 https://doi.org/10.1051/shsconf/202213903020

Suitability of self-organizing service composition approach for smart healthcare ecosystem: A study

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Abstract. Future IoT systems will be deployed in open environments where the functionality of millions of IoT devices that are heterogeneous will be abstracted. In such a large scale system manual service composition is not feasible and often erroneous. A self-organizing service composition is a well known approach to deal with the problems in IoT systems. In a self-organizing service composition, the service composition is a runtime and autonomous process and human intervention is minimal. The atomic components will interact among themselves in a decentralized manner to form complex composites according to a set of self-organizing rules. The features of a self-organizing software composition are aptly suitable for the IoT domain. Smart healthcare has provided affordable healthcare for patients and enables them to self manage emergencies. This paper aims to establish the suitability of a self-organizing service composition for the smart healthcare ecosystem with special focus on real time monitoring applications.

1 Introduction

An IoT system can be envisioned as a set of devices capable of communication, data storage, and transmission using wireless technologies. Computing technologies enable physical devices to be virtual abstractions. These abstractions are provided as automated services that improve human and machine interactions. The Internet of things has proliferated in many fields, including healthcare, termed smart healthcare. Smart healthcare ecosystems provide affordable healthcare to patients and enable them to self-manage emergencies. Remote health monitoring is one of the several advantages of a smart healthcare ecosystem. Using IoT, healthcare applications encompass various services, from helping patients manage severe chronic diseases to monitoring daily fitness goals [1].

The components in smart healthcare ecosystems are sensors and computing devices, and data storage components. Together with technologies such as wireless communication, data analytics, cloud computing, and fog computing, these components form the smart health care ecosystems. Sensors are used to continuously monitor the health vitals of the patients and transmit the data to the fog or cloud layer for processing using wireless communication

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technologies and networking protocols. Wearable and implantable devices also collect and transmit data, termed IoTD (IoT Data).Computing devices such as mobile phones collect data from patients using personal health applications. Electronic health records are an important source of data in the healthcare ecosystem and are often stored in data servers [2][3].

Cloud Computing provides resources for data storage and analysis. Physicians can analyse data stored in the cloud to monitor the patient's health and suggest treatment plans. The cloud has many benefits for long term data storage and analysis in healthcare. The challenge with cloud computing is latency. Fog Computing is used to reduce the latency in cloud computing [2].

Various applications, frameworks and technologies have been designed by researchers to provide quick and easy medical assistance to everyone [1]. Applications recommend treatment plans and services are provided based on patients' non-functional requirements. Providing these vital medical services can be enhanced by improving the service composition mechanisms [3].

A single service cannot meet a user's complex requirements. A composite service is composed of different services provided by different service providers in an IoT system to meet the users' requirements [4]. A composite service is combined using a service composition mechanism. Service composition in an IoT system is a complex task and is usually done manually. However manual service composition in IoT systems is not suitable for a large-scale IoT system.

A self-organizing service composition approach is a bottom-up process and is a well known technique to deal with the inherent problems in IoT systems (uncertainty, scale, dynamism, and complexity) [5].In this approach, service composition will be a runtime and autonomous process. The atomic services interact in a decentralized manner to form complex composites. The interaction between the atomic services is according to a set of self-organization rules. These rules are defined taking inspiration from biological and physical systems in nature. The services are composed at runtime and require minimal human intervention, unlike other service composition mechanisms. Self-organizing service composition is a novel method and one needs to explore the features of a self-organizing service composition approach and how it is the most suitable approach for large scale IoT systems.

In Section 2, we will discuss the components of a smart healthcare ecosystem and the applications in the IoT domain. Section 3, we will discuss the service composition process and list different service composition techniques and optimization algorithms used in service composition. In Section 4, we will analyse the suitability of the self-organizing service composition approach for a smart healthcare ecosystem. In Section 5, we will conclude by establishing the suitability of self-organizing service composition approach for a smart healthcare ecosystem.

2 Components of a smart healthcare ecosystem

IoT-based healthcare applications are on the rise and have several advantages. Some of the important benefits for the patient are easy access to healthcare at a low cost. The current pandemic has created an unprecedented need for healthcare professionals, and IoT-based health care applications can significantly help professionals treat patients quickly and remotely. In an IoT system, sensors continuously monitor the health vitals of the patient, and the information is sent to the healthcare professionals (doctors, nurses, paramedical professionals). This information enables them to treat the patients in hospitals or remotely monitor the patient [6].

Stationary medical devices and sensors are the basic building blocks of a smart healthcare ecosystem. Sensors can either be off-body sensors or on-body sensors[1]. An off-body sensor is in the surroundings of the patient and transmits the health vitals through low-power wireless technologies [7]. An on-body sensor is in close proximity to the patient's body and transmits the data. It can be a wearable sensor or an implantable sensor. Some of the sensors used in a smart healthcare ecosystem are electrocardiogram (ECG), temperature sensors, blood pressure, blood glucose, electromyogram, heart rate, and oxygen saturation rate sensors. Some of the medical devices and sensors are tabulated below [1, 2, 6].

Table1: Sensors and medical devices

Sensors and medical devices		
Scanner	Audio Sensors	Automated Insulin Delivery (Closed-Loop System)
Heart Monitor	Gyroscope	Coagulation Testing Device
Ventilator	Motion Sensors	GES(Gastro Electrolyte Analyser)
MRI Scanner	Accelerometers	Pacemakers
Pulse Indicator	Fitness Sensors	Deep Brain Stimulation
Sphygmomanometer	Proximity Sensor	Cochlear Implants
Glucometer	Real-Time Location Sensor	Gastric Electrical Stimulation (GES)
Blood Sample Analyser	Photoplethysmographic (PPG) Sensor	Implanted Insulin Pens
Oxygen Concentrator	Ultrasonic Sensor	Smart Pill Bottle

As sensors are resource-constrained devices, low power communication technologies are preferred [7]. Some of the low power communication technologies are Bluetooth low energy (BLE), Low power Wi-Fi, Zigbee, Low Power Wide-Area Network (LPWAN), and iBeacon. Other communication technologies used are satellite communication and NFC (Near field communication).NFC has RFID as its underlying technology, which is also used for remote health monitoring [2, 6, 7]. Wireless Body Area Network (WBAN) forms a network of sensors in smart healthcare applications to provide communication among sensors and actuators within, on, or anywhere close to a human body [2].

In a smart healthcare ecosystem, cloud computing provides configurable resources that can be accessed from anywhere and anytime through the Internet. In Health care applications, cloud computing stores data for long-term processing and analytics. Physicians can monitor a patient's health and suggest appropriate medication [2]. One of the challenges in cloud computing is latency. Storing and processing data using cloud computing is time-consuming and is feasible for emergency healthcare services. One way to reduce this latency is by using fog computing or edge computing. Fog computing allows sensors and network gateways store and perform preliminary data processing [2]. A fog node provides facilities that enable real time monitoring in healthcare applications [7]. The healthcare architecture used in smart healthcare ecosystems is depicted below [2]

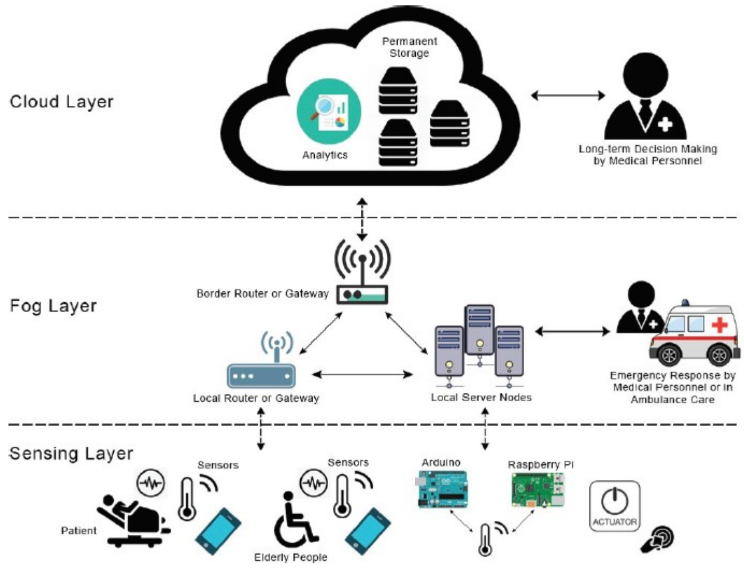

Fig. 1. Healthcare Architecture [2]

A smart healthcare ecosystem provides services for patients, including continuous real-time monitoring, chronic disease diagnosis, follow-up services, telemedicine services, and elderly health care services [2]. Real-time monitoring services are provided for patients with chronic illness, the elderly, and emergency services [8].Patients with chronic illness may require frequent hospitalization and continuous monitoring of health vitals such as ECG, blood pressure, oxygen rate, SpO2 levels, and monitoring of other health vitals. Healthcare applications have been developed for elderly patients. Their movements are remotely monitored in case of an emergency; the healthcare providers are immediately alerted for real-time monitoring of the patients.

3 Service Composition Process

The Service Composition approach starts with the service discovery process, a set of discoverable services are published by the cloud service provider. A context-aware approach to web service discovery is followed for personalized web service discovery [9]. N. Chen, N. Cardozo, and S. Clarke propose a self-organizing, goal-driven service composition model that enables task resolution and execution in mobile pervasive environments [10]. In order to support flexible service discovery they propose a decentralized heuristic planning algorithm. The second step in the service composition process is service selection. Many bio-inspired algorithms are used to select the optimal set of services according to the QoS parameters specified by the user. Some of the algorithms used in service task selection include the Artificial Bee Colony (ABC) algorithm, Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) algorithm. Other metaheuristic algorithms used for optimization of the service selection process are an improved max-min ant system (MMAS), matrix-coded genetic algorithm with collaboratively evolutional populations (MCGACEP), full connection-based parallel adaptive chaos optimization with reflex migration (FC-PACO-RM), and multi-objective hybrid artificial bee colony algorithm(MOHABC)[11].

The service composition follows service selection; the formal method used for service composition is generally a design time process using tools for service composition and formal verification. Service Composition is a NP-hard task, and various techniques have been used to solve the problems faced by service composition. P. Asghari, A. M. Rahmani, and H. H. S. Javadi present a systematic literature review classifying IoT service composition approach as functional properties approach and non-functional properties approach [4]. In the functional properties approach, they focus on the behaviour of the service composition.In non-functional properties approach, they study the aspects of service composition that consider the QoS factors of composited services. Marzieh Hamzei and Nima Jafari Navimipour study the efficiency of the service composition and categorize the service composition into framework, Service Oriented Architecture (SOA) and RESTful, heuristic, and model-based [12].The various service composition techniques found in literature are tabulated below [4, 12]

Table2: Service Composition Approaches

Formal methods	**Infrastructure based**
Timed automata	Energy-aware service discovery chains
Input/output (I/O) automata	Energy-aware cloud service composition(Energy based weather)
Timed automata	Energy Efficient multiple Cloud Computing (E2C2)
Team automata	Decentralized artificial potential fields
Petri nets	Smart home-care service composition
Coloured Petri net	Qos-based service reconfiguration method
Petri-net based model checking method	Bayesian classification technique
Process algebras	**IP-based service composition approaches**
Calculus of communicating systems(CCS)	Service co-location composition
Calculus of sequential processes(CSP)	Agent-based service composition
Algebra of communicating processes(ACP)	Interface-based service composition
Language of temporal ordered systems(LOTOS)	Dynamic mixed and Mashup platform
	High embedded smart platform

Model checking methods Kripke structure (ks)-based model checking method Probabilistic-based model checking method SLA-based real-time monitoring model **Model-based techniques** Dynamic selection model Decentralized coordination technique Directed graph composition scheme	**Multi-agent service composition approaches** User-centric service composition Third-party service composition Decentralized Service Mashups composition **Adaptive service Composition** Novel Petri net-based composition algorithm Trust-based social approach A dynamic service composition for services orchestration by using a heuristic planning technique Dynamic and adaptive service composition framework based on Weasel

Several optimization algorithms are used in service composition to improve the quality of service parameters [4, 12**]**.Some of the optimization algorithms are Ant colony optimization, Fruit fly optimization algorithm, Genetic-Particle Swarm Optimization (GPSO), Gray wolf optimization algorithm, Lion optimization algorithm, and Hybrid teaching–learning-based optimization. Aranelles and K. Lau present a review to address the functional scalability of service composition and propose six scalability factors based on the service composition mechanisms orchestration and choreography [13].

The last process in the service composition process is service execution. Many service composition algorithms are now incorporating adaptive service composition in order to protect against service failures that occur during the service composition process.

4 Suitability of the self-organizing service composition approach for a smart healthcare ecosystem

A self- organizing system provides robustness and adaptation to dynamic environments that are typical requirements in an IoT system. The inherent problems faced by IoT systems are

1. Dynamism: IoT systems face uncertain network environments, which may be due to poor device mobility or poor network connections [10].
2. Complexity: As the number of components increase , the number of interactions between the software components becomes larger and more complex [14].
3. Functional scalability: The functionality of one device can be virtualized by more than one software component.As the number of things and components increase, it leads to a combinatorial explosion problem [15, 16].

Self-organizing service composition is a well known bottom-up approach to deal with the inherent problems of IoT systems. Self Adaptation and Self-Organization differ in the adaptation mechanisms followed. Self-adaptation mechanism requires an adaptation manager (external controller) that controls the entire adaptation process [17].

In a self-organizing service composition, the services interact among themselves in a decentralized manner with the help of self-organizing rules that are based on biological and physical systems in nature. These rules are patterned as reusable bio-inspired mechanisms or patterns classified as basic mechanisms, composed mechanisms and top-level mechanisms[18].The mechanisms and their usage are tabulated below [18, 19]

Table 3: Bio-inspired mechanisms in self-organizing service composition

Basic mechanisms	**Aggregation Pattern**	Applies a fusion operator such as merging , filtering, transforming or aggregating, to the information and maintains only the relevant information.Reduces memory and network overload.
	Spreading Pattern	Increases the global knowledge among the agents. A copy of the information is progressively sent among the neighboring agents and reduces the lack of knowledge among the agents.
	Evaporation Pattern	In Evaporation the relevance of information is progressively reduced and recent information becomes more relevant
Composed mechanisms	**Gradient Pattern**	Provides Global Knowledge
Top-level mechanisms	**Gossip pattern**	Obtains a shared agreement regarding the value of certain parameters in the system in a decentralized way
	Chemotaxis Pattern	Perform motion coordination in large scale systems
	Morphogenesis Pattern	Depending on the agent's position in the system, it selects different agents
	Quorum Sensing Pattern	Uses local Interactions to estimate the number of agents

These patterns of a self- organizing system make the service composition pervasive, context-aware, adaptive and self-aware.

The features of a self-organizing service composition are [20]

i) Spontaneous and open interaction among the services, i.e., there is a seamless interaction among the services, and the model allows for dynamic deployment of new services.

ii) Context and situation awareness helps acquire information about the context and dynamic adaptation to context

iii) Mechanisms for Proxemic interactions and location-based activities aiding to deal with spatial information and support for navigation in such a space

iv) Self-adaptation which includes self-managing, self-healing, and self-configuring. Another feature of the services is the ability to self-organize their interaction patterns with little or no configuration and management.

The requirements of a smart healthcare ecosystem are adeptly satisfied by a self-organizing service composition.

The requirements of a smart healthcare ecosystem are [1]

- **Anticipatory-**In a self-organizing system, the agents interact with each other anticipating the response of the other agents they interact with [21].
- **Transparent-** Data transparency and data reliability is an important prerequisite for a smart healthcare ecosystem. A self-organizing system ensures data transparency, reliability, and cost effective methods for data distribution [22]

- **Ubiquity**- Robustness in a self- organizing service composition allows for anonymous and uncoupled interactions between the agents, the interactions being ubiquitous in nature [22]
- **Intelligence**-Agents in a self-organizing service composition are autonomous and capable of intelligent behaviour [21]
- **Context-aware**-Context awareness is an important feature in healthcare systems wherein the applications collect contextual information about the patient and use the same to make intelligent decisions [23]. Context-awareness is often developed as a system for healthcare applications [24], while context awareness is an integral feature of a self-organizing service composition in a self-organizing service composition [20].
- **Location and environment awareness:** In real-time and remote monitoring, a sudden emergency warrants proximity and location awareness. Some conditions are based on the geographical and climatic conditions of the place. With location awareness, the treatment is more customizable to the patients' preferences [25].
- **Adaptive**: A self-adaptive service composition is attuned to uncertainties caused by changes in the operational environment; it can resolve the uncertainties at runtime by collecting additional data about the uncertainties **[**17**].**
- **Service Availability**:-A review of the IoT healthcare monitoring applications finds that most real-time monitoring applications developed are not flexible. A flexible system allows for adding or removing IoT devices as per the requirements of the services performed [8]**.**In a self-organizing service composition, the system allows for dynamic deployment of new services that abstract the functionality of the devices that represent them.
- **Responsive-** The interactions between the agents in a self-organizing service composition are spontaneous and open. This makes it possible for the system to be responsive [20]
- **Connected-**Agents are connected. There is a seamless transfer of information between the agents **[**19]

5 Conclusion

Service composition is a complex process many researchers have tried to solve the problems in service composition. In this study, we found that the self-organizing service composition is most suited for the IoT domain, specifically for the smart healthcare ecosystem for all applications including real time monitoring applications.

Different researchers have tried to implement features in IoT service composition such as a context aware or location aware system, there are several solutions offered for self adaptability. However all the features desirable in the IoT domain such as efficient deployment of services, context awareness, location aware interaction among agents and self adaptation are all found in self- organizing service composition approach. The features of a self -organizing service composition are aptly satisfying the requirements of a smart healthcare ecosystem. Self-organisation provides systems with better scalability and robustness, the most important feature of the self- organization is run time composition of services where interactions among the agents are decentralized. Run time service composition is most feasible for large scale IoT systems as it can adapt to deployment of new services at runtime .Hence adding and removing of agents is simple and more efficient in a self organizing service composition. Since the self-organizing service composition offers all the features and advantages required for the IoT domain it should be considered for implementation especially for a smart healthcare ecosystem.

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