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Editorial

Integration of Cloud computing and body sensor networks

1. Introduction

Wireless Sensor Networks (WSN) [1,2] are revolutionizing distributed sensing in a wide range of application domains, ranging from home automation to process monitoring, healthcare analysis, weather forecasting, military situation awareness, and traffic control. Sensor nodes in a WSN can generate a large amount of real-time, in-situ contextual data about a specific monitored space, e.g. agricultural field, city quarter, building, room, human body. The capabilities of a WSN do not only involve collection and forwarding of raw sensor readings, but also include in-node/in-network data processing (e.g. aggregation and merging) and, sometimes, in-network complex elaboration, such as event detection, object tracking and classification based on even sophisticated distributed classification algorithms.

A specific class of WSN is Body Sensor Networks (BSN) that represents an emerging platform for many human-centered applications, spanning from medical to sports performance monitoring, gaming, and social networking. As a result of the advancements of ubiquitous and increasingly powerful wearable devices, to support the wide variety of application contexts, there exists a growing number of health monitoring systems with sophisticated capabilities. Moreover, there is enormous public interest in products that allow individuals, ranging from children to elders, to monitor and improve their own health and lifestyle.

In a common healthcare scenario, assisted livings monitored by BSN are able to gather data streams to not only process in real-time but also store them into remote medical data repositories. This implies a huge amount of data to be transmitted, stored and analyzed. In the coming years, BSN are likely to be exploited to allow for implicit social interaction among people, who can exchange private/public information through their worn BSN nodes when they come into contact. BSN of co-located people can be also exploited as a mobile sensor infrastructure to support other context-aware applications such as disaster, medical emergency and mass event management. In such context, management of a large number of disparate BSN as well as cooperative BSN to support various applications is a crucial issue to deal with. Moreover, the huge amount of data, that a BSN is able to deliver, demands a powerful, scalable storage and processing infrastructure to perform both online and offline analysis of BSN data streams.

BSN, with their huge amount of gathered sensor data and their limited processing power, can be empowered by exploiting a Cloud computing infrastructure to realize an integrated platform that provides: (a) the ability to utilize heterogeneous sensors; (b) scalability of data storage; (c) scalability of processing power for different kinds of data analysis; (d) global access to the processing and storage infrastructure; (e) easy sharing of results; and (f) pay-as-you-go pricing for using BSN services.

In the last few years, there have been an increasing number of initiatives to develop distributed platforms based on BSN for e-Health applications. Many national and international research projects in academia, industry and government focus on the development and deployment of Health Care platforms in which wearable wireless sensors are attached to patients for enabling 24/7 monitoring of vital parameters, such as CodeBlue, DexterNet, and SPINE (Signal Processing In-Node Environment). Apart from companies working in the e-Health domain, there are also initial important investments in this field from Telecommunications operators that foresee e-Health at home as a strategic business. There are already several international forums (workshops and conferences) focusing on Health-Care and BSN: BSN, Bodynets, Pervasive Health, PETRA, and so on.

2. Motivations and challenges

The need of integrating BSN with Cloud computing can be motivated by discussing the following issues related to BSN:

Data management. BSN data management deals with how data is produced (also known as processed or raw sensor data streams), continuously and in real-time efficiently collected, stored and eventually transferred for processing. Such management may be distributed in time and/or space [3]. Time distribution refers to activities taking place at different times, while being coordinated to have a common goal. Space distribution means that activities may take place at different locations, while they are networked. A Cloud computing infrastructure can facilitate such data management through the provision of large-scale storage platform.

Data processing. The collected data from single BSN is usually processed to obtain higher level information and/or data cumulative charts related to a single monitored assisted living. In the presence of a large number of incoming sensor streams from multiple BSN, processing of data to produce critical information/decisions in real-time requires fast processing that is usually computation intensive. The exploitation of the computational resources of a Cloud infrastructure can fully support such demand of intensive computation power.

Data analysis. Annotated BSN datasets can be imported into analysis tools and data modeling is performed for further use in various applications and decision making systems. The analysis operations depend on suitable storage and middleware technologies to perform highly swift data processing. It can be availed by exploiting

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the processing power of Cloud to provide faster response. Moreover, workflow-oriented methods can be exploited to define effective automatic processes to extract knowledge from the annotated BSN datasets.

Application development. The development of large-scale BSN applications is a complex task, involving not only the programming in-the-small of the BSN worn by single assisted livings but particularly the programming in-the-large of applications able to coordinate distributed collection, processing and storing of body sensor streams produced by BSN in an application-specific context. To this purpose, Software as a Service (SaaS) [4] approach based on Cloud infrastructure, coupled with an efficient BSN framework, can be exploited. It is also important to define the paradigm that the SaaS approach could be centered on.

In this special issue, we are specifically interested in the integration of BSN with a Cloud infrastructure that poses challenges related to data management, developing and computing. In the following we first briefly enumerate the main BSN-related issues, followed by a more in-depth discussion of specific challenges regarding the integration of BSN with Cloud computing to perform effective distributed body sensor stream management and large-scale BSN application development.

Specific BSN issues to deal with [5] include:

Wireless communications. BSN mostly use wireless connectivity for data exchange. The wireless communications should be able to reduce interference and increase the co-existence of sensor nodes with other networked devices. This is to ensure that the functionalities of BSN nodes are not degraded due to the presence of other devices capable of possible interruption in seamless data transmission.

System interoperability. A BSN system requires ensuring seamless data transfer across different standards to promote information exchange, plug-and-play device interaction and uninterrupted connectivity.

Sensor heterogeneity. A BSN system should be capable of integrating various different sensors in terms of complexity, power efficiency, storage, and ease-of-use. Moreover, it should provide a common interface between the sensors and a storage service to facilitate remote storage and viewing of sensed data as well as access to external processing and networked analysis tools.

Security. Transmission of BSN data streams should be secured to prevent potential intruders.

Privacy. One key concern of BSN users is to protect the privacy of personal data. A BSN system should ensure that assisted living's privacy is maintained even when data is being analyzed using an external tool. In addition, social awareness and acceptance is required for wider applications of BSN.

Data validation and consistency. Data collected from multiple sensor nodes need to be collected and analyzed in a seamless fashion. BSN sensors are subject to inherent communications, hardware and network failures that may result in erroneous datasets. It is crucial that the sensed data is validated and data quality is maintained to reduce any noise in the data and identify possible weakness in the infrastructure.

System programming. Developing applications on BSN requires many efforts due to the lack of proper software abstractions and the difficulties in managing resource-constrained embedded environments. For these reasons, in the last years several frameworks and middlewares have been conceived and made available to support high-level programming of BSN applications. However, there is still the need of defining new paradigms and tools for a more effective programming of efficient BSN systems.

Development methodologies and tools. Apart from programming frameworks, the development of BSN applications needs to be tackled by exploiting specific software engineering methodologies able to support the development lifecycle of such systems: from analysis to implementation and deployment.

On the other hand, integration of BSN with a Cloud computing infrastructure poses the following major research challenges:

Interfacing the Cloud with BSN. There should be an interface between BSN resources and the Cloud fabric. Communication interfaces are to be built to manage network connectivity between BSN and the Cloud. BSN nodes may be exposed as Cloud services and indexed via indexing services. Provision should be offered to manage sensing processes and data. Sensor virtualization will therefore be a key approach. Moreover various services for the underlying sensor resources, such as power management, security, availability, and QoS, need to be specifically provided.

Sensor stream management. Data management will include data format conversion into standard formats, data cleaning and aggregation to improve data quality, and data transfer to storage Clouds.

Massive scale and real time processing. Integration of heterogeneous BSN generating big data is a challenge due to the amount of information that is required to be processed in real-time. If BSN is used to generate real-time multimedia content such as streaming video, audio and images, it poses additional challenges to efficiently and accurately process and store the data in a Cloud environment.

Complex event processing. Real-time data streams from BSN may trigger certain events and services in the Cloud. This data streams are analyzed and results are used in applications for decision making by identifying contextual and situational information/knowledge.

Advanced off-line data analysis and analytics. While heterogeneous and real-time BSN data feeds allow improving decision making by using data and decision-level fusion techniques, the definition of business intelligence tools to maximize knowledge extraction from massively collocated information (big data) in the Cloud is a challenge.

Large-scale computing frameworks. The allocation of computational and storage resources as well as data migration in the Cloud is critical when multiple BSN data sources are highly decentralized. This is particularly challenging when the data sets and their corresponding access/search services are geographically distributed within the Cloud.

Development methodologies and tools. The development of large-scale BSN systems is a complex task that needs suitable and effective software engineering methodologies/approaches. Specifically, an application needs to be designed at a higher level of modeling abstraction, implemented according to a given approach and then seamlessly deployed onto the distributed BSN/Cloud platform.

3. Related work

In the recent years, there have been an increasing number of initiatives to develop distributed platforms based on BSN mainly for e-Health applications. Many national and international research projects in academia, industry and government focus on the development and deployment of health care platforms in which wearable sensors are attached to patients for enabling round-the-clock monitoring of vital parameters. Examples of such projects include CodeBlue [6], DexterNet [7], SPINE [8–10], and Titan [11]. These systems provide programming abstractions based both on low-level TinyOS system programming for sensors, and on J2ME and Android API for mobile devices; however, they do not address the issues of integrating a Cloud infrastructure to provide extended scalability, seamless data streaming and data analysis.