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物联网网关：将无线传感器网络连接到物联网

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摘要

随着传感器、无线移动通信、嵌入式系统和云计算技术的发展，物联网技术在物流、智能仪表、公安、智能建筑等领域得到了广泛的应用。物联网因其巨大的市场前景，受到世界各国政府的密切关注，被视为继互联网和移动通信网络之后的第三波信息技术浪潮。IOT 网关是无线传感器网络与传统通信网络或互联网之间的桥梁，在 IOT 应用中发挥着重要的作用，有利于无线传感器网络与移动通信网络或互联网的无缝集成，以及与无线传感器网络的管理和控制。在本文中，针对 IoT 典型的应用情景和远程操作的需求，我们提出了一个基于 Zigbee 和 GPRS 协议的 IoT 网关。介绍了无线传感器网络与移动通信网络之间的数据传输问题，对不同的传感器网络协议的协议转换，以及传感器网络的控制功能，最后给出了原型系统的实现和系统验证。

关键词：IOT; WSN; Zigbee; GPRS

1 绪论

物联网被认为是继互联网和移动通信网络之后的第三次热潮，其特点是更完善的感知和测量，更全面的互操作性和智能。物联网技术可以有效地促进材料生产和服务管理的融合，促进物质世界与数字世界的融合。随着 IOT 技术的发展，IOT 最重要的应用领域包括基础设施建设、公共安全、环境保护、现代农业、智能产业、城市管理、商业服务等领域。

1999 年，麻省理工学院自动 id 实验室首次提出了物联网的概念，研究利用无线传感器网络和射频识别技术实现目标定位和状态识别。2005 年，国际电信联盟(ITU)发布了《国际电联互联网报告 2005：物联网》，正式提出了物联网的概念，它指出：无处不在的物联网通信时代到来了，在这个时代，世界上的所有物体都可以通过网络主动地交换信息。2009 年，IBM 提出了"智能星球"的概念，旨在将传感器嵌入到电网、铁路、建筑物等多个物理物体中，并通过智能处理技术使它们变得智能。从信息技术的角度来看，物联网是一个巨大的全球信息系统，由数亿个对象组成，可以基于标准化和可互操作的通信协议进行识别、感知和处理。IOT 系统在宽带移动通信、下一代网络和云计算技术的支持下，可以智能地处理对象的状态，为决策提供管理和控制，甚至在没有人工干预的情况下相互自主协作。

如今，传统的移动通信网络和互联网主要用于人们之间的信息传输，而 WSN 可以通过构建独立的无线网络来实现目标间的短距离通信。但是，由于通信协议和传感技术缺乏统一的标准化，由于 WSN 通信协议的限制，WSN 数据不能远程传输，WSN 与移动通信网络或互联网难以连接。因此，随着物联网的发展，一种叫做物网网关的新型网络设备被发明出来，其目标是解决各种传感器网络和移动通信网络或互联网之间的异质性，加强对 WSN 和终端节点的管理，并将传统的通信网络与传感器网络连接起来，使网络通信更容易，并管理传感器网络的设备。因此，实现 IOT 网关系统的关键问题是解决 WSN 和传统电信网络中不同传感器网络的异质性和协议的多样性。此外，为了实现 IOT 管理和控制的功能，有必要为所有 IOT 网关构建一套统一识别的指令和标准。

本文的其余部分的组织结构如下：第二部分介绍了 IOT 网关系统和标准的相关工作。第三部分介绍了物联网在智能家居的解决方案，介绍了典型的基于 WSN 的

IOT 应用程序架构和 IOT 网关的特点。IOT 网关系统的系统要求和软件架构在第四部分给出。第四部分给出了最初的实现问题。最后，第五部分给出一些结论性的评论。

2 相关工作

IOT 网关系统的标准化和设计已经有一些学术和工业工作。国内外电信运营商在 WSN 与电信网络结合的应用中开展相关业务，根据行业用户的需求进行积极探索。在国外标准化机构中，ETSIM2MTC[5]和 3GPP 均建立了相关标准。ETSIM2MTC 的主要目标是对 M2M（机器对机器）的标准化进行一些研究，他们已经进一步研究了 3GPP 和 ETSI 的现有成果。ETSIM2MTC 现在专注于 M2M 的定义和应用示例，在此基础上，继续进行业务需求和标准化，但还没有涉及任何特定的技术。3GPP 在 2005 年启动了 M2M 的研究团队。其主要工作是讨论其需求、可行性和框架。同时，国内企业也按照国外的标准化工作开展了设备规范工作。中国电信还宣布了用于 WSN 终端管理的 MDMP 协议，并在农业和智能家居领域进行了应用演示。

在设计和实现，中国电信上海研究所提出了一个家庭系统 IOT，表明网关是信息采集和控制的核心单元，中国电信上海研究所总结，网关系统的关键特点是协议转换、状态控制、信息采集、终端寻址和认证。在[7]中提出了 WebofThings 架构，通过智能网关，可以将真实对象转换为 RESTful 资源，集成到现有系统中，以便被外部 HTTP 主机直接访问。智能网关通过蓝牙与传感器节点进行交互，为传感器节点分配 URL，通过 JSON 数据段等 HTTP 数据包将采集到的感知数据转发到 Web 服务器，从而连接传感器网络和传统电信网络[7]。总之，在现有的 IOT 相关系统中，网关发挥着主导作用，基本上实现了数据传输和转发的功能。然而，管理和控制问题很少被考虑。

3 IoT 网关

3.1 使用方案

物联网的应用包括物流、智能仪表、智能建筑等，我们用智能家居来说明，这是物联网的典型应用场景。

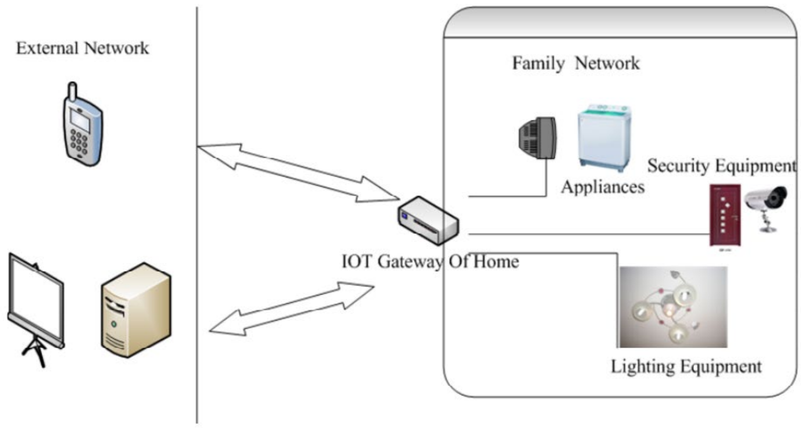

图 4.1：智能家居使用方案

智能家居是一种嵌入式传感器、信息家电、网络通信和自动化设备等的新型住宅。以提供一个舒适、安全、绿色、方便的生活环境。随着传感器、微电机系统、无线通信的发展，智能家居中嵌入式设备之间的内部通信变得更加容易。一方面，家庭 IOT 网关在将多个智能设备连接在一起，形成家庭网络，并在各种家用电器之间共享资源和信息方面发挥着非常重要的作用。另一方面，家庭 IOT 网关也起着将外部网络连接到家庭网络的另一个作用，并提供了对外部网络的访问接口，如图 4.1 所示。在这种情况下，一些常见的家用电器，如电视机、洗衣机、灯、摄像头，都嵌入了传感器和无线通信模块，可以构建多个特殊的家庭无线网络。家用 IOT 网关集成了几种常用的自组织网络协议，并支持具有不同网络协议的设备之间的相互通信。用户可以通过 IOT 网关控制家庭智能设备。此外，家庭内的 IOT 网关还集成了 2G/3G 移动通信网络模块和互联网，以方便与外部网络的连接。通过这种方式，用户可以通过家庭 IOT 网关在任何地方访问和控制任何设备。

3.2 基于 WSN 的 IOT 应用程序架构

典型的 IOT 应用程序架构可分为三层，如图 4.2 所示：

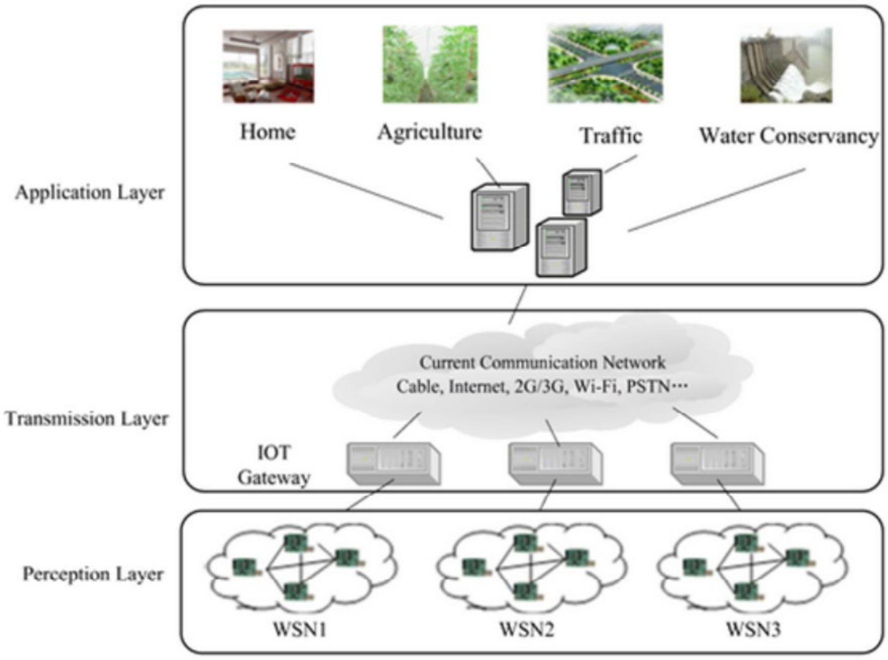

图 4.2：典型 sing 物联网应用结构

1）感知层：在感知层，系统的目标是获取、收集和处理来自物理世界的数据，其中包括两部分：传感器设备和无线传感器网络。前者包括 RFID 标签、传感器节点、摄像头等。后者是一种由许多传感器节点组成的自组织无线网络。这些设备可以协调地监控物理环境的状态。具体来说，感知层首先通过数据采集设备采集数据，然后使用 RFID、蓝牙等技术将数据传输到下一层。最重要的是，这一层是 IOT 系统的基础，具有信号检测、短程无线电技术等关键技术。

2）传输层：在传输层，该系统旨在基于传统的移动宽带通信网络、Wi-Fi 等通信技术构建的大面积或长距离传输数据，实现感知与通信网络的集成。因此，从感知层收集到的数据可以成功地传输到远程目的地。远程有线和无线通信技术，网络技术在这一层很重要。

3）应用层：数据处理和服务提供是应用层的两个主要目的。来自传输层的数据由相应的管理系统处理，然后向各种用户提供各种服务。

3.3 IOT 网关的特性

IOT 网关作为连接传感器网络与传统通信网络的桥梁，可以提供协议转换和设备管理的功能。关于通用网关，IOT 网关具有以下特点：

1)广泛的访问能力：目前短接通信技术标准多种多样，包括 Zigbee、Z-Wave、Rubee、WirelessHART 等。然而，它缺乏协议兼容性。

2)可管理性：IOT 应用程序将终端传感器节点作为触手，在大型服务器上运行的程序作为大脑，来感知和控制物理世界。因此，有必要管理数百万个终端传感器节点。同时，IOT 网关的管理不仅意味着子网中的传感器节点的管理，也意味着网关设备的管理。前者旨在获取节点的识别、状态和属性，并实现远程启动、关闭、控制和分析。后者旨在实现网关设备的控制、诊断、配置、升级和维护。

3)协议互通：传统的网络和传感器网络需要在 IOT 场景中交换信息。IOT 网关应支持传统网络和 WSN 之间的协议无缝互通。

4 IoT 网关系统的设计

4.1 系统要求

基于家庭使用场景，IOT 网关应支持 WSN 中的内部数据协作和聚合，以及在互联网、2G/3G 网络、DSL 网络和其他网络接口之间的数据传输。IOT 网关系统的系统要求如下：

1)数据转发：IOT 网关系统的基本功能是接收来自传感器网络终端或互联网终端的数据，然后透明、正确地将数据传输到其他网络。

2)协议转换：在 WSN 中提出了 IEEE802.15.4/Zigbee 网络通信协议，而互联网网络是基于 TCP/IP 协议的。这意味着 IOT 网关系统应使用短距离无线通信协议(如 Zigbee)从传感器节点获取数据包，并使用 2G/3G、DSL 等网络接口将数据包发送到电信网络或互联网。因此，IOT 网关应该在接收到 WSN 协议后对传感器数据进行分析和重新打包，然后根据电信协议对重新打包的数据进行封装和发送。

3)管理和控制：除了接收或上传数据外，IOT 网关还应支持对传感器节点的管理和控制。例如，当网关接收到来自远程服务器的命令时，它应该处理这些命令，然后将它们发送到传感器节点，从而使远程服务器可以通过 IOT 网关来管理和控制传感器网络。

4.2 软件架构

IOT 网关系统由传感器节点、网关和应用平台等传感器节点三个子系统组成，如图 5.1 所示。

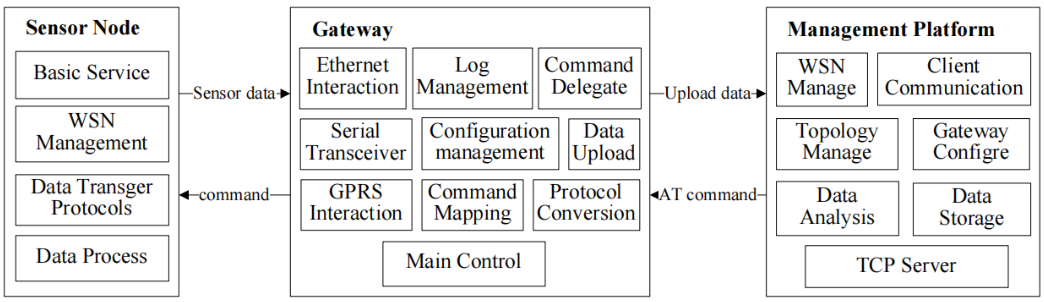

图 5.1：物联网关系统软件结构

传感器节点位于系统的感知层，其主要功能不仅是收集传感器数据，并将信息传输到网关，还可以接收来自网关的命令。为了实现这些目标，传感器节点与数据处理模块一起部署，以解析命令并发送数据，数据传输协议和基础服务模块用来调度数据包，和时间同步模块。

IOT 网关位于传感器节点和应用平台之间的中间层，它不仅接收来自传感器节点的感知数据和来自应用平台的命令，而且还将数据传输到应用平台。GPRS 交互模块和以太网交互模块部署在网关中，与应用平台交换数据。串行收发器模块被部署用于与接收节点交换数据。命令映射模块解析来自应用平台的命令，实现传感器网络管理或网关管理。协议转换模块用定义的格式打包感知到的数据。日志管理和配置管理模块实现了网关的管理功能，记录了网关中的重要事件和配置信息，提供了上传功能。汇聚节点中的数据上传和命令代理模块负责数据采集、将数据发送到串行口、调度网络命令。应用平台位于系统的管理层，其目的是通过网关管理网关和传感器网络，将数据存储在数据库中，并提供用户控制界面。TCP 服务器和客户端通信模块实现数据传输、传感器网络配置和网关配置，实现网关和传感器网络管理、数据分析和统计支持的控制管理。

5 实施问题

本节将介绍有关 IOT 网关系统的一些初始实现问题。

5.1 无线传感器节点

传感器节点的硬件结构如图 6.1 所示。原型系统中的传感器节点为 TelosB 节点，该节点以 MSP430 为 CPU，以 CC2420 为无线通信模块，与温度、光数据采集模块集成。

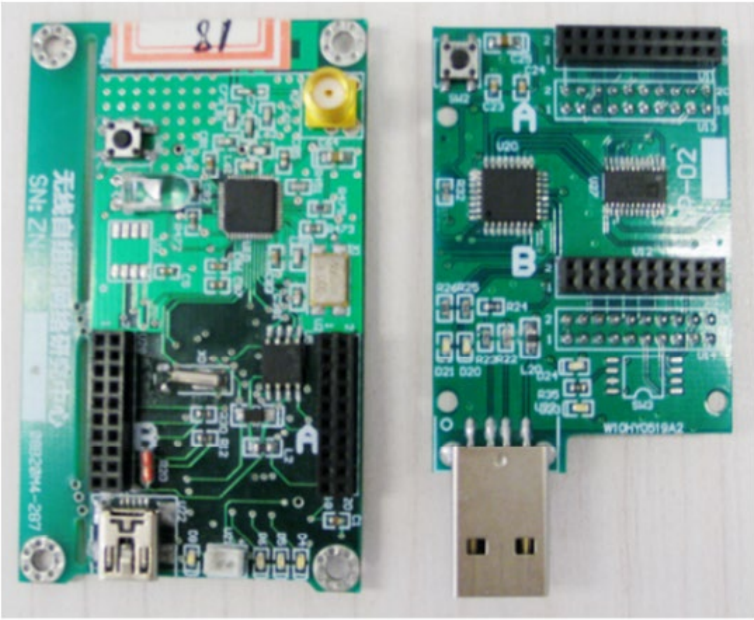

图 6.1：传感器结点硬件结构

在 TelosB 节点中，我们使用 TinyOS 操作系统，并在 nesC 中实现这些模块。这里我们只展示了我们定义的数据包格式。节点上的数据包格式可分为两种类型：数据报告和命令代理。

1)数据报告：传感器节点收集到的数据通过内置的无线芯片发送到接收器。接收器通过串行端口连接到网关。所以数据最终通过串口报告给网关。我们报告的数据以“\x7E\x45”开头，以“\x7E”结束。具体的格式被定义为“7E45 00 X1X2 00 00 X3 00 X4 有效负载(AM)F1F2 7E”。表 6.1 显示了报告数据的形式。有效载荷字段的长度值根据有效载荷类型而变化。主要有两种典型的数据类型：光/温/湿度数据，见表 6.2；路线报告数据，见表 6.3

2)命令代理：此模块不仅从网关接收和传播该命令，而且还执行该命令来控制 mote 的工作状态或配置 mote 的参数。保证格式的有效性是至关重要的，以便 mote 能够解释和执行它。传播命令以‘\x7E\x44’开头，以‘\x7E’结束，具体来说，它被定义为一个字符串，如‘7E44 00 00 x1x2 00 00 X3 00 X4 有效载荷(AM)F1F2 7E’。

表 6.1 是传播命令的每个字段的指令，其中 paylad(AM)字段的类型根据用户的应用程序而变化，例如，经典风格列为下面：打开或关闭几个模式，如表 6.4 所示；打开或关闭所有模式，如表 6.5 所示。

表 6.1：节点上的数据的分组格式

Field	Description
X1X2	Destination Address
0000	Source Address
X3	The Length of Payload
00	Group ID
X4	AM Type
载荷	Effective data
F1F2	CRC Code

表 6.2：光照/温度/湿度数据的有效载荷场定义

Field	1	2	3	4-5	6-7	8-9
Name	SeqNum	NodeID	Value	Seconds	Node2	Ticks

表 6.3：路径报告的有效载荷字段定义

Field	1-2	3-4	5-6
Name	NodeID	ParentID	ETX

表 6.4：打开或关闭多个节点的命令

Field	1	2	3	4-5	6-7	8-9
Name	Type	SubType	SeqNum	Node1	Node2	Interval

表 6.5：打开或关闭所有节点的命令

Field	1	2	3	4-5
Name	Type	SubType	SeqNum	Interval

5.2 IOT 网关

WSN 网关的硬件结构如图 6.2 所示。图 6.2(a)中 IOT 网关的主板分别使用 ARM9 三星 S3C2440 400MHzCPU、64M 闪存和 64Msdram 作为处理器、存储和内存，其中 ARMLinux 和 Python 作为操作系统和编程环境。图 6.2(a)中嵌入的 Sink 节点模块采用 MSP430 和 CC2420 作为处理器和无线通信模块，TinyOS 和 nesC 作为操作系统和编程语言。图 6.2(b)中的 GPRS 模块采用华为 EM310 模块作为无线通信模块。

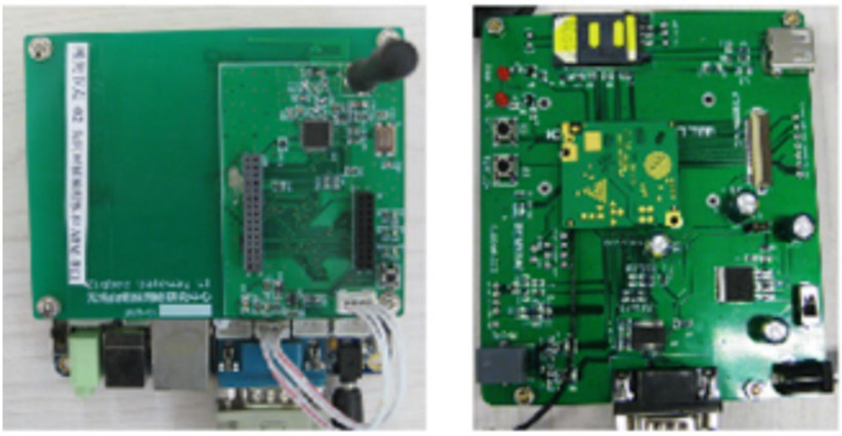
(a) (b)

图 6.2：网关的硬件结构。(a)主板；(b)GPRS 模块

具体来说，网关的主要功能是从串口读取数据，将数据写入串口，并转发感知数据。将 Linux 操作系统移植到 ARM9 主板后，我们需要实现数据传输、协议转换和命令代理功能，以满足上述要求。在图 6.3 中，我们说明了 IOT 网关的主程序的过程。系统打开后，Linux 操作系统首先启动，然后主程序将初始化应用程序。我们的设计提供了两种与远程服务器的交互模式：GPRS 交互和以太网交互。前者通过发送 AT 命令启动 GPRS 模块，同时设置串行通信速度，建立数据传输的套接字连接。后者通过设置远程服务器的 IP 地址和侦听端口来建立套接字连接。它们都提供了一个统一的接口，所以主程序选择其中一个来轻松启动。

在所有模块初始化之后，IOT 网关开始进行端口监听并等待外部事件中断。一旦检测到中断事件，主程序就会通过检查数据的类型来确定适当的响应。如果从源端受到命令，主程序分析该命令并将其发送到 WSN。如果命令要求向服务器报告网关信息或网关日志，主程序会调用远程服务器交互模块的接口，将远程服务器的配置数据和日志发送到远程服务器。如果该命令以传感器节点为目标，则主程序通过调用协议分析模块的接口来分析该命令，然后调用串行数据收发机的接口，向接收器传感器发送信息。如果从 WSN 接收到数据，主程序通过调用协议分析模块来分析数据，然后调用远程服务器交互模块，将感知到的数据发送到远程服务器。

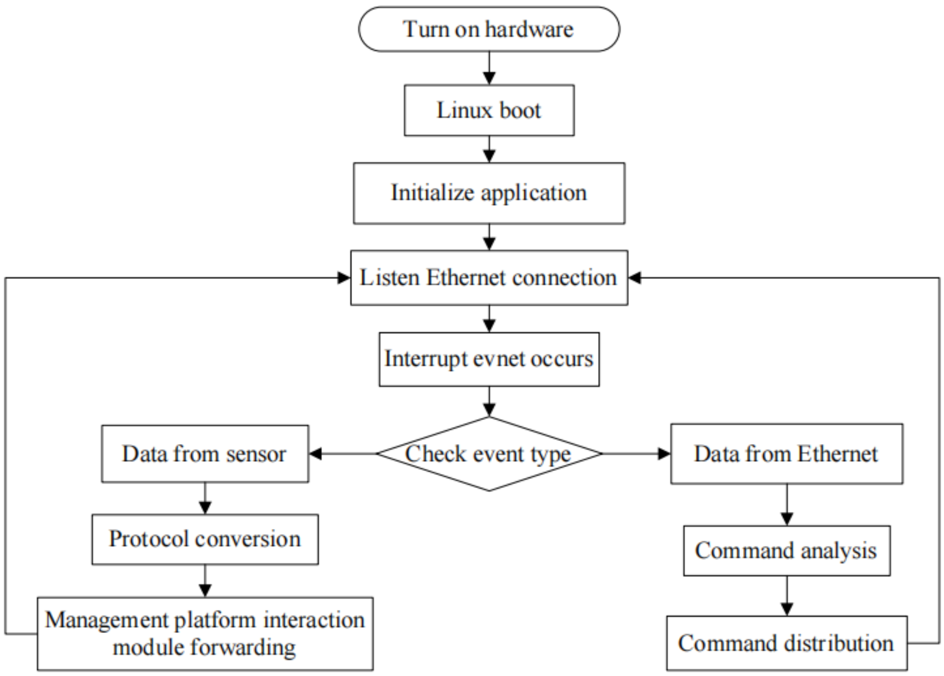

图 6.3：网关主程序的工作流程

5.3 应用程序服务器

应用程序服务器使用 Python 作为运行时环境。图 6.4 显示了在应用程序服务器中部署的主要模块。

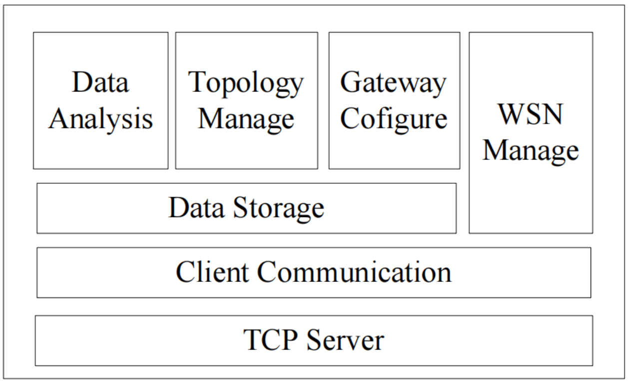

图 6.4：应用程序平台的结构

在 TCP 服务器中，我们实现了支持以 GPRS 的数据报告和以太网发送功能。在 TCP 服务器中采用了套接字通信技术。我们在主过程中打开三个线程。第一个线程是侦听客户端的连接并接受多个套接字连接。第二个线程通过客户端通信模块读取命令并且用以太网或 GPRS 送到 IoT 网关。或者读取来自 IoT 网关的数据并分析，然后送到客户端通信模块。第三个线程通过以太网连接网关和 TCP 服务器。

在图 6.5 中，我们展示了数据报告和命令发送的工作流程。图 6.5(a)显示了数据报告的过程，数据从 IOT 网关传输到 TCP 服务器，接收和解析后阅读 XML 文件数据格式，数据可以融入一个特定的数据结构，然后发送到客户端通信模块。

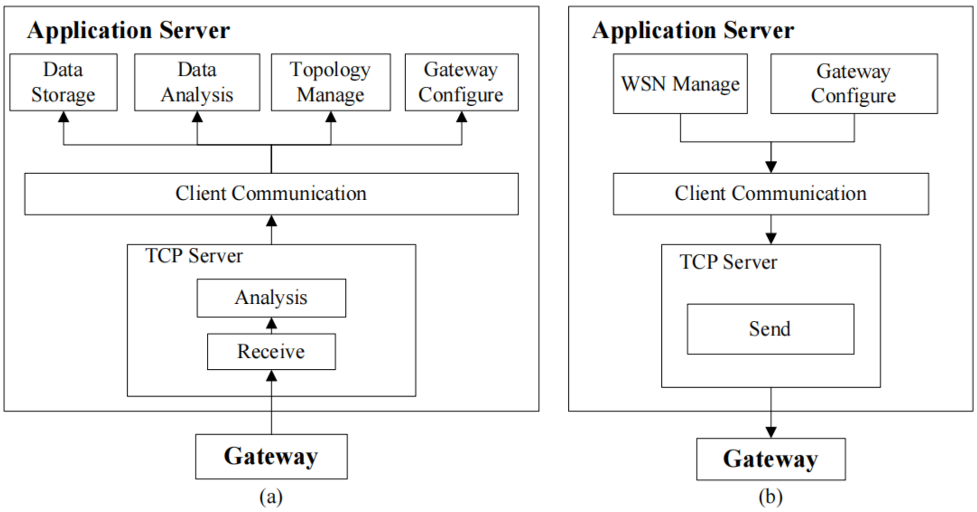

图 6.5：网关与服务器之间的命令和数据的工作流。(a)数据报告；(b)命令发送

客户端通信模块将接收到的数据发送到相关的应用模块，包括数据存储模块、数据分析模块、拓扑管理模块、网关配置模块等。图 6.5(b)为命令发送过程，WSN 管

理模块生成 WSN 指令（如 ON/OFF 指令），网关配置模块生成网关管理指令（如网关日志信息请求）。解析后，将命令转换为 AT 命令，发送到客户端通信模块，通过套接字通信传输到 TCP 服务器模块。

该应用平台提供数据显示、拓扑管理、节点状态分析、网关配置、WSN 管理等功能。如图 6.6(a)所示，应用服务器以实时模式和数据库模式对数据进行解析后，显示来自网关的分类感知数据。图 6.6(b)显示了 WSN 节点的拓扑管理，它在从 IOT 网关中收集和分析路由和邻居信息后，可以绘制出网络拓扑。图 6.6(c)为节点的状态分析，图 6.6(d)为 IOT 网关的日志信息。图 6.6(e)为数据库中存储的网关配置信息。图 6.6(f)显示了 WSN 配置模块，它可以向 IOT 网关发送 AT 命令，包括打开或关闭目标节点的命令，以及时间同步。

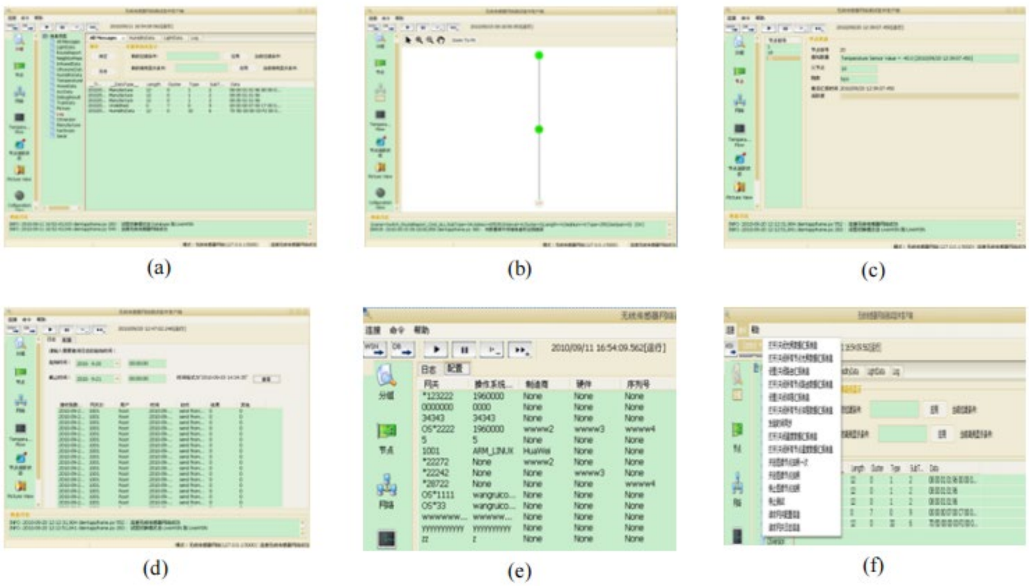

图 6.6：应用程序功能的原型化。(a)传感数据；(b)WSN 拓扑结构；(c)节点的状态分析；(d)网关日志；(e)网关配置；(f)AT 命令发送

6 总结与展望

IOT 网关是 IOT 应用程序系统中的一个关键组件，是电信网络、互联网、WSN 之间的桥梁。本文提出了一种基于 Zigbee-GPRS 协议的 IOT 网关原型实现，实现了数据转发、协议转换、WSN 的管理和控制。因此，它可广泛应用于智能家居、工业监控、智能电网、环境监测等领域。在未来的工作中，我们将考虑 IOT 网关的高级功能，包括故障处理和安全管理。

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IOT Gateway: Bridging Wireless Sensor Networks into Internet of Things

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***Abstract*—With the development of sensor, wireless mobile communication, embedded system and cloud computing, the technologies of Internet of Things have been widely used in logistics, SmartMeter, public security, intelligent building and so on. Because of its huge market prospects, Internet of Things has been paid close attention by several governments all over the world, which is regarded as the third wave of information technology after Internet and mobile communication network. Bridging between wireless sensor networks with traditional communication networks or Internet, IOT Gateway plays an important role in IOT applications, which facilitates the seamless integration of wireless sensor networks and mobile communication networks or Internet, and the management and control with wireless sensor networks. In this paper, we proposed an IOT Gateway system based on Zigbee and GPRS protocols according to the typical IOT application scenarios and requirements from telecom operators, presented the data transmission between wireless sensor networks and mobile communication networks, protocol conversion of different sensor network protocols, and control functionalities for sensor networks, and finally gave an implementation of prototyping system and system validation.**

***Keywords*-gateway; IOT; WSN; Zigbee; GPRS**

I. INTRODUCTION

The Internet of Things is regarded as the third wave of information technology after Internet and mobile communication network, which is characterized by more thorough sense and measure, more comprehensive interoperability and intelligence. The technologies of the Internet of Things can effectively facilitate the integration of material production and service management, the integration of the physical world and the digital world. With development of IOT technologies, the most important IOT application areas cover infrastructure construction, public security, environment protection, modern agriculture, intelligent industry, urban management, business service and other fields[1].

In 1999, MIT Auto-ID Labs first proposed the concept of the Internet of Things, which investigates to realize object localization and state recognition using wireless sensor networks and radio frequency identification technologies[2]. In 2005, International Telecommunication Union (ITU) released 'ITU Internet Report 2005: Internet of Things', formally proposed the concept of the Internet of Things, which noted that ubiquitous Internet of Things communication era dawned, in which all objects in the world can exchange information via the networks actively[3]. In 2009, IBM presented the "Smart-Planet" concept which aims to embed sensors in several physical objects such as power grid, railway, buildings, and make them smart by intelligent processing technologies[4]. From the perspective of information technology, Internet of Things is a huge global information system composed of hundreds of millions of objects that can be identified, sensed and processed based on standardized and interoperable communication protocols. With the support of broadband mobile communication, next generation networking and cloud computing technologies, the IOT system can intelligently process the objects' state, provide management and control for decision-making, and even make them cooperate with each other autonomously without human's intervention.

Nowadays, the traditional mobile communication network and Internet are mainly used in the transmission of information among people, while the WSN can realize the short-distance communication among the objects by constructing wireless networks in ad-hoc manners. However, it's difficult to connect the WSN and mobile communication networks or the Internet with each other because it lacks of uniform standardization in communication protocols and sensing technologies and the data from WSN cannot be transmitted in long distance with the limitation of WSN's transmission protocols. Therefore, with the development of the Internet of Things, a new type of network equipment called the Internet of Things Gateway is invented, whose goal is to settle with the heterogeneity between various sensor networks and mobile communication networks or Internet, strengthen the management of the WSN and terminal nodes, and bridge traditional communication networks with sensor networks to make network communication easier and manage the devices of sensor networks. Therefore, the key issues of implementing IOT Gateway system is to address the heterogeneity of different sensor networks and diversity of protocols in the WSN and traditional telecommunication networks. Besides, it's necessary to build a suite of uniform identified instructions and standards for all the IOT Gateways in order to realize the functionality of IOT management and control.

The rest of the paper is organized as follows: Session II starts with related works of IOT Gateway system and standards. Session III introduces a use scenario of IOT appli-

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cation in smart home, presents the typical WSN-based IOT application architecture and characteristics of IOT Gateway. The system requirements and software architecture of IOT Gateway system are given in Session IV. Session V gives the initial implementation issues and finally some concluding remarks are made in Session VI.

II. RELATED WORKS

There are already some academic and industrial works on standardization and design of IOT Gateway system. Domestic and international telecom operators have launched related business in applications combining WSN and telecommunications networks, conducted active exploration according to the demands of industrial users. Among the foreign standardization organizations, ETSI M2M TC[5] and 3GPP all established related standards. ETSI M2M TC's main goal is to do some research on M2M(Machine-To-Machine) standardization, who have already further their works on the existing achievements of 3GPP and ETSI. ETSI M2M TC now focuses on M2M's definition and application examples, with this basis, proceeds business requirements and standardization, but didn't address any specific technology yet. 3GPP launched research team on M2M in 2005. Its main work is to discuss the demands, feasibility and framework. Meanwhile, domestic enterprises also carried out equipment specification work in accordance with the standardization work abroad. China Telecom also announced the MDMP protocol for WSN terminal management, and carried out demonstrating applications in agriculture and smart home.

As for design and implementation, Shanghai Research Institute of China Telecom proposed a home system of IOT, which indicated that gateway was the core unit of information gathering and control, Shanghai Research Institute of China Telecom summarized that the key features of gateway system were protocols conversion, state control, information gathering, terminal addressing and authentication[6]. Web of Things architecture was proposed in [7], through the intelligent gateway, the real objects can be transformed into RESTful resources to be integrated into the existing systems, in order to be directly accessed by external HTTP hosts. Intelligent gateway interacts with sensor nodes via Bluetooth, which allocates URL for sensor nodes, forwards the collected perception data to Web server through HTTP packets including JSON data segment, thus, linking the sensor network and traditional telecommunications network[7]. In a word, in the existing systems related to IOT, gateway plays a leading role, basically, implementing the functions of data transmission and forwarding. However, the management and control issues are less considered.

III. IOT GATEWAY

A. Use Scenario

The application of Internet of Things covers logistics, SmartMeter, intelligent building and so on, we illustrate IOT Gateway with smart home, which is a typical IOT application. Smart home is a new type house which is embedded with sensors, information home appliances, network communications and automation equipment, etc. in order to provide a comfortable, safe, green, convenient living environment. With the development of sensors, micro-motor system, wireless communication, the intercommunication among the embedded equipments in smart home becomes easier. On one side, the in-home IOT Gateway plays a very important role in interconnecting multiple smart devices together to form in-home network and share resources and information among various home appliances. On the other side, in-home IOT Gateway also plays another role to connect the external networks to the in-home network, and provides the access interface to the external networks as the Fig. 1 shown. In this scenario, several common home appliances, such as TV set, washer, lights, camera, which are embedded with sensor and wireless communication modules, can construct several ad-hoc in-home wireless networks. The in-home IOT Gateway integrates several common ad-hoc network protocols and supports the intercommunication among the equipments with different network protocols. The users can control the in-home smart equipments through the IOT Gateway. Besides, the in-home IOT Gateway also integrates 2G/3G mobile communication network modules and Internet to facilitate the connectivity with external networks. In this way, the users can access and control any equipment anywhere, any time through the in-home IOT Gateway.

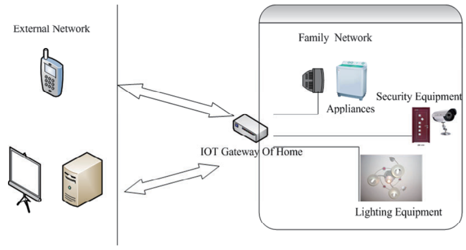

Figure 1. Use scenario in smart home

B. WSN-based IOT Application Architecture

The typical IOT application architecture can be divided into three layers shown in Fig. 2 as follows:

1) Perception Layer: In the perception layer, the system aims to acquire, collect and process the data from the physical world, which consists of two parts: the sensor device and wireless sensor networks. The former one includes RFID label, sensor nodes, and camera and so on. The latter one is a self-organizing wireless network which consists of many sensor nodes distributed in a large area. These devices coordinately monitor the state of physical environment. In details, the perception layer collects the data through data acquisition device at first, and then the data is transferred to the next layer using RFID, Bluetooth or other technologies.

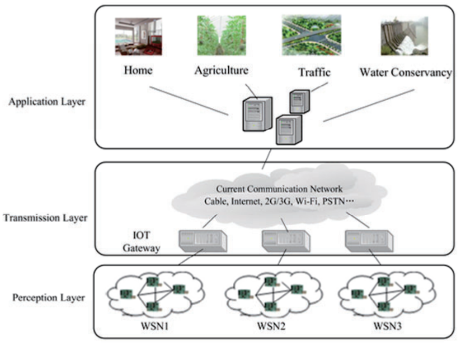

Figure 2. Typical IOT application architecture

Above all, this layer is the basis of IOT system with critical technologies including signal detection, short-range radio technology and so on.

2) Transmission Layer: In the transmission layer, the system aims to transfer data in a large area or long distance, which is constructed based on the traditional mobile broadband communication network, Wi-Fi and other communication technologies to realize the integration of the perception and communication network. Thus the data collected from perception layer can be transferred successfully to remote destination. Long-range wired and wireless communication technologies, network techniques are important in this layer.

3) Application Layer: Data processing and services providing are two major purposes of the application layer. The data from transmission layer is handled by corresponding management systems and then various services will be provided to all kinds of users.

C. Characteristics of IOT Gateway

As the bridge to connect sensor networks with traditional communication networks, IOT Gateway can provide the functionalities of protocol conversion and device management. Referred to the general gateway IOT Gateway has the following characteristics:

1) A wide range of access capability: Currently short-range communication technology standards are diverse including Zigbee, Z-Wave, Rubee, WirelessHART, etc. However, it lacks of protocol compatibility.

2) Manageability: The IOT application takes terminal sensor nodes as antennae, programs running in large server as the brain, to perceive and control the physical world. Therefore, it's necessary to manage millions of terminal sensor nodes. In the meanwhile, the management of IOT Gateway not only means sensor node management in the subnet, but also means the gateway device management. The former one aims to acquire the node's identification, status and properties, and realize remote startup, shutdown, control and analysis. The latter one aims to realize the gateway device's control, diagnosis, configuration, upgrade and maintenance.

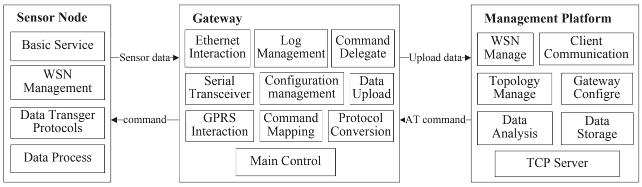

Figure 3. The software architecture of IOT Gateway system

3) Protocol interworking: Traditional network and sensor network need to exchange information in the IOT scenarios. The IOT Gateway should support protocol interworking between traditional network and WSN seamlessly.

IV. DESIGN OF IOT GATEWAY SYSTEM

A. System Requirements

Based on the in-home use scenario, IOT Gateway should support internal data collaboration and aggregation in WSN, and data transmission among Internet, 2G/3G networks, DSL networks, and other network interfaces. The system requirements of IOT Gateway system is listed as follows:

1) Data Forwarding: The basic function of IOT Gateway system is to receive data from sensor network terminals or Internet terminals, and then transfer data to the other networks transparently and correctly .

2) Protocol Conversion: IEEE 802.15.4/Zigbee network communication protocols are proposed in WSN, while the Internet network is based on TCP/IP protocol. It means that IOT Gateway system should use short-distance wireless communication protocol (e.g. Zigbee) to acquire the packet from the sensor nodes, and use the 2G/3G, DSL and other network interfaces to send the packets to telecommunication networks or Internet. Therefore, IOT Gateway should analyze and re-package the sensor data based on WSN protocols after receiving it, and then capsulate and send the re-packaged data based on telecommunication protocols.

3) Management and Control: Besides receiving or uploading data, IOT Gateway should also support managing and controlling the sensor nodes. For example, when the gateway receives the commands from the remote server, it should process the commands and then dispatch them to the sensor nodes so that the remote server can manage and control the sensor network through IOT Gateway.

B. Software Architecture

IOT Gateway system is composed of three subsystems: sensor node, gateway and application platform as Fig.3 shown.

Sensor node is in the perception layer of the system, its main function is not only to collect sensor data and transfer information to gateway, but also to receive commands addressed from the gateway. To achieve these goals, sensor node is deployed with Data Processing module to parse the commands and send the data, Data Transfer protocols and

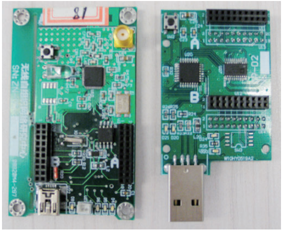

Figure 4. The hardware structure of sensor node

Table I
THE PACKET FORMAT OF DATA ON THE NODES

Field	Description
X1X2	Destination Address
0000	Source Address
X3	The Length of Payload
00	Group ID
X4	AM Type
Payload	Effective data
F1F2	CRC Code

Table II
PAYLOAD FIELD DEFINITION OF LIGHT/TEMPERATURE/HUMIDITY DATA

Field	1	2	3	4-5	6-7	8-9
Name	SeqNum	NodeID	Value	Seconds	Node2	Ticks

Table III
PAYLOAD FIELD DEFINITION OF ROUTE REPORT

Field	1-2	3-4	5-6
Name	NodeID	ParentID	ETX

Table IV
COMMAND OF OPEN OR CLOSE ONE MORE NODES

Field	1	2	3	4-5	6-7	8-9
Name	Type	SubType	SeqNum	Node1	Node2	Interval

Basic Service modules to dispatch data packets, and Time Synchronization module.

IOT Gateway is in the middle layer between sensor node and application platform, it not only receives sensed data from sensor node and commands from application platform, but also transmits data to application platform. GPRS Interaction module and Ethernet Interaction module are deployed in gateway to exchange data with application platform. Serial Transceiver module is deployed to exchange data with sink node. Command Mapping module parses the commands from application platform, implementing sensor network management or gateway management. Protocol Conversion module packages the sensed data with defined format. Log Management and Configuration Management modules implement the management functions of gateway, recording the important events and configuration information in gateway, providing the upload functionality. Data Uploading and Command Agent module in sink node are responsible for gathering data, sending data to serial port, and dispatching network commands.

Application platform is in the management layer of the system, whose purpose is to manage gateway and sensor network through the gateway, store the data in the database and provide user control interface. TCP Server and Client Communication module implement data transmission, Sensor Network Configuration and Gateway Configuration realize the gateway and sensor network management, Data Analysis and Statistical supports for control management.

V. IMPLEMENTATION ISSUES

This section presents some initial implementation issues about the IOT Gateway system.

A. Wireless Sensor Nodes

The hardware architecture of the sensor node is shown in Fig.4. The sensor node in the prototyping system is TelosB node, which uses MSP430 as the CPU and CC2420 as the wireless communication module, integrated with temperature and light data collection module. In the TelosB node, we use TinyOS operating system and implement the modules in nesC. Here we just present the packet format we defined. The packet format on the nodes is divided into two types: Data Reporting and Command Agent.

1) Data Reporting: The data collected by the sensor nodes is sent to the sink by built-in wireless chip. Sink is linked to the gateway through serial port. So the data is reported to the gateway by the serial port finally. The data we report starts with '\x7E\x45' and ends with '\x7E'. The specific format is defined as "7E 45 00 X1 X2 00 00 X3 00 X4 Payload(AM) F1 F2 7E". Table I presents the form of the reporting data. The length value of the Payload field is varied according to the payload types. There are mainly two typical data types: light/temperature/humidity data, shown in Table II; route report data, shown in Table III

2) Command Agent: This module not only receives and disseminates the command from the gateway, but also executes the command to control the mote's working state or configure the mote's parameter. It is critical to guarantee that the format is valid, so that the mote can interpret and execute it. The dissemination command starts with '\x7E\x44' and end with '\x7E'Specifically it is defined as a string like "7E 44 00 00 X1 X2 00 00 X3 00 X4 Payload(AM) F1 F2 7E".

Table I is the instruction for each field of dissemination command, in which Payload(AM) field's style varied according to user's application, for example, the classical style listed as bellow: open or close several motes, shown in Table IV; open or close all motes, shown in Table V.

Table V
COMMAND OF OPEN OR CLOSE ALL THE NODES

Field	1	2	3	4-5
Name	Type	SubType	SeqNum	Interval

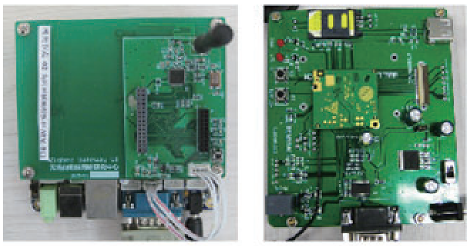
(a) (b)

Figure 5. The hardware structure of gateway. (a) Mainboard; (b) GPRS module

B. IOT Gateway

The hardware structure of WSN Gateway is shown in Fig.5. IOT Gateway's mainboard in Fig.5(a) uses ARM9 Samsung S3C2440 400MHz CPU, 64M Flash and 64M SDRAM as the processor, storage and memory respectively, in which ARM Linux and Python work as operating systems and programming environment. The Sink node module embedded in Fig.5(a) uses MSP430 and CC2420 as the processor and wireless communication module, TinyOS and nesC as the operating system and programming language. GPRS module in Fig.5(b) uses Huawei EM310 module as the wireless communication module.

In detail, the main functions of the gateway are to read data from serial port, write data to the serial port and forward sensed data. After transplanting Linux operating system into the ARM9 mainboard, we need to implement the data transmission, protocol conversion and command agent functions to meet the requirements mentioned above. In Fig.6, we illustrate the process of main program of IOT Gateway. After the system is turned on, the Linux operating system boots first, and then the main program will initialize the applications. Our design provides two modes of interaction with the remote server: GPRS Interaction and Ethernet Interaction. The former one starts GPRS module by sending AT commands, which also sets the serial communication speed to establish socket connection for data transmission. The latter one establishes the socket connection by setting the remote server's IP address and listening port. Both of them provide a unified interface, so the main program selects one of them to start easily.

After all the modules initialized, IOT Gateway starts with port listening and waiting for external events interruption. Once the interruption events are detected, the main program determines the appropriate response by checking the type of data. If the data is received from remote server which means

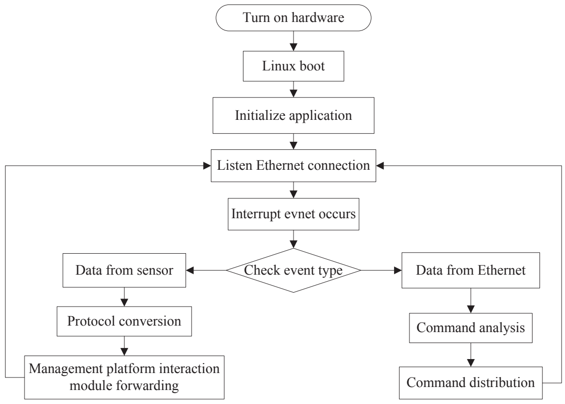

Figure 6. The workflow of gateway's main program

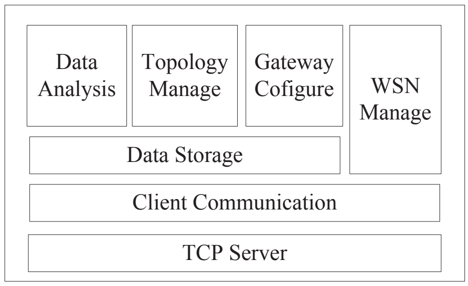

Figure 7. The structure of application platform

that the data is a command, the main program analyzes the command and sends it to the WSN. If the command asks for reporting the gateway information or gateway log to server, the main program calls the remote server interaction module's interface to send logging and configuration data to the remote server. If the command is target with the sensor nodes, the main program analyzes the command by calling the protocol analysis module's interface, and then calls serial data transceiver's interface to send information to the sink sensor. If the data is received from WSN, the main program analyzes the data by calling protocol analysis module, and then calls the remote server interaction module to send sensed data to the remote server.

C. Application Server

The application server uses Python as the runtime environment. Fig.7 shows the main modules deployed in the application server.

In TCP Server, we implement data reporting and command sending functions which supports GPRS and Ethernet communication channels. Socket communication technology is adopted in TCP Server. We open three threads in the main process. The first one is to listen on the client's connections and accept multiple socket connections. The second one is to read the commands via Client Communication module and send it to IOT Gateway by GPRS or Ethernet, or to read

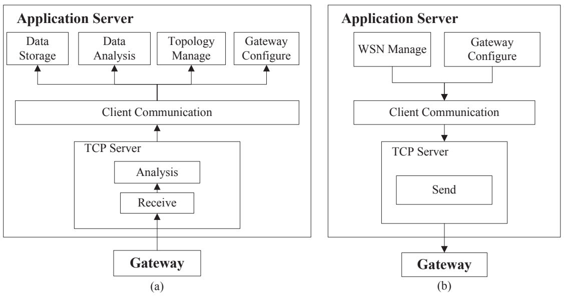

Figure 8. Workflow of command and data between gateway and server. (a)Data reporting; (b)Command sending

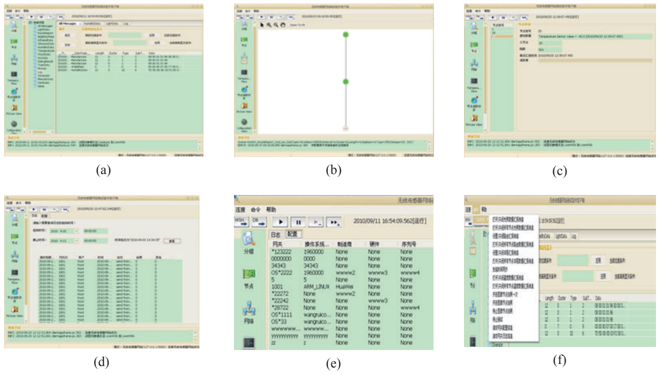

Figure 9. Prototyping of application functions. (a)Sensed data; (b)WSN topology; (c)Node's status analysis; (d)Gateway log; (e)Gateway configuration; (f)AT command sending

data from the IOT Gateway and parse the data, then send it to the Client Communication module. The third thread is to connect TCP Server and the gateway via Ethernet.

In Fig.8, we show the workflow for data reporting and command sending. Fig.8(a) shows the process of data reporting, in which the data is transmitted from IOT Gateway to the TCP Server, after received and parsed by reading the XML file about data formats, the data can be fitted into a specific data structure, then it is sent to the Client Communication module. Client Communication module sends the received data to the relevant application modules including Data Storage module, Data Analysis module, Topology Management module and Gateway Configure module. Fig.8(b) shows the process of command sending, in which WSN Management module can generate WSN's instructions (such as ON/OFF instruction), and Gateway Configure module can generate Gateway management instructions (such as request for the gateway log information). After parsed, the command is converted into AT command, sent to the Client Communication module, transferred through socket communication to the TCP Server module.

The application platform provides the functions including data display, topology management, node's status analysis, gateway configuration, WSN management. As shown in Fig.9(a), the application server displays the classified sensed data from the gateway after parsing the data in real time mode and database mode. Fig.9(b) shows WSN node's topology management, which can draw network topology after collecting and analyzing the routing and neighbor information from the IOT Gateway. Fig.9(c) shows the node's status analysis, and Fig.9(d) shows the log information of the IOT Gateway. Fig.9(e) shows the gateway configuration information stored in the database. Fig.9(f) shows WSN configuration module which can send AT commands to IOT Gateway including the commands for opening or closing the target node, and time synchronization.

VI. Conclusions and Future Work

The IOT Gateway is a key component in IOT application systems, which is working as a bridge between telecommunication network or Internet and the WSN. This paper presents a prototyping implementation of IOT Gateway based on Zigbee-GPRS protocols, which realizes data forwarding, protocol transformation, WSN management and control. Therefore, it can be widely used in smart home, industrial monitoring, smart grid, environment monitoring etc. In future works, we will consider advanced functions of IOT Gateway including fault handling and security management.

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