# Systematic Mapping Study on Osmotic Computing*

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***Abstract***. *Osmotic computing is an emerging research field that studies the migration, deployment and optimization of microservices over both edge and cloud infrastructures. In this paper, a systematic method was used to develop an osmotic computing map and to classify the existing papers. Each of 21 relevant studies are classified into categories in three different dimensions (publication type; applied methods and techniques; and paper maturity). The frequencies of each category show what kind of research was prevalent in the past to identify the gaps and new research possibilities. Osmotic computing is a new paradigm with many future research opportunities, such as configuration, networking, security, monitoring, and orchestration of microservices deployed on this complex environment.*

**Keywords.** Osmotic computing, cloud computing, edge computing, microservice

## 1 Introduction

In recent years, cloud computing is popular paradigm that enables flexibility and pay-as-you-go model for small and medium enterprises. Its three models (infrastructure as a service, platform as a service, and application as a service) cover many practical use cases. Some organizations use hybrid clouds where sensitive data and application are running locally, and computationally and storage intensive applications are running using public cloud providers' resources. Recently, some of the cloud resources are moving closer to users, e.g. new paradigms such as fog computing and edge computing emerge. These paradigms are driven mostly by Internet of Things (IoT) devices and services. Edge computing provide some processing and storage capacity near IoT devices (microcontrollers, actuators, sensors), without immediate usage of cloud providers' resources (e.g. Google Cloud, Amazon Web Services, or Microsoft Azure).

Osmotic computing is a new paradigm that aims at distributed and federated environments driven by increase in computing/storage capability at the edge, and enables the automatic deployment of microservices over both edge and cloud infrastructures (Villari, Fazio, Dustdar, Rana, & Ranjan, 2016). So, osmotic computing deals with deployment, networking, and security issues of services and microservices across cloud and edge, and providing reliable IoT support with specified levels of quality of service (Villari et al., 2016). For some use cases such as disaster management and healthcare, the prevailing cloud-centric IoT model needs to be revised into more adaptable and decentralized model. Osmotic computing decompose applications into microservices, and microservices in containers (e.g. Docker and Kubernetes) are deployed opportunistically in cloud and edge systems, following resource availability and application requirements.

The remainder of the paper is organized as follows. In Section 2, a brief description of osmotic computing is given. Section 3 and Section 4 show the key elements of the research protocol and describe how the mapping study was conducted. Section 5 reports the results of the mapping research. Finally, Section 6 lists the main themes of the primary studies, and Section 7 outlines the conclusions and proposes possible future research directions.

## 2 Osmotic Computing

Osmotic computing paradigm was introduced by (Villari et al., 2016). They have defined the osmotic computing and listed possible future works regarding this new paradigm. Villari et al. (2016) have proposed the following research directions: microservice configuration; microservice networking; microservice security; edge computing; microservice workload contention and interference evaluation; monitoring; and microservice orchestration and elasticity control. Their proposals for osmotic computing future research are summarized in Table 1.

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**Table 1.** Research directions for osmotic computing (Villari et al., 2016)

| Research direction | Description |
|---|---|
| Microservice configuration | - develop holistic decision frameworks that automate configuration selection across microservices in cloud and edge |
| Microservice networking | - development of interoperability layer for remote orchestration of heterogeneous edge devices<br>- metadata ontology for the characterization of federated networks in cloud and edge |
| Microservice security | - a coherent security policy within both cloud and edge to enable microservice execution and migration<br>- add security capabilities to the container engine |
| Edge computing | - understanding the types of microservices that would be more relevant to execute at the edge than at the cloud, and vice versa |
| Microservice workload contention and interference evaluation | - novel microservice consolidation techniques that can dynamically detect and resolve resource contention via microservice performance characterization, workload prioritization, and coordinated deployment |
| Monitoring | - need to investigate scalable metrics across multiple levels of osmotic computing |
| Microservice Orchestration and Elasticity Control | - investigation of machine learning techniques for developing predictive models to forecast workload input and performance metrics across multiple microservices on cloud and edge |

# 3 Systematic Mapping Methodology

To present the summary of the existing work, the method of systematic mapping study was chosen. The main aim of these studies is to give an overview of a research field. Petersen et al. - (Petersen, Feldt, Mujtaba, & Mattsson, 2008) and (Petersen, Vakkalanka, & Kuzniarz, 2015) listed five essential steps to perform a systematic mapping study in software engineering:
1. Definition of research questions – Research questions are specified to determine the research scope of the systematic mapping study.
2. Conduct search – Studies are found by executing a search string derived from research questions on scientific databases.
3. Screening of papers – Irrelevant papers are excluded based on the defined inclusion and exclusion criteria.
4. Keywording using abstracts – In this step, researchers need to read abstracts, look for keywords (main concepts) and build classification scheme.
5. Data extraction and mapping of studies – The relevant studies are presented and summarized in the form of a systematic map.

## 3.1 Research Scope of the Systematic Mapping

Research questions were defined to be answered by means of systematic mapping study:
RQ1: What types of papers are published in the osmotic computing?
RQ2: What are the most used techniques/methods for osmotic computing papers?
RQ3: What is the maturity of osmotic computing papers?

## 3.2 Conduct Search

The studies were identified by using a search string "osmotic computing" on the following databases: IEEE Xplore, Scopus, INSPEC, and Web of Science Core Collection. The full text search was performed on 19th April 2019. A total of 106 publications were identified and their distribution per scientific database is shown in Table 2.

**Table 2.** Distribution of the found publications

| Source | Number of publications |
|---|---|
| IEEE Xplore | 37 |
| Scopus | 26 |
| INSPEC | 30 |
| Web of Science | 13 |

## 3.3 Screening of Papers

Irrelevant studies (publications that are not relevant to answer the stated research questions of the systematic mapping) were excluded based on the analysis of their titles, abstracts and keywords. Book chapters, scientific conferences and journal papers on osmotic computing were included. Duplicate studies and papers not written in English were excluded. If several papers reported the same findings, only the newest work was included. If abstract was not good enough to determine whether the focus of the work is on osmotic computing, introduction and conclusion was read to determine whether to include this article or not. Finally, the list of all 21 studies considered to be relevant is listed in Table 3.

**Table 3.** List of relevant studies

| Id | Authors | Paper title |
|---|---|---|
| P1 | (Pacheco, Cano, Flores, Trujillo, & Marquez, 2018) | A Smart Classroom based on Deep Learning and Osmotic IoT Computing |
| P2 | (Filocamo et al., 2018) | An Innovative Osmotic Computing Framework for Self Adapting City Traffic in Autonomous Vehicle Environment |
| P3 | (Buzachis & Villari, 2018) | Basic Principles of Osmotic Computing: Secure and Dependable MicroElements (MELs) Orchestration Leveraging Blockchain Facilities |
| P4 | (Sharma, You, Kumar, & Kim, 2017) | Computational Offloading for Efficient Trust Management in Pervasive Online Social Networks Using Osmotic Computing |
| P5 | (Morshed et al., 2017) | Deep Osmosis: Holistic Distributed Deep Learning in Osmotic Computing |
| P6 | (Oyekanlu, 2018a) | Distributed Osmotic Computing Approach to Implementation of Explainable Predictive Deep Learning at Industrial IoT Network Edges with Real-Time Adaptive Wavelet Graphs |
| P7 | (Okafor, Ugwoke, & Obayi, 2017) | Evaluation of virtualized osmotic cloud network using discrete event Branch-and-Bound heuristics |
| P8 | (Carnevale, Celesti, Galletta, Dustdar, & Villari, 2018) | From the Cloud to Edge and IoT: a Smart Orchestration Architecture for Enabling Osmotic Computing |
| P9 | (Sharma, Srinivasan, Jayakody, Rana, & Kumar, 2017) | Managing Service-Heterogeneity using Osmotic Computing |
| P10 | (Gamal, Rizk, Mahdi, & Elnaghi, 2019) | Osmotic Bio-Inspired Load Balancing Algorithm in Cloud Computing |
| P11 | (Oyekanlu, 2018b) | Osmotic Collaborative Computing for Machine Learning and Cybersecurity Applications in Industrial IoT Networks and Cyber Physical Systems with Gaussian Mixture Models |
| P12 | (Villari et al., 2016) | Osmotic Computing: A New Paradigm for Edge/Cloud Integration |
| P13 | (Villari, Galletta, Celesti, Carnevale, & Fazio, 2018) | Osmotic Computing: Software Defined Membranes meet Private/Federated Blockchains |
| P14 | (Nardelli, Nastic, Dustdar, Villari, & Ranjan, 2017) | Osmotic Flow: Osmotic Computing + IoT Workflow |
| P15 | (Rausch, Dustdar, & Ranjan, 2018) | Osmotic Message-Oriented Middleware for the Internet of Things |
| P16 | (Souza, Cacho, et al., 2018) | Osmotic Monitoring of Microservices between the Edge and Cloud |
| P17 | (Buzachis, Galletta, et al., 2018) | Towards Osmotic Computing: Analyzing Overlay Network Solutions to Optimize the Deployment of Container-Based Microservices in Fog, Edge and IoT Environments |
| P18 | (Buzachis, Bernava, Busa, Pioggia, & Villari, 2018a) | Towards Osmotic Computing: Future Prospect for the Health Information Technology (HIT) Systems of ISASI-CNR (ME) |
| P19 | (Buzachis, Bernava, Busa, Pioggia, & Villari, 2018b) | Towards the Basic Principles of Osmotic Computing: A Closed-Loop Gamified Cognitive Rehabilitation Flow Model |
| P20 | (Longo, De Matteis, & Zappatore, 2018) | Urban Pollution Monitoring Based on Mobile Crowd Sensing: An Osmotic Computing Approach |
| P21 | (Souza, Wen, et al., 2018) | Using Osmotic Services Composition for Dynamic Load Balancing of Smart City Applications |

# 4 Classification Scheme

The next step proposed by (Petersen et al., 2008) is to read abstracts of the selected primary studies and write out relevant keywords and concepts to understand the contributions of each study. This helps to define a set of categories. Using this technique, data aimed at answering three research questions of this systematic mapping study was collected. For each of 21 relevant studies, a form was filled in Excel file. In this work, publications are classified into categories in three different dimensions. Dimensions and their corresponding categories are presented in Table 4.

**Table 4.** Classification dimensions and their categories

| Dimension | Categories |
|---|---|
| publication type | book chapter, conference paper, journal article |
| applied methods and techniques | blockchain, machine learning, simulation |
| paper maturity | review/initial work, use case/prototype, model/framework/middleware, architecture |

# 5 Mapping

Next, the relevant papers are sorted into the established classification schema. One paper can be mapped to multiple categories, so the total numbers on sides of the map may not be equivalent. The frequencies of each category show what kind of research was prevalent in the past and then gaps and new research possibilities can be identified. In this work, the results will be shown as answers to research questions stated in the first step of systematic mapping study process.

RQ1: What types of papers are published in the osmotic computing? Of 21 primary studies 15 are conference papers, and 6 are journal paper. We did not find any book chapter on the osmotic computing topic. This is expected, because osmotic computing term was coined in 2016, so we expect more journal paper and book chapters in the future.

RQ2: What are the most used techniques/methods for osmotic computing papers? Many papers are actually review papers, initial work, and use cases, so they do not use specific technique or method. The remaining papers use the most machine learning methods. For example, three papers use deep learning (P1, P5, and P6). Ant colony and artificial bee colony methods are used in two papers (P4 and P10), and one paper (P11) uses Gaussian Mixture Models. Except machine learning, P7 uses simulation (more concretely, discrete event simulation heuristics; and two papers use blockchain technology (P3 and P13).

RQ3: What is the maturity of osmotic computing papers? Since osmotic computing term was coined in 2016, it is not surprise that this is new research field which is not mature yet. Research directions listed in Table 1 in this work, are mostly not accomplished yet. Most of the primary studies are classified into use case/prototype category (P1, P4, P6, P8, P13, P16, P18, P19) and review/initial work category (P3, P5, P12).

# 6 Themes of the papers

In this section, main themes of the 20 primary studies will be listed. The first paper – P12 (Villari et al., 2016) that uses the term osmotic computing was described in Section 1 and Section 2 of this work, so we will not include it in this section. The main themes are shown in Table 5.

**Table 5.** Main themes of primary studies

| Id | Main theme |
|---|---|
| P1 | An osmotic computing architecture for an IoT smart classroom is used for testing a deep learning model for person recognition. A smart classroom prototype was implemented for testing deep learning inferences on each one of these layers. |
| P2 | Proposal of an innovative Osmotic Computing solution for self-adapting city traffic in autonomous vehicle environment. |
| P3 | Proposal of a MELs orchestration approach through a Software Defined Membrane (SDMem) that leverages blockchain facilities obeying the osmosis principles. |
| P4 | A pervasive trust management framework is presented for pervasive online social networks. The concept of osmotic computing is used to perform computational offloading. |
| P5 | The paper analyses the research challenges involved with developing a class of holistic distributed deep learning algorithms that are resource and data aware and are able to account for underlying heterogeneous data models, resource (cloud vs. edge vs. mobile edge) models, and data availability while executing-trading accuracy for execution time. |
| P6 | An osmotic computing approach is used to illustrate how distributed osmotic computing and existing low-cost hardware may be utilized to solve complex, compute-intensive Explainable Artificial Intelligence (XAI) deep learning problem from the edge, through the fog, to the network cloud layer of IIoT systems. |
| P7 | Using discrete event simulation heuristics to evaluate the osmotic distributed data centre network for smart grid service provisioning. This paper has presented a heuristic validation summary for osmotic computing network leveraging cloud elasticity concept for deviation correction in terms of cost and efficiency. |
| P8 | The paper presents a first version of the osmotic computing architecture, focusing just on the microservices deployment aspect. Indeed, the design of the Osmotic Smart Orchestrator has been investigated, presenting different enabling technologies, use cases related to osmotic component registration, orchestration training and prediction and microservices deplyment. Therefore, the core of the orchestration process will be an Artificial Intelligence (AI) module that will learn through the monitoring of the Osmotic resources deployed on cloud, edge and/or IoT. |
| P9 | A fitness-based osmosis algorithm is proposed to provide support for osmotic computing by making more effective use of existing fog server resources. The proposed approach is capable of efficiently distributing and allocating services by following the principle of osmosis. The results are presented using numerical simulations demonstrating gains in terms of lower allocation time and a higher probability of services being handled with high resource utilization. |
| P10 | Since the hybrid artificial bee colony and ant colony optimization proved its efficiency in the dynamic environment in cloud computing, the paper then exploits the advantages of these bio-inspired algorithms to form an osmotic hybrid artificial bee and ant colony (OH_BAC) optimization load balancing algorithm. |
| P11 | Several GMMs including 2-GMM and 3-GMMs are constructed using the C28x DSP and Embedded C to show that GMM designs could be achieved in form of an osmotic microservice from the IIoT edge to the IIoT fog layer. The osmotic collaborative computing method advocated in this paper will be crucial in ensuring the possibility of shifting many complex applications such as novelty detection and other machine learning based cybersecurity applications to edges of large scale IoT networks using low-cost widely available DSPs. |
| P13 | This paper aims to use a federated blockchain (based on a private version of blockchain where stakeholders interact with each other) working on a distributed Registry (e.g. Fabric, Sawtooth, etc.) to track all data operations during interactions. |
| P14 | In the osmotic flow model, an IoT workflow application is modelled as a directed (potentially cyclic) graph with data transformation tasks as its nodes, and dataflow dependencies (or control flow dependencies for computational synchronization, if/as needed) between data transformation tasks as its vertices. |

| | |
|---|---|
| P15 | The paper proposes an architecture based on two diffusion models: broker and client diffusion. From a static centralized deployment in the cloud, we bootstrap a network of brokers that diffuse into the edge based on resource availability, and the number of clients and their proximity to edge resources. |
| P16 | A monitoring system for osmotic computing that implements the proposed unified monitoring model is proposed. They conduct extensive experimental evaluation of osmotic monitoring system in order to study the scalability of the proposed solution. |
| P17 | This paper investigates connectivity issues leveraging different network overlays. In particular, the authors analyse the performance of four network overlays (OVN, Calico, Weave, and Flannel). |
| P18 | They motivate the need to move the traditional HIT systems into innovative infrastructures based on the osmotic computing paradigm. In particular, they introduce two real uses cases, Ataxia and Dyslexia projects. |
| P19 | The authors propose a possible OC flow model applied to a real gamified cognitive rehabilitation use case. Moreover, this cognitive rehabilitation use case introduces the development of a customized virtual reality system based on a serious game which allows the patient to carry out physical and cognitive rehabilitation therapies using a natural user interface based on Microsoft Kinect. |
| P20 | This work focuses on the design and the development of the middleware which integrates data coming from mobile and IoT devices specifically deployed in urban contexts using the osmotic computing paradigm. |
| P21 | The authors propose an Osmotic Execution Framework that leverages state-of-the-art microservices techniques to deploy and execute a smart city application in a distributed environment including edge and cloud. |

# 7 Conclusion

This work represents the current state-of-the-art of the new paradigm called osmotic computing by using a systematic mapping method. Maturity of the existing work is still low, the most papers are classified into review/initial work category and use case/prototype category. The most promising future research themes are configuration, networking, security, monitoring, and orchestration of microservices deployed on different elements of osmotic computing. The most promising methods to solve the mentioned issues are different types of machine learning algorithms. Some of the works use deep learning and other types of machine learning, but many possible applications and different machine learning algorithms have still not been used in osmotic computing. Furthermore, many existing papers lack real (industrial) use cases and many research directions listed in Table 1 of this work are not adequately solved yet. Osmotic computing remains complex research and practical problem and many challenges are not yet adequately tackled, so there are many possibilities for future research on osmotic computing issues. For now, there is also a lack of application of osmotic computing in an industrial area, so future will show the acceptance of this new computing paradigm in the industry.

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