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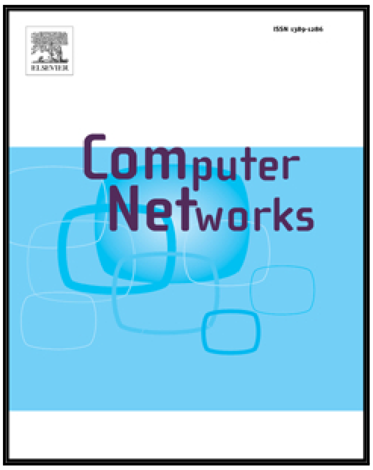

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Recent Advances on Cooperative Wireless Localization and Their Application in Inhomogeneous Propagation Environments

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***Abstract*—In this survey, we review recent advances on cooperative localization techniques and identify critical challenges in realistic cooperative localization systems. Particularly, we focus on the inhomogeneity of radio propagation environments, which has substantial impact on the accuracy of positioning systems that assume a homogeneous propagation model. Popular cooperative localization algorithms based on maximum-likelihood estimation, convex relaxation and optimization, and message passing are surveyed, with more emphasis placed on Received Signal Strength (RSS) based approaches due to their potential application in low cost devices. It is shown that most existing algorithms are based on the assumption of a propagation environment with a priori known spatially invariant propagation models. The extension of existing algorithms to capture the inhomogeneity of propagation environments are studied.**

***Index Terms*—Cooperative localization, inhomogeneous environment, maximum-likelihood estimation, convex relaxation, message passing.**

I. Introduction

Cooperative wireless localization has been studied extensively in the past decade. Fig. 1(b) illustrates the concept of cooperative localization, where all available measurements between blindfolded nodes, and those between blindfolded devices and reference nodes, are used to jointly estimate the positions of blindfolded devices [1]. As is shown in the diagram, there are significantly more measurements available under cooperative localization than under classic non-cooperative positioning systems shown in Fig. 1(a).

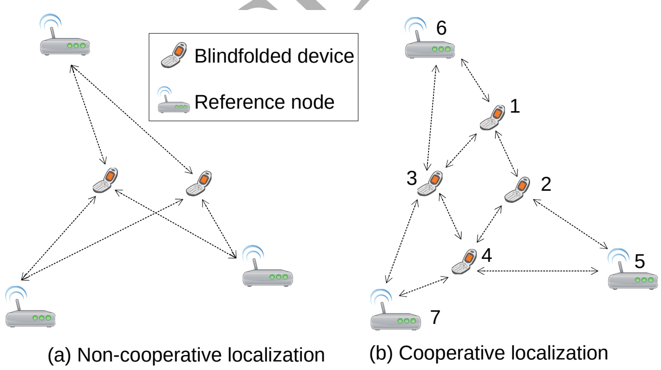

Fig. 1: Illustration on non-cooperative and cooperative localization.

Cooperative localization can be performed based on various types of measurements, such as Time-of-Arrival (TOA) [2]–[5], Time-Difference-of-Arrival (TDOA) [6]–[8], Angle-of-Arrival (AOA) [9], [10], and Received Signal Strength (RSS) [11], [12]. Provided that the bandwidth of radio frequency (RF) ranging signals is sufficiently wide, e.g., over 100 MHz, high positioning accuracy can be typically achieved based on TOA or TDOA measurements, e.g., less than 20 cm [13], [14]. This is due to the high accuracy in estimating ranges/pseudoranges. However, apart from the requirement of wideband ranging signal, specialized hardware is also necessary at extra cost and complexity [15].

A less intrusive approach for cooperative localization is based on RSS measurements, which are easily accessible in almost all wireless communications devices (including low-cost devices) [16]. RSS measurements have been used for non-cooperative localization based on fingerprinting [14] and trilateration [16]. In these cases, the position of a blindfolded device is estimated by matching against RSS signatures at surveyed locations, or based on ranges estimated from RSS measurements and empirical path loss models, respectively.

RSS-based trilateration does not require specialized hardware or high RF bandwidth in TOA/TDOA based systems, nor does it need laborious site survey in fingerprint based systems. However, the positioning accuracy is typically poor, due to the fact that range estimation errors based on RSS measurements are typically multiplicative (rather than additive in TOA/TDOA based systems) and grow with the actual ranges [17]. In this sense, cooperative localization is of particular interest to RSS based systems, as it can substantially reduce the ranges over which the RSS measurements are taken and thereby avoid excessive range errors, as illustrated in the RHS of Fig. 1 [17].

An assumption underlying most existing positioning techniques is a homogeneous propagation environment. In the case of RSS measurement, typically a single empirical (log-normal) path loss model is used globally for an entire environment [18, eq. 3], [19]. In the case of TOA/TDOA measurement, additive range errors have been typically assumed to be independent of location [18, eq. 6]. However, most practical environments exhibit strong inhomogeneity, or spatial variations, especially in indoor and cluttered environments (cf. the free space). Obstacles, scatters or reflectors result in locality distinctively differences from the rest of an environment, which causes critical challenges to positioning systems [20]. One may still employ a coarse-gained global measurement error model in the positioning algorithms. However, these models fail to