A Simulation Tool for Real-Time Hybrid-Cooperative Positioning Algorithms

Francesco Sottile, Istituto Superiore Mario Boella, Italy
Mauricio A. Caceres, Istituto Superiore Mario Boella, Italy
Maurizio A. Spirito, Istituto Superiore Mario Boella, Italy

ABSTRACT
The authors propose a simulation tool (ST) able to test real-time hybrid GNSS/terrestrial and cooperative positioning algorithms that fuse both pseudorange measurements from satellites and terrestrial range measurements based on radio frequency communication performed between nodes of a wireless network. In particular, the ST simulates devices belonging to a peer-to-peer (P2P) wireless network where peers, equipped also with a GNSS receiver, cooperate among them by exchanging aiding data in order to improve both positioning accuracy and availability. Furthermore, the authors propose a method to increase the robustness of cooperative algorithms based on the estimated position covariance matrix. In particular, the proposed approach assures a faster estimation convergence and improved accuracy while lowering computational complexity and network traffic. Finally, the authors tested the sensitivity of the implemented positioning algorithms through the ST in two different scenarios, first in presence of high level of pseudorange noise and then in presence of a malicious peer in the P2P network.

Keywords: Computer Science, Global Navigation Satellite Systems (GNSS), GPS, Radio Frequency, Ultra Wide-Band (UWB), Wireless Localization, Wireless Sensor Network (WSN)

INTRODUCTION
Nowadays, various services in wireless communication networks depend on mobile positioning. In fact, information collected or communicated by a wireless node is often useless if it is not associated to the node’s location. For example, a generic WSN monitoring application (Garcia-Hernandez, Ibarguengoytia-Gonzalez, & Perez-Diaz, 2007), where nodes collect data such as temperature, humidity, etc., requires the nodes’ position to recognize where the data come from. Moreover, location-based technology allows the deployment of many other applications, including asset tracking, intruder detection (Yan, He, & Stankovic, 2003), healthcare monitoring (Budinger, 2003), emergency 911 services (Caffery & Stuber, 1995) and so forth (Liu, Darabi, Banerjee, & Liu, 2007).

DOI: 10.4018/jertcs.2012070105
Usually, positioning techniques infer the position of unknown nodes by applying a two-step estimation process (Caffery & Stuber, 1998). In the first step, ranging estimation is performed by means of various techniques such as received signal strength (RSS) (Hashemi, 1993; Laitinen, Juurakko, Lahti, Korhonen, & Lahteenmaki, 2007), time-of-arrival (ToA) or time difference-of-arrival (TDoA) (Caffery & Stuber, 1998). Then, the position of the unknown peers are inferred in a two or three dimensional plane by applying a localization algorithm which takes as inputs the range measurements and the positions of anchor peers, whose coordinates are known a priori.

Recently, much attention is focused on the signal-of-opportunity (SoO) approach (Yang & Nguyen, 2009) which consists in the exploitation of terrestrial communication systems (e.g., wireless sensor network (WSN), ultra-wideband (UWB), Wi-Fi, cellular networks, etc.) with a purpose other than navigation in order to guarantee and improve global navigation satellite systems (GNSS)-based services and enhance the robustness of the overall GNSS end-user performance. In general, GNSS provide accurate position estimation when the receiver’s antenna is able to acquire at least four satellites (Del Re, 2011). This condition is generally verified in open sky outdoor environments. On the contrary, in GNSS-challenged environments such as urban canyons, under dense foliage and indoors, the line-of-sight (LoS) between satellites and the receiver’s antenna is often obstructed and the GNSS-based localization performance degrades or fails completely. Therefore, in such environments, hybrid and cooperative localization methods, which fuse both pseudorange measurements from GNSS satellites and terrestrial based ranging measurements from neighbouring peers, have been recently proposed in the literature to improve both availability and positioning accuracy (Sottile, Wymeersch, Caceres, & Spirito, 2011; Caceres, Penna, Wymeersch, & Garello, 2010; Caceres, Sottile, Garello, & Spirito, 2010).

This paper extends the work reported in Sottile, Caceres, and Spirito (2011) which proposes a simulation tool (ST) able to test hybrid “GNSS-terrestrial” and cooperative positioning algorithms in realistic and GNSS-challenged scenarios. The proposed ST is a system level simulator, where the physical layer is not simulated. However, range and pseudorange measurements are generated according to realistic models, described in more details in Sottile, Caceres, and Spirito (2011). In addition, the ST is able to test cooperative positioning algorithms, where peers help each other by exchanging positioning aiding packets including, for instance, position and covariance matrix estimates. The proposed ST simulates also communication among peers and executes the selected cooperative positioning algorithm in parallel. This approach makes the ST different from other proposed tools. For instance, the simulator presented in Ma (2009) focuses on a multi-stage simulation framework where in a first step the communication is simulated through the ns-2 engine, and in a second step the corresponding results are loaded into Matlab, which in turn runs a localization algorithm based on extended Kalman filter. Other positioning tools exist, for instance, GPS Toolbox (L3Nav, n.d.) and Wi-Fi Positioning Access Point Simulator (Spirent, n.d.). The former includes a set of software modules developed in Matlab environment for simulation and analysis of GPS-only applications. In fact, it does not take into account terrestrial range measurements. The latter is a tool to design and test Wi-Fi-based positioning solutions with the possibility to integrate GPS signal as well. However, it does not take into account the cooperation among users.

Moreover, we propose an approach to make cooperative positioning algorithms more robust to inaccurate information flowing in the P2P network. In particular, the proposed method selects the most reliable neighbouring peers on the basis of the exchanged estimated position covariance matrix. The proposed approach improves both estimation convergence and final positioning accuracy while lowering network traffic and latency. Finally, we tested the sensitivity of the implemented positioning algorithms through the ST in two different...
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