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Fundamental Metrics for Wireless Sensor Networks localization

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ABSTRACT

During the last decade, Localization in wireless sensor networks (WSNs) is a broad topic that has received considerable attention from the research community. The approaches suggested to estimate location are implemented with different concepts, functionalities, scopes and technologies. This paper introduces a methodological approach to the evaluation of localization algorithms and contains a discussion of evaluation criteria and performance metrics followed by statistical/ empirical simulation models and metrics that affect the performance of the algorithms and hence their assessment. The major contribution of this paper is to analyze and identify relevant metrics to compare different approaches on the evaluation of localization schemes.

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1. INTRODUCTION

A Wireless Sensor Network (WSN) is formed by hundreds of small, low-cost nodes which have limitations in memory, energy, and processing capacity [1]. In this type of networks, one of the main problems is to locate each node. The vision of many researchers is to create smart environments, controlled through planned or ad-hoc deployment of a potentially large set of sensor nodes, each with transceivers for wireless, short-range communication, capable of detecting environment conditions such as temperature, movement, light, acoustic events or the presence of certain objects. WSN will enable fine-grained observation and control of the physical world. The futuristic scenario in sensor networks appears in large numbers of unattended autonomous nodes which operate in a dynamic environment. This kind of sensor will be able to organize itself. It will be aware of its physical position.

The sensor nodes will carry out dynamic tasks in a distributed form, very frequently confronting change in the topology network and failures in the network nodes due to the lack of power, physical damage or environmental interferences. These nodes will report environment events like temperature, pressure, humidity, vehicular movement, noise levels, lighting conditions, the presence or absence of certain kinds of objects, acoustic events, and mechanical stress levels on attached objects, and so on. We can say that localization will act as a bridge between the virtual and physical world [2]. Evaluating the relative performance of localization algorithms is important for researchers, either when validating a new algorithm against the previous state of the art, or when choosing existing algorithms which best fit the requirements of a given WSN application. However, there is a lack of unification in the WSN field in terms of localization algorithm evaluation and comparison. In addition, no standard methodology exists to take an algorithm through modeling, simulation and emulation stages, and into real deployment. As a result it can be hard to quantify exactly how and under what circumstances one algorithm is better than another. Moreover, deciding what performance criteria localization algorithms are to be compared or evaluated against is important for the success of the resulting implementation given that different applications will have differing needs. Since localization algorithms are expected to be used in real applications, it is not conclusive to verify their performance in simulation only.

2. LMPORTANCE OF LOCALIZATION

Sensors are used for gathering environmental data such as temperature, pressure, humidity, radiosity. The collected data assist in predicting likely occurrence of events such as bush fire, radio-active leaks, failures in structures, and many other impending disasters including earthquakes, floods, and weather changes. Early prediction of such events helps in planning adequate response system that may either prevent those events or mitigate the consequential damages. The response system should have the ability to extract context from the gathered sensory data if it were to predict the events correctly and operate at the expected level of efficiency. A context is defined by ambiences among which location (both spatial and temporal) is the most critical ingredient [3].

WSNs with sensing capabilities can gather vital security-related metrics such as radio communication, signs of accelerated activities, or vigorous movements in an area to aid in developing a security response and advanced warning system. But these sensed metrics are useless unless they are accompanied by corresponding location information. Although location information can be fed manually, it may not be feasible in a large deployment area. So it is necessary to develop a system that can automatically update location information of all nodes in the deployment area.

Navigation and vehicle tracking is another area where the use of WSNs is found to be extremely useful. Vehicle tracking with autonomous interception mechanism can be deployed in an outdoor area. It senses entry as well as movement of an offending evader in the area. A cooperative mobile agent may be dispatched for intercepting the evader as soon it gets detected before any damage is done. The successful realization of such a tracking and interception system is dependent on the location information in two tiers. First, the sensors must be able to detect the evader as soon as it enters the area and be able to track it while the evader continues to move around in the area under observation. Second, the update on the location information of the evader must be routed to intercepting mobile agent so long as it continues to pursue the evader. Apart from context-related computations in application level tasks discussed above, the knowledge of sensor locations is also essential for network level operations in WSNs.

In this paper, we attempt to review the existing literature with emphasis on the metric of sensor localization techniques.

3. METRICS IN LOCALIZATION

For the different ways of estimating location information, we have to name metrics to distinguish the similarities and divergences between different approaches. In this section we present the most typical metrics to classify different techniques.

3.1. Localization Accuracy

The most important metric for localization techniques is accuracy and precision [3]. We can define accuracy as how much the estimated position deviated from the true position is. Precision indicates how often we expect to get at least the given accuracy for example 20 cm accuracy across 95% of the time.

Accuracy of estimated locations obtained from various localization schemes. According to the localization process, the sources of localization error may include physical sources, localization algorithms, and refinement process [4, 5]. The errors due to physical sources are represented by wide range of noises and quantization losses. Ranging techniques vary from ultrasonic to radio, and to laser, etc. A summary on the range accuracy was presented in [6]. The most attractive among simulations are the ones with low-cost and ready-to-use features like time of arrival (TOA) of ultrasonic signal and radio signal strength (RSS) or radio signal strength indication (RSSI). The only concern about these techniques is that they produce highly noisy measurements and are over sensitive to environmental effects [7].

Localization algorithms encounter two types of error sources. One is system error, which comes from the localization algorithms themselves that work with underlying assumption of accurate range measurement or range-free features. The other source of error is related to connectivity and the fraction of nodes serving as anchors. The last two metrics have significant impacts on the performance of localization algorithms. The effect of system error becomes manageable, when both distance and angle with orientation are available. But the size and the cost of the hardware capable of measuring distance and angle prevent such system from implementation, especially for dense WSNs [8].

It is of particular interest to study the impact of range errors on the performance of localization algorithms, because range errors are inherent to WSNs employing simple and low-cost range measurement hardware. According to the empirical study on the impact of range errors on multihop localizations [9], high density and Gaussian noises are the two prerequisites for the noisy disk model to work. The study also suggests statistical approaches fix the problem resulted from range errors.

Cramer–Rao lower bound (CRLB) is commonly adopted in the error analysis of the localization schemes. It is a lower bound on the variance of the estimator that estimates the locations. Given the knowledge on the distribution of measurements, it is shown in [10–12] that the bound on the localization error can be obtained through calculating the CRLB. Therefore, the localization schemes are able to evaluate their performances by comparing the localization accuracy with the corresponding CRLB.

3.2. Scalability and Autonomy

A location-sensing system may be developed to find tags, objects, people, assets or animals on the surface of the earth, in a city, buildings or in a single room. We can classify the location-sensing systems in a rough manner into systems which work outside and inside areas [13]. This classification lets us identify special problems that the system will have to address such as diffraction, multipath and interference problems. Besides, the number of objects in the system plays an important role because every system has its own limit to find a number of objects per time with a given amount of infrastructure per area. An important consideration in the location-sensing systems is to select the best-fit radio frequency technology, since the increase of the objects to be localized in the network, demands for more communication and that can congest the channel if the threshold is exceeded. This characteristic is also known as responsiveness or sampling [2] and is defined as how quickly the location system outputs the location information.

The degree of autonomy has some of the most significant consequences in the system design; this metric is closely related to the scalability of the system. We can say that a system has high autonomy when there is little or no human intervention necessary to operate the system and the nodes act as totally independent entities [14]. The autonomy of a system is achieved through the use of extensive and sophisticated internal processes that make their own coordination possible. The self-coordination of the network is important because it is closely related to the possibility to extend the system. We classify the autonomy and self-organization into centralized or distributed system in a rough manner, that means, the system could or may not require the help of a central entity to monitor and control the activities of the elements.

3.3. Communication Costs

We can evaluate the cost of the location sensing system in different ways; including cost in terms of time spend for installation, money, computational effort or energy [15]. The time cost of the system includes factors such as the length of the installation process and the needs for system administration. The capital cost of the system can be directly mapped to the money needed to set up and operate the system such as the amount of infrastructure installed, the salaries of support personnel and the maintenance of the system.

The computational cost is a crucial metric and is closely related to the location algorithm of the system. It determines the architecture of the location-sensing system which can be organized either in a centralized or a distributed manner [16]. The centralized systems control and monitor the system functions with the help of a central engine. The systems where the location algorithm is put into each node of the network to compute its own position is called decentralized or distributed system. As energy efficiency is critical to WSNs, it is necessary to consider the computation and communication costs of the localization process in the evaluation of localization schemes.

Centralized algorithms like the SDP or MDS-MAP [17] demand range measurements from all the nodes. This is expensive in terms of forwarding the measurements to the processing point and solving the high-dimension matrix. Distributed algorithms, on the other hand, require collaborations among neighboring nodes to some extent. In particular, the multihop localization faces the trade-off between the communication cost on propagating the anchor locations and the degree of accuracy. For the refinement on location estimations, the number of iterations is apparently in the center of the trade-off between the energy consumption for refinement of localization results and the degree of accuracy achievable through refining.

3.4. Network and Anchors Density

It is worth noticing that localization algorithms always require a certain level of connectivity [18]. So, localization schemes are based on connectivity, range measurements, angle information, or any combinations thereof. The discussions on the localization algorithms suggest that dense networks lead to better localization performance. However, a dense network does not necessarily guarantee high accuracy in location estimations. The density of the network is usually represented by the number of nodes within an area or the radio range of nodes. The anchor-based localization schemes, aiming at providing absolute locations, require a high density of anchors to ensure low level of localization errors [19].

4. CONCLUSION

In this paper we presented, different methods to implement localization and the main metrics that a system designer has to take into account to understand and value the different location-sensing systems.

In the simulation results of various localization schemes, where the accuracy was examined through the trade-offs between accuracy and measurement performance, percentage of anchors, deployment of anchors, density of non anchors, etc. Besides randomly generated networks, a typical deployment of nodes is the grid of non-anchor nodes within a particular area. The localization accuracy of a solution is usually quantified using the average Euclidean distance between the estimated locations and the true locations normalized to the radio range or other system metrics. For mobility-assisted localization, the effect of node density is not as important as in static localization scenarios. In addition, communication/ computation cost may not be of same importance to the off-line simulations as to the real implementations.

REFERENCES

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “A survey on sensor networks” IEEE Communications Magazine, vol. 40, no. 8, pp. 102–114, 2002.

[2] Estrin, D., Culler, D., Pister, K., Sukhatme, G.: Connecting the physical world with pervasive networks. Pervasive Computing, IEEE 1 (2002) 59-69

[3] Hightower, J., Borriello, G.: Location systems for ubiquitous computing. Computer 34 (2001) 57-66

[4] S. Slijepcevic, S. Megerian, and M. Potkonjak. Location errors in wireless embedded sensor networks: sources, models, and effects on applications. *SIGMOBILE Mobile Computing Communications Review*, 6(3):67–78, 2002.

[5] H. A. Oliveira, E. F. Nakamura, A. A. F. Loureiro, and A. Boukerche. Error analysis of localization systems for sensor networks, *GIS 2005: The 13th Annual ACMInternationalWorkshop on Geographic Information Systems*, pages 71–78, 2005.

[6] A. Savvides,W. Garber, R. Moses, and M. Srivastava. An analysis of error inducing parameters in multihop sensor node localization. *IEEE Transactions Mobile Computing*, 4(6):567–577, Nov.-Dec. 2005.

[7] G. Mao, B. Fidan, and B. Anderson, “Wireless sensor network localization techniques,” Computer Networks, vol. 51, no. 10, pp. 2529-2553, Jul. 2007.

[8] L. Wang and Q. Xu, “GPS-Free Localization Algorithm for Wireless Sensor Networks,” Sensors, vol. 10, no. 6, pp. 5899-5926, Jun. 2010.

[9] K. Whitehouse, C. Karlof, A. Woo, F. Jiang, and D. Culler. The effects of ranging noise on multihop localization: an empirical study. *IPSN 2005: The 4th International Symposium on Information Processing in Sensor Networks*, pages 73–80, 2005.

[10] N. Patwari, I. A.O. Hero, M. Perkins, N. Correal, and R. O’Dea. Relative location estimation in wireless sensor networks. *IEEE Trans. Signal Processing* , 51(8):2137–2148, 2003.

[11] C. Chang and A. Sahai. Estimation bounds for localization. *SECON 2004: The 1st IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks*, pages 415–424, 2004.

[12] S. Venkatesh and R. M. Buehrer. Multiple-access insights from bounds on sensor localization *Pervasive Mobile Computing*, 4(1): 33–61, 2008.

[13] M. Jadliwala, S. J. Upadhyaya, and J.-P. Hubaux, “Secure Distance-Based Localization in the Presence of Cheating Beacon Nodes,” IEEE Transactions on Mobile Computing, vol. 9, no. 6, pp. 810-823, Jun. 2010..

[14] J. Wang, R. K. Ghosh, and S. K. Das, “A survey on sensor localization,” vol. 8, no. 14, pp. 2-11, 2010.

[15] J. Rezazadeh, M. Moradi, A. S. Ismail," Efficient localization via Middle-node cooperation in wireless sensor networks" In International Conference on Electrical, Control and Computer Engineering (INECCE, 2011), pp. 410-415, 2011.

[16] Z. Yang and Y. Liu, “Quality of Trilateration: Confidence-Based Iterative Localization,” IEEE Transactions on Parallel and Distributed Systems, vol. 21, no. 5, pp. 631-640, May. 2010.

[17] S. Y.Ruml, “Improved MDS-based localization”. In INFOCOM, pp. 2640-2651, 2004.

[18] J. Jeong, S. Guo, T. He, and D. Du, “APL: Autonomous Passive Localization for Wireless Sensors Deployed in Road Networks,” 2008 IEEE INFOCOM - The 27th Conference on Computer Communications, pp. 583-591, Apr. 2008..

[19] N. Bulusu, J. Heidemann, D. Estrin, and T. Tran. Self-configuring localization systems: Design and experimental evaluation. *Transactions on Embedded Computing Systems*, 3(1):24–60, 2004.