IPv6 Header Compression Scheme for Power Internet of Things

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Abstract. In power Internet of Things, to enable the underlying nodes to communicate with an IPv6 network, a 6LoWPAN adaptation layer must be supported through a gateway to seamlessly connect them to implement IPv6 and IEEE802.15.4 protocols. The 6LoWPAN adaptation layer can improve the transmission efficiency of data packets by compressing IPv6 data headers. According to the characteristics of energy metering systems in smart grids, UDP is used as a default transmission layer protocol. Based on existing header compression schemes LoWPAN_HC1 and LoWAPN_IPHC, an adaptive hybrid header compression scheme LoWPAN_HC_Energy was proposed for energy metering systems. The experimental results illustrated that the scheme performs satisfactorily in both local and global links, and its compression efficiency is approximately 2% higher than that of existing compression schemes .

Keywords: Energy metering system · Gateway · 6LoWPAN · Header compression

1 Introduction

With the rapid development of computer and embedded technology, the Internet of things (IoT) is becoming increasingly popular in people's lives [1] and the concepts of smart earth and city are gradually emerging [2]. In smart grids, an energy metering system is a subset of smart energy, which is used to solve energy metering and metering data management functions in smart energy [3].

The main component of energy metering systems is an IoT system, which is composed of three parts: a bottom sensor, gateway, and user [4]. The sensor in the system is mainly responsible for collecting energy measurement data, and the gateway is responsible for collecting and processing underlying data and displaying it to the user. The gateway plays a bridging role in the system, which is responsible for the connection between an internal wireless sensor network and external Internet users [5].

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With the emergence of an IoT wave, under the demand of 'Internet of everything', the IPv4 protocol can no longer afford the large number of network address requirements and the IPv6 protocol has been ushered in an excellent opportunity of development and application. To make metering systems compatible with future network protocols, gateways should provide system support for IPv6 to seamlessly connect underlying sensor nodes with IPv6 networks. Due to an incompatibility between IPv6 and IEEE802.15.4 protocols, IPv6 adaptation over low power wireless personal area networks (6LoWPAN) layer [6] must be completed through the gateway. Figure 1 presents the location of the 6LoWAPN adaptation layer in the network protocol layer and efficient conversion between IPv6 packets and IEEE802.15.4 frames.

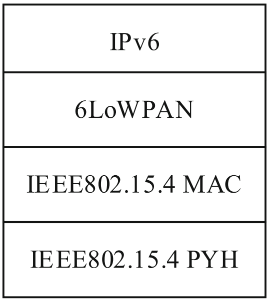

Fig. 1. Network protocol layer

Figure 2 illustrates the IPv6 packet header. The maximum transmission unit (MTU) length is 1280 byte, and the IEEE802.15.4 MTU is 127 byte, which does not meet IPv6 requirements. Therefore, when the packet transmitted through IPv6 is greater than its MTU, it must be fragmented and reorganised using 6LoWPAN.

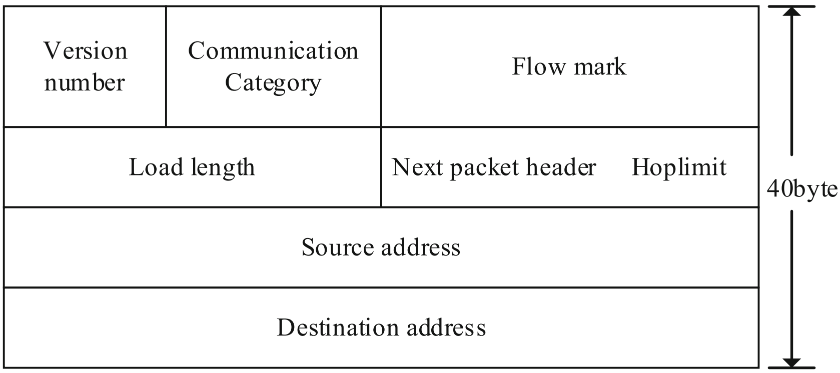

Fig. 2. IPv6 data header

In addition, after the removal of necessary fields, the maximum payload in IEEE802.15.4 and fixed header length in IPv6 are 93 and 40 bytes, respectively. If it is directly transmitted without compression, the transmission efficiency obtained is low. Therefore, header compression is required to improve the data transmission efficiency.

Studies on 6LoWPAN mainly include implementing 6LoWPAN and improving the 6LoWPAN efficiency in packet fragmentation and reassembly, header compression, and other aspects. Wang Xiaoan proposed a design and implementation of 6LoWPAN sensor nodes [7] and applied it to the real-time monitoring system of the agricultural environment [8]. Geng Daoqu studied the packet scheduling method of 6LoWPAN access to IPv4 [9] and proposed an adaptive joint gateway that can simultaneously communicate with both IPv4 and IPv6 networks [10]. Liang Bao proposed a TCP-based 6LoWPAN header compression scheme [11], and then He Donghui proposed a universal header compression scheme: 6LoWPAN_GHC [12]. In the case of bandwidth and limited resources, effective packet header compression of IPv6 is very important. [13] Proposed an improved header compression scheme, which can better compress the Pv6 multicast address, ICMP header and routing extension header [14]. In an open stream network with satellite links, a method with a high header compression ratio is proposed. MAC headers can also be compressed in OpenFlow networks with satellite links [15, 16]. In order to improve the efficiency of data transmission, IPv6 data header compression is necessary.

This paper combines the characteristics of the energy metering system to modify the available header compression schemes LoWPAN_HC1 and LoWAPN_IPHC and presents a design of an adaptive header compression scheme LoWPAN_HC_Energy for energy measurement systems.

2 Introduction and Modification of Header Compression Scheme

2.1 Introduction to LoWPAN_HC1

In 2007, the 6LoWAPN working group proposed LoWPAN_HC1 [13] that is a header compression scheme suitable for local link networks. This scheme sets the specific compression format of the data packet to the 1-byte LoWAPN_HC1 compression control header field. In optimal compression, the fixed header information of 40 bytes can be compressed to 2 bytes. Figures 3 and 4 present the overall coding format of LoWPA_HC1 and specific fields of 'HC1 coding', respectively.

01000010	HC1 encoding	HC2 encoding	Hop limit

Fig. 3. LoWPAN_HC1 compression scheme

In HC1 encoding, an 'IPv6 source/destination address field is used to determine an address compression mode in the gateway header. When set to 11, the IP address can be calculated from a network prefix and MAC layer address. The network address is composed of the network prefix and IID compression and is directly omitted in the

IPv6 source address	IPv6 destination address	Transmission type and stream label	Next header type	HC2 encoding type

Fig. 4. HC1 encoding field

IPv6 header. A 'transmission type and flow label' field determines whether transmission type and flow label field in the IPv6 data header are compressed. A value of 0 indicates no compression, and a value of 1 denotes the default route, which compresses it. The 'next header type' field indicates the next header type in a data packet. 00, 01, 10, and 11 indicate no compression, NH is the IDP header, NH is the ICMP header, and NH is the TCP header, respectively. An 'HC2 encoding type' field indicates whether NH is compressed. When HC2 encoding field is 0, no compression is performed. The HC2 encoding field of 1 indicates that UDP is compressed. The HC1 encoding field of '11111011' indicates that the compression target is a local data packet, and the transport layer uses a UDP protocol and compresses it. At this time, LoWPAN_HC1 exhibits the highest compression efficiency. The HC2 encoding field is used to set the compression parameters of UDP. Figure 5 illustrates the encoding field.

Source port	Destination port	Length	Reservedword

Fig. 5. HC2 encoding field

2.2 Header Compression Scheme for Energy Metering System LoWPAN_HC1_Energy

In the HC1 encoding field of LoWAPN_HC1, the type of the adjacent joint part is set through the 'next header type' field, and UDP compression is set through the HC2 encoding type. In energy measurement systems, we recommend to use UDP as default transport layer protocol and to compress it. Figure 6 presents the encoding format used by the protocol.

01000010	HC_E encoding	Hop limit

Fig. 6. LoWPAN_HC1_Energy compression scheme

Figure 7 presents the encoding format of the HC_E field. The first 5 bits are similar to the HC_1 encoding field, which is used to set the IPv6 source/destination address, transmission type, and stream label compression. Because UDP is used as the default transport layer protocol, the setting of the last three digits of LoWPAN_HC1 for the protocol type can be replaced by compression setting for the UDP header. A hop limit remains constant.

In this manner, the UDP protocol can be compressed by default, and the compressed header length can be reduced by 8 bits compared with its reduction using the header compression scheme LoWAPN_HC1.

IPv6 source address	IPv6 destination address	Transmission type and stream label	UDP source port	UDP destination port	UDP length

Fig. 7. HC1_E coding field

2.3 Introduction to LoWPAN_IPHC

LoWPAN_HC1 only exhibits a good compression effect on the local link. In the global network, because source and destination addresses use different routing prefixes, LoWPAN_HC1 cannot effectively compress the IPv6 address, which results in a highly reduced compression efficiency of the scheme.

The 6LoWAPN working group proposed a new header compression scheme LoWAPN_IPHC in 2011 [17].

The LoWPAN_IPHC adaptation layer header is the global shared Context Table. Some frequently-occurring IPv6 address prefixes can be saved, and the address in the packet header is represented by the index of the table. Context Identifier Extension (CID) replaces the public address prefix, thereby reducing data packet size. Although the LoWPAN_IPHC adaptive layer header can increase the application layer space, Context Table can only store 16 address prefixes [18].

As a new header compression scheme, LoWPAN_IPHC overcomes shortcomings such as LoWPAN_HC1 can effectively compress only local network data packets and can more effectively compress various communication scenarios. LoWPAN_IPHC sets the parameters of IPv6 header compression through the LoWPAN_IPHC field, and Fig. 8 presents the specific contents of the field.

1	1	1	Communication type and flow label	Next head	Maximum hop limit
Context	Source address	Source address compression mode	Whether to multicast	Destination address	Destination address compression mode

Fig. 8. LoWPAN_IPHC coding field

Different from LoWAPN_HC1, the scheme compresses the maximum hop count HLIM field to 2 bits, where 00 indicates that the maximum hop limit is not compressed and the 8-bit hop limit in the IP header is retained and 01/10/11 indicates that the hop limit field is compressed and set to the common 1/64/255 hop, respectively. In addition, the scheme uses the source address compression control (SAC)/source address compression mode (SAM) to set the compression method of the source address, and either multicast, destination address compression, or destination address compression mode to set the compression method of the target address. The SAM set to 0 indicates that the stateless compression method is used. At this time, the compression method used in SAC is similar to LoWPAN_HC1. The SAM of 1 indicates the use of a context-based compression method for compression. Table 1 presents the specific meaning of each field in SAC at this time.

Table 1. SAM field meaning

SAM	Field meaning
00	Undefined
01	Compression, using a 64-bit address, specific address information can be obtained from upper and lower layers
10	Compression, using a 16-bit address, specific address information can be obtained from upper and lower layers
11	Compression, address omitted, specific address information can be obtained from upper and lower layers

The method of destination address compression is similar to that of source address compression and is not repeated here. For details, please refer to the document RFC6282 [19].

2.4 Header Compression Scheme for Energy Metering System LoWPAN_IPHC_Energy

We modified the compression scheme LoWPAN_IPHC according to the characteristics of the default UDP protocol adopted by the energy measurement system, and the header compression scheme (Fig. 9) can be achieved. Figure 10 presents the specific coding field of LoWPAN_IPHC_Energy.

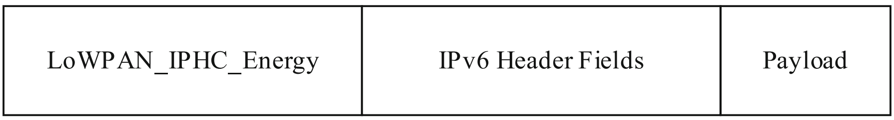

Fig. 9. LoWPAN_IPHC_Energy compression scheme

1	1	1	Communication type and flow label	Port compression mode P	Maximum hop limit
Context	Source address	Source address compression mode	Whether to multicast	Destination address compression	Destination address compression mode

Fig. 10. LoWAPN_IPHC_Energy coding field

When UDP is compressed in LoWPAN_IPHC, the specific parameters of header compression are set through the LoWPAN_NHC field, which mainly includes the setting of two parameters: 'checksum' and 'port compression mode'. In the energy metering system compression scheme LoWPAN_IPHC_Energy, the 'checksum' field setting is deleted. By default, checksum is used to check the system and HLIM is further compressed. The setting of checksum field to 0 indicates no compression; otherwise it will jump the maximum. The number limit is set to 64. In this manner, the compressed header length is reduced by 8 bits in LoWPAN_IPHC_Energy compared with in LoWAPN_IPHC.

3 Adaptive Header Compression Scheme

Header compression schemes LoWPAN_HC1_Energy and LOWPAN_IPHC_Energy are slightly modified versions of LoWAPN_HC1 and LoWPAN_IPHC created to slightly improve the compression effect. During communication in local networks, the compression effect of the LoWAPN_HC1 scheme is better. During communication on global networks, LoWPAN_IPHC can considerably effectively compress IPv6 headers. Therefore, two compression methods can be integrated to compress data packets. In the energy measurement system, if a current communication range belongs to local communication, LoWPAN_HC1_Energy is used for header compression, otherwise LoWAPN_IPHC_Energy is used for header compression. Adaptive compression scheme LoWPAN_HC_Energy can further improve the compression efficiency by integrating two compression schemes.

1	1	1	Type control C	LOWPAN_X_Engery

Fig. 11. LoWPAN_HC_Energy message format

Figure 11 presents the data message format of LoWPAN_HC_Energy. The first three digits '111' are used as the category identifier of the data packet, and the fourth digit 'category control' is used to select the type of the compression scheme to be used. When set to 0, the LoWPAN_HC1_Energy compression scheme is used, otherwise the LoWAPN_IPHC_Energy compression scheme is used. Next 12 bits are used to set the specific compression method of the scheme. Figures 12 and 13 present the meaning of specific fields.

When the 'Type Control' field is 0, LoWPAN_HC1_Energy is used for compression. The compression scheme uses the same coding format as the HC_E field does in LoWPAN_HC1_Energy, and 4 bits are added beforehand as reserved bits to obtain the 12-bit LoWAPN_X_Energy field to set compression parameters.

Reserved bit	IPv6 source address	IPv6 destination address	Communication type and flow label	UDP source port	UDP destination port	UDP length

Fig. 12. LoWPAN_HC_Energy compression format 1

When the 'type control' field is 1, LoWPAN_IPHC_Energy is used for compression, the HLIM field is omitted, and the maximum hop limit field is not compressed. Other fields remain reserved, and the 12-bit LoWAPN_X_Energy field completes the control of the compression parameters.

1	1	1	Communication type and flow label	Port compression mode	Maximum hop limit
Context	Source address	Source address compression mode	Whether to multicast	Destination address	Destination address compression mode

Fig. 13. LoWPAN_HC_Energy compression format 2

4 Experiments

For comparison, a compression ratio was used as a compression scheme index. Let the size of the data packet before and after compression be I and C, respectively, and the compression ratio P can be calculated using Eq. 1.

$$P = 1 - C/I \quad (1)$$

The compression efficiency of compression scheme LoWAPN_HC1_Energy was related to whether the data packet is a local link. The 'probability of transmitting a data packet as a local link' was considered as an abscissa, and the 'compression rate' was considered an ordinate. Under various compression schemes with different probabilities, the observed data packet was the compression effect of the local link. Table 2 present the results and the specific data results.

Table 2. Compression effect of each header compression scheme

Compression scheme	Average compression ratio	Maximum compression rate	Minimum compression rate
LoWPAN_HC1	12.98	17.42	9.39
LoWPAN_HCI_Energy	14.88	19.32	11.29
LoWPAN_IPHC	15.88	16.64	14.91
LoWPAN_IPHC_Energy	17.76	18.56	16.77
LoWPAN_HC_Energy	17.96	18.92	17.13

Compared with LoWPAN_HC1, the compression rate of LoWPAN_HC1_Energy increased by approximately 1.90%; compared with LoWPAN_IPHC, the compression rate of LoWPAN_IPHC_Energy increased by approximately 1.88% (Table 2).

With an increase in the probability of the transmission packet of being a local link, the compression effect of LoWAPN_HC1 and LoWPAN_HC1_Energy gradually increased. Simultaneously, the compression effects of LoWPAN_IPHC and LoWPAN_IPHC_Energy were not affected. The compression effect of the adaptive compression scheme was always relatively ideal and was always large for LoWPAN_HC1_Energy and LoWPAN_IPHC_Energy.

5 Conclusions

In the context of the continuous development of smart cities and smart energy technologies, the IPv6 protocol is required by the IoT system for network scalability. Because the IPv6 data header is considerably large, completing the efficient transmission of IPv6 is difficult through an IEEE802.15.4 payload. Therefore, to improve the data transmission efficiency, IPv6 data header compression is necessary.

In the energy metering system, UDP is used as the default transport layer protocol and performs compression, which can improve the compression efficiency of existing compression schemes. LoWPAN_HC_Energy combines the characteristics of existing two header compression schemes, the adaptive method can be adopted to compress different types of data headers differently, and the compression effect of the data packet can further be improved.

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