

Open Data Platform Tools for Energy Service Ecosystem in Urban Superblocks

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Abstract—Superblocks, or large city-blocks with some degree of energy autonomy, have yet unanswered challenges related to data utilization. Within superblocks, a service-based data ecosystem could provide benefits in the form of higher-level control applications and flexibility for the energy community. In this paper, we use open data platforms and tools, namely FIWARE and Eclipse Arrowhead, to find a system design for energy data services. The research questions relate to recognizing what features and functions are required from data platforms to provide appropriate solution, and which of them are supported by the studied data platforms. The proposed solution is then tested with a prototype implementation in limited scale to gauge its viability. We conclude that FIWARE and Arrowhead complement each other and when used in unison fill most of the requirements established in this paper.

Index Terms—Energy Management, Smart Building, Internet of Things (IoT), Energy community, Open Source, FIWARE, Eclipse Arrowhead

I. INTRODUCTION

The larger energy service ecosystem can benefit from urban superblocks, but they come with challenges in data utilization. In a superblock, one or more integrated city blocks produce some or all of their energy through local energy resources, such as solar panels, and connect to the main power grid to fill the energy gap or sell any excess energy [1]. Furthermore, this can be expanded to energy resources other than electricity like district heating [2]. However, such an energy ecosystem, or energy community, comes with a challenge of how to collect, manage, and utilize measurement data from the different subsystems. This data utilization would include providing energy measurement information through data services, refining data with additional context into useful control parameters for high-level management, or releasing some of the data points or services to third party developers to create new applications to utilize the data.

This paper studies an approach based on open data platforms and their tools for an energy service ecosystem of superblocks. While there may be commercial platforms that provide such development environment and tools already, the utilization of open-source platforms can be valuable in energy management; they can be modified more thoroughly to suit any

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environment-specific requirements. Openness can be present regarding integration, operation as well as open source code. Likewise, in larger data ecosystems, servitization is beneficial compared to vendor-specific interfaces, monoliths, or silos. Services conceptualize data end-points, which leads to more intuitive APIs and simpler implementation of data providers and consumers. Finally, open platforms such as FIWARE [3] and Eclipse Arrowhead [4] provide tools that support service ecosystems, including but not limited to authorization, discovery, and service registry.

The research questions of this paper are as follows:

- 1) What key features and functions are imposed on a service platform for energy services in an urban superblock?
- 2) How could open initiatives such as FIWARE and Eclipse Arrowhead Framework support such needs?

Next, Section II reviews the related work. Then, Section III outlines the needs and challenges of energy services and applications management. The needs are derived from the objectives of the superblock energy management concept or vision outlined. Section IV discusses the suitability of the features of FIWARE and Arrowhead for data management and services for superblocks. For a proof of concept, Section V presents a data collection system. Finally, Section VI discusses the results, followed by a conclusion in Section VII. The paper follows the *design science research* method outlined by Hevner et al. in [5]. That is, the research has three cycles: relevance cycle for concrete benefits from the design, rigor cycle as the knowledge output, and design cycle as the actual design and evaluation.

II. RELATED WORK

The underlying theme for this paper is related to the fourth industrial revolution (Industry 4.0 or I4.0) that aims to make automation smarter and more integrated with modern network technologies, facilitating data exploitation [6]. I4.0 stems from industrial automation but extends to all fields of industry, including applications in smart cities [7].

The use of service-oriented architecture and platforms in IoT systems has received study from various perspectives. In [8], Paniagua investigated modern IoT systems and proposed architectural design principles to reduce engineering effort through enabling autonomous integration and increased

interoperability. The work approached the problem from a more theoretical point of view, whereas we examine the design principles through a concrete use case. In another study, Pettinen and Hästbacka [9] examined the applicability of Arrowhead in industrial automation. They found Arrowhead unsuited for certain control applications with hard real-time requirements due to its relatively slow response time and lack of determinism, and reinforced Panigua’s findings that Arrowhead is more suitable for soft real-time applications. On the other hand, Arrowhead can help in the orchestration of IoT systems that span cloud and edge [10].

FIWARE is a generic IoT platform and provides information models for a range of domains, including but not limited to smart manufacturing [11] and smart cities [12]. Besides information models, it follows the progress of security technologies, including blockchain [13] and data spaces [14].

III. RECOGNIZING REQUIREMENTS

A. Superblock Ecosystem

The core concept in this paper is the so called “superblock”. That is, one or more integrated city blocks can produce some or all of their electricity through solar panels or other locally available energy resources, such as bio fuel, and connect to the main power grid to fill energy gaps or sell any excess production. Superblocks introduce various possibilities in energy management, and this paper focuses on monitoring and controlling in such a diverse energy ecosystem.

The production and consumption of energy, and especially their balancing, requires communication between the parties and system components. These components include energy producers, such as solar panels or geothermal energy, energy storages, like stored heat and batteries, and energy consumers, such as heat pumps, ventilation, and other appliances as shown in Fig. 1. In addition, electric vehicles are particularly interesting from an energy ecosystem viewpoint as they can act both as a (high-power) electricity consumer as well as a source of stored electric energy. Often, such actors are called prosumers [15].

B. Required Features and Functions

In order for such an ecosystem to operate and balance itself, there are two main requirements for the information infrastructure:

- 1) There must be appropriate measurement data available to enable the understanding of the current state, to model the actor behavior, and to enable predictions about future needs and control schemes.
- 2) The active energy system components need to exchange information in an interoperable manner either directly with each other or through a top-level management and control entity.

Once requirement 1) about data has been fulfilled, new control applications and innovative solutions can be developed, for example, based on machine learning (ML) and artificial intelligence (AI). Regarding requirement 2), this research

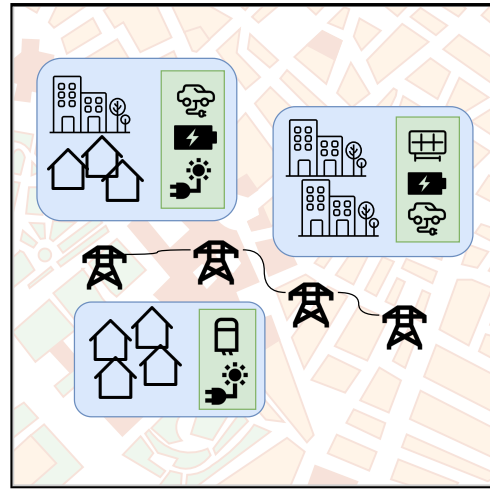


Fig. 1. Urban superblocks can provide services for energy balancing.

studies interoperability from the viewpoint of the control interfaces required from active energy system components. These requirements can be refined further into the requirements of the service platform, as elaborated in the following paragraphs.

a) *Service Management:* The information of service consumers and providers must be registered and managed by the service platform. This may include services for both data and functionality actors. In addition, to allow service consumers to find the correct service provider for them, a service discovery mechanism is beneficial if not mandatory for the platform to function.

b) *High-level energy management:* Any low-level control is performed in the respective systems, but there must be coordinating control from the higher level to optimize energy usage or production. This depends on what data applications can be developed based on the data available from the energy systems. Data platforms with the appropriate functionality could offer a base for such development.

c) *Data storage:* The availability of data about energy usage enables reactions to energy balance quickly and effectively. Electricity readings may be the most prevalent energy data type, but in a longer time frame, heating-energy-related measurements can provide insight on how much energy is consumed for heating (e.g., to illustrate the effect of changes in indoor temperature). Therefore, the service platform needs to collect and provide information to the energy producers, consumers and other solutions dependent on energy data.

d) *Information models:* The data platform should be easily accessible by any valid application including third party energy systems operating within the superblock. Common information models, especially if standardized, enable communication between systems even if they come from multiple vendors.

e) *Security, such as access control:* Both information and cyber security must be considered. Building-related data can reveal the activities of human users or organizations, which makes them sensitive and therefore subject to access

restrictions. On the other hand, security is critical in case of control activities, since even with safeguards to avoid disastrous events from bad control inputs, an illegal access could still induce considerable costs or otherwise undesirable consequences. The concrete security measures may include access control through authorization and authentication, and data encryption. In this paper, we limit the scope of security considerations to authorization and authentication of the data consumer.

f) *Data autonomy and sovereignty*: The superblocks operate in an ecosystem where some actors produce data to let the others exploit this, which necessitates the consideration of fair data usage and federation. A service platform should enable multiple locations for data storage and sharing while maintaining the correct data ownership. This aligns with the goals of Gaia-X, which aims to provide an infrastructure for federation and data sharing in a large ecosystem where the actors follow commonly agreed rules for data sharing and usage [16]. Respectively, the actors need software tools to connect their data sets, which can be accomplished with International Data Spaces (IDS) [17].

IV. ANALYSIS OF FIWARE AND ECLIPSE ARROWHEAD FOR ENERGY COMMUNITIES

A. FIWARE

FIWARE is a modular context management platform designed for IoT applications. In a related implementation, the only mandatory module is the Orion Context Broker, which operates as the entry point for the data into the system. The module provides a Restful API for entities, such as a wireless IoT sensors to query for or update data in the system, or subscribe for to any changes in any specific piece of data. FIWARE also has its own modules for analyzing, visualizing and processing data, as well as database modules to keep a complete history record of the data. FIWARE supports a variety of different modules for this purpose, but in this paper we only consider STH-Comet, a Short Time Historic (STH) module, due to its simplicity [3].

In terms of platform requirements, FIWARE can be used to provide the data services on the platform. In addition to the data storage through modules like STH-Comet, FIWARE has a variety of useful data models for energy services. These models include data schemes for three-phase AC measurements, solar panel readings, weather reports and batteries to name a few.

B. Eclipse Arrowhead

Eclipse Arrowhead is a framework for service-based systems of systems, enabling functionality, such as dynamic discovery and authorization [4]. This is accomplished with several core components, including but not limited to the service registry, orchestrator, and authorizer. The registry contains information on services, such as names and network endpoints. Orchestrator on the other hand handles any incoming requests to the platform and, if a service endpoint is requested, chooses the best instance of the service from the registry based on the

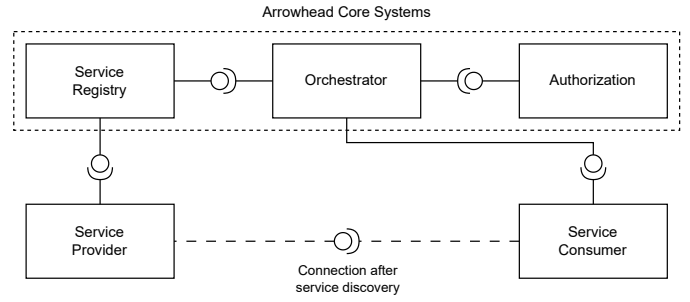


Fig. 2. Connections between service consumer, service provider, and Arrowhead Core Systems.

implemented orchestration logic. For example, the orchestrator can be programmed to prioritize splitting incoming traffic to services to avoid congestion, or choose services that are in the same cloud as the client. Orchestrator also handles client authorization through the authorization core component if necessary. The basic structure of Arrowhead and the connections between the service consumer and provider are illustrated in Fig. 2.

Since Arrowhead is used only when linking service consumers and providers together through service discovery, no energy data ever goes through Arrowhead itself. It cannot be used to enforce data models on the registered services nor does Arrowhead need to, since it is used as the service aggregator. Therefore, it cannot be used as a standalone service platform, but together with a more conventional data storage solution like FIWARE it can be used to provide valuable service management capabilities.

C. Comparison

See Table I for an overview of capability differences between FIWARE and Arrowhead. Plus-signs denote native support for the feature while minus-signs mark poor or no support without making changes in the source code. In essence, FIWARE had solutions for data management requirements while Arrowhead was usable as the service management entity. If used together, they complement each other enough to form a system that could answer most of the requirements mentioned in Section III-B. FIWARE had capabilities for storing the data in meaningful information models or schemas and handle the context management much better than Arrowhead. On the other hand, Arrowhead could easily perform service management and discovery, for which FIWARE has very little support for if any.

Both FIWARE and Arrowhead are capable of authorization and authentication, although FIWARE does not provide native functionalities for either. However, access control framework can be gained through the official modules. Both are able to use HTTPS for secure data transfer. Arrowhead lacks support for data sharing and federation, but FIWARE provides at least basic capabilities according to [14].

TABLE I
COMPARISON OF CAPABILITIES BETWEEN FIWARE AND ARROWHEAD

	FIWARE	Arrowhead
Data Storage	+	-
Information Models	+	-
Context Management	+	-*
Service Management	-	+
Service Discovery	-	+
Authorization	+	+
Authentication	+	+
Data Sharing	+	-

* Arrowhead has support system modules for context management

V. EXPERIMENTAL IMPLEMENTATION/PROPOSED SOLUTION

To test the two data platforms in practice, we devised and built a test system for a superblock prototype, which consisted of an office building with various workshops and a large multipurpose event hall. FIWARE and Arrowhead comprised the central software systems that provided the main database and service management capabilities for any applications outside the core components. In addition, a third-party system was contracted to install measurement devices and collect the initial raw data as it would resemble a realistic scenario more closely.

The overall system architecture is summarized in Fig. 3. First a mesh network of wireless sensors collected air quality data, such as temperature and humidity, and relayed the data to the data supplier through a network hub. Data was then parsed and passed forward for data storage.

FIWARE provided services for data storage and retrieval. The entry point was the FIWARE's Orion module, which contains the most recent measurements. Any incoming data was automatically saved as history data into the Comet module through a publish-subscribe pattern. The potential service endpoints would be registered to Arrowhead, either through an adapter service that translated measurement data into something more readable or usable, or simply using a direct endpoint from the Comet module.

Arrowhead provides multiple supporting services for the interaction between data providers and consumers. To access a service through Arrowhead, a client application would first need to register into the Arrowhead as service consumer. After the registration is complete, the client can send a service query to the orchestrator, which would select the best service for the client based on the query parameters. Once the service provider has been chosen, the client would receive information about the provider including the service endpoint from where the service was available.

The purpose of this setup was not to perfectly simulate a full superblock network traffic or to get the most valuable measurements about energy consumption. Instead, thought this small scale experiment, we wanted to confirm that our solution had viability beyond literary analysis. Air quality data was deemed sufficient to prove this viability, even if measurements about actual electricity usage would have been preferable.

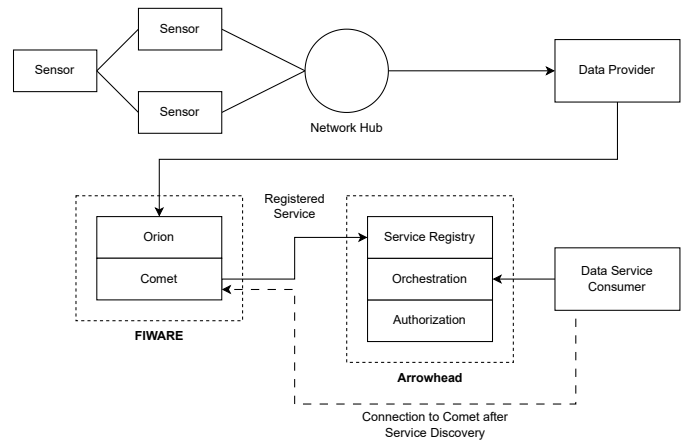


Fig. 3. System architecture for the implementation.

VI. RESULTS SUMMARY AND DISCUSSION

After collecting measurements for a few months, we made the following observations in terms of the established platform requirements:

a) *Service Management*: In a system with single service provider, like our experimental implementation, it can be argued Arrowhead to be unnecessary middleware. In the larger scale however, Arrowhead's capability for dynamic selection of service providers for the service consumers can be a benefit in full-scale implementation with multiple service providers.

b) *High-level energy management*: Arrowhead supports forming systems of systems, i.e. also realizing logical hierarchies between systems. The dynamic nature of the service model further enables changing and evolving the compositions as needed.

c) *Data Storage*: FIWARE's data storage capabilities were adequate in our experiment. However, full-scale implementation for a superblock may present challenges for FIWARE that cannot be perceived from our limited experiment. As both platforms primarily provide an entry point or location to services providing the data, neither restrict external data processing functions from being used and run separately. However it is worth noting that FIWARE can also host some processing functions within the platform itself whereas in the Arrowhead model they are integrated as separate (micro)services.

d) *Information Models*: While FIWARE has developed wide range of "smart data models" that can be used to format data, a custom data model was created for the experimental implementation. While this setup functioned with one data supplier, there are competing data models and different data vendors with incompatible data systems to FIWARE. A standardized way to express data is still to be agreed upon in the industry.

e) *Security*: When run in secure mode, Arrowhead uses certificates to ensure any service requests come from a trusted entity. In addition, the Authorization module is used to manage access between service consumers and providers, meaning that even those with a valid certificate, a service consumer can

only access those service providers it should have access to. However, aside from ensuring that the service providers are accessible, there's little in terms of data integrity in Arrowhead, especially since most of the actual data transmission happens between the service provider and consumer after the service query. That being said, there are some limitations in both FIWARE and Arrowhead, so finding complementary security mechanisms, for example for ensuring data integrity or data encryption, could be beneficial.

f) Data autonomy and sovereignty: Due to the limited scope of the experimental implementation, neither Arrowhead nor FIWARE were properly studied in terms of data sharing and federation capabilities. These, including technical means, are studied in initiatives such as GAIA-X and IDS [17].

This study contains some threats to its validity, since none of the more quantitative features, such as scalability or performance, were studied in-depth with metrics. However, the qualitative analysis gives promising information that the solution concept proposed in this paper could be applied to the smart city environment.

VII. CONCLUSION AND FUTURE WORK

This paper studied open data platform tools, namely FIWARE and Eclipse Arrowhead, in an urban superblock data ecosystem. We approached the problem through two research questions and created an experimental implementation to verify our findings.

Regarding urban superblocks, the domain-specific needs were observed to derive the features and functions required from ICT implementation. These are data storage, information models, context management, service management, service discovery, authorization and authentication, and data sharing. We found neither FIWARE nor Arrowhead could fulfill these requirements by themselves, but complemented each other sufficiently to create an appropriate system architecture for superblock data services in a limited experimental implementation.

In the future, a prototype setup that encompasses an entire superblock should be studied and whether our proposed combination of open data platform tools is sufficient solution to the challenges that implementation may present. In addition, future research could be done to standardize the data format used in sending building automation measurements, such as temperature or humidity, as well as energy related measurements. This would likely require participation from several parties from the automation industry and their willingness to share their own solutions to form such standard.

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