Dynamic node placement for multi-hop localization in cluttered environments

Muzammil Hussain
Department of Computer Science
University of Oxford
Oxford, United Kingdom
Email: muzammil.hussain@cs.ox.ac.uk

Niki Trigoni
Department of Computer Science
University of Oxford
Oxford, United Kingdom
Email: niki.trigoni@cs.ox.ac.uk

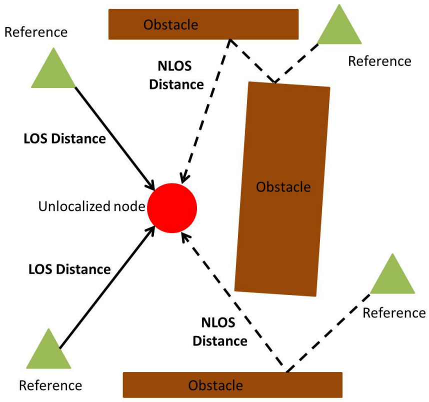

Fig. 1. Classification of distance measurements as line of sight (LOS) and non line of sight (NLOS)

I. Overview and Motivation

Accurate localization in wireless sensor actuator networks (WSANs) is crucial since a primary purpose in their deployments is accomplishing tasks based on a spatial dimension in the environment - be it sensor data collection or actuation.

Localization accuracy is severely debilitated in the presence of obstacles between the references with known positions and the unlocalized node. The reason is the occurrence of reflected non-line-of-sight (NLOS) distance measurements, as shown in Fig. (1), in contrast to line-of-sight (LOS) distance measurements that are found in a clutter-free scenario. The large positive biases of NLOS distances typically result in large localization errors. For example, GPS satellite signals suffer from NLOS incidence in urban canyon environments, i.e., in a city block with tall skyscrapers, which obscure the direct view between the GPS receiver and the GPS satellites. Similarly, an underwater robot, mapping a closed cluttered industrial tank will have difficulty in localizing accurately with obstacles between itself and the surface anchors.

Various NLOS detection and mitigation techniques for cellular and Ultra WideBand (UWB) localization have been proposed in the literature [1]–[10]. Wylie et al. [8] and Jourdan et al. [9] require both the identification and characterization of the NLOS distances. Chen [7] uses the least squares residual as an indicator of the inherently unknown NLOS error in a given set of LOS and NLOS distances. However all these require that *the NLOS distances form the minority of the total available distance measurements.*

II. Distributed Multi-hop Localization in Cluttered Environments

In our previous work [11], we showed that the application of multi-hop localization in cluttered environments can yield significant improvements in localization accuracy. We proposed the use of 'localizers' for enabling better localization accuracy in the presence of clutter between the references and unlocalized nodes. Localizers help these nodes to localize more accurately than they would in case of single-hop localization, which will involve distance measurements with large NLOS errors. The benefits of multi-hop localization in clutter are especially pronounced when all references/anchors are occluded from the node/robot that needs to be localized. In this case, all distance measurements from the references to the unlocalized node are NLOS in nature. We saw that DV-Distance [12], [13] has significant advantages over iterative localization [14] as a multi-hop localization technique used in NLOS-prone environments. A centralized optimal localizer placement algorithm, OPTPLACDVDIST, was proposed, which, for a given clutter topology, will output optimal positions for localizers such that the multi-hop distance error between a reference and the unlocalized node is minimized. Fig. (2) shows a sample output generated by OPTPLACDVDIST for the given clutter topology.

III. ADAPTPLACDVDIST implementation

While OPTPLACDVDIST [11] illustrates that a relatively small number of localizers, carefully placed in midst of the clutter, can produce significant improvements in the localization accuracy in an obstacle-prone environment, it makes two strong assumptions. First, it assumes that the clutter topology is known beforehand and, second, it assumes that the localizers can position themselves accurately in their pre-determined optimal positions.

We propose ADAPTive PLACement for DV-DISTance (ADAPTPLACDVDIST) as a solution to this problem. Unlike OPTPLACDVDIST, it is a distributed placement algorithm which does not require prior knowledge of the clutter topology.

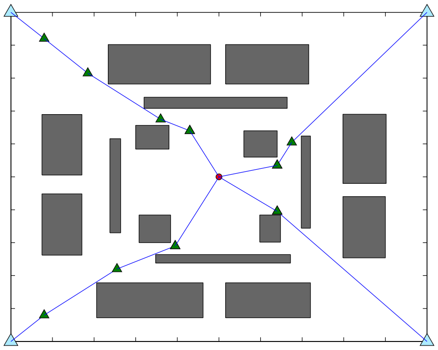

Fig. 2. Optimal localizer placements computed by OPTPLACDVDIST when the reference communication range is 500 units. The enclosure is of dimensions 100 × 100 units. The large blue triangle represent the references, the smaller green triangles represent the localizers and the node to be localized is represented by the small red disc.

(a) Mobile robot capable of measuring distances using MIT Cricket motes

(b) Demonstration of ADAPTPLACDVDIST for two localizers between a reference and a mobile robot/node. Here, the reference is obscured between the wooden clutter.

Fig. 4. ADAPTPLACDVDIST demonstration using distance measuring robots built using the iRobot Create platform and MIT Cricket motes.

Initially, the node is localized using the DV-Distance algorithm with the localizers at random positions scattered throughout the clutter. Thus, the node forms distinct multi-hop chains, consisting of intermediate localizers, to at least $(D+1)$ references, where D is the dimensionality. Once the node is able to have initial distance estimates to references, the node initiates the ADAPTPLACDVDIST algorithm. The aim of the algorithm is to move the localizers in each of the multi-hop chains such that their final positions minimize the multi-hop distance between the references and the node. The key component of the algorithm is the *alignment* procedure undertaken by every localizer. During the procedure, a localizer moves so as to align itself with its two adjacent neighbours, which can be either localizers themselves, a reference or the node itself, as shown in Fig. (3). At any given time, only one localizer in the multi-hop chain can undertake the alignment procedure, with all other localizers being stationary. The localizers in a given multi-hop chain with perform the alignment procedure in a sequential manner between chain's two ends, i.e., the reference and the node. The algorithm converges when all the localizers in the given multi-hop chain can no longer move to a position such that their distances to their respective adjacent neighbours are reduced.

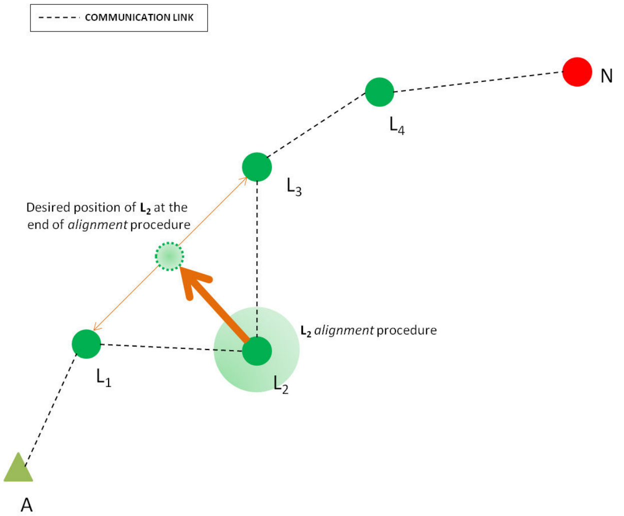

Fig. 3. The alignment procedure. Reference A, localizers L_1, L_2, L_3, L_4, and node N form the multi-hop chain. Localizer L_2 moves to align itself with its neighbours L_1 and L_3, by moving in a direction that reduces the sum of distances to L_1 and L_3.

IV. DEMONSTRATION DESCRIPTION

Our demonstration will show the working of the ADAPTPLACDVDIST algorithm on the iRobot Create robotic platform. MIT Cricket motes [15] are used for measuring distances. Fig. (4a) shows a prototype which has two Cricket motes mounted on a Create to produce a mobile robot which is capable of measuring distances to other robots/motes. Since the ultrasound transceiver on MIT Cricket mote is directional (≈180° span), we devise a technique whereby omni-directionality for the Cricket mote is simulated by rotating two Cricket motes, which are fixed back-to-back to each other as seen in Fig. (4a)), through a 90° angle. We use wooden blocks to represent the clutter. The algorithm is implemented in Java, with the Roombacomm Java library [16] used to interface with the Create robot through the serial port. The original TinyOS code on the MIT Cricket motes has been modified to enable the transmission and reception of various messages used by the algorithm, in addition to the default distance measurement functionality of the MIT Cricket motes themselves.

For this demo, we employ three Create robots and one reference node. We use two Creates as localizers and the remaining one as the robot to be localized (though for the demonstration, we do not localize the robot but only establish the minimum length multi-hop path to the single reference). We initially place the localizer in positions that are far from the straight line connecting the reference and the robot. We place wooden blocks between the later two, such that the reference is no longer visible from the robot. First, the robot will obtain an initial multi-hop path between itself and the reference, through the DV-Distance algorithm. Thereafter, it will initiate the ADAPTPLACDVDIST algorithm. The two localizers will perform the *alignment* procedure repeatedly until they minimize the multi-hop distance between the reference and the robot. The robot is then moved around to a new position, though still obscured from the reference, and subsequently the localizers adjust themselves to new positions accordingly.

V. CONCLUSIONS

In this demo, we present the ADAPTPLACDVDIST algorithm which offers a practical method of employing distributed localization, in particular DV-Distance, for mitigating the effect of clutter vis-a-vis NLOS distance measurements. ADAPTPLACDVDIST requires each localizer to communicate with only its adjacent, local neighbours, thus offering a scalable solution. The key insight of this work is that, for certain clutter topologies, the distance error of a *minimal-length* multi-hop path formed with intermediate localizers, between a reference and the unlocalized node can be significantly less than the single-hop NLOS distance error. Consequently, the localization accuracy is substantially improved. The benefits of ADAPTPLACDVDIST, compared to existing NLOS mitigation techniques, are more pronounced in situations where all references are occluded by obstacles.

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