A Mobile Care System With Alert Mechanism

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***Abstract*—Hypertension and arrhythmia are chronic diseases, which can be effectively prevented and controlled only if the physiological parameters of the patient are constantly monitored, along with the full support of the health education and professional medical care. In this paper, a role-based intelligent mobile care system with alert mechanism in chronic care environment is proposed and implemented. The roles in our system include patients, physicians, nurses, and healthcare providers. Each of the roles represents a person that uses a mobile device such as a mobile phone to communicate with the server setup in the care center such that he or she can go around without restrictions. For commercial mobile phones with Bluetooth communication capability attached to chronic patients, we have developed physiological signal recognition algorithms that were implemented and built-in in the mobile phone without affecting its original communication functions. It is thus possible to integrate several front-end mobile care devices with Bluetooth communication capability to extract patients' various physiological parameters [such as blood pressure, pulse, saturation of haemoglobin (SpO_2), and electrocardiogram (ECG)], to monitor multiple physiological signals without space limit, and to upload important or abnormal physiological information to healthcare center for storage and analysis or transmit the information to physicians and healthcare providers for further processing. Thus, the physiological signal extraction devices only have to deal with signal extraction and wireless transmission. Since they do not have to do signal processing, their form factor can be further reduced to reach the goal of microminiaturization and power saving. An alert management mechanism has been included in back-end healthcare center to initiate various strategies for automatic emergency alerts after receiving emergency messages or after automatically recognizing emergency messages. Within the time intervals in system setting, according to the medical history of a specific patient, our prototype system can inform various healthcare providers in sequence to provide healthcare service with their reply to ensure the accuracy of alert information and the completeness of early warning notification to further improve the healthcare quality. In the end, with the testing results and performance evaluation of our implemented system prototype, we conclude that it is possible to set up a complete intelligent healt care chain with mobile monitoring and healthcare service via the assistance of our system.**

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I. Introduction

In recent years, healthcare for elderly people has been an important research topic. The commonly seen chronic diseases for elderly people include hypertension and arrhythmia. The current healthcare for such diseases is still mainly from outpatient services. Due to the development of information and communication technology (ICT), the feasibility of home telecare has been highly raised. In the literature, the telecare services were first provided by utilizing traditional public switched telephone network (PSTN). Lee *et al.* used a cable television (CATV) network to transmit electrocardiogram (ECG) data to healthcare center and to provide function of video conversation between healthcare providers and patients [1]. Because of the fast development and popularity of the Internet, the telecare medical applications to provide long-term monitoring and healthcare by transmitting personal physiological information via the Internet have become highly feasible [2]. Guillén *et al.* have proposed a telehomecare multimedia platform utilizing videoconferencing standards H.320 and H.323, and a standard TV set based on integrated services digital network (ISDN) and Internet protocol to let patients upload their physiological information to a healthcare center and to provide home telecare services such as teleconsultations [3]. Apart from that, to provide a safer and more comfortable inpatient and resident healthcare environment and to achieve the purpose of illness prevention, it has been another trend for development of home telecare system to integrate various miniature flexible noninvasive biosignal sensors inside patients' clothing for ease of daily dressing and for long-term monitoring and vital signs extraction of the patients [4].

However, the above-mentioned healthcare systems have restricted the activity area of patients to be within the medical healthcare institute or within the residence area. To provide more freedom to patients, it is important to integrate wireless communication technology for modern healthcare systems [5]–[11]. Lin *et al.* [5] have utilized a personal digital assistant (PDA) to monitor and collect the physiological parameters extracted by a physiological signal module attached to patients. The physiological information is then immediately transmitted to a remote central management unit for analysis by medical personnel via wireless local area network (WLAN). Home telecare service has been further extended to become mobile care service [6]–[11] due to the ubiquity of global system for mobile communications (GSM) and general packet radio service (GPRS). Anliker *et al.* [6] have proposed a wearable multiparameter medical monitoring and alert system called advanced care and alert portable telemedical MONitor (AMON). In their system, front-end wrist-worn monitoring device is connected to back-end telemedicine center via GSM mobile network such that healthcare service to patients is not restricted to specific areas. Rasid and Woodward [7] designed a Bluetooth telemedicine processor to first process extracted physiological signal and then transmit the processed physiological information wirelessly to a Bluetooth mobile phone, which then uploads the physiological information to a back-end medical healthcare institute via a GPRS mobile network. It has also been broadly applied to the design of a healthcare system to utilize a GSM/GPRS mobile network to provide healthcare service with functions of emergency alerts and early warning messages [6], [8]–[11]. All of the above-mentioned GSM/GPRS communication parts are designed and implemented by using commercial modules such that the user-end healthcare devices are of larger form factor, which subsequently reduces the desire of patients to carry the devices and increases the power consumption. The popularity of mobile phones has highly increased recently. For example, in the U.S., the popularity of mobile phones was 70% up to 2005 with expected popularity of 87% in 2010, while in 2002, the popularity of mobile phones in Taiwan was already near 100%.[1] It thus becomes feasible to use commercial mobile phones as platforms for physiological signal processing. Moreover, some mobile phones provide a Java programming design environment and Bluetooth interface. This can reduce the form factor of user-end physiological signal extraction devices and save power, and thus, increase the patient's desire of usage. The healthcare services of emergency notification messages can also be realized by utilizing the commercial mobile phones' GSM/GPRS communication capabilities.

This paper proposes to utilize Bluetooth commercial mobile phones as physiological signal processing platforms to construct a ubiquitous mobile care system to increase the feasibility of mobile care services and to increase the desire of users. As described above, this paper focuses on the advantages of mobile devices and utilizes Bluetooth mobile network to integrate multiple front-end physiological parameter extraction devices. It also refers to the alert mechanism of Kafeza *et al.* [8] to extend to each role of telecare to construct an intelligent mobile care platform to actively provide healthcare services to multiple parties of patients and healthcare providers without spatial and temporal limitations and thus improve the quality of healthcare.

The rest of the paper is organized as follows. Section II outlines the system analysis and healthcare scenarios. Section III depicts the system architecture. Section IV describes the design of system software. Section V gives the system implementation results. Overall system performance and experiments are evaluated and described in Section VI. Finally, Section VII provides some discussions and conclusions based on the implemented mobile care system.

II. System Analysis and Healthcare Scenarios

Our proposed healthcare system mainly takes care of chronic patients who can live normally when the health condition is stable, while are in desperate need of help and assistance to reduce the probability of deteriorating health conditions or even death when their physiological conditions become abnormal or when they fall ill. Such chronic patients can perform some simple self healthcare and monitoring functions via mobile phones through our proposed system when health condition is stable. When the patient's health condition becomes abnormal, the proposed system can automatically inform physicians or healthcare providers to further provide medical and healthcare services and can thus effectively reduce the cost of healthcare.

In general, a healthcare scenario includes different roles such as patients and various healthcare providers. Analysis on information exchanged between different roles can induce an alert, which can be implemented via short message technology in mobile communication networks [10]. Through implementation of alert mechanism, our mobile healthcare system provides a general information transmission service to achieve various intelligent healthcare functions. We use two healthcare scenarios to demonstrate the function of our proposed system. One is "patients do not upload physiological parameters on schedule" and the other is "the result of measurement is abnormal and our system automatically informs care providers."

A. Patients do not Upload Physiological Parameters on Schedule

In the first healthcare scenario, the subject is a patient with hypertension or with cardiac diseases. The patient falls asleep at noon. In this healthcare process, the alert message transmission process of the alert system is as shown in Fig. 1(a) and is described as follows.

1) The patient does not upload blood pressure/ECG data on schedule.
2) The care center automatically sends an urgent alert to notify the patient.
3) The patient does not receive the alert or does not reply to it for some reason.
4) The care center raises the urgency level of the alert and resends the alert to notify the healthcare provider.
5) The healthcare provider goes to the location of the patient to provide necessary healthcare services.
6) The healthcare provider replies with the result of alert processing.

B. Result of Measurement is Abnormal and our System Automatically Informs Care Providers

Take the case of a chronic patient with hypertension as an example. Wherever the patient goes, he or she will carry a mobile phone and a Bluetooth hemadynamometer. When the patient's condition is not good, he or she will feel uncomfortable, for example, he or she might have a headache or feel dizzy. In this healthcare process, the alert message transmission process of alert system is as shown in Fig. 1(b). The process of healthcare giving is described as follows.

1) The blood pressure of a hypertension patient increases for

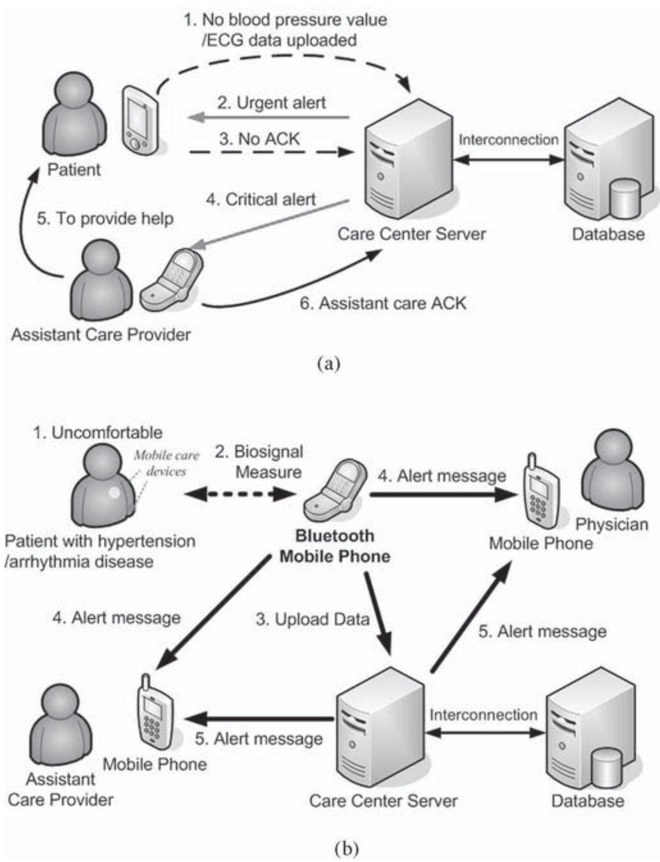


Fig. 1. Alert message transmission diagram for (a) not uploading physiological parameters on schedule and (b) automatic notification of abnormal conditions.

2) The Bluetooth hemadynamometer measures the physiological parameters such as blood pressure and pulse rate, and then transmits the data to the mobile phone wirelessly.
3) The mobile phone uploads the physiological data to the database in healthcare center server in hospital.
4) If some abnormal conditions are identified by simple programs that run in the mobile phone, short messages are sent immediately to the physicians or the other healthcare providers.
5) If some abnormal conditions are identified by professional judgment via the healthcare center server, related personnel such as local officers are informed instantly or an ambulance is dispatched immediately to perform necessary rescue in the location of the patient.

III. System Architecture

The system architecture deployment diagram of our proposed mobile healthcare platform is as shown in Fig. 2. The whole system architecture mainly consists of front-end personal mobile device and back-end care center server.

The front-end personal mobile device comprises a physiological parameter extraction device and a mobile phone integration device. The physiological parameter extraction device consists of various physiological parameter extraction devices for blood mobile phone needs to receive and integrate data from various physiological parameter extraction devices and provide communication link between patients and healthcare center server. The mobile phone supports Java 2 Micro Edition (J2ME) [12] in software, and Bluetooth and GSM/GPRS modules in hardware to integrate functions on personal mobile-end. The software includes two major software package modules: blood pressure and pulse monitor module and ECG monitor module. Back-end healthcare center server consists of a GSM/GPRS module that can transmit and receive short messages, and a care center host. The GSM/GPRS module and personal computer (PC) with Internet connection are used to develop functions needed for healthcare center server.

IV. System Software Designs

The software modules in personal mobile phone is analyzed and designed with an object-oriented method, and represented by using unified modeling language (UML) [13]. The design phases are as follows: requirement analysis, object model design, code implementation for software model, simulator execution, and upload to real mobile phone Nokia 7610 [2] for final test. While for the healthcare center host, Borland C++ Builder 6.0 software is used to develop window application programs. ActiveX data objects (ADO) components are used to access ACCESS database, and advance technology (AT) command instruction set is used to control GSM module to transmit and receive short message. The function and design of each software module is introduced as follows.

A. Blood Pressure and Pulse Monitor Software Module

Blood pressure and pulse monitor software module provides a way for mobile phone to utilize Bluetooth wireless connection to integrate with Bluetooth hemadynamometer to control the Bluetooth hemadynamometer to measure and extract blood pressure and pulse. The measurement result can also be displayed directly on the mobile phone, and can transmit short messages to physicians or other heath care providers to provide proper healthcare. The use case diagram for this blood pressure and pulse monitor software module is as shown in Fig. 3(a).

The physiological parameter measurement application program of blood pressure and pulse monitor module provides three functions. The first function is to provide a user graphical user interface (GUI) to let the patient operate mobile phones and hemadynamometers easily, and display information such as physiological parameter measurement values and alert notices. The second function is the Bluetooth application programming interface (BT API) to let application programs utilize Bluetooth functions. The last function is the short message service (SMS) API [14] to let application programs transmit and receive short messages containing physiological parameter measurement values and alert notices.

To extract the physiological parameters measured with front-end Bluetooth hemadynamometer, our presented system uses Bluetooth mobile phone with JAVA APIs for Bluetooth Wireless Technology (JABWT) to develop client application program

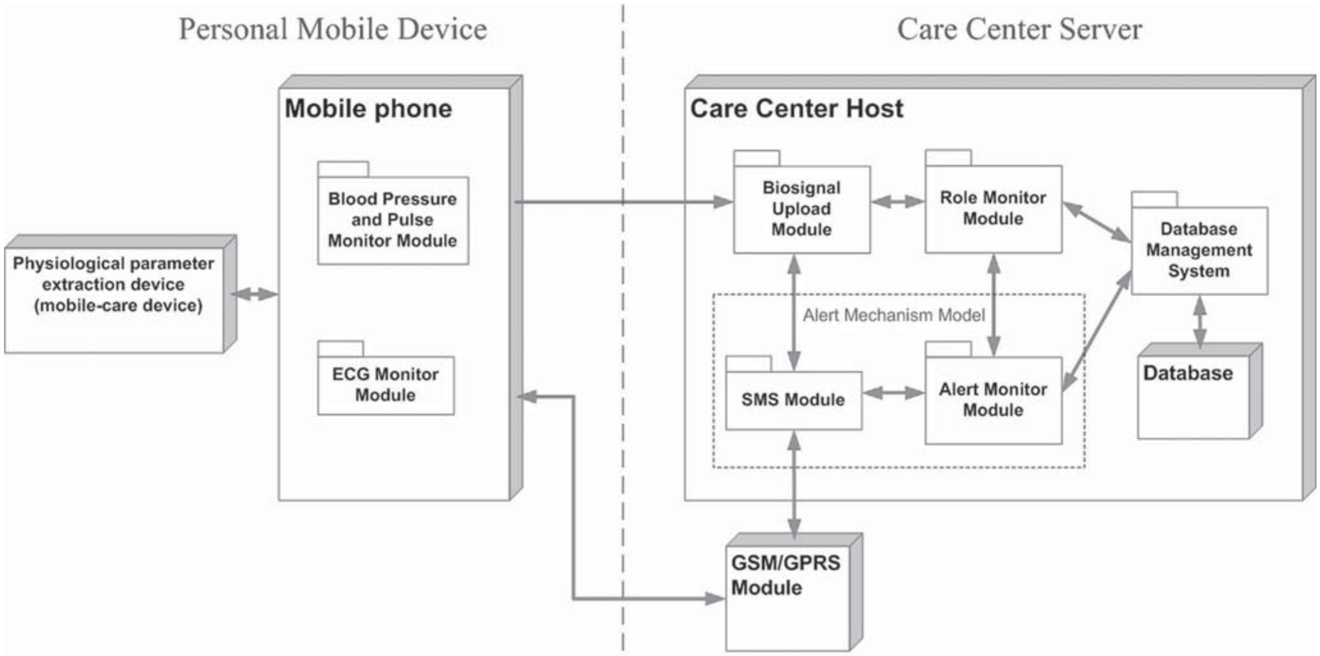
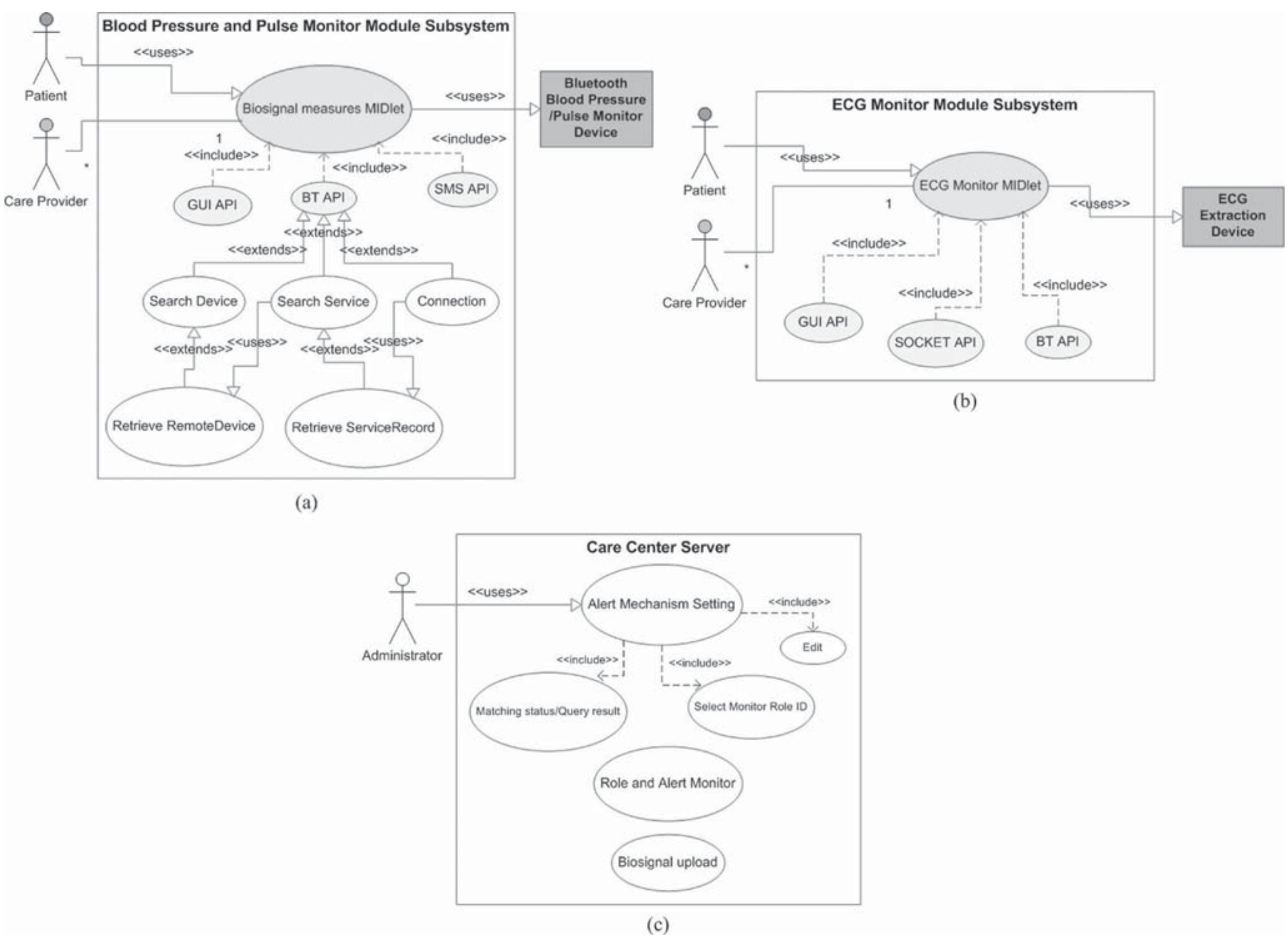


Fig. 2. System architecture deployment diagram.



MIDlet [15] to control and use Bluetooth hemadynamometer to realize the physiological parameter extraction function on patient ends. MIDlet utilizes JABWT to control hemadynamometer to accomplish commands such as blood pressure measurement and parameter setting.

The methods for interface `DiscoveryListener` in `javax.bluetooth` API have to be implemented in programs to let MIDlet receive `RemoteDevice` and `ServiceRecord` found by `DiscoveryAgent`. Connection address attributes in remote device service records are used to setup connection to utilize services provided by remote devices. Since `RFCOMM` is provided in the Bluetooth hemadynamometer, the API of `Javax.microedition.io`'s `StreamConnection` interface can be used to set up connection (btspp://). After the connection has been set up, mobile phone application programs can easily use serial port transmission protocol to communicate with Bluetooth hemadynamometer to transmit control commands and receive physiological parameter measurement data. Finally, the data can be transmitted to physicians or other healthcare providers with short messages.

B. ECG Monitor Software Module

The ECG monitor software module utilizes wireless Bluetooth function to integrate with front-end ECG physiological parameter extraction devices as a mobile healthcare device for cardiac patients. The use case diagram of the ECG monitor software module is shown in Fig. 3(b).

Patients use MIDlets for ECG monitoring to control and extract ECG data from front-end ECG extraction device, to transmit measured ECG data to mobile phones via Bluetooth after segmentation, and to calculate real-time variation of heart rate (HR) according to R-point positions that are automatically computed by using ECG detection techniques. If the calculated variation of HR is lower than the threshold (typically 10%) set by healthcare providers according to different patients' conditions, the abnormal ECG data will be transmitted with multimedia short messages (MMS) via GPRS to physicians, healthcare providers, or healthcare center to provide further healthcare and treatment. The ECG monitor software module provides three major functions: GUI API to display ECG, HR calculated values, and to let patients operate and control ECG extraction devices; BT API to set up Bluetooth connection between the ECG extraction device and the mobile phone; SOCKET API to upload ECG data to the healthcare center server via Socket connection.

ECG detection techniques in ECG monitor MIDlet application programs utilize "Modified So and Chan" R-wave detection algorithm [16] that needs little computation, and is capable of adjusting adaptation detection parameters.

C. Healthcare Center Server Program Design

The healthcare center server provides following functions: alert mechanism setting, role and alert monitoring, and physiological parameter uploading. The use case diagram of healthcare center server is shown in Fig. 3(c).

The alert mechanism setting function provides managers a

TABLE I
STRATEGY TABLE FOR DIFFERENT LEVELS OF URGENCY

Urgency Level	Strategy
Normal	E-mail
Urgent	SMS to Patients' Mobile Phone
Critical	SMS to Care Providers' Mobile Phone
Very Critical	Ambulance with Approval of Care Provider

TABLE II
PRIORITY TABLE FOR THE ROLE OF HEALTHCARE PROVIDERS

Name	Priority
Kevin	1
Jacky	2
Evans	3

alert mechanism. Three functions are provided: display results of queries and status of matching; select candidates of monitored roles; and edit content of data tables.

Role monitoring and alert monitoring functions are the core of the healthcare center server software [8], [10]. To execute strategy matching module, the strategies to be executed should be set beforehand, as shown in Table I. The scenario of healthcare in Fig. 1(a) can be used to demonstrate the strategies corresponding to different levels in Table I. The urgencies are classified into four levels with corresponding strategies. If the urgency level is normal, e-mails will be used for notification. If the urgency level is urgent, short messages will be transmitted to patients' mobile phones. If the urgency level is critical, short messages will be transmitted to patients' care providers to assist the patients. If the urgency level is very critical, with the approval of care providers, ambulances will be notified to perform emergency rescues. Note that since the physiological information of each patient is different, the system setting such as related parameters of emergency conditions and healthcare services provided in different levels are set by care providers according to personal condition and medical history of each patient.

Each strategy sets the roles to be notified first, and then execute role matching. The role matching first has to define different priorities for each person of the same role as shown in Table II and then transmits messages according to the priority.

The current urgency level can be changed by priority urgency module according to the elapsed time. The relationship between urgency level and elapsed time can be formulated as priority urgency level function as follows:

$$U(t) = \begin{cases} \text{Normal}, & \text{if } t \le T \\ \text{Urgent}, & \text{if } T < t < T + dt_1 \\ \text{Critical}, & \text{if } T + dt_1 < t < T + dt_1 + dt_2 \\ \text{Very critical}, & \text{if } T + dt_1 + dt_2 < t < T + dt_1 + dt_2 + dt_3. \end{cases} \quad (1)$$

In the priority urgency level function, t, T, dt_1, dt_2, and dt_3 represent the elapsed time after alert is transmitted, the default deadline, the urgent deadline, the critical deadline, and the very critical deadline, respectively.

The complete operation procedure of alert mechanism is depicted as follows. To start alert mechanism, the strategy match-

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