Ubiquitous Terminal Assisted Positioning Prototype

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Abstract—Statistical Terminal Assisted Mobile Positioning is a methodology that enhances the performance of existing localization techniques, by exploiting historical measurements collected at the terminal side. We propose a unified positioning framework in which different types of network related measurements may be employed by multiple techniques to derive coarse position estimates, while filtering is applied as a post processing step to further increase accuracy. The proposed architecture is applicable to User Plane location architectures, while its open and modular design allows easy integration of new positioning algorithms and post processing techniques. The implementation of this concept in Ubiquitous Terminal Assisted Positioning prototype concentrates particularly on Quality of Position issues and compatibility with currently available standards and communication protocols.

I. INTRODUCTION

Location Based Services (LBS) include personalized applications offered to the mobile user through the identification of his/her current location. During the late 90's LBS did not get widely accepted for many reasons such as the lack of standards, poor content quality, low network throughput, customer perception issues and inadequate tracking performance. However, nowadays most obstacles have been overcome, while the market has become more mature to accept the advent of advanced applications. This is also the result of the deployment of next generation wireless networks and standardization activities carried out by the 3rd Generation Partnership Project (3GPP) and Open Mobile Alliance (OMA).

So far, a wide variety of positioning techniques has been proposed, which are characterized by a trade-off regarding the accuracy achieved, the applicability to legacy terminals and the relevant deployment costs. These techniques employ signal strength and angle or time of arrival measurements to perform positioning and are often considered as short term choices or fallback solutions in hybrid schemes based on GPS; see [1] for an overview. Further to the most common positioning techniques, more sophisticated methods appear in the literature. They rely on time processing of noisy measurements in the form of filtering, which can alleviate high positioning errors by incorporating proper mobility models. Filtering including the well studied Kalman filters [2], can be applied on the raw measurements or on a series of coarse position estimates derived through standard techniques. In the case of raw measurements, the performance of the underlying positioning algorithm is greatly improved by estimating the terminal’s motion, from noisy observations. Different variants of Bayesian filters [3] have been discussed in the literature, including Extended Kalman Filter (EKF) [4] and Particle Filter [5]. In the case of coarse position estimates, filtering is employed as a post processing technique that generates a smoothed location sequence to reflect the terminal’s mobility pattern more accurately. Popular post processing techniques include Kalman Filter [6], [7] and Particle Filter [8].

Statistical Terminal Assisted Mobile Positioning (STAMP) is an advanced localization methodology that is generic and applicable to legacy cellular networks and to Beyond 3G (B3G) heterogeneous environments, where multiple Radio Access Technologies (RAT) such as GSM, UMTS and WLAN coexist. The main idea of STAMP is the utilization of historical position estimates derived by any positioning technique [9]. Location related information, such as Received Signal Strength (RSS) values and timing measurements from the available access network, are collected and stored during the standard operation of the Mobile Terminal (MT). When an LBS session is established the list of measurements is uploaded to the Positioning Server and then exploited through multiple positioning techniques to provide estimates of the history of the MT’s motion. As a final step statistical processing, with the aid of Kalman filtering, is employed to derive a more accurate estimate of the current MT location. At the same time tracking capabilities and velocity estimation may also be provided.

The practical aspects of implementing STAMP, as part of the Ubiquitous Terminal Assisted Positioning (UTAP) system, are investigated in the context of MOTIVE project [10]. The project aims to deliver a positioning system prototype that will serve as a complete platform to enable LBS deployment. The proposed architecture is compatible with User Plane architectures, based on the emerging Secure User Plane Location (SUPL) standards defined by OMA [11]. Location related information collected by the MT is transferred through data packets over secure IP connections, independently of the access technology and network infrastructure, thus minimizing network modifications. However, an agent is required at the MT side to handle the communication exchange. Additional positioning techniques can be easily integrated into this platform as add-on components. Quality of Position (QoP) is provided according to the application requirements and the technique selected to perform localization. QoP is treated as a
set of attributes, such as the accuracy of the position estimate and the system response time, associated with a request for the MT’s location.

This paper provides a description of the UTAP system prototype. The abbreviations, commonly used in literature, as well as the OMA related acronyms are tabulated at the end of this Section. The STAMP concept is introduced in Section II, followed by the platform requirements and the proposed architecture in Section III. The UTAP system prototype and the current implementation status are presented in Section IV. Section V outlines the results of applying STAMP in commercial GSM and WLAN networks with some indicative positioning scenarios. Finally, Section VI provides concluding remarks and discusses future work related to the UTAP system.

### Acronym List

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AP</td>
<td>Access Point</td>
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<tr>
<td>BS</td>
<td>Base Station</td>
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<tr>
<td>CGI++</td>
<td>Cell Global Identity + received signal strength measurements</td>
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<td>CPICH</td>
<td>Common Pilot Channel</td>
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<td>DCM</td>
<td>Database Correlation Method</td>
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<td>DM</td>
<td>Device Management</td>
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<td>DOP</td>
<td>Dilution of Precision</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<td>GSM</td>
<td>Global System for Mobile communication</td>
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<td>LBS</td>
<td>Location Based Service</td>
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<td>MLP</td>
<td>Mobile Location Protocol</td>
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<td>MT</td>
<td>Mobile Terminal</td>
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<td>OMA</td>
<td>Open Mobile Alliance</td>
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<td>PS</td>
<td>Positioning Server</td>
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<td>QoP</td>
<td>Quality of Position</td>
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<tr>
<td>RAT</td>
<td>Radio Access Technology</td>
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<tr>
<td>RSS</td>
<td>Received Signal Strength</td>
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<td>STAMP</td>
<td>Statistical Terminal Assisted Mobile Positioning</td>
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<td>SUPL</td>
<td>Secure User Plane Location</td>
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<td>ULP</td>
<td>Userplane Location Protocol</td>
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<td>UMTS</td>
<td>Universal Mobile Telecommunications System</td>
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<tr>
<td>UTAP</td>
<td>Ubiquitous Terminal Assisted Positioning</td>
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<tr>
<td>WLAN</td>
<td>Wireless Local Area Network</td>
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## II. OVERVIEW OF STAMP CONCEPT

The STAMP concept is depicted in Fig.1 for a MT moving through an area covered by multiple RATs. The MT periodically stores all available network measurements while in idle mode, thus forming a list of location related information, denoted as the STAMP List. Each entry in the STAMP List contains a vector with the actual measurements and a special field, which indicates the corresponding type of access technology. In this paper GSM, UMTS and WLAN RSS measurements are considered. However, this can be extended in order to include available measurements required by any positioning technique. All entries are time-stamped, thus rendering the STAMP List, a record of historical information reflecting the MT’s motion. When the STAMP List is full, updating is performed in a sliding window fashion by discarding the oldest and incorporating the current measurement vector. A set of parameters is constantly monitored, as part of the MT’s standard operation in idle mode [12], [13] in order to assist the Network Selection, Cell Selection and Reselection functions. These parameters include the Cell Identity and RSS values from the primary and a set of neighboring cells in GSM/UMTS networks. In a WLAN environment the AP MAC Address and RSS values may also be monitored to ensure optimum performance. Moreover, according to radio coverage conditions MTs supporting both GSM and UMTS connectivity, may monitor only the first, the second or both networks. Multi-homed terminals available in the near future will have the ability to be simultaneously attached to several wireless access networks. Since these monitoring procedures are part of the MT’s standard functionality, adding a module to handle the STAMP List management is the only software modification required at the terminal side.

At the LBS application initiation, the STAMP List is uploaded to the Positioning Server; see Fig.1. The STAMP List may also be augmented with additional information available during active mode, such as Timing Advance (TA) for GSM or Round Trip Time (RTT) for UMTS. Based on the type of collected measurements and the QoP requirements the most appropriate positioning technique can be selected, to provide a coarse position estimate for each entry in the STAMP List. Subsequently, statistical processing in the form of filtering, is used as a post processing step, to smooth the positioning error in the sequence of position estimates and increase the accuracy of the current MT’s position. For instance, Bayesian filtering in the form of Kalman or particle filters can be employed.

An important factor that affects the performance of the method is the STAMP List size, i.e. the number of measurement entries stored locally at the MT. This is closely related to convergence issues regarding the subsequent use of statistical processing. Therefore, the STAMP List should be long enough, so that an adequate number of coarse position estimates are provided to the Kalman filter. On the other hand, the size should be kept as low as possible to avoid excessive memory requirements on the MT and reduce the network overhead.

![Fig. 1. Representation of the STAMP concept.](Image)
imposed by the messages exchanged. In [14], simulation analysis revealed that acceptable accuracy can be achieved if the STAMP List size is 40. This can be well handled both by the MT, regarding on-site storing requirements and network resources, considering the communication overhead.

The Sampling Period, i.e. the time interval between two consecutive entries in the STAMP List, is another crucial parameter. The proper value depends on the accuracy requirements of the LBS application, as well as the access technology that the measurements are related to. The Sampling Period should be short enough to allow for accurate positioning in the recent past, while a longer value is desirable to accommodate low battery consumption requirements. This trade-off has been further analyzed in [14], using different mobility scenarios in order to investigate the effect of user speed.

STAMP is compatible with any technique that exploits network related measurements. New and proprietary techniques, including terminal assisted E-OTD, OTDOA or fingerprint methods, can be incorporated. STAMP hides the diversity of techniques making the localization procedure completely transparent to the end user. It should be noted that STAMP is applicable even in case of a single RAT and/or positioning technique. In [9], STAMP has been applied in a GSM network to improve the accuracy of the CGI++ technique.

III. PROPOSED ARCHITECTURE

The UTAP system comprises the Positioning Server (PS) and the UTAP clients. Clients, i.e. position requestors, can be MTs or any other external LBS applications. Two distinct scenarios are supported regarding the source of the positioning request that correspond to the Terminal and Network Initiated cases, respectively. The proposed UTAP system architecture supports the basic functionality and satisfies the requirements of STAMP methodology. It is based on a typical client-server model as depicted in Fig.2.

At the PS side, a hierarchical modular design is followed. In order to facilitate system scalability, functional verification and validation, as well as modification of interfaces to be compliant with current protocol versions, the use of separate components, performing distinct and well-defined tasks, was chosen. Compatibility with existing architectures and standardized communication protocols for transferring available network related measurements is also important, in order to have a platform that fits into existing service oriented architectures. The ability to expand the system to support upcoming wireless access technologies, such as WiMAX, is another key factor. Easy integration of additional positioning algorithms and/or statistical processing techniques was also considered. Taking into account that several positioning algorithms are available, QoP provisions are necessary to optimize system performance in terms of response time and meet the positioning requirements of individual LBS applications. For instance, positioning requests may have different QoP requirements in terms of positioning accuracy, Maximum Location Age and Maximum Delay. The first attribute ensures that only the technique providing the required accuracy will be employed. The second one is used to allow for a previously estimated position to be returned as the current position. The last one is used to exclude those positioning techniques that are computationally inefficient, even if they achieve the desired level of accuracy. Following the high level design principles, the components that facilitate the operation of the PS are presented below.

The Pre-Processing module handles the establishment and termination of the connection with the client through the Client Handler module, as well as the parsing of information carried within the messages exchanged. If the message that carries position related information is valid, its contents are represented in an appropriate internal message format. Subsequently, this is passed to the Controller module that controls the information flow within the PS. When a connection is established, the Controller handles the Network and Terminal Initiated sessions. It holds all session specific data, including unique session id and session specific timer. A Location Cache, in which previous position estimates are stored for later reference, is also maintained and updated. If the QoP requirements, such as the Maximum Location Age set by the application allow it, a cached position will be returned to the client without triggering the Algorithms module to perform actual positioning. The Controller has access to the Privacy & Security Management module to ensure the privacy and security of the involved parties. Every positioning request made by external clients is authenticated and authorized, otherwise rejected, based on the specific user profile and settings, as well as emergency and lawful regulations that may apply in the future.

The Algorithms module is responsible for delivering position estimates according to the QoP requirements and the location related information contained in the request. More specifically, the Algorithm Selector loads and initializes all available positioning algorithms at the PS start-up. When a positioning request is processed, the algorithm components that cannot provide a position estimate are filtered out. This case includes a wrong network type or lack of support for the specific area. Then, the most suitable algorithm is selected to process the actual location query. The decision is affected by the uploaded location related measurements, e.g. a subset of all available techniques are applicable when RSS values from

![UTAP system architecture](image-url)
a GSM network are employed. In order to select a specific technique, QoP issues related to the positioning accuracy and computational time are also taken into consideration. Therefore, some techniques may be filtered out because they exceed the QoP thresholds set in the positioning request. Finally, the estimated position is returned. Regarding GPS enabled devices, the GPS coordinates are the location measurements. GPS is considered an optional positioning technique to be selected, depending on Dilution of Precision (DOP) accuracy parameters. These parameters include the Horizontal, Vertical and Position DOP (HDOP, VDOP, PDOP), which are calculated mathematically from the positions of the usable satellites. Thus, WLAN fingerprinting may be selected, for example in a street canyon, if the GPS precision is low.

The Algorithm Selector has also the ability to switch among different algorithms, while processing the location related information, to support a hybridization scheme. This is valuable when, for example, the MT is moving from indoors (WLAN fingerprinting) to outdoors (cellular techniques or GPS) and vice versa. This scenario is presented in Section V-C with real measurements. The series of estimated positions, derived from a single or multiple techniques after processing the STAMP List, is then forwarded to the Statistical Processing module.

The Algorithm Interface provides the communication interface between the Algorithm Selector and the independent algorithm components. This interface ensures that additional positioning algorithms can be easily integrated in the future. Apart from performing the actual positioning when finally queried, every component should be able to provide a fast initial QoP estimate based on the current measurement. This is necessary to assist the Algorithm Selector in the selection process. For example, a RSS based algorithm using trilateration should return higher positioning error as initial QoP prediction, if the Base Stations (BS) included in the current measurement are aligned, resulting in poor geometric conditions.

The Statistical Processing module implements a post processing technique that filters the series of coarse position estimates according to the positioning error provided by each positioning method. This final step alleviates high errors, while smoothing the sequence of coarse position estimates. Thus, higher accuracy is achieved regarding the current terminal location. Accuracy enhancement is illustrated in Sections V-A and V-B with real measurements for an indoor and an outdoor moving scenario, respectively.

At the terminal side, the UTAP agent is a software component that is responsible for the STAMP related functionality. It maintains and manages the STAMP List, processes all incoming positioning requests, generates responses and handles all low level API communication to access and collect radio layer measurements. Measurements from all available RATs are stored in the STAMP List, in an appropriate format.

It should be noted that the UTAP system architecture is consistent with OMA SUPL specifications [11]. The UTAP agent upgrades the device to a SUPL enabled terminal. The Userplane Location Protocol (ULP) [15] and Mobile Location Protocol (MLP) [16] are the communication protocols employed for transferring the messages created by MTs and LBS applications to the PS, respectively. Time-stamping of measurements is included in the specifications, while the support for multiple historical measurements was submitted to OMA as a Change Request for SUPL and has been accepted [17]. Therefore, the STAMP concept and the proposed architecture are compliant with User Plane positioning roadmaps.

IV. PROTOTYPE IMPLEMENTATION

The development of the prototype is based on the UTAP system architecture, presented in Section III. The UTAP agent has been implemented in C++ and installed on Symbian OS (Series 60) enabled MTs. The STAMP List management functionality currently supports the collection of RSS values from GSM, UMTS and WLAN networks that are stored locally at the MT. The Sampling Period has a fixed value of one second, however in future implementations it can be configured dynamically following the OMA Device Management (DM) procedures [18]. A client simulation program has also been developed to test the communication flow between the SUPL enabled terminal and the PS. Through this command line application a RSS measurement survey file collected for a route is properly encoded and sent to the PS as consecutive positioning requests. Actual location coordinates are also included for calculating the positioning error. In order to add some flexibility, the STAMP List size is a user defined parameter.

All individual components comprising the PS, as depicted in Fig.2, have been realized. Regarding the positioning algorithm components, the Database Correlation Method (DCM) [19], CGI++ [20] and Common Pilot Channel (CPICH) have been implemented and integrated into the PS. They all rely on RSS values collected by available wireless access networks, but follow two distinct approaches; fingerprint matching and trilateration. The CPICH technique is similar to CGI++ and employs RSS measurements from UMTS networks. The Statistical Processing module implemented in this prototype, is based on the Kalman filter iterative algorithm described in [6]. The coarse position estimates \((x, y)\), provided by the positioning algorithms, are treated as measurements disturbed by zero mean Gaussian noise with covariance matrix \(R = \sigma_R I_2\). The parameter \(\sigma_R\) reflects the mean positioning error introduced in the estimates when a specific technique is used. In that sense, \(\sigma_R\) is easily obtained by performing real measurements in the area of interest and calculating the average error of each positioning algorithm offline.

A management GUI has been designed to control the features of the PS, such as enabling or disabling algorithm components and interactively setting some algorithm specific attributes. The option to depict the resulting position estimates on different layers of digital maps is also provided; see the localization scenarios in Section V. This feature is not part of the system’s standard functionality, as the primary goal of UTAP system is the provision of high quality location estimates to external LBS applications. This option is implemented for visualization, verification and testing purposes.
A subset of the SUPL family protocols was exploited in this implementation, while some modifications were made to support additional functionalities. Since WLAN positioning is not yet fully supported, this feature was added. GPS QoP indicators such as HDOP, VDOP and PDOP, were also added to indicate whether the GPS position meets the required QoP. The option to include a location tag to the uploaded measurements is also provided, as an additional feature for GPS enabled terminals. This can be helpful, for example when a user is asked to contribute RSS fingerprints from a specific area to the operator’s database for a reward. ULP messages are encoded in XML and exchanged over TCP/IP connections. In general, the non-roaming, proxy modes for both Network and Terminal Initiated cases are implemented. Moreover, the SUPL Location Center (SLC) and the SUPL Positioning Center (SPC) [11] are merged into a single entity.

V. LOCALIZATION SCENARIOS

In order to verify the functionality of individual modules comprising the UTAP system, some indicative scenarios were considered. At the same time preliminary accuracy results for the positioning algorithms and statistical processing components were obtained. RSS samples have been collected in different routes, including indoor and outdoor scenarios. The STAMP List size was fixed to 30 samples. The estimated positions, as presented in Fig.3, are plotted on digital maps. Accuracy results are reported including the mean positioning error $m_e$ and the standard deviation $\sigma_e$ for the whole route. It should be mentioned that a thorough evaluation of the prototype and analysis of the results is out of the scope of this paper. As a future step, we will assess the UTAP system through extensive trials, examine the system performance and analyze the accuracy results obtained under different conditions.

A. Indoor Positioning

In this scenario, a user walking inside a building is considered. In order to build the reference fingerprint database, 378 WLAN fingerprints have been collected indoors and outdoors close to the building walls in a 13K m$^2$ area covered by 27 WLAN APs. Samples containing RSS measurements from all hearable APs are then collected by a WLAN attached mobile device and stored in the STAMP List. The DCM algorithm is enabled through the management GUI and successive position estimates are depicted on a floor plan map of the VTT premises located in Espoo, Finland as shown in Fig.3a. The true locations and DCM position estimates are shown in green and blue dots, respectively. When only DCM is used results show that $m_e = 4.7m, \sigma_e = 3.16m$. Red dots denote the position estimates derived after the statistical processing of the DCM estimates. In this case, the positioning error is slightly improved ($m_e = 3.2m, \sigma_e = 1.90m$).

B. Outdoor Positioning

An outdoor scenario is depicted in Fig.3b. A MT within a vehicle is collecting measurements from the commercial GSM network of Vodafone-GR, in an urban area of Athens, Greece covered by 20 BSs. For this route, each sample contains RSS measurements from 6 BSs. The CGI++ component provides coarse position estimates (blue dots), while true positions are shown in green dots. The component has been initialized with the necessary network information, including the Cell IDs, as well as the coordinates, transmit power, height and frequency of each BS which are required by the Hata propagation model. Results show that $m_e = 212m, \sigma_e = 94m$, when only CGI++ is used. The estimated positions obtained after Kalman filtering, are shown in red dots. Statistical processing leads

![Localization scenarios using the Positioning Server management GUI.](image-url)
to considerable improvement regarding the accuracy achieved ($m_e = 167\text{m}$, $\sigma_e = 78\text{m}$). In this scenario, the average positioning error provided by the plain Cell ID technique is 280m. The standard Hata propagation model was employed [21], however utilizing a calibrated propagation model is expected to enhance the performance of CGI++. Moreover, calibrating the filter parameters will further increase the effect of the statistical processing.

C. Hybridization & Ubiquitous Positioning

In Fig.3c the hybridization concept is illustrated for a user passing through a building. The same fingerprint database, as in Section V-A, is used. GPS and DCM are the positioning techniques under consideration and the most suitable for each sample is selected, based on the estimated QoP. The true locations, DCM estimates and GPS positions are shown in green, blue and yellow dots, respectively. In the $AB$ segment, DCM estimates are only available when the user approaches the main building walls. GPS location estimates are heavily affected by the building and some times indicate a route through the walls. Inside the building ($BC$ segment) only DCM estimates are available. Statistical processing is applied on the estimates derived after hybridization to further increase accuracy (red dots). When the user moves outdoors ($CD$ segment), DCM accuracy degrades and it takes time for the GPS estimates to get accurate enough. This also affects the performance of the Kalman filter and the estimated velocity, shown in red arrows, increases rapidly. If WLAN fingerprints were available for that part of the route the achieved accuracy would be higher. Even so, in the hybrid GPS/DCM scheme $m_e = 8.36\text{m}$ ($\sigma_e = 7.1\text{m}$), while $m_e = 11.06\text{m}$ ($\sigma_e = 8.69\text{m}$) if only GPS is used.

VI. CONCLUSIONS

In this paper, a terminal assisted localization methodology, applicable in existing wireless networks and positioning techniques, has been presented. The deployment of STAMP implies only additional software modifications at the terminal and network side. The proposed architecture follows the SUPL architecture specifications and has been designed under consideration of existing standards and communication protocols, such as ULP and MLP. Furthermore, it is in line with market trends showing that terminal manufacturers will deliver SUPL enabled devices within the next years. Moreover, the modular architecture provides an open platform that facilitates fast integration of new and custom positioning techniques.

Future work will focus on fine-tuning and testing the end to end communication in the UTAP system in order to examine and analyze the system performance and stability. We plan to test the system in a commercial UMTS network and implement additional positioning techniques, such as probabilistic DCM and post processing methods, such as Kalman filter variants and map-matching. We will also evaluate the UTAP system in real life conditions by investigating the effect of user speed and density of infrastructure. Further steps will concentrate on enhancing the QoP provisions and providing uninterrupted positioning, especially in hybrid schemes where different measurements and multiple positioning techniques are available.

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