PROJECT "LOCUS": LOCalization and analytics on-demand embedded in the 5G ecosystem, for Ubiquitous vertical applicationS

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Short Abstract:	The goal of this deliverable is to improve and update the project vision with respect to the original one presented in the project proposal. This allows also to renew the project roadmap for enhancing the LOCUS impact.
Keyword List:	Vision, Roadmap, Impact

Executive Summary

The Project Vision and Roadmap is a tool for helping the LOCUS Coordinator and Partners to reach two main aims:

- maintaining a clear vision of the most relevant intellectual and scientific directions in the research performed worldwide within the scope of the project; and
- coordinating the efforts and the activities for pursuing an efficient roadmap and for a proper management of the required actions.

A clear vision and a sound roadmap significantly affect the pace and evolution of the work planned and therefore its capability to move towards both R&D and economic/societal results.

This document, D1.2, includes inputs from authoritative white papers on B5G and 6G, as well as from recommendations of the Advisory Board and authors' own views, which update the project vision.

The Project roadmap has been then improved, based on such trends and Advisory Board recommendations. A subset of recommendations and suggestions coming from the updated vision has been already implemented; another subset is left for future work, as described in Section 3.

The deliverable is public and thus can be used to communicate the project vision to the external world and potentially be useful to fellow researchers and professionals.

According to the LOCUS workplan, this version of D1.2 is identified as preliminary; it will be updated at the end of the project with a final version, to describe the collective project vision at that time, taking also into account all the work performed by the project, with the aim of offering a legacy for future work.

Version Control Table			
Version N.	Purpose/Changes	Author (s)	Date
1.0	First draft	Andrea Conti	06/12/2020
1.1	Revision	Marco Chiani, Davide Dardari	12/01/2021
1.2	Revision	Nicola Blefari Melazzi	18/01/2021

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1 Introduction

The Project Vision and Roadmap is a tool for helping the LOCUS Coordinator and Partners in maintaining a clear vision of the most relevant intellectual and scientific directions in the research performed worldwide within the scope of the project, as well as coordinating the efforts and the activities for pursuing an efficient roadmap and for a proper management of the required actions.

A clear vision and sound roadmap significantly affect the pace and evolution of the work planned and therefore its capability to move towards both R&D and economic/societal results. With aim of keeping an eye on evolution to adapt the roadmap toward a more useful and impactful research, the deliverable builds on authoritative white papers on beyond 5G and 6G, as well as on recommendations of the LOCUS Advisory Board and on authors' own views.

1.1 List of Abbreviations

ABBREVIATION	FULL NAME
5G	fifth generation
6G	sixth generation
DOW	description of work
GNSS	global navigation satellite system
LBS	location based services
MIMO	multiple-input multiple-output
PVR	project vision and roadmap
RAT	radio access technology
RTLS	real-time location services
SLAM	simultaneous localization and mapping
UWB	ultra-wideband

Table 1: Abbreviation List

1.2 Table Index

2 Project Vision and Related Updates and Improvements

2.1 Project Initial Vision

Context-awareness is essential for many existing and emerging applications. Context information greatly relies on location information of people and things. Global navigation satellite systems are denied in indoor environments, current cellular systems fail to provide high-accuracy localization, 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 behaviour of physical targets, to extract relevant feature of interests.

LOCUS is improving the functionality of 5G infrastructures to: i) provide accurate and ubiquitous location information as a network-native service; ii) derive more complex features and behavioural patterns out of raw location and physical events; and iii) expose them to applications via simple interfaces. Localization, together with analytics, and their combined provision “as a service”, will greatly increase the overall value of the 5G ecosystem, allowing network operators to better manage their networks and to dramatically expand the range of offered applications and services. The current freedom to act on 5G system design, and availability of software network paradigms and AI techniques, uniquely combine in this historical moment to make it possible to radically improve the future network by endowing it with accurate on-demand localization and analytics.

LOCUS will showcase its solutions in the framework of three scenarios: Smart Network Management based on Location Information of 5G equipment; Network-assisted Self-driving Objects; People Mobility & Flow Monitoring, including emergency services.

The initial vision of the project, originally presented in a first submission of the LOCUS idea to the European Commission in November 2016 and then again in March 2019, in the proposal of the current project, is still fully valid in terms of scientific interest, technology developments, market prospects, and user needs. Particularly important is the integration of RAT-dependent and RAT-independent solutions for high-accuracy localization even in harsh wireless environments, such as indoor.

Quoting and extracting from our original document:

> *“The overall Location Based Services (LBS) and Real-Time Location Systems (RTLS) market is poised to significantly grow in the near future...However...as much as 60% of the global LBS revenues have so far been taken by very few leading players, namely major US and Chinese over-the-top companies... that rely on global satellite systems technology and on their own custom over-the-top technologies, and seek relatively*

little "active" assistance from the network infrastructure, even if they do rather gather information about cell towers and Wi-Fi nodes that the mobile client can detect.

While this can be sufficient for non-critical and loose-time-scale/loose-accuracy LBS services, it is inadequate for addressing several important situations and for unleashing a wealth of business opportunities, e.g.: i) critical spatiotemporal applications (e.g., emergency handling, self-driving objects) demand for ubiquitous availability (including indoor), higher accuracy (up to a few centimetres level) and ultra-low-latency response time (order of milliseconds, e.g. for vehicle navigation); ii) applications like logistics and production (e.g., factories, seaports, etc.): in these cases, both indoor and outdoor accurate positioning is required; iii) application areas like smart cities, smart venues/stadiums, e.g. for retail, define an area that can deliver higher revenues to operators as well as to the respective vertical entities...

Only technologies deeply integrated in the mobile network ecosystem may provide the functionality needed to support such use cases, as opposed to the aforementioned loose overlay approaches... This situation is definitely not the result of a lack of interest in localization and context awareness technologies...Rather, we believe that the heart of the matter resides in the fact that, so far, localization aspects (and especially business exploitation of both localization information and derived knowledge...) have never been considered first-class citizens in the network evolution, but have rather been addressed as a valuable, but still aside, add-on to the main communication services that emerging networks are called to provide."

The situation depicted above is the main reason why LOCUS aims at natively incorporating, within the network infrastructure, tools and application programming interfaces needed to enable and foster the location/context-based services, together with powerful business analytics. We envision that localization and related analytics should be fully integrated in the cellular world: the 5G network and its evolution, both in the short and in the long term, should address not only communication but also localization and sensing functionality. As for feasibility, there is still available freedom to act on the 5G system specification (and of course on beyond 5G systems) and the availability of novel software network paradigms and AI techniques uniquely combine in this historical moment, making it possible to radically improve 5G networks by endowing them with on-demand localization and dedicated analytics.

2.2 Updated Project Vision

The LOCUS initial vision and the main LOCUS objective are still very actual and fully in line with the future evolutions of the network toward 6G. As a matter of fact, the recently published "6G white paper on localization and sensing"[1] makes exactly the same point:

> *"In contrast to 5G and earlier generations, (in 6G) localization and sensing will be built-in from the outset to both cope with specific applications and use cases, and to support flexible and seamless connectivity... Typically, wireless networks are praised for their communication features alone, while their inherent localization and sensing benefits are overlooked."*

Going further, the same white paper also identifies key technologies to provide improved, and even revolutionary functionality to empower new or enhanced localization and sensing use cases. We briefly report here such technologies because we believe that they are of significant interest and also because they are the result of a cooperative effort of researchers in the field coming from different institutions and countries. It is to be noted that authors of such white paper include also researchers involved in LOCUS[1]:

- ***RF spectrum for future localization and sensing systems****: allocate services across channel bandwidths which are at least five times larger compared to 5G, above 100 GHz, will bring the following advantages: i) signals do not penetrate objects, thus there is a simpler relation between propagation paths and environment; ii) larger bandwidths and higher frequencies lead to better performance; iii) shorter wave-lengths imply smaller antennas, which can be packed in smaller devices in large num-bers; iv) high-rate communication links simplify exchanges of maps.*
- ***Intelligent Reflective Surfaces****: they further enhance the performance of localization and sensing, e.g., enabling tracking/surveillance applications in NLOS communica-tions and autonomous localization, and providing additional technical opportunities, such as exploiting the wavefront curvature, which allows the reduction of the number of reference nodes required to provide positioning information.*
- ***Beamspace processing for accurate positioning****: beamspace channel response con-tains spatial information of not only the link ends but also the interacting ob-jects/humans in between; it can be exploited also for localizing and tracking active mobile users in a changing environment and even device-free targets (with very high resolution, if performed at high frequencies).*
- ***Machine learning for intelligent localization and sensing****: AI and, specifically, ma-chine learning are required to solve the complex and dynamic problems arising in the above presented situations.*

[1] C. de Lima, D. Belot, R. Berkvens, A. Bourdoux, D. Dardari, M. Guillaud, M. Isomursu, E.-S. Lohan, Y. Miao, A. N. Barreto, M. R. K. Aziz, J. Saloranta, T. Sanguanpuak, H. Sarieddeen, G. Seco-Granados, J. Suutala, T. Svensson, M. Valkama, H. Wymeersch, and B. van Liempd (Eds.). (2020). ***6G White Paper on Localization and Sensing*** [White paper]. (6G Research Visions, No. 12). University of Oulu. *https://arxiv.org/abs/2006.01779* .

As regards possible opportunities and use cases, the white paper identifies the following, after having once more highlighted that "*localization, sensing and communication must all coexist, sharing the same time-frequency-spatial resources in the envisioned 6G systems*".

- *THz imaging with very high resolution;*
- *simultaneous localization and mapping;*
- *passive sensing using transmitters of opportunity;*
- *active sensing with radar and communications convergence;*
- *channel charting;*
- *context-aware localization systems; and*
- *security, privacy and trust for localization systems.*

Regarding the evolution to beyond 5G and 6G networks, new perspectives were also offered in a dedicated chapter of the "5G Italy Book",[2] co-authored and co-edited by LOCUS partners. This chapter pointed out that:

> *"the mobile network will become more intelligent, with learning mechanisms to modify itself based on users' experience; situation-awareness will lead decision making and networking; this will allow fast and flexible spectrum reallocation, with consequent large bitrates available to the users; other human senses will be communicated, and 3D/holographic type communication will improve the quality of the tele-interaction; users will not necessarily need to bring a smartphone but will benefit of wireless-devices-as-a-service, with distributed devices available to anyone; the devices battery life will be substantially extended."*

Among the technologies that are expected to enable such evolution, the aforementioned chapter includes machine learning & AI, fast dynamic spectrum allocation, wireless energy transfer, free-space optical communications, sub-Terahertz and Terahertz communications, massive MIMO and intelligent surfaces, network intelligence, high-accuracy indoor localization, cybersecurity, network digital twins, enhanced sensing, as well as quantum sensing, communication, computing, and networking.

2.2.1 Advisory Board recommendations and related actions

The Project vision has been further updated and enriched by the Advisory Board of the LOCUS project, which provided the following recommendations.

[2] M. Chiani, E. Paolini, F. Callegati, "Open issue and beyond 5G," chapter of "The 5G Italy Book 2019: a Multiperspective View of 5G", M. Ajmone Marsan, N. Blefari Melazzi, S. Buzzi, S. Palazzo Editors, https://www.5gitaly.eu/2019/en/5g-italy-book-2/.Note: M. Chiani is also involved in the project LOCUS.

- Localization technology should include not only 5G New Radio but also the integration with other technologies such as GNSS, Wi-Fi, Bluetooth, UWB, and radar, as well as non-radio technologies such as inertial measurements and vision.
- Consider new approaches to localization that employ machine learning and the probabilistic values of observables rather than the observed measure only.
- Implement a vision in which sensing, communication, and localization all coexist and share network resources.
- Explore the use of bands at higher frequencies (e.g., Terahertz).
- Complement localization with simultaneous mapping of the environment.
- Investigate machine learning/data analytics approaches which exploit the “power of the crowd” in refining the models used for localization and mapping.
- Study of localization/tracking techniques exploiting the waveform curvature in near-field conditions.
- The performance of localization algorithms should be obtained in scenarios described in 3GPP Technical Reports and, when possible, compared also with performance limits.
- Define a network architecture for better exploitation of location information and location-based analytics.
- Define location-based analytics that allow the monitoring of people flows; this is particularly important in emergency situations such as pandemic.
- Investigate how increasing network resources can provide better localization accuracy as well as how an improved localization accuracy can enable a more efficient network management.
- Define a broad set of use cases for verifying location-based analytics obtained with the algorithms developed in LOCUS.
- Implement proof of concepts demonstrators that exploit the developed network architecture in accordance with some of the predefined use cases.

3 Project Roadmap

The Project roadmap has been updated, based on worldwide research trends and Advisory Board recommendations. A subset of recommendations and suggestions coming from the updated vision has been already implemented; another subset is left for future work, as described in the following.

3.1 Actions Taken toward the Updated Vision

In compliance with the Project updated vision, the project consortium has implemented actions listed in the following.

- Investigated and developed techniques for heterogeneous localization using RAT-dependent and RAT-independent technologies.
- Developed localization techniques, including those based on soft information, with preliminary testing by simulation in scenarios defined in 5G technical reports.
- Defined a virtual network architecture for enhanced exploitation of location information and location-based analytics.
- Defined location-based analytics, including one on flow monitoring, and put forth a working group on COVID-19 technological solutions.
- Defined use cases and corresponding network functionalities.

3.2 Actions Planned toward the Updated Vision

In addition to the actions already taken, the project consortium has planned the actions listed in the following.

- Study radio-based simultaneous localization and mapping (SLAM) techniques in a 5G ecosystem at millimetre waves.
- Consider the vision in which sensing, communication, and localization all coexist and share network resources, and explore the use of bands at higher frequencies.
- Implement proof of concept demonstrators that exploit the developed network architecture in accordance with some of the predefined use cases.

In summary, LOCUS is actively working to contribute to make its updated and enriched vision a reality and to contribute to the path towards expected beyond 5G and 6G improvements.

4 Risk analysis and management

This updated roadmap will follow the Risk Analysis and Management as described in Deliverable D1.1. In particular, it is planned a periodic analysis on the status of the risks identified in the Description of Work and on possible new risks and related actions on our part. At this time there is nothing to add to that list in terms of overall project vision and no specific mitigation actions are deemed necessary.