A Systematic Review of Scheduling Algorithms and Resource Management in Context-aware Applications: A Meta-analytic Approach

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Abstract: Computer resource management and scheduling algorithms have been exploited in order to run applications in an efficient and effective way. Since this area is heavily exploited and has a range of application domains, it is possible to apply various techniques from other distributed computing areas, such as context-aware applications. In this paper, we present a systematic literature review that addresses context-aware applications with resource management and scheduling algorithms. In total, 11 studies were selected from years 2000 to 2017, which covered the inclusion criteria of this systematic review, presenting techniques and improvements for the area. From the analyzes of the selected studies, it was found a diversity of application domains using a variety of technologies.

1 INTRODUCTION

A number of resource management and job scheduling techniques are currently being used in various types of high-performance applications. With computing resources and the need to efficiently perform job scheduling in applications, the administrator must have some functions such as optimizing the use of resources, minimizing the jobs waiting time, reducing energy consumption, reducing the cost to complete an application and performing resource management (Paul and Aggarwal, 2014).

With a large number of available applications and evaluation methods, many approaches have been proposed to improve resource and job managements. Context-aware computing is one of the areas that has been highlighting, where systems are able to adapt to the environment. Since this area is relatively new and it is closely linked to distributed computing, it is necessary to identify and understand contributions, authors and institutions that maintain relevant publications. Without this factor, it is difficult to identify domains that may receive further research in the future.

In this systematic review, we present the results of studies found in the literature that address the research topic, in order to explore context-aware systems related to resource management and job scheduling. In this way, we seek to present the state of the art through a meta-analytic approach, analyzing authors, institutions and other aspects.

Four digital libraries that index computing studies were used, and papers from years 2000 to 2017 were analyzed. After the selection by the inclusion criteria and three stages of papers analysis, 11 studies were selected.

The structure of the present review is presented as follows. In the next section the research protocol used in this review is presented. The Section 3 presents an overview of the selected papers. The Section 4 presents the results obtained from the search performed through a meta-analytic approach. The Section 5 discusses limitations of this study and in Section 6 the final considerations are presented.

2 RESEARCH PROTOCOL

A systematic literature review is a process based on necessary information to identify, evaluate and select relevant studies in the area of interest. It is a process controlled by a research protocol defined at the beginning of the systematic review to provide consistency and robustness in the results (Tranfield et al., 2003).

As a first step, a research protocol was developed for selection of the studies in this systematic review.

In order to be selected (in addition to the inclusion criteria), the published studies: (1) must that have a relationship with scheduling algorithms on any context-aware platform or (2) application with context-aware resource management.

The search was performed in four digital libraries: *IEEE Xplore*, *SpringerLink*, *ACM Digital Library* and *Scopus*. The digital libraries were chosen according to affinity with the computing area. Firstly, a primary word was chosen and then, it was combined with words related to the area. The word combinations used on all platforms are shown in Table 1.

Table 1: Combinations used in the searches.

"Context awareness AND job scheduling"
"Context awareness AND resource manager"
"Context awareness AND job management system"

The databases searches were set up so that the resulting studies presented at least one of the word combinations in title, abstract or keywords. In each digital library it was necessary to configure the search to retrieve only studies related to the research area. For searches performed in the IEEE Xplore database, the advanced search was used to selected only conference publications, as well as studies published in journals and magazines. For searches performed in the ACM Digital Library, only studies published in conferences and magazines were selected. For SpringerLink searches, studies published in conferences and journals were selected, belonging to *Computer Science* and *Software Engineering/Programming and Operating Systems* sub-areas. For Scopus searches, only studies in the sub-areas corresponding to Computing were selected.

For papers selection, the studies should meet the following pre-established inclusion criteria: (1) complete study, starting from 5 pages, (2) published in congresses or journals and available in one of the four databases, (3) related to context-aware applications with scheduling and resource management techniques, (4) published in English, (5) published between 2000 and 2017 and (6) available for access in the CAPES portal (CAPES, 2017).

2.1 Keywords Definition

This subsection presents concepts related to knowledge areas involved in this systematic review, including context-awareness, resource manager, job scheduling and job management system.

- **Context-awareness:** *context* can be interpreted as "any information that can be used to characterize the situation of an entity (person, place or object) that is considered relevant to the interaction between the user and an application, including the user and application themselves" (Dey, 2001). *Context-awareness*, in turn, allows the modeling of systems that are able to get contextual information from circumstances in which they operate, reacting to that context based on rules or artificial intelligence. In the last years, this concept has come to be considered part of a process that involves the user, thus producing general and sophisticated contexts models (Abowd et al., 1998) (Yürür et al., 2016).

- **Resource Manager:** the main functions are related to receiving job requests for execution, allocating and monitoring resources. The manager must also be smart enough to leave the running nodes idles as short as possible (Eijkhout, 2014).

- **Job Scheduling:** the scheduling algorithm is responsible for receiving and responding to user requests, which implies deciding when and where the execution for each request will begin. Since there can be multiple concurrent requests, conflicts occur and they must be resolved through the scheduling algorithm (Yahyapour, 2002) (Hovestadt et al., 2003).

- **Job Management System:** the job management system is a component in the cluster that is responsible for controlling jobs of the users. The main goals of the job management system are to efficiently use the nodes, provide a job submission interface for users and allow the users to configure their cluster (Eijkhout, 2014).

2.2 Data Selection and Collection

The first step of this systematic review was the removal of duplicate papers in the databases, and studies that did not meet the initial inclusion criteria. Subsequently, the titles, keywords and abstract of each study were read. According to the inclusion criteria for this review, studies were included when they meet these criteria in the title, keywords or abstract. After the selection of the studies, information and basic characteristics of each one were extracted such as title, authors, keywords, abstract and authors affiliation. We also analyzed locals of publications, citations of all studies, frequency of words, among other information to build the present review.

With the searches performed, 34 articles were found using the pre-established combinations. Of these, 2 articles were excluded because they were duplicated in the databases or did not meet the inclusion criteria, leaving 32 articles for title, keywords and abstract readings. From these readings, 11 articles were

Table 2: Papers selected and general information.

Approach	Selected Through	Database	Published in	Impact Factor	Citations
Context-aware job scheduling for cloud computing environments (Assunção et al., 2012)	Title, abstract and keywords	IEEE Xplore	IEEE Fifth International Conference on Utility and Cloud Computing (UCC)	-	26
CASH: context-aware scheduler for Hadoop (Kumar et al., 2012)	Title and abstract	ACM Digital Library	International Conference on Advances in Computing, Communications and Informatics	-	28
Interaction-aware energy management for wireless network cards (Crk et al., 2008)	Keywords	ACM Digital Library	ACM SIGMETRICS Performance Evaluation Review	-	16
A context-aware approach to emergency management systems (Bhavanishankar et al., 2009)	Title and abstract	ACM Digital Library	International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly	-	9
Bridging the application knowledge gap: using ontology-based situation recognition to support energy-aware resource scheduling (Hähnel et al., 2014)	Abstract	ACM Digital Library	13th Workshop on Adaptive and Reflective Middleware	-	-
On improving resource utilization and system throughput of master slave job scheduling in heterogeneous systems (Hsu et al., 2008)	Title and keywords	SpringerLink	The Journal of Supercomputing	1.326	16
Performance evaluation of a discovery and scheduling protocol for multihop and hoc mobile grids (Gomes et al., 2009)	Title, abstract and keywords	SpringerLink	Journal of the Brazilian Computer Society	0.707 (printed)	9
Big media healthcare data processing in cloud: a collaborative resource management perspective (Das et al., 2017)	Abstract and keywords	SpringerLink	Cluster Computing (The Journal of Networks, Software Tools and Applications)	2.040	1
Building mobile multimedia services: a hybrid cloud computing approach (Kovachev et al., 2014)	Abstract	SpringerLink	Multimedia Tools and Applications	1.530	26
Supporting ubiquitous IMS-based teleconferencing through discovery and composition of IMS and web components (Doolin et al., 2008)	Keywords	SpringerLink	Journal of Network and Systems Management	1.588	7
Bringing context to Apache Hadoop (Cassales et al., 2014)	Abstract and keywords	Scopus	8th International Conference on Mobile Ubiquitous Computing	-	3

selected because they covered the initial inclusion criteria of this review. The Figure 1 illustrates the studies selection protocol applied in the papers.
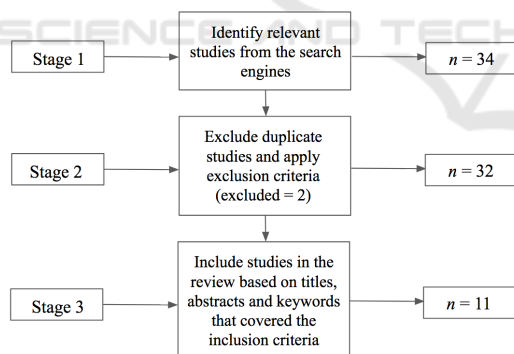

Figure 1: Stages of the study selection process.

3 SELECTED WORKS

Through the methodology used in this SMS (Section 2), 11 papers were selected. An overview of the characteristics of the studies are presented in Table 2.

Assunção et al. (2012) presented a model that aims to rationalize the use of computational resources in cloud environments, combining context awareness techniques and an adaptable job scheduler. Through the analyzes performed with social simulations, gains were obtained in terms of performance, quality of service and reduction of wasted jobs. Kumar et al. (2012) proposed a new context-based scheduling algorithm for Hadoop (CASH), in order to make the scheduler aware and take advantage of the cluster's heterogeneity. Crk et al. (2008) proposed mechanisms that are aware of user interaction through screenshots and mouse events classification. The approach produces significant improvements in terms of energy savings, accuracy, punctuality and computational overhead. Bhavanishankar et al. (2009) proposed an emergency management architecture that processes request layers with a context-aware approach. The proposal performs event management, time management and computational resource management. Hähnel et al. (2014) presented a generic approach to resource management based on ontology, where the task scheduler is context-aware and it gets information about application execution. Experiments have shown that the system can perform situation recognition for resource management within 4 seconds. Hsu et al. (2008) presented an efficient strategy for master slave job scheduling in heterogeneous underlying networks. The experiments compared with other algorithms presented higher throughput and response time. Gomes et al. (2009) presented a discovery and scheduling protocol for mobile ad-hoc networks. The experiments presented positive results in load balancing between nodes, reduc-

ing runtime and maintaining acceptable levels in mobility scenarios. Das et al. (2017) presented a local and global cloud confederation model for executing heterogeneous requests, in order to support services that involve health data processing. Kovachev et al. (2014) proposed i5CLoud, a hybrid cloud architecture for scalable and fast mobile multimedia services for the market. In the experiments performed, participants evaluated the quality of context-aware services provided by i5CLoud, completing short-term tasks that simulated documentation in a cultural heritage. Doolin et al. (2008) addressed a research approach that combines generalized computing techniques with IMS network principles to facilitate composition of communication sessions based on the context of users. Finally, Cassales et al. (2014) presented improvements to Hadoop, by introducing context awareness into scheduling algorithms. Experiments have demonstrated that context awareness allows Hadoop to scale based on real availability of resources, improving task allocation patterns and rationalizing the use of resources in heterogeneous dynamic networks.

4 RESULTS OF THE REVIEW THROUGH A META-ANALYTIC APPROACH

After the application of the research protocol and the inclusion/exclusion criteria in the papers, a meta-analytic approach was performed in the resulting studies. The meta-analysis has taken several aspects into consideration, which are presented in the following subsections.

4.1 Authors Affiliations

First, it was analyzed the affiliation location of all authors, illustrated in Figure 3. All affiliations were analyzed, since several studies have authors from different institutions and countries. For this reason, the sum of the affiliations in the Figure 3 exceeds the total of papers selected in the review. From the obtained data, we can observe the great distribution of countries that make researches related to the area. This may be due to the fact that it is a new area with many questions to be addressed.

4.2 Citations and Locals of Publication

Table 2 presents the total number of citations that each study obtained. We can observe that even though the

studies are relatively new, the studies present a relatively high citation total, which represents an area of great scope and growth.

We can also observe in Table 2, information that was collected on papers publication. Of the 11 selected studies, 5 studies were published in journals and there is a great diversity of publication vehicles. It is important to note that all journals have an impact factor according to their respective websites and, considering the scope of published journals, this area opens up several possibilities for research. Among the journals, it is possible to observe that some of them have a well-open scope for computing, whereas others are of a very specific scope, such as *Multimedia Tools and Applications* and *Journal of Network and Systems Management*. The rest of the studies were published in international congresses, in which we can observe consolidation in large areas and acceptation of context-aware applications.

4.3 Publication Year

Figure 2 illustrates the number of studies selected per year of publication. We can observe that the studies were published in a maximum of 10 years, showing that it is a relatively new research area.
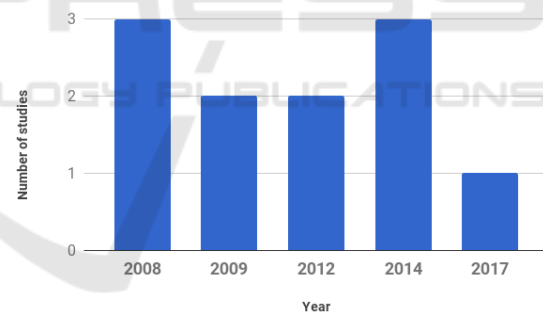

Figure 2: Publication year of the studies.

4.4 Words Frequency in Abstracts

Figures 4 and 6 show the frequency of words in the abstracts of all the selected studies. As we can observe, there are a lot of platforms such as *Cloud Computing* and *Grids*, which appear more often, since contextual searches represent a recent area of research. The observed frequency is due to the fact that cloud computing and grids are taking the place of clusters since around 2007 and represent hot topics due to their abilities (Wang et al., 2008).

There is a great use of words related to energy management, computer networks, architecture and resources, which represent areas with many issues to be
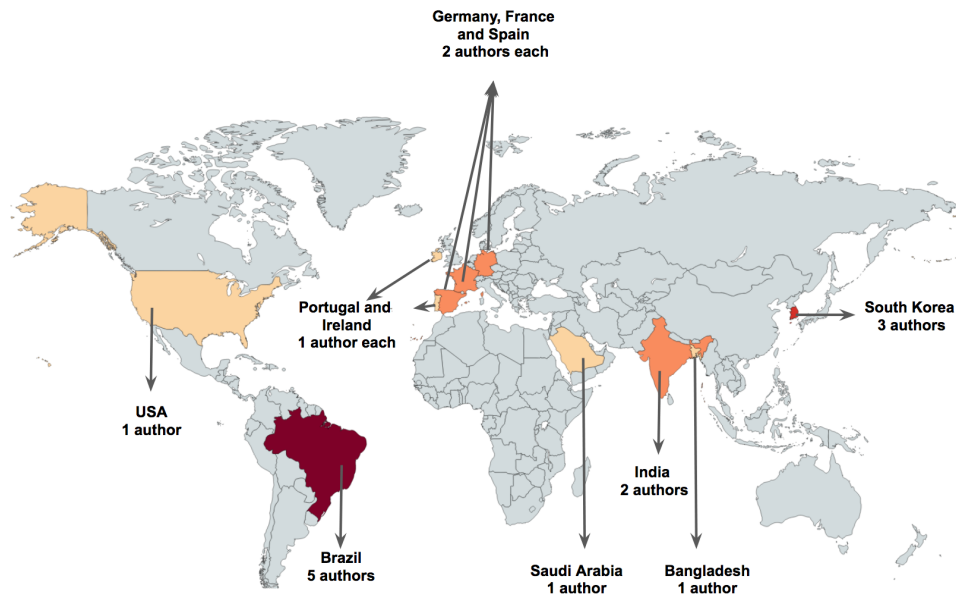
Figure 3: Authors affiliation.

answered, especially with respect to energy management. Likewise, there are terms widely addressed in the studies, such as ubiquitous computing, pervasive computing, and virtualization. It is important to note that the concept *context-awareness* was not taken into account, since it is one of the primary words of the search for this systematic review.
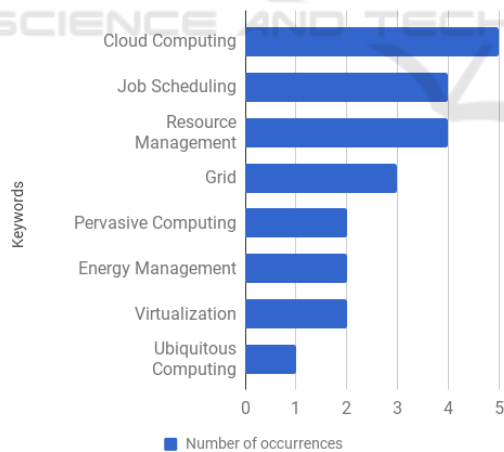

Figure 4: Number of occurrences of keywords.

4.5 Total of Papers by Subarea

Since this area is in great expansion, we approach all types of resource management and job scheduling, therefore, the selected studies address different areas. In this way, subareas were created from the selected studies, in which it is possible to classify the studies.

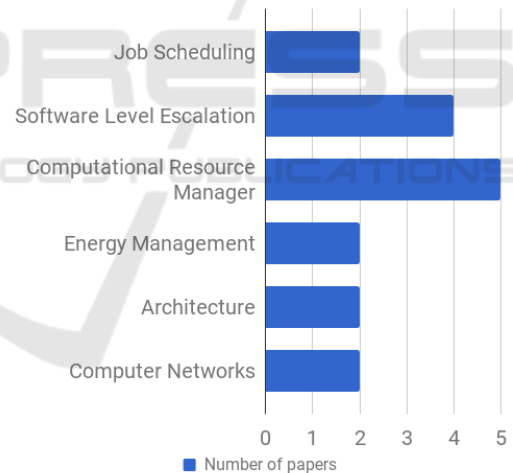The Figure 5 illustrates the total number of studies by main subarea and papers classified in more than one subarea.

Figure 5: Total of papers by subarea.

5 LIMITATIONS

Although the search protocol was designed to cover the largest number of studies related to the area, some studies could not be included, since it was necessary to limit the terms searched to include the databases and the period of publication previously mentioned. Following the research protocol and the large number of papers, in the Springer and Scopus databases it was necessary to select only one category and one subcategory, thus explaining possible studies missing

ad applications approach aware cloud cluster communication computing context context-awareness data development discovery efficient energy environment execute fnf grids hadoop heterogeneous hoc improvement ims jobs management mapreduce mechanisms mobile model multimedia network nodes paper performance pervasive processing propose protocol require resource results scheduling services session systemtask techniques technologies users
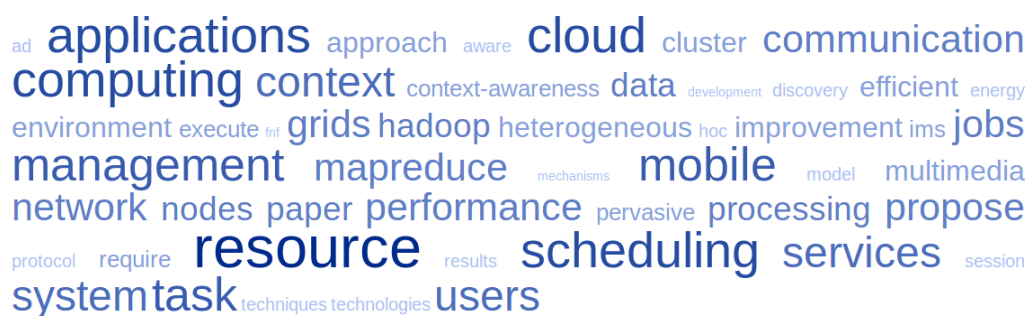
Figure 6: Words frequency in the studies abstracts.

on these search engines.

Another critical point concerns the different terminologies used in the studies. Although there is a similarity between the terms, some studies use the terms differently, which may lead to the exclusion of some studies. To avoid misclassification, we adopted an accepted definition for the keywords used throughout this systematic review.

Some studies may also have been excluded because of the publication date, since this review retrieved publications only from 2000 to 2017. Previous studies, or studies that were published since then could meet the review criteria. Even in this period, studies may have been excluded by title, keywords and abstract readings for not clearly containing the objectives.

Due to the fact that the context-aware computing is a recent area applied to high-performance computing, it would be possible that we would not find many studies if the inclusion criteria were restricted, so this systematic review addressed all methodologies for resource management and scheduling algorithms, independent of the platform that was carried out in the studies. Despite this, only 11 papers were selected to compose this systematic review, indicating a very low number of relevant researches that effectively covered the areas of interest and the pre-defined criteria.

6 CONCLUSIONS

The use of resource management systems and scheduling algorithms applied to distributed systems and applications can be performed in several ways, always taking into account the needs of each user. Due to this area have several applications, we seek to find and classify studies related to context-aware computing.

This systematic literature review on context-aware applications with resource management systems and scheduling algorithms in systems and clusters pre-

sented different application domains. Since it is a relatively new area of distributed platform research, several subareas have been found and categorized in this review.

After the primary and secondary selections, 11 complete studies were analyzed. In this context, after an analysis of the title, keywords and summary of the selected studies, a meta-analytic approach was presented, showing the main studies in the field, publication locals, countries with more authors and the most recurrent terms.

From these considerations, our future work includes analyzing and validating the experiments of the present study, and implementing the same protocol in a broader area of context-aware applications. Also, we aim to expand the qualitative analysis performed and provide recommendations to the professionals that can be useful as a guide for further research.

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REFERENCES

Abowd, D., Dey, A. K., Orr, R., and Brotherton, J. (1998). Context-awareness in wearable and ubiquitous computing. *Virtual Reality*, 3(3):200–211.

Assunção, M. D., Netto, M. A. S., Koch, F., and Bianchi, S. (2012). Context-aware job scheduling for cloud computing environments. In *2012 IEEE Fifth International Conference on Utility and Cloud Computing*, pages 255–262.

Bhavanishankar, R., Subramaniam, C., Kumar, M., and Dugar, D. (2009). A context aware approach to emergency management systems. In *Proceedings of the 2009 International Conference on Wireless Communications and Mobile Computing: Connecting the*

World Wirelessly, IWCMC '09, pages 1350–1354, New York, NY, USA. ACM.

CAPES (2017). Portal de Periódicos da CAPES. Disponível em: http://www. periodicos. capes. gov. br. Acesso em: 08/2017.

Cassales, G., Charao, A., Kirsch-Pinheiro, M., Souveyet, C., and Steffenel, L. (2014). Bringing context to apache hadoop. In *8th International Conference on Mobile Ubiquitous Computing, Rome, Italy*.

Crk, I., Bi, M., and Gniady, C. (2008). Interaction-aware energy management for wireless network cards. In *Proceedings of the 2008 ACM SIGMETRICS International Conference on Measurement and Modeling of Computer Systems*, SIGMETRICS '08, pages 371–382, New York, NY, USA. ACM.

Das, A. K., Adhikary, T., Razzaque, M. A., Alrubaian, M., Hassan, M. M., Uddin, M. Z., and Song, B. (2017). Big media healthcare data processing in cloud: a collaborative resource management perspective. *Cluster Computing*, pages 1–16.

Dey, A. K. (2001). Understanding and using context. *Personal and ubiquitous computing*, 5(1):4–7.

Doolin, K., Mullins, R., Abad, R. M., Moreno, M. G., Mota, T., Farshchian, B. A., and Gómez, M. (2008). Supporting ubiquitous ims-based teleconferencing through discovery and composition of ims and web components. *Journal of Network and Systems Management*, 16(1):92–112.

Eijkhout, V. (2014). *Introduction to High Performance Scientific Computing*. Lulu. com.

Gomes, A. T. A., Ziviani, A., Lima, L. d. S., and Endler, M. (2009). Performance evaluation of a discovery and scheduling protocol for multihop ad hoc mobile grids. *Journal of the Brazilian Computer Society*, 15(4):15–29.

Hähnel, M., Mendez, J., Thost, V., and Turhan, A.-Y. (2014). Bridging the application knowledge gap: Using ontology-based situation recognition to support energy-aware resource scheduling. In *Proceedings of the 13th Workshop on Adaptive and Reflective Middleware*, ARM '14, pages 3:1–3:6, New York, NY, USA. ACM.

Hovestadt, M., Kao, O., Keller, A., and Streit, A. (2003). Scheduling in hpc resource management systems: Queuing vs. planning. In *Job Scheduling Strategies for Parallel Processing*, pages 1–20. Springer.

Hsu, C.-H., Chen, T.-L., and Park, J.-H. (2008). On improving resource utilization and system throughput of master slave job scheduling in heterogeneous systems. *The Journal of Supercomputing*, 45(1):129–150.

Kovachev, D., Cao, Y., and Klamma, R. (2014). Building mobile multimedia services: a hybrid cloud computing approach. *Multimedia tools and applications*, 70(2):977–1005.

Kumar, K. A., Konishetty, V. K., Voruganti, K., and Rao, G. V. P. (2012). Cash: Context aware scheduler for hadoop. In *Proceedings of the International Conference on Advances in Computing, Communications and Informatics*, ICACCI '12, pages 52–61, New York, NY, USA. ACM.

Paul, D. and Aggarwal, S. K. (2014). Multi-objective evolution based dynamic job scheduler in grid. In *Complex, Intelligent and Software Intensive Systems (CISIS), 2014 Eighth International Conference on*, pages 359–366. IEEE.

Tranfield, D., Denyer, D., and Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British journal of management*, 14(3):207–222.

Wang, L., Tao, J., Kunze, M., Castellanos, A. C., Kramer, D., and Karl, W. (2008). Scientific cloud computing: Early definition and experience. In *2008 10th IEEE International Conference on High Performance Computing and Communications*, pages 825–830.

Yahyapour, R. (2002). *Design and evaluation of job scheduling strategies for grid computing*. PhD thesis, Universität Dortmund.

Yürür, Ö., Liu, C. H., Sheng, Z., Leung, V. C., Moreno, W., and Leung, K. K. (2016). Context-awareness for mobile sensing: A survey and future directions. *IEEE Communications Surveys & Tutorials*, 18(1):68–93.