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Combining Wireless Communications and Navigation — The WHERE Project

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Abstract — Wireless communications and navigation have different constraints to cope with. On the one hand, communication systems traditionally aim at high spectral efficiency with specific requirements such as low latency and low power consumption. On the other hand, navigation is usually based on the transmission of known data signals at low data rates with fine synchronization capabilities for efficient signal acquisition and tracking. The ICT project WHERE (Wireless Hybrid Enhanced Mobile Radio Estimators) [1] will focus on exploiting the positioning information to enhance communications and vice versa within heterogeneous and/or cooperative wireless systems. The paper gives an overview and outlines the upcoming goals of the FP7-ICT project WHERE. The WHERE project is an ICT STREP project involving 14 partners. It started in January 2008 and is running until June 2010.

I. INTRODUCTION

Future wireless communication systems have to enable and provide a multiplicity of services for a tremendously increasing number of mobile users. Globally, the number of wireless cellular customers is expected to surpass 50% of the population already in 2009 [2]. Therefore, an efficient use of wireless communication systems is necessary to cover the increased demand on data rate. Frequency spectrum as the main and most valuable resource in wireless communications is limited. An efficient use of this resource is one of the main objectives in the development of future wireless systems. A variety of projects in European research framework programmes are aiming to develop technologies for ubiquitous mobile and broadband network access which is mandatory for many services people will use in their everyday lives. For an efficient use of the available resources in a heterogeneous Radio Access Network (RAN) infrastructure, the availability of position information will allow a more efficient allocation of the available resources or even the prediction of required resources in mobile scenarios and heavily loaded networks.

A first straightforward example for the benefit of positioning information is shown in Figure 1. The Mobile Terminal (MT) is moving slowly along the trajectory. It is possible to hand over to a small hot-spot cell, which locally provides significantly higher data rates than the radio access network cells do. As the position as the velocity is known at the MT the hand over and potential advantages (like pre-scheduling high data rate downloads or buffered streaming applications) can be scheduled already in advance.

For a high MT speed along the trajectory, the dwell time of the MT in the hot-spot cell area is so low that the effort for a handover exceeds the achievable gain in data rate. In such a case it is beneficial to remain connected to the former RAN cell (Base Station 1 (BS1)) or hand over directly to BS3. The most problematic area in mobile radio communications are the cell borders. At the cell borders the mobile terminal needs more power or more bandwidth to sustain the high data rate links. On the other hand this will increase the inter-cellular interference in the neighbouring cells as the envisaged frequency reuse factor for future mobile radio systems is 1. Therefore, very effective and adaptive radio resource management on the link and on the system layer is mandatory.

Figure 2 shows a hybrid cellular system scenario aiming to design a cooperative spectrum allocation, where in the inner circle we have a frequency reuse factor of 1 and in the outer areas cooperative radio resource management still offers high spectrum efficiency by avoiding interference, applying soft and location based handover, exploiting macro diversity techniques, etc. All this will be enabled by the knowledge of the position at the MTs and the BS.

Location based RAN functionalities, as motivated previously, require an accurate estimation of the MT location parameters, i.e., the position itself and even derivatives like the MT velocity including its direction. Global Navigation Satellite Systems (GNSS), such as the US Global Positioning System (GPS) or the future European satellite navigation system Galileo, are providing position information. However, their accuracy strongly depends on the scenario. Especially
in urban or even indoor environments, navigation based on GNSS becomes inaccurate or impossible, since the necessary amount of 4 directly visible satellites is not reached. As an example, Figure 3 shows an urban canyon scenario, where angle describes the sector of direct visibility of navigation satellites (aperture angle). Figure 4 illustrates the Cumulative Distribution Functions (CDFs) of the number of directly visible navigation satellites for a fixed position of the MT in the middle of the urban canyon. The width of the street $W$ and the height of the buildings $H$ for this example are both equal to 30m. The analysis shows that it is almost impossible to directly receive 4 or more navigation satellites for either the European satellite navigation system Galileo or the GPS. Even the combination of both systems provides a probability of less than 30% that line-of-sight signals from at least 4 satellites can be received simultaneously in this critical scenario.

The previous examples highlight the current needs for more efficient and intrinsically synergetic radiolocation/communication means in demanding environments (e.g., urban canyons or indoor). In this context, one major goal of the European FP7-ICT WHERE project is to demonstrate that the combination of various wireless systems (e.g., short-range complementing cellular systems), coupled with adapted algorithmic strategies (e.g., hybrid data fusion, fingerprinting) and proper data signalling or protocols, can enhance location accuracy, location reliability, as well as the continuity of the location service (e.g., in terms of coverage or availability). In parallel of these investigations (i.e., after delivering realistic values for achievable location accuracy and reliability), another related purpose of the project consists in putting forward advanced location based communication schemes (e.g., handover prediction, resources allocation).

The remainder of this paper is structured as follows. In Section II. and III. different use cases for improved localization and communication is presented. Section IV. shows how we intend to characterize the wireless channel for the different use cases. The first step is characterizing the wireless channel. In Section V. the second step addresses modeling the channel including the derivation and the application of different mobility models. Finally, in Section VI. we summarize the outcome of this introductory paper.

II. USE CASES FOR LOCALIZATION

In the previous section, demanding scenarios were given for motivating more sophisticated techniques regarding the combination of communications and navigation systems. In the following, examples of current practical situations are given to indicate the already given awareness in this field of research.

Navigation in very dense populated areas (e.g., Tokyo, Japan): Due to lack of space many of expressways are constructed as multi-level viaducts running above local roads. For a user navigating on a lower platform, the GNSS signals can be blocked and the navigation information does not match its platform. The user driving on the upper platform would require an accurate (3-D) information about the height of the drivers position. As some of the lanes cross each other any GNSS or GPS based navigation does not work. A front-seat view out of driving car shows Figure 5. There is the need of an additional navigation dimension which can be given by sensing information of a local sensor network.

Autonomous guided vehicle (AGV): In large logistic centers (e.g., harbors) the complex logistics operations need to be efficient. Therefore, AGVs take over many processes which
require an accurate, safe, cooperative navigation and communication between the AGVs for a smoothly flow [3].

**Navigation and communication of rescue teams:** Rescue teams (e.g., fire fighters) enter a scene which can be allocated indoor and/or outdoor. These scenes are dynamic and can be rapidly changing. Systems capable of continuously locating member of a rescue team helps to maintain orientation and to localize other rescue team members. Location information has to be forwarded to all involved team members, and therefore, a suitable wireless communications system has to facilitate data exchange [4].

**Interactive guiding application:** Within museums or exhibitions additional information can be given via hand-held devices to the visitors. Information has to be communicated related to the position of the user. This requires a tight communication between the position of the sample to be described and of the user to guarantee a correct guidance through the exhibition [5], [6].

**Assisted living:** Smart home applications can use the additional information of an assisted living device. For example, this supports a medical state monitoring of elderly persons and could trigger an alarm in a situation of a severe acute person’s state [7].

**Navigation for blind persons:** Blind persons today may have different ways to navigate through their daily life. A guide dog guides them by stopping at intersections or obstacles. Alternatively a white cane helps blind people to navigate. All these methods require interaction from their environment. In the project Nav4blind [8] a navigation system localizes and navigates the user through his daily environment with an accuracy of about 10cm. This is a challenging task considering that the digital mapping data of the environment is less accurate.

In Table I some requirements are given for the given use cases regarding the accuracy, environment, and number of users.

### III. Use cases for communication

Today the localization information is hardly used to enhance communications. Cognitive radio is a vibrant research topic for future mobile radio communications which acts as an enabler to address the scattered frequency spectrum. So far two different approaches are discussed in cognitive radios (1) a sensing transceiver scans the potential frequency band for possible other legitimated sources to reduce the power in the allocated frequency band or change the allocated frequency band. (2) a cognitive pilot channel (CPC) broadcasts information about the current spectrum allocation which is used depending on the position of the mobile user. This information about potential information can be assessed.

The localization information can be used as an additional enabler for the benefit of the mobile user to assess the frequency bands combined with the localization information. In [9] the differences of environments are outlined in conjunction with the delay spread the potential mobility. Both parameters could go in line to restrict to ‘reasonable’ decision about indoor offices with closed doors which is mostly non-LOS or indoor corridors which mostly a LOS component. Here the position itself could for example help to startup the right filters for channel estimation.

### IV. Channel characterization

To achieve complementing fingerprinting data bases specific and dedicated measurement campaigns for OFDM and for Ultra Wideband (UWB) in the same environments will be performed within the WHERE project. Fingerprinting techniques are based on a position dependent profile (e.g. a power-delay profile). Such profiles may become even more informative the richer the multipath propagation environment and they remain well defined in the non-LOS case. Fingerprinting techniques require a data base of profiles, as a function of position. This database can be constituted with exhaustive measurements of the profile in all possible positions. Or it may be constituted by profile prediction (e.g. ray tracing) techniques that use geographical information about the area (buildings and other reflecting/diffracting objects). Profile databases are needed both for the performance evaluation of fingerprinting algorithms and for demonstration purposes.

Measurement campaigns for profile database constitution are potentially quite expensive and time-consuming. Profile databases can be constituted in 3D, 2D and 1D scenarios. The simplest case is obviously the 1D case, in which profiles get determined along a certain trajectory. Such a trajectory could correspond to a road, which could be representative of an urban canyon in case of a dense urban environment. A 1D profile database requires a relatively simple measurement campaign, but may already be useful for algorithm evaluation and demonstration purposes. In the case of localization of cars, constraining the potential positions to roads is obviously a reasonable simplification. At this point, one general remark is that observed signals, and more specifically the multipath...
profiles that can be precisely resolved at the receiver, should account for complex propagation mechanisms conditioned upon geometry, and hence, can be interpreted as meaningful radio signatures that are representative of mobile positions.

As for UWB signals, the multipath diversity resulting from fine intrinsic resolution capabilities is expected to be even more judiciously exploited in confined and obstructed environments with fingerprinting and pattern recognition techniques. The idea here would consist in feeding positioning algorithms with complete UWB profiles or with a set of (potentially combined) metrics derived from resolved multipath components (e.g. arrival times of significant echoes, channel spread, RSS).

Consequently, as a complementary contribution to fingerprinting database obtained with WiFi or cellular systems, it is proposed within the WHERE project to perform a specific 2D measurement campaign providing a database composed of Impulse Radio (IR) UWB profiles in a typical indoor environment (e.g. office). The measurement set-up will be mainly based on a Digital Sampling Oscilloscope (DSC) and a pulse generator. For each tested mobile position, received profiles will be collected with respect to several reference points surrounding the investigated scene (up to 4). The refinement of the measurement grid should enable to emphasize the spatial correlation of resolved multipath components, while preserving reasonable database complexity. In addition, investigated bandwidths should be, as much as possible, compliant with the last European regulatory trends and/or international standardization (e.g. IEEE 802.15.4a standard). Finally, these UWB measurements could be advantageously exploited for the purpose of complementing models related to non-fingerprinting radio-location metrics (e.g. time of arrival (ToA)).

V. MOBILITY AND ITS MODELING

Mobility is included in localization algorithms in order to obtain a more accurate description of the variability and thereby improve localization solutions. A main objective in the WHERE project is to provide mobility models to be included in localization methods based on state-space models. State-space models are two-stage models which firstly model the mobility dynamics by a latent/hidden process and secondly model the obtained distance measurements. Mobility models are based on states which typically model a given set of mobility parameters like position, velocity and acceleration. Additional refinements to be considered include spatial correlation between the mobility parameters of different nodes. This appears when the movement of any single node is closely related to that of its neighbors. Furthermore geographic restrictions should be taken into account and be included into the model parameters. Mobility models will be enhanced by considering the spatial variability of channel features along occupied trajectories (spatially correlated multi-path components and radio-location metrics, timely transitions in the channel configuration, etc.). Thus, they can also take into account impairments resulting from the radio channel, such as the bias in ToA which appears in non-line-of-sight (NLoS) situations.

In [10] the authors used a sample set of 100,000 mobile users to verify established mobility models. In contrast to random walk models the human trajectories show a high degree of temporal and spatial regularity. The gained knowledge will allow to improve cooperative methods, either localization or communication, between the mobile users.

VI. SUMMARY

In this paper we emphasize the main components of the ICT project WHERE: 1) Introduce different scenarios where positioning information can aid a communication system and vice versa. The scenarios also highlight the different use cases. Mobile users on foot behave different and expect different information compared to a mobile user in his car. These and more scenarios are under investigation in the FP7 project WHERE of the European Commission. 2) We outline how to tackle the wireless channel as the resource for either localization or enhanced communication. 3) Finally, we introduce briefly mobility models and how they will be used in the near future.

The project co-operates with many other IST and ICT projects [11]. The aim of this paper is to show the topics of this project to stimulate awareness in and feedback from the community in an early stage.

VII. PARTNERS

The partners of the WHERE project are: German Aerospace Center (DLR), Aalborg University, Advanced Communications Research & Development (ACORDE), Commissariat à L’Énergie Atomique - LETI, Institut Eurécom, Siradel, Université de Rennes 1, Instituto Telecomunicações, Mitsubishi Electric ITE, Sigint Solutions Ltd., University of Surrey,
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REFERENCES