

Thesis Overview:

Target Tracking in Wireless Sensor Networks

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A Wireless Sensor Network (WSN) consists of a group of tiny devices called sensors that communicate through wireless links. Sensors are used to collect data about some parameters and send the collected data for further processing to a designated station. The designated station is often called *command and control center* (CCC), *fusion center* (FC), or sink. Sensors forward the collected data to their leaders or cluster heads, which in turn send it to the centralized station. There are many applications of a WSN such as environmental monitoring, raising alarms for fires in forests and multi-storied buildings, monitoring habitats of wild animals, monitoring children in a kindergarten, support system in play grounds, monitoring indoor patients in a hospital, precision agriculture, detection of infiltration along international boundaries, tracking an object or a target, etc.

Motivation

Tracking an object or a target is an important application of a WSN and needs a special consideration. Target tracking is needed in surveillance, guidance, and navigation of moving objects or vehicles. A network of connected vehicles in a smart city may track vehicles for guiding them to appropriate routes towards their destination and help them in case of collisions and emergencies. Targets can be human beings, medical vehicles, autonomous vehicles, wild animals, drones, military aircrafts, ships, submarines, etc. Target tracking has civilian as well as military applications.

Sensors that are part of a WSN possess limited computational, communication, and storage capabilities. In a region of interest, sensors are spread in bulk. Sensors should not communicate directly to other sensors that are lying outside their ranges. Instead, sensors should form clusters and individual sensors should communicate through their cluster leaders to conserve energy. The topology of a WSN may change if some of the sensors move from their positions. The transmission range of sensors is limited, and therefore, communication to the CCC or FC may involve multiple hops. Sensors are operated through batteries and depletion of the battery power may render them useless if not recharged. The unique characteristics of a WSN make tracking a target a challenging task.

Objectives of Thesis

The major focus of the thesis is to design schemes or protocols for target tracking in a WSN. For tracking a target, one needs to compute the location of the target periodically using locations of sensors in its vicinity and measurements received from sensors. All sensors might not be equipped with positioning devices, therefore, locations of sensors used to estimate the position of the object might not be highly accurate. Consequently, devising a scheme for accurately estimating the successive locations of an object is an important issue in tracking a target. Further, the process of tracking should not incur a long duration i.e. it should be fast enough so that appropriate decisions are taken at the centralized stations in a timely manner. Consequently, tracking the object as fast as possible forms another major issue. The design of a protocol to address issues of accuracy and mitigating delays in tracking a target is the first objective of the thesis.

The trajectory of a target can be constructed connecting consecutive points lying on the path followed by the target. Most of the moving objects such as aeroplanes and vehicles follow a trajectory that is often smooth. Using cubic spline, one can smooth out the trajectory of the target and extend it to predict the next location of the target provided that a set of previous locations of the target is known. The prediction can be used to activate sensors in advance for tracking the target. Activating sensors in the vicinity of the next location of the target enables one to reduce the

energy consumption as compared to the scenario where most of the sensors in a WSN are active. Designing a protocol to study the impact of cubic splines on tracking a target is the second objective of the thesis.

Sensors that compute the distance estimates might not have enough resources to communicate with the centralized station directly. Therefore, sensors send their distance estimates to a neighboring node that acts as a cluster leader. The cluster leader accumulates the distance estimates from sensors in its vicinity. It computes the location of the target and sends it to the centralized station. The centralized station keeps track of the locations sent by the cluster leaders for tracking the movement of the target. There should be a scheme for organizing a WSN into clusters and selecting cluster leaders in such a fashion so that the energy consumption, distances among leaders and sink, and distances among leaders and members of respective clusters are optimized. To examine the impact of an optimization based leader selection scheme on tracking a target is the third objective of the thesis.

The speed of a target might not be constant i.e. it may vary with time. If the speed of the target increases, it is likely that it may rapidly become out of range from the nodes of the cluster. Therefore, the range of the cluster should be increased so that more number of sensors are able to detect the target and estimate its location. If it moves slower, the number of sensors that is more than a required threshold might be detecting and observing the target. In the latter case, the number of sensors monitoring its movement can be reduced to mitigate the energy consumption. Designing a scheme that takes into account varying speed of the target is the fourth objective of the thesis.

For tracking a target, sensors in the vicinity of the target need to be activated. As the target moves, its vicinity changes, therefore, sensors in a WSN should be activated in the neighborhood of the next location of the target. The next location of the target can be predicted based on its previous location and the velocity. For prediction of the next location of the target, one may use a technique such as the Kalman filter. On the other hand, leaders of clusters along the trajectory of the target should be selected based on their leadership credentials and there should be a mechanism for delegating the leadership to the newly selected leader by the old leader of the cluster. Designing a protocol to address the issue of leader delegation is the fifth objective of the thesis.

Contributions of Thesis

The problem of target tracking in a WSN is a challenging task. In this thesis, we designed protocols and schemes for target tracking in a WSN. The contributions made in the thesis are as follows.

- We proposed a protocol for tracking an object in a WSN. The protocol consists of two phases. In the first phase, sensors estimate the distance of the object and send it to their cluster leader. In second phase, the cluster leader accumulates the distance estimates, selects a set of estimates, and computes the location of the object using the locations of the estimator nodes and the estimated distances.
- We proposed a cubic spline based protocol for tracking a target in a WSN. The proposed protocol operates in two phases: estimate and predict. In the first phase, the cluster head computes the location of the target using distance estimates received from the neighboring sensors. In the second phase, the next location of the target is predicted using its previous locations. During the prediction phase, cubic splines are used to smooth out the trajectory of the target.
- We presented a scheme for selection of cluster leaders which is energy efficient. The scheme is based on the combination of the k -means clustering and Artificial Bee Colony (ABC) optimization. The clusters were created using k -means clustering approach and the optimal cluster leader was chosen using ABC optimization. The objective function for optimization is composed of the remaining energies of sensors, distance among cluster leaders and sink, and distance among the leader and members of a cluster.
- We proposed a dynamic cluster formation based target tracking scheme for WSN. A model for prediction of the location of the target together with an adaptive clustering scheme is presented. The range of the cluster adapts to the speed of the target. Also, we described how to select an efficient cluster head so that the power consumption inside a WSN is minimized. The effectiveness of the proposed scheme is evaluated by carrying out extensive simulations.
- We proposed a sensor activation scheme for tracking a target in a WSN. The next location of the target is predicted based on its previous location and the velocity using Kalman filter. The leaders of clusters along the trajectory of the target are selected based on their remaining energies and their distances from the target. A mechanism for delegating the leadership to the newly selected leader by the old leader of the cluster is presented.

During the period of carrying out the work related to the thesis, we came across many research directions that can be explored in future. Some of them are described as follows.

- Sensors that detect the target estimate the distance to the target and send these distance estimates to the cluster head for computing the location of the target. It is assumed that the target is moving and the sensors sending their distance estimates are static. It may also happen that sensors may move from their positions. Devising a scheme for tracking a target in such a situation forms a direction for future work.
- We assumed the distribution of sensors in the network to be uniform. There might be a WSN where the distribution of sensors is non-uniform i.e. some portion of the network may have high densities while others portions have low densities of sensors. The design of a tracking scheme in a WSN with variable densities of sensors forms a direction for the future work.

Further, one may explore the directions where moving vehicles or a fleet of vehicles may offer to be tracked in a multiple target tracking environment such that energy spent during the process of tracking is optimized.

Publications Related to Thesis

1. T. Ahmad, A.M. Abbas, "ObTraP: An Object Tracking Protocol for Wireless Sensor Networks", *Proceedings of 2nd IEEE International Conference on Computing, Communications, and Automation (ICCCA)*, pp. 1-6, Noida, India, April 29-30, 2016.
2. T. Ahmad, A.M. Abbas, "CSplineT: A Cubic Spline Based Target Tracking Protocol for Wireless Sensor Networks", *Proceedings of IEEE International Conference on Information Technology (InCITe)*, pp. 1-6, Noida, India, October 6-7, 2016.
3. T. Ahmad, A.M. Abbas, "EEAC: An Energy Efficient Adaptive Cluster based Target Tracking in Wireless Sensor Networks", *Journal of Interdisciplinary Mathematics*, Taylor and Francis, vol. 23, no. 2, pp. 379-392, May 2020.
4. T. Ahmad, "EnergyEC: An Artificial Bee Colony Optimization Based Energy Efficient Cluster Leader Selection for Wireless Sensor Networks", *Journal of Information and Optimization Sciences*, Taylor and Francis, vol. 41, no. 2, pp. 587-597, April 2020.
5. T. Ahmad, A.M. Abbas, "LeDA: Leadership Delegation Based Activation Scheme for Target Tracking in Wireless Sensor Networks", *International Journal of Information Technology*, Springer, <https://doi.org/10.1007/s41870-021-00616-y>.

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