國 立 交 通 大 學

網路工程研究所

碩 士 論 文

整合 WSN、WiFi 以及 3G 網路建構患者自控止痛系統

System Integration of WSN, WiFi and 3G Network for iPCA system

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整合 WSN、WiFi 以及 3G 網路建構患者自控止痛系統

學生：陶嘉瑋　　　　　　指導教授：簡榮宏博士

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摘　　要

本論文提出一個結合無線感測網路、WiFi 網路與 3G 網路之患者自控止痛整合資訊系統，利用本系統我們可以提供麻醉科醫師一個更完善的術後疼痛管理。為了更有效率的收集有用的止痛資訊，我們在三種醫療裝置上配備無線感測模組，使其可透過無線感測網路傳送患者自控止痛器及相關生理資訊，並透過 WiFi 網路傳至後端整合系統。本系統亦實作了一個簡單的加密與重傳機制來增加在實際應用時的安全性與可靠性，並且設計了一個橋接無線感測網路與 3G 網路之無線網路閘道器，使本系統亦可提供於 3G 網路覆蓋範圍內的患者使用。為了驗證本系統於真實世界之可行性，我們實際在彰化基督教醫院架設本系統，用以協助醫護人員監控患者之健康狀況，並提供患者一個即時的醫護人員通報系統，使患者可將自身不適狀況透過本系統以簡訊方式通知醫護人員。結果顯示，我們的系統能夠真實的運作在現行的醫療體系中，提供醫護人員一個更完善的術後疼痛管理與更有效率的患者自控止痛器資訊整合。

System Integration of WSN, WiFi and 3G Network for iPCA System

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ABSTRACT

This thesis proposed an information integration system, iPCA, which integrated the wireless sensor network (WSN), WiFi and 3G network to help anesthesiologists providing better post-operative pain control. To reduce labor work and to collect analgesic usage information and physiological data efficiently, we connected three kind of medical instruments with WSN end point through WSN and WiFi. We used the simple encryption and retransmission mechanism to make the data transmitted in the secure and reliable way. We also designed a WSN/3G wireless gateway to bridge the WSN network and 3G network. Thus, the patients can equip with our system as long as he is under the coverage of 3G network. To verify the feasible of our system, we did the field trial in the Changhua Christian hospital to help the medical staff monitor the patient's health conditions, and provide the patient a real-time notifying system via the short message service to alert the medical staff about the abnormal status. The results showed the iPCA system can actually work well for the real patient, and the iPCA system also provided better post-operative pain control and an efficient way to collect the PCA usage information for medical staff.

Acknowledgements

I would like to dedicate my special thanks to my advisor Dr. Rong-Hong Jan, for his guidance and enduring support during the whole composing thesis process. Also, thanks to all persons in Computer Network Laboratory for their advice and full-support for the last two academic years.

Honestly and most importantly, I wish to thank my family for putting up with me and supporting me during the ups and downs of writing this thesis.

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Chapter 1
Introduction

In recent year, the interest in applications of computer network has increased significantly due to technological innovations and the improvements of the Internet. And the objective of development has also shifted from increasing hardware performance to providing better services and wider applicability. Medical care is the most needed one among many potential applications of information network technology. How to provide a safer, healthier and more comfortable environment where patients can receive better treatment and the medical staff can obtain more complete information has been increasingly important. To achieve these purposes, integrating the medical service with wireless network to make it more efficient is exactly a meaningful topic.

Among so many medical cares, the pain management is a recently prevalent topic in pain medicine that we will focus on in this thesis. The most common complain that the medical staff got from the patient is the pain from the patients' feel, especially from those who have received surgeries. Pain can affect our life, and may let people suffer from more harm than illness itself when it become intolerable. It makes the patient both physically and mentally uncomfortable. Along with the progress of medical science, people gradually become aware of the importance of pain management. Intramuscular (IM) opioid injection is the most commonly used treatment for postoperative pain relief. However, different surgeries cause different degrees of pain, and pain endurance varies among people. IM opioid injection does not take effect until several tens of minutes, and it is hard to know beforehand the correct analgesic dosage to meet the patient's need.

PCA (Pain Controlled Analgesia) [1] is a delivery system for pain medication that makes pain treatments effective and flexible by allowing patients to adjust the dosage of anesthetics themselves. From previous researches [2], [3], [4], [5], PCA has been considered as one of the most effective techniques for postoperative analgesia and been widely used in hospitals for the management of postoperative pain, especially for major surgeries. PCA provides the medical staff with a convenient way to control pain, but it requires sustained attention, e.g. manually collecting each patient's PCA data, printing out analgesia usage data, entering readings into appropriate databases, etc.

In previous researches, there are many innovative applications that combine the network technique and medical instruments. In the literatures [6], [7], [8], [9], the authors used the computer and PDA to monitor the patient's electrocardiogram remotely. The literature [10] developed an on-line virtual clinic system, the patient can go to see a doctor via the on-line video and voice. In the literature [11], they proposed a Radio Frequency Identification (RFID) system to check the medical staff's identity and trace the patient's position.

In order to utilize appliance efficiently and to increase convenience for the medical care, the system integration of WSN, WiFi and 3G network for medical care service called iPCA system is proposed in this thesis. The iPCA system combines the WSN, the WiFi network and the 3G network to collect and transmit the PCA related data to databases for pain management. It allows the connectivity among the back-end server, the PCA device and the medical device (e.g. vital sign monitor etc.) in an integrated, cooperative environment. The iPCA system is designed to increase comfort and ensure the automation of data maintenance could significantly reduce the labor work to increase efficient.

Figure 1-1 illustrates iPCA architecture, which is centered on a WSN/WiFi/3G network gateway connected to WSN and WiFi/3G network. This gateway connects to medical device through WSN and collects the data of health-related signals monitored by the medical device. In this architecture we connected three kinds of medical devices by using the WSN end point. They were PCA, vital sign monitor (VSM) and a discomfort notifying handheld (DNH) where DNH is used to notify discomfort.

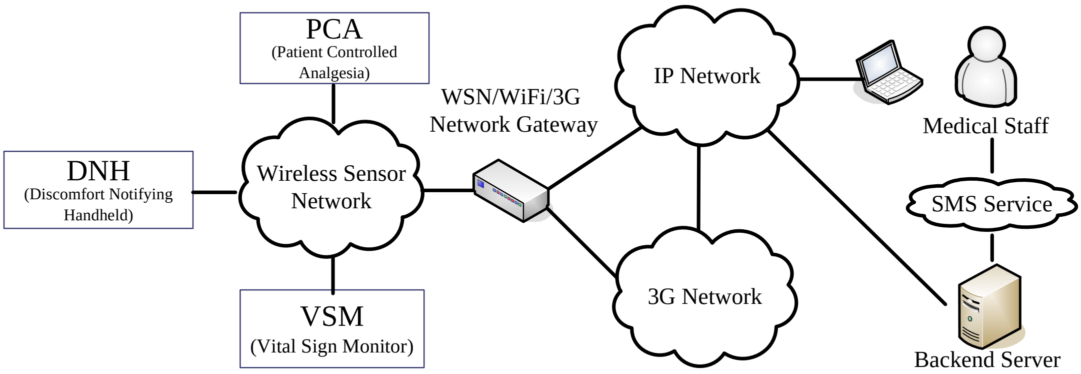


Figure 1-1. iPCA system architecture

The medical staff can connect to the back-end server to monitor the status of WSN-based monitor system through IP-based network. The wireless gateway communicates with the back-end server by using the virtual COM port technique or socket based connection. And it encapsulates the collected WSN data which contains health-related signals from patients in IP-based packets. In addition, the back-end server can actively notify the medical staff when an abnormal state occurs on the patient. For example, the patient can send an alerting message to the back-end server when an abnormal state occurs. Once the back-end server has received this alerting message, it relays the message to the medical staff using 3G Short Message Service (SMS) [12]. The medical staff can do appropriate processing immediately upon receipt of the message.

In this thesis we propose iPCA architecture, integrated with SMS, to support the connectivity among WSN and WiFi/3G network. The main objective of this integrated system is to remotely monitor and collect the data of the devices in the WSN via back-end server. In addition to collecting the data of health-related signals from the patients, the back-end server can also send alerting messages actively via a mobile terminal when an abnormal state occurs. An implementation of the iPCA system is described as an illustration of the feasibility of the proposed architecture.

The remainder of this thesis is organized as follows: Chapter 2 describes the proposed iPCA system architecture. The implementation of the iPCA is presented in Chapter 3. Chapter 4 describes the field trial in the hospital and the summary is given in Chapter 5.

Chapter 2
Proposed System Architecture

The proposed iPCA system can divided into three subsystems: front end, back end, and middle end subsystems (as shown in figure 2-1).

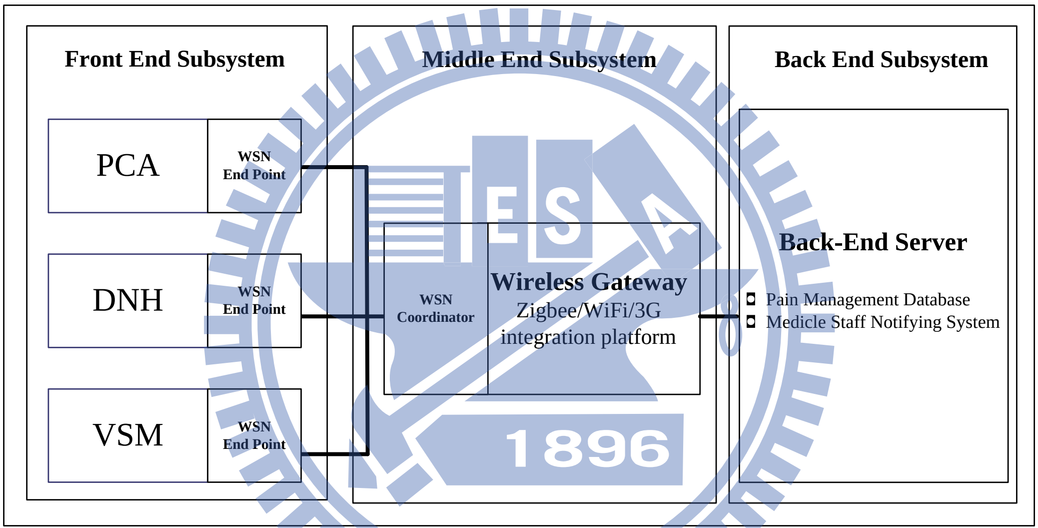


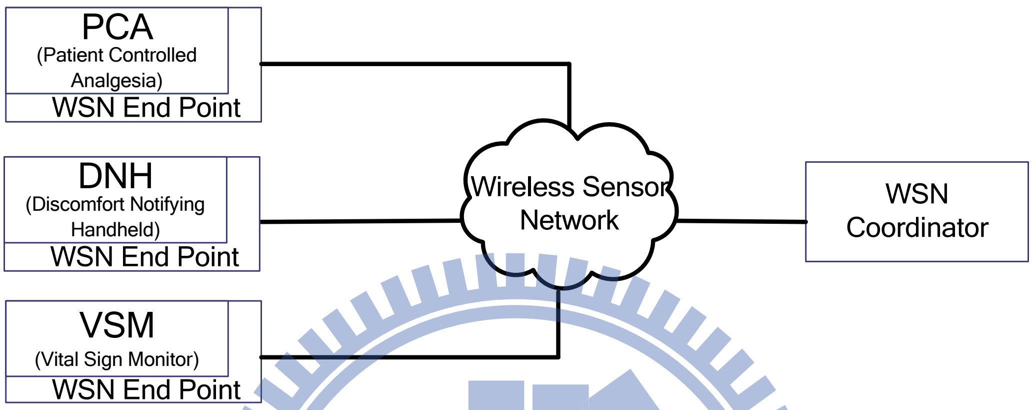
Figure 2-1. Three subsystem in iPCA

(1) The front end is a WSN-based monitor system that collects the health-related signals from the patients (see the figure 2-2(a)). We designed the WSN management protocol for WSN coordinator to manage the medical device (e.g. PCA, DNH and VSM).

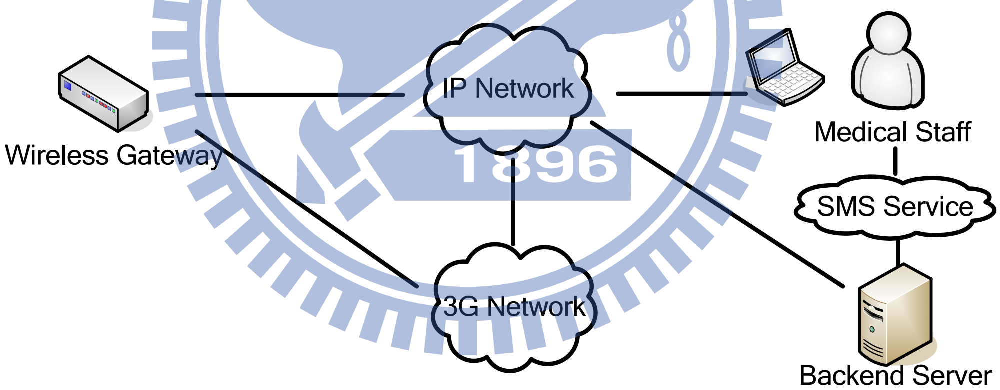
(2) The back end includes a medical staff notifying system and a pain management database (see the figure 2-2(b)). The back-end server receives the data from medical devices via middle end subsystem and builds the pain management database. Medical staff can access the back-end server through IP network. When an abnormal status occurs, it will use the short message service to send a

alert message to medical staff through 3G network.

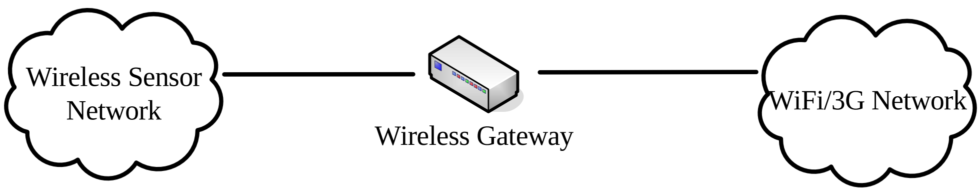
(3) The information integration network lies in the middle end (see the figure 2-2(c)). It bridges the front and the back ends. We designed the wireless gateway to connect the WSN and WiFi/3G network.



(a) Front end subsystem



(b) Back end subsystem



(c) Middle end subsystem

Figure 2-2 Subsystem Architecture

2.1 Front End Subsystem

In the front end subsystem, we propose a WSN management protocol, a Buffer-ACK mechanism and a character-based cipher block chaining (CBC) encryption mechanism. The WSN management protocol allows WSN coordinator to monitor and collect the data of medical devices. The Buffer-ACK mechanism is designed to deliver the collected data from medical devices to WSN coordinator reliably. The character-based cipher block chaining (CBC) encryption mechanism is applied to protect the data over the open communication networks.

2.1.1 WSN Management Protocol

The proposed management protocol employs the concept of a coordinator model, as shown in figure 2-3. The coordinator model consists of a WSN end point attached to each medical device and the WSN coordinator connecting to the wireless gateway. The model is used to monitor and organize WSN end points. The WSN coordinator periodically probes the WSN end points to invite them to associate with. When the WSN end point associates with the coordinator, it will receive a short address from coordinator.

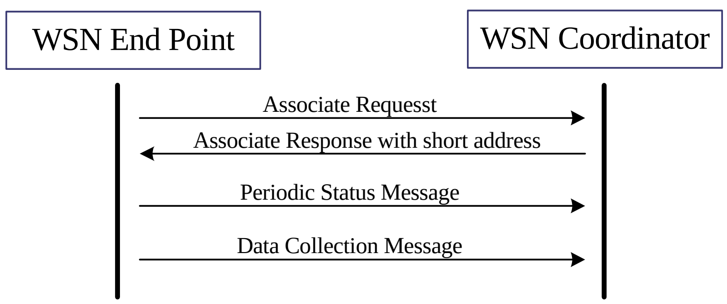


Figure 2-3 Coordinator model

The WSN end point periodically broadcasts its status message for announcing its active status. Then the WSN coordinator collects these status messages, analyzes the WSN end point's status and sends the status report containing the status of each medical device to back-end server. When the medical device was triggered by patient or medical staff, the WSN end point will send the data collection message that contain the medical data to the WSN coordinator. The WSN coordinator will receive the message and forward the message to the back-end server.

The format of the message sent from WSN end point is shown in Figure 2-4(a); the "sequence" field is a decimal number used within each message to identify a particular revision of the message. The "Type" field specifies status message or data message. The "Device" field is used to identify this message belong to which medical device (e.g. PCA, DNH, and VSM). "ID" is the unique patient identity in this system. "Data" is the medical information generated by the medical device. The format of the status report message sent from WSN coordinator is shown in Figure 2-4(b); its format is same as the message mentioned above except the data field which is replaced by the status of each medical device in order to indicate to the on/off line of the medical device. The fields P, D and V are represented the status of the PCA device, DNH and VSM.

Seqence	Type	Device	ID	Data

(a) The message sent from WSN end point

Type	ID	P	D	V

(b) The message sent from WSN Coordinator

Figure 2-4 Message format of management protocol

2.1.2 Buffer-ACK Mechanism

In the WSN network, there is no mechanism to provide reliable transmission. When we implemented this work in the hospital, we find the data transmitted from the medical device in the ward got loss because of the restraints of obstacle in the hospital (e.g. door, distance, and limitation of deployment). This situation especially occurs in transmitting the PCA data because the data size of PCA is large (about 3k~17k bytes). Thus, it needs a retransmission mechanism to transmit the data completely. For the reliability purpose to collect the PCA data, we designed a Buffer-ACK mechanism to make sure the integrity of the data collected from PCA device.

The Buffer-ACK mechanism is shown in figure 2-5; the WSN end point will buffer the PCA data in its memory after it transmits the data to WSN coordinator. The WSN end point will account the number of message in this transmitting and append this variable in the last message. After the last message transmitted, the WSM end point will start a timer to begin the retransmission procedure. The WSN coordinator will check this variable appended in the last message with the number of massage it received. If it is equally, the WSN coordinator will send back an ACK message to the WSN end point to stop the retransmission procedure of the WSM end point. Otherwise, the WSN coordinator will not send the ACK message to WSN end point; the WSN end point will wait the time out and retransmit the PCA data. Thus, we can transmit the PCA data in a more reliable way.

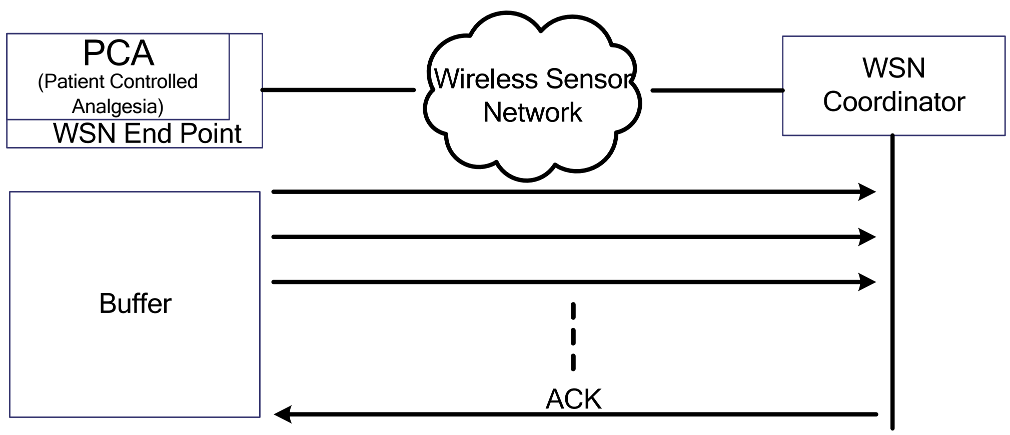


Figure 2-5 Buffer-ACK mechanism

2.1.3 Character-Based Cipher Block Chaining Encryption

In order to provide a secure way to transmit the data in WSN, we designed a Character-based Cipher Chain Block Encryption mechanism. As shown in Figure2-6, we take one character as a block for encryption. First, every plaintext block does the XOR operation with sequence number and secret key. Then the result from above operation should do the XOR operation with the previous ciphertext block. So every encryption result will be affected by the previous ciphertext block and sequence number. They can cause different ciphertext even though the same plaintext has occurred many times. And for the encryption of first block, we set an initialization value (IV) to implement the mechanism, as shown in figure 2-6.

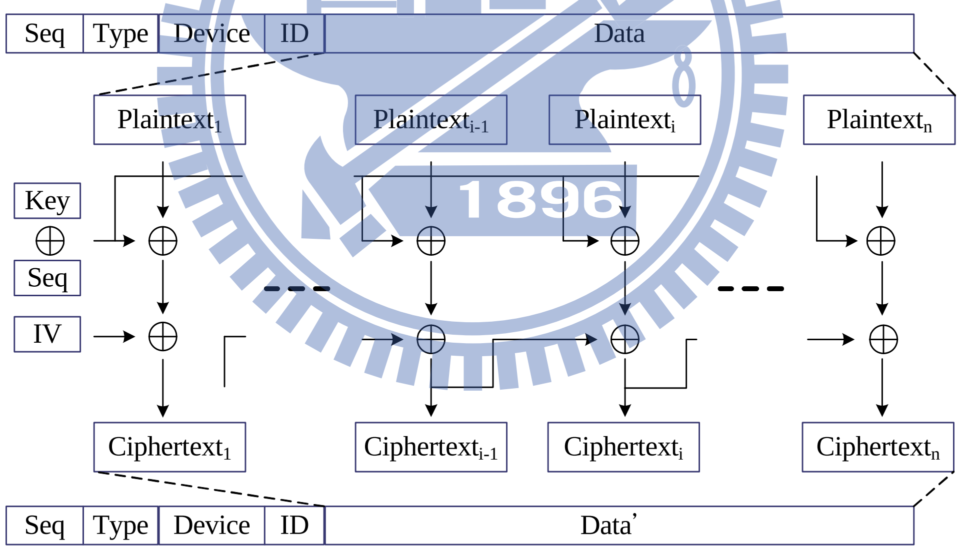


Figure 2-6 Character-based cipher block chaining encryption mechanism

2.2 Middle End Subsystem

The middle end subsystem connects the back-end server and receive the data from the front end subsystem. In the middle end subsystem, we designed a wireless gateway that will provides the interlinking of the WSN and the WiFi/3G network. Specifically, such a gateway performs the protocol translations between the WSN and the WiFi/3G network, and allows the back-end server to monitor and collect data. In the following we will introduce the architectures of WSN/WiFi and WSN/3G wireless gateways, respectively.

2.2.1 Virtual COM Port Connection for WSN/WiFi Wireless Gateway

The wireless gateway provides serial ports, 802.11b/g wireless LAN interface to connect any RS-232/422/485 devices to wireless LAN, as shown in figure 2-7. We use the Advantech's product that applies Virtual COM port technique. The software of virtual COM port can enable virtually any serial device or equipment to be remotely accessed, controlled, monitored, or shared on an 802.11b/g wireless network. The data received by the wireless gateway are transparently redirected to back-end server.

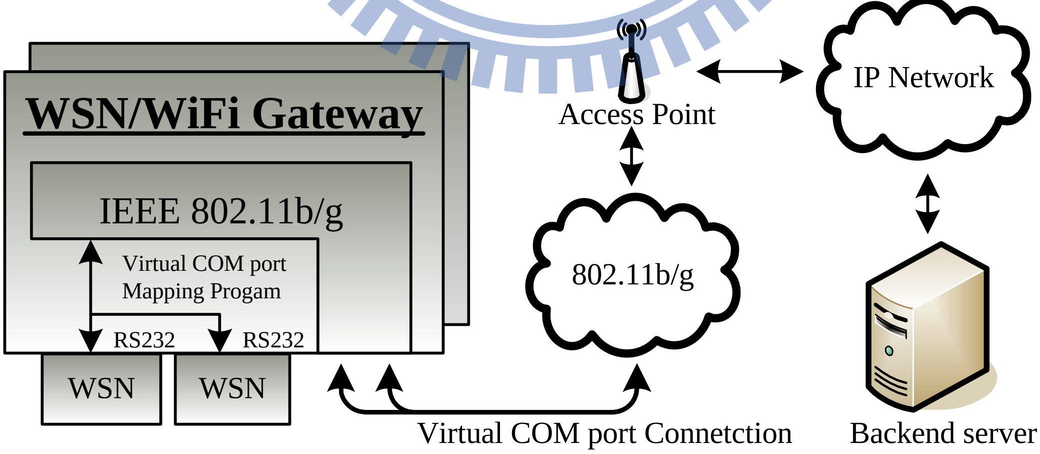


Figure 2-7 Virtual COM port connection

2.2.2 Socket Based Connection for WSN/3G Wireless Gateway

For the homecare purpose, we need to design a WSN to 3G wireless gateway. The 3G network provide the large network coverage and high data rate to improve the drawback of tradition GSM network. Thus, using 3G network technique can let patient use this system everywhere under the coverage of the 3G base station.

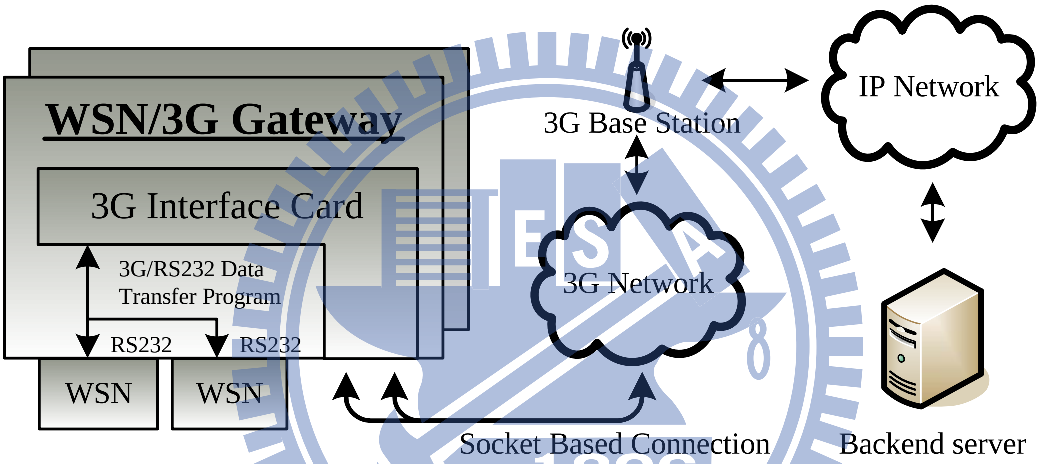


Figure 2-8 Socket based connection

We develop the WSN/3G wireless gateway in the Linux-based development system and use the 3G network card to access the Internet, as shown in figure 2-8. Then, we construct the 3G/RS232 tunnel by the socket based network programming. The wireless gateway receives the data from WSN coordinator through the RS232 serial port and constructs a connection between the wireless gateway and back-end server. When getting start, the wireless gateway would actively construct the socket connection to the back-end server and wait the data sent by the WSN coordinator. Then, it receives the data from WSN coordinator and coverts the signal to 3G network through the 3G network interface. And, if the data from WSN coordinator received before the socket connection constructed, the wireless gateway will buffer the data in its memory. After the socket is successfully constructed with back-end server, the wireless gateway sends the data which is buffered in memory before. This behavior could increase the reliability in wireless gateway for data transmission.

2.3 Back End Subsystem

The back-end server constructs the connection to the wireless gateway to receive the data from medical devices and builds the pain management database and medical staff notifying system. Medical staff can access the back-end server through IP network. When an abnormal event occurs, the abnormal status will be shown in the pain management server and the back-end server will use the short message service to send an alert message to medical staff through 3G network.

2.3.1 Connection to the Wireless Gateway

There are two types of wireless gateway, WSN/WiFi and WSN/3G. Thus, we have to implement two connection methods between the wireless gateway and the back-end server (see the figure 2-9). For the WSN/WiFi wireless gateway, we use the COM port mapping software provided by Advantech to connect to the wireless gateway. The COM port mapping software is a serial COM port redirector that creates virtual COM ports and provides us to access the serial devices connected to Advantech serial device servers (wireless gateway). From the WSN/3G wireless gateway aspect, we establish the TCP socket server in the back-end server and wait for the wireless gateway the client to connect.

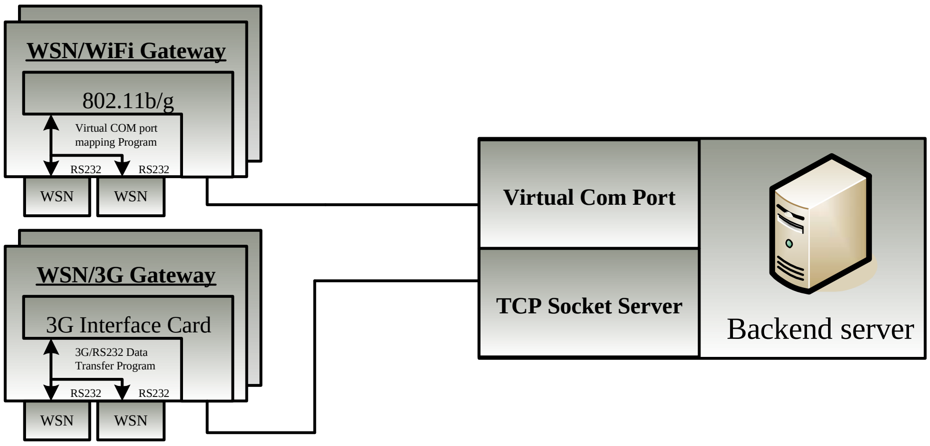


Figure 2-9 Connection to wireless gateway

2.3.2 Medical Staff Management System

As shown in figure 2-10, the back-end server provides the medical staff management system that medical staff can manage the patient's information (personal information and pathology etc.) in it. The data sent by medical devices (e.g. PCA, VSM and DNH) will be parsed in the back-end server and the resulting data will be stored into the management database. The medical staff can login the back-end server and use the management program we provided to access the processed data. The back-end server also receives the status report from WSN coordinator, thus we can use the management program to monitor the status of WSN end point deployed in advance in the ward room.

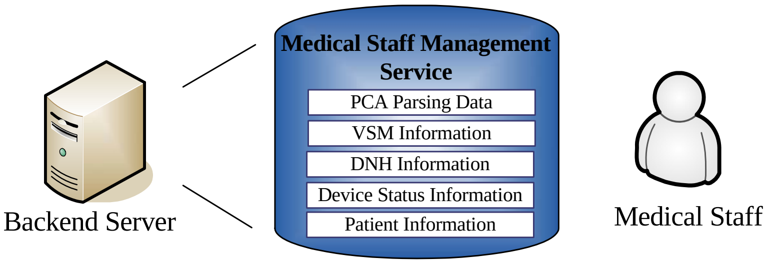


Figure 2-10 Medical staff management system

The database stored in the back-end server can be mined for the meaningful information for patient care. The medical staff uses the record in the database which contained attributes such as basic health status, age, gender, weight, PCA control parameters, and amount of anesthetics used in the different time intervals to predict for PCA control parameters setting. The doctor can use such information to adjust the PCA parameter to improve the patient's pain care.

2.3.3 Short Message Service Notifying System

In the back-end server we also provide the short message service notifying system to actively alert the medical staff for the abnormal status, as shown in figure 2-11. When the patient feels the discomfortable or painful, he can send a alerting message. The back-end server receives this alerting message and then pushes it to the mobile terminal by using the SMS AT command set through the COM port. Through information contained in the AT command, the mobile terminal will send this message to the doctors mobile phone who is responsible for this patient. This information includes the phone number of the doctor and the content of this alerting message. Thus, we can send the abnormal status to the doctor in time and then the patient can obtain the better and more real time service of medical care.

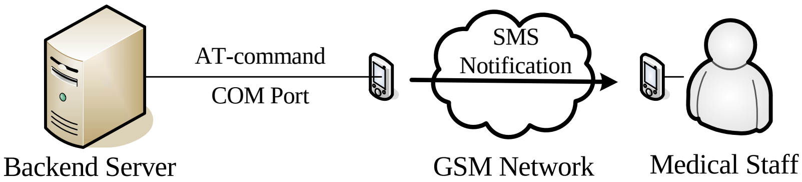


Figure 2-11 Short message service notifying system

Chapter 3
iPCA implementation

In this chapter, we will present a prototype of iPCA and implementation experiences in developing iPCA software components, as shown in figure 3-1.

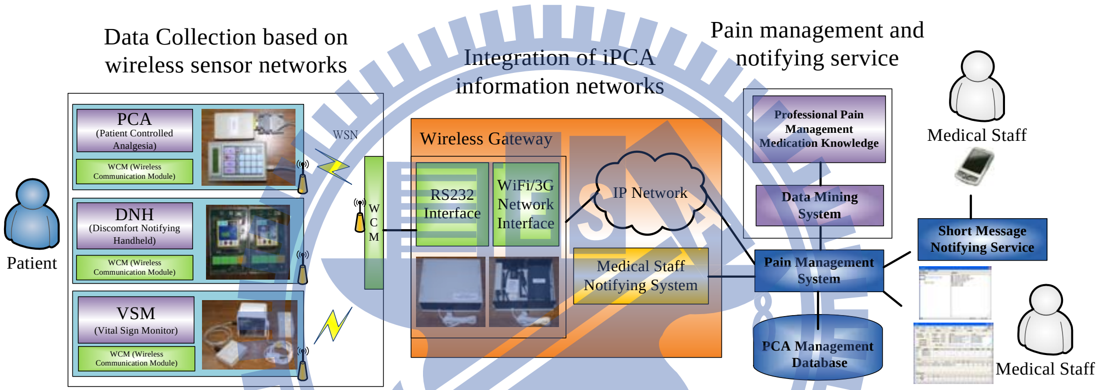


Figure 3-1 iPCA system prototype

We have implemented an iPCA prototype that consists of a wireless gateway, three medical devices (PCA, DNH and VSM) with WSN end point and back-end server that provides management and notifying service.

3.1 Data Collection Service

We connected three kinds of medical devices with WSN end point. They were PCA, VSM, and a handheld device named DNH to notify discomfort.

3.1.1 The WSN module

We use the WSN module Jennic-HSCC designed by NCTU HSCC (High-Speed Communication & Computing Laboratory) to do this work, as shown in figure 3-2.

The Jennic-HSCC is a WSN module that is based on the Jennic JN-5139 chip [13]. This chip is a low power and low price wireless microprocessor that integrates with 32-bit RISC microprocessor and is complete compatible with 2.4GHz IEEE 802.15.4. It is also equipped with 192k ROM and 8k~96 KB RAM (according the type of chip) and integrate with the digital and analog peripheral hardware. In this work we integrate the Jennic JN-5139 with the stand serial port that we can send and receive the data from medical device through the RS-232 serial port. And the Jennic also provide the Jennic environment system and SDK thus we can easily program the behavior of the chip to achieve our goal.

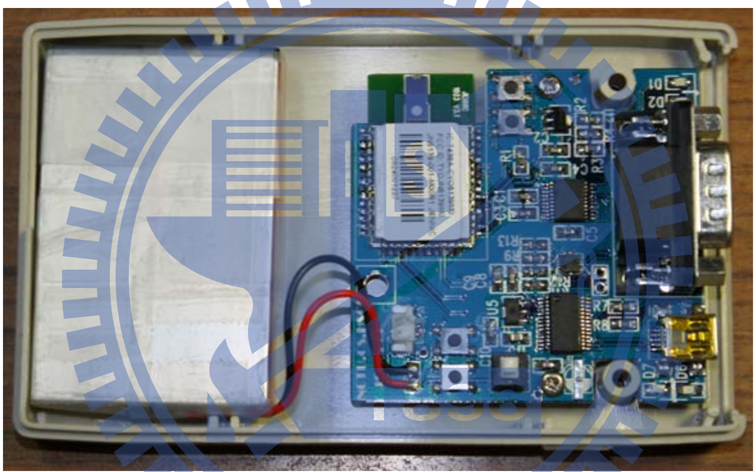


Figure 3-2 The WSN module – Jennic-HSCC

3.1.2 Connection of PCA with WSN End Point

The PCA device manufactured by Abbott [14] was connected with the WSN end point via a RS-232 serial port. The Abbott PCA device is an ambulatory pump designed to deliver analgesic to patients in hospitals, outpatient treatment centers, or at home. Delivery mode, concentration units (mg, μg or ml), delivery rate, bolus operation, bolus volume, 4-hour delivery limit and loading dose can all be programmed. As presented in Figure 3-3, it transmitted the analgesic usage data to the WSN end point via a RS-232 serial port when the medical staff pressed the "Print" button on the PCA, and in turn, the data were forwarded to the pain management server through a wireless gateway.

Figure 3-3 Connection of PCA with WSN end point

3.1.3 Connection of VSM with WSN End Point

Likewise, we connected the VSM of Criticare [15] with a WSN end point by a RS-232 serial port, as shown in Figure 3-4. The VSM can periodically collect the data of SpO_2, heart rate and blood pressure from the patient, and pass them to the WSN end point through the RS-232 serial port. As same as the PCA device, the data from VSM also were forwarded to the pain management server via wireless gateway.

Figure 3-4 Connection of vital sign monitor with WSN end point

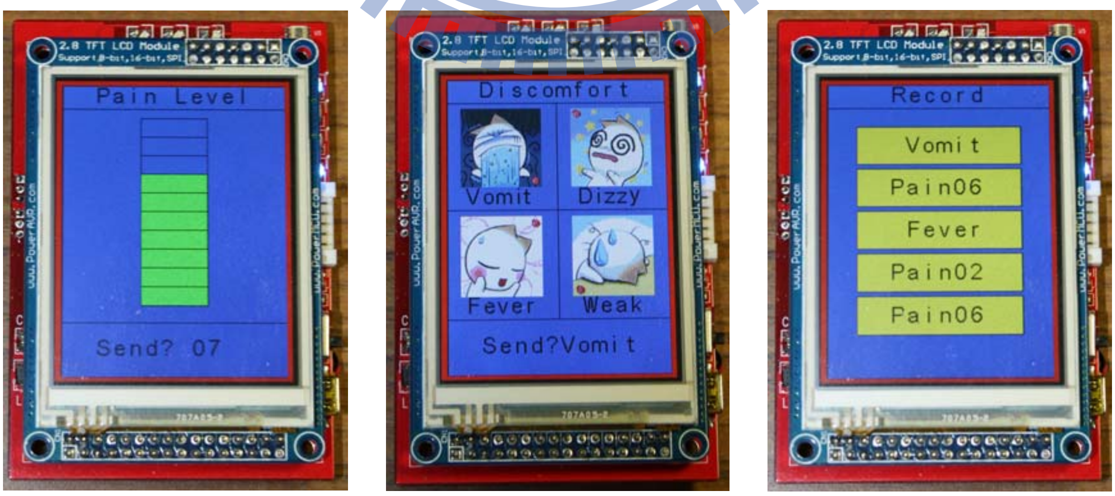
3.1.4 Discomfort Notifying Handheld Device

We designed two types of the DNH device, one is the button based handheld device and the other is the touch panel based handheld device. The button based DNH device was an ATmega-128 CPU-based [16] board, which was equipped with a LCD displayer and four buttons. We connected it to a WSN end point via a serial port. DNH had two modes which are pain scale mode and discomfort symptom mode. These two modes are shown in figure 3-5(a) and 3-5(b), respectively. In the pain scale mode, the patient could select a scale between 1 and 10 according to the pain level. In the discomfort symptom mode, the patient could acknowledge different symptoms, including vomit, dizziness, fever and weak. In either mode, the message could be sent to the WSN end point via the serial port and then forwarded to the pain management server through the wireless gateway.

(a) Pain scale mode (b) Discomfort symptom mode

Figure 3-5 Button based DNH with WSN end point

The touch panel based DNH device was also an ATmega-128 CPU-based board, which was equipped with a LG 2.8” TFT LCD module. Likewise, we also have two modes in this DNH device. They are pain scale mode and discomfort symptom mode which are shown in figure 3-6(a) and 3-6(b), respectively. We also provide an addition mode called record mode which is shown in figure 3-6(c). The record mode logs the last five statuses that patient pressed. With the help of the DNH device, the medical staff can more quickly know the patient’s status when they feel pain or discomfort.



(a) Pain scale mode (b) Discomfort symptom mode (c)Record mode

Figure 3-6 Touch panel based DNH with WSN end point

3.2 Integration of Information Network

We integrated the backbone IP, WiFi, 3G network and WSN network into the iPCA system to help us remotely access and monitor the medical devices in the WSN network. We will introduce two types of wireless gateway in the following sections.

3.2.1 WSN/WiFi Wireless Gateway

An access point was used to bridge IP and WiFi network, and an Advantech Eki-1352 wireless gateway [17] was installed to connect WSN coordinator to the WiFi network, as shown in figure 3-7. The Advantech Eki-1352 wireless gateway will connect to the access point through the WiFi network and start the virtual COM port mapping program to wait for the back-end server to connect with via IP network. The data collected at the WSN coordinator could be forwarded to the pain management server through the wireless gateway and the access point.

Figure 3-7 WSN/WiFi wireless gateway

3.2.2 WSN/3G Wireless Gateway

We designed a WSN/3G wireless gateway to bridge the WSN and 3G network, as shown in figure 3-8. In the hardware part, we used the linux-based embedded development board that was equipped with the USB port and RS-232 serial port. This embedded development board we used here is Kaise KS_2410 [18]. In order to access the 3G network, we also need a USB-based 3G wireless network module and a 3G SIM card. In the software part, we use the embedded arm-linux operation system with the linux kernel version above 2.4 to implement this work. We also need the following open source codes: USB library source code (libusb), USB mode switch source code (usb_modeswitch) and the Internet point to point protocol (PPP) source code, to install the USB based 3G wireless network module to the embedded development board..

Figure 3-8 WSN/3G wireless gateway

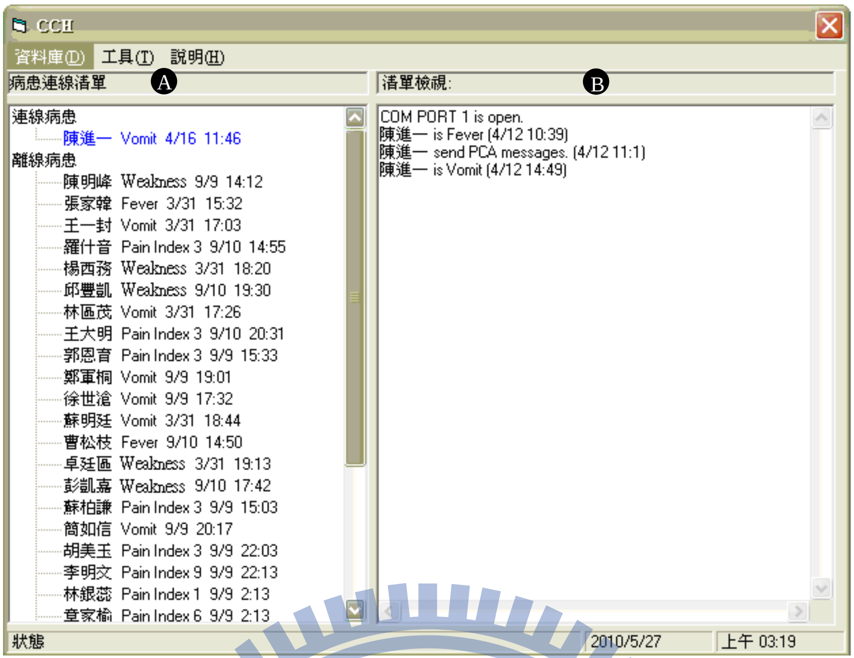
In order to bridge the WSN and the 3G network, we separate the bridge procedure into two parts. In the first part, we write the shell program to mount the 3G network module via the open source codes mentioned above. When the 3G network module successfully mounted then we used AT-command to communicate with 3G network module and used the PPP protocol to dial the 3G network module to the telecommunications company. Thus, the embedded board we used can connect to the Internet. In the second part, we write a socket based client program to forward the data from the RS-232 serial port which was sent from WSN network to back-end server through 3G network. It will construct a tunnel to the back-end server and wait data from RS-232 serial port for sending. For the reliability purpose, we also record the data we send in the log file. When the connection with back-end server is interrupted, we can retransmit the data after the connection is reconstructed. Using this WSN/3G wireless gateway, we can efficiently bridge the WSN network and 3G network.

3.3 Pain Management and Notifying Service

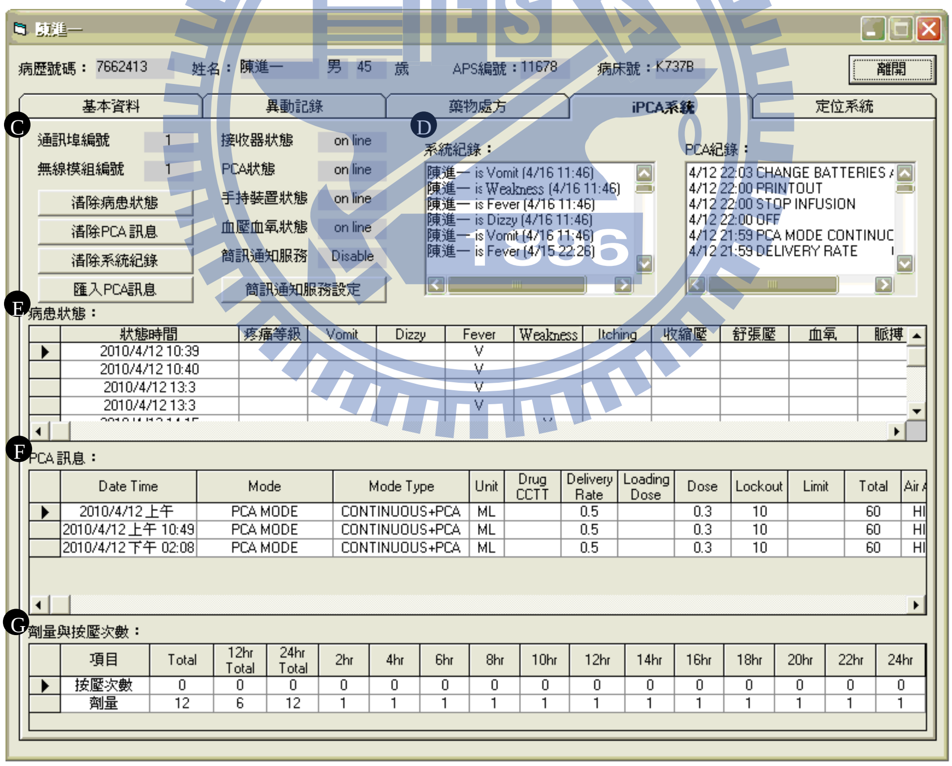
We developed a pain management server to gather and maintain the data such as patients' analgesic usages, vital signs, health conditions. The medical staff can access the management server to observe the patients' status in time. When an abnormal status occurs, the server can actively notify the Medical staff.

3.3.1 Pain Management Interface

We use the microsoft visual basic to develop our pain management server. With this user-friendly interface, as shown in figure 3-9, the staff could easily access and update the patient's data. On the other hand, the patient could signal his/her health condition with the hand-held device, DNH, at any time to update the records. The medical device, VSM, can periodically update the patient's vital condition. The PCA device can also transmit the PCA usage data via the WSN network when the medical staff presses the "Print" button on the PCA.



(a) The main page



(b) The patient's personal page

Figure 3-9 The snapshots of pain management interface

The figure 3-9(a) shows the main page of pain management interface. The area A is the patient connection list that will show each patient on line or off line. The status adjacent to the patient's name is patient's last message of the management server received. We can use the function in the tool bar called "database" to add and delete a patient's information in the patient connection list. The area B, "log list", will log the data received from the medical device and the connection between server and wireless gateway. When medical staff clicks the patient's name in the area A, the patient's personal page, as shown in the figure 3-9(b), will pump out and show the patient's information and the pain related data in the database for the medical staff. On the top of the patient's personal page, you can select one subpage among the basic information, transaction record, medicine prescription, iPCA system and location-based system service. The former three subpages are used for medical staff to record the patient's personal and pathology information. The last one is the location-based system service, and it will combined by us in the future. The iPCA system subpage is used for managing and monitoring the data of medical device. In the area C, we can find the status of each medical device and reset the log and the message of the PCA. The short message notifying system can also be enable here to actively send the discomfort message to the medical staff. The area D will show the system record and show the PCA raw data. The data received from VSM and DNH can be parsed and stored in database as shown in the area E. The area F will show the PCA data parsed by the management server, and the server will analyze the PCA data to obtain the dosage and the number of pressing count for trigging the analgesia per 2 hours, as shown in area G. The data stored in the database also can be used for mining for useful PCA information. Analysis of the data could help anesthesiologists or medical staff to configure the PCA to improve patient satisfaction.

3.3.2 Implementation of Short Message Notifying System

We integrate the SMS into this system for the patients who need special care. In this part, we use the Sony Ericsson k600i as our mobile terminal to connect with back-end server through the USB serial port, as shown in figure 3-10(a). When the DNH sends the discomfort message, we use the AT-command in the back-end server to trigger the mobile terminal to send the message to the medical staff's phone we assigned, as shown in figure 3-10(b). Then the medical staff can know the discomfort status through the SMS. The short message notify function of each patient can also be active by the medical staff through the management server interface we mentioned in the section 3.3.1. With the short message notifying system, we can notify the medical staff of the patients' discomfort in a more efficient and immediately way.

(a) Management server end (b) Medical staff end

Figure 3-10 Short message notifying system

Chapter 4
Field Trial in Changhua Christian Hospital

In order to verify the feasibility of our iPCA system, we do the field trial in the Changhua Christian Hospital (CCH) and practically collect the data of real patients who needed using the PCA device to reduce their pain after the surgeries. As shown in figure 4-1, we deploy our iPCA system in the area called Seven-One ward in CCH to exactly test the feasibility of our system.

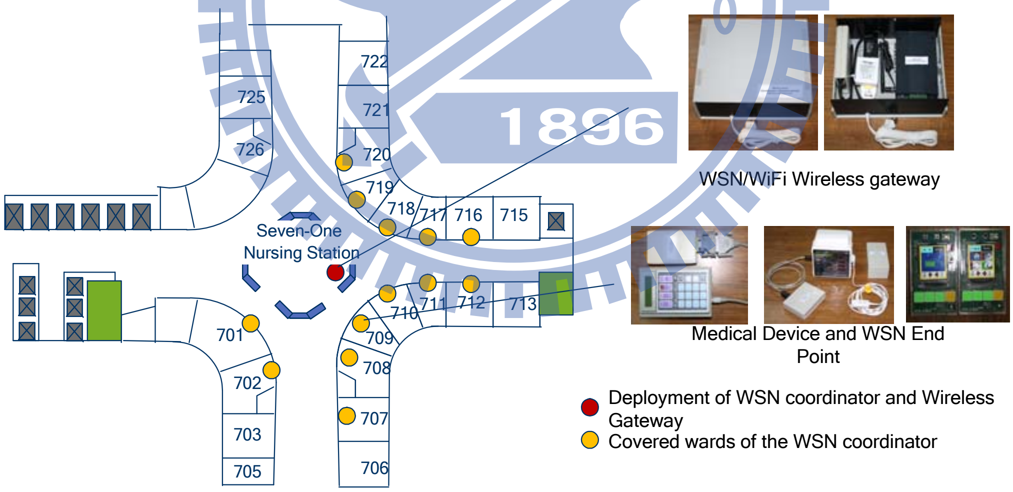
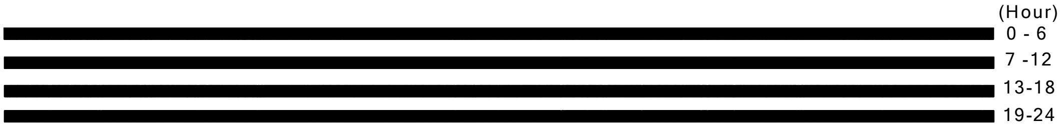


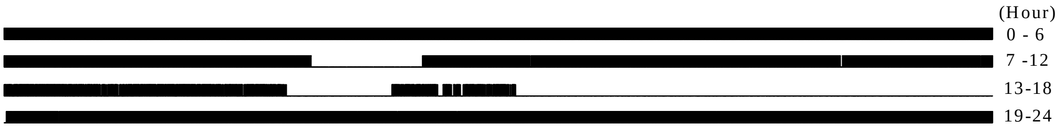
Figure 4-1 Field trial in Seven-One ward of CCH

In the hospital, we have two restrictions causing us unable to deploy the WSN/WiFi wireless gateway in the ward. The first one is the electric power support. The Advantech Eki-1352 is a high power cost device so it must have the electric power to support its operation. However, for the safety of electric power, the hospital has strict rules on the permit of electric power usage. Thus, we do not deploy the WSN/WiFi wireless gateway in the ward. The second reason is to prevent the patient from worrying about the effect of the device. Due to above reasons, we deploy the WSN/WiFi wireless gateway in the Seven-One nursing station to coordinator the WSN end point and forward the data of the medical device. The nurses in the nursing station can help to take care the device and we can easily use electric power there. Because the signal is strong in the nursing station, the Eki-1352 can easily associate with the access point, called e-car, built by CCH to connect to the IP network. The WSN end point is put with the medical device to collect the data from PCA, VSM and DNH. And we put the medical server in the anesthesiology department office which is in the 3F of CCH's building to receive and analyze the data from medical device.

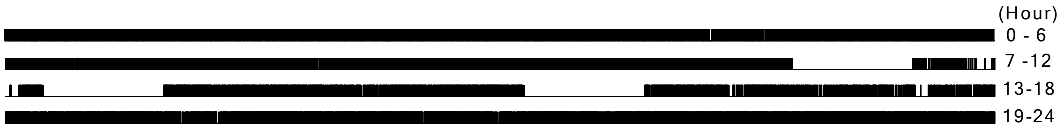
Through the field trial in the CCH, we find a phenomenon, instable connection, between WSN end point and WSN coordinator. The distance between the some WSN end point and coordinator is long because we can not deploy the coordinator into the ward. Thus, we can find large obstacles (ex. door, wall and other ward) between them that will cause the instable connection. And when the medical device transmits the data to the coordinator, the bad connection also will cause the data lost. We do the experiments to find the connection time between WSN coordinator and WSN end point in each ward in the 24 hours, as shown in figure 4-2. The line with black dot is the on-line status of the WSN end point and the line without black dot is the off-line status. We can see the connection time between each ward and the coordinator will be interrupted at certain times. It causes that the WSN end point keep in the off-line status, and the data sent between WSN end point and WSN coordinator will loss in this instable situation. Thus, the data transmitted by the PCA will be lost in these instable intervals.



(a) Nursing station

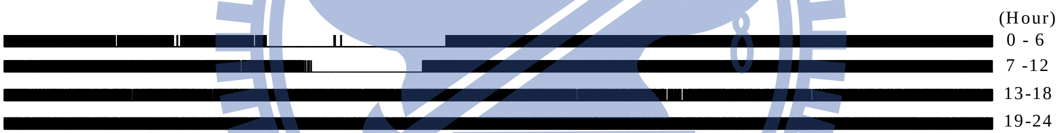


(b) 702 ward



(c) 709 ward

(d) 716 ward



(e) 717 ward

Figure 4-2 The connection time between WSN end point and coordinator

We summarized the signal reception ratio and the max disconnection time in the 24 hours in different wards in table 4-1. According these records we can find the instable connection situation getting worst when the ward is farther from the nursing station. Because the obstacles between the nursing station and ward will become more according the distance between them. So it’s necessary to provide some reliable way to make sure the data can accurately transmit to the coordinator.

Table 4-1 The reception ratio and max disconnect time in different wards

Ward	702	709	716	717
Reception Ratio	76.9%	77.9%	79.6%	86.3%
Max Disconnect Time (min)	174.6	43.8	43.8	38.2

Thus, we proposed the Buffer-ACK mechanism mentioned in the section 2.2.2 to transmit these data reliably.

Chapter 5
Conclusion and Future Work

In this paper, we proposed a real-world application of sensor network integrated with WiFi, 3G and SMS to anesthesiology. We also built an information integration system entitled iPCA, which is capable of collection and analyzing analgesics related data in a wireless environment. Not only it helps reducing the labor work, but it also improves effectiveness and efficiency in PCA treatment. This architecture consists of a WSN network, a wireless gateway and back-end server. In the WSN network, we connected WSN end point with three medical devices (PCA, DNH and VSM). The WSN coordinator will manage the WSN network and forward the data to wireless gateway. Here, we designed two types of wireless gateway, WSN/WiFi and WSN/3G gateway, to integrate the WSN network to the IP network. The back-end server managed and analyzed the data collected from WSN network. When an discomfort status occurs, it can alert the medical staff through SMS. The data stored in the management database can also be used for evaluating the appropriate PCA parameter with data mining algorithm to assist anesthesiologists in PCA control.

We also did the field trial in the CCH to verify the feasibility of our system. And we found a phenomenon that causes the instable connection and proposed a Buffer-ACK mechanism to improve the reliability of our system. The results demonstrated the feasibility of our combination to medical applications.

We plan to extend the work in the following directions. First, we will integrate other medical instruments with iPCA to collect a wider variety of vital health signs, and using them as additional descriptive attributes that can provide medical staff more accurate prediction. Second, we will incorporate authentication and encryption into iPCA to address the issues of privacy and security. Third, we will promote our system to the home care service through 3G network and do the field trial. With the architecture of the integrated system proposed in the paper, we hope not only to improve its performance and expand its applicability, but also to link the research on sensor network with medical application.

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