A pervasive health monitoring service system based on ubiquitous network technology

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Abstract

Objectives: The phenomenon of aging society has derived problems such as shortage of medical resources and reduction of quality in healthcare services.

Method: This paper presents a system infrastructure for pervasive and long-term healthcare applications, i.e. a ubiquitous network composed of wireless local area network (WLAN) and cable television (CATV) network serving as a platform for monitoring physiological signals. Users can record vital signs including heart rate, blood pressure, and body temperature anytime either at home or at frequently visited public places in order to create a personal health file.

Results: The whole system was formally implemented in December 2004. Analysis of 2000 questionnaires indicates that 85% of users were satisfied with the provided community-wide healthcare services. Among the services provided by our system, health consultation services offered by family doctors was rated the most important service by 17.9% of respondents, and was followed by control of one’s own health condition (16.4% of respondents). Convenience of data access was rated most important by roughly 14.3% of respondents.

Discussion/conclusion: We proposed and implemented a long-term healthcare system integrating WLAN and CATV networks in the form of a ubiquitous network providing a service platform for physiological monitoring. This system can classify the health levels of the resident according to the variation tendency of his or her physiological signal for important reference of health management.

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1. Introduction

Taiwan had over two million senior citizens aged over 65 in 2002, and the elderly constituted 9.02% of the total population. Since the elderly population had exceeded the 7% threshold set by World Health Organization (WHO), Taiwan had officially become an aging society. The phenomenon of aging society has derived problems such as shortage of medical resources and reduction of quality in healthcare services. To cope with these problems, Taiwan government has actively planned and promoted various telemedicine and long-term care projects [1–4] in recent years.

Telemedicine mainly utilizes telecommunication technology to provide various remote healthcare services such as
medical diagnosis, treatment, education and healthcare to the patients [5–7]. Telemedicine also integrates limited medical resources to provide the healthcare services needed between hospitals and patients at home. This can effectively and efficiently utilize related resources and reduce the spatial distance and temporal distance [8–15]. However, many diseases do not urgently need immediate medical diagnosis and treatment. For example, for the chronic patients with cardiopathy or hypertension, it is adequate to trace and control the patients’ conditions via the healthcare services such as physiological signals monitoring and recording. Due to the development of information and communication technology (ICT), the feasibility of home care or community care has been highly raised. Because of the fast development and popularity of Internet, the tele-care medical applications to provide long-term monitoring and healthcare by transmitting personal physiological information via Internet have become highly feasible. Chae et al. [16] implemented and evaluated a telemedicine system with a 33 kb narrow-band approach to determine its effectiveness in providing quality services in home environment. Maglaveras et al. [17] describes a generic contact center for health project. This application proves the usefulness of wireless technology in providing healthcare services all around the clock and everywhere the citizen is located, it proves the necessity for restructuring the medical knowledge for education delivery to the patient. Andrade et al. [18] presents a software technology where the medical and nursing staff will be equipped with a handheld computer connected by radio to a central server. The server acts as a database for multimodal electronic patient record information. Mendonça et al. [19] describes the approaches for and the design of extensions to a clinical information system used to improve information access and communication at the point of care using information-based handheld wireless applications.

There are many researches in the literature that have based on different network technologies to propose various designs and applications for tele-healthcare service systems. For example, various switch-based networks such as asynchronous transfer mode (ATM) and integrated services digital network (ISDN) [20–22] and various wired communication networks such as cable television (CATV) networks [23] have been utilized to provide medical information transmission. To consider the convenience and portability for users to perform physiological signals monitoring and data transmission, it has been a trend to introduce the wireless mobile communication network technology. Various mobile communication network technology such as Bluetooth [24], global system for mobile communications (GSM) [25–29], wireless application protocol (WAP) [30], wireless local area network (WLAN) [31], and universal mobile telecommunications system (UMTS) [32] have all been utilized for this purpose.

In order to achieve the goal of ubiquitous healthcare, and to consider the high popularity of CATV in Taiwan, we propose a cable access point (CAP) device to integrate two main technologies of WLAN and CATV networks and base on it to construct a ubiquitous healthcare network infrastructure. Since this network infrastructure integrates WLAN and CATV networks, it can provide a high speed and highly accessible wideband network environment. Besides, to take into account the different locations the users might be at, we have also proposed a three-tier framework of data servers, namely home gateway, public

![Ubiquitous network architecture](image)
gateway, and medical gateway to continuously monitor and record the users’ vital signs no matter whether they are at home or in the public places. The remainder of this paper is organized as follows. Section 2 describes the methodology concerning each key technology and system process. A system application in Chiayi City in Taiwan and the results of CAP testing are presented and investigated in Section 3. Finally, some conclusions are provided in Section 4.

2. **Methodology**

2.1. **CAP-based ubiquitous network architecture**

Due to free space losses in wireless networks, it is hard to maintain data quality in long-range transmissions. Facilitated by the current over 90% popularity of CATV in Taiwan, we applied a CAP device with an authentication, authorization, and accounting (AAA) security certification mechanism insuring access efficiency and security over wireless broadband networks. The CAP-based network architecture was constructed by integrating cable modems (CMs) with a WLAN. This ubiquitous network provides users with easy access in public places and at home. Fig. 1 shows the architecture of the CAP-based ubiquitous network. The WLAN was compatible with the 802.11b/b+/g standard, and the CAP device used a high-gain (12 dBi) antenna to enlarge the wireless signal coverage area. The system also provided a signal repeater to ensure seamless two-way transmission between CAPs and the client end. The CAP was an outdoor wireless communication devices consisting of a cable modem and a wireless access point possessing an authorization and authentication ability. The CAP supported the DOCSIS 1.0/1.1/2.0 protocol for data transfer to a cable modem termination system (CMTS) at the CATV head-end. The CMTS was located between the CATV network and the Internet router, and was capable of receiving signals from several cable modems and transferring them to the Internet.

2.2. **AAA-client mechanism**

The AAA service consists of a subscriber database and a server that has authentication and authorization functions (the AAA server in Fig. 1). It is responsible for the processing of user identification (ID) verification and access permission according to the database. However, in order to further enhance the safety and validity in wireless access link services between the end users and AAA server, we propose an AAA-client mechanism which is realized in the proposed CAP device for information security consideration.

The proposed verification process, as shown in Fig. 2, considers both the ability of Media Access Control (MAC) address translation in Layer-2 and the routing function in Layer-3 of the Open Systems Interconnection (OSI) model. After receiving an 802.11 packet, the CAP device extracts the MAC address from the packet and compares it with the extensible authentication protocol (EAP)-verified MAC table. If there is a match, then
Fig. 3 – (a) The function blocks of wireless health monitor device and (b) packet format.

2.3. Wireless health monitoring devices

The wireless health monitoring devices not only receives physiological signals, but also transfers the physiological data through the wireless network to the back-end health management server, so that complete and continuous personal physiological records can be kept. The components of these devices include vital sign sensors, microprocessors, LCD displays, and wireless transmission devices (Fig. 3(a)). Vital signs monitored by different kinds of vital sign sensors are amplified and converted to digital signals after analog to digital converter (ADC) processing, and the microprocessor then judges whether the signals exceed standard values and displays each measurement result on the LCD screen. In addition, the microprocessor also transfers all measurement data to the health gateway through a wireless transmission device. When the sensor wearer is out of the range for transmissions, the data can be recorded in an on-board storage medium, and can be uploaded to the server when the wearer is again within the transmission range of the health gateway. We use a two-level Butterworth Filter to separate the signals of blood pressure and pulse rate. A low-pass filter (cut-off frequency is 40 Hz) is used to extract the value of blood pressure, and a band pass filter (0.25–5 Hz) is used to extract the pulse rate signal. The separated signals are then sent to different ADC channels to be fetched and calculated by the microcontroller.

Fig. 3(b) shows the packet format for data transmission. The preamble data element has a length of one byte and has a content of “0xA5”; Health_Gateway_ID indicates target health gateway for data transmission; Sensor_ID shows the ID of Wireless Health monitoring device; the Packet Sequence element is the transmission sequence. When several separate data
items need to be transferred through the network, this field determines packet transmission order. Length records the total length of the transmitted data including checksum; the Data element shows the contents of the data, and chiefly consists of two parts: one part is data type, which is used to categorize the packet contents as, for instance, configuration command or upload data type, and the other part contains the body of data. The length of the Data element may differ depending on the data transferred. For example, there are six bytes for a body content of 'date and time' in the date–time configuration command. There is a total of 10 bytes for systolic pressure, diastolic pressure, heart rate, and date and time when uploading types of vital signs such as blood pressure. The monitoring device will delete the data after completing data transmission and receiving confirmation.

2.4. Health gateway

There are three types of health gateway with different roles, namely medical gateway, home gateway, and public gateway. The medical gateway is a middleware server at the hospital end, and is mainly used to store patients’ health data uploaded from home gateways or public gateways for doctors’ use in diagnosis. The home gateway is responsible for storing all types of data uploaded from wireless health monitoring devices and regularly transferring that data to the medical gateway. A schematic diagram of home gateway is shown as Fig. 4. The Information Gathering module is responsible for connecting with all types of monitoring devices. The Data Upload module is the home gateway’s network transmission interface for uploading collected personal health data to the
medical gateway via the wide area network (WAN). Besides transmitting and receiving data, the home gateway also provides a data aggregation function allowing the user to easily set up personal health folder. Finally, the home gateway’s analyzer module can compare and analyze vital sign data with standard values, and show the result in graphic form via a graphical user interface (GUI) so that users can have a clear picture of their own physiological condition. The main functions of a public gateway are similar to those of a home gateway, it is used in a public place so that users can conveniently monitor or upload personal health data to medical gateway even when not at their homes.

As for the identification of the users, if the users are at home their identification can be easily obtained since the equipment set up at home is assigned a unique serial number during deployment. If there are two or more users at home, or if the users use the kiosk in public area to upload data, each user can use his or her personal ID card to confirm his or her identification. If the user forgets to bring his/her ID card, a manual username/password process can be used to register in the system and the user can then utilize the various functions of our system.

3. System application and experimental field trial

3.1. Application area

Chiayi City is a major urban area in southern Taiwan with a population of 270,000. The elderly account for 10% of the population, and almost 100% of homes in the city receive CATV broadband transmission. This study therefore decided to cooperate with the city government’s long-term healthcare service system to test the ubiquitous network system. Participating organizations included the public health bureau, the social welfare bureau, a medical center, and long-term healthcare organizations. The first phase of system implementation was completed in December 2004. The 25 CAPs that have been installed thus far cover about 20% of the area of Chiayi City (Fig. 5). Relying on the backbone of CAP sites, we used kiosks as public gateways. These kiosks were set up at public places such as the city government, cultural centers, and parks, and provided measurement devices for vital signs data. Users could upload these data items to the medical gateway after keying in the password of their personal account. Similarly, a user could easily record various physiological parameters at home and transfer the data to the medical gateway through his or her home gateway in order to establish a personal health file. Beyond collecting uploaded public health data from public gateways and home gateways, the medical gateway also provided a portal site allowing users to both access various community medical and communicate with their family doctors.

3.2. CAP testing results

Two experiments were conducted to test the CAP’s physical effectiveness. The first experiment is to evaluate the impact of CAP height on transmission effectiveness. We set up two CAPs at different height, CAP#1 at 4.5 m and CAP#2 at 1.7 m, then used personal computers (PCs) that could send and receive wireless signals at distances of 1.5, 50 and 100 m, respectively to connect to the two CAP devices. We found that the lower CAP#2 offered better transmission quality (see Table 1). The CAP#1’s transmission quality was affected by some obstructions such as leaves when the signal path was long. Thus a lower CAP height should be chosen when implementing a system in a community where there are many streetlamps and roadside trees.

The second experiment is to evaluate signal quality between the CAP and a PC at different distances. We fixed the height of the CAP and tested network communication link quality at distances ranging from 5 to 155 m from the CAP device. We found that while noise was not affected by distance and always stayed within the range of −97 to −100 dBm. The signal and signal to noise ratio (SNR) value would gradually decrease as the distance increased, from 71 to 27 dB at the distance of 155 m. This clearly indicates that distance affects the quality of the network connection. The experiments showed that a CAP could maintain good data transmission within an effective radius of 150 m.

3.3. Questionnaire survey

In Taiwan, about 90% of the elderly choose to live in their familiar communities. Nearly 50% of the living expenses of the elderly are supported by their children. In the initial stages of our proposed and implemented system, the required expenses of system construction and back-end medical services are fully supported by the government. The elderly participating in this project thus do not have to pay for everything and thus give positive appraisals to our system. For sustainable operations of this service system we further conduct a questionnaire survey to investigate the opinion of the relatives of the elderly. There are three main objectives for our questionnaire survey. The first one is to see whether the relatives of the elderly are willing to use our services at their own expenses. The second objective is to understand the users’ priorities of paid medical healthcare services from our system. The last objective is to comprehend the important factors that will affect the willingness of using our system. Three thousand questionnaires are sent out in our survey. Two thousand valid questionnaires are collected with an effective collection rate of 67%. Among the respondents, 57% of them are female and 43% of them are male. The age range is from 31 to 35 years old. The survey indicated that 38% were very satisfied and 47% were satisfied with medical healthcare provided in the community. As the questionnaire survey shows, over 93% of the users are willing to pay at a fee rate of 30 US dollars per month to use the services provided by our system. When analyzed by service items (see Table 2), health consultation service
Table 2 – The public’s satisfaction rate on service items provided by the system

<table>
<thead>
<tr>
<th>Service items</th>
<th>Numbers</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health consultation services provided by professional family doctors</td>
<td>801</td>
<td>17.9</td>
</tr>
<tr>
<td>Effective awareness of the condition of the healthcare takers by the relatives</td>
<td>734</td>
<td>16.4</td>
</tr>
<tr>
<td>Convenience in timely data accessing when patient are referral</td>
<td>638</td>
<td>14.3</td>
</tr>
<tr>
<td>Provide 24 h healthcare</td>
<td>559</td>
<td>12.5</td>
</tr>
<tr>
<td>Release care burdens for family members</td>
<td>489</td>
<td>10.9</td>
</tr>
<tr>
<td>Mutual beneficial to the healthcare providers and receivers</td>
<td>406</td>
<td>9.1</td>
</tr>
<tr>
<td>No location limitation</td>
<td>383</td>
<td>8.6</td>
</tr>
<tr>
<td>High autonomy</td>
<td>259</td>
<td>5.8</td>
</tr>
<tr>
<td>Others</td>
<td>204</td>
<td>4.5</td>
</tr>
<tr>
<td>Total</td>
<td>4473</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 3 – Survey result on important factors that affect the public’s will in using the community medical services

<table>
<thead>
<tr>
<th>Service items</th>
<th>Numbers</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whether any professional family doctors to provide medical consultation services</td>
<td>1143</td>
<td>23.0</td>
</tr>
<tr>
<td>Whether public could obtain timely professional assistance and support</td>
<td>1062</td>
<td>21.4</td>
</tr>
<tr>
<td>Whether there are complete referral service items in community medical healthcare system</td>
<td>889</td>
<td>17.8</td>
</tr>
<tr>
<td>Confidentiality on basic personal information for the healthcare</td>
<td>573</td>
<td>11.7</td>
</tr>
<tr>
<td>Response speed from medical staff</td>
<td>431</td>
<td>8.7</td>
</tr>
<tr>
<td>Provide completely healthcare information</td>
<td>449</td>
<td>9.0</td>
</tr>
<tr>
<td>User interfaces are friendly</td>
<td>113</td>
<td>2.3</td>
</tr>
<tr>
<td>Complete operation instructions</td>
<td>195</td>
<td>3.9</td>
</tr>
<tr>
<td>Pleasant experiences from relatives or friends who ever used the system</td>
<td>97</td>
<td>1.9</td>
</tr>
<tr>
<td>Others</td>
<td>14</td>
<td>0.3</td>
</tr>
<tr>
<td>Total</td>
<td>4966</td>
<td>100</td>
</tr>
</tbody>
</table>

provided by family doctors was rated most important by the greatest number of respondents (17.9%), and was followed by control of personal health condition (16.4%) and convenience of data access (14.3%). Furthermore, we also conducted a questionnaire survey concerning factors that might affect the public’s interest in using this service. This survey found that 23% of respondents felt that “Whether any professional family doctors to provide medical consultation services” to was the most important consideration (see Table 3). The next most important consideration was whether the public could obtain timely professional assistance from medical institutions (21.4%). Data confidentiality was in fourth place (9.3%), which showed that the public also pays a certain amount of attention to system security.

4. Conclusion

In this paper we proposed and implemented a long-term healthcare system integrating WLAN and CATV networks in the form of a ubiquitous network providing a service platform for physiological monitoring. The system includes not only a CAP device, but also a security authentication mechanism needed for two-way vital signs and data transmission. As shown by experiment, a lower CAP position should be chosen to obtain better network transmission quality when there are many streetlamps or roadside trees in the community.

In order not to affect the everyday life of the elderly, our system adopts a fixed location service model. The elderly do not have to carry any equipment with them. Rather the related systems are installed in the locations that the elderly often go for activities such as the elderly’s homes or the parks. The elderly can acquire various health consultations or perform physiological parameter measurement at these locations. We hope that by this the inconvenience of the elderly of carrying equipment with them can be effectively avoided. We also hope that with the power of interaction in the society and through the reminding of the elderly to each another, the willingness of the elderly to build up their personal long-term health file can be further increased. The system as a whole has been installed in Chiayi City to provide residents with healthcare services. The results of a questionnaire survey of 2000 residents indicated that the overall satisfaction rate towards community medical healthcare is 85%. When analyzed by service items, health consultation service provided by family doctors was rated most important by the greatest number of respondents (17.9%).

This system is a health management system. Professional medical personnel evaluate the required number of daily or weekly measurement of every resident managed by our system. If a resident does not upload physiological signal for over three times, our system will transmit reminding messages to the resident, the resident’s relatives and the health manager. As for the residents who upload physiological signal normally, our system will calculate the health curve for each case by using linear regression analysis. This system will subsequently classify the health levels of the resident as “normal”, “remind”, or “recommend for revisiting” according to the variation tendency of his or her physiological signal and transmit the information of health level to the resident, the resident’s relatives and the health manager for important reference of health management.
Summary points

What was known before the study?

- Because of the fast development and popularity of Internet, the tele-care medical applications to provide long-term monitoring and healthcare by transmitting personal physiological information via Internet have become highly feasible.
- Besides, to provide a safer and more comfortable resident healthcare environment and to achieve the purpose of illness prevention, it has been another trend for development of tele-care system.
- In the literature, some research teams have proposed the approaches for and the design of extensions to a clinical information system used to improve information access and communication at the point of care.

What the study has added to our knowledge?

- Wireless LANs are set up based on existing cable modem system and are integrated as a wireless healthcare network. Through CATV network, the physiological signals of the healthcare taker can be uploaded via gateway by cable modem to CATV head-end and can then be transferred to the hospital.
- An AAA-client mechanism as ID authentication mechanism has been constructed to ensure the security of data. This mechanism can provide system management services such as authentication, authorization and accounting.
- A health gateway has been built up to store and analyze the physiological data to produce the personal health file of the elderly.
- From the results of our questionnaire survey conducted to determine the willingness of users, over 93% of the users are willing to pay 30 US dollars per month to use the services planned in this research. The top three most interested services of the users are as follows: (I) health consultation services provided by professional family doctors, (II) effective awareness of the condition of the healthcare takers by the relatives and (III) convenience to obtain the data—to easily obtain the data when the elderly are referral. As for the factors that affect the willingness of the user to use our system, the most important factor is whether the omnibearing healthcare from family doctors can be obtained. Other factors such as the instantaneity of services, the completeness of referral service via this system and the security of data are also important in affecting the willingness of the user.

Our future development efforts will primarily focus on increasing the coverage of the CAP network. We believe that ubiquitous network environments allow users easily manage their personal health information, reducing the burden on caregivers and also conserving limited medical resources.

Acknowledgement

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