D2C-DM: Distributed-to-Centralized Data Management for Smart Cities based on two ongoing case studies

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Abstract. Smart city environments follow different technological management strategies (such as resource management, data management, and so on) between end-users to city planners and technological devices (e.g., sensor, camera surveillance, etc.) to enhance citizens' quality of life through the variety of the smart services. Data management is one of the most critical issues in smart cities because data is a core resource in the smart city. Without proper data, no smart services in the smart cities exist to make a connection between end-users and technological devices. A few numbers of distributed-to-centralize data management architectures have been proposed. In addition, there are several different distributed schema by several technological options exist (e.g., cloudlet, fog, etc.) but almost all of the studies used a distributed-to-centralized data management architecture based on fog to cloud technologies. Therefore, the fog-to-cloud data management architecture can use both potentials of fog and cloud technologies, including the decrease in communication latencies, organizing distinct policies (e.g., data filtering, data compression, etc.) and so on. In this paper, first, previous studies of distributed-to-centralized data management architectures through two different smart city scenarios has been revisited. Afterward, the easy use and adaptation of the distributed-to-centralized data management architecture to any smart city scenario has been shown. In addition, the advantages of this data management architecture have been highlighted including efficiency rates for the data collection and data storage, and reducing data and network traffic. Finally, a number of the lesson learned from previous case studies have been addressed.

Keywords: IoT, Smart City, Data Management, Distributed Data Management, Centralized Data Management, Fog-to-Cloud Data Management, Sensor Data Management.

1 Introduction

Nowadays, smart cities are pointed as interesting and challenging research topics. In history, the beginning idea of the smart city was to install a number of different types of technological devices (such as sensors, camera surveillance, etc.) in the city. Then all installed devices are able to collect abundant data for future purposes and demands across the city. In addition, several challenges imposed by many produced data in a smart city (coming from different data sources and devices). It is evident that these (raw) data are not useful for user demands and their related purposes. After that, the smart cities go beyond convert this raw data into meaningful information by using several computing models and analysis techniques (for instance cloud-, cloudlet-, fog-computing models). Moreover, the big data trends are pushed many additional challenges and complexities to manage all produced data (through data analysis, data processing, data storage, etc.) in the smart city scenario [1, 2]. Then, the scientific society moves forward to solve those challenges and complexities by different technological management strategies (such as resource management, data management, and so on) between end-users to city planners and technological devices (such as sensors, camera surveillance, etc.) to enhance citizens' quality of life through variety of smart services.

Data management architecture bring an advanced level of solutions to provide an easy and safe access to data sources and their related repositories in order to discover new value and insight of the collected data. Moreover, data management can be imagined during their entire life cycles (is called Data LifeCycle [1, 3]), including data acquisition, data preservation, or data processing. In the context of the smart cities, data management architecture introduced by two main different views: centralized (mostly related to the cloud technologies [4, 5]) and distributed (for instance, fog-to-cloud, cloudlet and other related technologies [6, 7]). On the one hand, the majority of the data management architectures suggested a centralized schema for the data management (e.g. [4, 5]). On the other hand, there are few interests in distributed-to-centralized data management (D2C-DM) architectures. In addition, fog (distributed) to cloud (centralized) technologies are used for almost all of the proposed D2C-DM architectures known as F2C data management architecture [8-11].

In this paper, previous studies about D2C-DM architectures in two different smart city scenarios have been reviewed [8-11]. Then, it has been discussed that the easy use and adaptation of the D2C-DM architecture to any smart cities scenario. In addition, it has been noted that the pros of such D2C-DM are countable, including efficiency rates for the data collection and data storage, and decreasing data and network traffic. Finally, a number of the lesson learned from previous studies regarding D2C-DM architectures have been described.

The rest of this paper is structured as follows. Section 2 presents some insights about resource and data management strategies in the context of smart cities. Section 3 discusses main concepts related to the data management architectures in smart cities (from D2C-DM architectures). Section 4 explains two recent studies about the D2C-DM architecture based on fog-to-cloud technologies. Those works highlight the easy use and adaptation of the distributed data management architecture to any example of the smart city scenario on the one hand. On the other hand, the efficiency rates of using both centralized and distributed data management have been shown (including optimization rates for some phases of the Data Acquisition and Data Preservation Blocks). Section 5 describes several lessons learned from previous case studies through D2C-DM based on F2C data management architecture. The last section concludes this work and presents our future works and directions.

2 Related Works

Smart city environments have been proposed by several different technological management strategies (such as resource management, data management, and so on) between end-users to city planners and technological devices (e.g., sensor, camera surveillance, etc.) to enhance their citizens' quality of life.

Resource management strategies suggested by different perspectives in smart city areas. On the one hand, the centralized perspective (mostly related to the cloud computing) supposed that all physical devices and resources (including storage media, servers and so on) must be in one centralized place [4, 5]. On the other hand, the next option is the distributed perspective that is used in different technologies (e.g., fog computing technology [12, 13]) or other distributed technologies [6, 7]. For instance, fog computing provides the facility to use the potential of the physical devices and resources where data is produced. Moreover, recently there are some proposal to combine the resources of the centralized and distributed technologies together for further purposes. One example is in [14], and author offered a F2C computing that mixed the potentials of the cloud computing (centralized) model with the fog computing (distributed) model.

Data management strategies are one of the most important issues in smart cities because data is a core resource in the smart city. Without relevant data, no smart services in the smart cities exist. The data management strategies follow the same idea (as the resource management strategies proposed). Then, data management proposed by centralized and distributed architectures in smart city environments. There are many references for the centralized data management (CDM) [4, 5] but there are minor related works about distributed data management [8-11].

As part of the data management strategies, data aggregation techniques offer an interesting solution to utilize specific types of processing for gathering, mixing, reducing, or presenting information somehow as a summary [15]. There are numbers of the data aggregation models to organize data aggregation techniques in the centralized (cloud) environments [16, 17]. Those related works supposed that the cloud technologies are responsible for performing the data optimization techniques (including data aggregation, data filtering and so on) but there are only a few works about the data aggregation proposal for the real-time services and distributed systems [16, 18]. On top of that, there is a new proposal to use some data aggregation techniques through the cross layers of the D2C-DM architecture in smart cities [9, 10]. This work extended to the new proposal for the Data Preservation block [8, 10]. In addition, it was believed that the data storage media (from distributed to centralized) can also get interesting benefits by using the data aggregation techniques through the cross layers of the D2C-DM architecture in the smart city.

To sum up, we can realize that the majority of the proposed data management architecture has been designed for a CDM scenario, and only minor proposals have been suggested for the D2C-DM architecture. Therefore, in this paper, we aim to highlight that the easy use and adaptation of the distributed data management architecture to any example of the smart city scenario on the one hand. On the other hand, it has been shown the efficiency rates of using both centralized and distributed data management with respect to the recent studies [8-11]. Finally, we present a number of the lesson learned about the advantages of the D2C-DM architecture.

3 Data Management Architecture In Smart Cities

Two main references exist for the data management architecture in smart city scenarios, centralized and distributed. First, many references architectures offered a CDM architecture. The CDM architecture mainly goes beyond to the cloud computing technologies [4, 5]. Second, few numbers of references can be found for the D2C-DM architecture [8-11, 19]. In addition, those architectures mainly used the fog technologies to handle their scenario for the distributed schemes.
This section is divided into two main subsections. First, we describe the CDM architecture and their related topics. Second, we explain the DDM and their benefits.

3.1 The CDM Architecture

CDM architecture refers to a centralized place (mainly in the cloud technologies) that is able to organize and manage all data sources from the city. Then, the centralized place is responsible for gathering all obtained data (including sensors, third-party applications, and other data sources) and mixing all the data together. In addition, a centralized place makes a huge facility for all other data actions (including processing, storage, aggregation, filtering, etc.). As an example, Fig. 1 illustrated a CDM architecture in the smart city (based on cloud computing) [4]. This model proposed by four layers (including physical, network, cloud, and application layers). The physical layer consists of all physical devices to sense all city actions by raw data (namely is called data collection). The network layer is responsible for transferring the sensed data to the centralized cloud environment. The third layer (cloud layer) provides facility to perform processing, computing and analyzing all raw data and then convert them to the meaningful information for further services and applications demands. Finally, the last layer (service layer) is able to make the data access into the cloud layer for several purposes (such as convert, interpret or combine them for related services and applications). In centralized scenarios, a centralized place (such as cloud technologies) has defined by almost unlimited ubiquity resources (e.g., storage and computing capacities). However, several concerns are addressed to the CDM architecture, such as network overloading, high communication latencies, and so on [12].
With the focus on data management in a centralized place, there are several studies [4, 15, 21] argue that all data acquisition stages (including data aggregation, data filtering, data classification and so on) and data preservation stages (including data storage, data sharing and so on) can be handled through centralized technologies (such as cloud). In a particular example in a smart city scenario (as shown in Fig. 2 [17]), data is able to be collected in the city by different data sources. Afterward, the top centralized layer (mainly is cloud technologies) is ready to utilize some other data actions (such as data filtering, data aggregation, etc.).

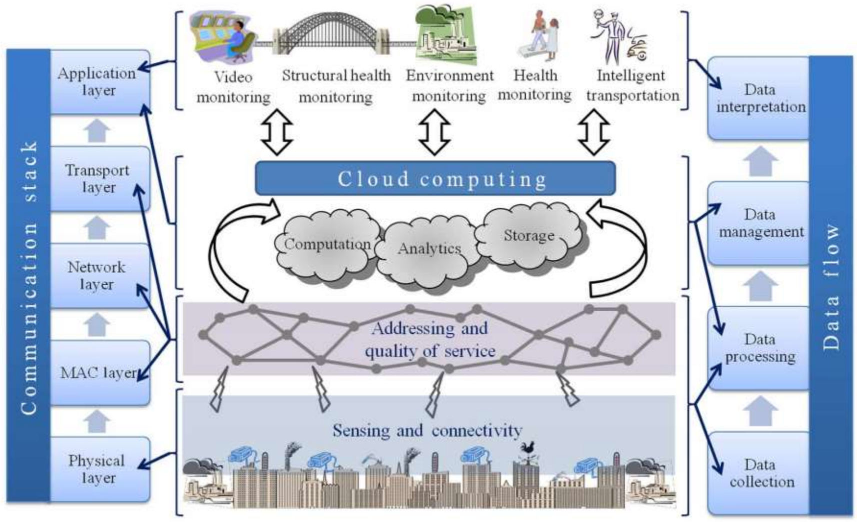

Fig. 1. An example for the cloud data management in smart cities [4]

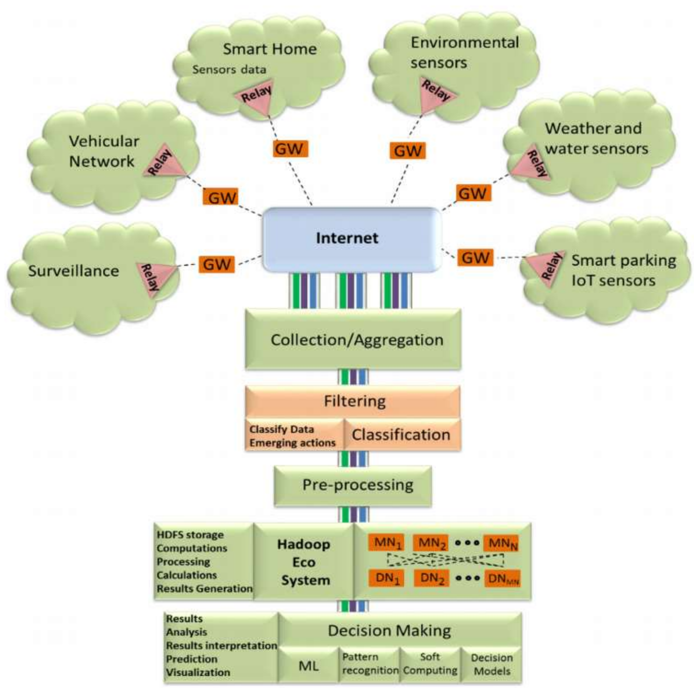

Fig. 2. Data management in the cloud computing technoliges [17]

3.2 The D2C-DM Architecture

There are a few numbers of the proposal for D2C-DM architecture. Most of them are used the fog technologies to perform the D2C-DM in the smart cities [8-11, 19]. The base of the D2C-DM is to manage the data from creation to consumption (which is namely Data LifeCycle [1, 3]). Therefore, in [10, 20] has been proposed a Smart City Comprehensive Data LifeCycle (SCC-DLC) model to show the idea of data management through their entire life cycles (from data acquisition to data preservation and processing, this includes other fundamental aspects related to data quality and data security, among others) in a city (as shown in Fig. 3). In addition, the main organization of the SCC-DLC model is described with three blocks (including Data Acquisition, Data Processing, and Data Preservation). Each block covers a set of different phases as described briefly below and in more details in [10, 20]:

- The Data Acquisition block is responsible for performing the data collection, data filtering (including data aggregation and some other related data optimization techniques), data quality, and data description phases.
- The Data Processing block is able to handle the actions related to data process and data analysis phases.
- The Data Preservation block provides some facility for the data classification, data archive, and data dissemination techniques.

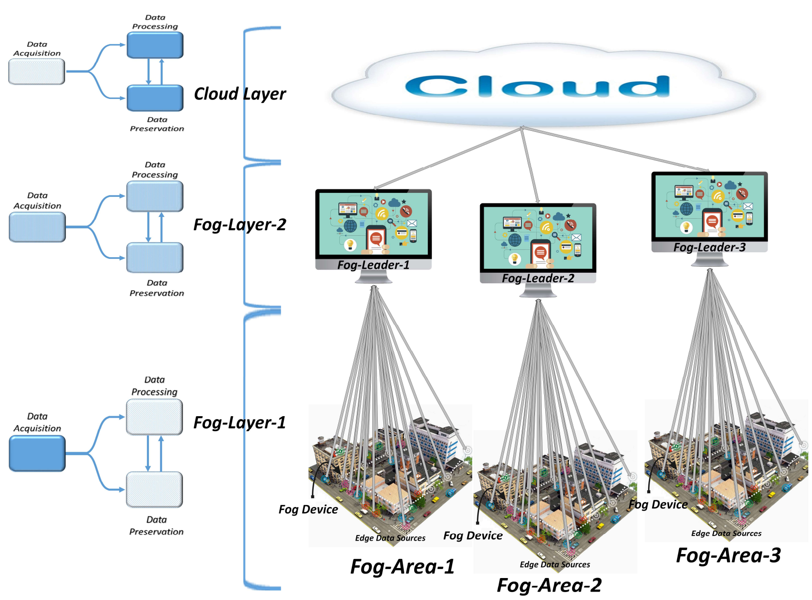

Fig. 3. Proposal for the F2C data management architecture in smart cities [9]

As depicted in Fig. 3 [9], the Fog-Layer-1 covers Fog-Area-1 which includes several edge-data-sources. The Fog-Device is the strongest node among edge-data sources. The Fog-Device can coordinate some level of the processing, computing, and storage with respect to the combined capacity of its devices. The Fog-layer-2 is ready for more complex computing under the Fog-Leader node tasks (similarly, Fog-Leader is the strongest node among Fog-Device nodes). Finally, the cloud layer is positioned as a top level in the F2C data management architecture. The cloud layer has the highest level of computing and storage capabilities.

4 Scenario Explanation: Optimization Of Data Acquisition And Data Preservation Blocks Through D2C-DM Architecture

This section revisited the two previous studies of the D2C-DM architecture (based on fog-to-cloud data management) in two different smart city scenarios and described below. First use case adapted to the Barcelona smart city [8-11] under Sentilo platform [21]. Then, we explore further through the previous studies and their practical results to extract new insight for the Data Acquisition and Data Preservation blocks through D2C-DM architecture. Second, use case fitted to the Zero Emission Neighborhoods (ZEN) center [22] idea through the smart cities in Norway [11].

4.1 Case Study In Barcelona, Spain Through Sentilo Platform

Barcelona is one of the largest cities in the northeast of Spain. The idea of Barcelona smart city was proposed in the period from 2007 to 2012. The beginning idea was to install a ubiquitous network and a set of services for residents of a Barcelona city. Then, several physical sensors positioned across the Barcelona city in order to develop the quality of services to the city residents [23]. Nowadays Barcelona has further research interests to manage all obtained sensors data through different platforms (for instance, Sentilo [21]) in Barcelona smart cities [8-10, 24].

With respect to the idea of data management in Barcelona's smart city, in [8-10] were extended the traditional sensors data management architecture of Barcelona smart city through Sentilo platform [21, 24]. The traditional data management architecture (through Sentilo platform) was designed under centralized schema through cloud computing technologies as shown in the left side of the Fig. 4. The traditional data management architectures deal with five categories of information and services (Energy, Noise, Garbage, Parking, and Urban) under the Sentilo platform [21, 24]. For more information, each category of information and services included with different types of information (for instance, the energy category comes with electricity meter, external ambient conditions, gas meter, internal ambient conditions, network analyzer, solar thermal installation, and temperature). Therefore, the collected sensors data is 7.1 GB per day, and this data size was immediately stored in the data storage(s) at the cloud layer [8-10, 24].

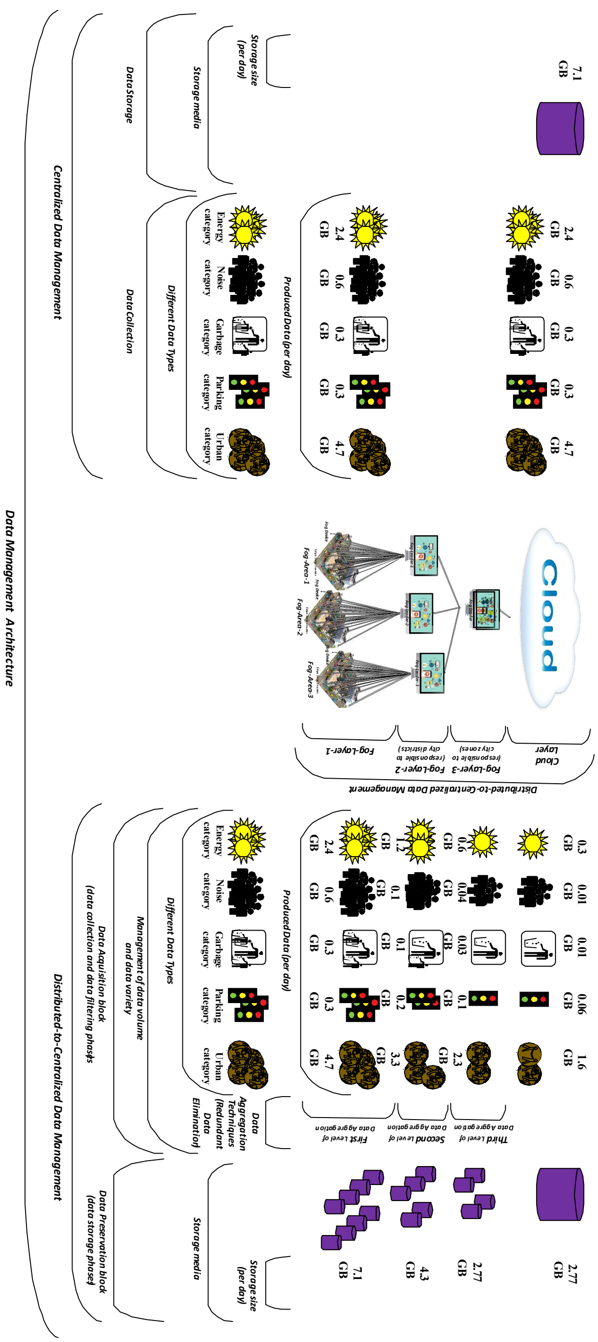

Fig. 4. The Data Acquisiton and Preservation blocks (some part of the figure extracted form [8-10, 24])

Later, in [8-10] suggested a D2C-DM architecture based on fog-to-cloud technologies. As shown on the right side of Fig. 4, the suggested F2C data management architecture has a four-layer from fog to cloud technologies (including Fog-Layer-1, Fog-Layer-2, Fog-Layer-3, and cloud). The suggested data management architecture is able to manage the sensors data through Sentilo platform [21, 24]. The hierarchal distributed architecture provides a flexible number of layers with respect to the city structure (including numbers of districts and zones) or the business model requirements. As illustrated in Fig. 4, there are several numbers of areas in the city, named Fog-Areas (including with numbers of the Fog-Devices in the city). Additionally, a Fog-Leader node (at Fog-Layer-2) is assumed as a node in the same district with further capacity (in terms of processing and storage) to organize the resources and data in the Fog-Area. Similarly, a Fog-Leader node (at Fog-Layer-3) is responsible to coordinate the resources and data in the same zone (zone includes specific numbers of districts with respect to the urban structure of Barcelona). Then, the collected sensors data is estimated 1.2 GB for the energy, 0.6 GB for the noise, 0.3 GB for the garbage, 0.3 GB for the parking and 4.7 GB for the urban categories as described in [8-10, 24]. After that, the optimization technique (including redundant data elimination) added to the different layers of the data management architecture (including Fog-Device at Fog-Layer-1, Fog-Leader at Fog-Layer-2, and Fog-Leader at Fog-Layer-3). Then, the redundant data elimination technique is able to remove the dark and useless data (including the redundant data) at each measurement, and during one day. Finally, this optimization technique gave help to the data storage to reduce the number of stored data from 7.1 GB to 2.7 GB in the cloud layer as shown details in [8-10, 24].
To sum up, in this example, data aggregation techniques provided an interesting result for the F2C data management architecture, including reducing network traffics between layers, enhancing data quality by removing the useless collected data, decreasing usage of the data storage, etc. In addition, this result highlight data the potential of the D2C-DM architecture to organize data volume and data variety in the smart cities.

4.2 Case Study In Norway Through ZEN Center And The Related Pilots

The ZEN center constitutes eight different pilot projects in different cities in Norway (Bodø, Trondheim, Steinkjer, Evenstad, Elverum, Oslo, Bærum and Bergen) [11, 22]. The ZEN center moves forward to the smart cities idea through groups of buildings and their neighborhoods [11].
The previous works [11] proposed the hierarchy architecture based on D2C-DM architecture as depicted in Fig. 5. Moreover, the paper argued that the fundament of the hierarchal distributed architecture is proposed by principal axes, "Time" and "Location". Those axes illustrate the main idea about the D2C-DM architecture in smart cities through the different concept of the "data management architecture," "data types," and "DLC models" as described briefly below.

- The proposed architecture used two layers of data management architecture from distributed to centralized. Therefore, the architecture gets extra advantages by using both data management architecture to handle the data management complexities and challenges in the related scenario.

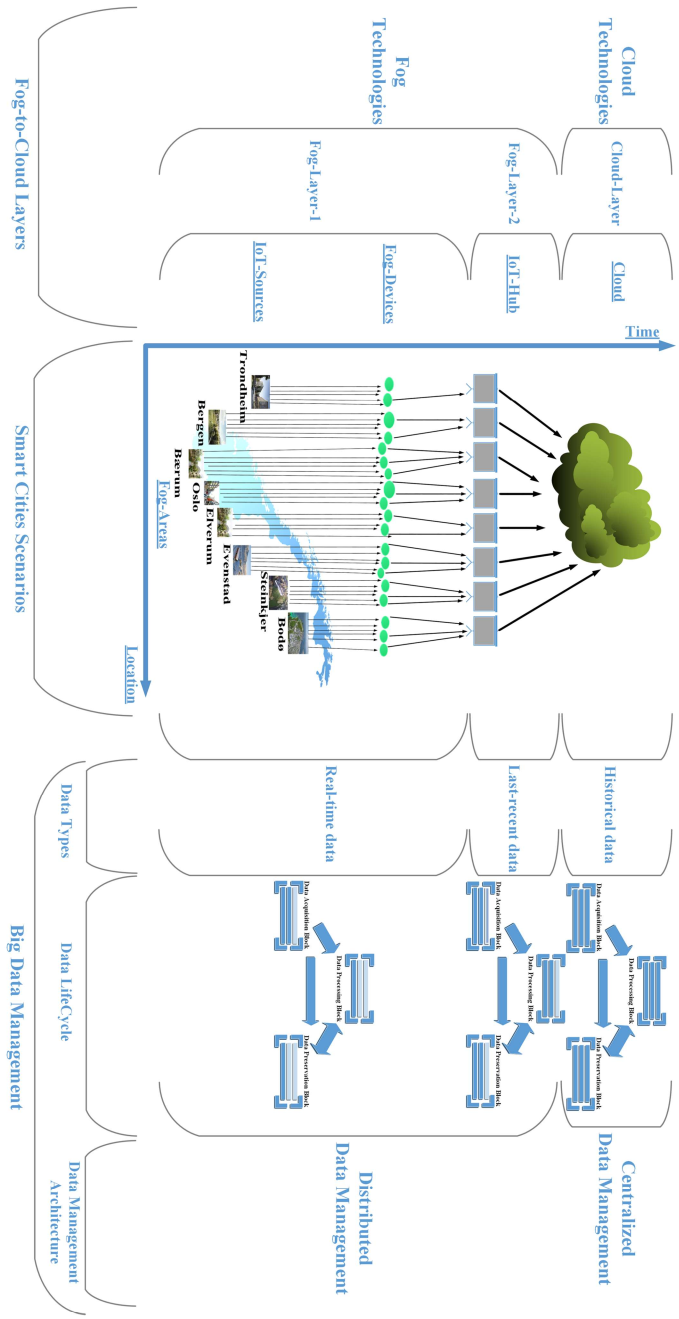

Fig. 5. The ZEN data management architecture based on F2C data management [11, 25]

- The proposed architecture covered different data types regarding time-alignment (including real-time, last-recent, and historical data). The real-time data is the closest data to the data sources, and the historical data is the furthest data to the data sources.
- The proposed architecture is able to organize all data life stages (from creation to consumption) in their scenario. Then the architecture makes a plan to manage all different data types and format through their entire life cycles in the hierarchal D2C-DM architecture.

5 Lesson Learned From Two Ongoing D2C-DM Case Studies

In this section, we present most interesting conclusions inferred from the results of our discovery to the previous studies and use cases about D2C-DM architectures. Further, then that, we offer some future directions aiming at a more efficient data management architecture. For the sake of the synthesis, we organize these conclusions in five main points:

- The D2C-DM architecture can be easily tailored to particular or several numbers of the smart city scenario(s). For instance, in our first use case [8-10], Barcelona is an example of a particular smart city scenario. The second example constitutes different smart cities in Norway (including eight different city pilots through ZEN center) [11, 22].

- The D2C-DM architecture provides a flexible architecture for the organization and management systems. Therefore, several organizing policies can be applied through cross layers of the D2C-DM architecture (e.g., data filtering, data compression, etc.) as shown below.
  - First, the centralized system (for instance, cloud technologies) can be a coordinator for the policies and tasks of the under layers. It means that the main task at a centralized system can be divided through small tasks. Then, the small tasks can be handled by the hierarchal distributed layers.
  - Second, several different policies and tasks can be applied locally through D2C-DM architecture.
  - Finally, the combined tasks can be launched through the D2C-DM architecture. It means that some local tasks can be handled in under layers as well as the main tasks. The main tasks can be planned and coordinated by the centralized layer (for instance, cloud or Fog-Leader).

- The data management designer draw their data management architecture for their related smart city scenario with respect to the required business models, city structures, available technologies, ease of use for data stakeholders, and other related issues. Therefore, it is possible to use different distributed technologies (for instance cloudlet) for the D2C-DM architecture in the smart city scenarios. So far, almost all D2C-DM architecture designed through fog-to-cloud data management architecture.

- There is no comprehensive reference to address how other data types and formats (such as external databases, third-party applications, and other data sources) can be added to the sensors data through the D2C-DM architecture in the smart cities. So far all references used the D2C-DM architecture for the sensors data management [8-11].

- The D2C-DM architecture can handle 6Vs challenges of Big Data concepts (including Volume, Variety, Velocity, Variability, Veracity, and Value) as we discussed in [11]. Section 4.1 (the first use case) showed that the data volume and data variety can be readily organized by applying data aggregation and optimization techniques through the cross layers of hierarchal distributed to the centralized architecture. In addition, there are several studies to demonstrate the facility of the architecture in order to handle the big data management complexities and challenges [19, 21, 26-29], to name a few.

6 Conclusion And Future Directions

This research paper explained a number of benefits for the D2C-DM: i) easy to use and adaptation of the D2C-DM architecture to any smart city scenario; ii) enhancing the advantages of the CDM architecture with distributed data management architecture (namely, D2C-DM architecture). However, there are still many works on the topic such as adding other distributed technologies (for instance cloudlet) and/or connecting other data sources (such as external databases, third-party applications, and so on) of the smart cities to the D2C-DM architecture's notion.

As a part of our future works and directions, we will discover more options related to developing our D2C-DM architecture (particularly through ZEN center pilots [11, 22]), such as adding other data sources and external third-party applications.

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