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Mathematical model for performance analysis of a context-aware device with composite service

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ABSTRACT

Recent advances in the development of smart devices and wireless network infrastructures have made it possible to provide a variety of rich services to diverse user groups. In order to make the best use of these technological benefits, the services provided by the device need to be developed and supplied with consideration for the user context that contains information about the environments with which the device and the user interact. The user context is mostly inferred based on the data that are dispersed in the user's environment and can trigger a service when enough data are gathered to infer a certain degree of user context. A service provided by the device usually consists of one or more smaller services taking the form of a composite service. In this regard, we investigate a context-aware composite service provision process and present an analytical tool for assessing the performance of the process by means of a mathematical model. The results from extensive experimental simulations indicate that a performance assessment based on the proposed mean value analysis model effectively confirms the characteristics of the composite service systems.

1. Introduction

The rapid proliferation of mobile smart devices and wireless networks has made it possible to realize a so-called pervasive computing environment in which federations of devices provide rich services to users. The advances of sensor networks and communication technology between devices (e.g., mobile ad-hoc networking) also play an important role in the gathering and processing of environmental data and user preference information. With the progress of distributed and mobile systems and the individual possession of smart devices, personalized services are gaining popularity, and individuals are enjoying various user-centric technological benefits in the pervasive computing environment [1].

In addition to the advances in devices and network infrastructure, several software technologies concerning interoperability and scalability have also contributed to enabling the composition of a service through a federation of services, resulting in richer services. For example, a personal schedule management service may be composed of a weather forecasting service, a contact list management service, and a travel management system that may be available in other devices. In this example, the personal schedule management service can be considered a composite service consisting of one or more other constituent services that we refer to as *atomic services* for the personal schedule management service. Note that any service can be a composite or atomic service, depending on its use.

By means of a combination of atomic services, a composite service is capable of offering new services that can add value to the atomic services upon which they are based. In order to take full advantage of the benefits of the composite services that are created by linking existing services, many efforts have been made to address the challenges imposed by

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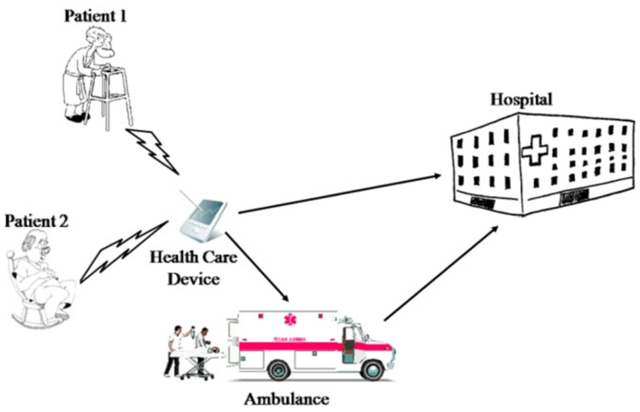

Fig. 1. Ubiquitous healthcare system for elderly people.

the composition of device services, such as the discovery and deployment of individual services, the use of composition languages, and middleware solutions to enhance interactions among individual devices [2]. With the recent progress of embedding computing resources into everyday electronic devices, devices that perform composite services have been gaining popularity more than ever [3]. This trend is expected to accelerate in that sensor technologies have evolved to enable those devices to sense the physical environment surrounding users.

In designing and deploying composite services, special care needs to be taken to accommodate user needs and preferences. In such a ubiquitous environment in which many users have diverse demands and a variety of devices have different service capabilities, it is important for those devices to provide users with appropriate services that are adaptive to the status of users and/or the surrounding circumstances. Information about the user status and circumstances is regarded as the user context [4]. In order to take the user context into account for a composite service, the device needs information about a user, which can be inferred from a variety of data collected from multiple devices or sensors around the user [5]. Once the collected data satisfies a predetermined condition for inferring the user context, e.g., when the total number of accumulated data in the device reaches a threshold, the device begins to process them to detect the user's situation in order to provide appropriate services in consideration of the user context. Here it should be noted that an instance of data at hand at a certain moment in time may not always be useful, because it can change depending on the time, location, and availability of device capabilities. Therefore, the recency of the data referenced by the devices should be considered a vital aspect in inferring the user context.

As we mentioned, a composite service is provided to users in the form of a series or a collection of atomic services, each of which is managed by different mechanisms, and a device providing those services can usually be shared by more than one user within a system. This situation imposes a challenge in delivering a composite service in such a way that the relevant user context information is effectively exploited, and that all of the constituent atomic services run efficiently. More importantly, the effectiveness of the composite services in terms of the delivery time to users is considerably more important when the composite services are related to time-critical services.

For instance, consider the following simple healthcare system with several patients, as depicted in Fig. 1. Patient 1 suffers from heart-related disease, and patient 2 has a diabetic problem. A healthcare device monitors these two patients with sensors capable of detecting the bio-signals of each patient. Sensors attached to the patients send these signals to the device to check for any abnormal symptoms relevant to their disease, such as a sudden increase in heartbeat, blood pressure, blood sugar level and so on. Once the amount of data received by the device reaches a predetermined level in terms of the number or duration of symptoms, this patient's situation is regarded as an emergency, and a composite service composed of three atomic services should be sequentially administered in a timely manner. These three atomic services are: (i) notifying emergency staff to dispatch an ambulance; (ii) searching for the nearest or most appropriate hospital for the patient from the database; and (iii) putting the medical staff on standby. If all of the relevant information needed to trigger the composite healthcare service mentioned above is regarded as the user context, this situation is representative of the aforementioned aspects that are associated with providing context-aware composite services to multiple users.

In designing and operating service delivery systems, the time-related performance of composite services should be taken into account depending on the number of sensors, sensor data collection period, device computing power, and recency of the sensor data. In this paper, we consider a service provision system that is composed of multiple users with various user contexts and several atomic services providing composite services. In particular, the system performance in terms of the service composition and the delivery times to provide services is assessed. For this purpose, we propose a queueing network approach to model the system in order to analyze the behavior of the system components and to evaluate the system performance. More specifically, a mean value analysis (MVA) is used to obtain the system performance measures, such as the overall throughput of the composite services (i.e., the number of composite services that a device provides per unit time), depending on the requirements for the amount of user context data. This can eliminate the need for time-consuming