International Journal of Data Science and Analysis
2015; 1(2): 8-13
Published online August 31, 2015 (http://www.sciencepublishinggroup.com/j/ijdsa)
doi: 10.11648/j.ijdsa.20150102.11

An Overview of Cloud-related Cyber-Physical Systems

Bo Shen

School of Computer Science and Engineering, Northwestern Polytechnical University, Xi'an, PR China

Email address:
shenbo@outlook.com

To cite this article:
Bo Shen. An Overview of Cloud-related Cyber-Physical Systems. *International Journal of Data Science and Analysis*. Vol. 1, No. 2, 2015, pp. 8-13. doi: 10.11648/j.ijdsa.20150102.11

Abstract: Cyber-physical systems are a kind of emerging large-scale distributed systems. The newly systems combine computing capacity, communication technology with control in a collaborative manner, and are considered as the next generation of engineered systems. With many sensors scatted spatially, a high volume of data is generated. In order to store and process the data, using cloud computing technology in CPS becomes a natural choice. In the paper we survey recent CPS researches related to cloud computing. We firstly examine the works using CPS approach to model data centers. Then we briefly survey cloud-based CPS applications from two perspectives: intelligence transportation system and smart grid. This paper helps the researchers to get a quick overview of cloud-related CPS studies.

Keywords: Cyber-Physical Systems, Cloud Computing, Data Center, Intelligence Transportation System, Smart Grid

1. Introduction

The past few years have witnessed a rapid development of communication technology and a significant improvement in computing capacity. These progresses inspire computing systems to accurately control physical devices in remote areas in a real-time and reliable manner. The requirements necessitate the cyber space and the physical space to be tightly coupled with each other to accomplish the desired goals. To deal with these issues, Cyber-Physical systems (CPS) have been proposed.

CPS are a kind of emerging large-scale distributed systems [1], [2], [3]. The newly systems combine computing capacity, communication technology with control in a collaborative manner. CPS are considered as the next generation of engineered systems. However, there are several significant challenges to be addressed. CPS require the close interaction between the two distinct spaces. The interactions involve the discrete dynamics in the cyber space and the continuous dynamics in the physical space. In the past years the developments and designs in the two spaces are parallel. The intrinsic feature of CPS necessitates efficient co-design methods between the two spaces at all levels. Using CPS approaches to design and implement industrial goals become more prevalent. The emerging applied fields include smart grid [4], intelligence transportation system [5], high-confidence medical systems [6], etc.

In the paper we survey recent CPS researches related to cloud computing. As the definition in [7], *cloud computing refers to both the applications delivered as services over the Internet and the hardware and systems software in the data centers that provide those services.* In the past years this computing paradigm is attracting extensive attentions from both academia and industry since its birth, and has become more prevalent. We classify the related works into two catalogues: CPS approach to model data centers and cloud-based CPS applications. In the following we briefly introduce the related works according to the classification.

2. CPS Modeling Approach in DATA Centers

The past decades have undergone an unprecedented explosion of data space. A plenty of emerging applications require a large amount of data to accomplish the data-intensive computing. Due to the complicated requirements of massive storage and computation, data centers are proposed to host a large number of servers for managing and processing the big data. The data center hardware and software is so-called cloud [7]. Multiple web-services providers, like Google, Facebook, Amazon, offer various online services, such as web search, online gaming, social network, to end-users based on cloud. According to the report by Koomey [8], [9], the power consumed by data centers all over the world was between 203 and 271 billion kilowatt hours of electricity in 2010. The energy consumed by data centers is mainly used for computation and cooling [10]. As the demands on cloud computing keep increasing in recent years, the number of data centers grows rapidly. The energy consumption significantly increases at the rate of 12% per year [11]. Meanwhile, the amount of electric energy used for computing and cooling in data centers is equal for the past years [8], [12]. To improve the energy efficiency is a key challenge in the research field of the data centers. Many previously-published studies try to optimize the energy usage while satisfy the Quality of Service (QoS) constraints from different perspectives. The data centers combine the cyber dynamics and physical dynamics, which motivates the recent trends of using CPS principles to model the data centers.

Parolini et al. [13] model the data centers from a CPS perspective. Considering the tightly coupled characteristics, they introduce a control-oriented model to represent the data center. The model consists of two coupled networks.

The cyber part is a computational network. The nodes in this network process jobs at the specified rates. Jobs can be moving along the connections among the nodes. Each node maintains a job queue. The queue dynamics is determined by workload execution and arrival process. The physical part is a thermal network. The dynamics of the physical network is characterized by the temperatures associated with each thermal node. The directed edges in the network represent the exchange directions of heat between thermal nodes. The two networks are coupled by the connections between the nodes in computational network and thermal network. The connections reflect the relationship between the computational performance and the physical features. The basic idea of the model is that servers affect both the QoS delivered by the computational network and the generation of heat in the thermal network. Based on the model, Parolini et al. propose three control strategies, named by baseline, uncoordinated and coordinated, to minimize the total power consumption while satisfy both the QoS and the thermal constraints from different abstractions of control approaches. Simulation results have shown that additional energy is saved by coordinating the control of the computational resources and the physical resources in data centers.

Rao et al. [11], [14] consider the problem of minimizing the total electricity cost under the constraints of the QoS requirements as well as the diversity of electricity price. The communication and computation capabilities of the data centers are classified into the cyber part. The different prices of electricity due to the temporal and spatial diversities are main physical factors. In order to support the cyber part and cool the data centers, electric power is delivered from multiple electricity markets to the distributed data centers. The performance of the cyber part is constrained by the physical factors. Computing rate of the server is limited by its physical limitation. The authors formulate the cost minimization problem as a constrained optimization problem and propose a solution based the generalized benders decomposition technique. The total electricity costs show a significant reduction based on the proposed model.

Tang et al. [15] formulate the problem of minimizing the data center cooling cost as the problem of Minimizing the Peak Inlet Temperature within a data center through Task Assignment (MPIT-TA). In their work the computing devices belong to the cyber part and the physical part include the cooling equipment. It is observed that by assigning a task properly in the data center, the temperature rise due to heat recirculation can be lowered. This phenomenon inspires the authors. They firstly show the effects of the coefficient of performance with the energy needs of the data center. The relationship between the supplied cold air temperature and the power consumed in the data center is established. Then they express the inlet temperatures in terms of the consumed power and the task power profile and placement, respectively. Their proposed model of the inlet temperature is the combination of a linear low-complexity heat recirculation model and a linear power model. The model also connects the physical factors with the cyber party. As a variety of the problem to minimize of the cooling cost, the problem of minimizing the peak inlet temperature can be solved by task assignment. Base on the variation, then they propose two solutions for the optimization problem: one solution is based on genetic algorithm and the other is based on sequential quadratic programming.

Li et al. [16] propose a cyber-physical forecasting model, named by ThermoCast, for data centers. Their work is a proactive thermal management mechanism. The model can predict the temperatures surrounding the servers in the data center to avoid potential overheating events. In the model the cyber part includes workload scheduling in servers. The physical part includes the cold-aisle vent temperatures, the locations of the servers, the local temperature distribution, etc. ThermoCast deploys multiple sensors to measure the temperature and the air-flow speeds. The basis of ThermoCast is thermodynamics laws and cyber-physical interactions. ThermoCast acquires appropriate values of various parameters from real-time sensor data and workload information. It establishes the relationship among the cold-aisle vent temperature, the location of the server, the local temperature distribution and the workload from nearby servers. By combining the thermal interactions with the workload scheduling algorithms, ThermoCast achieves high predictability. Compared with tradition thermodynamics-based solutions and data-centric solutions, ThermoCast can dynamically adapt to the changes of workload and computer room air-conditioning system. Meanwhile, ThermoCast shows good computational and physical scalability for large data centers.

Mukherjee et al. [17] propose a spatio-temporal thermal-aware job scheduling algorithm to minimize energy consumption in heterogeneous data centers under performance constraints from a CPS perspective. In their work the cyber part is the computing performance and the physical part is the energy efficiency. By finding that energy efficiency can be achieved by spreading the jobs in a temporal manner, they try to extend the job scheduling to the temporal dimension. Their work leverages the equipment heterogeneity and slack in execution estimates. They analyze the effect of job scheduling on the energy consumption in the data centers and formulate a non-linear optimization problem. Both off-line and on-line heuristic solutions for the problem are proposed. They shows that thermal-aware spatio-temporal job scheduling can yield a synergistic effect of energy efficiency benefits under deadline constraints.

Later Banerjee et al. [18] extend the work in [17]. By observing that the cooling energy depends on the cooling demands and the cooling behaviors, the authors focus on a cyber-physical oriented coordinated job and cooling management to reduce the total energy consumption in the data centers. They propose a cooling-aware and thermal-aware spatial job scheduling algorithm. The advantages of the proposed algorithm are two-folds: 1) it can dynamically change the computer room air-conditioning system setting to meet the cooling demands; and 2) the total data center energy consumption is reduced.

3. CPS Applications Data Centers

CPS approach has shown its power in the design and the implementation of the applications in the time-critical and safety-critical fields. In the following we conclude some CPS applications related to cloud computing. Based on various application fields, we classify the related works into two catalogues: intelligence transportation system, and smart grid.

3.1. Intelligence Transportation System

Nowadays, vehicles are equipped with several on-board units, such embedded computers, radio transceivers, data storage units, cameras, etc. These units endow the vehicles with the capacity of sensing, communicating, networking, computing and storing. Vehicular Cyber Physical Systems (VCPS) are proposed to take advantage of these capacities to reduce the traffic congestion, improve the traffic safety, and optimize the fuel efficiency. However, the communication, storage and computing capacity of a single vehicle are underutilized [19], [20]. The data sensed by a vehicle is also not fully utilized. Collecting the underutilized cyber resources and physical data from the vehicles on the road into shared platforms will have huge impacts on the intelligence transportation system and the society, which motivates the research field in VCPS cloud computing (VCPS-CC). Single vehicle can be considered as an instance of VCPS. The vehicle generates the sensing data and exchanges the data with VCPS-CC center. By aggregating the data from a large amount of vehicles, VCPS-CC center returns the optimized routing information to the vehicles, with the objectives to minimize the traffic congestion or the fuel consumption, etc. Data centers and the associated communication/computation infrastructure will play vital roles in intelligence transportation system. In this subsection we overview the related works.

Abid et al. [21] integrate the Vehicular Ad Hoc Networks (VANET), CPS and cloud computing into a framework. They propose a V-Cloud architecture to improve the safety and the comfort for the drivers. The V-Cloud architecture consists of three layers: in-car vehicular cyber-physical system, Vehicle-to-Vehicle (V2V) network, and Vehicle-to-Infrastructure (V2I) network. They further explain the detail of each layer. Finally they discuss the research challenges to in V-Cloud.

Wan et al. [22] combine the dynamic interactions between Mobile Cloud Computing (MCC) and VCPS. They propose a VCPS and MCC Integration Architecture (VCMIA) to provide mobile services and applications for drivers and passengers. In order to provide different service contents and access the mobile traffic cloud, the proposed framework consists of three layers according to the ranges of spatial regions: micro layer, meso layer and macro layer. The purpose of the micro layer is two-folds: 1) design and evaluate new applications for the traffic improvement by taking human factors into account; and 2) develop an integrated traffic-aware mobile Geographic Information System (GIS). VANET is formed from the perspective of the meso layer, which shares entertainment resources and safety information. The macro layer includes wired/wireless transmission and cloud services. The cloud centers provide various services to improve QoS. Furthermore, the authors analyze two significant cloud-supported service components in VCMIA: GIS with traffic-aware capability and cloud-supported dynamic vehicle routing. VIMIA is validated by an application scenario in the paper.

Later Wan et al. [23] extend the previous work by the introduction of context-aware technology and propose the cloud-assisted Context-aware Vehicular Cyber-physical systems (CVCs). The work aims to establish a context-aware pervasive system with cloud capability for the vehicles and the users. Similar to the previous work, the framework is divided into three interactive layers with the objective of improving the scalability: the vehicle computational layer, the location computational layer, and the cloud computational layer. Each layer can provide interactions and exchange information with a certain spatial range. Two significant service components, i.e., vehicular social networks and context-aware vehicular security, are analyzed in the paper. They show the efficiency of the proposed framework by the context-aware dynamic parking service.

Whaiduzzaman et al. [20] conclude that the Vehicular cloud computing architecture relies on three layers: inside-vehicle, communication and cloud. Inside-vehicle layer is used to collect useful information inside the vehicle by multiple kinds of functional sensors. The information includes: the health and behaviors of the driver, the temperature, the pressure, etc. Communication layer includes two kinds of communication: V2V communication via Dedicated Short Range Communications (DSRC) and V2I communication. The communication layer is responsible for data exchange among vehicles, infrastructures and the cloud centers. The cloud layer consists of three sub-layers: application, cloud infrastructure, and cloud platform. Application sub-layer provides various real-time applications and services to remote users. The cloud infrastructure include two parts: cloud storage for storing the collecting information and cloud computation for calculating the computational tasks. The cloud platform bridges the application and cloud infrastructure.

Bitam et al. [24] propose a cloud computing model called ITS-Cloud. The obvious difference from other works is that ITS-Cloud consists of two kinds of cloud: one is the statistic cloud and the other is the dynamic cloud. The statistic one is conventional cloud. The dynamic one is a temporary cloud. It consists of a set of interconnected vehicles or passengers that are willing to share their computing resources to others. These computing resources vary from simple Smart-phones to on-board units of the vehicles. The efficiency of the proposed ITS-Cloud is validated by a load balancing problem.

Yu et al. [25] propose a hierarchical cloud architecture for VCPS. The main difference of their work from the previous researches is that they create a pervasive cloud environment. The pervasive cloud integrates data centers, roadside units and vehicles to fully utilize the physical resources. They propose a hierarchical architecture that consists of three interacting layers: the vehicular cloud, the roadside cloud, and the central cloud. The vehicular cloud and the roadside cloud have limited resources with low latency. Meanwhile, the central cloud has sufficient resources with high latency. The proposed architecture allows vehicles to access different layers of clouds via different communication technologies. Therefore, the model is compatible with heterogeneous networks. The authors further discuss the resource management in the proposed architecture.

Li et al. [26] consider the VCPS from the perspective of seamless integration of the cyber systems, the transportation systems and the Human Factors (HF). Their research is based on the observation: the service provider can provide multiple services to the driver at one time, however, the driver cannot receive more than one service at the same time. The services should be delivered to the intended drivers carefully. The paper studies a family of the HF-aware Service Scheduling (HFSS) Problems with the aim to minimize the system-wide total utility loss due to unsuccessful delivery of some services. The authors prove the HFSS problems are NP-complete and propose a set of efficient heuristic algorithms to solve the HFSS problems.

3.2. Smart Grid

Modern smart grid integrates the computing, communication and control technologies. With the aid of information technologies, the electricity can be produced, distributed and used in a more efficient, and cost-effective manner [27]. It is considered as the largest CPS in the world. Smart grid deploys a large number of data sensors, such as smart meters, to measure, collect, and analyze the data about the running state of smart grid [28]. The huge amount of data can improve the power utilization. However, it also posts a great challenge on the data management and storage. How to manage the huge data generated by smart grid in an efficient manner becomes a promising research direction. Cloud computing is a proposed solution, which has been shown its efficiency in smart grid [29]. Generally speaking, there are at least two advantages when cloud computing is introduced into the information management in smart grid [27]: 1) with the capacities of computation and storage, the cloud providers can provide information management services for electric utilities; 2) cloud computing can improve the information integration level in smart grid. We briefly introduce the related works in the following.

Rusitschka et al. [30] propose a model for managing the real-time streams of smart grid data for the near real-time information retrieval needs of the different energy market actors based on cloud computing. The data generated by smart grid is characterized by time correlation. In order to store and process the data, the distributed data management and parallel processing scheme is proposed for the time series data. The authors also explain the ease-of-interfacing with the cloud has the potential to create usable de facto standards while enable inter-operability and extensibility. The proposed model is validated by a prototype of a real-time smart meter data management system based on the smart grid data cloud. The issues of confidentiality and privacy faced by cloud computing in smart grid are also discussed in the paper.

Simmhan et al. [31] propose a cloud-based software platform for smart grid CPS to deal with Dynamic Demand Response (D^2R) optimization. D^2R performs intelligent demand-side management and relieves peak load in power grids. Their software platform includes four parts: a semantic information integration pipeline to transmit real-time data; a secure repository to collaborate and share data and results; a scalable machine-learning model to predict demand; a web portal and mobile app to visualize the statistical energy-consumption. The authors have shown that D^2R increases the reliability, lows the peak load of smart grid, limits the environmental impact, and helps integrate the renewable. Moreover, Simmhan et al. [32] present an analysis of the security and privacy issues in a smart grid software architecture operating on different cloud environments.

Zhang et al. [24] first introduce a CPS-like next-generation residential distribution system. They identify the key features and components of the system. With the aid of distributed software agents, they translate the legacy centralized data storage and processing scheme to a completely distributed cyber-physical architecture. The key components of the framework are distributed file system (DFS) and corresponding distributed data processing model. The proposed framework is substantiated on a proof-of-concept test-bed using a cluster of low-cost and credit-card-sized single-board computers.

4. Conclusion

CPS are consider as the core technology of industry 4.0. The research on CPS is attracting increasing attentions from both academia and industry. The ever growing use of sensors has been generating a high volume of data. In order to store and process the data, to introduce cloud computing becomes a natural choice. In the paper we survey recent CPS researches related to cloud computing. We firstly examine the works using CPS approach to model data centers. Then we briefly look over cloud-based CPS applications, including intelligence transportation system and smart grid. There are several challenges which need to be addressed, such as security and privacy issues in CPS. In future we will focus the problems.

References

[1] K.-D. Kim and P. Kumar, "Cyber-physical systems: A perspective at the centennial," Proceedings of the IEEE, vol. 100, no. Special Centennial Issue, pp. 1287–1308, May 2012.

[2] E. Lee, "Cyber physical systems: Design challenges," in Object Oriented Real-Time Distributed Computing (ISORC), 2008 11th IEEE International Symposium on, 2008, pp. 363–369.

[3] R. R. Rajkumar, I. Lee, L. Sha, and J. Stankovic, "Cyber-physical systems: the next computing revolution," in Proceedings of the 47th Design Automation Conference, ser. DAC '10. New York, NY, USA: ACM, 2010, pp. 731–736.

[4] Y. Susuki, T. Koo, H. Ebina, T. Yamazaki, T. Ochi, T. Uemura, and T. Hikihara, "A hybrid system approach to the analysis and design of power grid dynamic performance," Proceedings of the IEEE, vol. 100, no. 1, pp. 225–239, Jan 2012.

[5] Y. P. Fallah, C. Huang, R. Sengupta, and H. Krishnan, "Design of cooperative vehicle safety systems based on tight coupling of communication, computing and physical vehicle dynamics," in Proceedings of the 1st ACM/IEEE International Conference on Cyber-Physical Systems, ser. ICCPS '10. New York, NY, USA: ACM, 2010, pp. 159–167. [Online]. Available: http://doi.acm.org/10.1145/1795194.1795217

[6] I. Lee, O. Sokolsky, S. Chen, J. Hatcliff, E. Jee, B. Kim, A. King, M. Mullen-Fortino, S. Park, A. Roederer, and K. Venkatasubra- manian, "Challenges and research directions in medical cyber-physical systems," Proceedings of the IEEE, vol. 100, no. 1, pp. 75–90, Jan 2012.

[7] M. Armbrust, A. Fox, R. Griffith, A. D. Joseph, R. Katz, A. Konwinski, G. Lee, D. Patterson, A. Rabkin, I. Stoica, and M. Zaharia, "A view of cloud computing," Commun. ACM, vol. 53, no. 4, pp. 50–58, Apr. 2010. [Online]. Available: http://doi.acm.org/10.1145/1721654.1721672

[8] J. Koomey, "Growth in data center electricity use 2005 to 2010," A report by Analytical Press, completed at the request of The New York Times, p. 9, 2011.

[9] M. T. Chaudhry, T. C. Ling, A. Manzoor, S. A. Hussain, and J. Kim, "Thermal-aware scheduling in green data centers," ACM Comput. Surv., vol. 47, no. 3, pp. 39:1–39:48, Feb. 2015. [Online]. Available: http://doi.acm.org/10.1145/2678278

[10] X. Fan, W.-D. Weber, and L. A. Barroso, "Power provisioning for a warehouse-sized computer," in Proceedings of the 34th Annual International Symposium on Computer Architecture, ser. ISCA '07. New York, NY, USA: ACM, 2007, pp. 13–23. [Online]. Available: http://doi.acm.org/10.1145/1250662.1250665

[11] L. Rao, X. Liu, M. Ilic, and J. Liu, "Distributed coordination of internet data centers under multiregional electricity markets," Proceedings of the IEEE, vol. 100, no. 1, pp. 269–282, Jan 2012.

[12] J. G. Koomey, "Worldwide electricity used in data centers," Environmental Research Letters, vol. 3, no. 3, p. 034008, 2008. [Online]. Available: http://stacks.iop.org/1748-9326/3/i=3/a=034008

[13] L. Parolini, B. Sinopoli, B. Krogh, and Z. Wang, "A cyber-physical systems approach to data center modeling and control for energy efficiency," Proceedings of the IEEE, vol. 100, no. 1, pp. 254–268, Jan 2012.

[14] L. Rao, X. Liu, M. Ilic, and J. Liu, "Mec-idc: Joint load balancing and power control for distributed internet data centers," in Proceedings of the 1st ACM/IEEE International Conference on Cyber-Physical Systems, ser. ICCPS '10. New York, NY, USA: ACM, 2010, pp. 188–197. [Online]. Available: http://doi.acm.org/10.1145/1795194.1795220

[15] Q. Tang, S. Gupta, and G. Varsamopoulos, "Energy-efficient thermal-aware task scheduling for homogeneous high-performance computing data centers: A cyber-physical approach," Parallel and Distributed Systems, IEEE Transactions on, vol. 19, no. 11, pp. 1458–1472, Nov 2008.

[16] L. Li, C.-J. M. Liang, J. Liu, S. Nath, A. Terzis, and C. Faloutsos, "Thermocast: A cyber-physical forecasting model for datacenters," in Proceedings of the 17th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, ser. KDD '11. New York, NY, USA: ACM, 2011, pp. 1370–1378. [Online]. Available: http://doi.acm.org/10.1145/2020408.2020611

[17] T. Mukherjee, A. Banerjee, G. Varsamopoulos, S. K. Gupta, and S. Rungta, "Spatio-temporal thermal-aware job scheduling to minimize energy consumption in virtualized heterogeneous data centers," Computer Networks, vol. 53, no. 17, pp. 2888– 2904, 2009, virtualized Data Centers. [Online]. Available:

[18] A. Banerjee, T. Mukherjee, G. Varsamopoulos, and S. Gupta, "Cooling-aware and thermal-aware workload placement for green hpc data centers," in Green Computing Conference, 2010 International, Aug 2010, pp. 245–256.

[19] M. Gerla, "Vehicular cloud computing," in Ad Hoc Networking Workshop (Med-Hoc-Net), 2012 The 11th Annual Mediterranean, June 2012, pp. 152–155.

[20] M. Whaiduzzaman, M. Sookhak, A. Gani, and R. Buyya, "A survey on vehicular cloud computing," Journal of Network and Computer Applications, vol. 40, no. 0, pp. 325 – 344, 2014. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1084804513001793

[21] H. Abid, L. T. T. Phuong, J. Wang, S. Lee, and S. Qaisar, "V-cloud: Vehicular cyber-physical systems and cloud computing," in Proceedings of the 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies, ser. ISABEL '11. New York, NY, USA: ACM, 2011, pp. 165:1–165:5. [Online]. Available: http://doi.acm.org/10.1145/2093698.2093863

[22] J. Wan, D. Zhang, Y. Sun, K. Lin, C. Zou, and H. Cai, "Vcmia: A novel architecture for integrating vehicular cyber-physical systems and mobile cloud computing," Mobile Networks and Applications, vol. 19, no. 2, pp. 153–160, 2014. [Online]. Available: http://dx.doi.org/10.1007/s11036-014-0499-6

[23] J. Wan, D. Zhang, S. Zhao, L. Yang, and J. Lloret, "Context-aware vehicular cyber-physical systems with cloud support: architecture, challenges, and solutions," Communications Magazine, IEEE, vol. 52, no. 8, pp. 106–113, Aug 2014.

[24] S. Bitam and A. Mellouk, “Its-cloud: Cloud computing for intelligent transportation system,” in Global Communications Conference (GLOBECOM), 2012 IEEE, Dec 2012, pp. 2054–2059.

[25] R. Yu, Y. Zhang, S. Gjessing, W. Xia, and K. Yang, “Toward cloud-based vehicular networks with efficient resource management,” Network, IEEE, vol. 27, no. 5, pp. 48–55, September 2013.

[26] X. Li, X. Yu, A. Wagh, and C. Qiao, “Human factors-aware service scheduling in vehicular cyber-physical systems,” in INFOCOM, 2011 Proceedings IEEE, April 2011, pp. 2174–2182.

[27] X. Fang, S. Misra, G. Xue, and D. Yang, “Smart grid - the new and improved power grid: A survey,” Communications Surveys Tutorials, IEEE, vol. 14, no. 4, pp. 944–980, Fourth 2012.

[28] J. Zhou, R. Hu, and Y. Qian, “Scalable distributed communication architectures to support advanced metering infrastructure in smart grid,” Parallel and Distributed Systems, IEEE Transactions on, vol. 23, no. 9, pp. 1632–1642, Sept 2012.

[29] M. Yigit, V. C. Gungor, and S. Baktir, “Cloud computing for smart grid applications,” Computer Networks, vol. 70, no. 0, pp. 312 – 329, 2014. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1389128614002382

[30] S. Rusitschka, K. Eger, and C. Gerdes, “Smart grid data cloud: Amodel for utilizing cloud computing in the smart grid domain,” in Smart Grid Communications (SmartGridComm), 2010 First IEEE International Conference on, Oct 2010, pp. 483–488.

[31] Y. Simmhan, S. Aman, A. Kumbhare, R. Liu, S. Stevens, Q. Zhou, and V. Prasanna, “Cloud-based software platform for big data analytics in smart grids,” Computing in Science Engineering, vol. 15, no. 4, pp. 38–47, July 2013.

[32] Y. Simmhan, A. Kumbhare, B. Cao, and V. Prasanna, “An analysis of security and privacy issues in smart grid software architectures on clouds,” in Cloud Computing (CLOUD), 2011 IEEE International Conference on, July 2011, pp. 582–589.
http://www.sciencedirect.com/science/article/pii/S1389128609002047