International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Evolution of Enterprise Application Integration: Role of Middleware Platforms in Multi-Domain Transformation

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Submitted:22/11/2022 **Revised:** 30/01/2023 **Accepted:** 17/02/2023

Abstract: The article explores the challenges and solutions associated with multi-domain interoperability in IoT gateways, with a focus on the integration of web and software platforms within smart ecosystems. Technologies that lower latency and cost while increasing dependability are being explored. However, there are obstacles to overcome before the Internet can maintain the increase in use and new applications. Creating new intra- and inter-domain federation protocols that enable the exchange of reachability and routing data is one of the fundamental obstacles yet to be overcome. Smooth data interchange and communication across heterogeneous systems, such as IoT devices dispersed throughout several domains, are essential for managing smart ecosystems effectively. In this study, the middleware landscape of smart cities is thoroughly examined, revealing the complexities of its evolution and the difficulties encountered. The key technologies, features, and functions that are essential for a middleware to successfully support a city's digital transformation are highlighted in our research, which is based on an evaluation of ten different middleware systems. Our analysis revolves on the functional and non-functional requirements. Additionally, we examine programming paradigms that influence the creation of smart city applications and the architectural styles that are essential to middleware development. Our research focusses on issues such interoperability, scalability, context management, security in the context of big data, dependability, quality of service, energy efficiency, and adherence to technical standards and laws when using middleware for smart city applications. Based on the thorough study, we provide a conceptual framework for middleware for smart cities that is influenced by the needs and difficulties noted in the body of current literature and middleware solutions.

Keywords: - *Software Platforms, Multi-Domain, Digital Transformation, Big Data, IoT Devices, Functional Requirements, Middleware, Smart City Middleware.*

I. Introduction

Today's worldwide, intricate Internet uses a variety of devices, protocols, technologies, and systems that follow guidelines established by international standardisation organisations. It has grown more difficult to oversee the worldwide adoption of new technologies, and standards often demand backward compatibility at the price of the efficiency boost that the new technology was supposed to provide [1].

Autonomous Systems (AS) may be defined as a collection of Internet Protocol (IP) prefix for one or more networks under the control of a single organisation or entity. Internal routing, rules, and policies are established by the administrative organisation, which also controls AS. Routeing and reachability data are sent between border routers in various AS domains using the standardised Border Gateway Protocol (BGP). BGP keeps track of network reachability locally using routing data [1]. This information is then utilised by BGP to create an AS connection graph, which is used to determine routing routes and implement policies at the AS gateway. Updated eight times in the last sixteen years, the present version of BGP, version 4, [1, 2], was first released as RFC 4271 in 2006. BGP may have sluggish convergence and is known to have many security issues despite its extensive usage.

When confirming permission for network layer reachability notification messages, BGP's lack of guarantee is another weakness. When BGP was first designed, it lacked the security features that would guard against deliberate or unintentional disruptions of the Internet. A distributed repository system called Resource Public Key Infrastructure (RPKI) was developed in order to solve this issue. Validation, however, requires extra AS

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implementation steps, which might cause performance and compatibility problems for older network infrastructure [2, 3].

In essence, a smart city is the culmination of several smart solutions from all facets of society that collaborate to enhance operational effectiveness, promote sustainable development, and improve quality of life. For many urban services, such as utility services [3, 4], healthcare, health care, the environment, public safety, education, and government, a variety of smart systems have been developed.

Essentially, a wide range of supporting technologies make it possible to realise such different systems. By enabling real-time data gathering, exchange, and analysis, information and communication technologies (ICT) constitute the foundation of these smart solutions, improving a range of urban services and advancing the larger goal of smart cities. Devices from the Internet of Things (IoT), such as sensors and actuators, are essential for automating responses and for monitoring infrastructure and urban settings [3, 5]. Artificial Intelligence (AI) and machine learning are two examples of advanced data analytics that transform the massive amounts of data produced by these devices into useful insights. These findings, for example, may be used to forecast crime, control energy usage, and improve traffic flow.

The complete needs of a smart city environment are not well met by many of the current solutions, which are specialised, concentrate on a single area or issue, and are often created from scratch with little software reuse. Although developing separate, vertical apps for every city domain may help with specific urban issues, this strategy misses out on possible cross-domain synergies [4, 5]. Integrated solutions that can communicate and work together are essential to a smart city's success because they maximise productivity and optimise resource use across all of the city's sectors. Therefore, the horizontal integration of various applications via common software platforms is what really propels the realisation of a smart city, even if domain-specific apps offer advantages [5].

An integrated software platform that serves as a nurturing environment for software developers is known as smart city middleware. It facilitates the creation, deployment, deployment, and management of applications especially suited for smart cities. It serves as an intermediary layer, promoting data integration, communication, and interoperability across various applications and systems within the digital ecosystem of a smart city [5]. The tools and interfaces that software developers need to create and administer programs that improve a city's intelligence and responsiveness are provided by this middleware.

An integrated software platform known as "smart city middleware" serves as a nurturing environment for software developers. It supports the creation, deployment, deployment, and management of applications especially suited for smart cities. Within the digital ecosystem of a smart city, it serves as an intermediary layer, promoting data integration, communication, and interoperability across various systems and applications [5]. This middleware gives software developers the tools and interfaces they need to create and administer programs that improve a city's intelligence and responsiveness in an effective and efficient manner:

(a) The fallacy that technology may be advantageous in and of itself;
(b) The inability of models like the strategic grid and the strategic opportunity matrix to direct users to particular opportunities due to their generality; [4, 7],
(c) The inability to recognise how the competitive environment is dynamic and ever-changing; and
(d) Ignoring the way technology is changing. Work on maintaining ICT-based advantage and "core-competence" thinking have addressed industry "foresight."

As "the art of shaping 'behavioural' space to meet the needs and aspirations of a business," organisational architecture. They use the categories of purpose, structural materials, style, and collateral technologies to characterise organisational development, drawing on comparisons with the processes of change in building structures [5, 6]. Style is the comprehensive approach an architect creates to combine the materials and the function of a structure. It is one feature of a design that is prominent.

Business ICT deployment is a multidisciplinary and multi-stakeholder problem. Different models under various disciplines would be required when many stakeholders are involved. This leads to the architect's challenge of maintaining consistency in the models [6, 7].

Improvements in data variety over the last several decades have led to much study on managing heterogeneous data [7, 9]. The data sets that are accessible in many scientific domains provide challenges when it comes to merging data with multiple models. Data integration is a technique for merging data from several sources. It should have a unified perspective across all underlying sources. It has two forms of architecture in general [7, 9]. One kind of physical model is data warehousing, in which information is replicated and kept in a warehouse from many sources. Virtual architectures are another kind of architecture [9, 10]. The virtual architecture is essentially made up of mediation, Federated Database Systems (FDBS), and the recently suggested Poly-stores.

One frequent way that domains align is via co-evolution. The introduction of a new software component that, due to its improved capabilities, causes a change in the business process is one example [11]. Another kind of architectural growth is shown by examining the enables, drives, and alignment linkages. It is necessary to translate architecture descriptions (ADs) from one domain onto another.

It is possible to convert changes in one, which are abstractions from changes at the occurrence level, into the necessary modifications for the mapping AD. The architectures will align once again after these necessary modifications are implemented. The conceptualisation dimension is orthogonal to the alignment dimension. A business strategy aims to achieve the objectives of business processes, while architecture deals with achieving them [11, 12]. Decisions regarding distribution routes, supply chains, e-markets, and outsourcing may be influenced by strategic choices made at the business architecture level.

Additionally, AI-powered training and data analysis are helping IoT gateways develop further, allowing them to provide predictive insights, automate processes, and efficiently manage resources. In real-time applications, these characteristics are extremely crucial, particularly when consistent decision-making, high efficiency, and low latency are required [12,13]. Gates that utilise secure access control, encoding, an immutable record, and other techniques to safeguard user privacy and data integrity prioritise security.

II. Middleware Solutions For Smart Cities

The present part discusses several kinds of smart city middleware systems seen in the literature. The query string that follows was used to find relevant studies: (The terms "Smart City" and "Smart Cities"), [14] AND (Middleware OR "Software Platform" OR Framework). Journal and conference proceedings papers were included in the review process, which drew from well-known digital archives for computer science, including IEEE Digital Library, ACM Digital Library, Science Direct, Springer Link, Scopus, and Google Scholar. A review of the titles, abstracts, and keywords of 278 publications was conducted using the required search terms in the selected digital libraries. After reviewing the chosen papers in further detail, this research focused on 41 publications that outline middleware solutions for smart cities. The final analysis's shortlisted papers were chosen based on a number of criteria, such as providing answers to at least two research questions, being peer-reviewed, and being relevant to the particular search terms. Papers that were not in English, released prior to 2010 [11], were short, or contained solutions that weren't appropriate for smart city settings were disqualified.

Table 1 A comparative analysis of related surveys. [14]

Survey	Scope	Evaluation Dimensions	Challenges Identified	Main Outcomes
[21]	IoT middleware with an emphasis on system needs and IoT features.	Architectural design; combines functional and non-functional requirements.	Functional: Management of information, event management, code management, and resource identification and management. Non-functional: Availability, security & privacy, ease of	An evaluation of existing IoT middleware technologies that have been divided into seven classes based on their architectural approach.

			development, popularity, and real-time. Architecture, abstraction in programming, interoperability, adaptation, context awareness, and self-governing behaviours.	
[22]	The IoT architectural framework in connection with smart cities.	IoT protocols and technology; machine learning and deep learning techniques; smart city domains.	Security and privacy; dependability: Heterogeneity Scalability Sensor systems: Large-scale data Social and legal barriers are open.	30 actual instances of IoT integration in smart cities.
[17]	The most advanced software systems for smart cities.	Smart city domains; functional requirements; enabling technology.	Lack of test beads, city models, platform upkeep, privacy, data management, heterogeneity, energy management, communication, scalability, and security.	An examination of 23 projects pertaining to smart city software platforms; a reference architecture to direct the creation of software platforms for smart cities in the future.
[25]	Technologies for middleware that are appropriate for systems based on the cloud of things.	Domains of smart cities; enabling technology; architectural styles that address functional and non-functional criteria.	Real-time; resource discovery; data analysis: quality of service; security and privacy: small footprint; standardisation.	20 middleware solutions are evaluated.

III. Enabling Technologies

The following sections cover the most important enabling technologies used in smart city platforms. These technologies impact the functionality, flexibility, and efficiency of smart city middleware in addition to being fundamental to the general operation and optimisation of these platforms [14, 15].

Sensors and actuators are examples of IoT devices that are essential for gathering and sending data from different city areas. IoT is an essential part of the middleware for smart cities as this data can be examined and used. The middleware plays a number of roles in this situation [15, 16].

Because smart city infrastructures are naturally diverse and handle dynamic data flows, centralised platforms are insufficient because of issues with scalability and latency [17]. Tasks are divided across linked tiers in the expanding trend towards distributed data processing, which is essential for fast, effective, and secure data processing in urban settings.

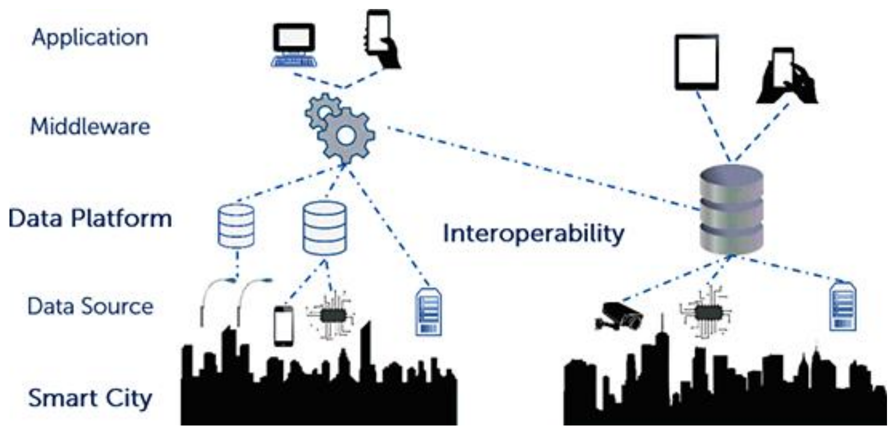

Fig. 1 Distributed data management and processing within the framework of middleware for smart cities. [17]

Big Data is the term used to describe the enormous volumes of organised and unstructured data produced by a variety of sources, like as social media, public services, IoT devices, sensors, [18], and many more, in the context of smart cities. In this case, the data may be identified by its intrinsic qualities, which include volume, velocity, variety, truthfulness, and value.

Using artificial intelligence (AI) as an enabling technology is becoming more and more important in the field of smart city middleware solutions. Large datasets may be processed and analysed by AI, especially machine learning and deep learning approaches, which can also find patterns, forecast outcomes, and even make judgements [11].

Computing, networking purposes, and physical processes are all integrated into cyber-physical systems, or CPS. Smart grids, autonomous car systems, medical monitoring, control of processes systems, distributed robotics, and automated pilot avionics are a few examples of CPS systems that may be found in a smart city. The idea of "Digital Twins," which are virtual replicas of real assets, systems, or processes, is a new viewpoint in this field [9, 12].

IV. Smart City Middleware Requirements

This section looks at the functional and non-functional requirements found in the middleware platforms under study in order to answer the research question about the fundamental needs for smart city middleware. The study is predicated on two main criteria: [17], explicit citations in the literature confirming a platform's application of a need, and the obvious existence of platform components that satisfy the requirement [15, 19]. This two-pronged strategy seeks to provide a comprehensive knowledge of the components that a smart city middleware needs to include.

Table 2 Technologies that enable the middleware solutions for smart cities. [18, 20]

Smart City Middleware	Internet of Things	Cloud Computing	Edge & Fog Computing	Mobile Crowd Senser ing	Big Data	Artificial Intelligence	Cyber Physical System	Cybersecurity	Semantic Web & Ontologies	Blockchain
Fog Flow	-	-	*	*	-	*	*	-	-	*
GAMBAS	-	-	*	*	-	-	-	-	-	-
InterSCity	-	-	-	*	-	*	-	*	*	-
LinkSmart	-	-	*	*	*	-	*	*	*	*

OpenIoT	*	-	*	*	*	*	*	*	*	*
MiSCi	-	-	*	-	-	*	-	*	-	-
Rimware	-	-	*	-	-	*	-	-	-	*
S2 NetM	-	*	*	-	*	*	-	-	-	*
SEDIA	-	-	-	-	-	*	*	-	-	*
SGeol	*	-	-		-	-	-	-	-	-

IoT devices, sensors, databases, and third-party systems are just a few of the many and diverse sources of data that middleware should be able to gather [20, 21]. The middleware may use REST APIs, adopt the publish/subscribe model, and make use of open data platforms to facilitate smooth integration from external sources.

In smart cities, middleware has to provide reliable data storage options with effective querying and retrieval features. It should support both unstructured data, like videos or material from social media, and structured data, such that found in relational databases [2, 15]. Middleware should adjust to sophisticated storage techniques, such as distributed databases and cloud architectures, as the complexity of smart city data requirements increases.

As data volume and user dynamics increase, scalability becomes an essential non-functional need for smart city middleware. In contrast to FIWARE, which is architected with scalability at its heart and prepared for the increasing data and service needs characteristic of smart city scenarios, CityPulse, for example, places a strong emphasis on its architecture to support large-scale data analytics [22]. By using a distributed context management strategy, FogFlow exhibits improved scalability.

A system's fundamental structure, component interactions, and design evolution principles are all determined by its architectural style [17]. The architectural styles seen in the middleware systems under study are introduced in the sections that follow. The main characteristics of these architectural styles are summarised in Table 3, which also lists the advantages and difficulties of each style.

Table 3 A comparison of the many middleware solution architectural styles. [18, 19]

Architectural Style	Benefits	Challenges
Service-Oriented	Platform independence, flexibility, maintainability, reusability, scalability, integration, and interoperability Scalability, and concurrency.	Transaction management, service versioning, performance, security, and complexity.
Distributed	Decentralisation, flexibility, load balancing, robustness, scalability, fault tolerance, and concurrency.	Complexity, consistency, interoperability, maintainability, security, and communication overhead.
Micro- services	Productivity in development, communication, fault isolation, fine-grained services, autonomous deployment, lightweight, and scalability.	Inter-service communication, data integrity, logging and monitoring, Coordination of services.
Agent-Based	Flexibility, Decentralisation, Autonomy, Robustness, Scalability, and Interactive Behaviour.	Overhead in communication, intricacy, coordination, resource use, security, and uncertainty.

Blockchain- Based	Immutability, decentralisation, and a decrease of middlemen Trust, transparency, smart contracts, and security.	Complexity, energy use, incorporating current systems, Performance, Uncertainty in regulations, Scalability.
Hybrid	Versatility, performance, flexibility, and adaptability.	Greater intricacy, possible incompatibilities, need knowledge.

V. Challenges And Open Issues

According to the examined literature, the main obstacles to using middleware solutions in developing smart city applications are addressed in this section [22]. Every obstacle that has been identified is an unresolved issue that needs further study and has a lot of potential for the future.

Many technological companies, however, create proprietary solutions that adhere to their own set of guidelines and regulations. For a smart city ecosystem to be coherent, middleware must act as a link between these proprietary solutions and open standards [23]. Consequently, although open standardisation is the goal of solutions like FIWARE and OpenIoT, they also need to take vendor-specific integrations into account.

Although scalability is a key consideration in the creation of platforms like FogFlow and InterSCity, there are always trade-offs between scalability and other features [23]. One such feature that may be jeopardised as systems grow is performance. Systems may encounter lower throughput or higher latency as they expand. Managing hundreds of device connections at once in such situations may result in longer reaction times, which may impact real-time decision-making procedures that are essential to some smart city activities.

In the field of smart city middleware, maintaining security and privacy is a complex problem with both technological and socio-organizational components [24]. Modern encryption techniques may be used by middleware programs like Rimware and Snap4City to protect data while it is in transit, but the growing complexity of cyberattacks need ongoing monitoring and adaptability.

Different approaches for creating middleware platforms were methodically investigated in this study. The results of the investigation revealed specific functional needs that fall into five major groups [25]. Data management, which includes data collection, integration, storage, retrieval, processing, and analytics, is the first element that jumps out as being crucial. Considering how much diverse data smart cities produce, this is crucial. Second, Device and Infrastructure Management ensures reliable infrastructure and strong connection by addressing the need of effectively allocating resources and managing IoT devices [18, 23].

VI. Conclusion

Middleware becomes a vital facilitator as smart cities advance towards digital integration and intelligence, bridging the gap between disparate systems and guaranteeing smooth interoperability. Ten middleware solutions were thoroughly investigated in this study in order to identify the essential needs for facilitating the creation, integration, and implementation of smart city applications as well as to understand the advantages of using a single software platform over fragmented alternative. A conceptual framework for smart city middleware was developed based on the solutions examined, providing a thorough manual for smart city stakeholders that takes into account both functional and non-functional criteria. Therefore, identifying the aspects that need concentrated investigation in future attempts is one of this study's contributions, which will be very helpful for middleware developers and academics.

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