Quality of Service Provisioning for Smart Meter Networks using Stream Control Transport Protocol

Sally C.W. Lu[1], Quincy Wu[1] and Winston K.G. Seah[2]
[1]National Chi Nan University, Taiwan
[2]Victoria University of Wellington, New Zealand

Abstract

A smart meter is crucial in the advanced metering infrastructure (AMI), which aims to assist the provider and customers working together to use electrical energy more efficiently. In recent years, many researchers have focused on providing stable interactive services between the provider and customers by integrating the information technology (IT) infrastructure and smart meter networks. A variety of data types such as control messages, electrical usage messages, and so forth can be transmitted between the provider and customers. Some of these messages, such as control messages, need low latency and high availability. Smart meter networks therefore need to provide Quality of Service (QoS) support that is able to satisfy the requirements of these messages. Many previous studies have proposed the use of the Internet Protocol (IP) network to implement smart meter networks; however, the best-effort service model of IP cannot meet the QoS requirements for smart meter networks. This article proposes to adopt the Stream Control Transmission Protocol (SCTP) as the transport layer protocol to deliver messages from smart meter networks to the server on the Internet and vice versa, which can provide a reliable and scalable communication service for smart meter networks.

1 Introduction

The cause of high electrical energy consumption is dominated by daily usage from many areas such as households, industries, transportation and so on. Electricity demand is not only causing electrical energy resources to be depleted at a dreadful rate but also speeding up global warming by generating considerable carbon emissions. A smart meter is an intelligent device which can measure electronically how much energy is consumed and communicate the collected data to another device. For example, smart meters can send the electricity consumption data of household devices to a server on the Internet. The server is responsible for collecting the messages from smart meter networks and analysing the data delivered by these messages. Customers are thus able to check how much energy they consume as well as the real-time pricing of electricity. On the other hand, based on these messages the utility companies can be well informed about the status of electricity usage from each customer, and encourage customers to reduce energy usage during times of peak demand, by providing some incentives.

Smart meters are transforming the traditional metering infrastructure towards to the advanced metering infrastructure (AMI) [1]. Although using smart meters instead of legacy meters will increase the cost in the short term, it can mitigate the need to build new power plants as well as optimize the utilization of electricity that has been bought from expensive energy sources.

Smart meter networks involve one-way or two-way communication depending on requirements of customers and providers. Meter communications can either be from a meter to other devices inside the same local area network, from the meter to the provider's information technology (IT) infrastructure or both. There are numerous communication technologies for both cases, including both wireless and wireline. ZigBee [2] and 6LoWPAN [3] are popular wireless communication standards which are adopted as communication protocols in smart meter networks. These two standards specify upper layer protocols above IEEE802.15.4. The main difference between ZigBee and 6LoWPAN is that ZigBee defines its own network layer protocol which is incompatible with IP, while 6LoWPAN uses IP as the network layer protocol.

Smart meters have powerful functions; it can send the electricity data and alert information from urgent events to the server on the Internet. Vast number of new messages can be generated by smart meters and the server. When the server receives messages from smart meter networks, it can calculate the pricing of electricity and send the information (in billing messages) back to customers. The server can also send control-type or request-type messages to change the status of smart meters or get information it needs.

The smart meter network is a service-oriented energy network that should provide Quality of Service (QoS) support that can meet the requirements of messages [4]. For instance, control messages need low latency and high availability while electricity usage messages require accuracy but are delay-tolerant. However, the current IP protocol does not meet the requirements of these messages because the fundamental service model of IP simply provides best effort service.

The Stream Control Transmission Protocol (SCTP)[5] has been proposed by the Signaling Transport Working Group (IETF SIGTRAN) of the Internet Engineering Task Force in order to transport signalling messages (e.g. SS7), which have requirements for reliable and timely delivery, over IP network. This article proposes the adoption of SCTP as the transport layer protocol for smart meter networks to transport control messages, electricity usage messages, billing messages, request messages, and other messages, in order to provide a reliable and scalable communication infrastructure between providers and customers.

2 Smart Meter Networks Communication

Smart meters are multi-utility and provide the opportunities and challenges for networked embedded system design and IT infrastructure integration. They not only generate real time messages and process them based on their capability but also collaborate with external IT services. Smart meters will be installed for millions of households and companies to provide connectivity to the provider's IT platforms on the Internet.

A realistic deployment scenario of smart meter networks is one where smart meters function as the gateway which will have advanced local communication abilities (e.g. ZigBee, 6LoWPAN, Bluetooth etc.) to communicate with all devices (e.g. outlet) in the local area network and Internet connection (e.g. via Ethernet ,Wi-Fi etc.) to the IT infrastructure (e.g. energy management system). Therefore, they are part of the local area network with other devices and serve as their intermediary for communication with the Internet world.

2.1 Local area network protocols: ZigBee and 6LoWPAN

IEEE802.15.4 is a wireless communication standard which only defines the physical layer and data link layer protocols. It is designed for wireless personal area networks (WPANs) and has low power consumption, low data rate and short distance transmission characteristics.

ZigBee is proposed by the ZigBee Alliance and specifies the upper layer protocols above IEEE802.15.4. It defines a unique network layer protocol which is incompatible with IP. In a nutshell, ZigBee devices in a local area network can communicate with one another but cannot directly communicate with the server on the Internet. Therefore, they need another mechanism such as a gateway to perform protocol translation from the ZigBee protocol to IP, and vice versa. This breaks the end-to-end paradigm needed to exercise some level of control over end devices. It would be better if a communication protocol for end devices is IPcompatible without the need for translation. Therefore, the IETF formed a working group "IPv6 over Low Power Wireless Personal Area Network" (6LowPAN) to study and develop IPv6-based protocols for use in wireless personal area networks. 6LoWPAN is also based on IEEE802.15.4 and focuses on the development of upper layer protocols. Furthermore, 6LoWPAN devices can communicate with the server on the Internet without the need for additional translation mechanism.

ZigBee and 6LoWPAN are popular wireless communication protocols to implement smart meter networks. The protocol stacks of ZigBee and 6LoWPAN are shown in Figure 1.

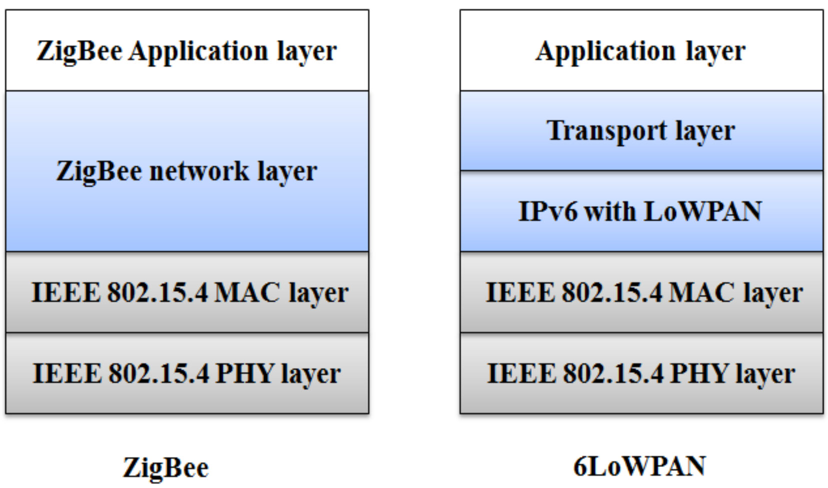

Figure 1 ZigBee / 6LoWPAN protocol stacks [6]

3 Architecture of smart meter networks

3.1 ZigBee-based smart meter network architecture

There are three general types of devices in a ZigBee network: a coordinator, routers, and end-devices. A coordinator plays a very important role in the ZigBee network. The primary coordinator duties are to establish, maintain and control the entire ZigBee network. Routers are responsible for forwarding data to other devices. End-devices collect the data and send the data to routers or a coordinator.

Figure 2 shows the architecture of a ZigBee-based smart meter network. The smart meter is a gateway in the ZigBee network. End-devices can be any electrical equipment such as outlets. The remote server on the Internet can send control messages to control the smart meter network or send request messages to request some information from the smart meter network through the Internet.

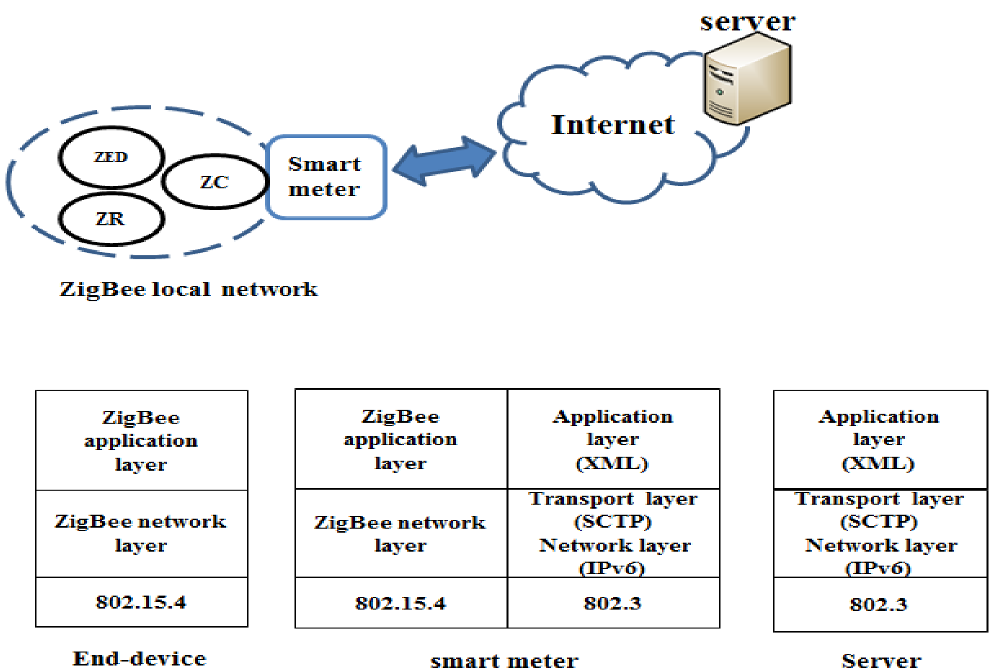

Figure 2 ZigBee-based smart meter network infrastructure

(ZED: ZigBee End-device, ZR: ZigBee router, ZC: ZigBee coordinator)

3.2 6LoWPAN-based smart meter network architecture

There are two types of devices in a 6LoWPAN network: routers and end-devices. The end-devices can collect the data and send to routers to forward. Figure 3 shows the architecture of the 6LoWPAN network.

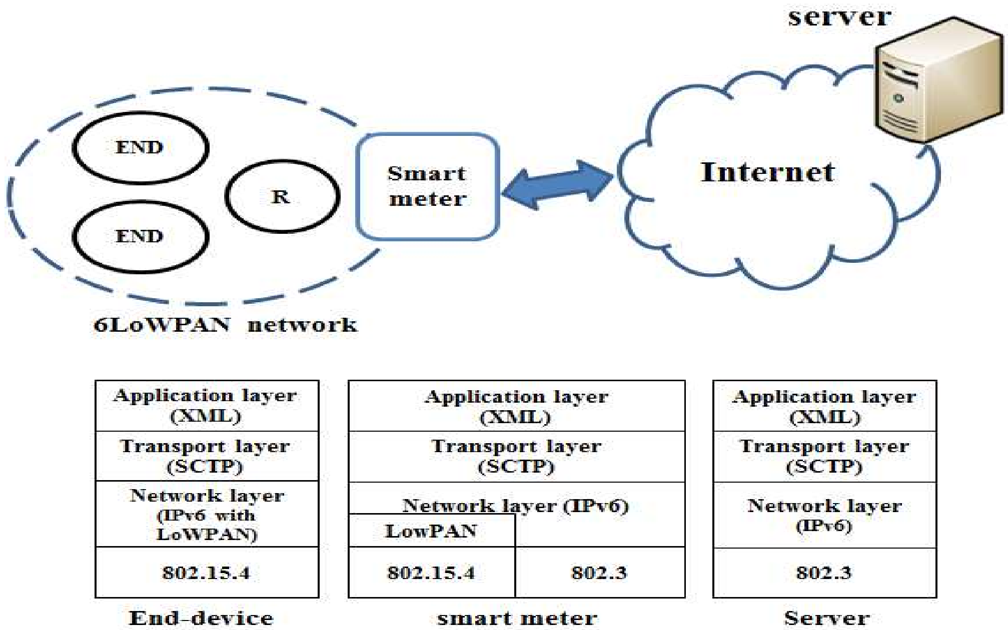

Figure 3 6LoWPAN-based smart meter network architecture

(END: end-device, R: router)

3.3 Hybrid smart meter network architecture

The server can manage distributed smart meter networks via the Internet even though some smart meter networks utilize ZigBee as a communication protocol while other smart meter networks utilize 6LoWPAN as a communication protocol. Figure 4 shows the architecture of a typical hybrid network.

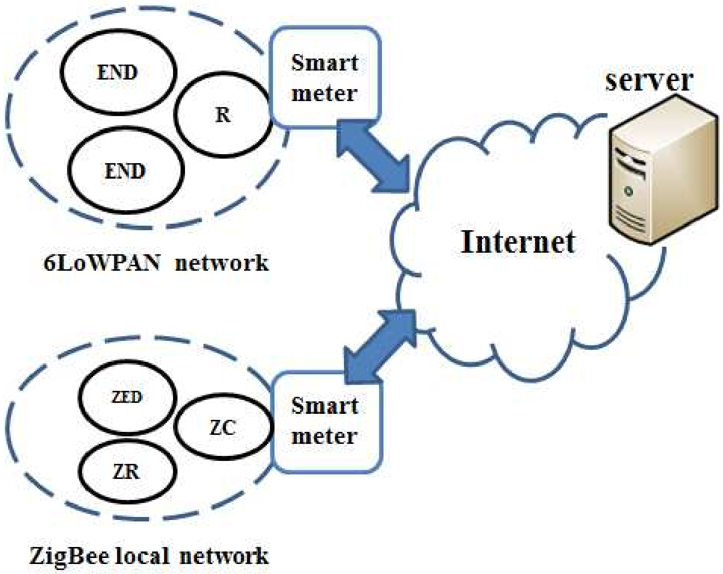

Figure 4 Hybrid smart meter networks infrastructure

4 Different Messages Classes in Smart Meter Networks

Smart meter networks are part of the service-based AMI. It supports the interaction between the provider and customers using predefined messages. This article proposes five fundamental message classes: control, request, billing, electricity usage and warning. Furthermore, these five message classes can be classified into three categories: operation, non-operation and asynchronous event, according to the different behavioural characteristics of these messages.

- **Operation**
  - **Control messages**

    The server can send control messages to control smart meters or any electrical equipment in the smart meter network.

    For example: the server can send a "Turn Off" control message to turn off a smart meter or an outlet.

- **Request messages**

  The server can request information from the smart meter network when needed.

  For example: the server can request the smart meter to transmit the electricity consumption data for a specific time period.

- **Non-operation**
  - **Billing messages**

    The server can calculate the pricing of electricity and provide the billing information to customers in real time which can help customers make informed choices to reduce their energy usage at an appropriate time.

    For example: the server can send the billing message to customers every week instead of every month.

  - **Electricity usage messages**

    The smart meter can send electricity consumption information to the server regularly based on a fixed interval or when requested.

    For example: the smart meter sends an electricity usage message to the server every ten minutes.

- **Asynchronous event**
  - **Warning messages**

    When some emergency events happen, the smart meter can notify the server immediately. The server can take contingency measures to handle such critical events.

    For example: When the value of voltage is over normal value, the smart meter can send a warning message to notify the server before the disaster occurs.

4.1 Text-based message format

In order to integrate heterogeneous systems, International Engineering Consortium proposed the IEC 61968 Common Information Model (CIM) [7] for information exchange between electrical distribution systems, while the World Wide Web Consortium (W3C) proposed Efficient XML Interchange (EXI); this suggests that we can use text-based XML as a standardized interchangeable format to transport smart grid (smart meter networks as part of a smart grid) messages. The Extensible Markup Language (XML) format is both human-readable and machine-readable. Many software tools support the processing of XML documents and it is easy to define XML documents.

This article assumes that the smart meter is installed in the household and can collect electricity consumption information from outlets, in order to define the five text-based XML formats for five message classes, as follows:

- **Control_On_Off (control message)**

  The server can turn on or off outlets or a smart meter; for example, when the server wants to turn on the outlet on the smart meter network, the XML format is shown in Figure 5, and the description of important XML tags is shown in Table 1.

```
<?xml version="1.0" encoding="UTF-8"?>
<SM>
  <type>1</type>
  <timestamp>2012-06-01 12:07:40</timestamp>
  <cmd>
   <devices>1</devices>
   <outlet>
          <oid>001</oid>
          <status>1</status>
   </outlet>
  </cmd>
</SM>
```

Figure 5 The Control_On_Off XML format

- **Retransmission (request message)**

The server can request a smart meter to retransmit the electricity consumption information for a specific time period. For example, the server requests the smart meter to retransmit the total energy consumption data from the outlet (OID=1) on first of June, 2012. The XML format is shown in Figure 6.


```xml
<?xml version="1.0" encoding="UTF-8"?>
<SM>
  <type>2</type>
  <timestamp>2012-06-01 12:07:40</timestamp>
  <cmd>
   <devtype>outlet</devtype>
   <oid>001</oid>
         <rtday>2012-05-31</rtday>
         <section_start>1</section_start>    //00:00:00 to 00:10:00
         <section_end>144</section_end>  //23:50:00 to 00:00:00
  </cmd>
</SM>
```


Figure 6 The retransmission XML format

- **Power_Cost (billing message)**

The server can send the pricing of electricity and related information to customers using a billing message.

For example, the server sends the cost of electricity (weekly cost: 20/05/2012-26/05/2012) to the customer, using the XML format as shown Figure 7.


```xml
<?xml version="1.0" encoding="UTF-8"?>
<SM>
  <type>3</type>
  <timestamp>2012-06-01 12:07:40</timestamp>
  <cmd>
      <month>5</month>
      <day_start>20</day_start>
      <day_end>26</day_end>
      <total_cost>100</total_cost> // TW dollar
  </cmd>
</SM>
```


Figure 7 The power-cost XML format

- **Query_power (electricity usage message)**

  The smart meter sends the electricity information (voltage (volt), current (milliampere), power (watt)) which it collected from outlets to the server every ten minutes. For example, the smart meter sends the electricity information from the outlet (OID=1) to the server. The XML format of the message is shown in Figure 8.

```
<?xml version="1.0" encoding="UTF-8"?>
<server>
 <type>1</type>
 <smlogin>
     <sid>001</sid>
     <timestamp>2012-05-31 23:50:00</timestamp>
 </smlogin>
 <rpoutlet>
     <devices>1</devices>
     <outlet>
         <oid>001</oid>
         <data>109,50,10</data>
     </outlet>
  </rpoutlet>
</server>
```

Figure 8 The query_power XML format

- **Warn_to_Change (warning message)**

  When some power usage information (voltage (volt), current (milliampere), power (watt)) shows that the threshold has been exceeded, the smart meter can automatically send a warning message to the server. For example, the smart meter detects that an abnormal event occurred from the outlet (OID=1) and notifies the server immediately. The XML format is shown in Figure 9.

```
<?xml version="1.0" encoding="UTF-8"?>
<server>
  <type>2</type>
  <smlogin>
      <sid>001</sid>
      <timestamp>2012-05-31 12:00:40</timestamp>
  </smlogin>
  <rpsm>
     <devices>1</devices>
     <outlet>
         <oid>001</oid>
         <report>1</report>
     </outlet>
  </rpsm>
</server>
```


Figure 9 The warn_to_change XML format

Table 1 Overview of XML tags

<table>
<tr><th>tags</th><th>description</th></tr>
<tr><td>SM</td><td>The server sends messages to the smart meter.
<table>
<tr><th colspan="2">Type tag (To distinguish type of messages)</th></tr>
<tr><td>Value : 1</td><td>Control_On_Off
<table>
<tr><th colspan="2">Status tag (To distinguish type of commands)</th></tr>
<tr><td>1</td><td>Turn On</td></tr>
<tr><td>0</td><td>Turn Off</td></tr>
</table></td></tr>
<tr><td>Value : 2</td><td>Retransmission</td></tr>
<tr><td>Value : 3</td><td>Power_Cost</td></tr>
</table></td></tr>
<tr><td>Server</td><td>The smart meter sends messages to the server.
<table>
<tr><th colspan="2">Type tag (To distinguish type of messages)</th></tr>
<tr><td>1</td><td>Query_power</td></tr>
<tr><td>2</td><td>Warn_to_Change</td></tr>
</table></td></tr>
<tr><td>oid</td><td>Unique ID for outlets</td></tr>
<tr><td>sid</td><td>Unique ID for smart meters</td></tr>
</table>

Given the various types of messages that are exchanged between smart meters and a server, we now discuss the QoS requirements of these messages.

5 The QoS requirements of messages

Smart meter networks will generate numerous messages from a wide range of devices and the server will also send numerous messages to smart meter networks. Smart meter networks accommodate three categories of messages (operational messages, non-operational messages, and asynchronous event messages) which are transmitted between the server and smart meter networks according to predefined policies.

Operational messages (e.g. control message) tend to be constant in volume and require timely transmission in terms of bandwidth, latency and availability requirements. Non-operational messages (e.g. electricity usage message) have less strict latency requirement than operational messages. Asynchronous event messages (e.g. warning messages) are generated by smart meter network devices in reaction to physical events. These messages could be generated in an unpredictable manner and some of events need to be communicated and then processed with very low latency according to the degree of urgency. Table 2 summarizes the network requirements for messages.

Table 2 Requirements for messages

Message Category	Latency Allowance	Bandwidth
Operational	Low	Medium/Low
Non-operational	Medium	Medium/Low
Asynchronous event	High/Medium/Low	Medium/Low

6 Method to meet the QoS requirements of messages

An advance metering infrastructure is required to interconnect smart meter networks together and provide a stable two-way communication system between the provider and customers. Due to the maturity of IP technology, it is widely used in telecommunications infrastructures and many applications are developed based on IP. Smart meter networks can be deployed by adopting standard IP-based embedded devices rather than other proprietary embedded devices. However, IP cannot guarantee QoS requirements for messages because the service model of IP is best effort. Hence, an additional mechanism is needed that it can interoperate with IP while having the QoS capabilities to meet the requirements of messages.

6.1 Using SCTP to transport messages

The design of SCTP not only has the advantages of TCP and UDP, but also other new features which strengthen SCTP's capabilities. We now identify several features of SCTP which can meet the requirements of messages in smart meter networks.

- **Multi-homing[8]**

  The multi-homing function provides a redundancy mechanism between two end points, by setting up an association with multiple IP addresses or multiple network interfaces. In the smart meter network, a smart meter can control the whole local network and act as the bridge to the Internet. The smart meter and the server can have two network interfaces (as illustrated in Figure 10) bound to an SCTP association. One of interfaces is a master network connection path and other one is a backup path. When the master path breaks down, it will automatically switch to the backup path to continue data transmission without interruption. The failover is done by SCTP, and it is transparent to the upper layer application. This feature is very important in the high availability environment.

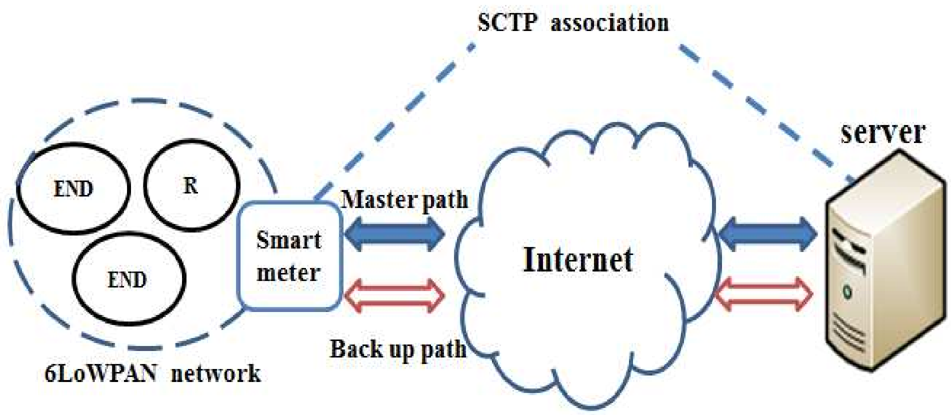

Figure 10 The smart meter network with SCTP multi-homing mechanism

- **Multi-streaming**

  The data from the upper layer application can be transmitted by multiple streams which are independent, as shown in Figure 11. If a segment is lost from a specific stream, segments following the lost one will be stored in the receiver buffer until the lost one is successfully retransmitted from the sender. This situation is called Head Of Line (HOL) blocking. However, data from other streams can still be passed to/from the upper layer application. The SCTP multi-streaming function can limit the HOL blocking effect within the scope of independent streams rather than the entire association.

  Many researches have focused on combining the SCTP multi-streaming function with other new features in order to support specific application requirements.

  - Priority stream scheduling[9]:

    This involves adding a priority stream scheduling scheme to SCTP. Priorities allow the sender to give precedence to data specified as critical during periods of increased network delay or decreased network throughput.

  - Preferential treatment[10]:

Mechanisms to introduce preferential treatment among streams have been proposed, which use the IP layer type-of-service header bits to take advantage of QoS support in the underlying network.

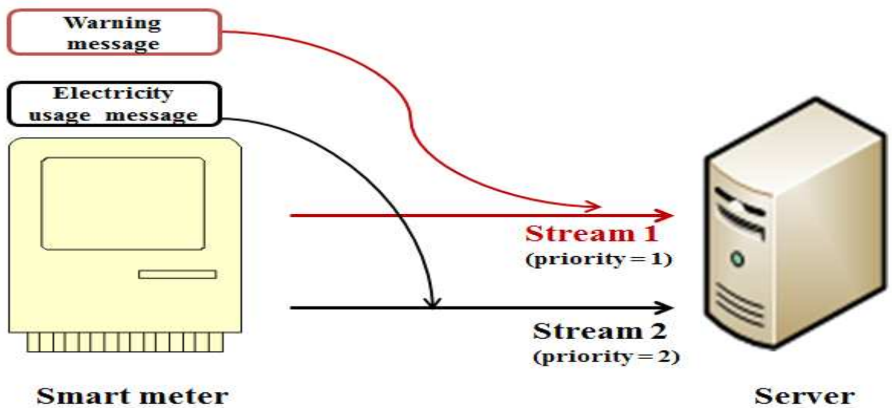

Figure 11 The smart meter network with SCTP multi-streaming mechanism

- **Protecting availability of services**

  One of the critical network threats is blind denial of services (DoS) attacks by flooding the target with a large number of setup requests, which will eventually exhaust the resources of the target host. SCTP eliminates the risk of DoS attacks by using a four-way handshake sequence and a cookie mechanism to store the setup request related information on client side or network, rather than allocate server resources, until the completion of authentication. This function can protect smart meters against the DoS attacks.

- **Protecting the integrity of messages**

  IPSec or Transport Layer Security (TLS) can be used to protect the confidentiality and integrity of the SCTP payload that contain messages of the smart meter network. IPSec is designed to provide security services at the IP layer, which interoperate with

IPv4 and IPv6. The TLS protocol provides an extensible security framework based on transport layer services. The protocol stacks of IPSec and TLS are shown in Figure 12.

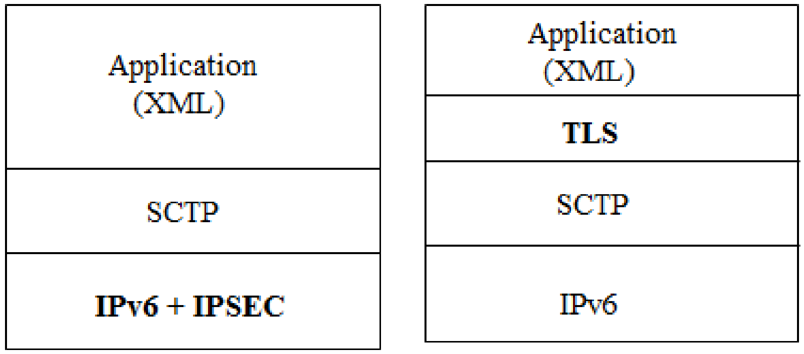

Figure 12 IPSec / TLS with SCTP

The billing and electricity usage messages contain confidential and sensitive information that cannot be arbitrarily change or revealed to any third party without proper authorization.

7 Smart meter networks with SCTP mechanism support

This article proposes the use of the SCTP as the transport layer protocol and the IP (IPv6) as network layer protocol to implement smart meter networks. The smart meter is a getaway in the smart meter network and has capabilities to manage electrical equipment (outlets) while communicate with the energy management server on the Internet. The scenario of the smart meter network is shown in Figure 13.

- SCTP multi-homing

The smart meter and server are both equipped with two network interface cards, namely, an Ethernet card and a Wi-Fi card. The Ethernet network is a master network connection path which will automatically switch to the backup WiFi network path when it breaks down.

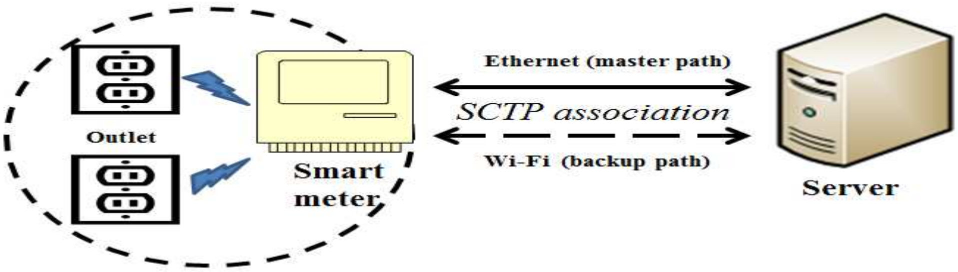

Figure 13 The scenario of the smart meter network with SCTP support

- SCTP multi-streaming with priority scheduling scheme

  There are five messages (control, request, billing, electricity usage and warning messages) transmitted between the smart meter and the server. Those messages are transmitted by independent streams with different priority.

  For example, the smart meter can send the electricity usage message to the server and concurrently send the warning message when it detects the abnormal events from the outlets. The smart meter can prioritize messages and classify those messages into corresponding streams with priority based on the predefined policies, as shown in Figure 11.

8 Conclusion

Smart meters are the key component of an advanced metering infrastructure, which provides an interactive service between providers and customers. It must be able to respond in real time, provide the electricity consumption information and perform appropriate actions promptly. There are many messages transmitted between providers and customers such as control messages, billing messages, and so forth. Smart meter networks which require QoS supports (low latency, high availability, integrity, etc.) of these messages will certainly bring a significant challenge on quality of services of smart meter networks. In this article, we propose the use of SCTP as the transport protocol for messages in smart meter networks.

The SCTP transport protocol can meet the QoS requirements of messages in smart meter networks, and interoperate with IP networks without the protocol translation overhead which is required by ZigBee networks. SCTP is a reliable and message-oriented protocol; it not only overcomes the shortcomings of TCP but also provides several new features. This article has discussed the use of SCTP multi-homing, SCTP multi-streaming and some security mechanisms to transport messages, so as to provide a good quality of communication mechanism for serviced-based smart meter networks.

Reference

[1] S. Karnouskos, O. Terzidis and P. Karnouskos, “An Advanced Metering Infrastructure for Future Energy Networks”, *Proceedings of the International Conference on New Technologies, Mobility and Security* (NTMS), May 2007, Paris, France , Pages 597-606.

[2] P. Baronti, P. Pillai, V.W.C. Chook, S. Chessa, A. Gotta, and Y. F. Hu, “Wireless sensor networks: a survey on the state of the art and the 802.15.4 and ZigBee standards”, *Computer Communications*, Volume 30, No. 7,May 2007, Pages 1655-1695.

[3] N. Kushalnagar, G. Montenegro and C. Schumacher, “IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals”, *RFC 4919*, August 2007.

[4] Y.-H. Jeon, “QoS requirements for the Smart Grid Communication System”, The International Journal of Computer Science and Network Security, Volume 11, No 3 , March 2011.

[5] S. Fu and M. Atiquzzaman, “SCTP: state of the art in research, products, and technical challenges”, *IEEE Communications Magazine*, Volume 42, Issue 4, April 2004, Pages 64-76.

[6] P. Yi, A. Iwayemi, and C. Zhou , “Building Automation Networks for Smart Grids”, *International Journal of Digital Multimedia Broadcasting*, Volume 2011, article ID 926363, 2 April 2011.

[7] L. Nordstrom and T. Cegrell, “Extended UML modeling for risk management of utility information system integration”, *Proceedings of the Power Engineering Society General Meeting*, June 2005. Volume 1, Pages 913-919.

[8] A. L. Caro *et al*., “SCTP: A Proposed Standard for Robust Internet Data Transport”, *IEEE Computer Magazine*, Volume 36, Issue 11, November 2003, Pages 56–63.

[9] G. Heinz, “Priorities in SCTP Multi-streaming”, Master’s Thesis, Computer and Information Sciences Dept., Univ. of Delaware, USA, May 2003.

[10] S. Samtani, J. Iyengar, and M. Fecko, “SCTP Multi-streaming: Preferential Treatment among Streams”, *Proceedings of the Military Communications Conference* (MILCOM), October 2003, Pages 966-970.