Future Directions on Enhanced Positioning Services with Predictions for Smart Factories

Elham Dehghan Biyar, Ahmet Cihat Baktir, Deniz Çokuslu, Yunus Donmez
Ericsson Research, Istanbul, Turkey.
firstname.lastname@ericsson.com

***Abstract*—Efficient indoor positioning of the industrial devices is a key pillar of the digitalized factories. In 5G/6G era, the integration of positioning, the network communication and the environmental information is important to enhance the accuracy and performance for various use cases. In this direction, there is a need of a unified framework that is able to aggregate knowledge about device positioning from multiple systems and provide value added services for the vertical industries to realize their use cases. In this paper, we propose a positioning service function that combines the relevant information gained from different sources for providing enhanced positioning services with predictions. In addition, this paper presents a methodology based on Asset Administration Shell (AAS) to implement the proposed functionalities. The proposed approach outlines future direction on enhancing positioning services in smart factories to improve network and service management. We further illustrate our suggested way forward through a smart manufacturing use case.**

***Index Terms*—6G, device positioning, Industry 4.0, smart manufacturing, Asset Administration Shell**

I. Introduction

The smarter operations of the industries rely on rapid and successful digital transformation. Towards the journey of industrial automation and innovative use cases such as extended reality and mobile robots, network solutions need to provide value-added services on top of wireless connectivity. One key source of creating value for enterprises is to integrate the capability of real-time positioning in dynamic environments. Next generation cellular networks in form of 6G aim to significantly enhance indoor and outdoor positioning systems and provide novel solutions to improve accuracy and reliability [1]. The positioning of active communication devices is an inseparable part of the ongoing recent standards (i.e., the Third Generation Partnership Project (3GPP)). With the evolving technology, expectations are becoming more and more stringent. For certain environments, sub-meter positioning accuracy is required by future applications such as smart factories. For 6G, beyond supporting new use cases, integration of positioning, network communication and environmental information is important to enhance the accuracy and performance of the positioning services [2]. Positioning technologies towards 6G is thoroughly discussed in the literature and gaining more precision with the new releases. TS 23.273 [3] introduces 5G Location services (LCS), which can report location information for a target UE (User Equipment) or group of UEs. Positioning techniques in 6G and ways to improve them are explored in [4], [5]. Several studies focused on non-satellite based positioning, especially for indoors scenarios and deployments [6], [7]. Positioning with fusion of data from different sources can provide better performance with higher accuracy. Even though there exist solutions providing precise positioning, to the best of our knowledge, the work on position prediction based on the fusion of data collected from different systems are limited.

In this paper, we propose a novel research direction in conjunction with positioning service function that enables data collection and management from diverse set of resources. The contextual data collected from different sources may include valuable and meaningful information to feed position prediction algorithms. We believe, the insights compiled by the positioning function can be potentially used for high performance position prediction for UEs. This paper also introduces a method to implement the proposed functionalities with AAS. AAS is one of the promising techniques capable of integrating various solutions and devices from different providers at a factory floor. Besides, we provided a detailed analysis of Automated Guided Vehicles (AGVs) use case.

II. Problem Context

Location estimation and predicting the movement of devices play a crucial role in planning certain industrial tasks (e.g., scheduling production processes). The current positioning services provided by the networks rely on the data generated in the 5G system, and networks does not define the ways of gathering and using data that is available outside of this system. As one of the closest technologies, 5G Network Data Analytics Function (NWDAF) can generate UE-related analytics and predictions (i.e., mobility, location accuracy, proximity, movement behavior) by collecting relevant information from network functions (NFs) and Orchestration and Management (OAM) [8]. The limited set of data defined by 3GPP may not be enough to maximize the performance (e.g., accuracy) and scope (e.g., output data type) of the UE-related analytics/predictions. There might be other set of data that can be provided by the device or another system, which cannot be collected by the network itself through the existing 5G interfaces or protocols. Adding new features from other systems can provide a more complex prediction model for

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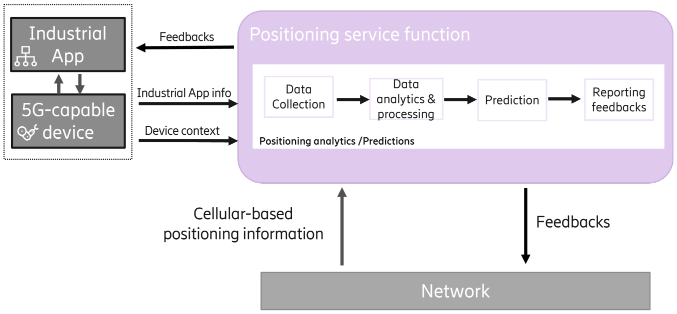

Fig. 1. Proposed positioning service function components.

positioning. This approach renders the positioning prediction model to better represent the underlying parameters.

To enhance the performance of positioning services with predictions, there is a need for a solution that can benefit from information gathered from the industrial applications, the 5G connected devices along with the 5G network. In this respect, this paper proposes an entity called "Positioning service function" that collects, processes and evaluates this set of information. This entity is capable of providing predicted position information for industrial devices. The provided solution proposes to benefit from contextual information gathered from 5G-capable end devices and industrial applications along with the set of data already aggregated in the 5G network. Collecting data from the end-user device related to the device state and industrial processes could provide valuable insights that can impact the predicted location. For instance, an industrial application planning the tasks and coordinating the robots (e.g., AGVs) may already know the destination coordinates for a particular robot. This application layer information is not available in the network or UE, but it is a promising feature that might enhance the positioning prediction performance.

III. System Model and Proposed Methodology

Figure 1 demonstrates our proposed "Positioning service function". This function consists of data collection, data analytics and processing, prediction, and reporting capabilities. It enables integration of different systems (industrial processes, network), and implements the capability of collecting data from various resources. The provided service removes the constraint of using a predefined set of input features and brings flexibility of adding more features or identifying the most relevant ones for further improvement in performance. The high performance positioning prediction service can be used by the network to provide enhanced performance management services, such as a proactive resource management scheme.

The estimated location can be used accordingly by network to optimize the resource utilization and provide service assurance for the devices. Moreover, the proposed solution can be useful by providing the estimated location beforehand for cases when a device is out of coverage. Therefore, this information can be used for enriched device management operations (e.g., asset management, optimizing the path planning). The detailed explanation of each component accommodated by the positioning service function is as follows.

A. Data Collection

This module is responsible of collecting context-aware data, cellular based positioning information and analytics from the network, the devices, and the industrial applications. In this regard, UE and position related information generated by the AMF, GMLC, OAM is collected from the 5G network. This set of information can be, but not limited to, UE locations, associated positioning technique and accuracy, handover operations, NWDAF analytics and predictions related to UE (e.g., mobility, movement behavior, proximity), UE moving direction, speed and timestamp. Moreover, the data collection module is capable of collecting data from devices and industrial applications related to the context as exemplified above.

Similar approach should be followed to fetch data from the 5G-capable device and industrial applications. The list of data that can be collected by the devices and/or the industrial application can be, but not limited to battery status, current location and destination coordinates, current path and trajectory, participated tasks in value chain and devices in collaboration, scheduled updates, radio network parameters: network quality reception, power used during transmission, etc. The data collection module can subscribe to periodic or event-based exposures provided by the systems. The standardized exposures (i.e., Service Enabler Architecture Layer (SEAL), Network Exposure Function (NEF), or any proprietary interface) can be used to retrieve the positioning, device or any industrial application related information and analytics.

B. Data Analytics and Processing

This module is in charge of processing the collected data, filtering and ensuring the compatibility among retrieved information. Besides, data integration is done by combining the data collected from different sources (i.e., network and device) based on common identifiers like device IDs or timestamps. This module is integrated with relevant methods to provide descriptive statistics by summarizing the historical data and generating insights. By using such techniques, this module can generate knowledge such as the mean number of UEs in a cell and the most crowded location during the day. This module can also accommodate techniques providing inferential statistics that uses the data and draw conclusions. Based on a given sample, inferential statistic methods such as analysis of variance (ANOVA) can be used to make generalizations about a larger population. For example, the movement of UEs in different groups (e.g., UEs consuming different services) can be further analyzed to see if there are statistically significant differences among the groups. This collection of information can be useful for further planning in business operations and network.

C. Prediction

Detection of the correlations and patterns within collected data that could probably be beneficial for location prediction is done in this module. Afterward, appropriate machine learning (ML) models for location prediction will be chosen. Training, validation and evaluation (Mean Absolute Error or Root Mean

Square Error) of the model to assess the accuracy will be executed. Based on the requirements, a linear model (e.g., linear regression) can be designed to predict the location coordinates for a given UE. Besides, the complex relations between the input features can be determined through a non-linear model (e.g., neural network). This module may be integrated with feature selection techniques [9]. Among a huge set of candidate input features, the feature selection approaches choose the most relevant and remove the redundant ones to reduce the feature space dimension and accelerate the training process. This process can be executed offline, while the original model continues running inference. If accuracy is improved with the arrival of new data set, the original model can be replaced with the one trained and tested offline. As an example, if it is concluded that battery status of the end-user device is not useful to predict the estimated location, it can be removed from the set of input features to reduce the complexity and enhance the performance.

D. Reporting

The predicted positions of the devices at the next time window, confidence and accuracy of prediction and all related analytics will be reported as feedback to the network, the industrial applications and the devices. The feedback provided to the network can be used for multiple purposes such as resource allocation, fault management, proactive configuration management and energy efficiency. In addition to the network, end-user devices and industrial applications can benefit from the generated feedback for control operations. Based on the predicted location, the path of the device can be optimized (e.g., obstacles on the path), asset management processes can be optimized, energy saving can be activated, and manufacturing tasks can be planned accordingly. The content of the reports and the ways of using them can be customized according to the use case requirements.

IV. Asset administration shell (AAS) for Value Added positioning Services

There could be various approaches to implement the proposed positioning service function for industrial domains. Since the main methodology aims to aggregate data from multiple independent systems, it is important to realize the end-to-end flow in an interoperable manner. One promising technique that is capable of integrating various solutions and devices from different providers at a factory floor is AAS.

A. What is Asset Administration Shell (AAS)?

AAS is an industrial specification that creates the digital representation of assets [10]. It is a widely adopted solution in Industry 4.0 as a result of the broad standardization effort. The structure of AAS, interfaces and information meta model are standardized by IEC. In addition, the interoperable information exchange and language for I4.0 components defined by VDI/VDE 2193 renders AAS as a key entity enabling interoperability between different systems with numerous communication models [11]. Along with I4.0 components, 5G system can be also represented in the digital world through AAS principles. This paper proposes to create the AAS of 5G network, named 5G Network (NW) AAS that accommodates the enhanced positioning prediction service for industrial deployments. AAS, in principle, consists of two parts: passive, active. The passive part consists of the data and information provided by the asset and other AAS instances. The submodels integrated into the passive part are used to represent various aspects of an asset such as its capabilities and energy efficiency and store the information related to the life cycle of the asset itself. On the other hand, active part implements the digital twin-like capabilities in AAS where any decision-making algorithm or analytical models can be implemented.

B. 5G NW AAS for Enhanced Positioning Services

The positioning related data exposed by the 5G network can be stored in 5G NW AAS. In order to have an interoperable communication with the industrial devices by eliminating vendor dependency and collect contextual data for prediction and analytics purposes, AAS of the devices can be implemented (i.e., 5G UE AAS). So, by using device proprietary interfaces and APIs, the contextual data of each end-user device can be stored in its own AAS, which can then be communicated with the 5G NW AAS through standard language and communication model. Data collected from different sources can be stored in AAS, in form of submodels. The data collection, data analytics & processing, prediction and feedback modules (positioning service function) can be implemented in the active part of 5G NW AAS. When needed, the active part functions can access the passive part, write, read or modify the content in the specific submodel accordingly. The examples of the submodels can be localization, positioning analytics and alarm/events that can be used to store various kind of information.

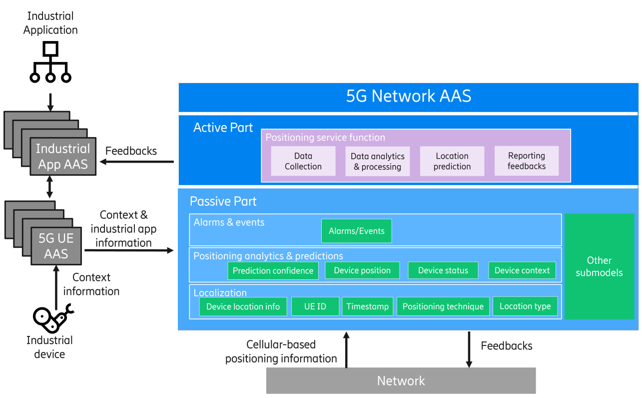

Fig. 2. Context-aware positioning prediction for industries

The envisioned structure of 5G NW AAS is illustrated in Figure 2. In addition to the information about alarms, events, device positioning and localization, there could be other submodels implemented in 5G NW AAS depending on the use case requirements and network exposures. By using the standardized I4.0 language, different AAS representations can interwork and exchange information that are useful to enhance the positioning prediction for devices. The standardized interfaces of AAS could also expand the scope of AAS towards external applications. In addition to the value-added services provided by AAS, it can be used as a unified exposure framework for industries. By hiding the low-level exposure details and abstracting the underlying complexity due to various solutions, 5G NW AAS can aggregate the knowledge from different systems and provide a simple view for the factory operators.

C. Use Case Analysis: Automated Guided Vehicles (AGVs)

In this use case, we aim at giving a more concrete example scenario to clarify the idea. The use case consists of a smart factory environment equipped with a private 5G network and 5G enabled devices. A smart 5G enabled AGV is considered as the specific UE, which is either embedded in the AGV or connected via a separate connection, to be examined during this use case. The aim is to enhance the position prediction performance (e.g., accuracy) of the UE using contextual information, that is gathered from the device with the help of AAS. As depicted in Figure 3, suppose that the AGV is moving at the trajectory. Without having detailed contextual information, current prediction methods can only make predictions based on the historical position data, which stochastically predicts whether the device will move towards a particular route (i.e., route A, B or C). This prediction may not be very precise because in every mission, which direction the AGV will move is unknown.

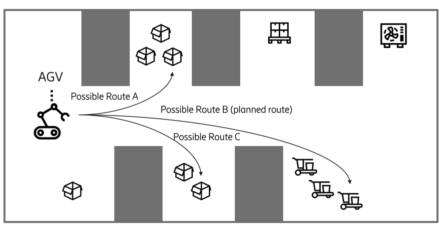

Fig. 3. Smart Factory AGV Use Case

After applying the proposed method, according to AGV's tasks in value chain and devices in collaboration, planned operation route of the AGV is provided as the contextual information to be used in prediction. This information will be transferred to the proposed positioning service function through AAS. The AGV is assumed to have a secure connection with its own AAS (i.e., 5G UE AAS), via the proprietary interface. The information about the planned operation route, along with other relevant set of data, can be exposed by AGV to its AAS periodically or in an event-based manner. Then, AAS of the AGV can exchange this information with the 5G NW AAS. This information and knowledge exchange can be realized through the standardized AAS communication model and interfaces. With this information, the path that the AGV will follow is known by the positioning service function embedded in the 5G NW AAS. Together with other position related information, such as AGV velocity, acceleration, heading, current position, current time and elapsed time, the prediction module calculates the future position of the AGV to be on top of the given path. Using the planned route information (route B in this example) as an input feature of the model increases the accuracy of the predicted location.

V. Conclusion

The development of 6G networks plays a crucial role in providing accurate, reliable, and up to date indoor positioning services for smart manufacturing. However, the network should have a seamless integration with industrial systems to further enhance the performance of positioning services. Our proposed positioning service function should overcome the challenges such as integration of multiple systems, data resources and interfaces for accurate position reporting. This function can potentially implement a high-performance positioning prediction to realize real-time localization of the industrial devices. Furthermore, this paper introduces AAS that can integrate various solutions and devices from different providers. Finally, to validate the proposed solution, an instance of AGV utilization in an industrial application planning and coordinating is analyzed. Potential future work can focus on the deployment aspects of the proposed solution and evaluate the performance under realistic conditions.

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