LOCUS: Localization and analytics on-demand embedded in the 5G ecosystem

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***Abstract*—Location information and context-awareness are essential for a variety of existing and emerging 5G-based applications. Nevertheless, navigation satellite systems are denied in indoor environments, current cellular systems fail to provide high-accuracy localization, and other local localization technologies (e.g., Wi-Fi or Bluetooth) imply high deployment, maintenance and integration costs. Raw spatiotemporal data are not sufficient by themselves and need to be integrated with tools for the analysis of the behavior of physical targets, to extract relevant features of interests. In this paper, we present LOCUS, an H2020 project (https://www.locus-project.eu/) funded by the European Commission, aiming at the design and implementation of an innovative location management layered platform which will be able to: i) improve localization accuracy, close to theoretical bounds, as well as localization security and privacy, ii) extend localization with physical analytics, iii) extract value out from the combined interaction of localization and analytics, while guaranteeing users' privacy.**

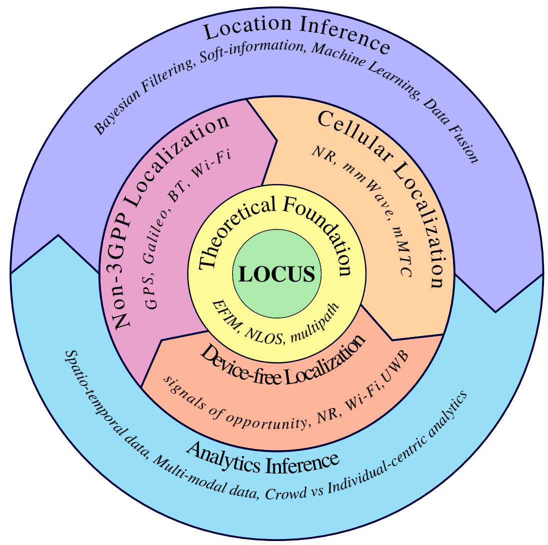

Fig. 1. LOCUS Technical Concept

I. Introduction

The overall Location Based Services (LBS) and Real-Time Location Systems (RTLS) market is ready to take off. According to a recent research report [1], this market is projected to grow from USD 16 billion in 2019 to USD 40 billion by 2024, at a Compound Annual Growth Rate (CAGR) of 20.1% during the forecast period (2019–2024). However, as much as 60% of the global LBS revenues have so far been taken by very few leading players, which rely on global navigation satellite systems' technology integrated into the end user device (such as GPS) and on their custom over-the-top (OTT) technologies. On the other hand, these solutions do not typically leverage active assistance from the network infrastructure going beyond the mere passive collection of signal strength from cell towers and WiFi nodes in range.

A localization system based on 5G components potentially can overcome these problems, offering the accuracy required and a high degree of security and location integrity. A location management layered infrastructure is under development within the H2020 project LOCUS [2]. Such an infrastructure will not only be capable of improving localization accuracy and security but also to extend it with physical analytics, and extract value out of it, meanwhile guaranteeing the end users' right to privacy. LOCUS functionality will, for instance, abstract sensitive parts (e.g., network structure related), develop positioning algorithms that exploit the activity in the standard, and generate insights and predictions for the (higher-layer) applications to exploit. Such work is timely: accuracy, latency, availability, scalability, and resource utilization are among the requirements for 5G positioning in 3GPP Rel. 17 [3].

In more detail, 3GPP Rel. 17 is currently extending the functionality of 5G architecture with additional components to enable positioning reference signals, measurements, and procedure information. Building on top of such components, adequate low-complexity algorithms and scenario-dependent deployment designs can enable future versions of 5G networks to: (i) provide accurate and ubiquitous information on the location of physical targets as a network-native service, and (ii) derive complex features and behavioural patterns from raw location and physical events for application developers.

This paper presents the advance beyond state of the art in the four main research areas involved in the LOCUS project: i) accurate 5G localization; ii) integration with non-3GPP technologies and device-free localization; iii) analytics algorithms and computing platforms; iv) location-aware network management. Fig. 1 illustrates how the aforementioned areas are related to each other. The LOCUS project will aim to perform an integration of diverse technologies for localization and analytics. It will integrate 3GPP and non-3GPP technologies for terminal localization and passive localization in the 3GPP 5G Core and integrate localization data from both terminal localization and passive localization for analytics.

The remainder of the paper is structured as follows. Sec. II presents the virtualization and software platform. Sec. III presents the localization techniques for enhancing location accuracy. Sec. IV introduces network management aspects. Sec. V presents localization analytics for new services. Sec. VI presents location security and privacy aspects. Finally, Sec. VII draws our conclusion.

II. Architecture

In LOCUS, the 5G architecture integrates localization and analytics functions, which are deployed exploiting the combination of edge and core virtualized infrastructures in agreement with the 5G Core service-based architecture approach defined in 3GPP. In the following, we initially provide more details about the proposed service-based architecture, and then we shed light on the virtualization and software platform.

A. Service-based architecture

Fig. 2 illustrates the LOCUS architecture. First, the localization enablers collect location information at the edge of the virtualized infrastructure by exploiting heterogeneous 5G and non-3GPP technologies, such as Global Navigation Satellite System (GNSS), Wi-Fi, Bluetooth, and device-free localization. The localization services are then offered as Location Management Functions (LMFs) to the upper layers. More in depth, the LMFs are exposed through REST APIs, following the 3GPP service-based approach, and they are aligned with both 3GPP specifications and 5G localization management system [4].

Apart from the new localization function, the service-based architecture implements a novel approach and is proposed for smart 5G network management based on location-based analytics functions that feed intelligent network optimization functions. Such network management and optimization services and functions are considered in LOCUS as 5G Network Data Analytics Function (NWDAF), in charge of collecting both network-internal and external information in a centralized manner, and thus being part of the 5G architecture as specified by 3GPP [5]. These services and functions are accessible to the operation support system (OSS) and business support system (BSS).

In addition to the network-management functionality, the proposed architecture provides room for the deployment of third-party localization applications and services for verticals, through the exposure of built-in location-based data and analytics functions. More specifically, the deployment of vertical-driven applications is ensured by providing application developers with access to a wide set of services and data sets, following a common and unified strategy, in terms of APIs and data models. This in turn enables the heterogeneous vertical services to be run on top of the LOCUS system and exploit the built-in location-based analytics and database services.

B. Virtualization and software platform

The innovative localization and analytics services are managed through a virtualization and software platform, which is one of the main pillars of the LOCUS solution. First, such platform allows to deploy and operate the various functions within the 5G edge and core infrastructures, by leveraging on existing and well-defined Network Function Virtualization (NFV) and microservices orchestration solutions (e.g., the ones specified by ETSI [7]) and implemented by open source tools such as Open Source MANO (OSM) and Kubernetes.

By following the microservices approach of the 5G Core service-based architecture, the LOCUS virtualization and software platform enables the packaging of the whole set of localization and analytics functions as cloud-native applications. This approach will allow chaining and integration of the LOCUS functions with the 5G Core components, to provide the required localization and analytics services. A key role in the LOCUS virtualization and software platform is played by the MAnagement and Network Orchestration (MANO) framework, which allows managing the lifecycle of the LOCUS components in an automated and dynamic way, following the requirements of the various 5G network optimization and vertical services. Beyond the alignment with the ETSI NFV principles for functions virtualization and their management, the localization services orchestration in LOCUS is also taking a step forward with respect to the current monolithic solutions, mostly dedicated to the management of NFV-like pipelined services, where the lack of agility in the service lifecycle and operation is a clear limitation. Indeed, LOCUS adopts a service-based architecture approach also in the MANO framework, following the principles of zero-touch service management defined in ETSI ZSM [8], that targets a novel, horizontal and vertical agile management and automation of emerging services, including 5G ones.

In this scenario, the LOCUS MANO layer manages the automated deployment, configuration, and operation of the heterogeneous localization and analytics microservices, including their integration with the 5G core components, by coordinating the selection of edge and core infrastructures for optimal operation. In line with the requirements of each specific 5G network optimization or vertical service, as well as with server-based and server-less approaches for the packaging, the deployment and the operation of the LOCUS functions are implemented through the virtualization of functions and the software platform. In addition, the LOCUS platform enables access to the built-in location-based analytics and database services through a dedicated API layer, which is exposed to third party localization application developers. This feature

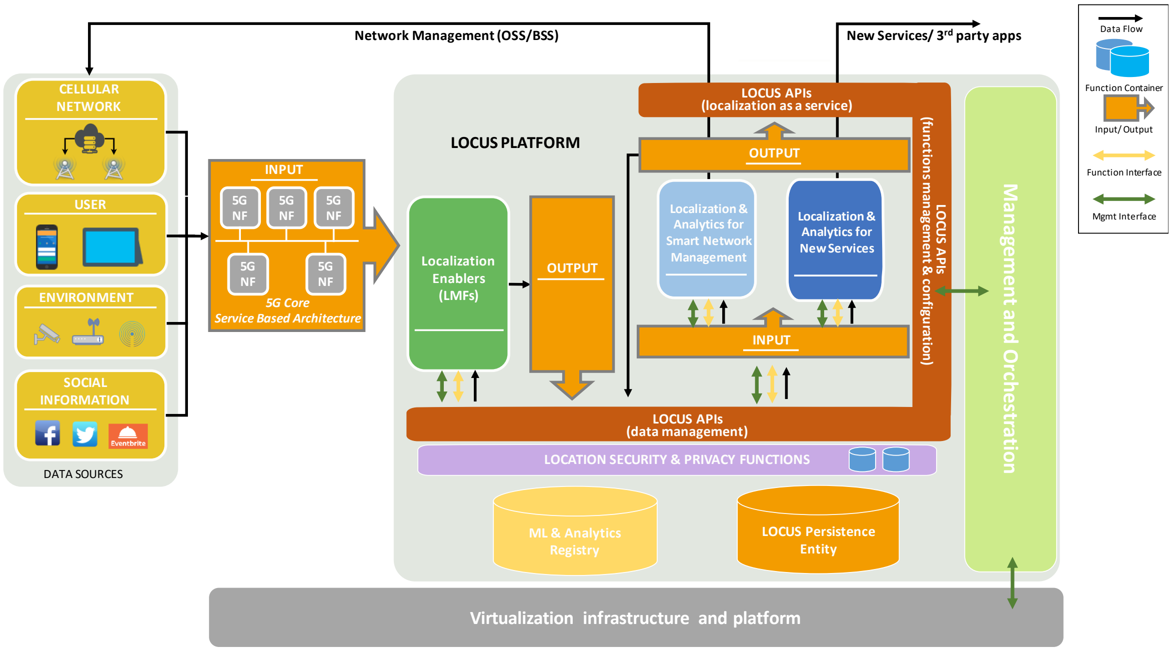

Fig. 2. LOCUS Architecture

will be realized by following a multi-tenant approach in both the MANO framework and the virtualized edge/core infrastructure, by ensuring well-separated running environments for localization enablers and functions for 5G network optimization, against analytics functions and applications that will serve vertical services. Such a multi-tenant approach allows us to separate the management and orchestration of the various services as well, thus having the lifecycle of vertical services and other LOCUS built-in applications not interfering with each other.

III. Localization Enablers

The 3GPP defines positioning architectures and methods to fulfill regulatory requirements and provide added value services to the end users. Current 5G localization solutions rely on single-value metrics such as uplink time-difference-of-arrival (UL-TDOA), downlink time-difference-of-arrival (DL-TDOA), received signal strength indicator (RSSI), and angle-of-arrival (AOA). Localization accuracy depends heavily on the quality of such estimates, which degrades in harsh propagation environments. In the following, we describe the advanced localization techniques that will be implemented in LOCUS, as well as the integration of the project with non-3GPP technologies and device-free localization.

A. Advanced localization techniques

The requirements and constraints of diverse mobile terminals (smartphones, wearables, cars, etc.), as well as the three main service classes enabled by the 5G technology, are considered:

Enhanced Mobile Broadband (eMBB): LOCUS will develop lightweight mmWave localization algorithms, which exploit the specific capabilities and beam patterns of analog/hybrid beamforming antennas of mmWave cellular systems.

Machine Type Communication (mMTC): two possible single value metrics have been proposed in 3GPP for mMTC and IoT scenarios: modified Observed Time Difference Of Arrival (OTDOA) and/or Uplink Time Difference of Arrival (UTDOA) [9], [10]. LOCUS will propose techniques for UTDOA estimation that comply with the network communication constraints of the mMTC service class.

Ultra-Reliable Low-Latency Communications (URLLC): The ability to allocate mini-slots for URLLC-based applications in 5G-NR complicates the design of Positioning Reference Signals (PRS) and Tracking Reference Signal (TRS) for OTDOA. LOCUS will provide solutions to reduce the localization service response time to a few milliseconds for URLLC applications. LOCUS will investigate the combined use of fast time-based and angle-based methods to achieve ultra-fast localization.

In order to increase the localization accuracy, efficient and scalable Bayesian filtering algorithms are employed for localizing multiple and fast-moving terminals. A further improvement in terms of localization accuracy can be achieved by relying on localization algorithms that fuse different metrics, e.g., using joint likelihood functions that account for the correlation among different metrics and mitigate the impairments caused by multipath and NLOS conditions [11], [12], [13], [15].

In addition to localization accuracy, the update rate of information, as well as privacy and security, will be critical application-driven requirements. For example, developing localization enablers to support emergencies will be a key area of focus for the LOCUS project. In particular, 3D indoor localization represents a vital tool for the emergency and security services in case of events like a multi-store building fire, kidnap and terrorism incidents, as well as indoor medical emergencies. In developing such enablers, LOCUS also investigates closely the use of quickly deployed drones at different heights, which can provide increased 3D localization accuracy with the support of the fixed 4G/5G network infrastructure.

B. Non-3GPP technologies and device-free localization

3GPP has defined procedures, protocols, and messages to take advantage of non-3GPP technologies. The idea is to leverage the fact that the UE has several radio interfaces such as Wi-Fi and Bluetooth that could be accessed and exploited by 5G for localization. The solutions must also take into account that the RAN does not have any control on any non-3GPP infrastructure deployed. As originally defined in LTE [10], there exist three positioning modes for integration with non-3GPP technologies:

- standalone: UE localizes itself without any aid from the network;
- UE-based: UE position is calculated by UE with assistance from the network;
- network-based: UE position is calculated in the network side with measurements sent from the UE.

These procedures, protocols, and messages are envisioned to be extended to NR network-based hybrid positioning [14]. LOCUS plans to explore the above positioning modes to support the integration of diverse non-3GPP technologies with the 5G localization concepts designed in the project and study the trade-offs in the KPIs for each mode. The observables that can be extracted with non-3GPP technologies (e.g. (e.g., 802.11 with Multi-User MIMO Channel State Information and Fine Time Measurements in Wi-Fi) will serve as input for technology-agnostic and low-complexity algorithms for heterogeneous data fusion. In addition, dimensionality reduction techniques will be complemented with machine learning and deep neural networks to extract the main features from a rich and heterogeneous set of measurements with diverse sources of noise [16]. Moreover, LOCUS will investigate communication protocols to support the integration of diverse non-3GPP technologies.

Another interesting related topic of investigation in LOCUS is device-free localization, i.e., the capability of detecting and tracking objects that do not communicate within the localization infrastructure. These technologies rely on signal designed for target detection and localization (active radar) or on signals emitted by other sources of opportunity (passive radar) that are exploited for localization [17], [18]. Signals for backscatter (illuminator of opportunity) can be both 5G next-generation Node-Bs (gNBs) as well as transmitters already deployed in the environment for other purposes. In contrast to 5G terminal localization, device-free localization can take advantage of any modulated signal at any frequency of operation. To this end, LOCUS will exploit a network of receivers (gNBs as well as community-based deployments of spectrum sensors), whose frequency configuration is adapted to the accuracy requirements of the specific scenario. The challenge addressed by LOCUS in this domain is the design of novel, optimized, low-complexity algorithms that allow developing a flexible and reconfigurable passive localization system integrating 3GPP cellular localization with non-3GPP technologies.

IV. Network Management in LOCUS

The LOCUS project will use the location information of the network users and advanced data analytics techniques to achieve enhanced, smart network management. In LOCUS, the innovative location-aware approach will support the design of new algorithms, which will be supported by location data from the UEs, the gNB, and the location servers. It will be based on advanced data analytics techniques, empowered by the NWDAF, in which the algorithms for network management will be integrated. This function is in charge of collecting both network-internal and external information in a centralized manner and has been proposed by 3GPP in [5] with procedures for network automation presented in [19]. The algorithms implemented in this context will target the following objectives: (i) achieve a resilient network that rapidly identifies network issues that could jeopardise a normal network behaviour and (ii) optimize a set of Key Performance Indicators (KPIs), such as service performance for the users, energy consumption for the operator, and ElectroMagnetic (EMF) exposure levels over the territory. In the following, we provide more details about the implemented solutions.

A. Network resilience

Network resilience has been classically addressed in Radio Access Networks through the self-healing function [20] of Self-Organising Networks (SON), which includes failure detection, diagnosis and, compensation. With 5G deployments, it will be necessary to consider new types of problems or network states (e.g., related to network virtualization), as well as to study how these will be manifested through the network and service performance indicators and the context [21]. In addition, more efficient compensation algorithms will be developed, taking advantage of multi-link communications or the use of unlicensed bands in 5G. In this line, LOCUS will study the statistical relation between the 5G specific failures, their effect on different services' performance, and the location of the users.

The proposed models in LOCUS will include the effects of failures on low layer indicators (e.g., L1 and L2 layers) as well as for an end-to-end (E2E) perspective. In addition, the location effect on the different failures (e.g., the impact depending on the location of the UE: at cell center or edge, etc.) will be integrated. Many works in the recent literature focus on the application of location into classical cell status classifiers [21], [22]. In particular, state-of-the-art algorithms intend to compensate for a cell outage in normal operational situations (i.e., outside an emergency context), by adopting network performance metrics and lacking a source of location information, which hinders a compensation fine tuning [23].

To the best of our knowledge, location-awareness for failure management has received limited attention so far.

B. Location-aware network optimization

Traditional self-optimization algorithms have significant limitations when applied to 5G networks, due to the new 5G features and related complexity. For example, regarding capacity and coverage optimization (CCO), previous solutions do not consider features such as multi-connectivity, limiting the degrees of freedom to be exploited [24], [25]. In this context, LOCUS will propose enhanced network optimization methods in 5G scenarios, driven by the context information obtained from the localization methods and data analytics. Having accurate mechanisms for UE localization is a pressing need to minimize coverage holes in cell-edge areas while maximizing capacity in central regions.

Moreover, LOCUS will focus on the design of traffic steering and load balancing mechanisms between small cells and macrocells depending on the venue, event details, traffic prediction, E2E services, and UE position and trajectory. The traffic steering and load balancing techniques will be guided by advanced forecasting techniques (e.g., based on recurrent neural networks). Radio resource allocation, scheduling, and handovers across different access points, as well as horizontally across technologies, are network optimization tasks that greatly benefit from accurate positioning, and that will be addressed in LOCUS. Radio resource allocation is currently based on channel feedback provided by terminals to the base stations. LOCUS enriches the feedback provided by terminals for resource allocation with low latency and accurate terminal positioning for anticipatory networking algorithms. This information is further complemented by State-of-the-art ML/AI models for prediction, to enable a proactive preparation of network resources in advance.

The aforementioned studies also rely on predictions in locations where no measurements are available. Building maps of metrics based on geo-located measurements were first introduced under the concept of Radio Environmental Map (REM) [26]. Last but not least, LOCUS will extend the REM concept to 5G measurements to take into account, for instance, the specificities of Massive MIMO as well as the dynamics of 5G networks. LOCUS will evolve the REM concept to build Spatiotemporal forecasts. For instance, by exploiting spatial and temporal correlation of the corresponding signals to build a prediction of a coverage issue in the future, and also to be used in several optimization and resilience algorithms for proper use cases. In this regard, new mechanisms to trigger appropriate additional measurements (if required by the optimization algorithm) are additionally envisaged.

V. Location-based analytics for new services

On top of innovative localization techniques, LOCUS will also implement an additional layer of ready-to-use analytics to provide verticals with elaborate knowledge learned from localization data. Such analytics primarily leverage basic spatiotemporal features offline or in near real-time. These features include people's presence, positions, headings, velocities, and trajectories. Furthermore, the analytics possibly fuse these features with additional ones, using external multimodal data sources, such as counting cameras [27], video feeds, on-device sensors (e.g., smartphone sensors), wireless scanners [28], mobile service usage databases, map services [29] (e.g., 2D or 3D maps), or demographic databases. All data will be processed through a dedicated hierarchical architecture, developed in the project and composed of virtualized platforms deployed at both the core and edge of the architecture, to guarantee low-latency, computationally efficient, privacy-aware, and scalable analytics. The latter is presented to verticals via a suitable interface and includes novel models to estimate, classify, and predict statistical measures (e.g., individual and crowd dynamics, origin-destination (O-D) matrices, etc.).

Spatiotemporal analytics based on physical models adopt one of two main approaches: (i) "individual-centric" to associate the measured data to single targets/terminals, and run knowledge discovery separately on each of them; (ii) "crowd-centric" (global predictors) to associate the measured data directly to a group of users, and run a crowd-level analysis. The second results in lower dimensionality and complexity, but also coarser granularity of the result [30]. Crowd-centric approaches require less demanding statistical models as an input to the analytics [31]. However, the lack of accurate models has curbed the development of such approaches. In the few studies in the literature, regression methods (e.g., SVM) are used to that end [32] as well as deep learning time-series neural networks (i.e., RNNs and specifically Long Short-Term Memory – LSTMs that allow inherent support for processing sequences) among others [33].

The analytics on the localization data would enable new services in domains such as smart city and smart mobility. The data- and knowledge-driven applications built around the analytics based on localization data may provide improved public safety, tourism, transportation, event management, city engineering, and urban planning. As a proof of concept, LOCUS will apply the aforementioned approaches to extract complex and meaningful features and behavioral (frequent and/or periodic) patterns, i.e., detection of points of interest or high people density locations, mining of mobility profiles and sequential patterns/trajectories. These will be further utilized in recommendation systems, e.g., to recommend through an App to a person the best place/ shop to visit in an indoor or outdoor setting based on the extracted information, similarities with other mobility profiles/ trajectories and –in the case of the person's explicit consent- the person's profile and preferences.

VI. Location Security and Privacy

To foster the exploitation of location data and relevant analytics, LOCUS pays topmost attention to both location security and privacy concerns to make sure that the technical solutions will rely on secure data in compliance with the user privacy rights.

The security requirements for localization techniques include the capability of identifying intentional interference, which involves hostile platforms performing data-level spoofing, signal-level spoofing, and meaconing attacks. LOCUS will adopt location verification solutions to detect and mitigate attacks to location security [35]. In particular, clustering algorithms, summary statistics, and density functions will be used to monitor and correct the degradation of location estimates through statistical analysis.

On the user privacy side, if sensitive data are revealed, the location privacy, trajectory privacy and identity privacy can be leaked. Location privacy has been a primary requirement in cellular networks since as early as the old GSM (2G). 5G has further invested into this, by standardizing a novel public key-based approach to conceal the subscriber identity [34]. LOCUS privacy mechanisms will target two main requirements: (1) the inability for an attacker to determine, from the registration/signalling messages, which user is connected to a cell. e.g. it should not be possible to retrieve the SUPI (Subscription Permanent Identifier) of a user connected/connecting at a given location; (2) the inability for an attacker to track the user movements across cells, e.g. temporary identifiers used in different/adjacent cells should be unrelated.

VII. CONCLUSION

The LOCUS project in H2020 will design and develop a location management layered infrastructure not only capable of improving localization accuracy and security, but also to extend it with physical analytics, and extract value out of it, meanwhile guaranteeing the end users' right to privacy, building upon the ongoing work of 3GPP. Localization, dedicated analytics, and their joint provision "as a service" will significantly increase the overall value of the 5G ecosystem and its evolution, as well as allow network operators to dramatically expand their range of offered services, enabling holistic sets of user, location- and context-targeted applications.

ACKNOWLEDGMENT

This work was supported by the European Union's Horizon 2020 research and innovation programme under Grant no. 871249. The authors wish to thank A. Conti as Technical Manager of LOCUS for his helpful suggestions.

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