A Zero Emission Neighbourhoods Data Management Architecture for Smart City Scenarios: *Discussions toward 6Vs challenges*

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***Abstract*—A huge volume of data are being generated from multiple sources, including smart cities, the IoT devices, scientific modeling, or different big data simulations; but also from users' daily activities. These daily new data are added to historical repositories, providing the huge and complex universe of the digital data. Recently, the Fog-to-Cloud (F2C) data management architecture is envisioned to handle all big data complexities, from IoT devices (the closest layer to the users) to cloud technologies (the farthest layer to the IoT devices), as well as different data phases from creation to usage from fog to cloud scenario. Moreover, the F2C data management architecture can have several benefits from the combined advantages of fog (distributed) and cloud (centralized) technologies including reducing network traffic, reducing latencies drastically while improving security. In this paper, we have several novel contributions. First, we described the previous studies of the Zero Emission Buildings (ZEB) in the context of the data flow and movement architecture. Second, we have proposed Zero Emission Neighbourhoods (ZEN) data management architecture for smart city scenarios based on a distributed hierarchical F2C data management. Indeed, we used the 6Vs big data challenges (Volume, Variety, Velocity, Variability, Veracity, and Value) for evaluating the data management architectures (including ZEB and ZEN). The result of the evaluation shows that our proposed ZEN data management architecture can address 6Vs challenges and is able to manage the data lifecycle from its production up to its usage.**

Keywords*— Smart City, IoT, Big Data, Vs Challenges, Data Management, Fog-to-Cloud Data Management

I. Introduction

The world human population is predicted to increase in mid-2050 to 9,804 million. In addition, over half of the world human population resides in cities [1]. This human population will request a better level of services in their city. Recently, smart city solutions are a great technological advancement to apply in several domains of the city (including smart building, smart energy, smart transport, smart health, smart environment and so on). Moreover, another challenge in today's world is to optimize the resource consumption (such as electricity, water etc) in the whole cities across the globe because of the reduction of energy use and greenhouse gas emissions will be one of the most challenging and important issue to reduce global warming at least during the next 20 years [2].

Data are one of the most valuable assets in the smart city environments. They provide a facility for a city to be smart. In fact, smart cities provide the ideal scenario to compose abundant data from any kind of source, from IoT devices (such as sensors, citizens' smartphones and etc) to third-party applications and social media. For this reason, there are several studies on data management and analysis. Those studies started traditionally from the context of Relational Databases Management Systems (RDBMS) and the recent Extract-Transform-Load (ETL) process for modeling the typical data life cycles in data warehousing [3]. On top of that, the emergence of Big Data environments added additional difficulties to the traditional data management and analysis systems [3, 4].

As a summary, in this paper, we have proposed a data management architecture for the ZEN center [5] with respect to the idea of the F2C data management architecture in the context of a smart city [6, 7]. In addition, we also have studied the experience of the ZEB center [8] in terms of data flow and movement as a previous research by the ZEN center. Finally, we used the 6Vs challenges for evaluating the data management architectures (including ZEB and ZEN projects) and the result of the evaluation shows that our proposed ZEN data management architecture can address 6Vs challenges and is able to manage the data lifecycle from its production up to its consumption.

The rest of this paper is organized as follows. Section II introduces core background related to the data management architectures in the context of a smart city. In Section III we described some main insights related to data management. In addition, we summarize briefly the main two data management architectures (including centralized and distributed). Moreover, we discussed data management complexities and challenges, including the concept of the 6Vs challenges. Section IV describes the particular scenarios in Norway, from the ZEB center to the ZEN center. In addition, our aim is to design the ZEN data management architecture with respect to the ZEB data movement experience. Then we used the 6Vs challenges for evaluating the data management architectures. Section V concludes the paper and presents our future research directions.

II. Related Work

There is two main proposal for the data management architecture for smart cities. i) centralized (cloud) data management architecture [9]; and ii) distributed data management architecture [6, 7].

On one hand, almost all related architectures proposed for the explicit data management schemes are centralized. This means that all collected data is available in a centralized environment, usually using cloud technologies. Although, data comes from many different sources spread all over the city (such as IoT devices, third-party applications, external databases, etc.). One example can be found in [10]. The authors draw a cloud centric vision for interaction between private and public clouds, later developed in [9] to create an information framework particularly tailored for smart city management. Then, the author mention that the cloud-computing platform is available for collecting, aggregating, and converting data into advanced information.

On the other hand, some authors work on a distributed schema for resource allocation and management, using technologies such as Fog Computing [11] or Fog to Cloud Computing [12]; Note that there is not an explicit focus on data management in the context of the distributed environments. One exception is in [13] where the author proposed some main concepts related to data collection at the fog level, mainly focuses on the distributed temporal data storage. Indeed, some architectures have proposed a distributed data management architecture from fog to cloud technologies [6, 7]. The recent architectures are able to manage all data life stages from creation to consumption; however, the recent works had some experience only in the sensors data.

To summarize, we can realize that all proposed data management architecture for smart cities have the following concerns and limitations:

- Only a few works have been designed for the distributed data management architecture;
- There is no work to address the set of 6Vs challenges through F2C data management architecture successfully;
- There is no data management proposal tailored the idea of the “zero emission neighborhood” in the context of the smart city.
- There is no previous work (based on F2C data management architecture) to contribute to different smart city scenarios.

For all of the above, we propose a hierarchical distributed data management architecture for ZEN center [5]. This architecture is able to address all the concerns and limitations above. Eventually, this architecture can be fitted to the idea of zero emission neighborhood.

III. DATA MANAGEMENT

Data management and organization during their entire life cycle, including data collection, data storing, and data processing, provides a complex and challenging task [14, 15]. The main purpose of data management is to ensure an easy and safe access to data sources and their related repositories, in order to be able to discover additional value through complex computing and analytical processes among the sources. For this reason, efficient data management and organization systems can be considered as an important topic for effective value generation.

This section is organized into two main subsections. First, we describe briefly the data management architectures in the smart city (including centralized and distributed data management) as we discussed in Section II. Second, we argue about Vs challenges generation (including 3Vs, 4Vs, 5Vs, 6Vs, and so on) as part of Big Data complexities concepts and then we address the main challenges of the Big Data paradigm applied to a smart city scenario.

A. Data Management Architecture in Smart City

As we discussed in Section II, there is two main proposal for the data management architecture in the concept of smart city: i) centralized data management (cloud data management) architecture; ii) distributed data management architecture. On one side, the advantages of the cloud-based frameworks are their ubiquity, as well as an (almost) unlimited resources capacity. However, accessing data from the cloud makes barriers for the network traffic, network latencies and security risks. On the other side, the distributed hierarchical F2C data management architecture can have several benefits from mixing fog and cloud technologies. Some of them are optimizing network traffic, reducing latencies significantly and improving security. Moreover, applications and services collect the data from a hierarchical distributed platform from fog to cloud (including both real-time and historical data).

B. Data Management Complexities and Challenges

Big Data creates some opportunities and challenges for data management. In short, most opportunities of Big Data refer to its economic impact [16], particularly dealing with optimizing production processes and supply chain, generating new goods and services, targeted marketing, improved organizational management as well as faster research and development. On the other hand, challenging effects of Big Data refer to the challenges highlighted by the existing 5Vs challenges, mainly summarized into Volume (huge volume of data), Variety (various data formats), Velocity (rapid generation of data), Value (huge value but very low density) [17], and Veracity (quality and security of data) [18].

The main challenges in Big Data have been traditionally described through the 3Vs challenges, Volume, Variety and Velocity, as defined by Gartner [19]. This model has been extended to the 5Vs challenges, which may be considered as 4+1, since the latter differs depending on the reference. Indeed, 4Vs parameters include Value, Variety, Velocity and volume. The additional one may be either Variability as stated by [20, 21] or Veracity as to be found in [18, 22, 23]. Recently, there is some effort to show that the challenges can assume 7Vs [24, 25], including both Variability and Veracity, and be adding Visualization as a new challenge. Some other authors propose Volatility, Viscosity and Virality as additional main challenges [26]; however, we think these are not mature enough to be considered in this work. After reviewing all definitions about the Big Data concepts [26], we proposed the 6Vs challenges model, considering Volume, Variety, Velocity, Variability, Veracity, and Value.

As of today, we intended to address the main challenges of the Big Data paradigm applied to a smart city scenario, which can be summarized as the 6Vs challenges, which are:

- VOLUME: In a smart city there are wide sensor networks deployed throughout the whole city. Such networks are generating huge volumes of data that must be efficiently managed to make them accessible for users and applications.
- VARIETY: The data types and formats generated are heterogeneous, since different types of sensors

generate different types of data, using distinct formats, templates and characteristics.

- VELOCITY: The data generation speed rate can be really high, and an effective data management system has to be able to deal with such velocity.
- VARIABILITY: In a smart city, each data source continuously generates new updated versions of the produced data. The updated version may overwrite the last version according to the specific data updating policy in place.
- VERACITY: The exponential data growth is unquestionably posing tremendous constraints and demands in the smart city, such as data quality or data security.
- VALUE: The most important challenge is value. The aim of the whole data management architecture is to provide a framework to use data and generate information, in summary, smartness to the city services.

IV. Real Use Cases For Data Management In The Context of The Smart Cities

As a particular use case of the western world, Norway is on the Scandinavian Peninsula in northern Europe and east of the Norwegian Sea. Similarly to the most of the western world, buildings use almost one-third of energy and of greenhouse gas emission. Therefore, it is necessary to pay attention to the building integrated solutions for renewable thermal and electrical energy system. It must be concentrated on using materials that require little energy in production specifically the ones that cause less emission of greenhouse gases must increase significantly in Norway [2].

This section is organized into two main subsections. First, we describe the previous studies of the Zero Emission Buildings (ZEB) in the context of the data flow and movement architecture and their discussion through 6Vs challenges for the ZEB data movement architecture. Second, we have proposed a Zero Emission Neighbourhoods (ZEN) data management architecture and their discussion through 6Vs challenges for the ZEN data management architecture.

A. Zero Emission Buildings (ZEB)

The ZEB center [8] aims to conform to the proposed idea by the European Union that all buildings are assumed to be "nearly zero energy" in the early future at 2020. However, the ZEB center assumes by removing the word "nearly" and planning for a net zero balance over the lifetime of a building. In addition, the ZEB center's goal has been to make wise solutions for the individual buildings [2, 8].

The ZEB center includes with nine pilot buildings (including residential, commercial and public buildings) in different cities of Norway (including Trondheim, Bergen, Arendal, Larvik, Sandvika and Evenstad) as shown in details Table I [2, 8]. These pilot buildings show how new and existing technologies can be integrated to make state-of-the-art zero emission buildings. In addition, several sciences (including Department of Electric Power Engineering, Department of Architecture and Technology, Department of Energy and Process Engineering, Department of Civil and Environmental Engineering etc.) have participated to achieve the ZEB center's objectives.

TABLE I. The Pilot Projects Through ZEN Center

Number	Pilot Building Project	City	Type of Building
1	Hemidal VGS	Trondheim	New high school and sports hall
2	ZEB Living Lab		New research and demonstration dwelling
3	Powerhouse Brattørkaia		New office building
4	Zero Village	Bergen	720 new dwellings in row houses and apartment buildings
5	Visund Haakonsvern		New office building
6	Skarpnes residential development	Arendal	5 new detached dwellings
7	ZEB House Multikomfort	Larvik	New detached demonstration dwelling
8	Powerhouse Kjørbo	Sandvika	Renovation of two office buildings
9	Campus	Evenstad	New office building and educational building

1) The ZEB Data movement architecture: As shown in Fig.1, the current ZEB data movement architecture has been designed for specific scenarios and use cases through the ZEB center, and which addresses a particular set of requirements and challenges. In this context, data comes from different sources spread all over the building (such as IoT devices). Data positioned in a centralized pilot site for all members of the ZEN center, typically in the centralized storage through each pilot. Then, each specific scenario and use case is the main responsible for his or her own tasks to collect, aggregate, and convert data into meaningful information.

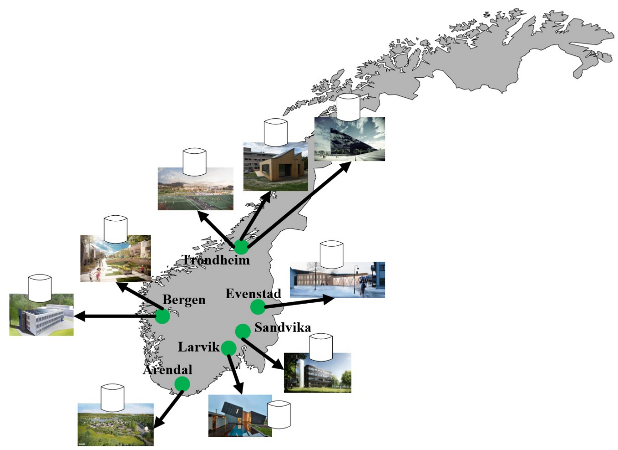

Fig. 1. The ZEB data movement architecture

Indeed, we realized that several proposals for data and software management model can be found through each pilot in the ZEB center. Each of them addresses the specific challenges and objectives of the particular application scenario. However, it is worth mentioning that each data and software model is to be meaningful for some particular scenarios requiring simple functionality, such as collecting, filtering and storing data. Nevertheless, other more sophisticated models could be designed to meet additional users' data requirements and details, such as data plan definition, data quality control, security assurance, business policies, to name a few. Thus, recognizing the relationship between the end-user/data's requirements and the data challenges is a key design step in the global data management strategy.

2) Discussion through 6Vs challenges for the ZEB data movement architecture: The ZEB data movement architecture generates huge amonts of data (data volume) with different data types and formats (data variety). In addition, the data generation speed rate can be really high (data velocity) and each data source continuously generates new updated versions of the produced data (data variability).

However, there is not much focus on the quality and security of data (data veracity) in the ZEB data movement architecture. On top of that, the ZEB data architecture provides facility to grab the value of data (data value) through the particular application scenario, but just partially since only the value of data is managed for each specific scenario and use case, not connectivity between all the building pilots.

Finally, we concluded that although a ZEB data movement architecture had been designed to successfully address their required challenges for each specific scenario and use case, but the current architecture could not be considered comprehensive, in the sense that the architecture was addressing all 6Vs challenges completely.

B. The ZEN Data management architecture

The ZEN center's goal goes forward for considering groups of buildings, instead of one building (The ZEB center's goal). Then a neighborhood is defined as a group of interconnected buildings with associated infrastructure. Therefore, the main idea concentrates to make zero emission neighborhoods and so-called "smart cities" [5].

The ZEN center will involve eight pilot projects in different cities (including Bodø, Trondheim, Steinkjer, Evenstad, Elverum, Oslo, Bærum and Bergen) of Norway as shown in Fig. 2 [5]. Similarly to the ZEB center, several sciences (including Department of Architecture and Technology, Department of Energy and Process Engineering, Department of Computer Science and etc.) will participate to achieve the ZEN center's objectives.

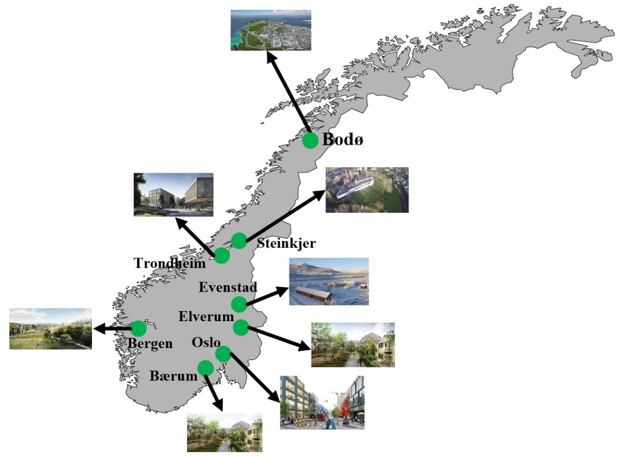

Fig. 2. The city location of the pilot projects through ZEN center

1) A proposal for the ZEN data management architecture: Our aim is to draw the data management architecture for the ZEN center and their related pilots. Then, we assume the hierarchy architecture allows a flexible number of layers according to the city structure or the business model requirements. Therefore, a proposed ZEN data management architecture consists of the following four layers architecture (namely Fog-Layer-1, Fog-Layer-2, and Cloud layer) based on the F2C data management architecture [6, 7] as illustrated in Fig. 3 and described below.

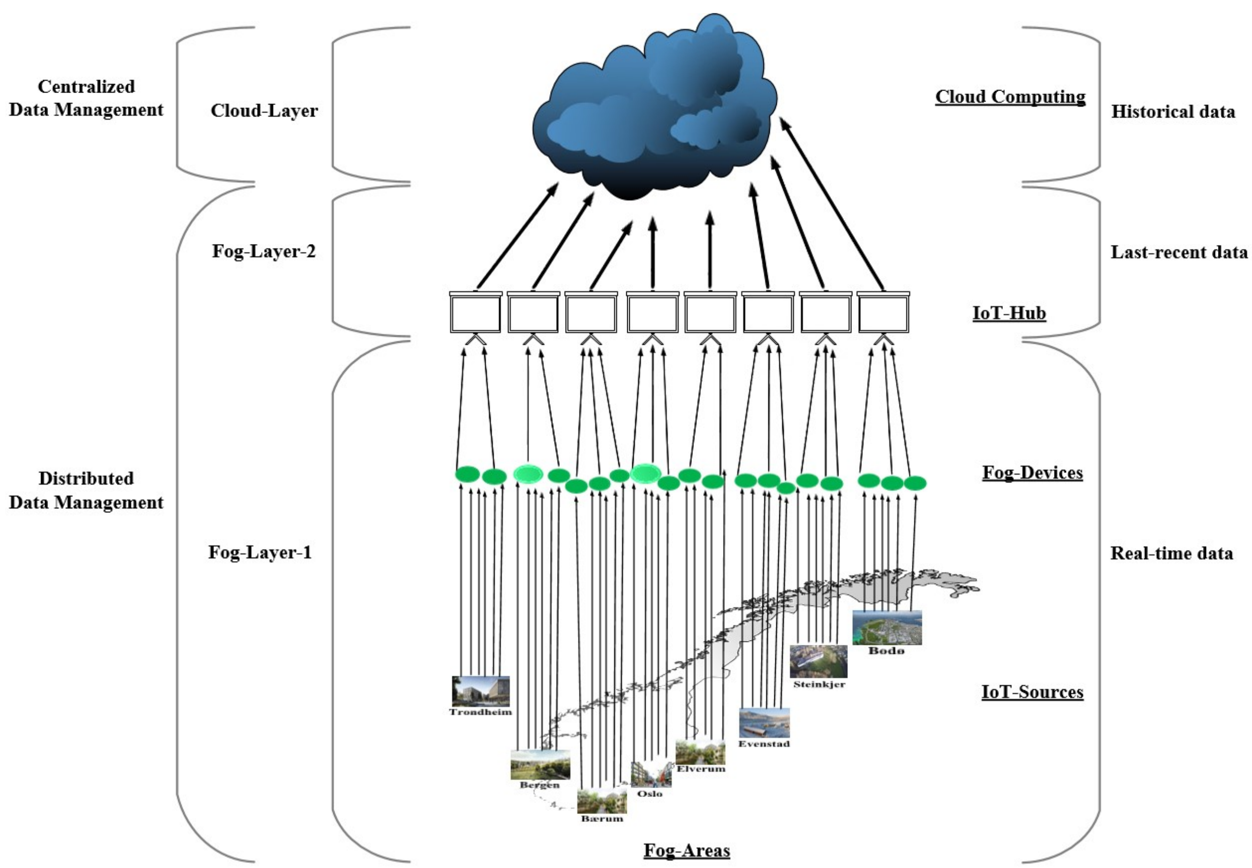

Fig. 3. Our proposed ZEN data management architecture

- Fog-Layer-1 is the nearest layer to the end-users in the pilot. In addition, Fog-Layer-1 is responsible for saving the real-time data. This layer constitutes with different IoT-Sources in the Fog-Areas in our ZEN scenario as shown below.
    - IoT-Sources: As shown in Fig. 3, there is the number of different data sources in the pilot cities (such as IoT devices, smartphones, vehicular sensors and so on). Those data sources are considered IoT-Sources in our pilot.
    - Fog-Device: In our pilot, we assumed that Fog-Devices are able to organize and control the IoT-Sources. Therefore, we define that the most powerful node (in terms of processing and storage activities) among the IoT-Sources can be positioned as a Fog-Device in the pilot. In addition, the number of Fog-Devices can be assumed very different in each Fog-Area, based on the size of "Fog-Area" and the number of "IoT-Sources".
    - Fog-Area: Our "Fog-Area" is connected to our pilot cities in Norway as shown in Fig. 3. Then, each pilot involved with some different types of the building (including commercial, sports hall, high school etc) and their neighbourhoods.
- Fog-Layer-2 is a middle layer between IoT-Hub and Fog-Layer-1 layers. Then, this layer is positioned somewhere in the city of the pilot but it is not very close to IoT devices, like Fog-Layer-1. In addition, Fog-Layer-2 is a place for saving the last-recent data. The layer includes with IoT-Hub as described below.
    - IoT-Hub: We imagine that IoT-Hub is the most powerful node (in terms of processing and storage) to organize many different IoT data. In addition, IoT-Hub can provide facility to connect with different external databases in our pilot projects.
- Cloud layer is located at the topmost position of our scenario. The cloud constitutes the strongest resources in terms of processing and storage. In addition, the cloud layer can be located far away from our city of the pilots (Maybe in a different country or continent). Indeed, Cloud-Layer is a main place for storing all the collected data by the ZEN pilots (as we called the historical data).

As a summary, in our ZEN scenario, the collected data are reachable for the pilots' services usage, normally through open-access interfaces. In addition, we classified data by its age, ranging from real-time to historical data. For example, the real-time data is the one produced and just used by the critical and real-time applications. Additionally, data can be considered historical (older data) as long as it is accumulated and stored on larger files or databases. In this case, historical data can be accessed further away (even if physically close) because gathering data from the cloud has the higher latency level.

2) Discussion through 6Vs challenges for the ZEN data management architecture: It is obvious that we are able to manage and optimize the volume and variety of data by different policies (for example, data aggregation can easily be applied in the different layers of fog to cloud environments to further reduce the volume of data to be transferred through the network). In addition, the hierarchical F2C data management architecture can cover the data velocity, data variability, and data value challenges because applications and services are able to obtain the data from a hierarchical distributed platform from fog to cloud (including realtime, last recent and historical data). Indeed, the data veracity (including data quality and security) difficulties can be controlled by applying different types of policies through F2C layers. On top of that, there are several ongoing studies and active researchers in these days to prove all our above-mentioned idea [6, 7, 27-31], to name a few.

Therefore, we envisage that the hierarchical F2C management architecture is able to address successfully the set of 6Vs challenges, including volume, variety, velocity, variability, veracity, and value of data, through the fog to cloud layers of ZEN data management architecture.

V. Conclusion

The contributions of the presented paper are diverse. In this paper, we have proposed a novel data management architecture for ZEN center based on a distributed hierarchical fog to cloud data management. The benefits of the proposed architecture are numerous. The most prominent advantage is that almost unlimited computing and storage capacities from the cloud layer can be tailored with the lowest level of the network traffic and communication latencies from the fog layers. However, by providing such a hierarchical and distributed model, some additional advantages can be gained:

- Our proposed architecture is able to address successfully the set of 6Vs challenges;
- The hierarchical data management architecture provides the facility for easing of planning and handling the complexity of data management throughout all data life stages (including data collection, data processing, data storage and etc.) from the distributed sources to the centralized technologies;
- The architecture provides benefits to get data access to real-time, last recent and historical data.
- The architecture makes huge advantages to set different types of policies (including checking data quality, applying data security, updating frequency mechanism, and so on) in each cross-layer (from IoT devices to cloud technologies) through city manager policies and business models.

- Our proposed architecture can contribute to different smart city scenario, including data access, data analysis, data sharing, etc;

As part of our future work, we will explore more options related to extending our ZEN data management architecture, such as adding data from other data sources and external third-party applications and so on.

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REFERENCES

[1] A. Sinaeepourfard, J. Garcia, X. Masip-Bruin, E. Marin-Tordera, X. Yin, and C. Wang, "A data lifeCycle model for smart cities," in International Conference onInformation and Communication Technology Convergence (ICTC), 2016, pp. 400-405: IEEE.

[2] A. G. Hestnes and N. L. Eik-Nes, Zero emission buildings. Fagbokforlaget, 2017.

[3] H. Hu, Y. Wen, T.-S. Chua, and X. Li, "Toward scalable systems for big data analytics: A technology tutorial," IEEE access, vol. 2, pp. 652-687, 2014.

[4] F. Almeida and C. Calistru, "The main challenges and issues of big data management," International Journal of Research Studies in Computing, vol. 2, no. 1, pp. 11-20, 2013.

[5] Research Center on zero emission neighbourhood. Available: https://fmezen.no/

[6] A. Sinaeepourfard, J. Garcia, X. Masip-Bruin, and E. Marin-Tordera, "Fog-to-Cloud (F2C) Data Management for Smart Cities," presented at the Future Technologies Conference (FTC), 2017.

[7] A. Sinaeepourfard, J. Garcia, X. Masip-Bruin, and E. Marin-Tordera, "A Novel Architecture for Efficient Fog to Cloud Data Management in Smart Cities," in IEEE 37th International Conference on Distributed Computing Systems (ICDCS), 2017, pp. 2622-2623: IEEE.

[8] Research Center on zero emission buildings. Available: https://www.zeb.no/

[9] J. Jin, J. Gubbi, S. Marusic, and M. Palaniswami, "An information framework for creating a smart city through internet of things," IEEE Internet of Things journal, vol. 1, no. 2, pp. 112-121, 2014.

[10] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A vision, architectural elements, and future directions," Journal of Future Generation Computer Systems on Elsevier, vol. 29, no. 7, pp. 1645-1660, 2013.

[11] F. Bonomi, R. Milito, J. Zhu, and S. Addepalli, "Fog computing and its role in the internet of things," in Proceedings of the first edition of the MCC workshop on Mobile cloud computing, 2012, pp. 13-16: ACM.

[12] X.Masip, E.Marín, A.Jukan, G.J.Ren, and G.Tashakor, "Foggy clouds and cloudy fogs: a real need for coordinated management of fog-to-cloud (F2C) computing systems," Jounal of IEEE Wireless Communications Magazine, 2016.

[13] S. Sarkar, S. Chatterjee, and S. Misra, "Assessment of the Suitability of Fog Computing in the Context of Internet of Things," Journal of IEEE Transactions on Cloud Computing, 2015.

[14] Y. Demchenko, Z. Zhao, P. Grosso, A. Wibisono, and C. De Laat, "Addressing big data challenges for scientific data infrastructure," in IEEE 4th International Conference on Cloud Computing Technology and Science (CloudCom), 2012, pp. 614-617: IEEE.

[15] R. Grunzke et al., "Managing complexity in distributed Data Life Cycles enhancing scientific discovery," in IEEE 11th International Conference on E-Science (e-Science), 2015, pp. 371-380: IEEE.

[16] J. GURIN, "DRIVING INNOVATION WITH OPEN DATA," THE FUTURE OF, p. 55, 2014.

[17] M. Chen, S. Mao, and Y. Liu, "Big data: A survey," Journal on Mobile Networks and Applications, vol. 19, no. 2, pp. 171-209, 2014.

[18] D. Gordijenko, "Big Security for Big Data: Addressing Security Challenges for the Big Data Infrastructure," in Secure Data Management: 10th VLDB Workshop, SDM 2013, Trento, Italy, August 30, 2013, Proceedings, 2014, vol. 8425, p. 76: Springer.

[19] I. A. T. Hashem, I. Yaqoob, N. B. Anuar, S. Mokhtar, A. Gani, and S. U. Khan, "The rise of "big data" on cloud computing: Review and open research issues," Journal of Information Systems on Elsevier, vol. 47, pp. 98-115, 2015.

[20] S. J. Samuel, R. Koundinya, K. Sashidhar, and C. Bharathi, "A SURVEY ON BIG DATA AND ITS RESEARCH CHALLENGES," 2006.

[21] C. P. Chen and C.-Y. Zhang, "Data-intensive applications, challenges, techniques and technologies: A survey on Big Data," Information Sciences, vol. 275, pp. 314-347, 2014.

[22] R. Narasimhan and T. Bhuvaneshwari, "Big Data–A Brief Study."

[23] R. Rossi and K. Hirama, "Characterizing Big Data Management," Journal on Issues in Informing Science and Information Technology (IISIT), vol. 12, 2015.

[24] E. MCNULTY. (2014). Understanding Big Data: The Seven V's. Available: http://dataconomy.com/seven-vs-big-data/

[25] (2015). Understanding the 7 V's of Big Data. Available: http://www.optimusinfo.com/blog/understanding-the-7-vs-of-big-data/

[26] A. Sinaeepourfard, J. Garcia, and X. Masip-Bruin, "Hierarchical distributed fog-to-cloud data management in smart cities," Doctoral thesis, Departament d'Arquitectura de Computadors, Universitat Politècnica de Catalunya (UPC), Barcelona, Spain, 2017.

[27] S. Kahvazadeh, V. B. Souza, X. Masip-Bruin, E. Marn-Tordera, J. Garcia, and R. Diaz, "Securing combined fog-to-cloud system through SDN approach," in Proceedings of the 4th Workshop on CrossCloud Infrastructures & Platforms, 2017, p. 2: ACM.

[28] F. Mehdipour, B. Javadi, and A. Mahanti, "FOG-Engine: Towards big data analytics in the fog," in 2016 IEEE 14th Intl Conf on Dependable, Autonomic and Secure Computing, 14th Intl Conf on Pervasive Intelligence and Computing, 2nd Intl Conf on Big Data Intelligence and Computing and Cyber Science and Technology Congress(DASC/PiCom/DataCom/CyberSciTech), 2016, pp. 640-646: IEEE.

[29] W. Han and Y. Xiao, "Big data security analytic for smart grid with fog nodes," in International Conference on Security, Privacy and Anonymity in Computation, Communication and Storage, 2016, pp. 59-69: Springer.

[30] J. Clemente, M. Valero, J. Mohammadpour, X. Li, and W. Song, "Fog computing middleware for distributed cooperative data analytics," in IEEE Fog World Congress (FWC), 2017, pp. 1-6: IEEE.

[31] F. Hussain and A. Al-Karkhi, "Big Data and Fog Computing," in Internet of Things: Springer, 2017, pp. 27-44.