SPATIAL QUERY LOCALIZATION METHOD IN LIMITED REFERENCE POINT ENVIRONMENT: AN EMPIRICAL STUDY

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Abstract

Intelligent Transport Systems (ITS) include telematics and all types of communications in vehicles, between vehicles (car-to-car), and between vehicles and fixed locations (car-to-infrastructure).ITS are advanced applications which, without embodying intelligence as such, aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated, and 'smarter' use of transport networks. Knowing the correct positions of vehicle network nodes is essential to many application scenarios in the field of wireless sensor networks rely on positioning information. Various new localization and spatial analysis techniques has been introduced by modern geographic information system (GIS) technologies, using digital information, for which various digitized data creation methods are used. There has been a growing interest in the use of location-based spatial queries, which refer to a set of spatial queries that retrieve information based on mobile users’ current locations. The wireless environment and the communication constraints play an important role in determining the strategy for processing spatial queries. This article assumes simplest approach, a user establishes a point-to-point communication with the server so that her queries can be answered on demand. This paper gives an overview of the existing methods of localization and especially their applicability to wireless mobile networks and presents a study of how empirical ranging characteristics affect spatial query localization in wireless sensor networks. Then we study the spatial query selection, generic structure, and operation of localization algorithm for ad-hoc sensor networks on a simulation platform.

Keywords: Intelligent Transportation System, Sensor Network, Localization, Spatial Query, GIS, Graph Embedding

Introduction

Intelligent transportation systems (ITS) improve transportation safety and mobility and enhance productivity through the integration of advanced communications technologies into the transportation infrastructure and in vehicles. ITS encompass a broad range of wireless and wire line communications-based information and electronics technologies and aims to bring connectivity to transportation through the application of advanced wireless. It can be achieved by mutual interaction of nodes equipped by sensors forming a sensor network, to provide connectivity with and between vehicles; between vehicles and roadway infrastructure; and among vehicles, infrastructure and wireless consumer devices. The concept of transportation connectivity, once it has developed from research into deployment, will bring with it benefits that we are just beginning to understand:

- A system in which highway crashes and their tragic consequences are rare because vehicles of all types can sense and communicate the events and hazards happening around them.
- A fully-connected, information-rich environment within which travelers, transit riders, freight managers, system operators, and other users are aware of all aspects of the system's performance.
- Travelers who have comprehensive and accurate information on travel options-transit travel times, schedules, cost, and real-time locations; driving travel times, routes, and travel costs; parking costs, availability, and ability to reserve a space; and the environmental footprint of each trip.
- System operators who have full knowledge of the status of every transportation asset.
- Vehicles of all types that can communicate with traffic signals to eliminate unnecessary stops and help people drive in a more fuel efficient manner.
- Vehicles that can communicate the status of on-board systems and provide information that can be used by travelers and system operators to mitigate the vehicle's impact on the environment or make more informed choices about travel modes.

Vehicular ad hoc networks (VANETs), a platform for vehicular communications, are a subgroup of mobile ad hoc networks (MANETs) with the distinguishing property that the nodes are vehicles like cars, trucks, buses or road infrastructure objects. This implies that node movement is restricted by factors like road geometry, course, encompassing traffic and traffic regulations. Because of the restricted node movement it is a feasible assumption that the VANET will be supported by some fixed infrastructure that assists with some services and can provide access to various traffic assisting applications. The fixed infrastructure can be deployed at critical locations like slip roads, service stations, dangerous intersections or places well known for hazardous weather conditions.

Knowing the correct positions of VANET network nodes is essential to many application scenarios in the field of wireless sensor networks rely on positioning information (David K. Goldenberg, Arvind Krishnamurthy, Wesley C. Maness, Yang Richard, Yang Anthony Young, A. Stephen Morse, Andreas Savvides, Brian D. O. Anderson, 2005). Knowledge of location information can also improve the performance of routing algorithms because it allows the use of geo-routing techniques. Equipping all sensor nodes with specific hardware such as GPS receivers would be one option to gain position information at the nodes. However, since GPS requires line-of-sight between the receiver and the GPS satellites, it may not work well indoors, underground, or in the presence of obstructions such as dense vegetation, buildings, or mountains blocking the direct view to these satellites. Another solution is to provide only a few nodes (so-called anchor or landmark nodes) with GPS and have the rest of the nodes compute their position by using the known coordinates of the anchor nodes (Thomas Locher, Pascal Von Rickenbach and Roger Wattenhofer, 2008).

One characteristic inherent to this approach is that the anchor density and their actual placement determine the solution quality. Obviously, in the absence of anchors, nodes are clueless about their real coordinates. The predominant type of approach, involves nodes measuring the distances between nodes themselves and their neighbors, with only some nodes called “beacons” having to be informed of their position through GPS or manual configuration.

Various new localization and spatial analysis techniques has been introduced by modern geographic information system (GIS) technologies, using digital information, for which various digitized data creation methods are used. For example road map, is a two-dimensional object that contains points, lines, and polygons that can represent cities, roads, and political boundaries such as states or provinces. GIS applications store, retrieve, update, or query some collection of features that have both non spatial and spatial attributes.

Spatial querying capabilities can be essential for sensor network query systems. For many applications, the ability to query sensor networks in an ad hoc fashion will be a key to their usefulness. Rather than re-engineering the network for every task, as is commonly done now, ad hoc querying allows the same net-work to process any of a broad class of queries, by expressing these queries in some query language. In essence, the network appears to the user as a single distributed agent whose job it is to observe the environment wherein it is embedded, and to interact with the user about its observations (Amir Soheili, Vana Kalogeraki, Dimitrios Gunopulos, 2005).

This paper presents a study of how empirical ranging characteristics affect spatial query localization in wireless sensor networks, described earlier in authors article Spatial Query Localization Method in Limited Reference Point Environment. Section 2 gives an overview of the existing methods of localization and especially their applicability to wireless mobile networks. Section 3 discusses the spatial query selection, generic structure, and operation of localization algorithm for ad-hoc sensor networks. This algorithm is studied on a simulation platform, which is described in Section 4. Also, Section 4 presents intermediate results for the individual experiment phases, while Section 5 provides a detailed overall comparison and analysis. Finally, we give conclusions in Section 6.

Related Work

Since most applications depend on a successful localization, i.e. to compute their positions in some fixed coordinate system, it is of great importance to design efficient localization algorithms. Precise knowledge of node localization in ad hoc sensor networks is an active field of research in wireless networking. Unfortunately, for a large number of sensor nodes, straightforward solution of adding GPS to all nodes in the network is not feasible because the presence of buildings, dense forests, mountains or other obstacles that block the line-of-sight from GPS satellites, GPS cannot be implemented.

The limitations of GPS have motivated the search for alternative ad-hoc methods, with a large number of localization systems having recently been proposed and evaluated.

Recently, novel schemes have been proposed to determine the locations of the nodes in a network where only some special nodes (called beacons) know their locations. In these schemes, network nodes measure the distances to their neighbors and then try to determine their locations. The process of computing the locations of the nodes is called network localization. Localization of nodes in VANET’s, in general, can be split up into two parts: First, the process of distance estimation or measurement and second, the localization algorithm. There are different approaches for estimating the distance between a node and its neighbors or fixed anchors. Some techniques rely on the calculation of these distances with physical measurements like radio signal, ultrasonic based-measurements or received signal strength indication (RSSI) measurements. Others try to approximate the distance with a hop-count indicator.

The approaches taken to solve this localization problem differ in the assumptions that they make about their respective network and device capabilities. These include assumptions about device hardware, signal propagation models, timing and energy requirements, network makeup (homogeneous vs. heterogeneous), the nature of the environment (indoor vs. outdoor), node or beacon density, time synchronization of devices, communication costs, error requirements, and device mobility.

Localization algorithms for wireless sensor networks can be classified according to a number of properties that each algorithm has (Jun-geun Park B.S, 2009).

Anchor-Based versus Anchor-Free: Many localization methods require beacons or anchor nodes that know their position on some absolute coordinate system with very high or absolute certainty. These methods are called anchor-based methods. In anchor-based methods, the localization problem can be formulated as finding a consistent set of locations of nodes in the network, given the information obtained from anchor-node relations as well as node-node relations, for example, GPS. On the other hand, anchor-free methods refer to the localization methods that do not require specialized anchor nodes. Since no information from outside of the network is used, an anchor-free method itself does not have a mean to localize the network on the absolute reference frame. Instead, it recovers relative locations of nodes on a relative coordinate system centered on an arbitrary origin.

Centralized versus Distributed: For centralized algorithms, computation occurs at one specific node or at a computer outside the network, whereas for distributed algorithms, computation load is distributed among nodes in the network. This classification is directly related to how the localization problem is formulated. Because a computing node must have all the necessary information in centralized algorithms, the information required for computation, such as inter nodes distances, must be relayed to the computing node. This difficulty in communication may prevent the centralized algorithms from being scalable over the size of the network. For this reason, distributed localization algorithms are more popular in wireless sensor networks. In distributed algorithms, each node splits up a computation job in some way.

Proximity, Distance, Angle-of-Arrival: Localization algorithms use various types of information or measurements to infer locations of nodes in the network. Proximity is one of the simplest forms of information that a sensor node can obtain about its neighborhood. While proximity information only provides coarse location estimate, some localization methods can estimate node positions with high granularity using multiple proximity measurements and a priori information about the proximity measurements, such as maximum detection range. Another type of information used for localization is distance. Distance between sensor nodes is obtained in various forms, such as, received signal strength (RSS), time-of-arrival (ToA), or time-difference-of-arrival (TDoA). Estimating distance from RSS is based on the relation between RSS and distance.

Distance measurement through ToA uses the relationship between distance and signal propagation time when the signal's propagation speed through the transmission medium is known. If the transmitter and the receiver are synchronized, inter-node distance can be calculated directly from a timestamp included in the ranging packet. TDoA uses two or more different sets of transmission pairs to eliminate the need of time synchronization in ToA. AoA information can be acquired from directional antennae or an antennae array. Because of the need for multiple antennae, AoA information is less suitable for sensor networks in which the size and complexity of each node is restricted..

Static Network versus Mobile Network: Most of the existing localization algorithms for sensor networks do not consider node mobility explicitly, assuming that the network is static. While many sensor platforms are not likely to move actively like robots, there are certainly situations that sensors exhibit mobility, thus rendering the network mobile. Mobile networks show different characteristics from static networks, such as changing topology, varying connectivity, and latency problem.

Scene Analysis Methods: Scene analysis involves the monitoring of a wide area around the subject of interest from a specific vantage point. The commonly deployed sensors have broad coverage area and range. Examples include ceiling-mounted video cameras or passive infrared (PIR) sensors.

Fingerprinting-based localization solutions: Scenes analysis approaches are composed of two distinctive steps (Mathieu Bouet, Aldri L. dos Santos, 2008). First, information concerning the environment (fingerprints) is collected. Then, the target’s location is estimated by matching online measurements with the appropriate set of fingerprints. Generally, RSS-based fingerprinting is used. The two main fingerprinting-based techniques are: k-nearest neighbor (kNN), a method consisting of a first time in measuring RSS at known locations in order to build a database of RSS that is called a radio map. Then, during the online phase, RSS measurements linked to the target are performed to search for the k closest matches in the signal space previously-built.

Probabilistic approach: Approach when the problem stated to find the location of a target assuming that there are n possible locations and one observed signal strength vector during the online phase according to a posteriori probability and Bayes formula. Thus, the location with the highest probability is chosen. Generally, probabilistic methods involve different stages such as calibration, active learning, error estimation, and tracking with history.

Non-fingerprinting-based solutions: RF-based localization can also be achieved without a priori analysis of the radio properties of the environment (i.e., without development of a radio map) (Yunhao Liu, Zheng Yang, 2010). Indoor localization based on triangulation of radio waves is a non-trivial problem because the transmitted signal can suffer obstructions and reflections. As a consequence, Non-Line-of-sight (NLOS) conditions emerge. In the presence of NLOS conditions, the radio signal can travel to the receiver through a non-direct path, giving rise to erroneous distance estimates.

Finally, system localization can be based on a combination of scene analysis and proximity techniques.

Spatial Query Based Localization

Consider a sensor network consist of N nodes at locations $S = \{S_1, S_2, \ldots\ldots, S_n\}$. Let S_{xi} refer to the x-coordinate of the location of node i and let S_{yi} refer to the y coordinate respectively. Determining these locations constitutes the localization problem. Some network nodes are aware of their own positions; these nodes are known as anchors or beacons. All the other nodes localize themselves with the help of location references received from the anchors. So, mathematically the localization problem can be formulated as follows: given a multi-hop network, represented by a graph $G = (V, E)$, and a set of beacon nodes B, their positions $\{x_b, y_b\}$ for all $b \in B$, we want to find the position $\{x_u, y_u\}$ for all unknown nodes $u \in U$ (Amitangshu Pal, 2010).

Thus, localization problem can be considered as task to reconstruct the positions of a set of sensors given the distances between any pair of sensors that are within some unit disk radius of each other. Such network localizability problem closely related to graph rigidity. A graph is called generically rigid if one cannot continuously deform any of its realizations in the plane while preserving distance constraints. A graph is generically globally rigid if it is uniquely realizable under translations, rotations, and reflections. So, all localizable nodes in a globally rigid graph must have at least three beacons in line of sight.

Fortunately, infrastructure can provide us with additional information sources that may be exploited to eliminate spurious solutions and lack of beacons to the layout problem. Geo location information in this case, can be viewed in form a restrictions on the order of the edges around the vertices of graph. While it is a not so trivial task using raster geospatial data, vector type layers can provide valuable information for proper node graph embedding and orientation. Combining scene analysis methods with existing geographic information databases can reduce beacon number required for localization process up to one beacon for whole network.

Further on we will assume the case when we have only one known beacon available and study spatial queries applicability for network nodes localization.

Location-based spatial queries refer to spatial queries whose answers rely on the location of the inquirer. Efficient processing of spatial queries is of critical importance with the ever-increasing deployment and use of wireless and mobile technologies. It has certain unique characteristics that traditional query processing and databases does not address.

There has been a growing interest in the use of location-based spatial queries, which refer to a set of spatial queries that retrieve information based on mobile users' current locations. The wireless environment and the communication constraints play an important role in determining the strategy for processing spatial queries. This article assumes simplest approach, a user establishes a point-to-point communication with the server so that her queries can be answered on demand, and it means that operating environment contains a remote wireless information server.

In this paper, we study a GPS-free localization algorithm for wireless node localization proposed earlier. Given approach can effectively overcome the potential flip ambiguity problem, taking into consideration digital map road geometry and traffic regulations. The same principle can be applied in a 3D case.

Experiments

As a reference implementation Oracle Spatial has been chosen, well-known integrated set of functions and procedures that enables spatial data to be stored, accessed, and analyzed quickly and efficiently. Spatial data represents here the essential location characteristics of real or conceptual objects as those objects relate to the real or conceptual space in which they exist.

Utilizing spatial features, algorithm, described in previous works, was implemented as spatial statements. Task requires two database tables. Each table has a column of type SDO_GEOMETRY. Other columns needed primarily as id numbers, descriptions and needs no further explanation. We assume that first table, AREA_MAP, contain a digital map itself, beacon b location and known distances D, 1..n from beacon to nodes in form of circles C, 1…n with center at beacon coordinates (b_x, b_y) and radius r_i equal to distance d_i. Second table, STAGING_MAP, serves as a staging area. Spatial data indexing procedure description omitted here, since it does not interfere with algorithm logic. Nevertheless, it is worth to mention that indexing is required for optimal spatial database performance.

Whole process takes two steps, two spatial statements. First statement finds all intersection points V, of circles C and road geometries stored in digital map, and inserts into staging area, keeping a track of to what circle c_i each particular point belongs. Statement uses primary filter ANYINTERACT to narrow query window and then, SDO_INTERSECTION function performs man job, selecting intersection points. Second step, Second statement selects from the staging area table distinct intersection point sets, satisfying distance matrix and node to beacon distance conditions. If graph, formed by nodes, is rigid enough, or additional map information makes it rigid enough, as a result we receive one distinct point, set corresponding to ground truth nodes locations. However, in case when information is not sufficient, it is possible to receive multiple location sets, product of graph rotation for one beacon case, or graph flip for two beacons case.

At the start of simulation we insert into database table two random digital map topology fragments, referred as map F and map G depicted in Figure 1 and Figure 2. Note that while map G has more asymmetric configuration, map F configuration is symmetric and more exposed to localization errors of type flip, rotation and flex (J. Zhang, M. Zhu, D. Papadias, Y. Tao, and D. L. Lee, 2003).

Then, we generate certain number of randomly placed, with a uniform distribution, nodes and one beacon within given map fragment. We assume that chosen number of nodes can measure distance to its neighbor nodes but some are not in line of sight (NLOS). Also, we chose a number of nodes with NLOS to beacon node. To emulate measurement error the measured range between connected nodes is blurred by drawing a random value from a normal distribution as a tolerance parameter in spatial queries used for localization.

Experiment scenarios as well as a number of chosen nodes and NLOS described in subsequent section. At the end of a run the simulator outputs a large number of statistics per each scenario. To make it simpler to understand, results are presented in a form of surface plot, where each

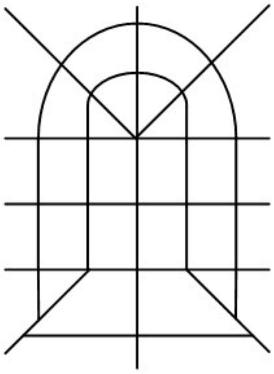

Figure 1 Sample map F.

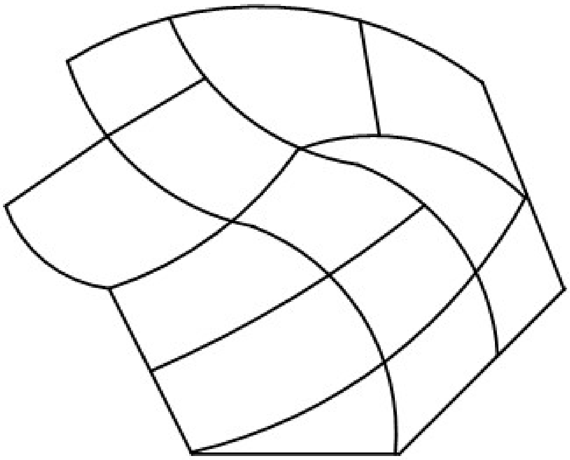

Figure 2 Sample map G.

scenario has one plot with one localization result, several localization results if it is not possible to calculate distinct location and alternative locations are possible, or no result what means that solution is not defined and the localization failed. Number of results plotted on as axis Y in a range from 0 to 50 solutions. Node to node distances NLOS percent on axis X and node to beacon NLOS percent on axis Z.

Simulation Results

In this section we present simulation results in three phases. Throughout this section we review several scenarios and will vary two parameters such as NLOS percentage between nodes and NLOS percentage between nodes and the beacon.

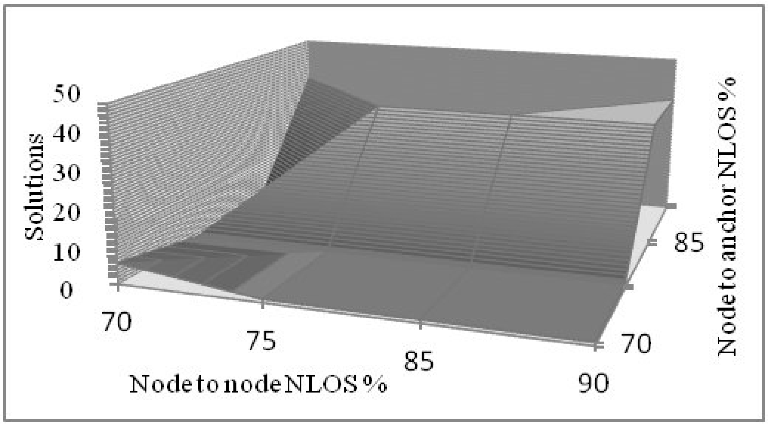

Figure 3 Map G, 5 nodes, placement 1.

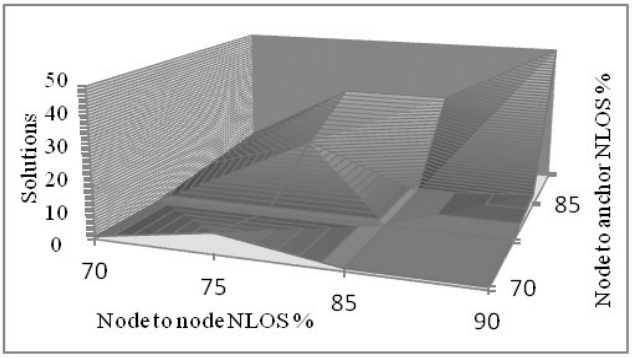

Figure 4 Map G, 5 nodes, placement 2.

First scenario uses asymmetric map G, range from 70% NLOS to 90% NLOS both for node to node and node to beacon distance measurements. Localization performed for 5, 25 and 45 nodes. For each case, three random placements have been made.

25 and 45 nodes cases showed stable distinct localization results for all random placements and in full NLOS range, therefore not plotted here. Nevertheless, 5 nodes case demonstrated multiple localization solutions as well, what can be seen on plot depicted on Figures 3, 4, and 5.

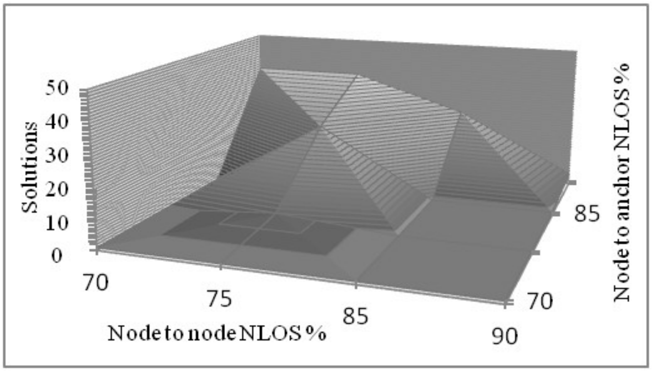

Figure 5 Map G, 5 nodes, placement 3.

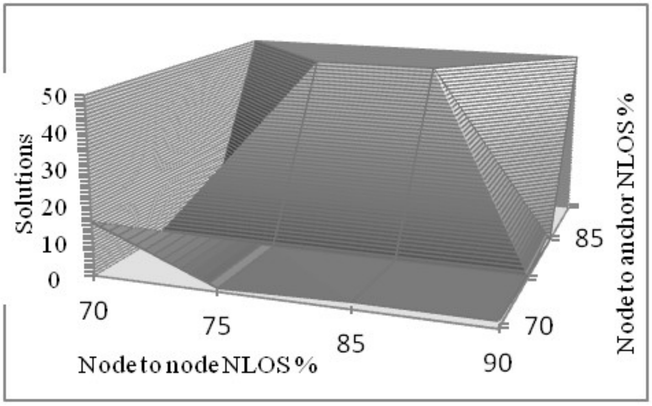

Figure 6 Map F, 5 nodes, placement 1.

Plots on Figures 6, 7 and 8 demonstrates the same scenarios results run on symmetric map F. While 25 and 45 nodes scenarios also performed stable and distinct localization results, 5 node scenarios showed even more multiple results what was expectable because of higher probability of flip and flex localizations ambiguity. However, all scenarios remained within a range of definition.

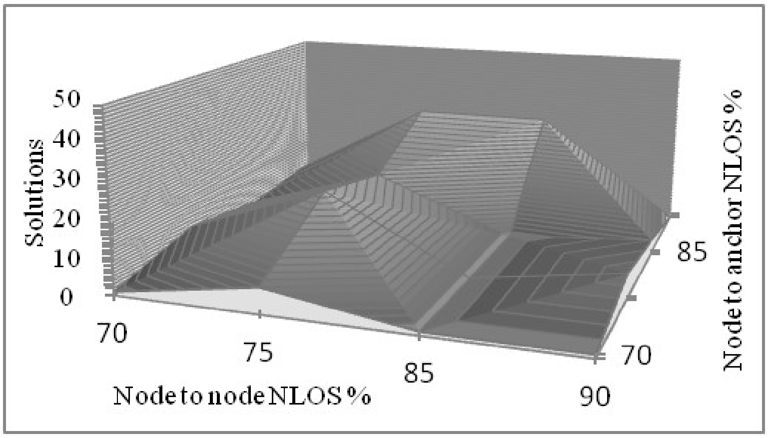

Figure 7 Map F, 5 nodes, placement 2

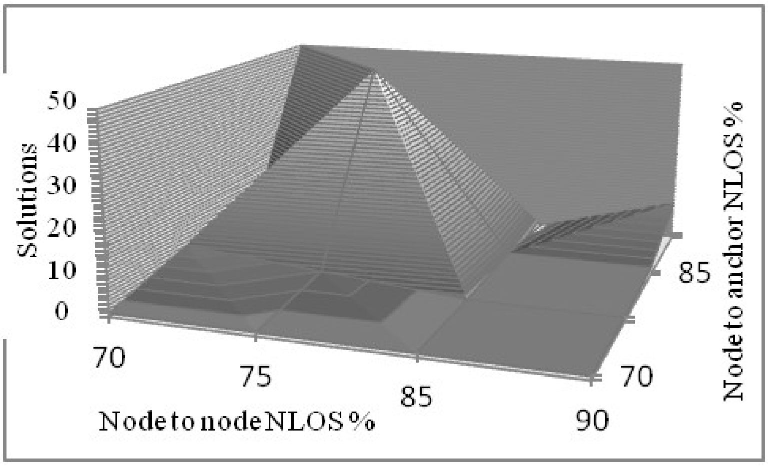

Figure 8 Map F, 5 nodes, placement 3

Next 6 scenarios (Figures 9, 10, 11, 12, 13 and 14) were intended to take a closer look to extreme cases and reach parameter values area where location is not defined. NLOS range becomes reduced up to 85 – 99% from distances and node number decreasing starting from 30 to 5 nodes.

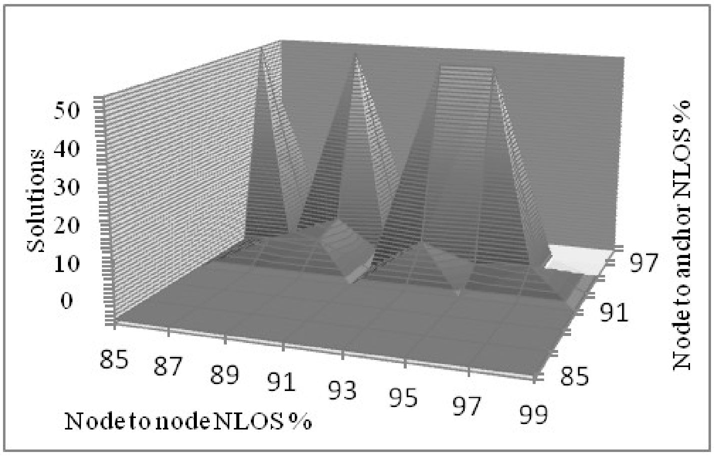

Figure 9 Map G, 30 nodes

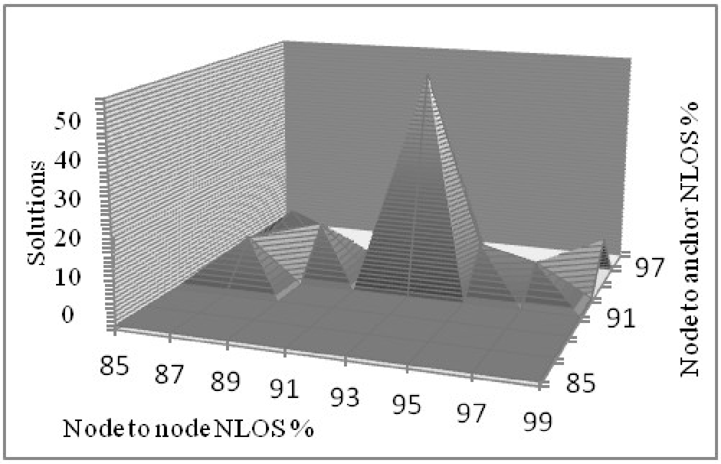

Figure 10 Map G, 25 nodes

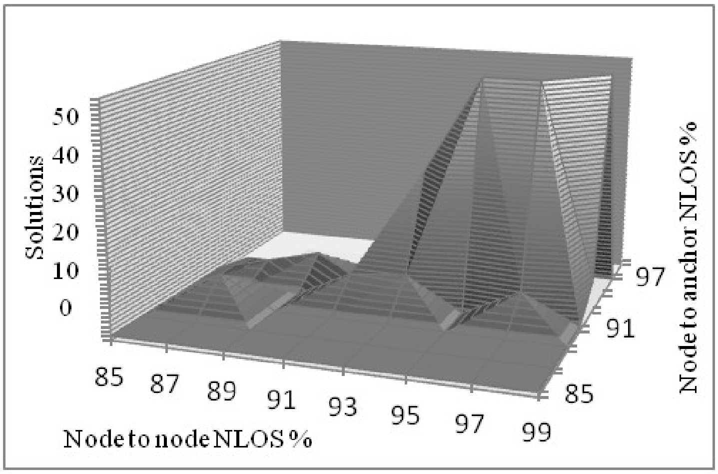

Figure 11 Map G, 20 nodes

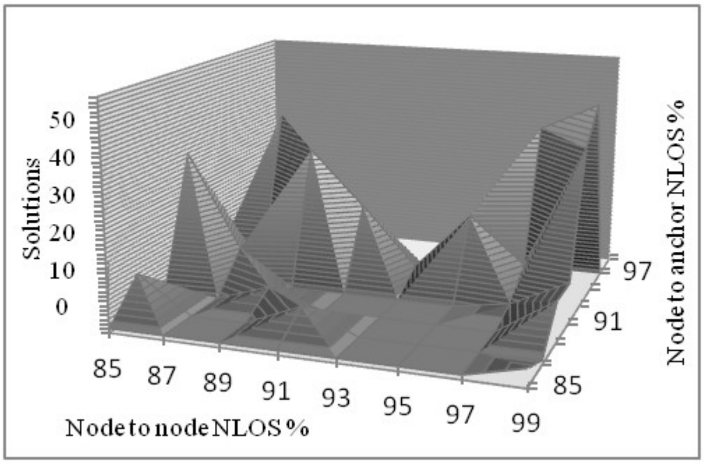

Figure 12 Map G, 15 nodes

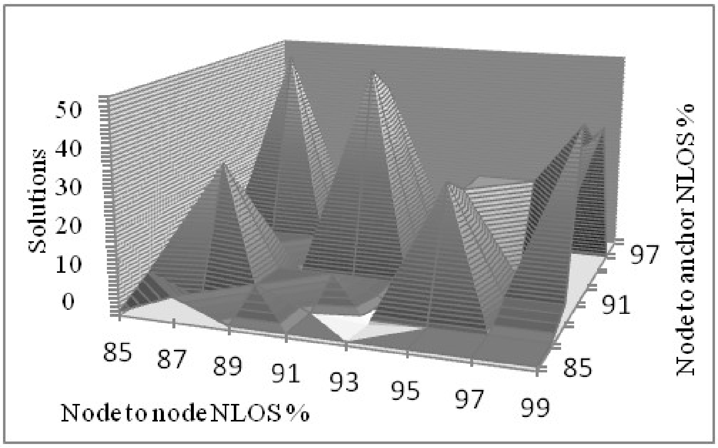

Figure 13 Map G, 10 nodes

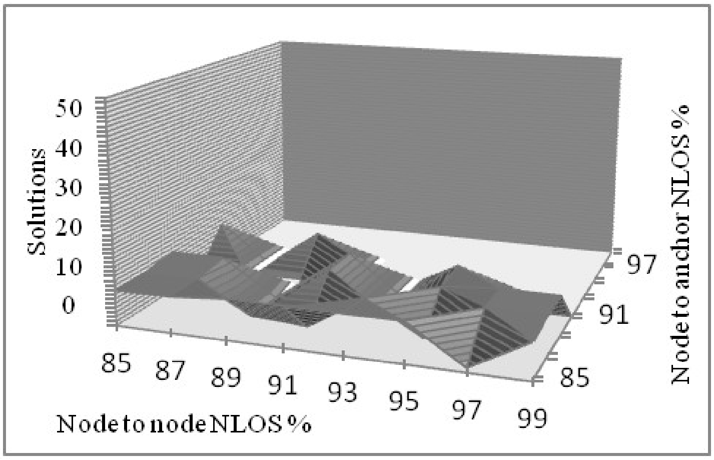

Figure 14 Map G, 5 nodes

Scenario with 30 nodes shows stable and distinct locations on full range of node to node NLOS while node to beacon NLOS does not exceed 90. At the same time, when node to beacon NLOS reaches 95% first areas with no solution appears. Last, and worst scenario on Figure 14, demonstrate absence of distinct solutions, large not defined areas and only few areas with multiple location results.

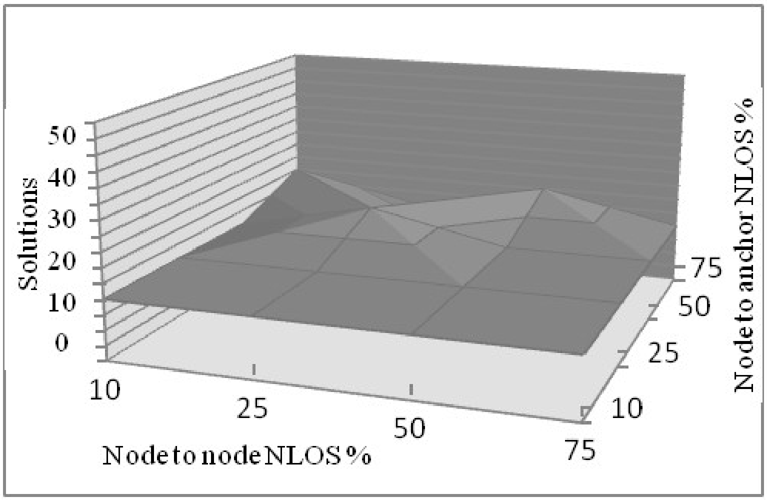

Figure 15 Map G, 20 nodes, errors 0m – 1m

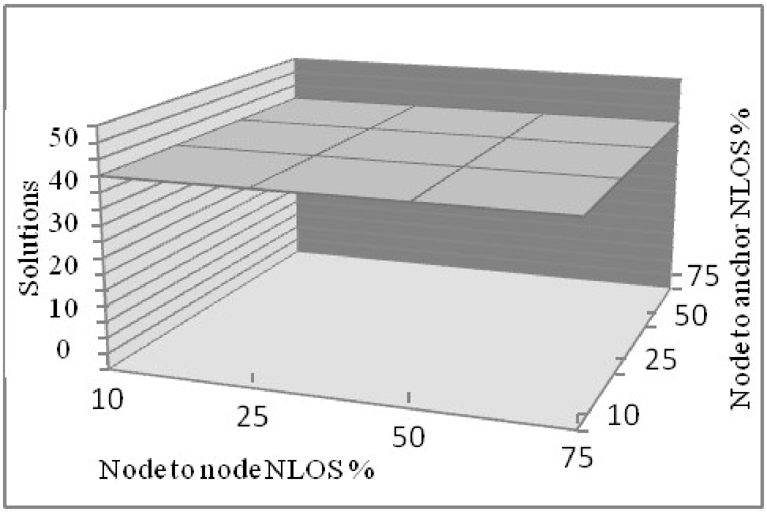

Figure 16 Map G, 20 nodes, errors 1m – 5m

In last two scenarios (Figure 15, 16) we introduce errors blurring measured distances by increasing spatial query tolerance. Three simulation scenarios were executed, where first one (Figure 15) uses NLOS range from 10 to 75% and error approximately corresponding 0 to 1 meter error on the ground. Second scenario (Figure 16) increases error to equivalent 1 – 5 meter on the ground, and demonstrates stable 12 alternative solutions over whole area. And last one scenario with error equivalent to 5 – 25 meters on the ground fails to localize nodes and therefore not included in plot list.

Conclusion

In this paper, we explored spatial query localization applicability to several scenarios. Simulations experiments have shown how not line of sight situations and intrinsic error from the distance measurements incurs additional, alternative localization results or makes certain scenario not localizable. In addition, one can note that there is a critical density, after which localization improvement is much more gradual.

Intuitively, one would expect that localization accuracy would improve as the network density increases. This is because increasing network density, and subsequently the number of neighbors for each node with unknown location adds more constraints to the spatial query solution. After some critical density, the effect of density on location accuracy becomes less apparent.

From the known localization algorithms specifically proposed for sensor networks, although algorithms developed independently, they share a common structure:

1. Determine the distances between unknowns and anchor nodes.
2. Derive for each node a position from its anchor distances.
3. Optionally, refine the node positions using information about the range to, and positions of, neighboring nodes.

Phase one, often is implemented as Sum-dist, DV-hop, and Euclidean algorithms, and phase as Lateration, Min-max or similar algorithm (Koen Langendoen, Niels Reijers, 2003). However, these algorithms always require at least three known anchors and rigid distance graph to determine network nodes locations.

Therefore, presented network objects localization spatial methods gives a good reason to pay special attention to localization methods based on scene analysis, allowing determining the position of objects that are fundamentally not localizable using other methods. Especially promising are scene analysis methods, based on the combination of the distance graphs with an area map. This option allows using standard maps, car navigation systems are usually equipped with, as well as the standard means of communication, supplemented by distance meter. At the same time offered the option of implementing the described embodiment, based on the spatial queries, allowing solving the problem of high computational complexity, typical for scene analysis methods. All this, with the help of the scenes analysis, allows transferring the issue of objects localization from theoretical considerations into practical implementation.

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