A Context Management Architecture for Decoupled Acquisition and Distribution of Information in Next-Generation Mobile Networks

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***Abstract*—The increasing demand for context awareness in an interconnected world necessitates an efficient Context-Management (CoMa) system to enable a wide range of services and applications in current and next-generation mobile networks such as 5G and 6G. This paper presents a context management architecture that enables the acquisition, processing, and distribution of contextual information to consumers. The architecture leverages a broker and publish/subscribe messaging model to ensure decoupling between providers and consumers, addressing the network providers' need for context awareness in their networks.**

***Index Terms*—Context Management, 6G Network, Internet of Things, Context-Awareness**

I. Introduction

Context management is expected to be crucial in the 6th Generation (6G) of mobile networks for several reasons.

Firstly, 6G networks are anticipated to be significantly more complex than current networks [1], which will make it difficult to manage the network without context awareness.

Secondly, the higher data volumes and more dynamic nature of 6G networks will require context management to ensure that devices and applications are properly identified and authenticated, and that network resources are allocated dynamically based on changing network conditions.

Thirdly, context management will be necessary to enable new personalized services and applications in 6G networks, such as context-aware virtual assistants and personalized healthcare monitoring.

Finally, context management can also help improve network security and privacy by identifying and mitigating potential threats based on the user's context, and by ensuring that data is collected, stored, and processed securely.

6G networks are expected to bring several key improvements that emphasize the integration of CoMa system:

Increased bandwidth and lower latency: 6G networks are expected to have significantly higher bandwidth and lower latency than older generations. This would allow for more data to be transmitted and received in a shorter amount of time, enabling more advanced features such as real-time monitoring, edge computing, and autonomous systems.

More advanced modulation schemes and beam-forming techniques: 6G networks are expected to use more advanced modulation schemes and beam-forming techniques, which would improve the reliability and capacity of the network. This would allow for more devices to be connected to the network and for the data to be transmitted more efficiently, enabling more accurate and reliable context data to be acquired.

Advanced security and privacy features: 6G networks are expected to include advanced security and privacy features such as secure multi-access, network slicing, and network virtualization. This would help to protect the context data from unauthorized access, and ensure that the data is only used for authorized purposes.

Support for new use cases and devices: 6G networks are expected to support a wide range of new use cases and devices, including Internet of Things Internet of Things (IoT) devices, autonomous systems, and extended reality applications. This would enable more context data to be acquired, and more advanced features and services to be provided.

In order to support the full range of requirements and challenges that 6G will face, it is necessary to develop advanced CoMa systems that are scalable, flexible, and able to handle large context data.

The remainder of the paper is organized as follows: Section II provides a brief overview of related work in the area of CoMa in mobile networks. In Section III we discuss concepts related to context management such as context modeling and reasoning. Section IV describes the proposed context management architecture, including its various components and their interactions. Section V concludes the paper with a summary of the proposed architecture and suggestions for future work.

II. Related Work

There have been a number of studies and proposals for CoMa architectures in the literature. For example, [2] proposed a CoMa architecture for the IoT that is based on a distributed, decentralized approach, and [3] presented a CoMa framework for mobile networks that are designed to support the integration of heterogeneous devices and systems. In [4], a CoMa architecture for 5G networks was proposed that is based on a hybrid cloud-edge model, and in [5], a CoMa architecture for vehicular networks was presented that is based on a service-oriented approach.

Other studies have focused on specific aspects of CoMa in mobile networks. For example, [6] proposed a CoMa system for managing privacy in mobile networks, and [7] presented a CoMa system for supporting location-based services in mobile networks. In [6], a CoMa system for supporting energy-efficient communication in mobile networks was proposed, and in [8], a CoMa system for supporting the integration of edge computing and IoT in mobile networks was presented.

III. Context Management In Mobile Networks

Context Management (CoMa) refers to the process of collecting, storing, and utilizing information and data that is relevant to a particular communication or interaction. In the realm of mobile networks, CoMa involves the ability to acquire and utilize data from devices, networks, applications, and users in order to support a wide range of communication and interaction scenarios. There are several types of context sources that are relevant to mobile networks:

- **Device Context**: refers to information about the characteristics and capabilities of a particular device, such as its hardware and software specifications, connectivity status, and location.
- **Network Context**: refers to information about the characteristics and state of the network, including its topology, bandwidth, and performance.
- **User Context**: refers to information about the preferences, habits, and characteristics of the user, such as their location, language, and personal preferences.
- **Application Context**: refers to information about the specific application or service being used, such as the type of data being transmitted and the requirements of the application.

In light of this, we've defined and organized a generic context model for mobile communication as shown in table I.

Table I
MOBILE NETWORK CONTEXT MODEL

Context Source	Context Domain	Context Parameters
Network	Topology, Services, Slices, Resource Usage, etc.	Base Station Coordinates, Power Consumption, etc.
Device	Soft- Hardware Data, Consumption Data	Hardware Model, OS, Battery Level
User	Geo-Location, Race, Social Status	City, Work, Habits, Preferences, etc.
Application	Network Requirements	Traffic, Protocol, etc.

Effective CoMa can bring a number of benefits to mobile networks. For example, it can enable more efficient communication and interaction, by allowing devices and systems to make informed decisions about the best way to transmit and receive data. It can also enable the development of new and innovative applications and services, by providing the necessary information and data to support these applications. In addition, it can improve the user experience, by allowing devices and systems to tailor their behavior and functionality to the needs and preferences of the user.

Network slicing is a technique introduced in the 5th Generation (5G) and future mobile networks to create multiple virtual networks, called "slices," on top of a shared physical infrastructure. Each slice is tailored to the specific requirements and use cases of a particular set of customers or applications and can have its own network configurations, policies, and services.

The main goal of network slicing is to enable different types of services to be provided over the same physical network, while at the same time ensuring that the resources of the network are used efficiently.

In order to achieve this, the network needs to be able to identify the context data of each device and user and assign them to the appropriate slice. This can be done through the use of CoMa techniques, such as data fusion and machine learning algorithms, to analyze the context data and determine the appropriate slice for each device or user.

Following are some critical steps a CoMa system would follow to help the network to better orchestrate and manage different slices:

- **Data Acquisition**: collect context data from User Equipments (UEs) such as location, device type, and current services used.
- **Data Fusion**: The mobile network operator combines this data with other information such as network performance metrics and external data such as weather and traffic information to create a more complete picture of the consumer's current situation.
- **Data Analysis**: Use statistical and machine learning algorithms to analyze the data and determine the appropriate network slice.
- **Data Provisioning**: Provides the appropriate network slice for the customer, which could include different levels of bandwidth, latency, and other network resources.
- **Security and Privacy**: To ensure the security and privacy of the data, the mobile network operator encrypts the data before it is transmitted and stores it. Access to the data is controlled through authentication and authorization mechanisms, and data minimization techniques are used to only collect the data that is strictly necessary for the application. Compliance with data protection regulations is also ensured.
- **Auditing and monitoring**: The mobile network operator keeps track of who accesses the data, when, and for what purpose through logs, to detect any potential security breaches or misuse of the data.
- **Trustworthiness of devices and systems**: Verification of the identity and security state of the customer's devices and systems providing the data before accepting it, and uses techniques such as digital certificates, tokens, digital signatures, message authentication codes, secure boot, anomaly detection, and reputation-based systems to ensure that the data

is coming from trusted devices and systems and that it has not been tampered with or compromised

A. Context Reasoning

Artificial Intelligence (AI) Reasoning refers to the process of using logic and evidence to reach conclusions or make decisions. In the specific case of CoMa in mobile networks, reasoning can be used to make inferences and decisions based on the available context information. There are several approaches to reasoning that can be applied in the in a CoMa system [9], [10], [11].

1) Rule-Based: One approach is rule-based reasoning, in which a set of rules or conditions are used to make inferences or decisions based on the available context information. For example, a rule-based system might be designed to automatically adjust the transmission power of a device based on the strength of the received signal and the type of data being transmitted.

2) Probabilistic: Another approach is probabilistic reasoning, in which probability theory is used to make inferences or decisions based on the available context information. Probabilistic reasoning can be used to model and predict the likelihood of different outcomes or events, based on the available context information. For example, a probabilistic reasoning system might be used to predict the likelihood of a device running out of battery power based on its usage patterns and the available charging options.

3) Decision-Theoretic: A third approach is decision-theoretic reasoning, in which decision theory is used to make optimal decisions based on the available context information. Decision-theoretic reasoning can be used to evaluate the expected utility or value of different actions or decisions, based on the available context information. For example, a decision-theoretic system might be used to select the most efficient routing path for data transmission based on the available network resources and performance metrics.

B. Context Management Life-cycle

Figure 1 is a depiction of a CoMa system life-cycle.

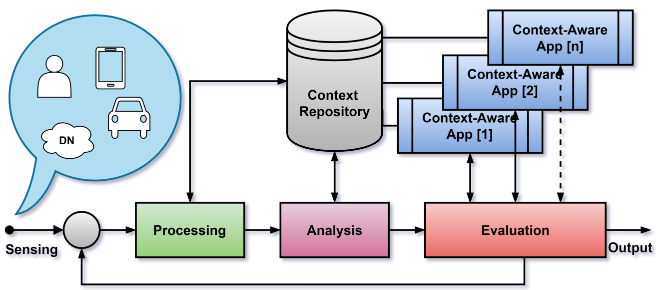

Figure 1. Context management life-cycle

Following is a description of the phases involved in managing the context in a mobile network:

1) Context Acquisition: This phase involves the collection of context information from various sources, such as devices, networks, applications, and users. This phase can involve the use of sensors, probes, and other devices to gather data about the environment, as well as the use of software and protocols to collect data from devices and systems.
2) Context Storage: This phase involves the storage and organization of context information in a central repository or database. The context storage phase can involve the use of database management systems and other technologies to store and index the context information, as well as the development of data models and schemes to define the structure and relationships of the context data.
3) Context Processing: This phase involves the processing and analysis of context information to extract useful insights and generate meaningful results. The context processing phase can involve the use of machine learning algorithms, data mining techniques, and other analytical methods to process and analyze the context data.
4) Context Dissemination: This phase involves the distribution and sharing of context information with other entities or systems that need it. The context dissemination phase can involve the use of protocols, Application Programming Interfaces (APIs), and other communication mechanisms to transmit the context data to the appropriate recipients.
5) Context Utilization: This phase involves the use of context information to support various applications and services within the mobile network.
6) Context Evaluation: This phase involves the assessment and evaluation of the CoMa process and the quality of the context information being generated and used. The context evaluation phase can involve the use of metrics and benchmarks to assess the performance and effectiveness of the CoMa system, as well as the identification and resolution of any issues or problems that may arise.
7) Context Update: This phase involves the ongoing maintenance and update of the CoMa system, including the capture, storage, processing, and dissemination of new context information, as well as the retirement or removal of outdated or irrelevant context data.

IV. Architecture and Data Exchange

The diagram in figure 2 represents the proposed CoMa system architecture that includes Context Providers, Context Consumers, a Radio Access Network (RAN), a Broker, a Query Orchestrator, a Query Parser, a Query Aggregator, a Context Repository, a Users Repository, and a Signature Repository.

The architecture provides context information to consumers through a broker, which acts as a central hub for communication between the various components. The broker provides a publish/subscribe messaging model, allowing context providers to publish context information and context consumers to subscribe to the information they need. Consumers can also submit queries to the broker to retrieve context information.

The Context Providers (UEs) component represents the various sources of context information, which may include sensors, devices, or other systems. These sources publish context information to the broker. The Context Consumers component represents the systems or applications that require contextual information to function. These consumers subscribe to the context information they need.

The RAN component provides high-speed data communication to mobile devices. It is also a source of context information, publishing data such as signal strength or network congestion.

The Broker acts as a mediator between context providers and consumers by publishing messages and query results to the appropriate consumers. The Query Orchestrator within the broker manages the processing of queries. It receives queries published by consumers and manages the aggregation of context information and the dissemination of results before they are sent to the proper consumers.

The Reasoning Engine component is a system that interacts with the Query Orchestrator. It receives data from the Query Orchestrator and uses its own algorithms and models to perform analysis and generate output. This output can be used to take important decisions regarding the network or specific clients depending on the specific use cases.

The Query Parser and Query Aggregator components assist with parsing and aggregating context information respectively. The Query Parser parses incoming queries to identify the relevant context providers and retrieve the required context information from the Context Repository. The Query Aggregator aggregates context information from multiple sources to provide a unified view of the context.

The Context Repository stores contextual information, which can be queried by consumers and used by the Query Parser and Query Aggregator. The Users Repository stores information about users of the system, which may be used to provide personalized context information. The Signature Repository stores signature information, which may be used to authenticate users or devices.

The Monitoring System monitors the system for performance, security, or other purposes. It also includes metrics related to the broker's performance, such as message throughput or latency. It may also collect data related to the health of the various components, such as CPU utilization or memory usage.

The architecture provides a flexible and scalable way to provide context information to consumers while maintaining control over access to that information. The use of a broker and a publish/subscribe messaging model allows for the decoupling of the various components and reduces the need for tight coupling between providers and consumers. The addition of a Query Orchestrator and other processing components provides additional flexibility in how context information is retrieved and processed. The inclusion of external systems like the Reasoning Engine and Monitoring System demonstrates the ability of the architecture to interface with other systems and provide a platform for further development and integration.

A. *Context Acquisition and Privacy*

There are a number of different techniques that can be used to acquire context data from multiple sources in a mobile network, depending on the specific context information being sought and the resources available. Managing differences in the data structure is a fundamental challenge when acquiring data from multiple sources. For instance, if we were to retrieve the temperature of a chipset from a device, we might have to cope with the fact that the result could be in degrees Celsius or Fahrenheit. Following are some specific ways to acquire context data from multiple sources:

- Sensors and probes: Sensors and probes can be used to gather context information about the physical environment, such as temperature, humidity, light levels, and other physical parameters. Sensors and probes can be embedded in devices or deployed in strategic locations to gather context data in real-time.
- Social media and online sources: Social media platforms and other online sources can be used to gather context data about locations, interests, activities, etc.
- User input and feedback: User input and feedback can be used to gather context data about the preferences, habits, and behavior of users within the mobile network. For example, surveys, questionnaires, and other forms of user feedback can be used to gather context data about user preferences and needs.

Privacy is a critical aspect of context acquisition. As context data is collected from multiple sources, it is important to ensure that the data is collected and used in compliance with privacy regulations and ethical standards. This involves implementing appropriate privacy policies, ensuring transparency in data collection and use, and obtaining user consent for collecting and using their context data.

Several techniques can be used to protect user privacy in the context acquisition process. One approach is to use data anonymization techniques, such as masking or tokenization, to remove personally identifiable information from context data. Another approach is to use encryption to protect the privacy of context data during transmission and storage.

In addition, context data should only be accessed by authorized parties, and access should be limited to the minimum necessary to perform the required task. This can be achieved through access control mechanisms, such as role-based access control and attribute-based access control.

B. *Context Query Handling*

The sequence diagram in figure 3 illustrates a communication scenario of a context query. It starts with the Context Consumer subscribing to a topic it wants to listen to and then publishing a context query to the broker.

The broker then forwards the query to the query orchestrator, which in turn forwards it to the Query parser for parsing. The parser retrieves the necessary context information from the context repository and returns it to the orchestrator. The orchestrator then forwards the parsed query to the aggregator.

The query aggregator retrieves additional context data from the context repository and user information from the user repository. It then aggregates the results and returns them to the query orchestrator, which in turn returns the query results to the broker.

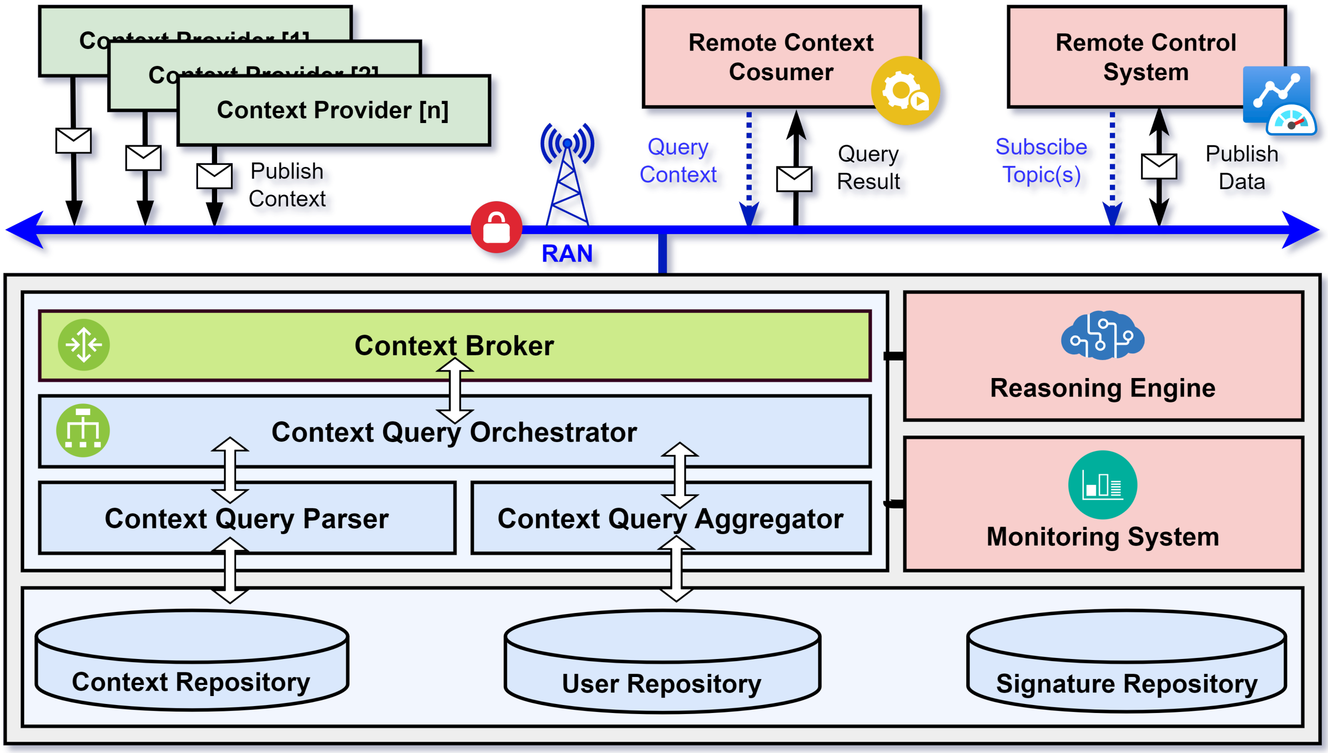

Figure 2. Context Management System Architecture

Finally, the Context Broker publishes the query results to the topic the consumer has subscribed to. The sequence diagram shows the various interactions between the different components of the system, and how they work together to provide context-aware services to the user.

C. Communication Framework

Operation of a Context-Management System (CoMaS) is among other things, a very communication-heavy task. Besides its central purpose of provisioning data, intermediate processing, and acting as an intermediate agent, the functionality of context-brokering extensively involves the bare process of information exchange between *agents* –which is actually not functionality to be brought by the CoMaS but required for it. In this regard, the information exchange consists of multiple layers: a higher-layer protocol for the logical communication with the CoMaS and, on the lower levels, the plain distribution of network messages.

It yields certain benefits to abstract the lower-layer communication obligations and to create a modular interplay of dedicated tools, as this separates the concerns and allows us to precisely tailor the application to a specific set-up. It is expected that sophisticated CoMaSs will especially be commissioned within already complex, integrated systems, where some kind of management and orchestration logic will likely be present and also in charge of configuring communication flows. Another scenario is the integration of a CoMaS into a software toolbox that is designated as the foundation for such overall systems [12], [13]. Shipping the CoMaS with its own solution for low-level network communication would cause the risk of conflicts, whereas the modular re-using of functionality enables us to rely on proven methods for common tasks.

Furthermore does an abstraction and modular interaction allow a more versatile applicability? By swapping the communication tool, the information distribution paradigm can be easily switched to e.g. pub/sub in one environment or direct E2E in another, without the CoMaS having to care about this.

Consequently, the CoMaS can focus on the data itself and supply a contact point for requests on-demand, while features like an event-based distribution of information updates are triggered by the communication abstraction and related features like set-up-dependent multi-cast can just be assumed given. Finally, the operation of the entire overall system is rendered more robust and flexible as from the point of utilizing tools (like the CoMaS) the network is zero-config available and the *virtual topology* of network partners is taken care of by the communication abstraction. By that, even alterations during runtime are possible, as only one central handler requires updates and subsequently supplies a running infrastructure for use by its inter-operating tools.

V. Conclusion and Future Work

In conclusion, the architecture presented provides an effective means of delivering context information to consumers through a broker and a publish/subscribe messaging model. The addition of a Query Orchestrator, Query Parser, and Query Aggregator enhances the flexibility of the system, while components like the Reasoning Engine and Monitoring System demonstrate the potential for integration with other systems.

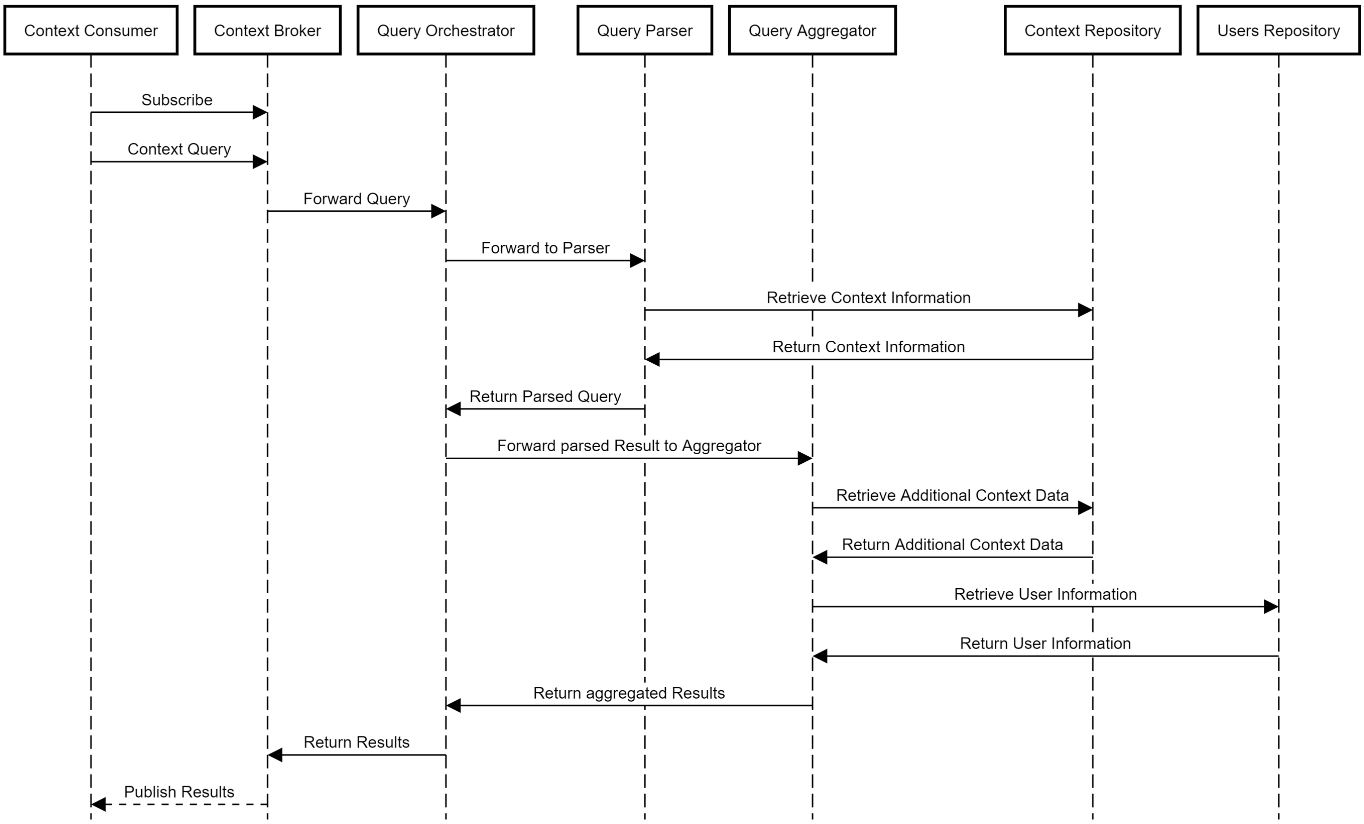

Figure 3. Context Query Process

Future work could involve exploring further integration with external systems, expanding the scope of the architecture to handle more types of contextual information, and developing improved privacy and security measures to protect sensitive information. Additionally, continued optimization of the architecture's performance and scalability could be beneficial for large-scale deployment.

VI. Acknowledgment

The authors gratefully acknowledge financial support from the German Federal Ministry of Education and Research (BMBF) as part of the project »Open6GHub« 16KISK003K.

References

[1] I. Tomkos, D. Klonidis, E. Pikasis, and S. Theodoridis, "Toward the 6g network era: Opportunities and challenges," *IT Professional*, vol. 22, no. 1, pp. 34–38, 2020.

[2] X. Zhang, J. Fan, Y. Chen, D. Li, and Y. Gao, "A distributed context management architecture for the internet of things," *IEEE Internet of Things Journal*, vol. 6, no. 2, pp. 2046–2057, 2019.

[3] S. Kim, D.-K. Kim, D.-G. Kim, and J. Kim, "A context management framework for mobile networks," *IEEE Transactions on Mobile Computing*, vol. 16, no. 8, pp. 2237–2250, 2017.

[4] J. Lee, H. Lee, H. Lee, and H. Kim, "A context management architecture for 5g networks," *IEEE Network*, vol. 33, no. 4, pp. 84–90, 2019.

[5] H. Zhang, Z. Chen, L.-C. Lai, and H.-H. Chen, "A context management architecture for vehicular networks," *IEEE Transactions on Vehicular Technology*, vol. 66, no. 9, pp. 8181–8195, 2017.

[6] A. Al-Fuqaha, M. Guizani, M. Mohammadi, S. Xu, M. Aledhari, and M. Ayyash, "A context management system for managing privacy in mobile networks," *IEEE Transactions on Mobile Computing*, vol. 14, no. 12, pp. 2522–2535, 2015.

[7] S. Kim, D.-K. Kim, D.-G. Kim, and J. Kim, "A context management system for supporting location-based services in mobile networks," *IEEE Transactions on Mobile Computing*, vol. 15, no. 10, pp. 2376–2389, 2016.

[8] Y. Zhang, J. Chen, S. Gao, F. Guo, and J. Chen, "A context management system for supporting the integration of edge computing and iot in mobile networks," *IEEE Access*, vol. 8, pp. 158 146–158 157, 2020.

[9] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Reasoning in the internet of things: A survey," *IEEE Access*, vol. 3, pp. 1605–1626, 2015.

[10] R. D. Souza, L. F. Pires, F. Q. Sousa, J. Gama, A. Omicini, and G. Guizzardi, "Rule-based reasoning in the internet of things: A survey," *IEEE Access*, vol. 6, pp. 46 466–46 488, 2018.

[11] J. Li, Z. Zeng, L. Chen, S. Gao, and W. Zhang, "Probabilistic reasoning in the internet of things: A survey," *IEEE Access*, vol. 6, pp. 84 458–84 478, 2018.

[12] D. Krummacker and H. D. Schotten, "InDeCo – Detach Communication from the Interconnection via an automatic zero-configuration, service-oriented Network Handling," in *Mobile Communication-Technologies and Applications; 25th ITG-Symposium*, ser. ITG, vol. 299, VDE. IEEE Xplore, VDE, 11 2021, pp. 1–12.

[13] D. Krummacker, C. Fischer, Y. Munoz, and H. D. Schotten, "Organic & Dynamic Infrastructure: Getting ready for 6G," in *Mobile Communication-Technologies and Applications; 26th ITG-Symposium*, ser. ITG, vol. 304, VDE. IEEE Xplore, VDE, 5 2022.