A DISCUSSION AND COMPARATIVE STUDY ON SECURITY AND PRIVACY OF SMART METER DATA

ABSTRACT

Cloud computing comes with a lot of advanced features along with privacy and security problem. Smart meter data takes the benefit of cloud computing in the smart grid. User’s privacy can be compromised by analyzing the smart meter data generated by household electrical appliances. The user loses control over the data while data is shifted to the cloud. This paper describes the issues under the privacy and security of smart meter data in the cloud environment. We also compare the existing approaches for preserving the privacy and security of smart meter data.

Keywords  Cloud computing · Smart meter · Security · Privacy.

1 Introduction

In recent years, cloud computing has been an emerging technology that is revolutionizing IT infrastructure and flexibility. Cloud computing refers to the delivery of on-demand computing resources over the network (typically the internet) [20][21]. Resources can be processors, storage, software, network, and many more. It drastically transforms the means of computing. It allows users to leverage the computing resources for the required time on the "pay-as-you-go" model [22]-[24]. Cloud computing also makes it possible to access resources from anywhere, while in the traditional computer system, you have to be there, where the physical resource is located [25]-[27]. Cloud users process and store their data on publicly owned or outsourced data centers. The location of these data centers may be across the world. Companies, organizations, governments, or others are keeping their applications up and faster through this technology [28]-[32]. It also helps the clients in avoiding up-front infrastructure costs. Many organizations are adopting cloud computing due to its characteristics like scalability, availability, robustness, pay-as-you-go, etc [33]-[36]. Cloud computing can be classified into two types of models, i.e., deployment model and service model. Organizations choose when, how, and which model is appropriate for use based on their specific requirements.

- **Deployment Model**
  There are four deployment models, and organizations choose one of them, depending on their specific requirements. These models are public, private, hybrid, and community cloud models. A third-party organization owns a public cloud and is accessible for public use or people under an organization. The private cloud offers a more controlled environment where access to IT resources is more centralized within the business. This model can be externally hosted or can be managed in-house. A hybrid cloud environment can be deployed for an organization seeking the benefits of both private and public cloud deployment models [37][38]. A cloud that is originated to serve a common function or purpose is called a community cloud. The deployment model is depicted in Fig. 1.
Service Model
There are the main types of cloud service models—Infrastructure-as-a-service (IaaS), Software-as-a-service (SaaS), and Platform-as-a-service (PaaS). The service model of cloud computing is depicted in Fig. 2. As their name, they offer services of Infrastructure, software, and platform, respectively. In IaaS, infrastructure components such as hardware, servers, storage, and other services are provided\[39\][40]. In SaaS, the services of any software are provided over the internet. Users can use this software without installing it on his machine. In PaaS, cloud computing providers deploy the infrastructure and software framework, but businesses can develop and run their applications. Web applications can be created quickly and easily via PaaS.

2 Motivation
In 2003, over 10 million people in North America got affected due to electrical blackout. Blackout happens due to load imbalance and lack of effective real-time analysis \[4\]. Electricity load should be matched with the electricity generation of the power grid. The problem of real-time analysis of every individual’s load and is done by introducing a smart grid. According to Electric Power Research Institute (EPRI), a fully developed smart grid can save up to $2 trillion in 20 years where the deployment cost between $338 to $476 billion \[12\]. By the end of 2018, the U.S. had over 86 million smart meters installed. In 2017, there were 665 million smart meters installed globally. Revenue generation is expected to grow from $12.8 billion in 2017 to $20 billion by 2022 \[13\]. Smart grids have been developed by integrating the traditional power grid to efficiently monitor power generation and energy usage through two-way communications between the consumer and utility provider. By smart grid technology, consumers can be notified for energy pricing of real-time data analysis. The utility also processes and analyzes the data for the generation and distribution of energy in the regions. Smart grid can be effectively used for essential tasks such as accounting, theft detection, and optimization. Utility loses $58.7 billion per year worldwide \[14\].

National Institute of Standards and Technology (NIST) presents the smart grid model consists of seven domains: Transmission, Distribution, Operations, Generations, Market, Consumer, and Service provider \[2\]. A smart meter is an important component of the smart grid that collects real-time data and transmits it to the utility provider. Smart meters are located and divided by different localities. Each locality consists one base station which aggregates data of all smart meter and sends to control center. By analyzing smart meter data, future loads can be predicted by deep learning.
algorithms, and energy can be saved on the consumer side and reduce energy at the production side. Machine learning and deep learning can be employed in smart grids to perform load prediction and energy patterns. An effort must be made to overcome the problem of ‘secure transmission and storing of smart meter data on the outsourced cloud with privacy-preserving.

3 Related Work

Data generated by smart meter is of huge amount as it sends reading at after every minute. This data is terabyte-level big data. So, storing and analyzing data is a very difficult task. Many encryption algorithms are proposed to hide the sensitive data of smart meter users. Z. Zhang et al. propose privacy-friendly cloud storage (PCS) scheme for storing smart meter (SM) data on an outsourced cloud. In this scheme, the author uses two clouds to preserve consumers’ privacy and homomorphic encryption to encrypt the smart meter’s data. After every minute, the smart meter sends the data to the cloud in encrypted form with asymmetric cryptography. Both clouds decrypt the data and encrypt it again, with homomorphic encryption having the property of performing operations on encrypted data. After encryption, all the data is stored on one cloud, which is then used for analysis. Stored data is of huge amount. Hadoop is used for handling big data generated by the smart meters of a large number of houses.

O. Rafik and S. Senouci propose an Efficient and Secure Multidimensional data Aggregation (ESMA) scheme, which consists of an FN which works as a data aggregation node. A FN uses paillier homomorphic encryption to aggregate the smart meter’s multidimensional data and convert it into a single ciphertext. ESMA also handles fault-tolerant. If a SM fails to send its reading, then the final result will not be affected. ESMA verifies the authenticity of data sent by the SM and FN to the control center. The query is also handled by the Control Center (CC) within the summation operation. Authors evaluate the ESMA scheme on 500 SM and 40 types of data and get affordable compared to previous schemes. The main disadvantage of this scheme is that this scheme can’t handle the data of a large number of houses because that would be of Tera-byte level. The summary of related works is shown in Table 1.

| Literature Reference | Approach | Pros | Cons |
|----------------------|----------|------|------|
| Z. Zhang et al. [1]   | Paillier HE • Hadoop for query processing | • Privacy-preserving • Secure Statistics over encrypted data | • High computation & communication cost |
| A. Abdallah and X. Shen [2] | Lattice based HE based data aggregation | • Data aggregation without involving SM and BS | • Communication cost is high in HAN |
| T. Wang et al. [3]    | Fog computing is introduced between • Data partition using Hash-Salomon code algorithm | • Whole data can’t be accessed if data at one • Ownership and management of data at cloud can be done | • Doesn’t support for large scale data • Computation cost is high |
| R. Lu et al. [4]      | Multidimensional data aggregation converted into single ciphertext | • Maintain privacy with authentication of every reading | • Storage and analysis problem at OC for large HANs |
| C. Fan et al. [5]     | Diffie-Hellman key exchange algorithm | • Secure batch verification system | • Time cost is high |
| M. Badra & S. Zeadally [6] | Data aggregation with lightweight symmetric HE • ECDH key exchange algorithm | • Saves from unauthorized modification of the data | • Computation cost is high • Latency is high |
| O. Boudia et al. [7]  | Aggregator node works for data aggregation of different HANs | • Verification of data at Aggregator node • Multidimensional data is aggregated | • Storage is insufficient for storing smart meter data at control center |
| S. Sarkar et al. [8]  | Introduce fog node between mobile terminal nodes and cloud data centers | • Improved latency of applications • Less power consumption of resources | • More hardware cost by adding fog nodes with mobile terminal nodes |

3
A Discussion and Comparative Study on Security and Privacy of Smart Meter Data

| Authors | Features |
|---------|----------|
| O. Rafik and S. Senouci [9] | 1. Some smart meter are connected with one FN and every FN is connected to Paillier HE 2. Multidimensional data is aggregated with fault-tolerant. 3. Batch verification and query response 4. Analyzing large data at control center takes more time |
| X. Zuo et al. [10] | 1. ElGamal cryptography without trusted Authority 2. Resist from attacks at Gateway and control center 3. Latency is high 4. Gateway does not large number of SM is connected |
| F. Okay and S. Ozdemir [11] | 1. Fog computing is used in smart grid. 2. Increased privacy and improved latency 3. Doesn’t support multidimensional data |

### 4 Research Gaps

On the basis of the literature review, the following research gaps are identified.

1. More computational and communicational cost.
2. Less privacy preservation of data.
3. Analysis of data of millions of customer with traditional tools is difficult.
4. Querying of data on the cloud is not secured.

### 5 Research Objectives

To fill the identified study gaps, the goal described below is developed.

1. To reduce communicational and computational cost.
2. To improve privacy using encryption algorithms.
3. To improve latency of transmission of data.
4. Secure query processing on the cloud.

### References

[1] Zhang, Zijian, Mianxiong Dong, Liehuang Zhu, Zhitao Guan, Ruoyu Chen, Rixin Xu, and Kaoru Ota. "Achieving privacy-friendly storage and secure statistics for smart meter data on outsourced clouds." *IEEE Transactions on Cloud Computing* 7, no. 3 (2017): 638-649.

[2] Abdallah, Asmaa, and Xuemin Sherman Shen. "A lightweight lattice-based homomorphic privacy-preserving data aggregation scheme for smart grid." *IEEE Transactions on Smart Grid* 9, no. 1 (2016): 396-405.

[3] Wang, Tian, Jiuyuan Zhou, Xinlei Chen, Guojun Wang, Anfeng Liu, and Yang Liu. "A three-layer privacy preserving cloud storage scheme based on computational intelligence in fog computing." *IEEE Transactions on Emerging Topics in Computational Intelligence* 2, no. 1 (2018): 3-12.

[4] Lu, Rongxing, Xiaohui Liang, Xu Li, Xiaodong Lin, and Xuemin Shen. "EPPA: An efficient and privacy-preserving aggregation scheme for secure smart grid communications." *IEEE Transactions on Parallel and Distributed Systems* 23, no. 9 (2012): 1621-1631.

[5] Fan, Chun-L., Shi-Yuan Huang, and Yih-Loong Lai. "Privacy-enhanced data aggregation scheme against internal attackers in smart grid." *IEEE Transactions on Industrial Informatics* 10, no. 1 (2013): 666-675.

[6] Badra, Mohamad, and Sherali Zeadally. "Lightweight and efficient privacy-preserving data aggregation approach for the smart grid." *Ad Hoc Networks* 64 (2017): 32-40.

[7] Boudia, Omar Rafik Merad, Sidi Mohammed Senouci, and Mohammed Feham. "Elliptic curve-based secure multidimensional aggregation for smart grid communications." *IEEE Sensors Journal* 17, no. 23 (2017): 7750-7757.

[8] Sarkar, Subhadeep, Subarna Chatterjee, and Sudip Misra. "Assessment of the Suitability of Fog Computing in the Context of Internet of Things." *IEEE Transactions on Cloud Computing* 6, no. 1 (2015): 46-59.

[9] Merad-Boudia, Omar Rafik, and Sidi Mohammed Senouci. "An Efficient and Secure Multidimensional Data Aggregation for Fog Computing-based Smart Grid." *IEEE Internet of Things Journal* (2020).
A Discussion and Comparative Study on Security and Privacy of Smart Meter Data

[10] Zuo, Xiangjian, Lixiang Li, Haipeng Peng, Shoushan Luo, and Yixian Yang. "Privacy-Preserving Multidimensional Data Aggregation Scheme Without Trusted Authority in Smart Grid." IEEE Systems Journal (2020).

[11] Okay, Feyza Yildirim, and Suat Ozdemir. "A fog computing based smart grid model." In 2016 international symposium on networks, computers and communications (ISNCC), pp. 1-6. IEEE, 2016.

[12] Jindal, Anish, Alberto Schaeffer-Filho, Angelos K. Marnerides, Paul Smith, Andreas Mauthe, and Lisandro Granville. "Tackling energy theft in smart grids through data-driven analysis." In 2020 International Conference on Computing, Networking and Communications (ICNC), pp. 410-414. IEEE, 2020.

[13] "Global Smart Meters Market Value to Reach $19.98 Billion". Smart Energy International. Clarion Energy. Retrieved 2020-12-22.

[14] C. P. Newswire, World loses $89.3 billion to electricity theft annually $58.7 billion in emerging markets, 02 2014, [online] Available: https://www.prnewswire.com/news-releases/world-loses-893-billion-to-electricity-theft-annually-587-billion-in-emerging-markets-300006515.html.

[15] S. Hosein and P. Hosein, “Load forecasting using deep neural networks,” in 2017 IEEE Power Energy Society Innovative Smart Grid Technologies Conference (ISGT), pp. 1–5, 2017.

[16] S. Tanwar, Q. Bhatia, P. Patel, A. Kumari, P. K. Singh, and W.-C. Hong, “Machine learning adoption in blockchain-based smart applications: The challenges, and a way forward,” IEEE Access, vol. 8, pp. 474–488, 2019.

[17] Cai, Zhipeng, and Tuo Shi. "Distributed Query Processing in the Edge Assisted IoT Data Monitoring System." IEEE Internet of Things Journal (2020).

[18] Vedaraj, M., and P. Ezhumalai. "HERDE-MSNB: a predictive security architecture for IoT health cloud system." Journal of Ambient Intelligence and Humanized Computing (2020): 1-10.

[19] Ramesh, Shruthi, and Manimaran Govindarasu. "An efficient framework for privacy-preserving computations on encrypted IoT data." IEEE Internet of Things Journal 7, no. 9 (2020): 8700-8708.

[20] Gupta, Rishabh, Deepika Saxena, and Ashutosh Kumar Singh. "Data Security and Privacy in Cloud Computing: Concepts and Emerging Trends." arXiv preprint arXiv:2108.09508 (2021).

[21] Aman Singh Chauhan, Dikshika Rani, Akash Kumar, Rishabh Gupta, and Ashutosh Kumar Singh. A survey on privacy-preserving outsourced data on cloud with multiple data providers. In Proceedings of the International Conference on Innovative Computing & Communications (ICICC), 2020.

[22] IShu Gupta, Rishabh Gupta, Ashutosh Kumar Singh, and Rajkumar Buyya. Mlpam: A machine learning and probabilistic analysis based model for preserving security and privacy in cloud environment. IEEE Systems Journal, 2020.

[23] Deepika Deepika, Rajnesh Malik, Saurabh Kumar, Rishabh Gupta, and Ashutosh Kumar Singh. A review on data privacy using attribute-based encryption. In Proceedings of the International Conference on Innovative Computing & Communications (ICICC), 2020.

[24] Saxena, Deepika, Ishu Gupta, Jitendra Kumar, Ashutosh Kumar Singh, and Xiaoqing Wen. "A Secure and Multiobjective Virtual Machine Placement Framework for Cloud Data Center." IEEE Systems Journal (2021).

[25] Singh, Ashutosh Kumar, Deepika Saxena, Jitendra Kumar, and Vrinda Gupta. "A Quantum Approach Towards the Adaptive Prediction of Cloud Workloads." IEEE Transactions on Parallel and Distributed Systems (2021).

[26] Kumar, Jitendra, and Ashutosh Kumar Singh. "Performance Assessment of Time Series Forecasting Models for Cloud Datacenter Networks’ Workload Prediction." Wireless Personal Communications 116, no. 3 (2021): 1949-1969.

[27] Kumar, Jitendra, Ashutosh Kumar Singh, and Anand Mohan. "Resource-efficient load-balancing framework for cloud data center networks." ETRI Journal 43, no. 1 (2021): 53-63.

[28] Kumar, Jitendra, Ashutosh Kumar Singh, and Rajkumar Buyya. "Self directed learning based workload forecasting model for cloud resource management." Information Sciences 543 (2021): 345-366.

[29] Kumar, Jitendra, and Ashutosh Kumar Singh. "Decomposition based cloud resource demand prediction using extreme learning machines." Journal of Network and Systems Management 28, no. 4 (2020): 1775-1793.

[30] Kumar, Jitendra, and Ashutosh Kumar Singh. "Adaptive Learning based Prediction Framework for Cloud Datacenter Networks’ Workload Anticipation." Journal of Information Science & Engineering 36, no. 5 (2020).

[31] Kumar, Jitendra, Ashutosh Kumar Singh, and Rajkumar Buyya. "Ensemble learning based predictive framework for virtual machine resource request prediction." Neurocomputing 397 (2020): 20-30.

[32] Kumar, Jitendra, and Ashutosh Kumar Singh. "Cloud datacenter workload estimation using error preventive time series forecasting models." Cluster Computing 23, no. 2 (2020): 1363-1379.
[33] Kumar, Jitendra, Deepika Saxena, Ashutosh Kumar Singh, and Anand Mohan. "Biphase adaptive learning-based neural network model for cloud datacenter workload forecasting." Soft Computing 24, no. 19 (2020): 14593-14610.

[34] Singh, Sukhman, Tarun Kumar Madan, Jitendra Kumar, and Ashutosh Kumar Singh. "Stock market forecasting using machine learning: Today and tomorrow." In 2019 2nd International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT), vol. 1, pp. 738-745. IEEE, 2019.

[35] Sharma, Vartika, Sizman Kaur, Jitendra Kumar, and Ashutosh Kumar Singh. "A fast parkinson’s disease prediction technique using PCA and artificial neural network." In 2019 International Conference on Intelligent Computing and Control Systems (ICCS), pp. 1491-1496. IEEE, 2019.

[36] Singh, A. K., and Jitendra Kumar. "Secure and energy aware load balancing framework for cloud data centre networks." Electronics Letters 55, no. 9 (2019): 540-541.

[37] Kumar, Jitendra, and Ashutosh Kumar Singh. "Cloud resource demand prediction using differential evolution based learning." In 2019 7th International Conference on Smart Computing & Communications (ICSCC), pp. 1-5. IEEE, 2019.

[38] Kumar, Jitendra, and Ashutosh Kumar Singh. "Workload prediction in cloud using artificial neural network and adaptive differential evolution." Future Generation Computer Systems 81 (2018): 41-52.

[39] Kumar, Jitendra, and Ashutosh Kumar Singh. "Dynamic resource scaling in cloud using neural network and black hole algorithm." In 2016 Fifth International Conference on Eco-friendly Computing and Communication Systems (ICECCS), pp. 63-67. IEEE, 2016.

[40] Saxena, Deepika, Rishabh Gupta, and Ashutosh Kumar Singh. "A Survey and Comparative Study on Multi-Cloud Architectures: Emerging Issues And Challenges For Cloud Federation" arXiv preprint arXiv:2108.12831 (2021).