in this paper through software, shown in Fig. 7.

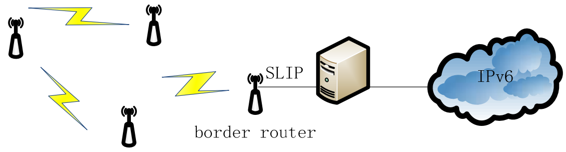

Fig. 7. Experimental network topology.

On the aspect of system connectivity, after the 6LoWPAN-based WSN established, IPv6 client test the connection between the external IPv6 user and the wireless sensor nodes via ping6 command. IPv6 users and WSN node establish the connection successfully, as shown in Fig. 8.

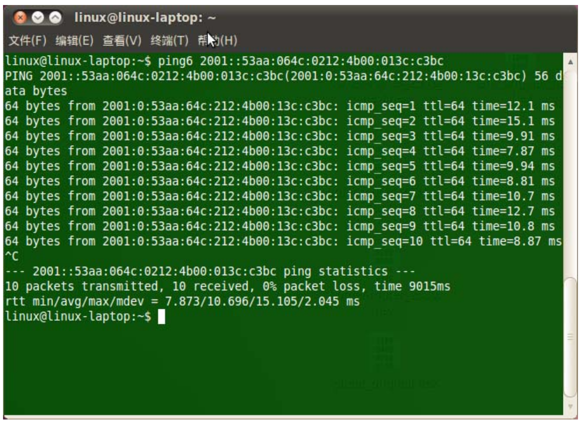

Fig. 8. IPv6 user ping WSN internal node.

Considering some special scenarios which required the WSN internal nodes initiate connections, such as when the temperature exceeded the limit system should notify the user, in experiment, a node actively send data to an external IPv6 user and the IPv6 client successfully receive data uploaded from internal node of the WSN, as shown in Fig. 9.

On transmission performance of the system, this paper compared the IPHC-NAT program with HC1, IPHC program about the aspects of network throughput and energy consumption. The throughput in this article was the average rate that a node successfully delivered data in communication channel, which could be obtained by computing the translate rate of systems ICMP6 package. Shown in Fig. 10, IPHC-NAT scheme was superior to HC1 and IPHC on the system throughput, because the data load of the MAC layer in our program was able to carry more IPv6 application data. When the data load reached 89 bytes, HC1 and IPHC needed to fragment the data with throughput decreasing. But this program did not need to fragment the data and the throughput was not affected significantly. With increasing of the load data, the program began to fragment the data with throughput decreasing. In contrast, IPHC-NAT solution obtains about 20 % -40 % improvement in throughput.

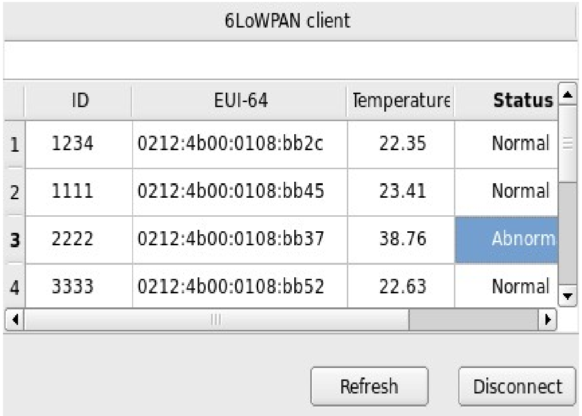

Fig. 9. WSN internal nodes actively upload data.

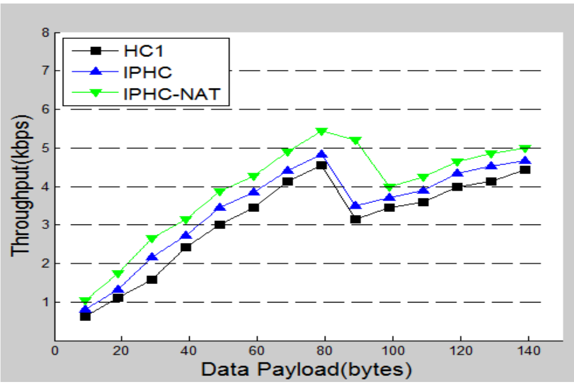

Fig. 10. Data payload and throughput.

Energy consumption was defined as product of the sending power and the time in which a node sent the data. As shown in Fig. 11, with the increase of data load, the energy consumption of our IPHC-NAT program and the original program HC1, IPHC increased linearly. When the data need to be fragmented, energy consumption significantly increased. When the system became stable after fragmentation, energy consumption returned to increase linearly. Since IPHC-NAT program do not need the node to run complex address compression algorithms, it effectively reduce the energy consumption of WSN system and extend the lifetime of wireless sensor networks.

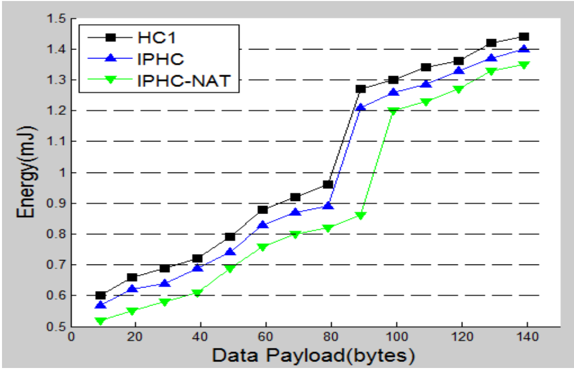

Fig. 11. Data payload and energy consumption.

5. Summary

In this paper, IPHC-NAT which is a new 6LoWPAN network address configuration, compression and conversion programs was proposed, allowing Transmission of 6LoWPAN packet data through 16-bit short address in wireless sensor network, while avoiding sensor node run complex address compression algorithms. Compared with traditional 6LoWPAN header compression solutions, IP communication cost of this program was further reduced. This paper designed and constructed a 6LoWPAN gateway, realized the bidirectional data transmission between the WSN internal nodes and external IPv6 users. Experimental results showed the feasibility of the IPHC-NAT program and the data transmission efficiency significantly better than the traditional 6LoWPAN network. It should be noted that there was still a lot of research work remained to be further studied, including the performance optimization of 6LoWPAN gateway and the study of 6LoWPAN network security mechanisms.

Acknowledgements

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