Service Agreements and Facilities for M-Health Vital Sign Monitoring

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Enschede, the Netherlands
September, 2006

Abstract

Ubiquity of wireless access to the Internet and the advancements of mobile devices enable mobile healthcare (M-Health). This is for instance shown by the EU and national projects MobiHealth, HealthServices24 and Freeband/AWARENESS. These projects develop and improve a sensor based healthcare monitoring and treatment system for several care programs (e.g. 24h cardiac monitoring and supervised COPD outdoor training).

This thesis focuses on the data transfer facilities for flexible vital sign monitoring, including the necessary agreements on the involved service subscription and use between the involved stakeholders of an M-Health monitoring system, like the patients, the care centers and the service providers of the supporting network services. UML class diagram models are defined to capture the services. The notion of Service Level Agreement is used to specify the mentioned relationships. The model enables the mapping of the vital sign quality parameters to network service capacity needs that are able to transfer of the vital signs.

One of the issues in the design of the UML class diagram is how to model the required facilitates for mobile tele-monitoring of patient’s vital signs in a flexible way. On one hand, needs of vital sign monitoring depend on the care programs, the recovery or the exacerbation of the disease, and the preferences of the care professionals. On the other hand, vital sign monitoring depends on the capability and the capacity of the supporting network infrastructure. This thesis addresses the development of an UML class diagram which accommodates the care program needs in alignment with the network capacities.

The other issue is that the model should be suitable for cases in which patients are enrolled in several care programs of a health care center and enable aggregated vital sign acquisition for the enrolled care programs.

Table of Contents

List of Figures

List of tables

Chapter 1 Introduction

1.1 Background

2.5/3G[1] wireless communication technologies provide the possibility to support remote health care, for example to monitor patients' health condition in their daily activity environments. Healthcare professional could retrieve the patients' data, which is transferred from the patients' locations and stored at a care center, and give treatment advices to the patient from locations away from the health care center. The combination of wireless communication technologies and health care, which is called M-health, will provide social improvements and economic benefits to patients and health care centers. M-health may be applied to reduce the treatment costs, improve patients' quality of lives [1].

In M-health monitoring, physiological signals (e.g. vital signs, like ECG, blood pressure, and oxygen saturation) of the patient are measured by various sensors. The measured physiological signals which reflect the condition of the patient may be transferred to the corresponding health care center. Health care professionals may retrieve these signals from the health care center for further diagnosis or treatment of the patient.

The measured physiological signals can be transmitted via wireless communication links for example a 2.5G technology GPRS[2] link. Wireless communication links are provided by Public Network Operators (PNO) such as KPN, Vodafone or Internet Service Provider (ISP). The patient or the health care center has to subscribe for a suitable capacity of wireless communication links (e.g. bandwidth) to transmit the measured physiological signals. The composition and quality (e.g. bit rate) of the measured physiological signals must match the capacity of available wireless communication links. So before the patient or health care center chooses the capacity of wireless communication links, they must know the composition and quality of the measured physiological signals.

From the discussion above, we observe that three stakeholders being involved in M-health: patient, health care center, and Public Network Operator (PNO) or Internet Service Provider (ISP). The relation between a patient and a health care center is that the health care center provides M-health service (e.g. physiological signal monitoring) to the patient. The relation

[1] G stands for Generation see appendix
[2] GPRS see appendix

between a PNO or ISP and the patient or the health care center is that the PNO or ISP provides communication service (e.g. wireless communication links) to support the M-health service monitoring. Moreover the relation between the PNO or ISP and the patient or the health care center depends on the relation between the patient and the health care center. These two relations must match with each other, for example the composition and quality of measured physiological signals must match the capacity of available wireless communication links provided by the PNO or ISP.

It is therefore considered necessary to have an M-health service agreement model to specify coherent by the relations between these three stakeholders. These relations are all about services (e.g. M-health monitoring service, wireless communication service). As services, there must be agreements or contracts to define the expectations and obligations of the involved stakeholders. For example, for M-health monitoring service, the obligation from the health care center is to provide physiological signals monitoring service. The obligation from the patients is to behave correctly according to the agreement, (e.g. the correct usage of the M-health monitoring service). The service agreement between the patient and the health care center determines the composition and quality of measured physiological signals. According to this service agreement, the health care center and the patient can derive the capacity of wireless communication links needed to transfer all the measured physiological signals correctly. Then the patient or the health care center can make a service agreement with the PNO or ISP about the needed wireless communication provisioning (e.g. subscribe correct capacity of wireless communication links). The obligation from the PNO or ISP is to provide the wireless communications links which patients or the health care center subscribed. The service agreement model relates these three stakeholders and maps the composition and quality of physiological signals onto capacity requirements of wireless communication links.

Moreover, it is possible that a patient suffers several diseases, for example this is very common for elderly people. Therefore M-health service may contain different care program services according to the specialty i.e. outdoor patient’s rehabilitation care and Cardio care [1]. This means that a patient may enroll more than one care program services, each of which requires to measure own physiological signals suitable for the medical tasks of the care specialty.

Separate measurement sessions of physiological signals for each care program are typically not efficient, especially because most of these programs share some of the measured physiological signals. This is a problem that the M-health service agreement model has to help to solve.

The following sections discuss the research questions, approach, the scope of the thesis, and the structure of the thesis.

1.2 Problem statement

This thesis addresses the following research questions:

- How to define an M-health monitoring service agreement model that captures the relations between the three stakeholders (patient, health care center, and PNO or ISP), and captures the necessary parameters to map the M-health monitoring services (e.g. composition and quality of physiological signals) onto appropriate wireless communication services (e.g. capacity of wireless communication links).

- How to refine the M-health service agreement model to make it suitable for a patient enrolled in several health care programs of one health care center. For example, how to show measured physiological signals for use in several health care programs.

1.3 Approach of the thesis

To solve the problems which are addressed in the previous section, the following approach is used:

- Problem domain analysis
  Study M-health cases to acquire knowledge of the health care problem domain in particular about care programs and associated physiological signals, including the required quality of the physiological signals.

- Service agreement model selection
  Adopt a service agreement model which can be applied on M-health to specify coherent relations in respect of the exchange of physiological signals between the stakeholders (patient, care center and ISP). The agreement model is expressed in UML class diagram.

- M-health monitoring service agreement model refinement
  Refine the adopted service agreement model to solve the two research problems which are discussed in previous section.

  - The model distinguishes two stages: a subscription phase and an operational phase. In the subscription phase the health care center defines the physiological signals to measure and determines the expected maxima of the composition and quality of physiological signals. According to the maximum set of physiological signals, the patient or the health care center subscribes for wireless communication links of an adequate capacity (e.g. maximum possible bandwidth to transfer the measured physiological signals). In the operational phase, the real usage of capacity of wireless communication links is calculated to convey the real measured physiological signals. It is obvious, that this operational capacity of the wireless communication links should satisfy the capacity subscribed.

For a patient enrolled in several care programs, a (non-redundant) union of physiological signal is selected from all the physiological signals required by the enrolled care programs. In the health care center, health care professionals could retrieve down scaled physiological signals according to their requirements. In the UML class diagram, which expresses the agreement model, these refinements specify the attributes and methods of the classes.

- This procedure is proceeded in two cycles; first cycle mainly focus on realizing the functions of the monitoring model, second cycle improves the model by taking into consideration the alternatives of the monitoring model, responsibilities of the classes in the model, and the weakness of the model, etc. The second cycle is not completely elaborated toward an implementation, but we give recommendations to improve the model and we provide design guidelines to some of the recommendations.

- Analyzing the behavior of the model using sequence diagram, and implement a demo to some extent to validate the M-health agreement model
  The demo is implemented in JAVA based on the UML service agreement model.

1.4 Scope of the thesis

This thesis focuses on the definition of a service agreement model for M-health monitoring service to solve the two research problems discussed earlier. The model is suitable for a patient enrolled in several health care programs of one health care center. This thesis describes the use of the service agreement to determine Internet or public network connection agreement with Internet connection providers or Public Network Operations. The service agreement model focuses on the configuration aspect of the agreements, for example the calculation of the maximum bandwidth requirement of the system to support the real-time transfer of physiological signals and the share of the measured physiological signals among the care programs. The attributes and methods of the UML classes that are defined in the model are limited to support these purposes.

1.5 Structure of the thesis

The structure of the thesis is organized as follows:

Chapter 1 Introduction
This chapter is an introduction of the thesis, including background, problem statement, scope, approach, etc.

Chapter 2 M-health case scenarios analysis
This chapter analyzes several typical mobile health case scenarios and introduces vital signs, and obtains the requirements for an M-health monitoring service model.

Chapter 3 Service Level Agreement
This chapter is a study of Service Level Agreement and related terms like Service Level Specification.

Chapter 4 First design cycle of M-health monitoring Model
This chapter defines an M-health Monitoring service Model according to the requirements of M-health. This model mainly focuses on the functional, and not considers too much alternatives of the models.

Chapter 5 Behavior of M-health monitoring model
This chapter discusses the behavior of the M-health monitoring service model

Chapter 6 Demo of M-health Service Agreement Model
This chapter implements a demo of the M-health monitoring service model

Chapter 7 Second design cycle of M-health monitoring Model
This chapter discusses the alternatives of the models we have defined in Chapter 4, and some recommendations of the models

Chapter 8 Conclusion and future work

Chapter 2 M-health case scenarios analysis

This chapter presents description of M-health monitoring and an analysis of two M-health care programs scenarios: outdoor patient’s rehabilitation and Cardio care. First section of this chapter introduces vital signs because vital signs are important to understand the scenarios analysis and crucial factors (e.g. quality of vital signs) to determine the infrastructure capacity in the service agreement model. The following sections are organized as: Section 2.2 presents the M-health monitoring infrastructure; Section 2.3 analyzes the case of outdoors patient’s rehabilitation; Section 2.4 analyzes cardio care; Section 2.5 summarizes characteristics of the M-health case scenarios.

2.1 Vital signs

Vital signs such as heartbeat, breathing rate, temperature, and blood pressure indicate human’s general physical conditions. In the following sub-sections, some vital signs which are relevant to our M-health care programs will be introduced.

2.1.1 ECG

Human being’s heart activity generates bioelectrical signals. The signals are recorded as a graphical representation, which is called electrocardiogram. The acronym ECG represents for this electrocardiogram. Electrocardiogram is used for detecting many heart problems. It may be used routinely for monitoring the patient's condition during and after surgery, as well as routine health care check. The physician can know the abnormality of heart function by evaluating and analyzing the heart rhythm depicted by electrocardiogram [2].

ECG leads

The ECG signals can be measured by placing pairs of electrodes on the human body. Signals on these pairs of electrodes are called ECG leads. There are two kinds of leads: Bipolar lead and Unipolar lead. Bipolar Lead is the lead in which the electrical activity at one electrode is compared with that of another. By convention, a positive electrode is one in which the ECG records a positive (upward) deflection when the electrical impulse flows toward it and a negative (downward) deflection when it flows away from it. Unipolar lead is lead in which the electrical potential at an exploring electrode is compared to a reference point that averages electrical activity, rather than to that of another electrode. This single electrode, termed the exploring electrode, is the positive electrode.

A standard has been established in electrocardiogram that specifies 12 leads and the corresponding positions of the electrodes on the human body [2]. Different parts of the heart can be seen from different positions by different ECG leads. So each ECG lead provides an individual shape of the heart activity. The 12 standard ECG leads are classified in limb leads and chest leads. Limb leads includes I, II, III, AVR, AVL and AVF. Leads I,II,III are bipolar leads, and leads AVR,AVL and AVF are unipolar. By convention, lead I is the positive electrode on the left arm and the negative electrode on the right arm (see Figure 2.1). It measures the potential difference between the two arms.

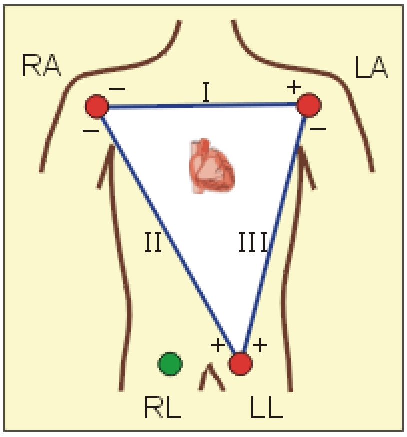

Figure2. 1 standard limb leads [2]

Lead II is the positive electrode on the left leg and the negative electrode is on the right arm. Lead III is the positive electrode on the left leg and the negative electrode on the left arm. An equilateral triangle is roughly formed by these three limb leads (with the heart at the center), and it is called Einthoven's triangle in honor of Willem Einthoven who developed the electrocardiogram in 1901[3]. These three leads are called Standard Limb Leads.

In addition to the three standard limb leads, there are three augmented limb leads: AVR, AVL and AVF. In practice, these are the same electrodes used for leads I, II and III (The ECG machine does the actual switching and rearranging of the electrode designations). The three augmented leads are depicted using the **axial reference system**[3] as shown in Figure 2.2. The AVL lead is at -30º relative to the lead I axis, which is obtained between the average signal obtained from three negative electrodes (right arm, left foot and right foot) and the signal

[3] detailed information see reference 3

obtained from a positive electrode placed on the left arm; AVR is at -150º , which is obtained between the average signal obtained from three negative electrodes (left arm, left leg and right foot) and the signal obtained from a positive electrode placed on the right arm; AVF is at +90º , which is obtained between the average signal obtained from three negative electrodes (left arm, right arm and right foot) and the signal obtained from a positive electrode placed on the left foot [3].

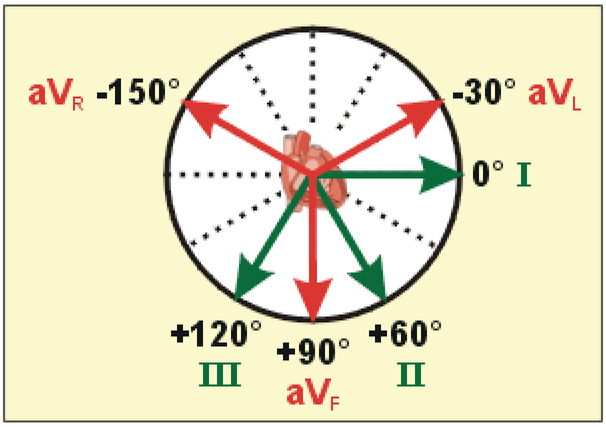

Figure2. 2 augmented limb leads[3]

The three augmented limb leads, coupled with the three standard limb leads, constitute the six limb leads of the ECG. These leads record electrical activity along a single plane, termed the frontal plane relative to the heart [3].

Whether the limb leads are attached to the end of the limb (wrists and ankles) or at the origin of the limb (shoulder or upper thigh) makes no difference in the recording because the limb can simply be viewed as a long wire conductor originating from a point on the trunk of the body.

Chest leads includes V1, V2, V3, V4, V5, V6. The limb leads provide views of the heart activity in the frontal plane and the chest leads provide views in the horizontal plane of the heart [2]. All these six leads are unipolar leads. Figure 2.3 illustrates the position of ECG chest leads in the body with corresponding electrode positions.

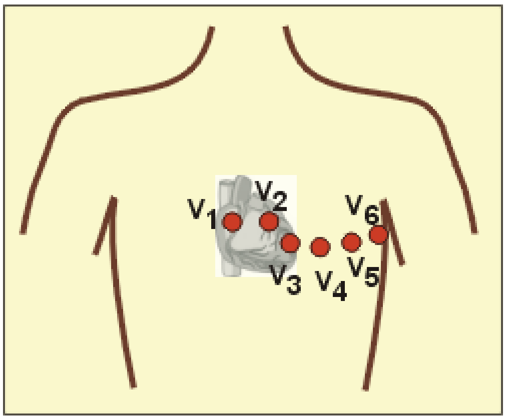

Figure2. 3 chest leads [3]

The meaning of each lead in chest leads and the way of obtaining them are described in the following lines [2]:

1. V1 is a lead obtained between the reference negative electrode and a positive electrode placed on the chest in the V1 position.
2. V2 is a lead obtained between the reference negative electrode and a positive electrode placed on the chest in the V2 position.
3. V3 is a lead obtained between the reference negative electrode and a positive electrode placed on the chest in the V3 position.
4. V4: is a lead obtained between the reference negative electrode and a positive electrode placed on the chest in the V4 position.
5. V5: is a lead obtained between the reference negative electrode and a positive electrode placed on the chest in the V5 position.
6. V6 is a lead obtained between the reference negative electrode and a positive electrode placed on the chest in the V6 position.

ECG Wave

The normal ECG wave uses five capital letters from the alphabet i.e. P, Q, R, S, and T to mark. The ECG wave is presented in two dimensions. The horizontal axis represents a time domain and the vertical axis represents voltage domain (see Figure 2.4).

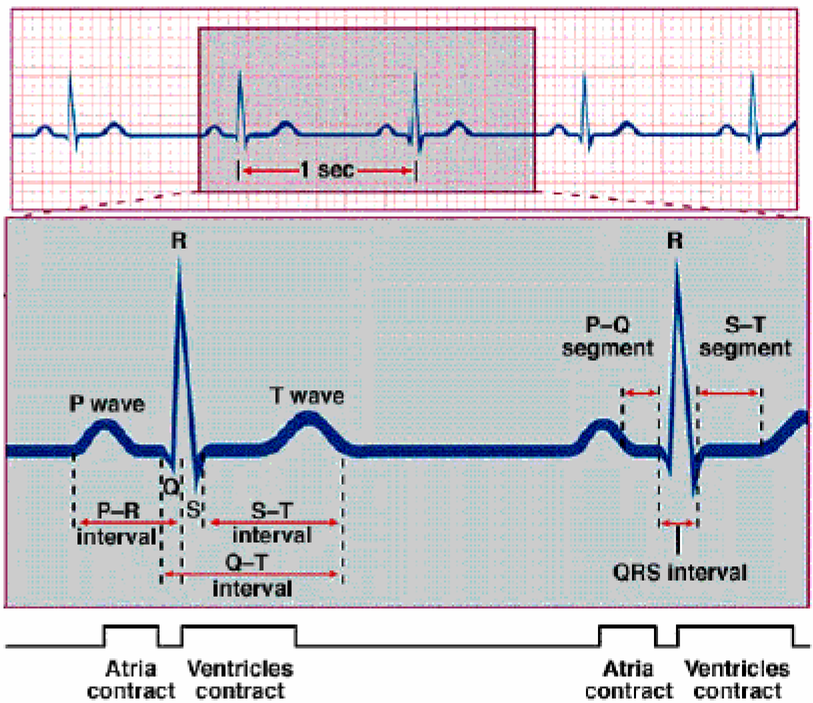

Figure2. 4 ECG wave

An upward deflection of a wave is called positive deflection and a downward deflection is called negative deflection [2]. Figure 2.5 shows 12 leads ECG wave shapes.

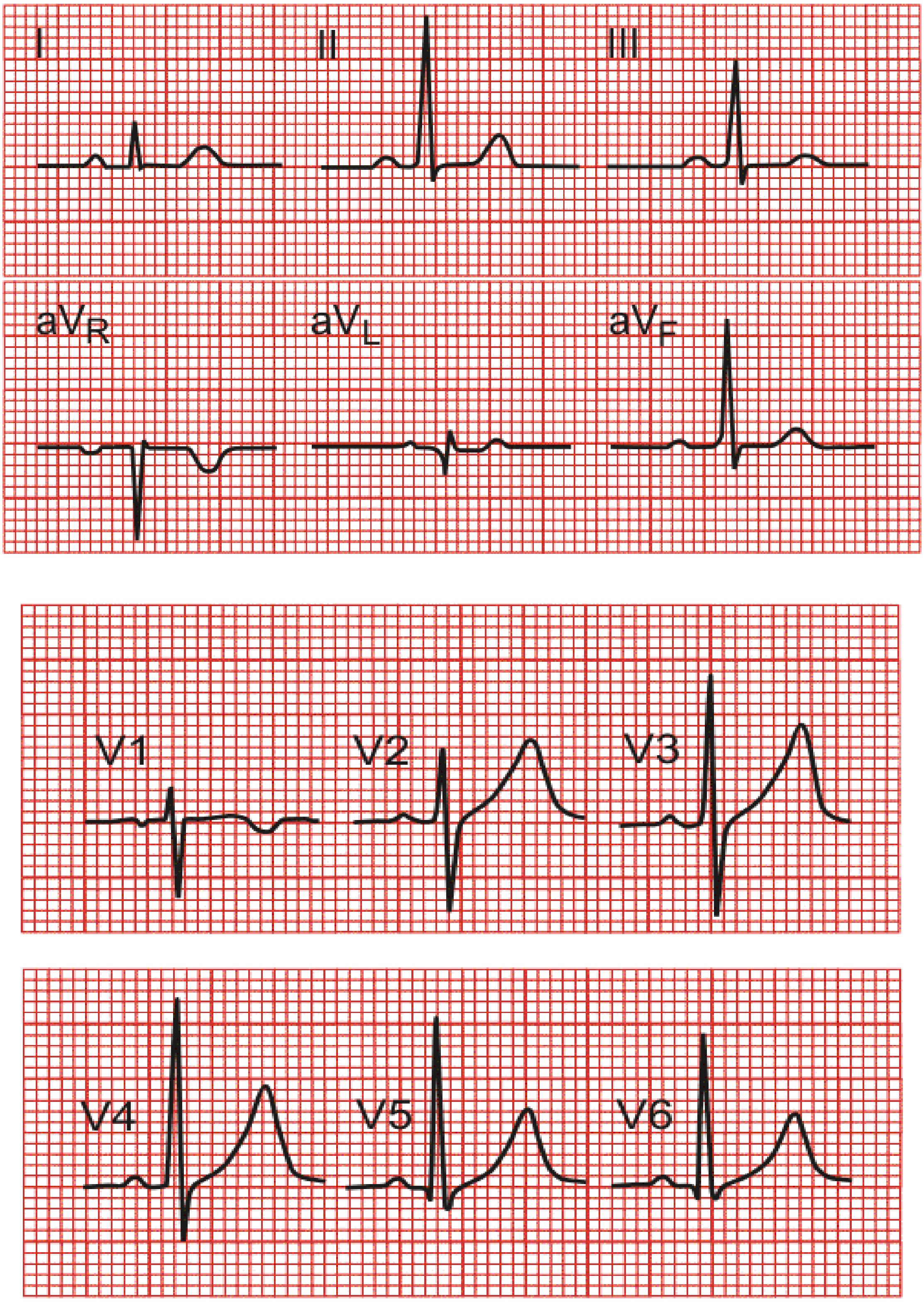

Figure2. 5 12 leads ECG wave shapes

How this ECG wave is generated from the heart is not the scope of this thesis. Here just introduces a basic concept and uses this result, if readers are interested in the generation of the ECG wave, references [2] and [3] are recommended.

2.1.2 Oxygen Saturation

Oxygen saturation is an indicator of percentage of hemoglobin saturated with the oxygen at the time of measurement. The instrument, well known as pulse oximetry, uses two sources of infra red light that are absorbed by hemoglobin and transmitted to a tissue to a photo detector [4]. Figure 2.6 shows oxygen saturation measurement.

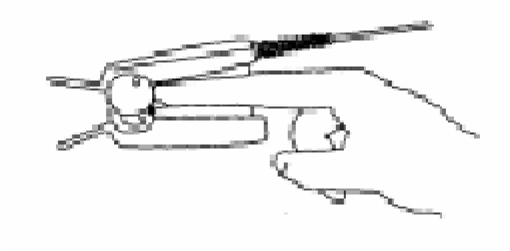

Figure2. 6 oxygen saturation measurement [4]

The plethysmogram can be obtained from the pulse oximetry. Figure 2.7 illustrates the plethysmogram. Oxygen saturation can be derived from the plethysmogram.

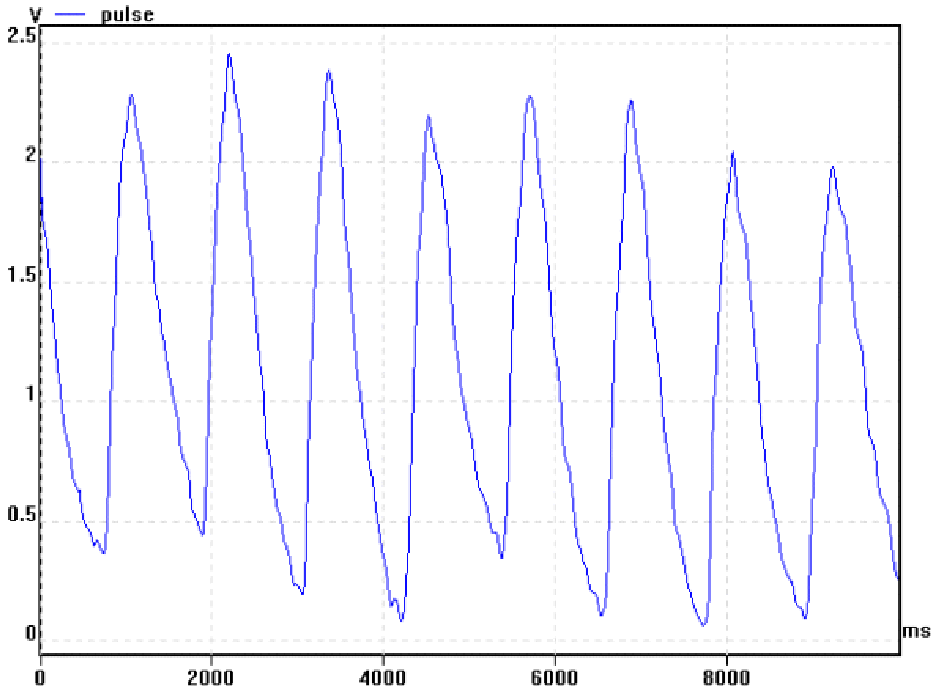

Figure2. 7 a plethysmogram

Normal oxygen saturation values are 97% to 99% in the healthy individual. An oxygen saturation value of 95% is clinically accepted in a patient with a normal hemoglobin level [4].

2.1.3 Blood pressure

Blood pressure is the force of the blood pushing the walls of the arteries [5]. An artery is the passage in which blood is carried from the heart to all parts of body in vessels. For a normal person heart beats 60-70 times per minute. Blood pressure is always given as two numbers, systolic pressure and diastolic pressure. Systolic pressure is the highest blood pressure when the heart pumps the blood into other parts of the body. Diastolic pressure is the pressure to the walls of the arteries between the intervals of heart beats. The normal blood pressure is that systolic pressure is less than 120 and diastolic number is less than 80.

2.1.4 Quality of Vital signs

The Quality of the measured vital signs determines the data rate generated at the patient’s side. This rate, in turn, determines the connection bandwidth requirements needed to transfer the signs. There are many factors which affect the quality of the digitized vital signs. We only list some of the factors which will be used in this thesis:

- The sample rate of continuous time vital signs (e.g. sample rate of ECG and plethysmogram).
- The compression rate of vital signs data, which is defined as the amount of transferred data (compressed data) per time-unit divided by the amount of data per time-unit generated from the sensors.
- The number of bits per sample value of the vital sign.

2.2 M-health monitoring infrastructure

2.2.1 Body Area Network

The M-health Body Area Network (BAN) is used to measure and transfer the vital signs to the health care center via the wireless networks (e.g. UMTS or GPRS). A BAN consists of sensors, a Front-End and a Mobile Base Unit (MBU) [1]. Figure 2.8 shows the BAN.

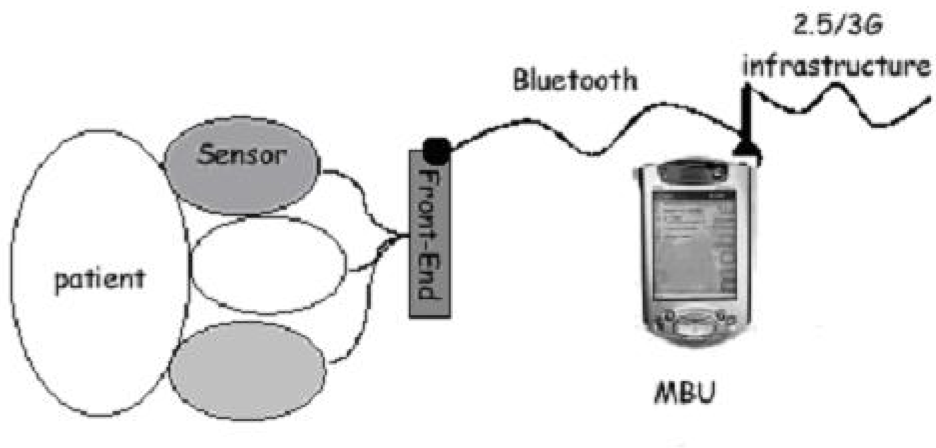

Figure2. 8 Body Area Network [1]

Sensors, which are used to measure the vital signs such as ECG, blood pressure, are attached on patient. Sensors are connected to the Front-End, which can amplify and digitize the measured signals from sensors. Then the Front-End sends the measured signals wirelessly to the MBU. The MBU is a handset device that controls the BAN. For example patient can click “start” button on MBU to start measuring the vital signs of the patient. The MBU is also responsible for transferring the data to health care center via wireless networks.

2.2.2 Networks to transfer vital signs

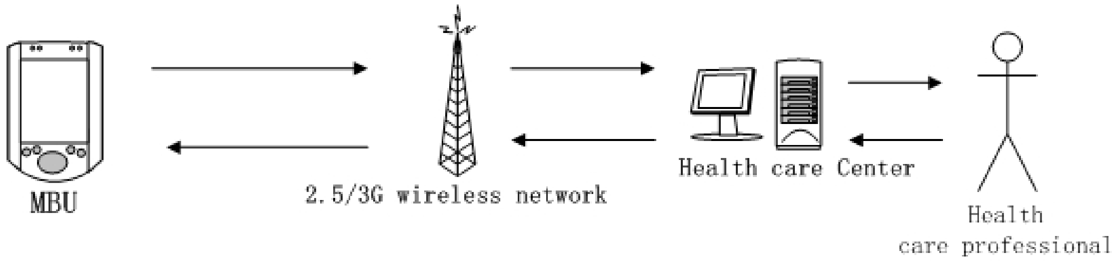

Figure2. 9 Infrastructure of the M-health monitoring

Figure 2.9 shows the infrastructure of the M-health monitoring. BAN transfers the measured vital signs to health care center via networks (e.g. 2.5/3G wireless networks). The vital sign data is stored in health care center. The remote located health care professional can retrieve these vital signs e.g. via wireless network. The feed back or diagnose of the health care professional can be transferred back to the BAN via wireless network as well.

2.3 Outdoor patient's rehabilitation

2.3.1 Background

Outdoor patient's rehabilitation care program is a program for chronic respiratory patients to improve their physical conditions. It has been shown that physical training can prevent the progress of the disease [1]. Normally patients do the rehabilitation exercise in health care center. However sometimes it is hard for patients to visit health care center regularly. Remote M-health monitoring can be used to control patients' outdoor training near patients' residence. The rehabilitation vital signs can be measured by a BAN and sent to a health care center via wireless networks. In this way the professional on or off site the health care center retrieves the vital signs and provides advice on the training. [1].

2.3.2 Scenario

This section describes the scenario of the outdoor training based on the control of the speed of walk. The scenario is described in two stages, and each stage consists of several steps [6]:

- Subscription stage

A patient subscribes an M-health monitoring service and the health care center specifies the vital signs which will be monitored and their qualities at the subscription stage. The health care center also subscribes a wireless network service and its capacity for transmitting the signs on behalf of the patient at this stage. There are three steps in the subscription stage:

1. The patient consults the health care professional and is advised to participate to the rehabilitation care program.

2. The patient registers in the health care center for the rehabilitation care program. An M-health monitoring service contract is signed by the patient and the health care center. Some of the parts of the contract are about the contents of the M-health monitoring service, such as measured vital signs and their qualities.

3. According to the contract signed by the patient and the health care center, the health care center on behalf of the patient signs a contract with a Public Network Operator (PNO) or an Internet Service Provider (ISP). This contract specifies a corresponding wireless network service and the capacity of this network service that are capable to transfer vital signs.

4. The patient is provided with a BAN including the sensors, the front-end and the MBU, and is taught how to use the BAN by health professionals.

- Operation stage

This stage is the real usage of the M-health monitoring service which has been subscribed.

1. The patient starts to do the rehabilitation exercise at his own locations. Daily, he turns the BAN on by clicking the “start’ button on MBU (Figure 2.8). He stays for a short period of time without doing any movement in order to collect the vital signs before the exercise. Around one minute later, he starts walking. The measured vital signs are sent to health care center via wireless communication links.

2. On the medical center side, data is received and displayed on the health care professional’s computer. The professional monitors patient’s performance by analyzing the vital signs of the patient and may request the patient to increase or decrease the walking speed according to his performance. According to the conditions of the patient, the professional may also adjust the initial composition of the vital signs and their qualities which are defined in subscription stage. However all of these changes must conform to the subscription stage specified the composition and the quality of the vital signs.

2.3.3 Parameters to be measured

The vital signs which are measured in this care program are the following [6]:

- Plethysmogram
- ECG-3 leads
- Mobility (walking speed calculated from mobility sensor)

Table 2.1 illustrates an example of calculating the bandwidth requirement of the outdoor patient's rehabilitation [5].

parameter	Resolution (Bits/sample)	Compression (%)	Sample rate (sample/second)	Data rate (kbits/second)
plethysmogram	24	100	128	3
ECG-3 leads	24	100	256	18
Mobility	24	100	128	3
data rate	24kbps			

Table2. 1 bandwidth requirement for outdoor patient's rehabilitation

Here we treat the data rate same as bandwidth, although it is not the case in reality. The data rate is calculated by formula: data rate = resolution × compression × sample rate. According to [6], the resolution of the Front-End of BAN is 24 bits/sample. The sample rates of continuous vital signs are different according to the requirements of the health care professional, normally it is 128 sample/second or 256 sample per second. The compression rate is 100%, which means that no compression of the measured vital signs [6].

2.4 Cardio Care

2.4.1 Background

Cardiac arrhythmias are very common, especially for elderly people, and in many cases are related to coronary heart disease. There are many medicines that are used to treat arrhythmias. Medicines need to be carefully chosen because of the side effects. Specific medicine therapy needs to be individualized for different patients. In some cases, misused medicine can make arrhythmias worse. For this reason, the benefits and risks of the medicine have to be carefully weighed before taking it [1].

If a patient is taking medicines for an arrhythmia, an electrocardiogram (ECG), oxygen saturation and blood pressure have to be monitored to check whether the treatment is working. Usually these vital signs are being taken in a cardiologist's office or in a hospital several days to several weeks. Sometimes it misses the opportunity to detect the bad side effects of the medicine [1].

If the M-health monitoring service is used for these patients, the vital signs of the patients can be measured anytime. Vital signs are transmitted via wireless communication links from the patient's house or somewhere else to a health care center; these vital signs will be analyzed by the cardiologist. This enables quick reactions for the effects of the medicines which patients have taken. Irregular patterns in these vital signs will be quickly detected and appropriate intervention can be affected [1].

2.4.2 Scenario

This section describes the scenario of the cardiac arrhythmias care. This health care program monitors the vital signs of arrhythmias patients after taking the medicines via the wireless communication links. Cardiologists will decide if the medicines are safe enough for the patient. Same like outdoor patient rehabilitation care program, this care program is also described in two stages, and each stage consists of several steps [1]:

- Subscription stage
  This stage has the same function that was discussed in Section 2.2.2

  1. A patient who suffers from arrhythmia needs to take medicines for the treatment. The cardiologist advises him to participate in this monitoring program.

  2. The patient registers for the cardiac arrhythmias care. An M-health service contract is signed by the patient and the health care center. Parts of the contract are about cardiac arrhythmias health care monitoring service, such as composition and quality of vital signs which will be monitored.

  3. According to the contract signed by the patient and the health care center, the health care center on behalf of the patient signs a contract with a Public Network Operator (PNO) or an Internet Service Provider (ISP) to determine a corresponding wireless network service and subscribe a network service which is capable to transfer measured vital signs of the required composition and quality.

  4. The patient is provided with a BAN including the sensors, the front-end and the MBU, and is taught how to use the BAN by health professionals.

- Operation stage

  1. After the patient takes the medicines for his treatment, he puts the required sensors on and starts the monitoring by clicking on the "start" button on MBU. The vital

signs are continuously monitored and sent to the health care center via wireless networks.

2. In the health care center, the transmitted vital signs are monitored by a cardiologist .The cardiologist analyzes the data and may adjust the composition of the vital signs and their qualities according to the situation of the patient. However all these changes must conform the subscribe stage.

3. In case of a serious impairment of heart rate, the patient is informed immediately to go to the cardiologist office.

2.4.3 Parameter to be measured

The vital signs which are measured in this care program are as following:

- ECG (4-leads)
- Blood pressure
- SatO2/ plethysmogram

Table 2.2 illustrates an example of calculating the bandwidth requirement of the arrhythmia care [6].

parameter	Resolution (Bits/sample)	Compression (%)	Sample rate (sample/second)	Data rate (kbits/second)
plethysmogram	24	100	128	3
ECG 4-leads	24	100	512	48kbps
Blood pressure	24	100	/	0.023
data rate				51.023kbps

Table2. 2 the bandwidth requirement of arrhythmia care

As we discussed in Section 2.2.3, we treat the data rate same as bandwidth. The data rate is calculated by formula: data rate = resolution × compression × sample rate. Since blood pressure is a discrete signal, it doesn't have a sample rate.

2.5 Summarizing M-health scenarios

From the previous scenarios, we observe that three stakeholders can be identified in M-health monitoring as explained in this report: patients, health care center/health care professional, and PNO or ISP. The roles of these three stakeholders are the following:

- Patients and health care professionals
  Patients and health care professionals are the stakeholders that use the M-health monitoring services.

- Health Care center.
  The health care center provides the M-health monitoring service to patients, in particular specifies the composition and the quality of vital signs for monitoring. The health care center is responsible to ensure the availability and the correct functioning of all facilities of diagnose or treatment.

- Public Network Operator (PNO) or Internet Service Provider (ISP).
  The PNO or ISP is responsible to provide the network connectivity service. In our case, the customers of the PNO or ISP are the patients and the health care center. In this thesis, we assume that health care center subscribes Internet services and specifies the capacity of the network service on behalf of patients and both the health care center and the patient are in the same network service domain provided with the same PNO or ISP.

The scenario of each care program can be divided into two phases: a subscription phase and an operational phase. The subscription phase specifies the monitoring service, to be used in the operational phase, which includes the composition of the vital signs and their qualities, and the needed network service and its capacity. The operational phase is the usage of the subscribed service, and obviously it must satisfy the subscription phase.

From Table 2.1 and Table2.2 we observe that some vital signs can be shared if the patient is enrolled in the two care programs in one health care center. Figure 2.10 illustrates this situation.

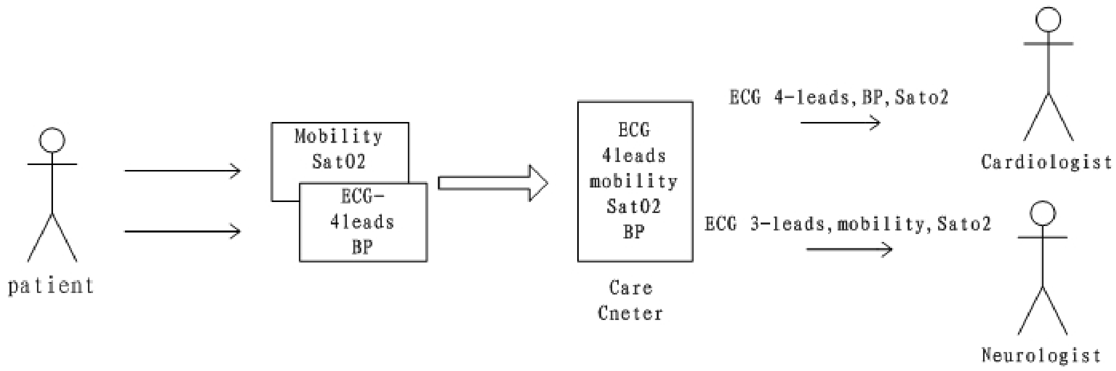

Figure2. 10 a patient enrolled two care programs

In this case, it is not efficient to have separate measurement sessions of vital signs for each care program. So it is better to combine the two measurement sessions into one, and the measured vital signs are transmitted to and optionally separated at the health care center. The health care professionals can retrieve these data according to their appropriate vital signs sets.

Chapter 3 Service Level Agreement and Service Level Specification

This chapter introduces the concept of Service Level Agreement (SLA) and the related concept Service Level Specification (SLS).

3.1 Introduction

We have discussed in Chapter 1 that we need an agreement to define the relations between the three stakeholders (i.e. patient, health care center and PNO or ISP). The concept of Service Level Agreement (SLA) can be used in this thesis to define these relations. SLA is the agreement between a service provider and a user [7]. It specifies the service and many aspects that are related to this service, such as the expected performance of the service, billing, and security.

SLA may contain many aspects of the relations between the introduced stakeholders. However in this thesis we only consider the part of a SLA that is relevant for an efficient way to transfer vital signs of the monitor service. In particular, we address two SLAs. A SLA between the patient and the health care center that determines the composition and quality of measured vital signs, and a SLA between the health care center and the PNO or ISP that determines network service and the capacity of communication links that are able to transfer the measured vital signs.

3.2 Service Level Agreement

As was mentioned earlier, a SLA is an agreement that exists between a service provider and a user. It is designed to create a common understanding about a service, service quality, and responsibilities, etc. SLA can cover many aspects of the relationship between the user and the service provider. Here we list some of them [8]:

- The type and nature of the service to be provided, which includes the description of the service to be provided.

- The expected performance level of the service, e.g. availability requirements, such as when the service is available, and what are the bounds on service outages that may be expected.

- The credits, charges, or other consequences for the service provider in not meeting its obligation.

- Escape clauses and constraints, including the consequences if the user does not meet his obligation.

A SLA may contain other aspects, such as security issues. In this thesis, we do not consider charges, security, etc and only focus on technical aspects which are related to vital signs monitoring in M-health.

Figure 3.1 shows the relations SLA between users and service providers expressed in a UML class diagram.

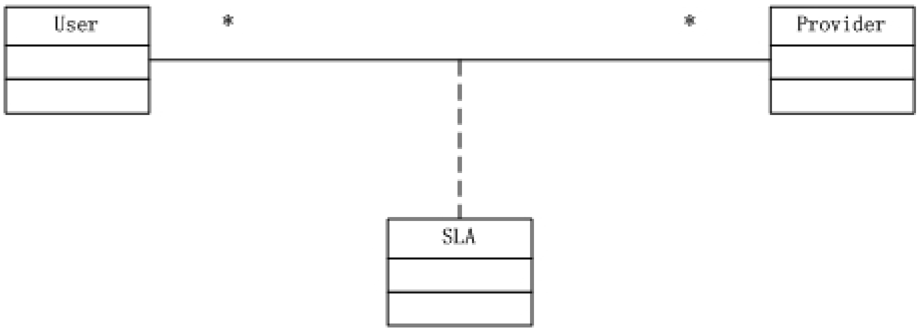

Figure3. 1 UML class diagram of SLA

Class User represents the end user of the service; Class Provider represents the service provider; Association Class SLA represents the Service Level Agreement, which defines the relation between User and Provider. This relation expresses the association between User and Provider, including its properties (e.g. type of service, performance). An association class is a modeling element in UML to model the situation that has both association and class properties. The multiplicity between User and Provider is many to many. It means that providers may have zero to many users, and vise versa.

3.3 Service Level Specification

Service Level Specification (SLS) is an important concept related to SLA. The SLS is the specification that enables the provisioning of the service as was agreed in the SLA. The SLS specifies how to provision and configure the service components to meet those agreed performances of the service defined in the SLA [9]. The SLS is more provider-oriented according to its definition. It is often hidden from the end user. The provider defines specific parameters in SLS to enable the promises made in the SLA.

We also found some other definitions of SLS. We list them as follows:

- The SLA specification is proposed to be comprised of two parts: the administrative/legal part and the SLS part.[10]
- The SLS is the technical way to specify the SLA.[11]
- A SLA can be considered to consist of static and dynamic sections. The SLS is the dynamic part of the SLA between the service provider and the customer. [9]

3.4 Relationship between SLA and SLS

In order to express the relationship between SLA and SLS in the UML class diagram, we first analyze the relationships in UML. Different relationships have different meaning and strength in UML, as shown in Figure 3.2. We adopt the guidelines of [17].

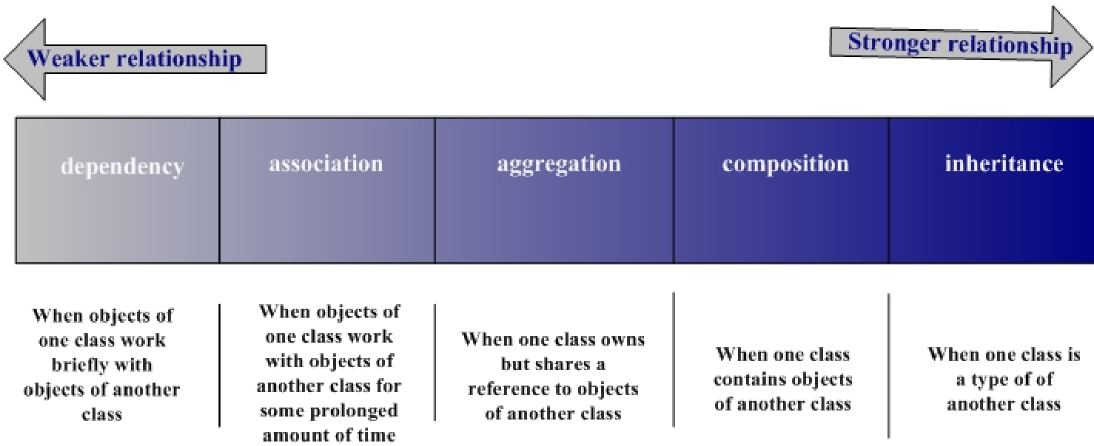

Figure3. 2 relationships strength [17]

The strength of a class relationship is based on how dependent the classes involved in the relationship are on each other.

Dependency

A dependency between two classes declares that a class needs to know about another class to use objects of that class [16]. We use a dependency to model objects of one class work briefly with objects of another class.

Association

An association defines a single type of relationship that can be established between two classes, and enables them to communicate [17]. We use an association to model communications between two or more classes. Although dependency simply allows one class to use objects of another class, association means that a class will actually contain a reference to an object, or objects, of the other class in the form of an attribute. If you find yourself saying that a class works with an object of another class, then the relationship between those classes is a great candidate for association rather than just a dependency [16].

Aggregation

Actually an aggregation is a stronger version of association. It indicates that a class actually owns but may share objects of another class. The classes between an association are peers. Each class remains independent of the other and neither class is superior to the other [17]. They simply communicate. Aggregation, on the other hand, defines a hierarchical relationship. It defines an assembly or configuration of elements to make a larger more complex unit.

Composition

A Composition is used for aggregations where the life span of the member object depends on the life span of the aggregate. The aggregate not only has control over the behavior of the member, but also has control over the creation and destruction of the member. In other words, the member object cannot exist apart from the aggregate. This greater responsibility is why composition is sometimes referred to as strong aggregation [17].

Inheritance

An Inheritance is the process of organizing the properties of a set of objects that share the same purpose. People use this process routinely to organize large amounts of information. Inheritance is used to describe a class that is a type of another class. The different between inheritance and association is "is a" or "has a" relation.

Relationship between SLA and SLS

The relation between SLA and SLS can be specified in different ways according to different definitions of SLS. Here we list some possibilities to express the relation in Table 3.1:

Relation between SLA and SLS	Explanation
SLS is dependent on SLA	SLS specifies the provisioning the service which is agreed in the SLA
SLS is a specialization of SLA	SLS is the technical way to specify the SLA
SLS is an association of SLA	SLS specifies the technical properties of the SLA
SLS is an aggregation of SLA	SLS is as a technical part of SLA, to specify the service.

Table3. 1 relation between SLA and SLS

We map table 3.1 to UML class diagram, as shown in Figure 3.3. SLS can be treated as the specification of enables the service agreed in the SLA. From this point of view, we can use dependency, association or aggregation to relate the SLA and SLS.

Dependency

If only limited parameters in SLA are used in SLS, dependency can be a choice. Otherwise, dependency is too weak to express the relationship between SLA and SLS.

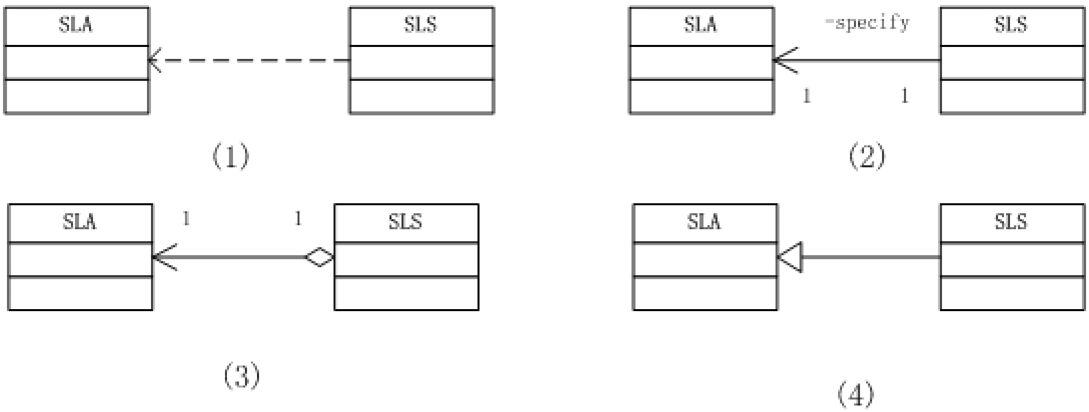

Figure3. 3 Four relationships between SLA and SLS

Association

In our case, SLS needs to know some parameters which have been defined in SLA to configure itself. So association is quite valid in this situation. We can use the name of the association to specify the relationship between two classes. For example, we use the name “specify” between SLS and SLA. Navigability can be used to in our case to avoid SLA access to SLS since SLS is often hidden from users. Then only unidirection is allowed. Multiplicity between SLA and SLS is defined to 1 to 1, and ensure that there is always a SLS to specify a SLA. However the association is also a weak relationship, SLS has to navigate to SLA to get the attributes. If SLA has a complicate structure, it is not so efficient for the navigation.

Aggregation

If we define the relationship between SLA and SLS as shown in Figure 3.3 (3), which means SLS contains SLA. However this will cause a problem. An aggregation is used primarily to define and protect the integrity of a configuration of objects. Aggregation defines a single point of control in one object, the aggregate, which represents the entire configuration. This ensures that no matter what others might want to do to the members of the assembly, the aggregate has the final word on whether the actions are allowed. That means if we need to change some parameters in SLA, we have to change them via SLS [17].

It is important to note that this model of control is a design choice. There is no syntax in UML or any programming languages to enforce this design choice. There is no code construct that prevents a programmer from calling an operation on a member object. The intention of aggregation is to inform the programmer of the designer's intent to work through the designated point of control, the aggregate object [17].

Specification

SLS can also be treated as a technical specification of the SLA. We can use inheritance to relate SLA and SLS. The advantage of inheritance is that SLS inherits all the attributes, relations, and methods automatically from SLA. It avoids the navigations. However at the same time, SLS also inherit many attributes, relationships, operations which are not relevant to SLS.

In our case, we choose association as the relation between SLA and SLS because it is strong enough for our model. Figure 3.4 illustrates it in UML class diagram.

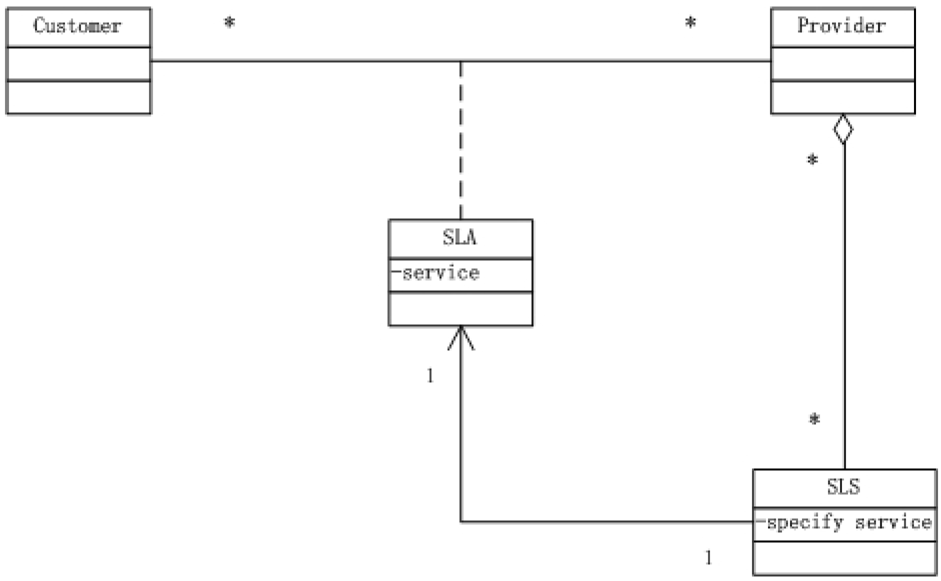

Figure3. 4 Relation between SLA and SLS

In Figure 3.4, The SLS is defined as a part of the provider by an aggregation because the SLS is used by the provider to provision the service that is agreed in SLA and it is hidden to the user.

3.5 SLAs in a distributed application environment

A user-provider relationship described in term of SLA can be established between the user and the different kinds of service providers, such as in M-health monitoring, health care center and PNO or ISP. This section discusses SLAs in a distributed application environment (e.g. M-health monitoring) with two layered of service providers.

3.5.1 SLAs in two layered distributed application environment

In a distributed application environment, there are very often two service providers involved: the provider of the application and the provider of the network connections which support the data transfer between the user and the application provider. So there should be three SLAs to define the relations between them (i.e. the end user, the provider of the application, and the provider of the network connections). Figure 3.5 shows these three SLAs.

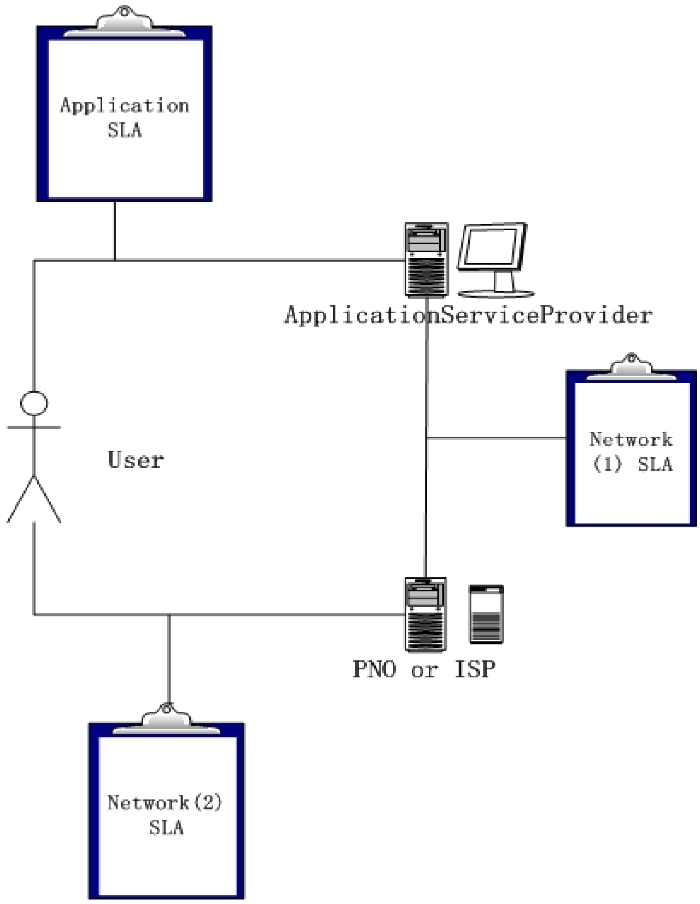

Figure3. 5 M-health monitoring SLA and Internet Service SLA

In practice, one does not need these three SLAs together. For example the Network (2) SLA between the user and the PNO or ISP may not be defined explicitly. The application service provider may reach on behalf of the end user an agreement with PNO or ISP to provide network service to the end user. One of the reason of this choice is that the application service provider has more knowledge about the application and knows the capacity of the network (e.g. from its SLS) to support the data transmit of the application.

3.5.2 Relations between the SLAs

In distributed applications, network services must support the applications to transfer the data between the user and the application provider. That indicates that the specification of the network SLA depends on the application SLA. Figure 3.6 shows the SLAs in UML class diagram.

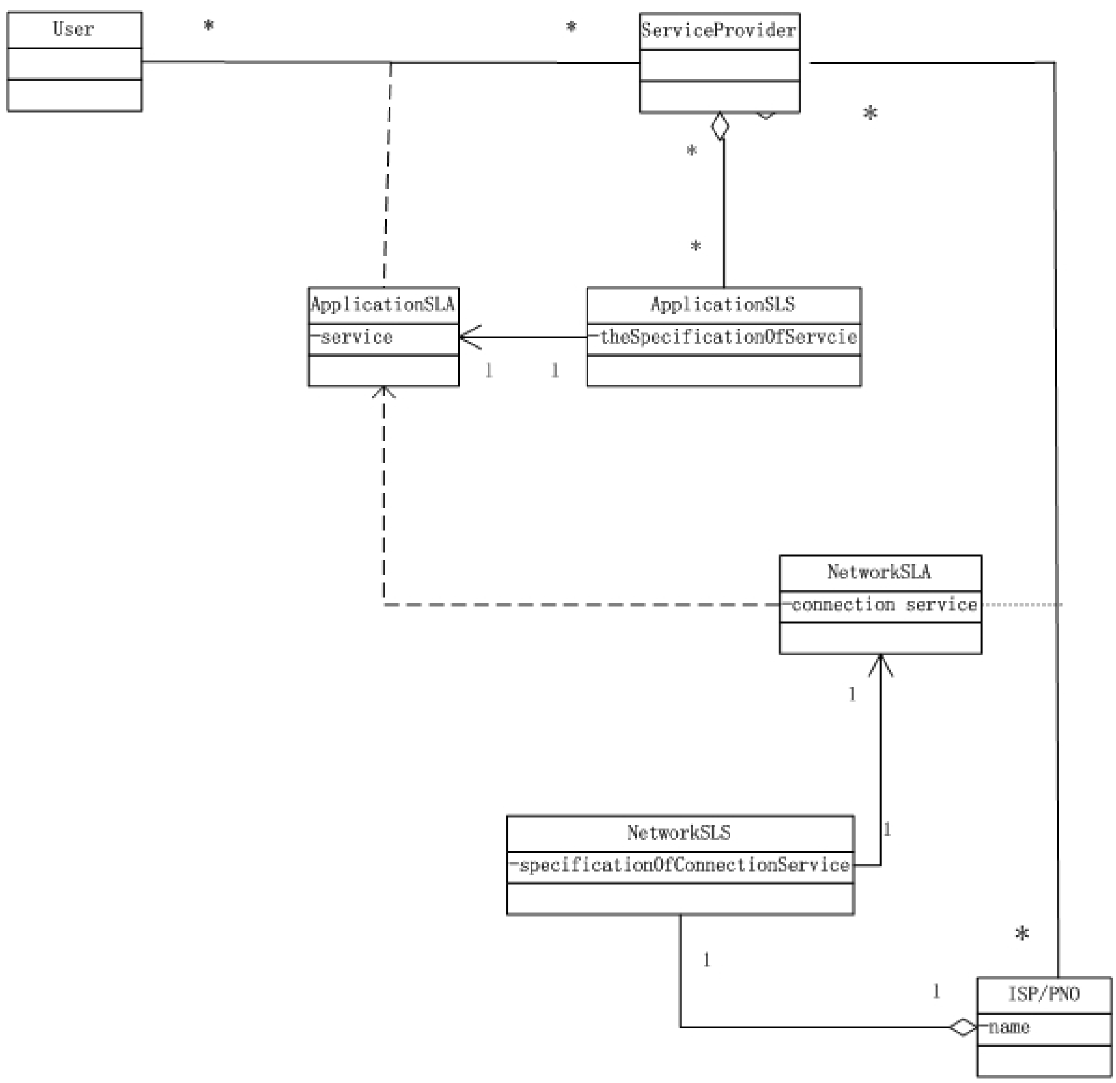

Figure3. 6 Two SLAs and their relations

In Figure 3.6 the NetworkSLA specifies the network service and its quality which is provided by ISP or PNO. In this situation, the role of the Service Provider is treated as a user of the ISP or PNO. The NetworkSLA has to be specified according to the ApplicationSLA to support the service agreed in the ApplicationSLA. In this situation we can use both dependency and association to model the relationship between the two SLAs.

The NetworkSLA is an agreement between the Service Provider and ISP or PNO, it is should not be affected by other party (the user). From the agreement point of view, an agreement should be known by both sides, but now it is not fair for ISP or PNO. However we can not avoid this relationship and ISP or PNO must agree and support the application service because this is the way to ensure the application service. To minimize this effect, we use dependency, a weaker relationship, to relate the two SLAs.

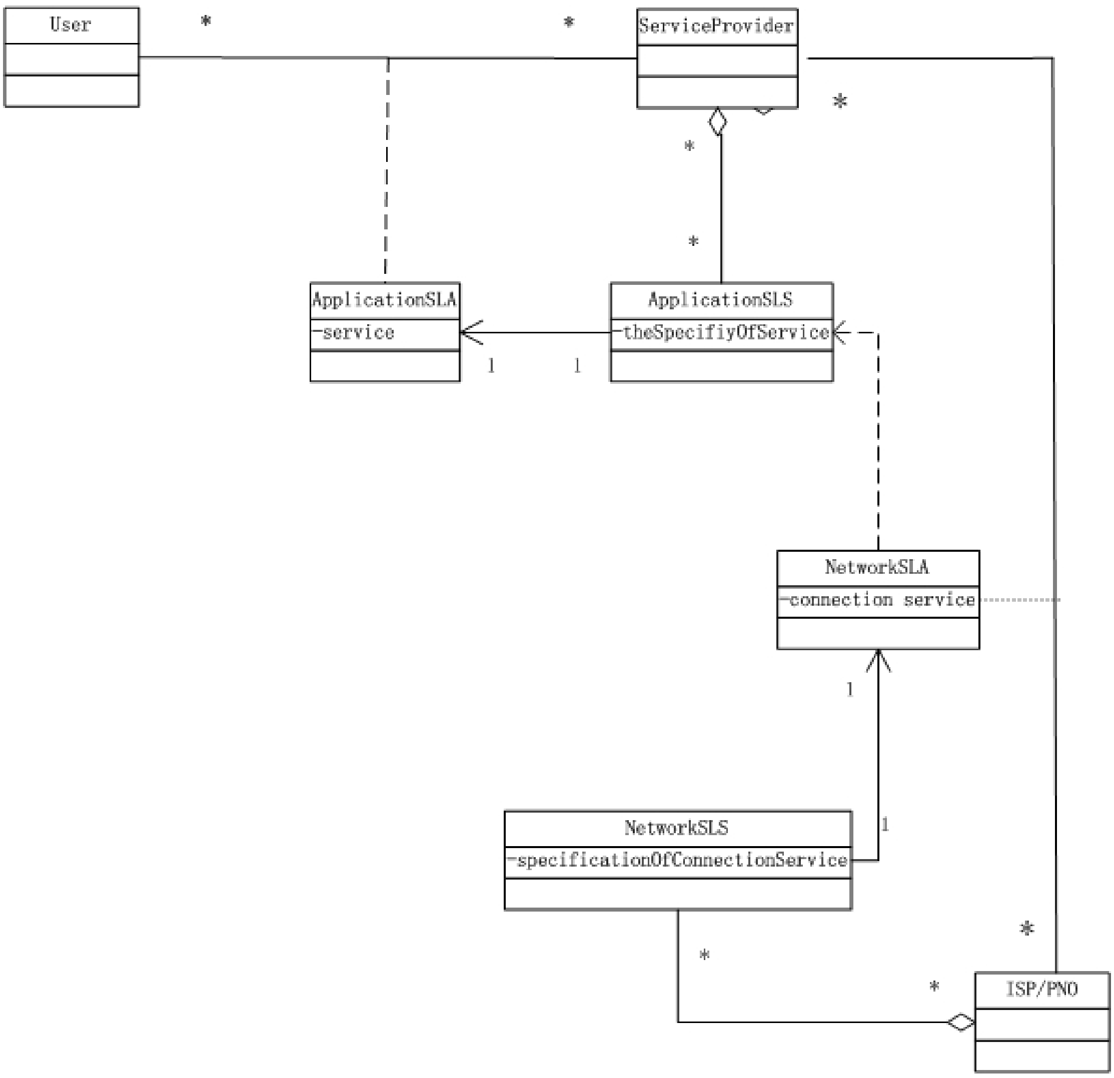

Figure3. 7 An alternative relation between SLAs

However the model in Figure 3.6 has a disadvantage: the NetworkSLA repeat some work of

ApplicationSLS. For example the ApplicationSLS uses the attributes of the ApplicationSLA for the configuration to provision the service that is agreed in the ApplicationSLA. The NetworkSLA uses the attributes of the ApplicationSLA to support the service agreed in the ApplicationSLA as well. In this case, the NetworkSLA can use the result of the Application SLS directly instead of the ApplicationSLA. Figure 3.7 shows an alternative model to avoid this problem.

The model in Figure 3.7 defines that the network SLA depends on the application SLS. On the other hand Figure 3.7 also more or less solves the unfair problem of NetworkSLA because ApplicationSLS is a part of ServiceProvider.

Chapter4 M-Health Monitoring Service Agreement Model

This chapter elaborates the service agreement model we have discussed in Chapter 3 (Figure 3.5) towards our M-health problem domain. In M-health the model captures the relations between the three stakeholders (i.e. patient, health care center, and PNO or ISP), determines the wireless network service and its capacity to support M-health monitoring service, and shares the vital signs for a patient enrolled several care programs in one health care center.

The concepts SLA and SLS described in Chapter 3 are used in the model to define the relations between three stakeholders. As was mentioned in Chapter 2, we focus on the M-health monitoring service and the capacity of wireless communication links to support the monitoring service.

As we discussed in Chapter 2, the M-health monitoring service is structured in two phases: subscription phase and operational phase. The subscription phase focuses on the specification of the M-health monitoring service, such as the care programs, vital signs and their quality specifications. According to the specification, the corresponding wireless network capacity is subscribed to support the vital signs transfer. The operational phase focuses on the application of the M-health monitoring service which has specified in the subscription phase, such as real usage of the wireless network capacity to transfer the measured vital signs. This chapter is structured in accordance with these two phases: Section 4.1 presents the service agreement model in a subscription phase; Section 4.2 presents the model in an operational phase.

4.1 Subscription phase

Subscription phase is the stage that patients subscribe an M-health monitoring service provided by a health care center. This phase specifies the M-health monitoring service which includes health care programs, vital signs to be monitored, and quality specifications of the vital signs; the subscription phase also specifies wireless network services which are capable to transmit the measured vital signs. So we have two SLAs to specify these two services respectively: an M-health SLA and a Network service SLA.

The M-health SLA constraints the M-health monitoring services, and the quality of services which are provided to patients, such as health care programs and the expected the composition and quality of vital signs for monitoring. According to the M-health SLA, the health care center configures its SLS to specify the SLA (e.g. the required bandwidth to support vital signs transfer).

The Network service SLA constraints the network services which are provided by a PNO/ISP, as well as the capacity to support the M-health monitoring (e.g. real time transfer of vital signs). According to the Network service SLA the PNO/ISP configures its Network SLS to provision the service which is stated in the Network service SLA.

As we discussed in Chapter 3, the health care center on behalf of patients signs the Network service SLA with the PNO/ISP to provide network services to patients. So we don't have a third SLA between the patient and the PNO/ISP in the model.

4.1.1 One care program model

This section discusses the model which only one care program can be chosen. Figure 4.1 shows the UML model.

The main structure of the model shown in Figure 4.1 came from the model shown in Figure 3.7. In the following sub-sections, we will explain the classes, attributes, methods and motivation of the design.

4.1.1.1 M-health SLA and M-health SLS

This subsection mainly discusses the classes and their attributes, operations which are related to M-health SLA and M-health SLS in Figure 4.1.

Class M-healthSLA in Figure4.1 references the M-health SLA of the M-health monitoring service. As we discussed before, the M-health SLA constraints the M-health monitoring service (i.e. care programs, vital signs to be monitored, and their qualities). Considered their functionalities, we arrange them as classes (i.e. class CareProgram,) with composition relationship to class M-healthSLA. For example class CareProgram represents a conceptual entity which has its own properties (i.e. name, vital signs), which don't directly belong to an SLA.

Class CareProgram in Figure4.1 references the care program of the M-health monitoring service. Class CareProgram contains three attributes:

- ***name***: This attribute give the name of a care program. It is defined as a String type, and is an identifier of a care program.
- ***vsSet***: Attribute vsSet refers to the vital sign set which contains all names of the required vital signs for the care program. It is modeled as a String array in the model. An alternative is to use enumeration data type to model vital sign set, but considers

that JAVA is used as the implementation language later, and this dta type is n ot appropriate because not all JAVA version support enumeration data type.

- ***careLevel***: Attribute careLevel refers to the level of the care program. It is defined as a parameter to specify the availability of the monitoring service. Actually there are many factors which affect the availability of the monitoring service. For simplicity, we only use this parameter to specify the availability. Here we classify the care program level into three levels: HIGH, MEDIUM, and LOW. HIGH care level requires high availability of service, and vice versa.

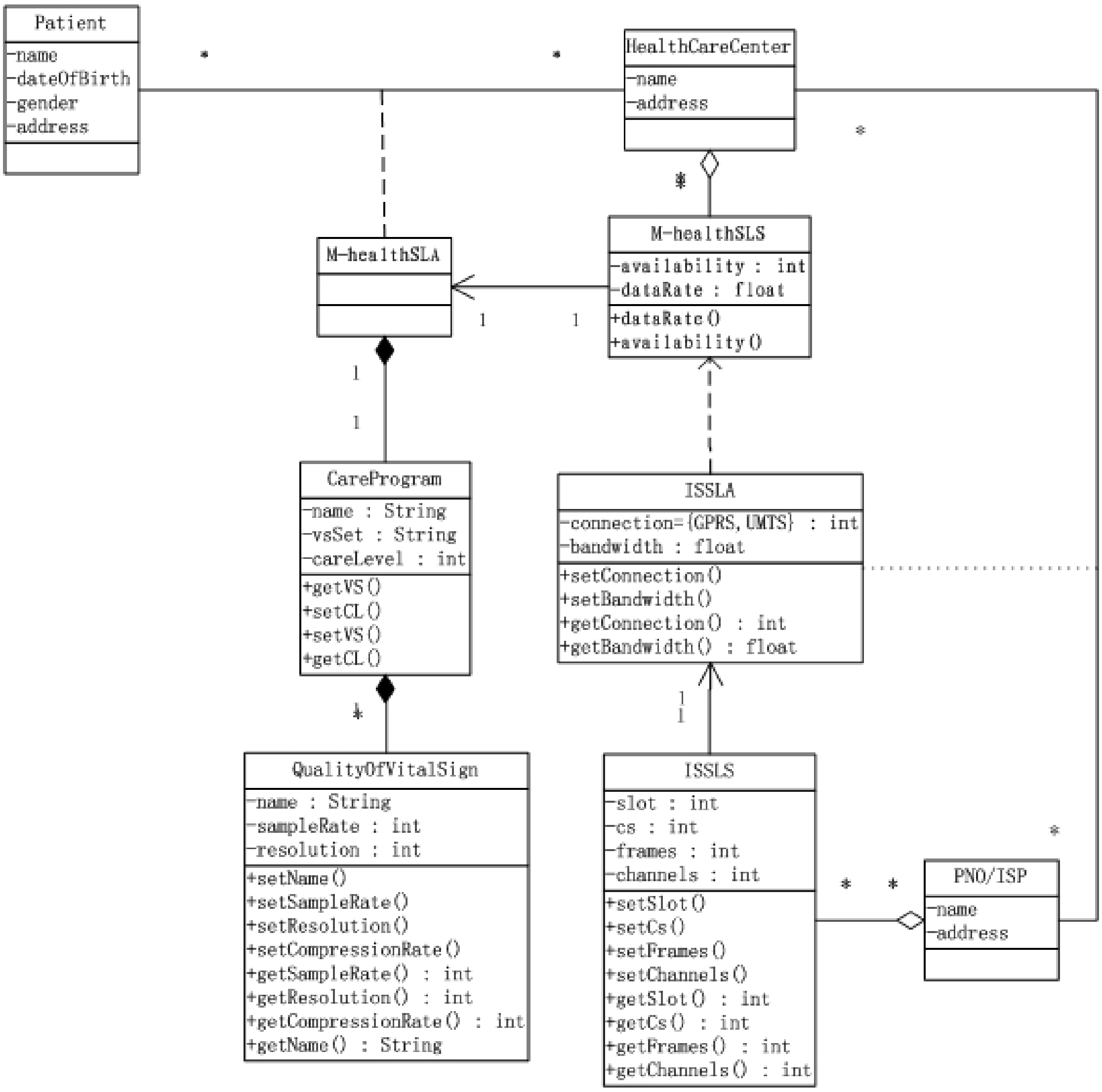

Figure4. 1 a patient subscribed one care program

Here we only define these three attributes of class CareProgram because these attributes are enough for our research work.

Beside the three attributes, Class CareProgram contains four methods to operate these attributes:

- ***getVS()***: Method getVS() reads the names of vital signs from the vital sign set. It returns vital signs' names.
- ***setVS()***: Method setVS() sets the name of vital signs to the vital sign set.
- ***getCL()***: Method getCL() is to get the care program level.
- ***setCL()***: Method setCL() is to set the care program level.

Here we don't discuss the responsibility to create the objects of the classes; we will discuss this in Chapter 5.

Class QualityOfVitalSign in the model references the quality specification parameters of the vital signs in the M-health monitoring service (i.e. sample rate, resolution).

According to the scenario analysis in Chapter 2, following attributes are contained in class QualityOfVitalSign:

- name: this attribute defines the name of the vital signs, and identifies the vital signs and their quality parameters. The name is determined by the vital sign names defined in vsSet of class CareProgram.
- sampleRate: it defines the sample rate of a vital sign.
- resolution: it defines the number of bits per sample of a vital sign.

Class QualityOfVitalSign contains six methods, all these methods are related to read (operation name prefixed by "get") and write (operation name prefixed by "set") the attributes of class QualityOfVitalSign.

- setName()
- setSamepleRate()
- setResolution()
- getName()
- getSampelRate()
- getResolution()

Class M-healthSLS in the model references the M-healthSLS in the M-health monitoring service. As we discussed in Chapter 3, SLS is a specification that enables the provisioning of the service agreed in the SLA. In the M-health environment, M-healthSLS specifies how to provision the service to meet those agreed performances of the service defined in the M-healthSLA (i.e. data rate generated from the sensors, availability of the service).

Class M-healthSLS contains two attributes:

- dataRate: it represents the data rate that will be generated from the sensors, which determines the bandwidth requirement of the M-health monitoring to support real time transfer of vital signs
- availability: it represents the availability of the monitoring service, as we discussed before, this attribute is determined by the attribute careLevel of class CareProgram.

Here we only specify two properties of M-health SLS, a SLS may contain other attributes for example, reliability of the service, but in this thesis, we only consider these two in our research.

4.1.1.2 Internet SLA and SLS

This section describes the ISSLA (Internet Service SLA) and ISSLS (Internet Service SLS). The ISSLA and ISSLS mainly specify the network service and its capacity that is capable to transfer the vital signs.

Class ISSLA in the model references the Internet service SLA in the subscription phase. As we discussed in Chapter 3, the health care center subscribes the Internet service with PNO/ISP on behalf of patients. The ISSLA describes what kind of wireless communication links is subscribed and the capacity. According to this, Class ISSLA contains two attributes:

- connection: it defines what kind of wireless communication links are subscribed (i.e. GPRS, UMTS)
- bandwidth: the bandwidth of the wireless communication links

Class ISSLA contains following methods:

- setConnection(): according to the bandwidth requirement in M-healthSLS, it sets the corresponding wireless communication services.
- getConnection(): get the connection type.
- setBandwidth(): it sets the bandwidth of the wireless communication services.
- getBandwidth(): get the bandwidth.

As we discussed in Chapter3, the relationship between ISSLA and M-healthSLS is defined as dependency. According to the data rate and availability requirement in subscription phase M-health SLS, GPRS, UMTS is subscribed accordingly. For example, if the data rate in M-healthSLS is 48kbs, GPRS can be chosen for data transferring (Here we didn't consider the overhead of the protocol and data compression).

Class Internet Service SLS (ISSLS) in model references the Internet Service SLS in the M-health monitoring service. It specifies how to provisioning of this GPRS or UMTS service, for example determines how many slots and what coding scheme if GPRS is used, or the number of Frames, Channels if UMTS is used. So Class ISSLS may contain following attributes:

- slot: it represents the number of the slot of the GPRS or UMTS
- cs: it represents what is the coding scheme the GPRS uses
- frames: it represents the number of the frames of the UMTS
- channels: it represents the number of the channels of the UMTS

It may contain other attributes to configure GPRS or UMTS networks, but this is beyond this thesis. So we only list these two as examples.

Class ISSLS contains following methods:

- setSlot()
- setCs()
- getSlot()
- getCs()
- setFrames()
- getFrames()
- setChannels()
- getChannels()

All these methods are used to set or get the parameters that are defined in class ISSLS. For example, like we discussed earlier, if 48kbs is the required bandwidth, and GPRS is chosen to transfer the data, the ISP/PNO may use CS2 and 4 time slots according to Appendix A.3. (Since generally GPRS network operators use CS1 and CS2 coding schemes, so we didn't consider CS3 and CS4 in this situation, but theoretically, CS3, 4 time slots or CS4 3 time slots are also possible choices.) So ISP/PNO can configure its wireless network accordingly. In this thesis we didn't cover other wireless technologies, such as WIFI, WIMAX.

4.1.2 A patient enrolled several care programs

However Figure 4.1 model doesn't solve the research problem that avoids separate measurement sessions of vital signs if a patient enrolled in several health care programs in a health care center. In order to solve the research problem, we extend class M-healthSLA in the model of Figure 4.1 and show specific health care programs explicitly.

4.1.2.1 Multiple of care programs

For multiple care programs, we have two alternative models as follows:

Alternative model A

Figure 4.2 shows extended class M-healthSLA. Here we define two classes that represent two specific care programs:

- **CardioCare**
- **RehabilitationCare**

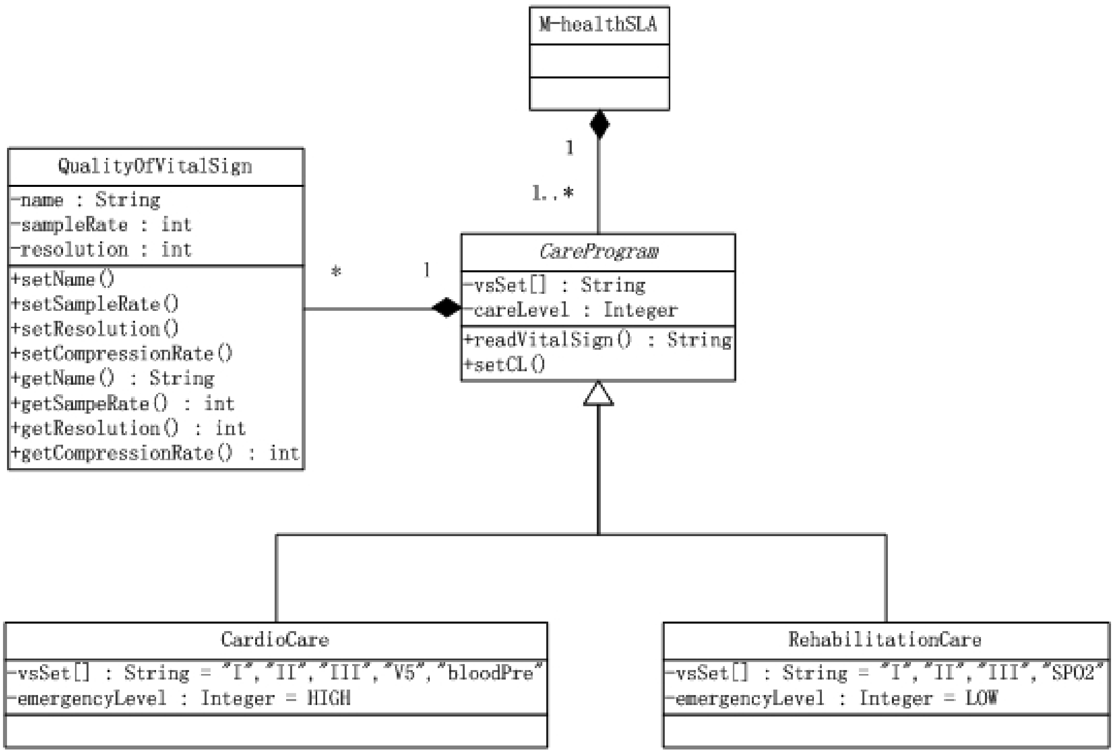

Figure4. 2 a model which a patient enrolled in two care programs

In this model, Class CardioCare and RehabilitationCare represent cardio care service and outdoor rehabilitation care service respectively. In this way, we extend the class CareProgram. Class *CareProgram* is defined as an abstract class. It represents an abstract concept of care program as a part of M-health SLA. Class CardioCare and RehabilitationCare inherit the attributes and methods from class *CareProgram*. Two specific classes are illustrated in the model and each one may define its own vital sign set which contains the monitored vital signs. For example, in Chapter 2 we have discussed that cardio care defines five vital signs (ECG I, II, III, V5, blood pressure) as default value of monitored vital signs, so the model in Figure 4.2 defines these vital signs as contents of vital sign set (vsSet). EmergencyLevel can be defined according to the physical situation of the patient by the health care specialist.

Alternative model B

Figure 4.3 illustrates an alternative model of a patient enrolls two care programs.

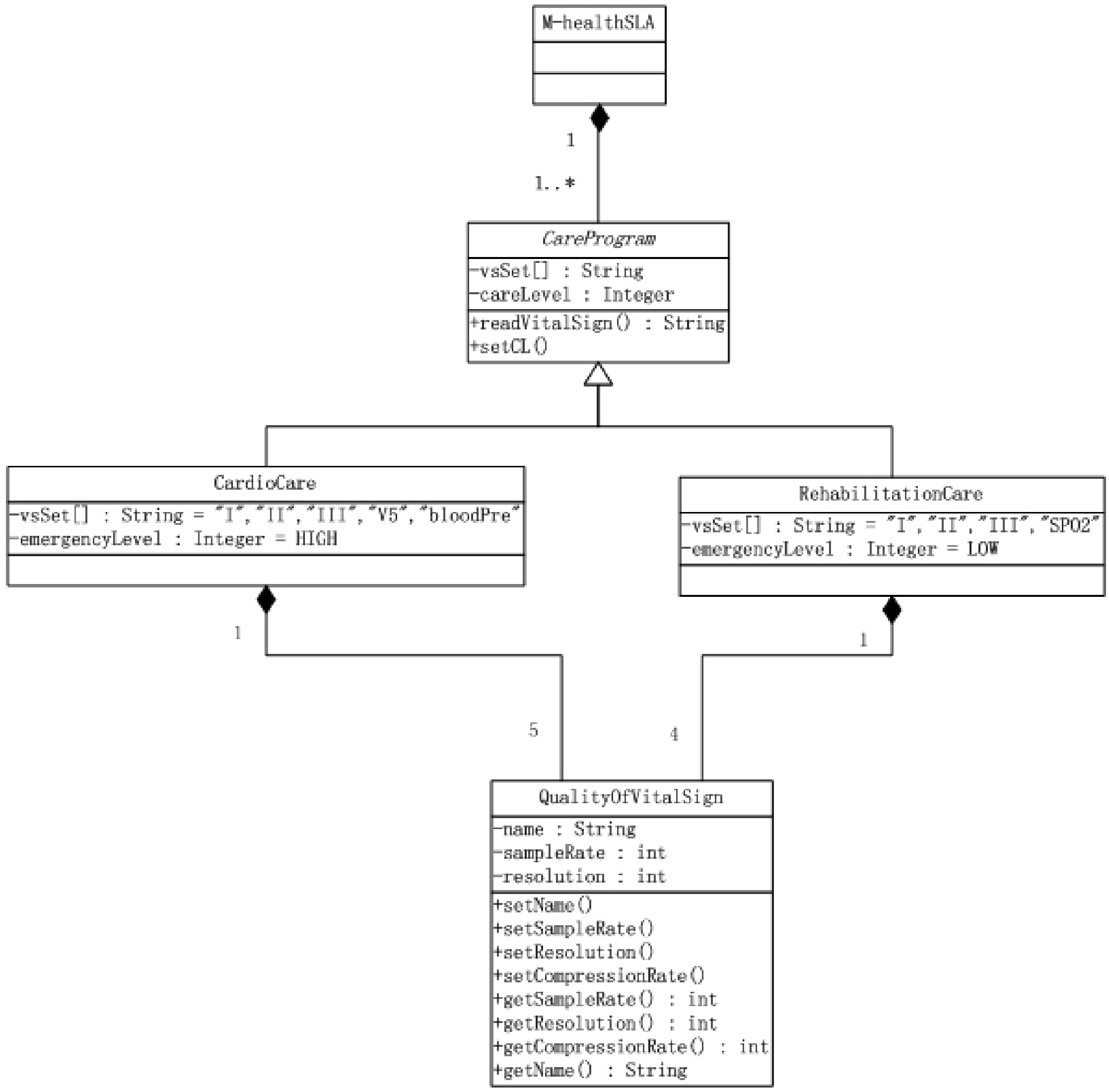

Figure4. 3 an alternative model of a patient enrolls two care programs

This model moves the class QualityOfVitalSign down to the class CardioCare and RehabilitationCare. The advantage of this model is that the multiplicities between class CardioCare, RehabilitationCare and QualityOfVitalSign can be determined by the number of the initial value of the vital sign set explicitly. For example, the one to five multiplicity between class CardioCare and QualityOfVitalSign represents each vital sign in the vital sign set has its quality parameters. The disadvantage of the model is that if there are many care programs, it will be too many relationships between specific care program and class QualityOfVitalSign.

The model shown in Figure 4.2 is that avoids the multi relationships between the specific care programs and the class QualityOfVitalSign. The specific care programs (e.g. Class CardioCare, RehabilitationCare) inherit this relation from class *CareProgram* directly. However this model is that the model can not show the exactly number of instances of class QualityOfVitalSign. This can be solved, for example by adding a “Note” on the relation.

4.1.2.2 Measured vital signs

We have discussed how to explicitly show the specific care programs in the model in the previous two sub-sections. However in Figure 4.2 some vital signs have to be measured twice if a patient subscribed these two care programs at the same time, such as ECG lead I, II, and III. Like we discussed in Chapter 1, two separate measurement sessions are not efficient, even not convenient in case of continuous 24 hours monitoring.

The main idea of solving this problem is as follow:

- The vital sign set in class *CareProgram* only represents the vital sign set that are required for the care program, and doesn't represent the vital sign set that will be measured anymore. Here we have to distinguish two concepts: vital signs to be measured by the acquisition system and required vital signs by the care program. Figure 4.4 explains the two concepts:

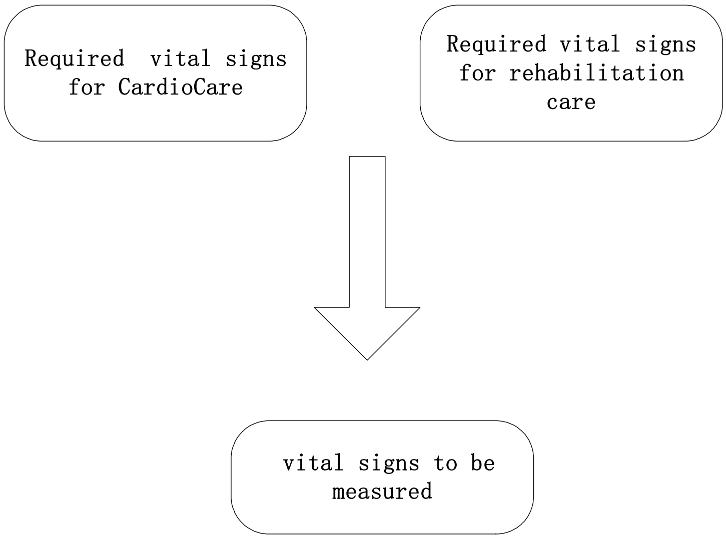

Figure4. 4 required vital signs and vital signs to be measured

Vital signs to be measured are the vital signs that will be collected from patients. It also can be seen as the sensor set. These vital signs come from required vital signs by the care programs. The vital signs to be measured combine the required vital signs by the care programs and select the non-redundant union vital signs from them.

Figure 4.5 shows the model to share vital signs.

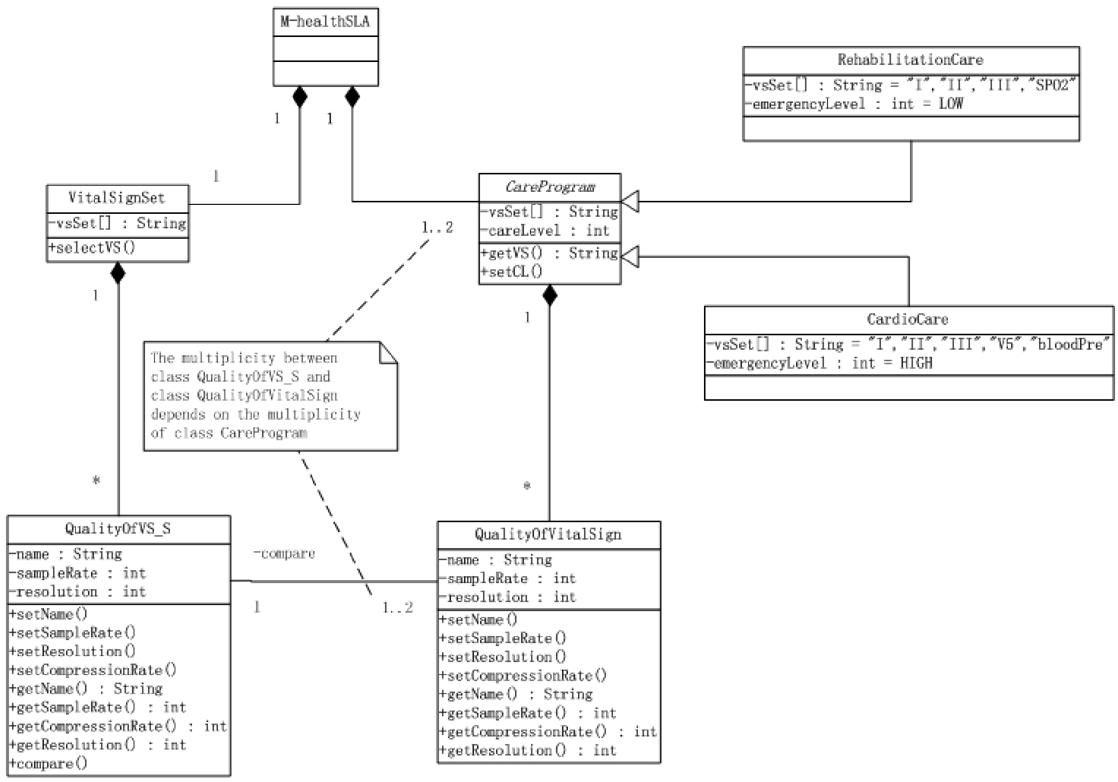

Figure4. 5 share vital signs

VitalSignSet

We define a new class **VitalSignSet** which references the set of vital signs to be measured. As we discussed before, the set of vital signs to be measured can be treated as the sensor set. The patient must know what sensor set he gets, and how to set these sensors. All these must be stated in M-healath SLA. So in this thesis we define the class VitalSignSet as a part of class M-healthSLA.

Class VitalSignSet contains the vital sign set that will be measured, quality of each vital sign in this set also needs to be defined (e.g. Front-end setting according to these parameters). So we define a class called QualityOfVS_S, which references the quality of vital signs to be measured. We have two classes which are related to quality of vital signs. The class QualityOfVitalSign can be treated as the care program-oriented quality specification of the vital signs. The class QualityOfVS_S can be treated as the acquisition-oriented quality specification of the vital signs.

Association

We define an association between class QualityOfVS_S and class QualityOfVitalSign. This association makes a short cut of setting acquisition-oriented quality parameters of vital signs according to the values of care program-oriented quality parameters of vital signs. Otherwise, the class QualityOfVS has to navigate to class QualityOfVitalSign via M-healthSLA. The multiplicity between class QualityOfVS_S and class QualityOfVitalSign depends on the mulitiplicity of class CareProgram. For example, if there are two objects of class CareProgram are instantiated, the multiplicity between class QualtiyOfVS_S and class QualityOfVitalSign is 1 to 2. That means two quality parameters of a vital sign from two care programs are compared and the most network resources demanding one is stored in one object of class QualityOfVS_S.

Attributes and Methods

Class VitalSignSet contains one attribute *vsSet* that references the set of vital signs to be meausred, which contains all vital signs required by all care programs and will be collected from the patient who enrolled in these care programs. This class provides the solution that avoids separate vital sign measurement sessions for each care program and shares some vital signs to be measured. Method *selectVS()* compares all the vital signs of care programs and determines a vital sign set which will be measured.

Class QualityOfVS_S has the same attributes and methods as class QualityOfVitalSign, except method compare(), which is used to compare the quality parameters of the two care programs and return the maximum values of the parameters. An alternative of the design is using an association class between class QualityOfVS_S and class QualityOfVitalSign to fulfill the function of the method compare(), but considered that the function of the compare the quality parameters can be treated as a responsibility of class QualityOfVS_S, so we still use a direct association.

Motivation

This design separates the model into two parts: specification of care program (including class Careprogram, QualityOfVitalSign) and vital signs to be measured (including class VitalSignset, QualityOfVS_S). Specification of care program part is for health care professionals to specify the monitoring service according to the medical demands, such as vital signs and their quality parameters. Vital signs to be measured part represent the sensor set, which collect vital signs from patient, and its quality parameters. Vital signs to be measured must satisfy all the care program specifications. The health care center can get all the information for vital sign data rate from the vital signs to be measured part. In a later stage, if new care programs have to be added, we don’t need to change the other parts of the model.

4.2 Operational phase

Operational phase is the stage after the customer subscribed M-health monitoring service. It is a usage stage of the M-health monitoring service which is provided by the health care center.

4.2.1 Operational phase model vs. Subscription phase model

The operational phase calculates the real capacity need of wireless communication links to enable the transmission of the measured vital signs over these wireless communication links.

In the operational phase health care professionals may adjust the composition and quality of vital signs according to the physical conditions of the patient, such as the removal of some vital signs, which are not necessary, or the decrease of the sample rate of continuous time vital signs. So real usage of the capacity of wireless communication links is not always equals to the capacity that is subscribed. However the operational capacity of the wireless links should be less than the capacity subscribed.

Operational phase model can be extended from subscription phase. The reasons are the following:

- Subscription phase calculates the maximum capacity demands on the wireless links to enable transmission of the vital signs to be measured. Operational phase calculates the required capacity according to the measured vital signs and their qualities (real situations), which are considered sufficient for the patient condition. From this point of view, both models have the same functions to calculate the capacity, so all the classes and relations that relate with capacity calculation of the subscription phase can be reused in the operational phase.

- Operational phase also has the situation that a patient is enrolled in more than one care program. Selecting measured vital signs are also needed in the operational phase. So this part also should be contained in operational phase.

However operational phase contains more than these. It also contains:

- The vital sign data

Operational phase contains the data; this implies the inclusion of data collection, transfer and store in the operational phase. Although according to the definition of SLA and SLS, the data is not part of them, the data still shows up in the model. The reason is that the data may give a broader view of the model.

- New classes

Although the operational phase is an extension of the subscription phase, it only uses the structure of the model. All the classes are different. Some classes have the same attributes and methods, but the meaning of the classes are changed. Some classes also contain new methods, such as health care professionals will add or delete vital signs according to the situation of the patient. These operations are not provided in the subscription phase.

4.2.2 Operational phase model

Figure 4.6 illustrates the operational phase model.

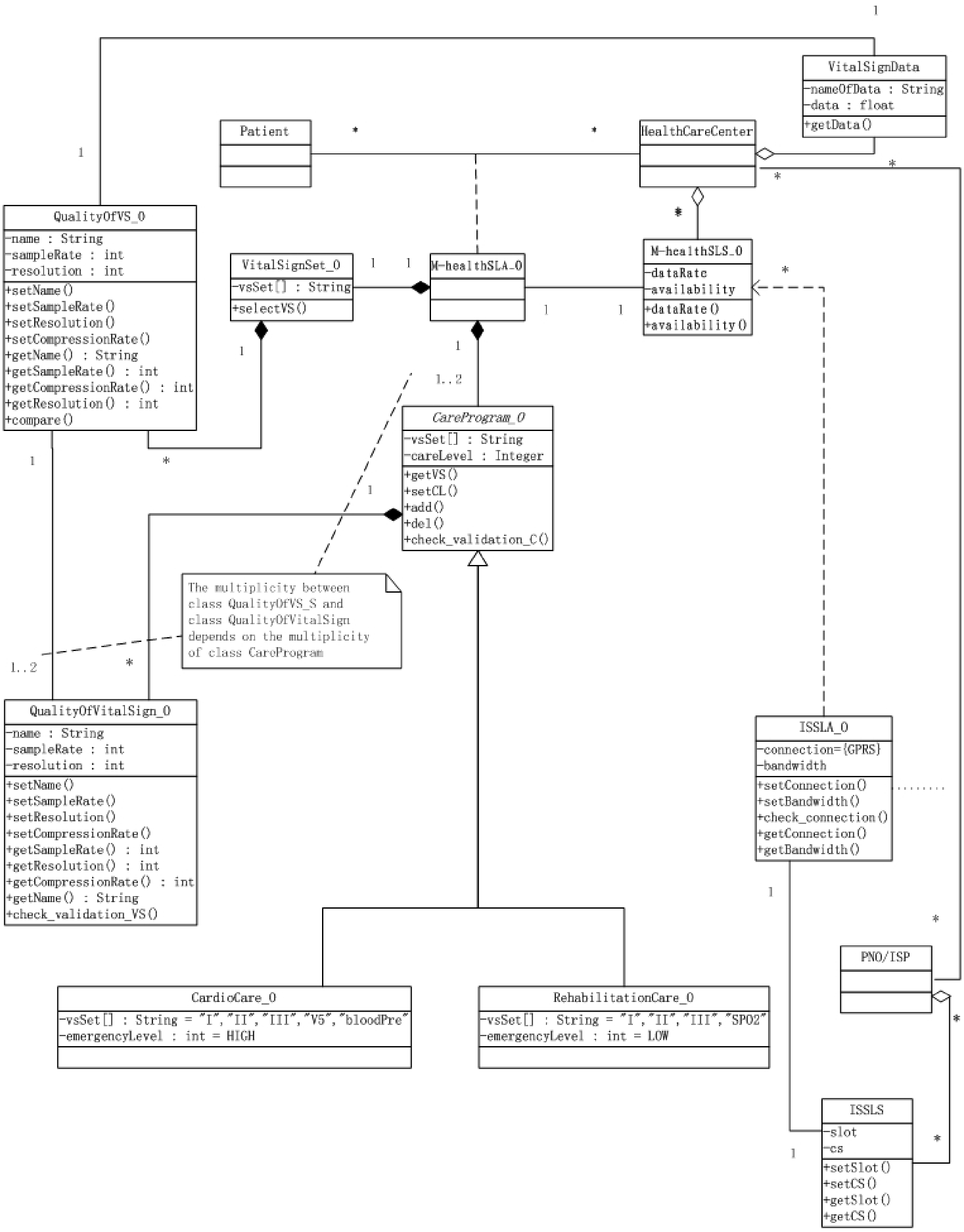

Figure4. 6 Operational phase model

A new class **VitalSignData** is defined to model the data in operational phase. Normally data is stored in the M-health care center. So we define it as a part of class HealthCareCenter. Class VitalSignData contains two attributes and two methods:

- Attributes
  nameOfVitalSign : the name of the vital sign
  data: stores the data
- Method
  getData() : to read the data
  setData(): to set the data

However different vital signs have different formats of data, such as blood pressure has two values: Systolic and Diastolic. Specified classes are defined to solve the problem. So we can define specific classes for these vital signs. Figure 4.7 shows the specified classes.

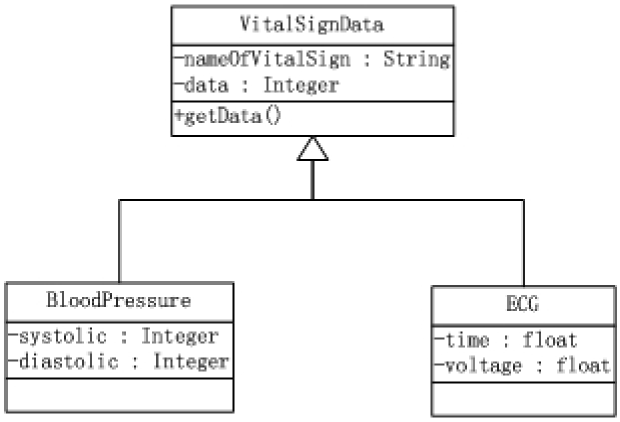

Figure4. 7 specified classes of vital sign data

Class **BloodPressure** has two attributes: *systolic* and *diastolic*. They represent the top number and bottom number of blood pressure respectively. ECG is presented in two dimensions wave: *time (ms)* and *voltage (mV)*, so these two are as attributes of class **ECG**. Actually data may contain more attributes than these, but that is beyond this thesis for data fetching, transfer, store.

The association between class VitalSignData and class QualityOfVS_O relates the vital sign data with its quality parameters.

From Figure 4.6, we see two new methods are defined in class ***CareProgram***: *add()* and *del()*.These two methods are used to add or delete vital signs according to the situation of the patient.

Class QualityOfVitalSign_O references the requirement of the quality parameters of vital signs in operational phase model (i.e. the demands of the health care professional) instead of the specification of the quality parameters in subscription model. Although they have the same attributes, they have different meanings. However the attributes defined in class QualityOfVitalSign_O must satisfy those that are defined in class QualityOfVitalSign in subscription phase. So we have a new method check_validat_VS() to check if the quality parameters in operational phase conform with those defined in subscription phase.

Class QualityOfVS_O references the settings of the sensors, in other words, it specifies the qualities of the measured vital signs. All these quality parameters determine the vital sign data rate. Actually it has the same function as it is in subscription phase, but the meaning is different.

Class *CareProgm_O* references the care programs in the operational phase, it also contains a new method check_validation_C() to check if the vital signs in the operational phase conform with those in the subscription phase.

ISSLA and ISSLS

In the model of Figure 4.6, we suppose that GPRS is subscribed as the wireless Internet service and maximum bandwidth requirement is 48kbs. According to the vital signs which will be transferred, the corresponding bandwidth is allocated (e.g. time slots or CS is allocated if GPRS is used). For example, if only 32kbs are needed in a certain period, ISP/PNO can use CS1, 4 time slots or CS2, 3 time slots according to the situation. If the channel is quite busy, the network may use CS1 to ensure higher reliability. However maximum bandwidth usage can not exceed the value which subscribed in the subscription phase, in this case it is 48kbs. So the method check_connection() in class ISSLA_O has the function to check if the bandwidth requirement exceed or not. Actually this may not happen in this model because it has functions to check the validation of vital signs and quality parameters in M-healthSLA. However Since ISP/PNO and health care center are different providers, ISP/PNO must also check the validation by itself.

4.3 Relationship between operational phase and subscription phase

From the definition of the subscription phase and the operational phase, it is not difficult to obtain the conclusion that the operational phase must comply with the specification in the subscription phase. We can interpret this kind of relationship as a dependency. We show this relationship in Figure 4.8.

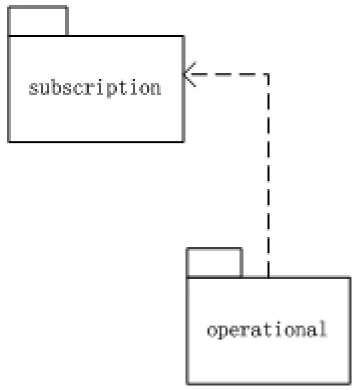

Figure4. 8 Relationship between subscription phase and operational phase

The package subscription represents the subscription phase; the package operational represents the operational phase. The relationship between these two packages is dependency.

- We can interpret this relationship at class level. Figure 4.9 shows the class diagram.

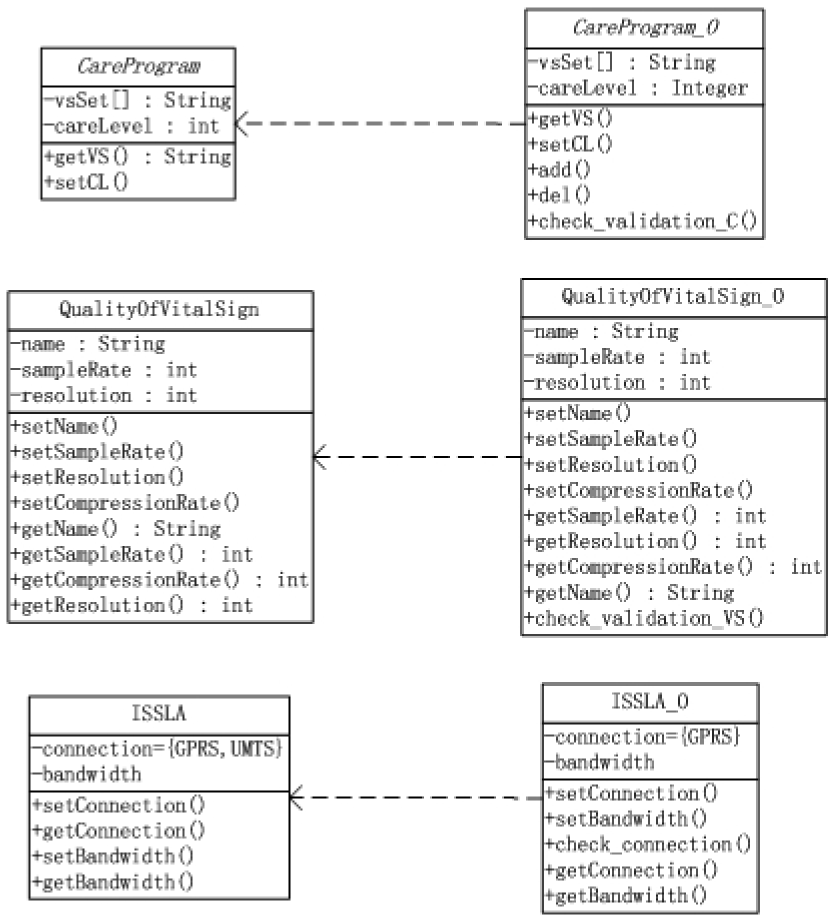

Figure4. 9 dependencies at class level

As long as subscription phase M-healthSLA is determined, operational phase M-healthSLA must comply with the contents which are stated in subscription phase M-healthSLA. This conformability consists two parts in the model:

- The vital signs which are required by the health care professional for a certain care program in the operational phase can not exceed the initial vital signs which have been defined in the subscription phase. For example, the initial vital signs for cardio care are defined as ECG I, II, III, V5 and blood pressure in the subscription phase, it is not allowed for the health care professional to have more vital signs than these. This is shown in Figure 4.9 the relationship between class *CareProgram* and class *CareProgram_O*

- The qualities of the vital signs which are required by the health care professional in the operational phase must comply with those which have been specified in the subscription phase. This is shown in Figure 4.9 the relationship between class QualityOfVitalSign and class QualityOfVitalSign_O.

- The last relationship shown in Figure 4.9 is the relationship between subscription phase ISSLA and operational phase ISSLA_O of ISP/PNO. As we discussed before, the bandwidth in operational phase can not exceed the subscribed bandwidth in subscription phase.

If we keep first two in the operational phase conformed to the subscription phase, the vital sign data rate will not exceed the maximum value defined in the subscription, and then it keeps the bandwidth usage lower than subscribed.

Chapter 5 Behavior of the M-health model

In Chapter 4, we discussed class diagram of M-health monitoring. However the class diagram is static. It only shows the relationships between the classes we have defined. The entire description of the classes and their relationships with each other is static. By reading this class diagram model, we can not ascertain any behavioral aspect of the M-health monitoring model. In this chapter we use sequence diagram to show the interactions among the collaborating objects. Then we can understand the M-health monitoring model in a dynamic way. We show the behavior of the model in the following sections according to some scenarios: Section 5.1 a patient only enrolls cardio care program; Section 5.2 a patient enrolls two care programs: cardio care and rehabilitation care. The most presented behavior diagrams are valid for the subscription phase as well as the operational phase. The diagrams which are only valid for either a subscription phase or an operational phase is explicitly indicated.

5.1 Behavior of the M-health model for a patient enrolls cardio care program

This section mainly discusses what objects will be created when a patient only enrolls the cardio care program, and the interactions between these objects. This section also discusses the responsibility of classes to create objects.

5.1.1 Initialization

We show a sequence diagram in Figure 5.1 of the initialization of the model when a patient enrolls the cardio care program. In the initialization, the objects of the classes are created, and initial values of the objects are assigned as well. The created objects are listed as follow:

- mSLA:M-healthSLA
- heart:CardioCare
- q1:QualityOfVitalSign
- q2:QualityOfVitalSign
- q3:QualityOfVitalSign
- q4:QualityOfVitalSign
- q5:QualityOfVitalSign
- vsSet:VitalSignSet

- mSLS:M-healthSLS

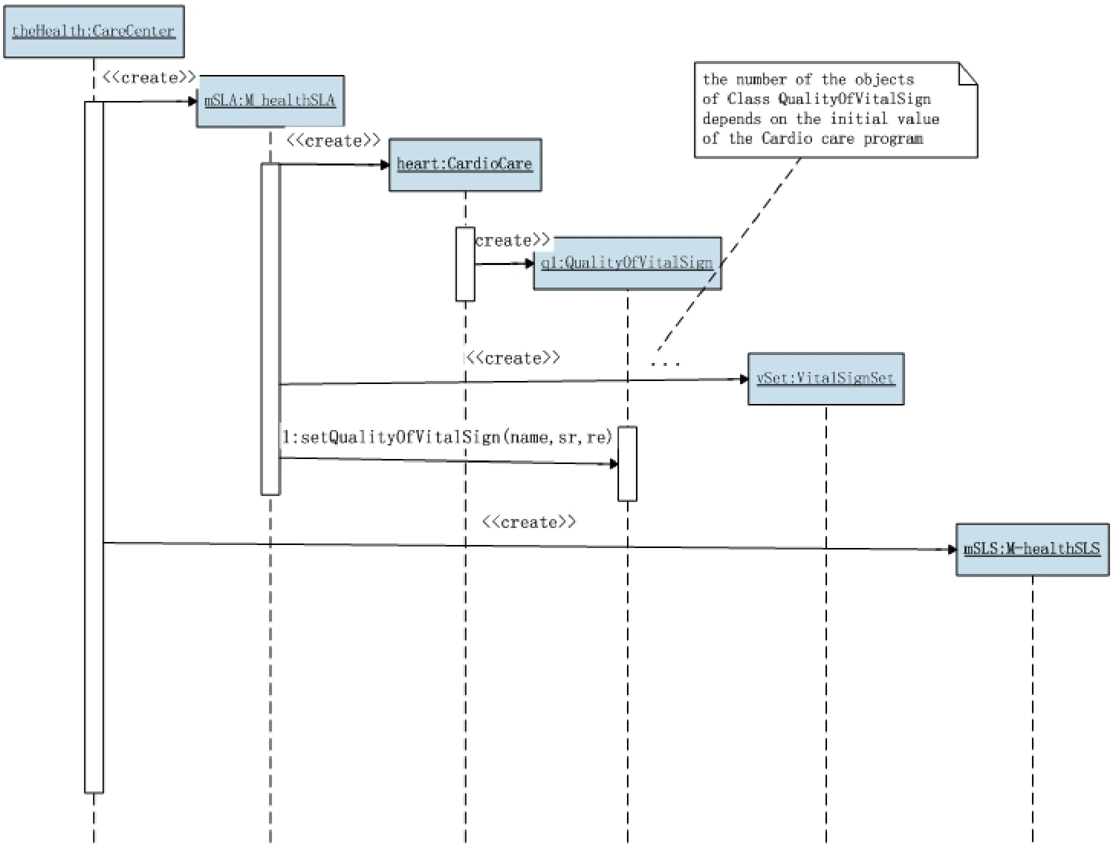

Figure5. 1 Initialization of the model when a patient enrolls Cardio care

Object mSLA is created by object of CareCenter which offers the monitoring service because compared to patient, a health care center has more professional knowledge of care programs, vital signs etc. So in this thesis, the health care center is responsible for initializing the M-healthSLA.

After mSLA is created, q1, q2...q5, and vsSet are crated by mSLA as well since all these are defined as a part of M-healthSLA, so they are initialized by mSLA. The number of the objects of class QualityOfVitalSign determined by the number of the initial values of the vital signs of the Cardio care. In the class diagram, we defined five initial values of the vital signs, so five objects are created in the sequence diagram, although we didn't draw all the objects considering the limited space.

After these objects are created, the health care center creates an object mSLS of M-healthSLS. Because M-healthSLS is defined as a part of the health care center, the health care center has the responsibility to create it. The mSLS is one to one relation to mSLA. So the health care center configures mSLS to provision the service which are agreed in mSLA.

After the creation of the objects, the initial values of the quality of vital signs are set. Message 1 in Figure 5.1 shows the interaction. The meaning of the parameters is:

- name name of the vital sign
- sr sample rate of the vital sign
- re resolution of the vital sign

Since we didn't draw all the objects in Figure 5.1, but actually 5 five messages are sent to set the quality of vital signs.

5.1.2 Behavior of the vital sign data rate calculation

The vital sign data rate calculation mainly contains two steps:

1. determine the measured vital sign set
2. calculate bit rate

Determine the measured vital sign set

As we discussed in Chapter 4, class VitalSignSet stores the vital signs to be measured. So first we have to determine this set according to the required vital signs of the care programs. Figure 5.2 shows the behavior diagram. The meaning of the messages interactions in Figure 5.2 are as follows:

- Message 1 shows that the selectVS() method is called.
- Message 2, 3 read and return the vital signs from the Cardio care.
- Message 4 creates the object of QualityOfVS, the number of the objects are determined by the number of the vital signs in the measured vital sign set. Since the VitalSignSet contains the vital signs which are described by QualityOfVS, we define the VitalSignSet as the creator of QualityOfVS here.
- Message 5 sets the name of the object of QualityOfVS.
- Message 6,7,8,9 get the quality parameters from objects of QualityOfVitalSign of the Cardio care. Object of VitalSignSet is responsible to get and set the quality parameters because we consider the guidelines of [17] that the aggregate has the control of the members of the assembly. In Chapter 7, we will discuss an alternative of the responsibility.
- Message 10,11 set the quality parameters to the object of QualityOfVS.

Since in this scenario only one care program is enrolled, it is no comparison of the vital signs of several care programs; we use the parameters directly in the Cardio care. Later we will see if two care programs are enrolled, the situation will be a bit different. First we have to compare the vital signs of two care programs, and determine the vital sign set which will be measured.

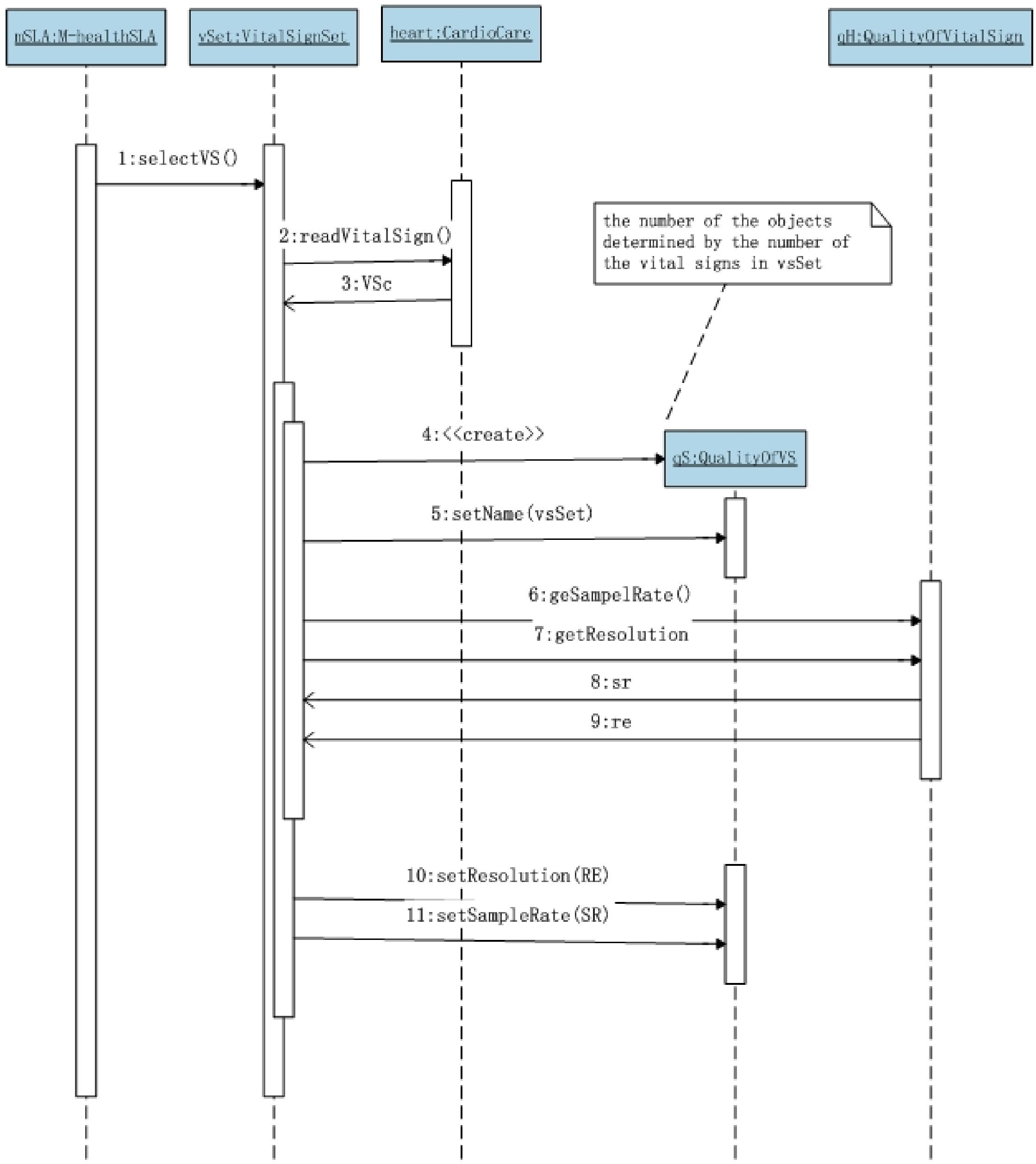

Figure5. 2 determination of the vital sign set

Data rate calculation

As we discussed in Chapter 1, the capacity of the network calculation is one of the research problems in this thesis. Measured vital sign data rate is the main part of the capacity of the network. Other factors, like compression ratio or overhead of transmission protocols, which affect the network capacity as well, are not considered in this scenario. The health care center or ISP/PNO can calculate the network capacity according to their configurations of the services .We show the behavior of the model of this function in Figure 5.3.

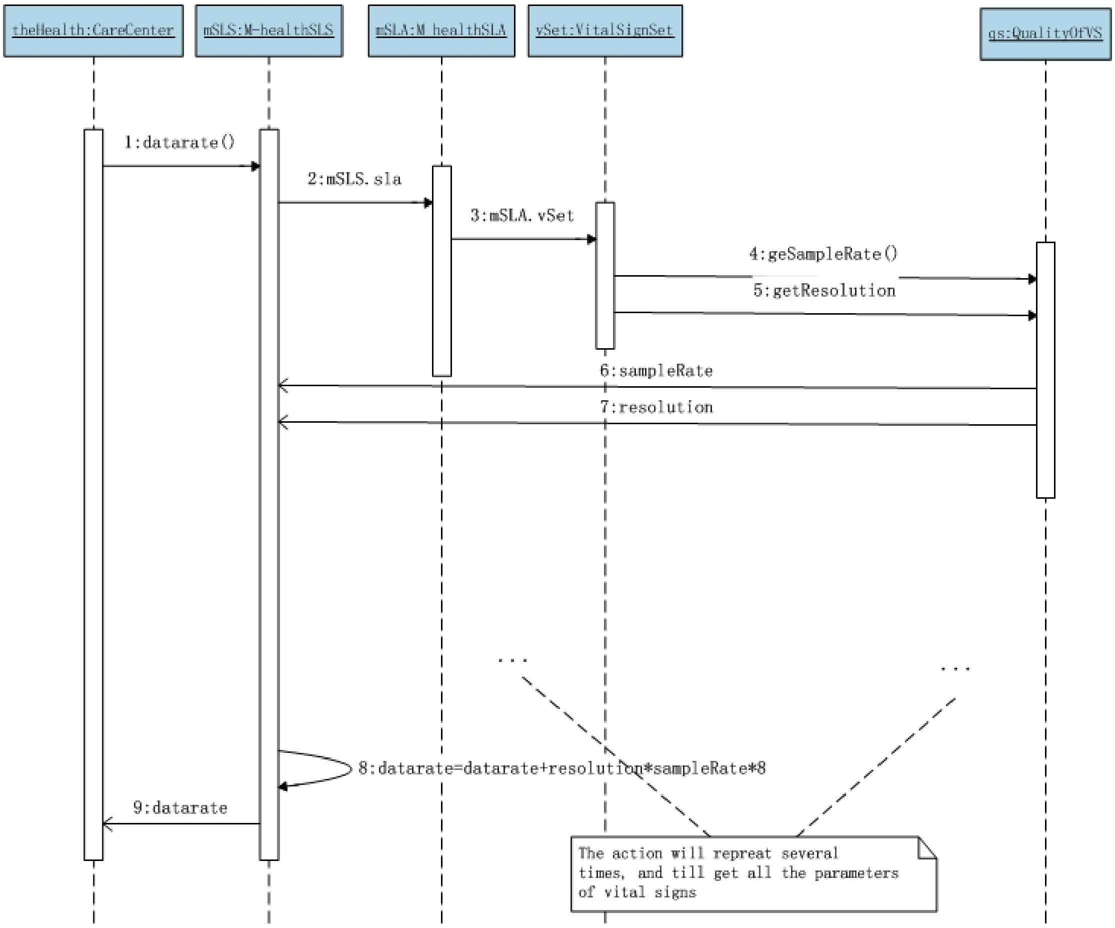

Figure5. 3 the vital sign data rate

The description of the sequence diagram of the data rare calculation is:

- Message 1 shows that datarate() method in M-healthSLS is called.
- Since the parameters are used to bandwidth calculation is stored in the objects of class QualityOfVS, Message 2, 3 navigate to the objects of class QualityOfVS.
- Message 4 and 5 get the quality parameters (i.e. sample rate, resolution) which are needed for the calculation.
- Message 6 and 7 return the quality parameters.
- The actions will repeat several times (depends on the number of vital signs which VitalSignSet has) till mSLS get all the quality parameters.
- Message 8 calculates the data rate.
- Message 9 returns the data rate which is calculated in previous step.

5.2 Behavior of the M-health model for a patient enrolls two care programs

This section mainly discusses what objects will be created when a patient enrolls two care programs, and how these objects interact with each other.

5.2.1 Initialization

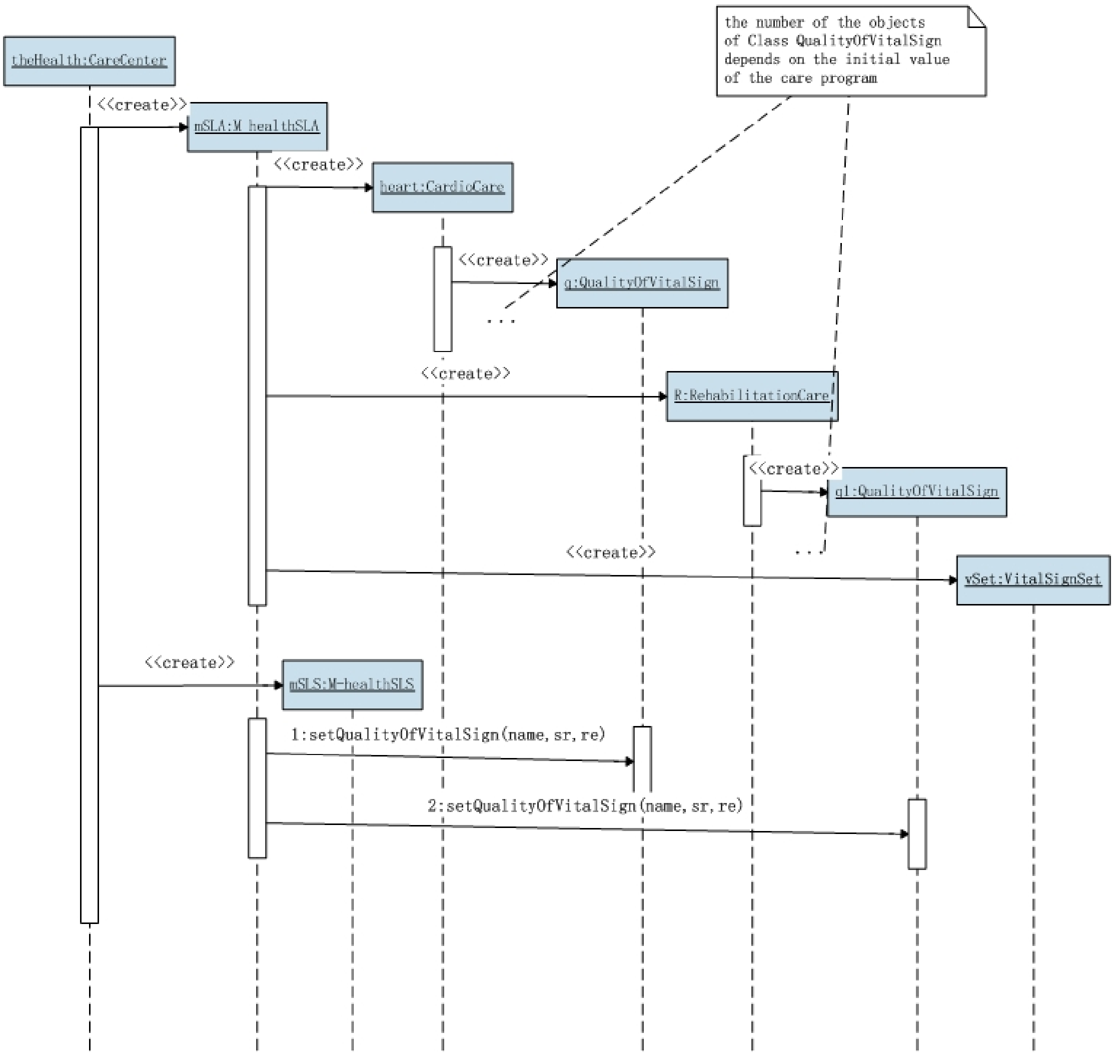

Figure5. 4 Initialization of the model when a patient enrolls two care programs

Figure 5.4 shows the initialization of the model when a patient enrolls two care programs. The all procedures look same like when a patient enrolls one care program, only differences are that one more objects of care program is created (i.e. object of class RehabilitationCare) and objects of the QualityOfVitalSign of this care program are created as well.

From Figure 5.4 we see that an object of class RehabilitationCare, called R, is created by mSLA, The object R creates the object of QualityOfVitalSign according to the number of the initial vital signs that it has. The responsibility of creation is same like we discussed in section 5.1.1, health care center creates the M-healthSLA and M-health SLS. M-healthSLA creates the care programs and quality of vital signs which are defined as parts of it.

5.2.2 Behavior of the vital sign data rate calculation

As we mentioned before, the data rate calculation mainly contains two steps: determine the measured vital sign set and calculate bandwidth. We also show the behavior diagrams in these two steps.

Determine the measured vital sign set

Figure 5.5 shows the sequence diagram:

- Message 1: the selectVS() method is called.
- Message 2,3 : get the vital signs from Cardio care.
- Message 4,5 : get the vital signs from Rehabilitation care.
- Message 6: select the vital signs from the two care programs, and get non-redundant vital signs to vsSet.
- Message 7: creates objects of class of QualityOfVS, the number of the vital signs in vsSet determines the number of the objects. In Figure 5.4 only one object is shown considering limited space.
- Message 8: sets the name of the objects of QualityOfVS.
- Message 9 ,10,11 and 12: get sample rate and resolution of a vital sign from qH (object of QualityOfVitalSign of Cardio care). As we discussed earlier, the object of VitalSignSet has the responsibility to control the object of QualityOfVS according to the guideline of [17].
- Message13,14,15 and 16: get sample rate and resolution of a vital sign from qR (object ofQualityOfVitalSign of Rehabilitation care).
- Message 17,18 : compares the resolution and sample rate to get the max values of them.
- Message 19,20: set the sample rate and resolution to the qS (object of QualityOfVS of VitalSignSet).

In Figure 5.5 we didn’t draw all the objects of QualityOfVitalSign of two care programs and QualityOfVS of VitalSignSet considering the limited space. Object vsSet contains all the vital signs which will be collected from the patient as well as the quality parameters of vital signs.

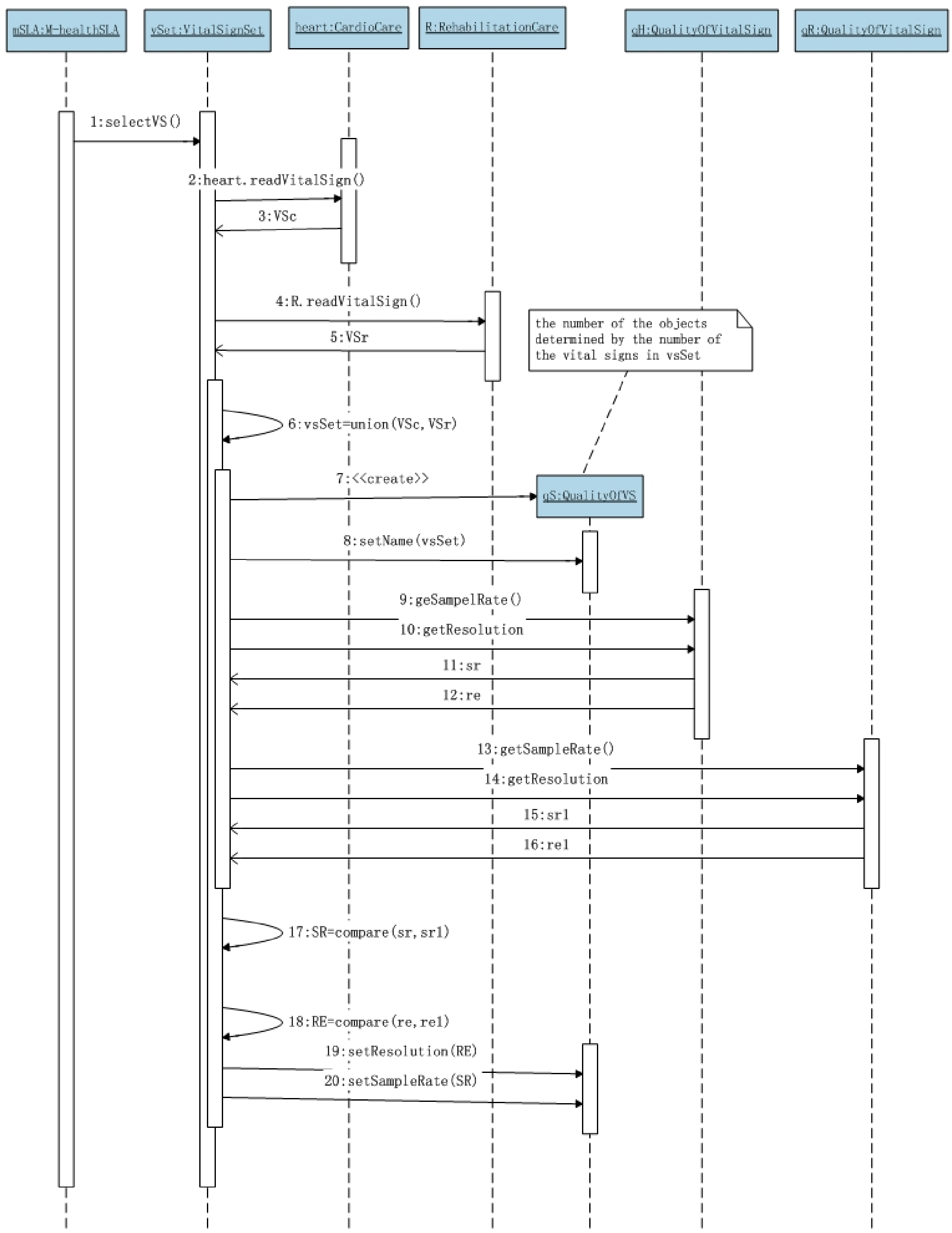

Figure5. 5 sequence diagram of vital signs selection

Calculate data rate

For data rate calculation, it is the same as for the patient enrolls one care program. Because all the data that is needed for data rate is stored in object of class VitalSignSet, it doesn't matter how many programs the patient enrolls. So we don't draw the sequence diagram any more here. This kind of design makes the model easier to extend. It cut the relationship between the data rate calculation with the care programs. All the information for data rate calculation is stored in the object of class VitalSignSet.

5.3 Behavior of the ISP/PNO

This section mainly discusses how the ISP/PNO behaves in the M-health monitoring model, which includes the initialization of the ISSLA and ISSLS, the map of the data rate to wireless connections and configures the ISSLS.

5.3.1 Initialization

After data rate which is generated from sensors of patient's side is determined, the health care center will establish ISSLA with PNO/ISP. Figure 5.6 illustrates the behavior of the ISSLA and ISSLS initialization.

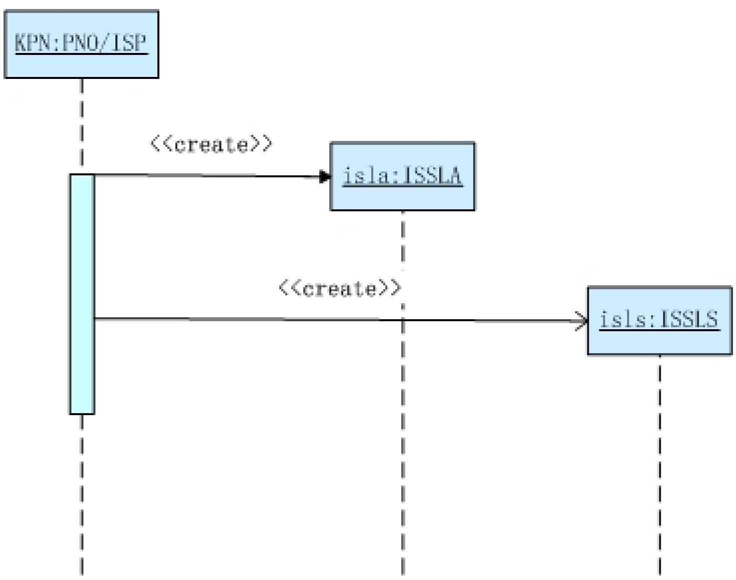

Figure5. 6 initialization of ISSLA and ISSLS

From Figure 5.6, we see that the PNO/ISP creates the ISSLA instead of the health care center. The reason is that the PNO/ISP has more professional knowledge of Internet Service than the health care center. Moreover there is a dependency relationship between ISSLA and M-healthSLS, ISSLA must be defined according to certain parameters which are defined in M-healthSLS (e.g. dataRate). Although the health care center doesn't participate in the creation of ISSLA explicitly, it does via its M-healthSLS.

5.3.2 Wireless connection configuration

The PNO/ISP specifies the ISSLA and ISSLS according to the parameters which are defined in M-healthSLS. Figure 5.7 shows the specification behaviors.

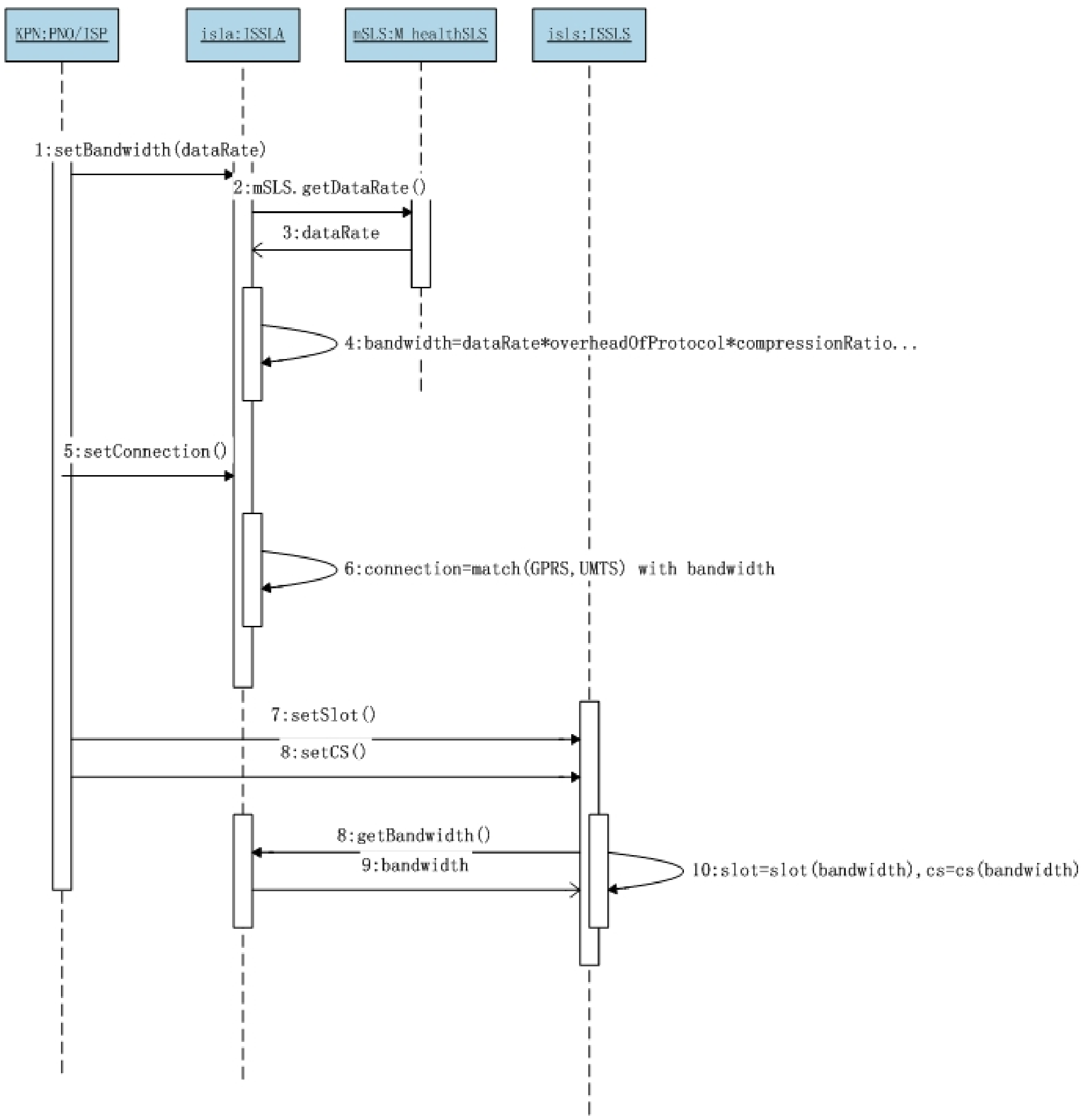

Figure5. 7 behavior of the ISSLA and ISSLS configuration

Message 1: set the bandwidth according to the data rate.
Message 2,3: get data rate from M-healthSLS.
Message 4: calculate the bandwidth according to some mechanism, such as plus the overhead of protocol, and compression rate etc. Since this is out of the scope of this thesis, we don't discuss the details how to translate datarate to bandwidth.
Message 5: set the connection according to the bandwidth
Message 6: According to the bandwidth requirement, connection is determined (e.g. GPRS or UMTS). The table Appendix A.3 can be used to set the connection according to the bandwidth.
Message 7,8 set the time slot and code scheme if GPRS is used
Message 9,10,11 set the time slot and code scheme according to the bandwidth (see table Appendix A.3).

5.4 Summary

We observe the model in a dynamic way in this chapter. The sequence diagrams illustrate the interactions between the objects which are created. They give us a better understanding of the M-health monitoring model.

Chapter 6 Demo and validation

To verify our design, we implemented a demo in JAVA program language under JBuilder9 Enterprise Edition with JDK 1.4 and validate the model with some scenarios. This chapter describes the implementation of this demo and validation. Section 6.1 introduces the implementation tools and environment. Section 6.2 discusses infrastructure of the demo. Section 6.3 introduces User interface.

6.1 Tools and environment

Rational Rose is used to generate Java code skeleton of the demo from the UML class model we have defined in Chapter 4. Actually Rational Rose is a very powerful visual modeling and development tool using the UML. It enables software application development, data modeling, web services design, business modeling, legacy application extension and component based modeling [14]. However we only use very limited functions of Rational Rose to generate Java code skeleton of the demo, such as logical view and component view are used in this thesis. The Logical view defines the attributes and methods of the classes and their types, initial values, etc, also the relationships between these classes and the multiplicity. The Component view contains the components which are related to the classes defined in Logical view, and these components can be used to generate java skeletal codes.

After the Java code skeletons are generated, we import these codes to JBuilder 9 Enterprise Edition to implement the demo. Considered that we have many user interfaces to develop, we choose the JBuilder 9 as the development tool.

6.2 infrastructure of the demo

Before discussing the infrastructure of the demo, the following lines describe the functionalities that can be expected from the demo:

- The demon is based on users' inputs and demonstrates output responses. The demo consists of two applications i.e. subscription application and operational application. Subscription application implements the subscription phase model, i.e. choose care programs, set the Care Level of care programs, configure the quality parameters of vital signs, determine the vital sign set that will be measured, and calculate the required bandwidth to support the M-health monitoring service. Operational application implements the operational phase model, i.e. reconfigure the vital signs of care programs, validate the parameters of vital signs against the parameters in the subscription phase, and calculate the real usage of the bandwidth.

- The demo implemented parts of the M-health monitoring model, which mainly focuses on M-health SLA and M-health SLS. It includes the creation of an M-health SLA and M-health SLS, and using the parameters in the M-health SLA to configure the M-health SLS. It doesn't contain the Network service SLA and Network service SLS, which are related to ISP/PNO.

- The demo is does not consider the distribution aspects of the model, and implemented in a central environment.

Figure 6.1 shows the infrastructure of the demonstrator. Package Demo includes the main application of the demonstrator as well as the user interface. Package subscription includes the implementation of the subscription phase model. Package operational includes the implementation of the operational phase model.

This structure describes the demonstration implementation structure. Since JAVA program language is used in our case, a package in Figure 6.5 can be considered as a JAVA package and dependencies between packages can be mapped to JAVA import statement.

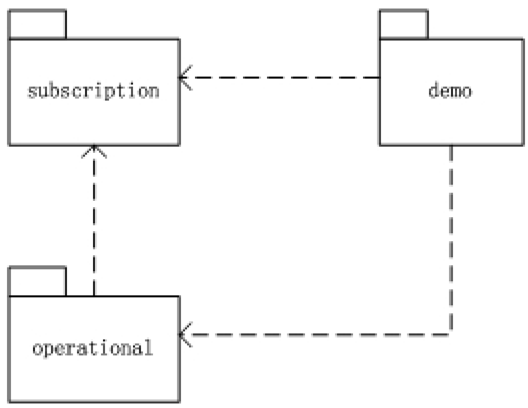

Figure6. 1 Infrastructure of the demo

- Demo package

This package mainly contains the application and the user interface. In this demo we didn't implement the patient and the health care center, so the application plays the role of the health care center to create of the M-health SLA and the M-health SLS and configure them.

- Subscription package

This package mainly contains the classes of the subscription phase model. We implement the creation of the M-healthSLA and the M-healthSLS, specification of the M-healthSLA, and the configuration of the M-healthSLS of the subscription phase model.

- Operational package

This package mainly contains the classes of the operational phase model. We implement the change of the requirement of the vital signs and their quality parameters; check whether the change is valid according to the specification of the subscription phase.

From the functions of these packages, it is easy to see their relationships. Package demo needs to use the classes from both package subscription and operational. Package operational uses package subscription to check the validation of the operational phase parameter setting.

6.3 User Interface

Demo package includes the main User Interface which contains two parts: subscription phase User Interface and operational phase User Interface. These two interfaces can be seen on Figure 6.2.

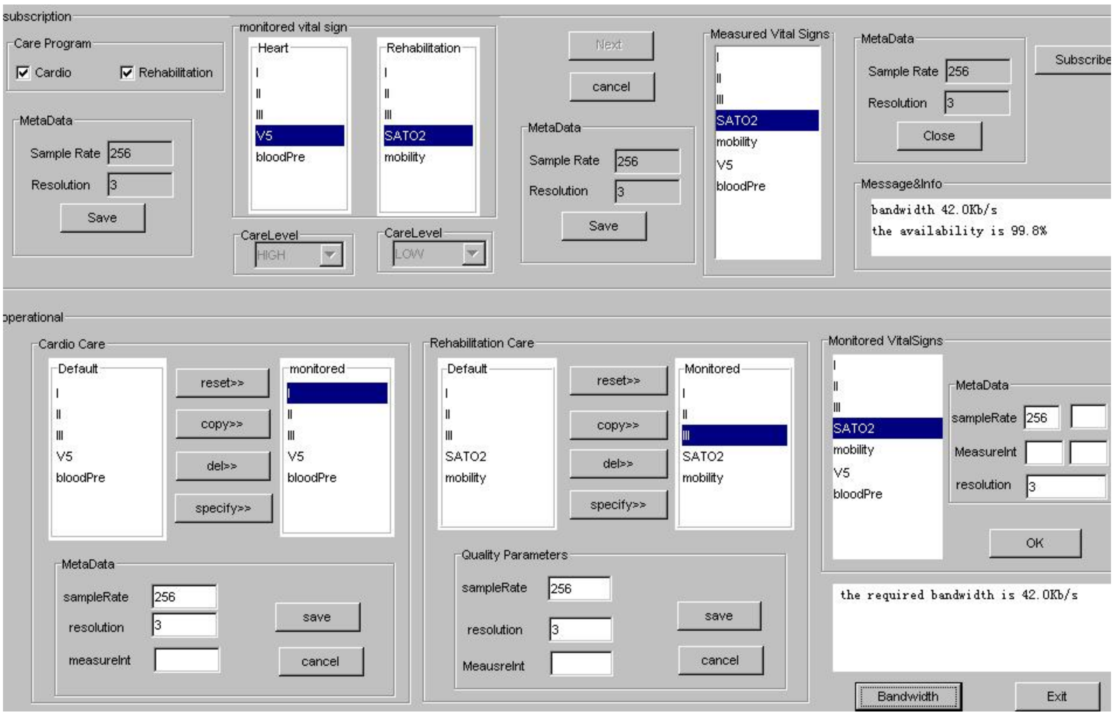

Figure6. 2 User Interface

The upper part of the interface is the subscription phase. It mainly provides the functions:

1. Choose the care programs
2. Specify the quality parameters of initial vital signs
3. Determine the Care level of the care program
4. Determine the measured vital signs and their quality parameters
5. Calculate the vital sign data rate and availability of the service

Figure 6.3 shows the choice of the care programs and specify the quality parameters of initial vital signs. This figure shows the care level specification as well.

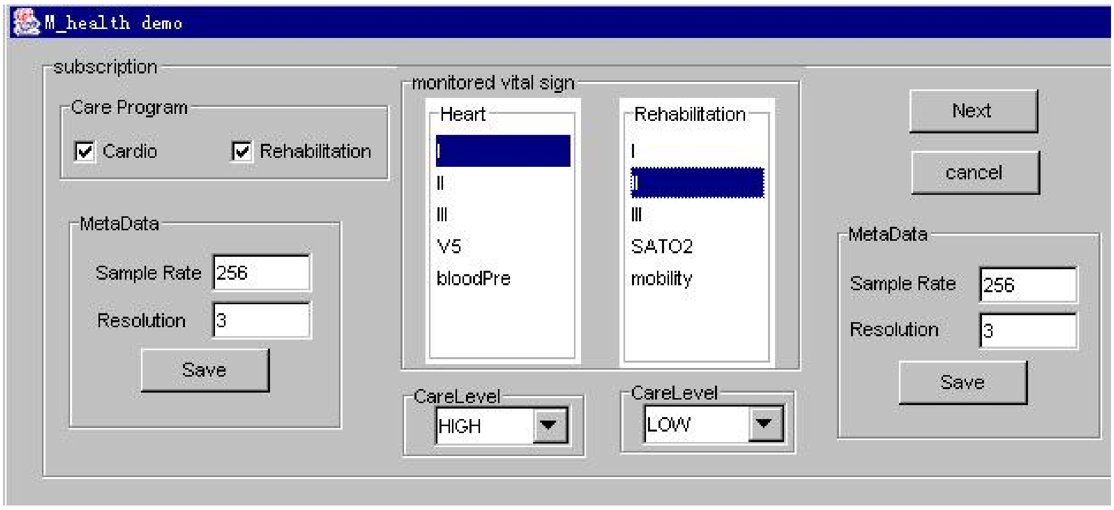

Figure6. 3 specification of vital signs (subscription phase)

After the care programs are checked, the corresponding objects of class CarePrograme created. The initial vital sign set is read from the objects and displayed. The health professional can specify the quality parameters. If the save button is clicked, the setSampleRate() and setResolution() methods of class QualityOfVitalSign are called. After the specification of the vital signs, we can go to the next step. When the next button is clicked, the method selectVs() of class VitalSignSet is called and select measured vital signs that will be collected from sensors. We can see the result of measured vital signs in Figure 6.4. After the measured vital sign set is determined, we can press the subscribe button, which dataRate() and availability() methods of class M-healthSLS are called. The subscribe result is shown on the screen.

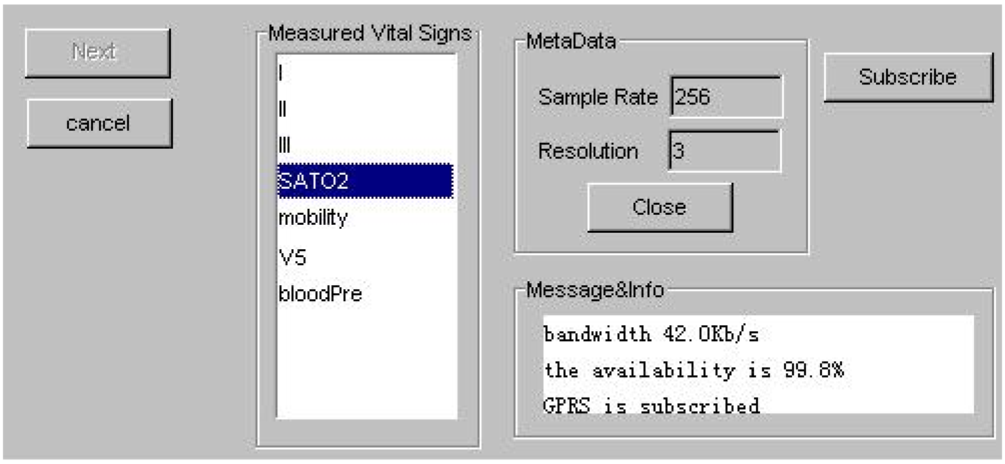

Figure6. 4 measured vital signs and network capacity

The lower part of the interface is the operational phase. It mainly provides the functions:

- Reset the vital signs of the care program
- Reconfigure the quality parameters of vital signs
- Determine the measured vital signs and their quality parameters
- Calculate the vital sign data rate

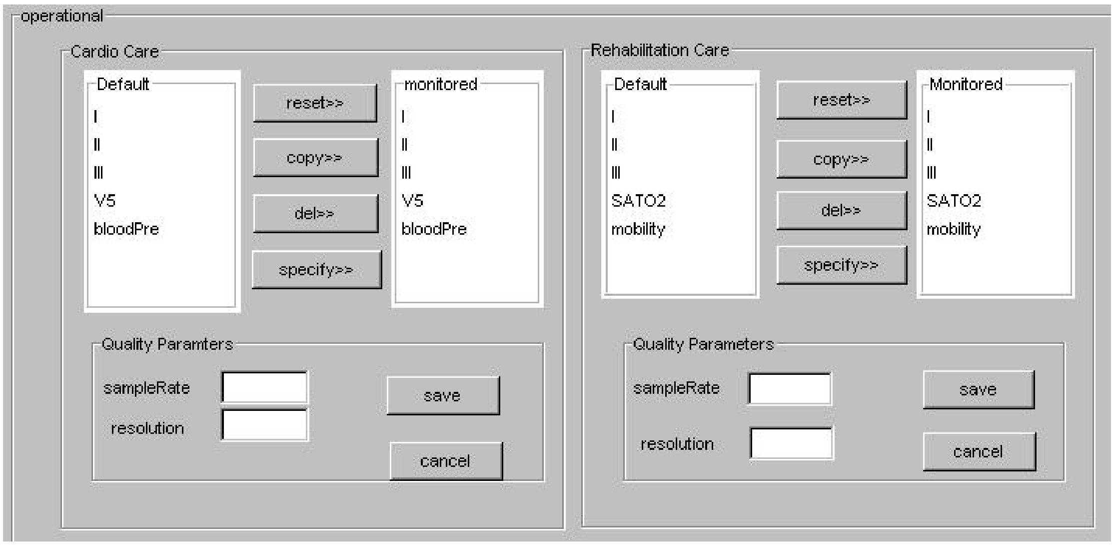

Figure6. 5 vital signs specification (operational phase)

From Figure 6.5 we see the two care programs respectively. In the operational phase, the health care professional may change monitored vital signs or their quality parameter according to the situation of the patient. However all the changes must conform to the subscription phase. We have discussed that two methods (check_validation_c() and check_validation_v())in class CareProgram_O and QualityOfVitalSign_O in operational phase to check if it conform to the subscription phase. When the copy or save button in Figure 6.5 is clicked, the method check_validation_c() or check_validation_v() is called to check the validation.

Figure 6.6 illustrates the calculation results and measured vital signs and their quality parameters. In the demo we always see the bandwidth is calculated, actually it is directly from the data rate which is generated from sensors. Since this thesis doesn't discuss the relationship between data rate and bandwidth, we just use the name bandwidth to represent the result.

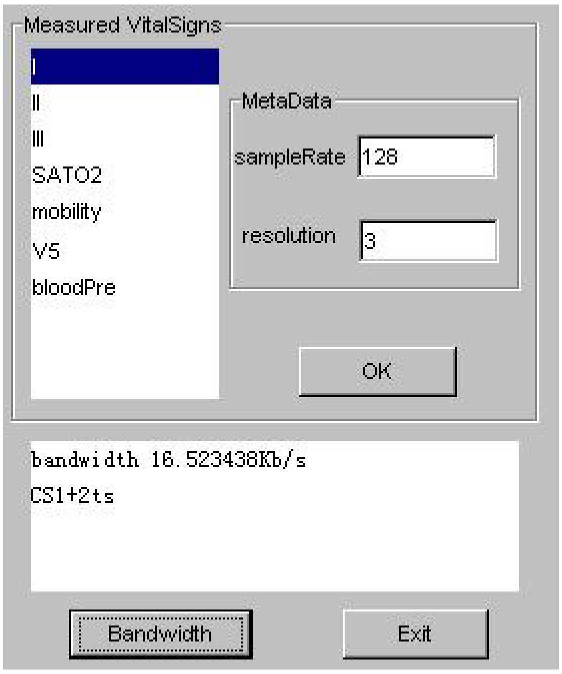

Figure6. 6 result of operational phase

6.4 Result test

We use some groups of quality parameters to test the calculation results. Table 6.1 shows the test parameters of Cardio care. Table 6.2 shows the test parameters of Rehabilitation care.

Vital signs	Sample rate	resolution
I	512	3
II	512	3
III	512	3
V5	256	3
Blood pressure	1	3

Table6. 1 Test parameters of Cardio care

Vital signs	Sample rate	resolution
I	256	3
II	256	3
III	256	3
SatO2	128	3
Mobility	128	3

Table6. 2 Test parameters of Rehabilitation care

Figure 6.3 shows the result. The left side shows the vital signs that will be measured from the patient. ECG I,II,III only measure once at 512 sample/second. The bandwidth requirement is around 48Kb/s, so this patient has to use GPRS code scheme 2 and 4 time slots.

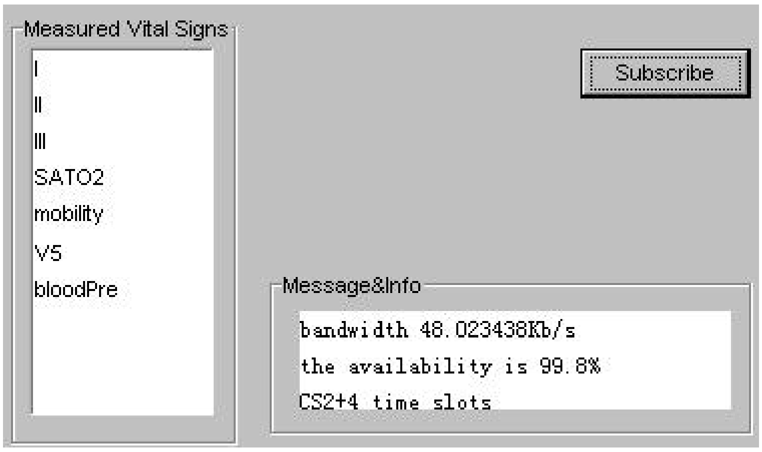

Figure6. 7 shows the result of the test

Chapter 7 Second design cycle

In this chapter, we discuss alternatives of the M-health monitoring model we have discussed in Chapter 4 including reassignment of the responsibilities of the classes we have defined in Chapter 4. We also propose some recommendations.

7.1 Relationship between SLA and SLS

In Chapter 3, we discussed several possibilities to model the relationship between SLA and SLS, and we made the design decision to choose unidirectional association. This relationship is applied in Chapter 4 to model the relationship between M-health SLA and M-health SLS. However a unidirectional association can not catch all the features of the relationship between SLA and SLS (Figure 4.6). From Figure 4.6, we see that the M-health SLA consists two parts: acquisition-oriented part (vital signs to be measured and their quality parameters, which including class VitalSignSet and class QualityOfVS) and care program specification-oriented part (required vital signs of care programs and their quality parameters, which including class CareProgram and class QualityOfVitalSign). In our model, a unidirectional association between M-healthSLA and M-healthSLS enables the method dataRate() in M-healthSLS to calculate the network capacity demands by using the attributes defined in class QualityOfVS. However this model only uses the acquisition-oriented part for the network capacity calculation function, in other words we only construct a part of a SLS, it does not specify the care program specification-oriented part. From the view of the definition of SLS, this is not a complete SLS.

An option is to use a generalization to define the relationship between SLA and SLS as we discussed in Chapter 3. Although the generalization also has disadvantages, it is a design decision to balance the advantages and disadvantages. Maybe there are other possibilities to solve the problem; it is can be done as a future work.

7.2 Alternative model to capture the relationship between care program and vital signs

In the model we defined in Chapter 4, vital sign set is contained in CareProgram. Class QualityOfvitalSign also contains the name of the vital sign. Actually it is a redundant of the vital signs. The purpose to do that in the first design cycle is to show the initial vital signs of care programs explicitly, which probably are determined by corresponding law or policy. An alternative model is outlined in Figure 7.1, which uses an association class to relate the class CareProgram and VitalSign.

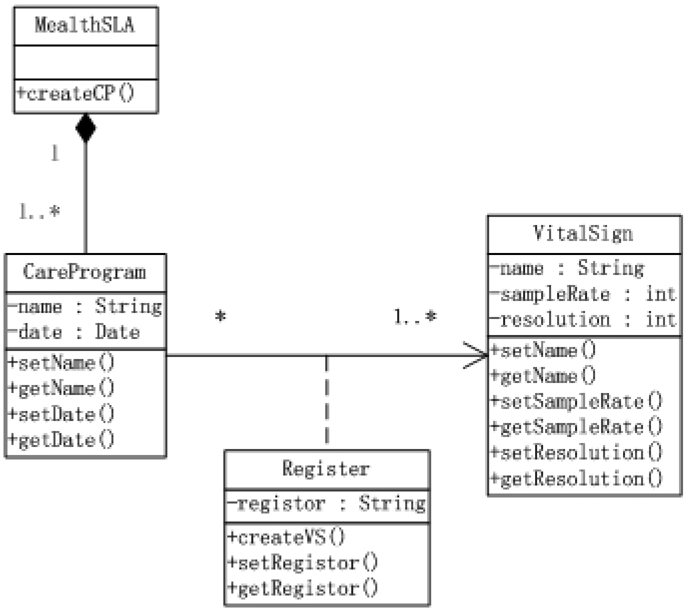

Figure7. 1 Alternative to model Careprogram and VitalSign

From Figure 7.1 we see two new classes: class Register and class VitalSign. Class VitalSign contains the name and properties of a vital sign, such as sample rate, resolution. Association class Register defines the relationship between CareProgram and VitalSign. For example, a health care professional can register vital signs for a care program. Class Register contains one attribute called registor, which represents who register the vital signs for the care programs. Class Register also has the responsibility to create objects of class VitalSign according to a certain policy. In this way we can avoid the redundant of the vital signs. However we can not see the initial value anymore in Figure 7.1. This problem can be solved by adding constraint to define a policy for health care professional to register vital signs. This can be done in a future work.

7.4 Responsibility

Determination of quality parameters of vital signs to be measured

As we discussed in Figure 5.2, the responsibility of determination of quality parameters of vital signs to be measured is assigned to class VitalSignSet. This design decision is made according to [17]. However this design also costs more interactions between objects. If we give the responsibility to class QualityofVS, for example, message 10 and 11 (set the resolution and sample rate of vital signs to be measured) in Figure 5.2 are not necessary anymore. Figure 7.2 shows the behavior diagram of class QualityOfVS has the responsibility of determination of vital signs to be measured.

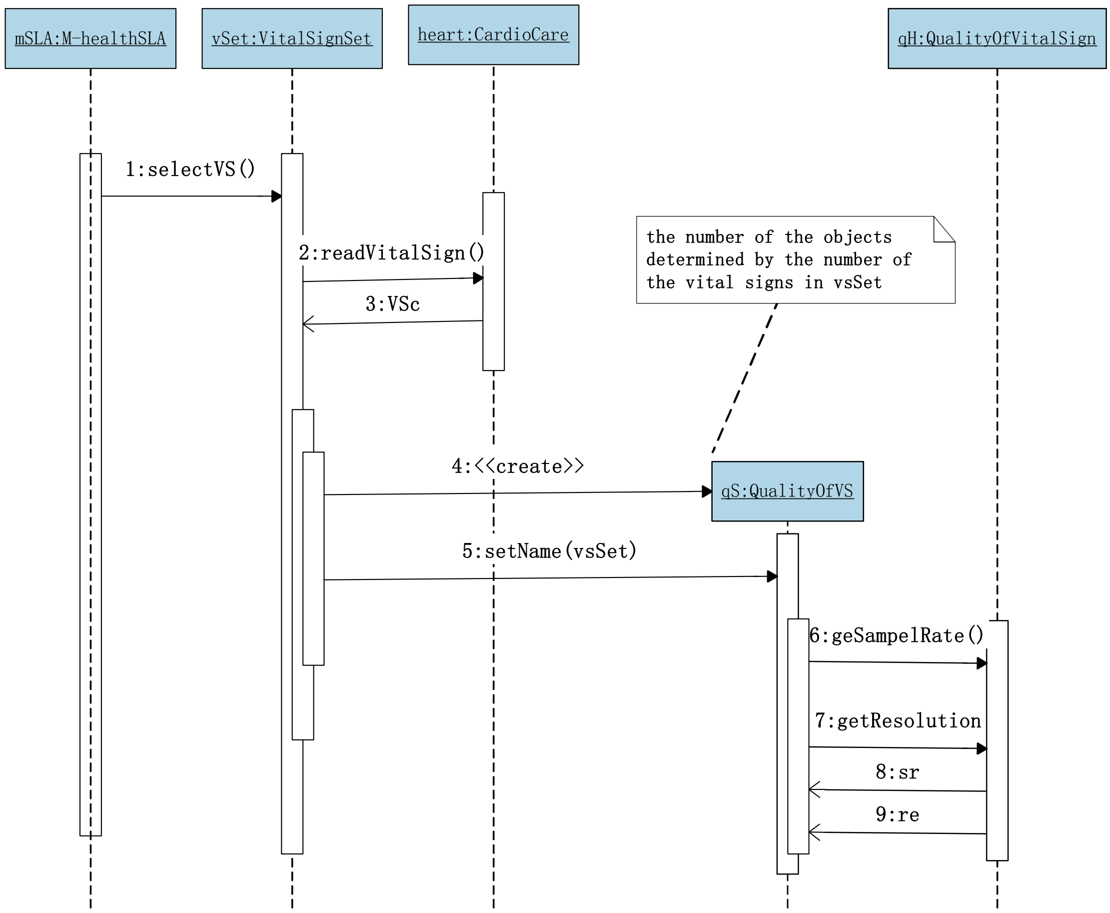

Figure7. 2 Alternative of responsibility behavior diagram

From Figure 7.2 we see that the interactions between objects are less then the one in Figure 5.2. Class QualityOfVS collects the vital sign quality parameters from QualityOfVitalSign.

Fetching quality parameters of vital signs

For the network capacity calculation in M-healthSLS, method dataRate() fetch the data from objects of QualityOfVS (Figure 5.3), which store the quality parameters of vital signs to be measured. From design point of view, it is better to assign the responsibility of fetching quality parameters of vital signs to M-healthSLA. QualityofVS is a part of M-healthSLA, and if according to the guidelines of [17], the operation of the QualityOfVS has to be done via the M-healthSLA. Then M-healthSLA is encapsulated. It cut the tight coupling between

M-healthSLA and M-healthSLS. Figure 7.3 illustrates the behavior diagram.

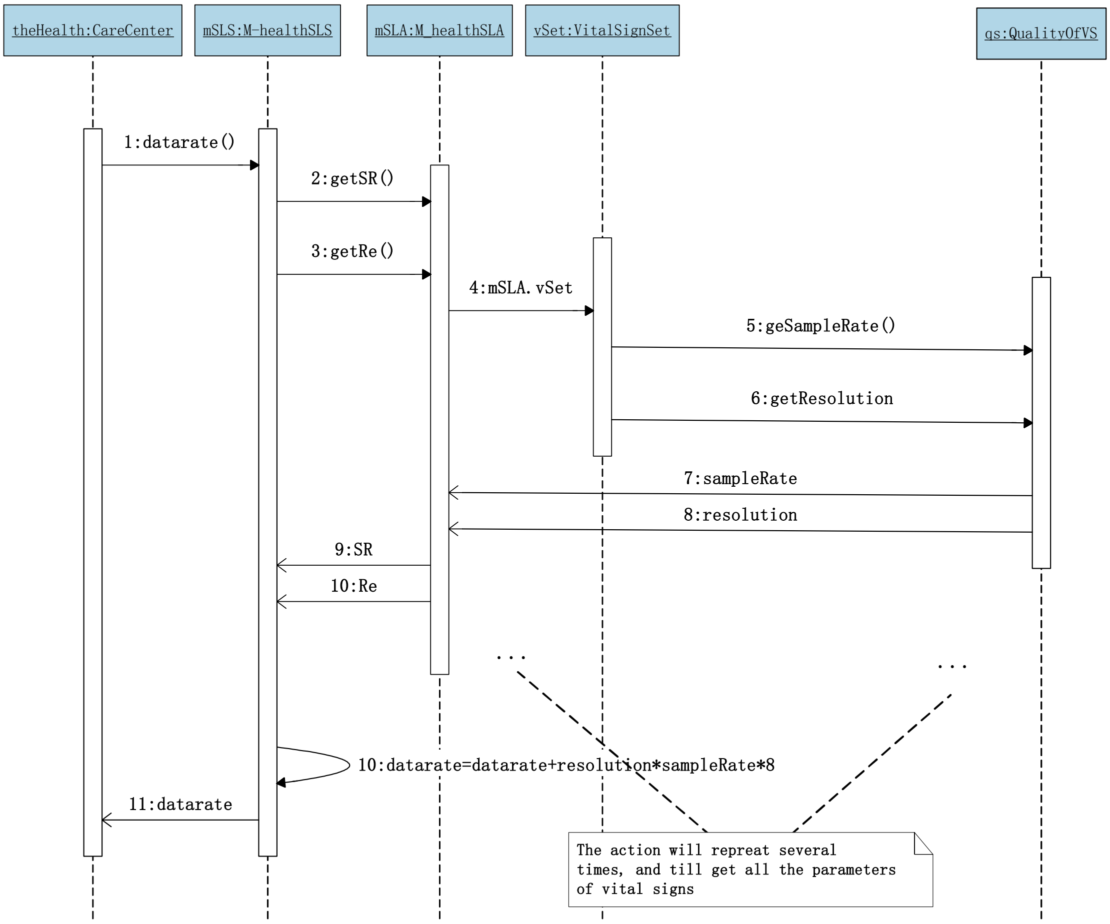

Figure7. 3 behavior diagram

From Figure 7.3, we see all the quality parameters (message 9, 10) are returned by M-healthSLA. Then no matter what kind of changes (e.g. new classes are added or new attributes or methods are added in M-healthSLA.) It will not affect the M-healthSLS.

Chapter 8 Conclusions

This Chapter presents several conclusions and recommendations from topics that discussed in this thesis.

8.1 Conclusions

In this thesis we have analyzed several scenarios of the M-health monitoring service, and identified three stakeholders who are involved in the monitoring service. We have analyzed their roles respectively and used the concepts of SLA and SLS to relate the relationships between the stakeholders according to their roles respectively.

Besides the concept of SLA and SLS, we also discuss the relationship between a SLA and a SLS, and what is the best way to model this relationship in UML. According to the different definition of the SLA and SLS, different relationship can be derived from it. For example, SLS can be defined as a specification of SLA to enable of provisioning of service agreed in the SLA. SLS can also be defined as an association of SLA to enable the service. We analyze the advantages and disadvantages of the designs.

Furthermore, we use UML to build an information model to capture M-health monitoring of patient’s vital signs in a flexible way. This model mainly solves two problems: network capacity calculation to support the monitored vital signs transfer and the shareable of the vital signs for different care programs. The model distinguishes two phases: subscription phase and operational phase. Subscription phase model mainly focus on the specification of the M-health monitoring service, such as the care programs, vital signs and their quality parameters. Then the network capacity is determined according to the data rate generated from the sensors. Operational phase mainly focus on the changing of vital signs and their quality parameters during the usage of the M-health monitoring service.

We use sequence diagram to analyze the dynamic behavior of the model. We show how the model works. We also implement a demo to validate the model. The demo includes a user interface and subscription phase and operational phase. We use some scenarios to analyze the demo and to see the valid results.

8.2 future works

In this thesis, we only focus on the network capacity to support the vital sign transfer. In the future work, the M-healthSLA may contain more aspects than this.

The model is not implemented for a distributed environment. This can be done as a future works. The future work can also discuss the relationship between the patient and ISP/PNO, a third SLA can be introduced.

We have two models: subscription phase and operational phase. The future work can be a discussion of the possibility to merge these two models as one model and how to do that.

In this thesis we address the modeling issue from a domain specific point of view. This approach focuses on understanding and capturing M-health monitoring domain specific issues. Another approach is using patterns, such as Entity-EntitySpecification, Entity-EntityRole, Entity-CompositeEntity. Such patterns have not been explicitly used in our current model. This can be considered as a future work.

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Appendix A

GPRS

GPRS (General Packet Radio Service) is a technology that provides high capacity of end-to-end IP packet services over the GSM network [12]. GPRS uses packet-switched technique to transfer data. Multiple users share the same transmission channel, and only use transmission channel when they have data to send. GPRS provides data transfer using unused Time Division Multiple Access (TDMA) channels in the GSM network. TDMA allows users using same radio frequency by dividing it into different time slots. Each user uses its own timeslot [13]. The maximum data rates are achieved at the situation that allocates multiple time slots in the TDMA frame. Maximum uplink (from terminal to network) and downlink (from network to terminal) speed is determined by the mobile terminal manufacturer. There are 29 multislot classes which manufacturer may build into the mobile terminal. Table A.1 lists some of the classes.

Class	Downlink(slot)	Uplink(slot)	Max. slots
1	1	1	2
2	2	1	3
3	2	2	3
4	3	1	4
5	2	2	4
6	3	2	4
7	3	3	5
8	4	1	5
9	3	2	5
10	4	2	5
11	4	3	5
12	4	4	5

A.1 multislot classes

GPRS specifies various radio channel coding schemes to allow different bit rates. Channel coding in GPRS protects the data that is transported over the air interface and is implemented to correct errors in the bit stream caused by the RF environment [12]. In a GPRS network, there are four coding schemes. Table A.2 shows these four coding schemes.

Coding Scheme	Code Rate	Coded bits	Data rate (kb/s)
CS-1	1/2	456	9.05

CS-2	~2/3	588	13.4
CS-3	~3/4	676	15.6
CS-4	1	546	21.4

A.2 four coding schemes

The choice of coding scheme depends on the condition of the channel provided by the GPRS network (e.g. quality of the radio link between cell phone and base station). If the channel is very busy, the network may use CS-1 to ensure higher reliability. The data transfer rate in this case is 9.05 kbit/s per time slot. If the channel is free, the network may use CS-4 to get optimum speed. The data transfer rate in this case is 21.4 kbit/s per time slot. Table A.3 shows the impact that different channel coding schemes and the number of slots can have on effective data rates. In general GPRS network operators use CS-1 and CS-2 coding schemes.

Code Scheme	1 time slot	2 time slots	3 time slots	4 time slots
CS1	9.05	18.1	27.2	36.2
CS2	13.4	26.8	40.2	53.6
CS3	14.6	29.2	43.8	58.4
CS4	21.4	42.8	64.2	85.6

A.3 coding schemes and data rates

UMTS

UMTS (Universal Mobile Telecommunications System) is one of the major third generation (3G) mobile communication systems being developed within the frame work defined by the ITU [12]. UMTS is an evolution of GSM/GPRS system, with a new radio interface based on WCDMA technology. WCDMA (Wideband Code Division Multiple Access) is a spread spectrum technology that uses unique digital codes to differentiate the users. It is based on CDMA which allows different users to transmit data simultaneously at different data rates. Because of the wide bandwidth of a spread spectrum signal, it is very difficult to jam or interfere with. Thus UMTS obtains higher capacity, better quality and higher bandwidth. Internet access may be at different rates (e.g. 64, 144, 384kb/s…).

The data carried by the UMTS transmission is organized into frames, slots and channels. A channel is divided into 10 ms frames, each of which has fifteen time slots each of 666 microseconds length. On the downlink the time is further subdivided so that the time slots contain fields that contain either user data or control messages.