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Research Article

Energy Efficient Mobility Prediction based Localization Algorithm for Mobile Sensor Networks

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Abstract: Aim of study is to develop energy efficient mobility prediction based localization algorithm for mobile sensor networks. Mobile sensors are being deployed in the environment like underwater sea monitoring, where they can move to any location to meet coverage requirements. Sensor networks choose to follow data centric approach to track the exact location of the nodes. Location information should be identified for application tasks and network operations. Novel localization algorithms need to be developed for mobile sensor networks with high accuracy and minimal energy consumption. The proposed localization algorithm for mobile sensor networks uses the mobility prediction localization and Mobility Prediction Localization (MPL) algorithm with Maximum Likelihood Estimation (MLE) technique for low and high accuracy respectively. The performance analysis shows that proposed MPL and MPL along with MLE achieve accuracy above 95.5% in the simulated environment. This study also analyses the number of anchor nodes to be deployed to achieve desired level of accuracy. The proposed algorithm uses minimal number of nodes for tracking while rest are in sleep mode for energy saving, thereby increasing lifetime of the nodes.

Keywords: Localization, maximum likelihood estimation, mobility aware, mobility prediction

INTRODUCTION

Wireless sensor nodes are tiny, low-power networked sensing devices with limited sensing, processing and communicating capabilities. These nodes are deployed in remote areas both densely and randomly for sensing and monitoring environmental changes. A new emerging trend for wireless sensor networks called mobile sensor networks is being used in the environments like underwater sea monitoring, detecting seismic activities, navigating ships and also in tracking of objects where sensors can move around in the monitoring area in any direction at any speed. These applications are strictly based on the location, because without location information processing of data will be meaningless. Another issue regarding mobile sensor network is that the nodes are identified only through the location address as they do not have global address. Locating these nodes plays a major role in reporting events, assisting in group and location based querying confined to a particular part of the sensor network. Even though localization problem in static wireless sensor network is solved, those methods cannot be applied directly to mobile sensor networks due to nodes mobility and dramatic topological changes. Generally, node localization is divided into self-node localization and single/multiple target node localization. In self-node localization, each node identifies itself by using location aware devices like Global Positioning System (GPS). But main disadvantage of GPS system is high cost, high location error in the indoor environments, energy consumption of GPS module and increase in the size of wireless sensor nodes. More than this, deployment of sensor nodes with individual GPS increases the overall cost and reduces the lifetime of nodes. To reduce the cost of network and the energy consumption of nodes, only beacon nodes or anchor nodes are deployed with the GPS module. The rest of the nodes can identify their location from the anchor nodes through localization method. Nodes without location aware device uses range based or range free localization for self-localization.

Novel localization algorithms need to be developed for mobile sensor networks with high accuracy and minimal energy consumption. The proposed localization algorithm for mobile sensor networks uses the mobility prediction based localization algorithm with maximum likelihood estimation technique for high accuracy and low computation by using minimal number of nodes involved in tracking, the rest of the nodes are put into sleep state for energy saving.

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LITERATURE REVIEW

This section reviews about the related work done so for in this localization problem. Benkhelifa and Moussaoui (2012) proposed speed and direction prediction based on localization. Anchor node travels with predefined trajectory and broadcasts its current location to the nearby sensors. Based on the received location information, the node predicts the speed and direction to the actual position. But to create mobile anchor node, the travelling path need to be studied which make this approach very complex in real world. Guangcheng *et al*. (2009) proposed a mobility prediction algorithm which coordinates sink and sensor node to meet different level of accuracy. The proposed model is optimized based on vehicular mobility. The imprecision of collected mobility may trigger wrong update procedure. The imprecision of mobile velocity has to be handled before triggering the respective location update algorithm.

Bishop and Pathirana (2005) uses direction of arrival along with received signal strength for increasing the accuracy of location estimations. Mobile node position was calculated using a Robust Extended Kalman Filter (REKF) and the estimate of the position is used track with less complexity. Direction of arrival requires new hardware and processing of data in single point may create single point of failure. Yi *et al*. (2013) proposed topological coordinate based tracking and prediction to track the object based on the topological coordinate domain. It uses principal component based TPMs to increases the accuracy. Even though this algorithm uses logical coordinates to localize, it requires the topological map to be known in advance. Zhong *et al*. (2011) and Bhuvaneswari *et al*. (2012) proposed scalable localization with mobility prediction for underwater sensor networks. Every node predicts its future mobility pattern based on known location information. Prediction of advance location from the previous location alone will not give more accuracy.

Park and Ha (2008) have proposed localization based on mobility trajectory, RSSI and computer vision based localization. This proposed algorithm outperforms mobility trail and RSSI based localization. Srinath (2006) proposed an algorithm that uses single mobile beacon equipped with a GPS. The mobile beacon moves with predefined speed to broadcast the current location information. In both approaches, mobile trajectory requires the travelling path to be known in advance. Baoli and Fengqi (2010) proposed an event triggered localization algorithm based on radio frequency fingerprint and received signal strength. The proposed algorithm shows that it is low cost localization with high accuracy. Yuan *et al*. (2009) proposed a received signal strength based localization algorithm. They have used a mobile anchor node which moves in the sensor area and thereby broadcast its current location. Based on the received location information, other nodes will calculate their information. Since received signal strength is prone to errors, this algorithm may trigger event based updates frequently. Shigeng *et al*. (2010) proposed an algorithm that uses estimated location information to improve the accuracy and stated that their algorithm performs well, even when the nodes are subjected to high mobility. This algorithm predicts the advance location based on the previous location. But still lacks in predicting the direction of movement. Sangho *et al*. (2011) made a survey on identifying path for mobile beacon and the deployment of the beacons. This proposed method reduces the number of static beacons as needed. But identifying the path for mobile beacon node to move in the sense area is introducing new problem.

The proposed algorithm uses mobile prediction logic for low accuracy applications and mobile prediction logic with maximum likelihood estimation for high accuracy applications. Hence it automatically adjusts the localization accuracy based on the application requirements. This makes the proposed algorithm to optimize the energy consumption, communication cost and sampling.

MATERIALS AND METHODS

The problem with existing work is constant number of samples are used for localization, periodic location updates to the neighbouring nodes, increased network traffic for frequent location updates, choosing nodes for target localization. In some cases, instead of static anchor nodes, mobile anchor nodes are proposed. But this mobile anchor nodes will create another problem called path identification. If this single mobile anchor node fails, then entire accumulated data will be waste.

To address these problems, the proposed work uses mobility aware based updates for location updates and static anchor nodes are for broadcasting location information. The proposed algorithm concentrates on localization in non-line of sight, scheduling the sensor node for location updates, optimization for accuracy and energy consumption and cooperative node localization. To accommodate for extremely low/high speeds, the proposed algorithm uses average mobility speed and the imprecision of measured average mobile velocity is handled through fuzzy logic. Based on mobile velocity, the location information is updated. The average mobility velocity is given to fuzzifier to obtain membership values. Based on the membership values, different level of location updates is triggered. All sensor nodes periodically update its local identifier, remaining energy, average mobile velocity and direction of movement. These location updates are maintained in the anchor node for specific time. If the sensor doesn't update its location information for specific time then it is assumed to have moved out of its coverage. Figure 1 shows the location update (including local identifier, remaining energy, average mobile velocity and direction of movement) of sensor nodes to the anchor nodes. All the nodes update its device identifier, remaining energy and average mobile

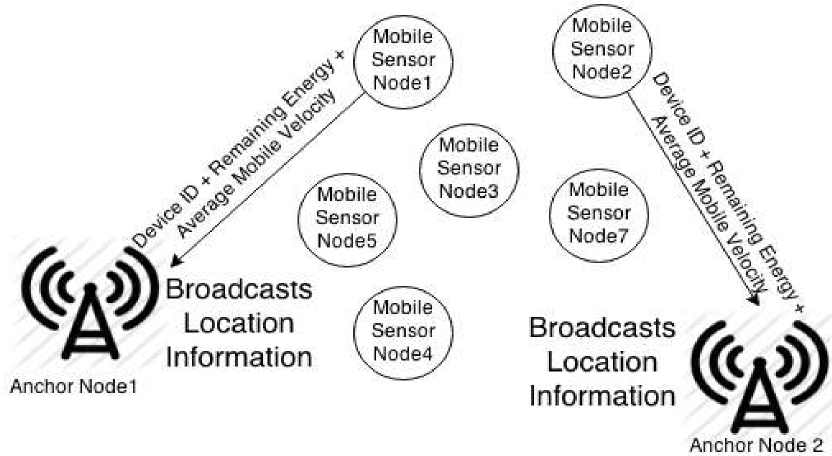

Fig. 1: Location update of sensor nodes

velocity to the nearest anchor nodes based on the mobile speed. In case of high mobility, the mobile sensor nodes update the information frequently. The anchor nodes calculate the approximate location of the mobile sensor nodes using average mobile velocity and direction of movement.

Proposed algorithm for applications that requires low accuracy:

Step 1: Receive the location broadcast from Anchor nodes and set mobile velocity threshold for low, average and high mobility respectively.

Step 2: Get mobile velocity for t seconds in Tn intervals.

Step 3: Apply fuzzy membership function on mobile velocity for triggering corresponding updates that are aware of mobility.

Step 4: If Mobile velocity has high membership in low mobility.

Step 5: Calculate mobile velocity, Direction of movement and new position of the nodes:

- Calculate mobile velocity $V = \frac{\sqrt{(x_i^2 + x_{i-1}^2) + (y_i^2 + y_{i-1}^2)}}{t_i - t_{i-1}}$
- Direction of movement $\varphi = \cos^{-1} \frac{x_i - x_{i-1}}{\sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2}}$

  Calculate new position $x_{i+1} = x_i + vt\cos\theta$, $y_{i+1} = y_i + vt\sin\theta$

Step 6: Update the new location information (Average mobile velocity, Direction of movement, Predicted location) at long interval.

Step 7: Else If Mobile velocity has high membership in low mobility, then calculate mobile velocity, Direction of movement and new position of the nodes.

- Calculate mobile velocity $V = \frac{\sqrt{(x_i^2 + x_{i-1}^2) + (y_i^2 + y_{i-1}^2)}}{t_i - t_{i-1}}$
- Direction of movement $\varphi = \cos^{-1} \frac{x_i - x_{i-1}}{\sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2}}$
- Calculate new position, $x_{i+1} = x_i + vt\cos\theta$, $y_{i+1} = y_i + vt\sin\theta$

Update the new location information (Average mobile velocity, Direction of movement, Predicted location) at medium interval.

Step 8: Else if node moves in high mobility then calculate mobile velocity, Direction of movement and new position of the nodes. Calculate mobile velocity, Direction of movement and Calculate new position. Update the new location information (Average mobile velocity, Direction of movement, Predicted location) at frequent interval.

Figure 2 shows the working flow of the proposed algorithm in detail. When an application or other sensor nodes wants to locate the target node, it simply sends the page request to the nearest anchor node. Anchor nodes periodically maintain the sensor nodes information. It collects average mobility and direction of movement from the sensor nodes. With this collected information it calculates the predicted information. But this predicted information may not have exact location of target node.

If the application requires exact location of the target node then the anchor node triggers the triangulation method to find the exact location of target node. The entire localization process is controlled by control node which is near to anchor node. The anchor node (Fig. 3) selects three sensor nodes (which have high remaining energy) approximately near to the target

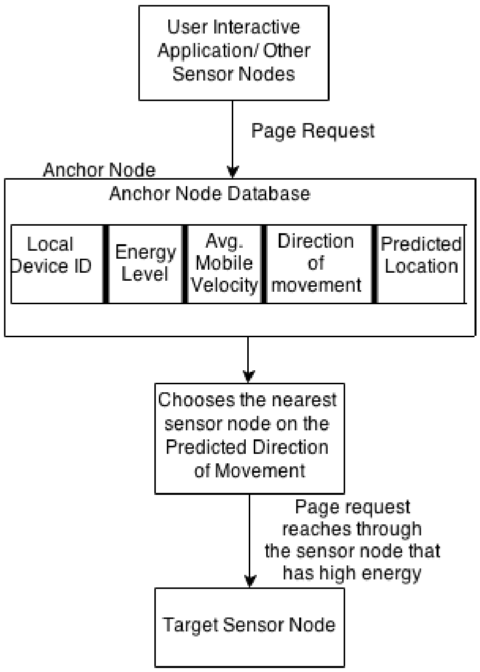

Fig. 2: Working flow of target localization algorithm

node based on the predicted location and direction of movement and then forwards to the control node.

The control node forwards this page request to the selected three nodes. That selected node does the triangulation based localization to obtain exact location information of the target node. The exact location information from the three nodes is send independently to the control node. The control node aggregates the data into single packet and forwards to the anchor node. Finally anchor node calculates the actual location using maximum likelihood estimation Eq. (1) and gives back the response for page request of the target node to the application or to other sensor node which has requested for the location of the target node.

Maximum likelihood estimation: Assume that mobile sensor nodes are distributed with some unknown mean and variance. The MLE estimates the mean and variance using the known location information of anchor nodes. Assume that sensors nodes are distributed randomly and they have joint density function. To use the method of maximum likelihood, joint density function has to be specified. Here x indicates the mobile sensor nodes and θ indicates the likelihood. The joint density function is given by:

$$f(x1, x2, x3, \ldots, xn) = f(x1, x2, x3, \ldots, xn \mid \theta)$$

Then likelihood of θ is:

$$liklihood(\theta) = f(x1, x2, x3, \ldots, xn \mid \theta)$$

The MLE of is θ that value of θ that maximizes the likelihood of θ:

$$liklihood(\theta) = \prod_{i=1}^{n} f(x_i \mid \theta) \quad (1)$$

For high accuracy demanding applications: Since the location information is updated based on the mobility, the error in mobile velocity may affect the accuracy of the algorithm. But some of the critical applications like animal monitoring require more accuracy. In such cases Anchor node receives the location information received from the sensor nodes and sends page request for the target to the nearest node which has high energy. The nearest node to the anchor node act as a control node for that localization process. The control node selects three nodes which has high energy to identify the exact information of target node. This forms the triangulation to calculate the exact position of the node. Figure 3 shows the selection of control node and triangulation

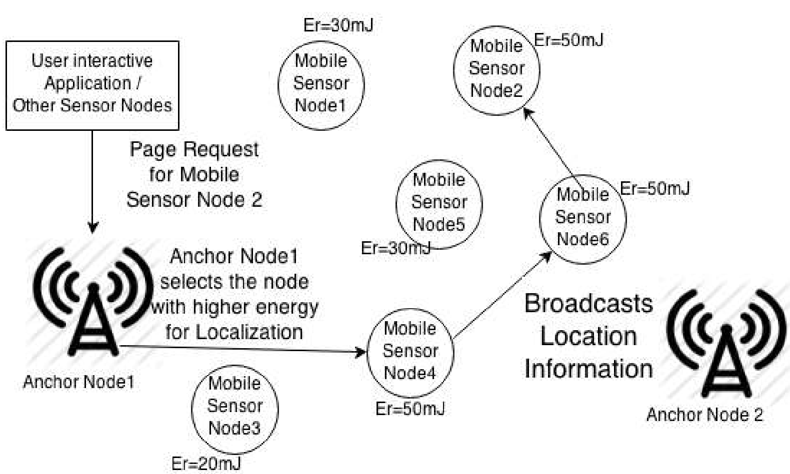

Fig. 3: Selection of nodes for target localization in high accuracy applications

method in localization. The anchor node selects mobile sensor node 7 as the control node and sensor node 7 selects sensor nodes 8, 6 and 4 for the triangulation method to find exact location of the target node using maximum likelihood estimation.

Algorithm for target localization using MLE:

- Get location update from the sensor nodes and select control node to take responsibility of localization. The control nodes select three nodes which are approximately nearest to the target node in terms predicted location and direction of movement.
- Form the triangulation to identify the exact location of the target node and the nearest nodes with high energy applies received signal strength based localization to identify the distance.
- Updates the distance of target node to anchor node and minimize the differences between the measured distance and estimated distance using Maximum Likelihood Estimation (MLE).

RESULTS AND DISCUSSION

The proposed algorithm is implemented in WSN localization simulator. Table 1 show the simulation parameter used in testing the performance of the proposed algorithm.

The proposed algorithm with varying application accuracy requirements has measured under different localization slots. Figure 4 shows the localization error of mobile prediction logic for low accuracy applications and mobile prediction logic with maximum likelihood estimation for high accuracy applications. It clearly shows that mobility prediction with MLE has high accuracy compare to MPL thereby supports for high accuracy demanding applications.

Figure 5 shows the communications cost involved in the proposed method. It shows that when number of packets increases, the accuracy also increases. Mobile prediction with MLE achieves above 99% of accuracy by sending average of 100 location identification control packets. Mobile prediction achieves 95.5% accuracy by sending average of 30 location identification control packets.

Figure 6 shows the sampling of data in mobile prediction with MLE and Mobile Prediction Logic (MPL). It clearly shows that MPL with MLE requires smaller sampling compared to MPL.

Figure 7 shows the energy consumption of MPL and MPL with MLE. Both of the proposed models consume almost similar energy to find the target node. The total energy consumed for target localization was 0.4%. But produces different level of accuracy based on the application requirements.

Table 1: Simulation parameters

Parameters	Value
Simulator	WSN localization simulator 2.0 (WSN, 2013)
Number of random anchors	15, 20, 28
Number of mobile and static sensors	322, 200
Total number of slots	30
Simulation time	150 sec
Localization algorithm	Mobility prediction logic, maximum likelihood estimation
Attack simulated	Replay attack (Wiki, 2014)
Mobility speed	0 to100 m/sec

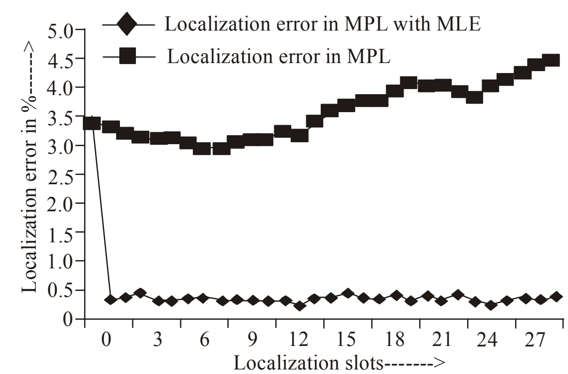

Fig. 4: Localization error of proposed algorithm

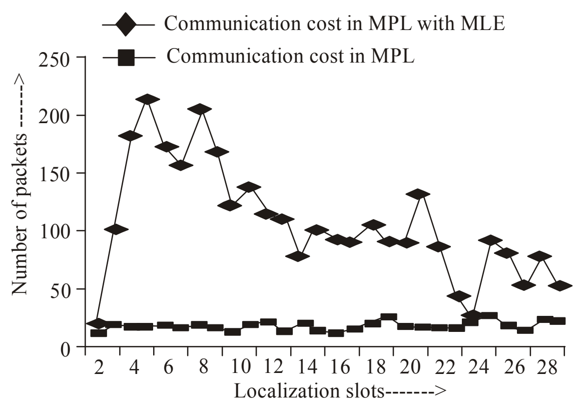

Fig. 5: Communication cost of proposed algorithm

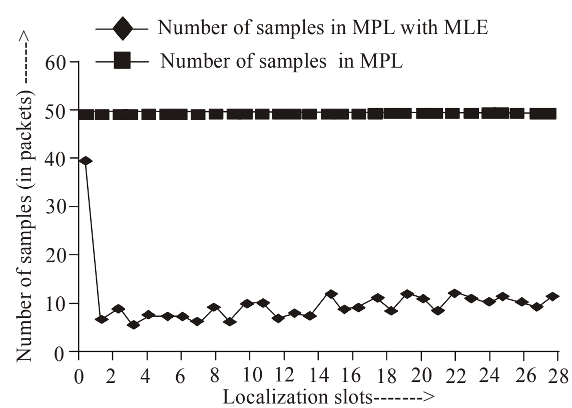

Fig. 6: Number of samples used for localization

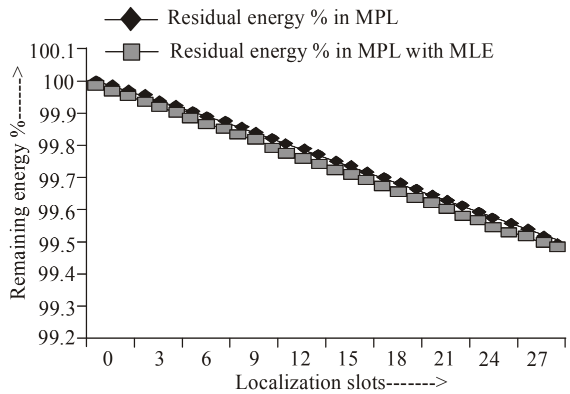

Fig. 7: Observation of remaining energy

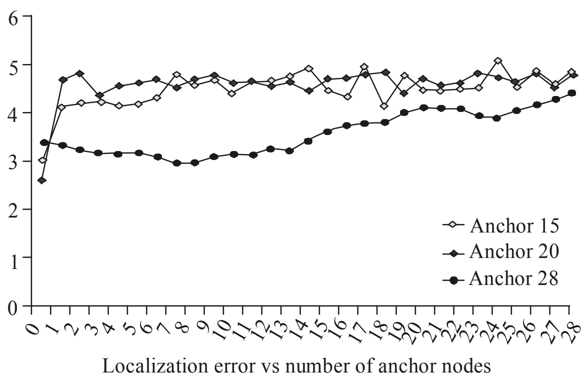

Fig. 8: Localization error with respect to the number of anchor nodes

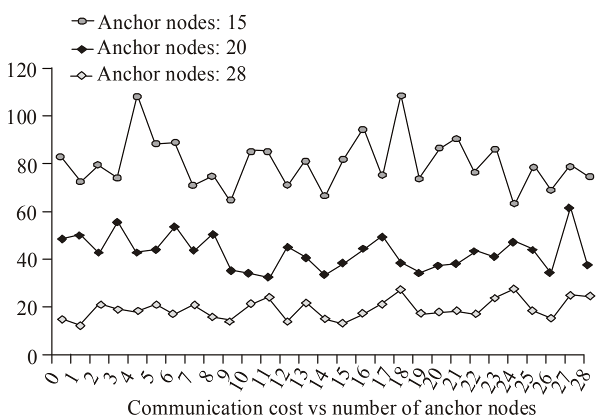

Fig. 9: Communication cost with respect to number of anchor nodes

Impact on the number of anchor nodes: Localization error and communication cost are strongly dependent on the number of anchor nodes used in the environment. If the number of anchor is high, then the accuracy also will be high. Figure 8 shows the localization error with respect to number of anchor is used. It clearly shows that accuracy of the algorithm strongly dependent on the number of anchor nodes used. The proposed algorithm achieves 95% of accuracy while the number of anchor nodes is 15. When we increase the number of anchor nodes, the localization error is being reduced. It infers that at least 3% of anchor nodes are needed for the sensor networks with density of 522 nodes.

Figure 9 shows the communication cost involved in localization with respect to the number of anchor nodes. When the number of anchor nodes increases, the proposed algorithm uses minimum number of packet for localization.

CONCLUSION

The proposed algorithm provides different accuracy level based on the application requirements. The proposed localization algorithm for mobile sensor networks uses the mobility prediction localization for low accuracy and mobility prediction based localization algorithm with maximum likelihood estimation technique for high accuracy. The proposed algorithm eliminates the flaws in the existing work including constant number of samples for localization, periodic location updates to the neighbouring nodes, increased network traffic for frequent location updates, choosing nodes for target localization. The proposed algorithm uses optimized number of samples based on the localization accuracy requirements, the locations are updated based on the mobile velocity, sensor nodes location are updated frequently only if it moves in high mobile velocity and chooses the nearest highest energy remaining sensor nodes to the target node for localization. The performance analysis shows that proposed mobility prediction localization and mobility prediction localization with maximum likelihood estimation has ~95.5, ~99% of accuracy respectively in the simulated environment respectively. The proposed algorithm uses minimal number of nodes to be involved in tracking while rest are in sleep mode for energy saving, thereby increasing the lifetime of the sensor nodes.

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