

Resources Management and Services Personalization in Future Internet Applications

Paweł Świątek, Piotr Rygielski and Adam Grzech

Abstract—The aim of this paper is to introduce a problem of e-health services quality management. The process of delivering e-health services to users consists of two major tasks: service personalization and resources allocation. In this paper we introduce a use-cases of e-health system and distinguish services that can be offered. In order to satisfy user requirements one has to manage resources properly especially when communication conditions change i.e. in an ambulance. An exemplary solution has been presented and conclusions for further work have been formulated.

I. INTRODUCTION

ADVANCES in information and communication technologies allow health service providers to offer e-services in virtually every aspect of health care. The collection of e-health services facilitated by current and future ICT architectures ranges from remote health monitoring, through computer-aided diagnosis, video-consultation, health education, remote surgery and many others [1].

Each of possible e-health services is a composition of atomic services provided by either ICT infrastructure or medical personnel. In some scenarios medical personnel can be both service provider and service consumer. Delivery of complex services as a composition of atomic services is the key feature of service oriented architecture (SOA) paradigm [2]. Application of SOA approach in e-health services delivery allows to personalize and flexibly adjust services to individual needs of service consumers.

According to the SOA paradigm each e-health service is composed of a set of atomic services providing required functionalities, which are delivered in certain predefined order. Each atomic service, which delivers certain functionality may be provided in different versions, which vary in non-functional characteristics such as: response time, security, availability, etc [2], [3]. Composition of complex services from different versions of atomic services allows to guarantee required quality of e-health services, which is very often critical in medical applications.

In this paper we present a general framework for QoS-aware SOA-based composition of e-health complex services. The presented approach is explained with use of an illustrative example — remote monitoring of patients health parameters. The remote monitoring example includes: definition of the remote monitoring problem as a business process, identification of complex services playing major roles in the monitoring

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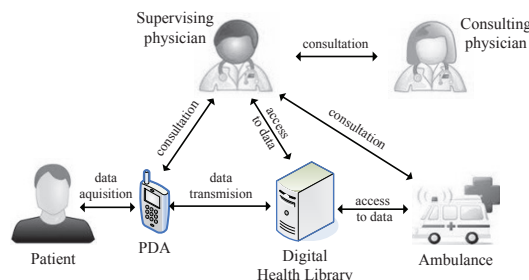


Fig. 1. Remote monitoring of patients health - an overview.

process, identification of the set of atomic services necessary to deliver required functionalities and composition of an exemplary complex service.

II. REMOTE MONITORING OF PATIENT'S HEALTH

As an example of e-health business process consider the process of remote monitoring of patient's health (see Fig. 1).

In this scenario it is assumed, that a patient is equipped with a mobile communication device (e.g. smartphone or PDA), which collects monitored data from sensors placed on the patient's body. Collected data is preprocessed on the patient's mobile device and sent for further processing and storage to Digital Health Library. Further processing of collected data may involve among others: modelling and identification of physiological processes, updating of medical knowledge base, expansion of medical case study database and decision making for computer-assisted diagnosis. In the last case decision making algorithm may recognize any abnormal situations in patient's health and notify medical personnel about such events.

Being alarmed, a physician should have an access to patients' health records, their current health state, medical knowledge bases and additional services such as consultation with patient or other physician. After gathering necessary information the physician decides whether detected abnormal situation poses a threat to patient's health and takes relevant action, e.g. sends an ambulance to the patient. In the life-threatening situation the physician monitors patient's status and instructs ambulance crew on how to proceed with the patient.

The whole process of remote monitoring of patients' health can be divided into three phases presented on Fig. 2: basic monitoring, supervised monitoring and monitoring in the ambulance.

Each of presented monitoring phases is in fact a separate business process composed of one or more complex services.

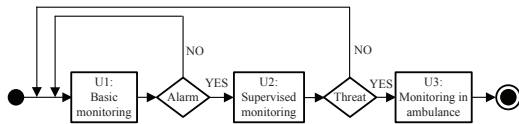


Fig. 2. The process of remote monitoring of patients health.

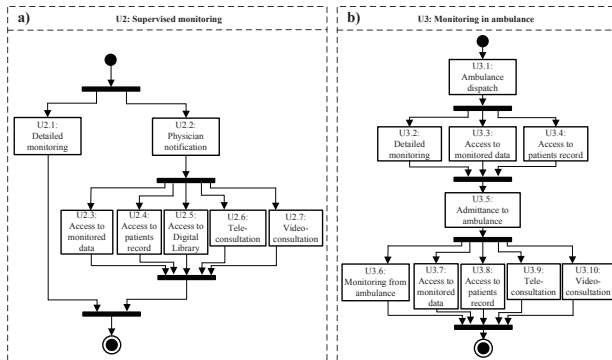


Fig. 3. The process of supervised monitoring (a) and the process of monitoring in an ambulance (b).

Basic monitoring covers routine day to day monitoring of patient's vital parameters (e.g. ECG for post-cardiac patients). Supervised monitoring refers to a case when abnormal behaviour of monitored parameters is detected. In such a case an alarm is activated and other parameters (e.g.: body temperature, pulse and GPS coordinates) are monitored by the physician providing him/her with information and services necessary to make decisions concerning further actions. Monitoring in ambulance applies to life-threatening situations in which an ambulance was dispatched to collect (possibly unconscious) patient. In this case both the ambulance crew and the physician should be provided with necessary information and communication services [1].

Processes of supervised monitoring and monitoring in ambulance can be decomposed into separate complex services. Such an exemplary decomposition of considered processes is presented on Fig. 3 a) and b) respectively.

A. Supervised monitoring

The process of supervised monitoring starts at the moment of generation of an alarm concerning abnormal behaviour of patient's health parameters. There are two immediate implications of such an alarm. The first is the change in patient's monitoring mode - more parameters are being recorded, possibly with denser time resolution. The second consequence is the notification of the patient's physician about possible health risks. From this moment the physician has access to personalised services allowing him/her to gather information about current condition of the patient and make decision about further actions. These services may include (see Fig. 3 a)): on-line access to monitored health parameters (U2.3), access to the patient's health record (U2.4), access to Digital Health Library containing knowledge about similar cases (U2.5), and tele- and video-consultation with patient and/or medical experts (U2.6 and U2.7).

B. Monitoring in ambulance

The process of monitoring in an ambulance consists of two stages. The first starts when the supervising physician finds the patient's health to be at risk and sends an ambulance to take the patient to the hospital (U3.1). From now on the crew of the ambulance has on-line access to monitored parameters of the patient's health (U3.3) as well as his/her health record (U3.4).

After being taken by the ambulance (U3.5) patients monitoring mode changes again. All required patient's health parameters are recorded now. Moreover, audio-video monitoring of the patient in the ambulance is performed as well (U3.6). Besides the previously accessible services (U3.7 and U3.8) the ambulance crew can communicate with the supervising physician through tele- and video-consultation services (U3.9 and U3.10).

III. REMOTE MONITORING AS BUSINESS PROCESS

Business process is a series of interrelated activities or tasks that solve a particular problem or lead to achievement of specific goal. In the SOA paradigm each of activities constituting in business process is represented as a complex service which delivers certain predefined functionality (see Fig. 4). Complex services, in turn, are composed of atomic services, which provide basic indivisible functionalities. The functionality of a complex service is an aggregation of functionalities of atomic services [4]. Similarly, the goal of a business process (its functionality) is an aggregation of functionalities of performed complex services.

The difference between business process and complex service lies in that the former is defined and composed by service consumer, while the latter is delivered by service provider as a whole. Service consumer may influence the choice of particular complex services by specification of Service Level Agreement (SLA) containing functional and non-functional requirements. Service provider, on the other hand, composes complex services from available atomic services basing on requirements stated in the SLA [5].

In special cases the whole business process may be specified by single complex service. Such situations may occur for example when available processes are managed by single entity basing on certain regulations (e.g. medical processes in health care). In general, however, this approach is inefficient and inelastic, since it does not allow consumers to modify their requirements.

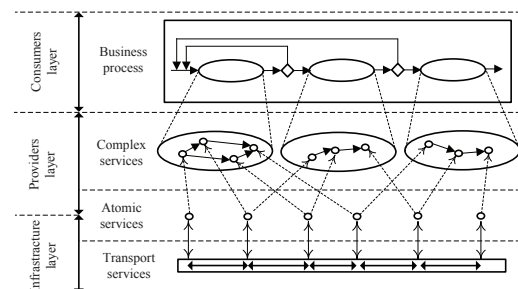


Fig. 4. Composition of business processes.

TABLE I
THROUGHPUT REQUIREMENTS FOR DIFFERENT SIGNALS AND QUALITY LEVELS CONSIDERED IN THE EXAMPLE.

Signal		Video	Voice	ECG	EMG	Heart sound	Heart rate
Required throughput [kbps]	High quality	5000	256	24	600	120	5
	Low quality	640	25	12	100	24	2

IV. SERVICES PERSONALIZATION AND RESOURCES MANAGEMENT

Depending on individual needs of service consumers and capabilities of execution environment each of available complex services can be delivered in many versions which differ in non-functional characteristics [6], [7]. As an example consider monitoring from ambulance service (U3.6) which allows to transmit monitored signals, voice and video from ambulance to supervising physician. Depending on individual case different health parameters are recorded and transmitted through the network (e.g.: ECG and pulse for cardiac patients or glucose for diabetics). Additionally, voice and video transmission may be required by physician. Moreover, individual requirements and amount of available system resources may influence the number and the quality of transmitted signals [8], [3].

Assume, that there are six signals possible to be measured and transmitted from ambulance to physician: video, voice, ECG, EMG, heart sound (HS) and heart rate (HR). Each signal can be measured and transmitted in two modes - high and low quality. High and low quality of health parameters can be reflected by higher and lower sampling rates. A transmission of high and low quality signals has different requirements for communication resources (see table I).

In general, preferences concerning the quality of requested complex service can be defined by penalty matrix $\mathbf{P}_l = [p_{ij}]$, where each element p_{ij} ($i = 1, \dots, I; j = 1, \dots, J$) represents a penalty for not delivering j -th signal in higher than i -th quality levels. The exemplary matrix for six signals considered above and three quality levels is defined by:

$$\mathbf{P}_l = \begin{bmatrix} p_{VID}^{HI} & p_{VOI}^{HI} & p_{ECG}^{HI} & p_{EMG}^{HI} & p_{HS}^{HI} & p_{HR}^{HI} \\ p_{VID}^{LO} & p_{VOI}^{LO} & p_{ECG}^{LO} & p_{EMG}^{LO} & p_{HS}^{LO} & p_{HR}^{LO} \\ p_{VID}^{NO} & p_{VOI}^{NO} & p_{ECG}^{NO} & p_{EMG}^{NO} & p_{HS}^{NO} & p_{HR}^{NO} \end{bmatrix}, \quad (1)$$

where for example $p_{21} = p_{VID}^{LO}$ is the penalty for not delivering video signal in high quality and $p_{11} = p_{EMG}^{NO}$ is the penalty for not delivering EMG signal at all. If penalty $p_{ij} = 0$ then i -th quality level of j -th signal is not required.

Denote by \mathbf{D}_l a binary matrix of quality level delivery, where each element d_{ij} ($i = 1, \dots, I; j = 1, \dots, J$) is defined as follows:

$$d_{ij} = \begin{cases} 1 & i\text{-th quality level for } j\text{-th signal is delivered} \\ 0 & i\text{-th quality level for } j\text{-th signal is not delivered} \end{cases} \quad (2)$$

Exemplary matrix \mathbf{D}_l for a complex service in which video and voice signals are delivered at low quality, ECG signal

is delivered at high quality, and remaining signals are not transmitted at all is presented below:

$$\mathbf{D}_l = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 \end{bmatrix}. \quad (3)$$

Given the penalty matrix \mathbf{P}_l and quality delivery matrix \mathbf{D}_l for certain complex service request req_l it is possible to calculate overall penalty p_l for not satisfying consumers preferences as follows:

$$p_l = \sum_{j=1}^J \mathbf{p}_{lj} \cdot \mathbf{d}_{lj}^T, \quad (4)$$

where \mathbf{p}_{lj} and \mathbf{d}_{lj} are j -th columns of matrices \mathbf{P}_l and \mathbf{D}_l respectively.

Let $\mathbf{R} = [r_{ij}]$ ($i = 1, \dots, I; j = 1, \dots, J$) denote the matrix of resources consumption, where each element r_{ij} represents the amount of resources required to deliver j -th signal at i -th quality level. In the example considered above resources requirements are stated in terms of required throughput (see table I). Therefore, the exemplary matrix \mathbf{R} is defined as follows:

$$\mathbf{R} = \begin{bmatrix} 5000 & 256 & 24 & 600 & 120 & 5 \\ 640 & 25 & 12 & 100 & 24 & 2 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}. \quad (5)$$

Note, that elements of the last row of exemplary matrix \mathbf{R} are equal to zero since the lowest quality level represents situation in which signals are not delivered at all.

The amount of resources r_l necessary to deliver complex service at quality level represented by certain matrix \mathbf{D}_l can be calculated as follows:

$$r_l = \sum_{j=1}^J \mathbf{r}_j \cdot \mathbf{d}_{lj}^T, \quad (6)$$

where \mathbf{r}_j and \mathbf{d}_{lj} are j -th columns of matrices \mathbf{R} and \mathbf{D}_l respectively.

For the model presented above a number of resource management tasks can be formulated. The goal of each task may be different. For example, one may want to minimize the average or maximal penalty caused by violation of consumers individual preferences or to maximize consumers satisfaction for each incoming complex service request. The aforementioned tasks can be formulated as follows.

Task 1: Average penalty minimization

Given: set $L(t)$ of service requests currently being served, capacity C of the system and matrices of penalties \mathbf{P}_l and resources consumption \mathbf{R} .

Find: set of quality delivery matrices $\{\mathbf{D}_l^* : l \in L(t)\}$ such that average penalty caused by violation of consumers individual preferences is minimized:

$$\{\mathbf{D}_l^* : l \in L(t)\} = \arg \min_{\{\mathbf{D}_l : l \in L(t)\}} \sum_{l \in L(t)} \sum_{j=1}^J \mathbf{p}_{lj} \cdot \mathbf{d}_{lj}^T \quad (7)$$

with respect to system capacity constraints:

$$\sum_{l \in L(t)} \sum_{j=1}^J \mathbf{r}_j \cdot \mathbf{d}_{lj}^T \leq C. \quad (8)$$

Task 2: Maximal penalty minimization

This task is similar to Task 1 and can be derived by substitution of objective function in (7) by following formula:

$$\{\mathbf{D}_l^* : l \in L(t)\} = \arg \min_{\{\mathbf{D}_l : l \in L(t)\}} \max_{l \in L(t)} \sum_{j=1}^J \mathbf{p}_{lj} \cdot \mathbf{d}_{lj}^T \quad (9)$$

Task 3: Maximization of service consumer satisfaction

Given: the amount of resources $C(t)$ currently available in the system, matrix of preferences \mathbf{P}_l for incoming service request req_l and resources consumption matrix \mathbf{R} .

Find: composition of complex service defined by quality delivery matrix \mathbf{D}_l^* such that penalty caused by violation of consumers preferences is minimized:

$$\mathbf{D}_l^* = \arg \min_{\mathbf{D}_l} \sum_{j=1}^J \mathbf{p}_{lj} \cdot \mathbf{d}_{lj}^T \quad (10)$$

with respect to system capacity constraints:

$$\sum_{j=1}^J \mathbf{r}_j \cdot \mathbf{d}_{lj}^T \leq C(t). \quad (11)$$

The goal of Task 3 is to compose complex services according do consumers preferences. It can be performed each time when new complex service request arrives to the system. It can also be used for request admission control and Service Level Agreement renegotiation. Tasks 1 and 2, on the other hand, are performed in order to optimize utilization of systems resources and to guarantee average or minimal service consumer satisfaction.

A. Numerical example

Consider an example in which two monitoring service requests req_1 and req_2 arrive to the system. Requests req_1 and req_2 are characterized by following preferences matrices:

$$\mathbf{P}_1 = \begin{bmatrix} \times & 0 & \times & 0 & 0 & \times \\ \times & 100 & \times & \infty & 200 & \times \\ \times & \infty & \times & \infty & \infty & \times \end{bmatrix} \quad (12)$$

$$\mathbf{P}_2 = \begin{bmatrix} 0 & \times & \times & 0 & 0 & \times \\ 1000 & \times & \times & 100 & 10 & \times \\ \infty & \times & \times & \infty & 200 & \times \end{bmatrix}$$

which mean that request req_1 requires voice and heart sound signal to be delivered at least at low quality and EMG signal to be delivered at high quality. Similarly request req_2 requires video and EMG signal at least at low quality and additional heart sound signal would improve consumers satisfaction.

Assume, that systems capacity is equal to $C = 2510kbps$ and that capacity requirements of available signals are given by matrix \mathbf{R} defined in (5). As a result of minimizing average penalty for not satisfying consumers preferences (Task 1

defined by (7) and (8)) following quality delivery matrices are calculated:

$$\mathbf{D}_1 = \begin{bmatrix} \times & 1 & \times & 1 & 1 & \times \\ \times & 0 & \times & 0 & 0 & \times \\ \times & 0 & \times & 0 & 0 & \times \end{bmatrix}, \quad (13)$$

$$\mathbf{D}_2 = \begin{bmatrix} 0 & \times & \times & 1 & 1 & \times \\ 1 & \times & \times & 0 & 0 & \times \\ 0 & \times & \times & 0 & 0 & \times \end{bmatrix},$$

resulting in overall penalty $p = 1000$ for not delivering high quality video signal for second service request req_2 . Delivery of high quality video signal in this example is impossible because HQ video capacity requirements are higher than overall capacity C of the system. Services composition and resources allocation represented by matrices \mathbf{D}_1 and \mathbf{D}_2 (13) are illustrated on Fig. 5 (state before moment t_1).

Assume, that at certain moment t_1 a third service request req_3 characterized by matrix \mathbf{P}_3 arrives to the system. In order minimize average penalty for not satisfying consumers preferences systems resources have to be reallocated. Final service composition and resources allocation depends on penalty matrices \mathbf{P}_1 , \mathbf{P}_2 and \mathbf{P}_3 .

In order to show the difference between final resources allocation assume two alternate matrices \mathbf{P}_3 :

$$\mathbf{P}_3^a = \begin{bmatrix} 0 & 0 & \times & 0 & 0 & \times \\ 1000 & \mathbf{250} & \times & \infty & \infty & \times \\ \infty & \infty & \times & \infty & \infty & \times \end{bmatrix}, \quad (14)$$

$$\mathbf{P}_3^b = \begin{bmatrix} 0 & 0 & \times & 0 & 0 & \times \\ 1000 & \mathbf{150} & \times & \infty & \infty & \times \\ \infty & \infty & \times & \infty & \infty & \times \end{bmatrix},$$

which differ in the penalty for not delivering voice signal in the high quality. Two different solutions of are represented by quality level matrices \mathbf{D}_1^a , \mathbf{D}_2^a , \mathbf{D}_3^a and \mathbf{D}_1^b , \mathbf{D}_2^b , \mathbf{D}_3^b :

$$\mathbf{D}_1^a = \begin{bmatrix} \times & 0 & \times & 1 & 0 & \times \\ \times & 1 & \times & 0 & 1 & \times \\ \times & 0 & \times & 0 & 0 & \times \end{bmatrix}$$

$$\mathbf{D}_2^a = \begin{bmatrix} 0 & \times & \times & 0 & 0 & \times \\ 1 & \times & \times & 1 & 1 & \times \\ 0 & \times & \times & 0 & 0 & \times \end{bmatrix}, \quad (15)$$

$$\mathbf{D}_3^a = \begin{bmatrix} 0 & 1 & \times & 1 & 1 & \times \\ 1 & 0 & \times & 0 & 0 & \times \\ 0 & 0 & \times & 0 & 0 & \times \end{bmatrix}$$

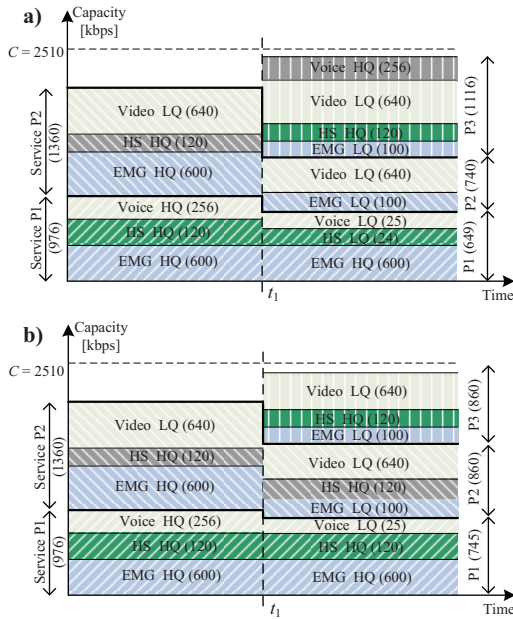


Fig. 5. Services composition and resources reallocation for two versions of third request preferences differing in the value of penalty p_{322} for not delivering HQ voice for request req_3 : (a) $p_{322} = 250$, (b) $p_{322} = 150$.

and

$$\begin{aligned}
 \mathbf{D}_1^b &= \begin{bmatrix} \times & 0 & \times & 1 & 1 & \times \\ \times & 1 & \times & 0 & 0 & \times \\ \times & 0 & \times & 0 & 0 & \times \end{bmatrix} \\
 \mathbf{D}_2^b &= \begin{bmatrix} 0 & \times & \times & 0 & 1 & \times \\ 1 & \times & \times & 1 & 0 & \times \\ 0 & \times & \times & 0 & 0 & \times \end{bmatrix} \\
 \mathbf{D}_3^b &= \begin{bmatrix} 0 & 0 & \times & 1 & 1 & \times \\ 1 & 1 & \times & 0 & 0 & \times \\ 0 & 0 & \times & 0 & 0 & \times \end{bmatrix}
 \end{aligned} \quad (16)$$

Final services composition and resources allocation represented by the above matrices are illustrated on figures Fig. 5a) and Fig. 5b) respectively. Note that in the presented example, depending on the penalty for not delivering HQ voice for request req_3 , HQ voice in req_3 is traded for HQ heart sound in req_1 and req_2 . The threshold value of this penalty is $p_{322} = p_{125} + p_{225} = 210$.

V. CONCLUSIONS

In this paper a general problem of e-health services management was introduced. It consists of two major tasks: service personalization and resources allocation. Service personalization allows to flexibly adjust delivered services based on individual needs of service consumers. Resources management allows to reserve and allocate resources necessary to deliver requested services and satisfy consumers preferences. In the presented approach both tasks of personalization and resource allocation are solved simultaneously as single optimization problem in which certain parameters concern the personalization task (penalty matrices), while other parameters regard allocation tasks (resources consumption matrix). Unfortunately formulated tasks are in general NP-hard, therefore heuristic

algorithms should be applied to effectively control processes of service composition, personalization and resources management.

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