International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 3 (2015) pp. 7659-7672

http://www.ripublication.com

Two-Way Energy Efficient Localization Scheme for Mobile Wireless Sensor Networks

Amit Kumar Bindal[1], Anuj Jain[2], Dr. Devendra Prasad[3], Dr. R. B. Patel[4]

[1]PhD. Research Scholar, [3]Professor & Head, Department of Information Technology,
[2] Assistant Professor , Department Of Computer Engineering,
M.M.University Mullana, Haryana India
[4]Professor, Department of Computer Engineering, Chandigarh College of Engineering & Technology, Chandigarh, India
[1]bindalamit@gmail.com, [2] jainanuj143@gmail.com, [3]dprasadvns@gmail.com,
[4]drpatelrb@gmail.com.

Abstract

Static sensors have been a prominent area of research for last many years. They have a wide area of applications. Mobility in WSN broadens the application area of WSNs, but it imposes challenge of increased energy requirements and mechanism to find the location of moving sensor nodes. In this article a 2-Way Energy Efficient Localization (TWEEL) scheme is proposed, which is energy efficient and provides better localization as well without employing GPS at all mobile sensor nodes hence reducing the cost. Accuracy is achieved by using twin mobile anchor nodes and energy efficiency is achieved using combined and coordinated movements of nodes towards a single common objective. The location of a sensor node is computed by measuring the distance to the virtual anchor point using TDOA (time difference of arrival) method. The proposed scheme is compared with Zhang and Yu scheme and results shows that TWEEL outperform Zhang and Yu scheme on various parameters.

Keywords:- WSN, GPS, TDOA,TWEEL.

I. INTRODUCTION

Wireless sensor network (WSN) is composed of large number of low-cost sensor nodes (SNs) to cooperatively monitor certain physical or environmental phenomena. It is an emerging technology that shows various applications both for public and military purpose. The network must be energy efficient and survive for a long time in order to operate these applications successfully. The battery power dependency of

SNs is one of the significant constraints of this type of network. Sometimes it is not feasible to recharge or replace the batteries, thus, efforts must be employed at all layers to minimize the power consumption, so that the network lifetime is increased. In hostile environment where reachability is not possible, the replacement of any dead sensor is not possible until its location is known, even though GPS is available to find the location of any sensor but it is not very much accurate and at the same time by using GPS cost of the network is tremendously increased. Another solution is to provide mobility to SNs in the area of deployment but Mobile wireless sensor networks pose a new challenge of localization of nodes in the field. Movement of nodes is only possible if location awareness is possible in the network. If they employ GPS at all the nodes then it will be costly and energy consuming. Therefore alternative solutions are highly desired.

II. RELATED WORK

In [1] Baoli Zhang et. al present an energy efficient localization algorithm for wireless sensor networks using a mobile anchor node. It is based on the distance measurement with extra hardware. The mobile node is equipped with a GPS receiver, RF (radio frequency) and ultrasonic transmitter. Each stationary sensor node is equipped with a RF and ultrasonic receiver. The mobile node periodically broadcasts its location information, and stationary sensor nodes take the positions as virtual anchor points. A sensor node’s location is computed by measuring the distance to the virtual anchor point using TDOA (time difference of arrival) method. After the first round localization is done, the un-localized sensor nodes can compute their locations with the help of localized stationary sensor nodes.

Mobile sink has been widely used in wireless sensor networks to balance energy consumption among sensor nodes and to prolong the network lifetime. But, as mobile sink moves, sensor nodes have to change their routes to mobile sink frequently, which results in a lot of energy consumption and also a very large transmission delay accordingly. Although using a static sink may lead to shorter network lifetime, it can get a relatively small transmission delay and need not to change their routes constantly. Yan bin Weng et. al. [2] proposed an energy efficient data gathering scheme with both a static and a mobile sink to work together in order to prolong the network lifetime and to reduce the transmission delay[14]. Their Mathematical analysis and simulation results show that it can greatly improve the network lifetime and reduce the transmission delay at the same time by using their scheme [12].

Routing protocols have a large scope of research work when implemented in WSNs, because the functioning of these protocols depends upon the type of network structure designed for the application or the network operations carried out using these protocols for a specific application model [3].

Tariq Benmansour, Samira Moussaoui propose a group mobility adaptive clustering scheme (GMAC) in [4] for mobile WSN based on a new group mobility metric Mobility Group[13], which use network topology information and a position predictor to determine if nodes move together or separately. In GMAC, the area of interest is divided in equal zones, and each sensor calculates its weight based on Mobility Group and residual energy. The sensor node with the greatest weight in its zone will become the cluster-head. Using RPGM mobility model [4] have performed simulations to illustrate the benefits of proposal comparing to ACE-L and LEACH. GMAC claims to outperform ACE-L and LEACH in terms of energy consumption and the amount of data packets received at the sink.

III. SYSTEM MODEL

The sensor nodes in the area to be monitored are deployed in random manner. The network is heterogeneous and comprises of two types of sensor nodes, Mobile Sensor Nodes (MSN) and twin Mobile Anchor nodes, i.e., Mobile Anchor Node (MAN_H) and Mobile Anchor Node (MAN_V) fly over the sensor field to broadcast their location information by leaving beacon points.

To reduce the need of energy refill, mobile anchor nodes are equipped with energy harvesting capability. We consider the fact that, in a military application not a single soldier or device works alone, rather a group pursue a target for a collective and common objective, however their roles may be different. The positions of all these nodes are in a certain order or at certain angle to avoid among themselves. Scout formation in military is quite common where all the soldiers move in a coordinated way and no soldiers are at right angle to each other so that they all can fire at the same time as shown in figure 1.

I) Assumptions

The following assumptions are made in the proposed localization scheme:

1. The mobile sensor nodes are energy restrained whereas the MANs are not. All the sensor nodes are deployed in an ad-hoc fashion and they are self-configured.
2. Every mobile anchor node is equipped with a GPS, RF transmitter and ultrasonic transmitter whereas the mobile nodes are equipped with RF and ultrasonic receiver only.

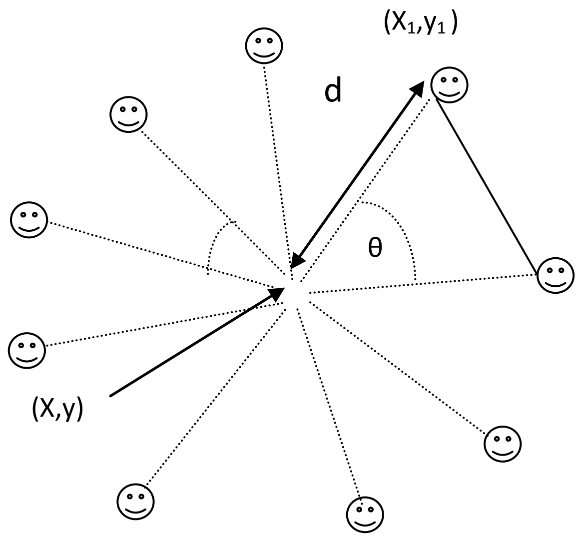

Figure 1: Coordinated movements of mobile nodes within group.

II) TWEEL Architecture

TWEEL estimates the distance by measuring the one-way propagation time of an ultrasonic signal and radio signal sent by the mobile anchor node. Once a stationary node receives the RF signal, it immediately turns on its ultrasonic receiver to listen to the ultrasonic pulse which will arrive a short time later. The time difference between the RF signal and ultrasonic signal is used to estimate the distance between the stationary node and mobile anchor node, as shown in Figure 2.

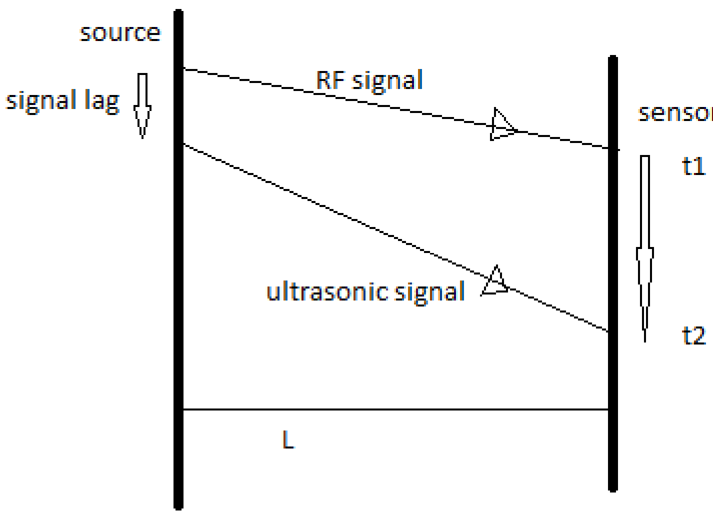

Figure 2: Distance Measurement between Anchor node and Sensor Node

The mobile anchor node's location information is carried by RF radio. Since the mobile anchor node sends RF signal and ultrasonic signal at the same time as shown in Figure 2. The distance between a MSN and MAN is calculated using equation (1).

$$\frac{L}{c_2} - \frac{L}{c_1} = (t_2 - t_L) - t_1 \tag{1}$$

Where, t_1 is the time when a mobile sensor node receives the RF signal, t_2 is the time when it receives ultrasonic signal;

t_L is the signal lag time between the RF and ultrasonic signal at sender side to avoid the signal miss by the stationary node;

C_1 is the speed of RF signal and C_2 is the speed of ultrasonic signal.

A) Location measurement/estimation

Initially each mobile anchor node broadcasts a beacon message in the deployment area. The mobile sensor node in the area which gets the beacon message marks that point as beacon point. The number of beacon points is quite large, but the mobile sensor node takes only three points per MAN out of these as anchor points with the help of their RSSI (received signal strength indicator) value by selecting the three highest values. The sensor node calculates the distance with these anchor points using equations (2-7).

A mobile anchor node travels to point P and broadcasts messages, if the SNR (signal to noise ratio) of the signal received by a stationary node is greater than a threshold, point P is said to be a virtual anchor point. Each stationary sensor node records messages (which includes the location of the virtual anchor point, distance between the stationary sensor node and the virtual anchor point) of three different virtual anchor points.

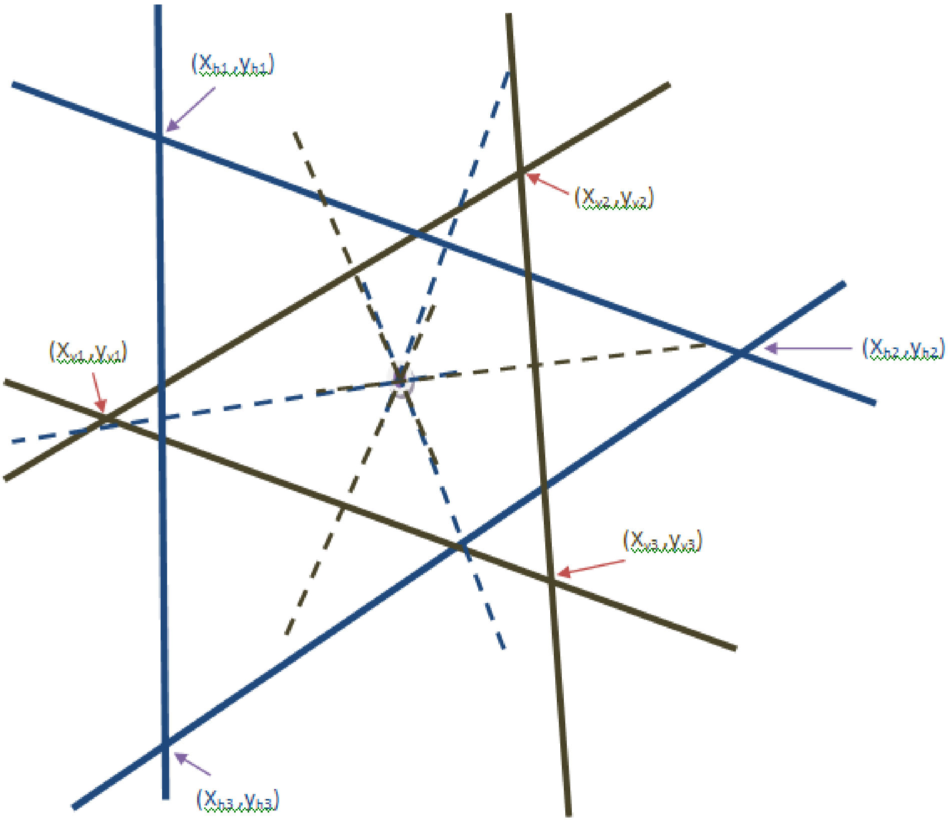

Figure 3: Sensor Location Calculation on horizontal and vertical movement axis

The location of the sensor nodes is calculated by the points shown in the figure 3. The following equations are the used to compute the distance between the virtual anchor points and the sensor node.

i) The distances from the selected anchor points received from MAN_H are calculated through the equations 2-4.

$$(x-x_{h1})^2+(y-y_{h1})^2=d^2{}_{h1} \quad (2)$$

$$(x-x_{h2})^2+(y-y_{h2})^2=d^2{}_{h2} \quad (3)$$

$$(x-x_{h3})^2+(y-y_{h3})^2=d^2{}_{h3} \quad (4)$$

ii) The distances from the selected anchor points received from MAN_V are calculated through the equations 5-7.

$$(x-x_{v1})^2+(y-y_{v1})^2=d^2{}_{v1} \quad (5)$$

$$(x - x_{v2})^2 + (y - y_{v2})^2 = d^2{}_{v2} \quad (6)$$

$$(x - x_{v3})^2 + (y - y_{v3})^2 = d^2{}_{v3} \quad (7)$$

iii) The other nodes of the group take the location of the representative node as reference and calculate their location with the help of prefixed distance d, angle a* between the representative mobile sensor node and them using formula $\sin\theta = d_2 / d$, and then the coordinates of all the points is computed as shown in figure 4.

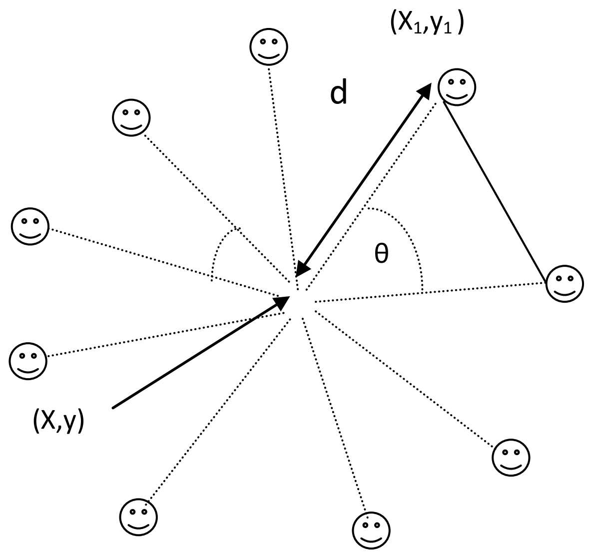

Figure 4: Location Estimation for the other member nodes of the group

1. Location of representative node is computed by using two mobile anchor nodes.
2. The other members of the group compute their location with the help of the result of Step 1.

Although all nodes calculate and determine their position, they still have to keep moving to achieve single motive for the assigned target as shown in Figure 5 where three groups are moving on a horizontal plane and approaching to a single target.

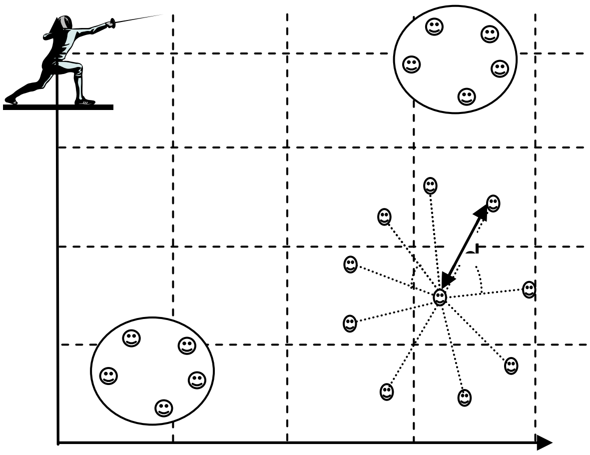

Figure 5: Coordinated movements of mobile nodes in inter groups.

Notations used in the algorithm:
Let **T** be the time required by mobile anchor node in localization process, **N** is the set of all nodes and $\mathbf{G_k}$ is the k^{th} group of nodes.

$$G_1 \cup G_2 \cup G_3 \cup ----- \cup G_n = N$$

$\mathbf{RepG_k}$ is the representative node for the K^{th} group.

$\mathbf{MsgQ_i}$ is the queue maintained at i^{th} node to store beacon messages.

poscal( ) is the function to select beacon messages and calculate the location of node.

1. Set Target=on;
2. While(Target≠off), Repeat through Step 3-6
3. If i=MANH ∨ i=MANV
a) Broadcast a message to set target=off if receives a command to abort from base station.
b) Move at the prefixed Trajectory.
c) Broadcast beacon message m at every time interval t where 0<t<R
4. If $i \in N$ and $i \in G_k$ where N is the set of all mobile sensor nodes and $G_k \subseteq N$
a) If i= $RepG_k$ and i receives message m

Check the RSSI and put the point in MsgQi;
b) If Loc(i)==null ∨ i= $RepG_k$

Delete three points b1,b2,b3 from MsgQi.
Call the procedure poscal(b1,b2,b3) to calculate the loc(i).
c) Else if i ≠ $RepG_k$, Then WAIT(t).

d) Else Broadcast Loc(i) to$\forall$p: p$\in$ G_k.

5. If i $\neq$ RepG_k and i receives Loc(p) and i,p$\in$ G_k Call the procedure poscal(p);
6. If Loc(i)=Loc(target)$\wedge$target$\neq$off
   Set target=off;
7. Exit

This algorithm runs in a O(RKT) time where K is the total no. of groups the nodes are divided into. O(KT) is the time complexity for one round and R is the number of rounds. R depends on the distance of Target from the current location of group nodes which depends on real life scenarios. Smaller the value of K faster will be the process to localize the nodes.

IV. SIMULATION

The number of working nodes plays an important role in energy efficient implementation of application in hand and localization error plays the key role to prove the integrity of the scheme. Few parameters need to be set properly by initially performing the simulation which helps to get an optimal number of live nodes for survivable network.

Simulation Metrics:

The following metrics are used to evaluate the performance of TWEEL. *Average Localization Error:* It is defined as the average difference between actual location and estimated locations of all nodes.

$$\Delta E_{av} = \frac{\sum_{i=1}^{N} \sqrt{(X_{ei} - X_i)^2 + (Y_{ei} - Y_i)^2}}{N}$$

Where N denotes the total number of nodes in the deployment area, (X_i ,Y_i) is actual location and (X_{ei} ,Y_{ei}) is estimated location of i^{th} node in the deployment area.

Average Energy Consumption:

It is defined as the ratio of the total energy consumption by all nodes to the total number of nodes.

$$P_{in} = \frac{\sum_{i=1}^{N} E_i}{N}$$

Where E_i denotes the energy consumption of i^{th} node.

Simulation parameters:

The following are the simulation parameters considered for the implementation of

TWEEL:

- Size of message is 12 bytes.
- Electronic power (E_{elec}) is 50 nJ/bit.
- Size of node ID 4 bytes.
- The distance between two nodes is less than the minimum transmission range.

For simplicity, communication links are assumed to be error free and network field is square in shape. A WSN of varying network sizes (|V|+|E|) with varying number of sensors is laid in the same field for varying observations.

Average Localization Error

The TWEEL is compared with Zhang's scheme on Average Localization error in Figure 6 and from Figure 6, it is clear that TWEEL outperforms Zhang's scheme which is due to the two way localization nature of TWEEL because by employing two mobile anchor nodes TWEEL achieve the better localization. Although TWEEL takes 6 anchor points and thus 6 messages per representative node in a group, but these 6 messages serve to entire group hence the total number of messages exchanged in TWEEL is lesser than Zhang's scheme.

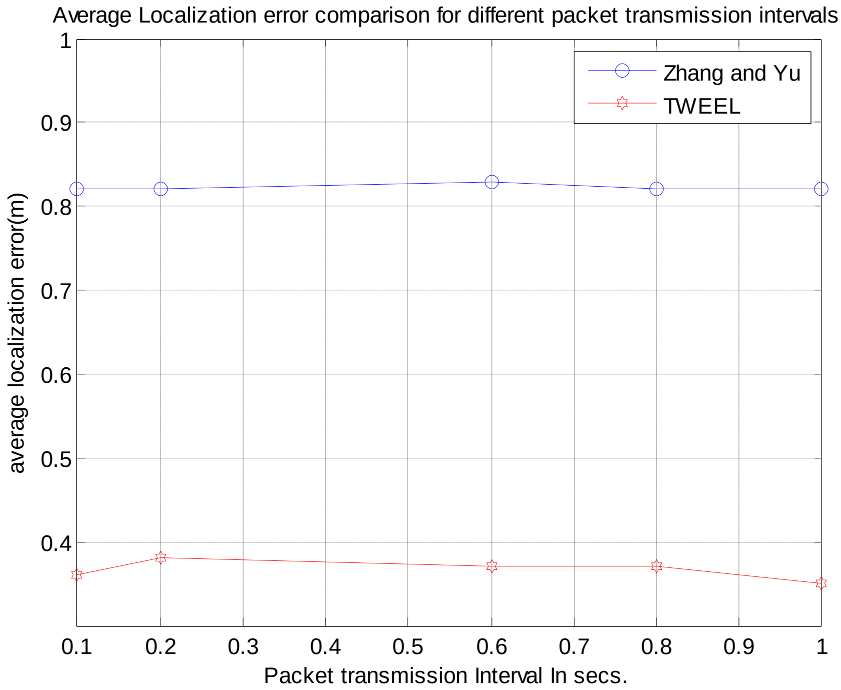

Figure 6 Average Localization Error

Average Energy Consumption

The average energy consumption per round in finding the location of high potential node is defined as the total energy consumed by all the nodes to the total number of nodes. In TWEEL node exchanges less number of messages and also perform less computation so the energy consumption is lesser as can be seen in the Figure7.

Effect of Group Node density on Localization Error

Average Group node density ρ_G is defined as the total number of nodes (N) to the total number of groups (K).

$$\rho_G = \frac{N}{K}$$

From figure 8 we can observe that initially average localization error increases as the group node density increases and after certain value of group node density the value of Average Localization error remains almost constant irrespective of the change in value of ρ_G.

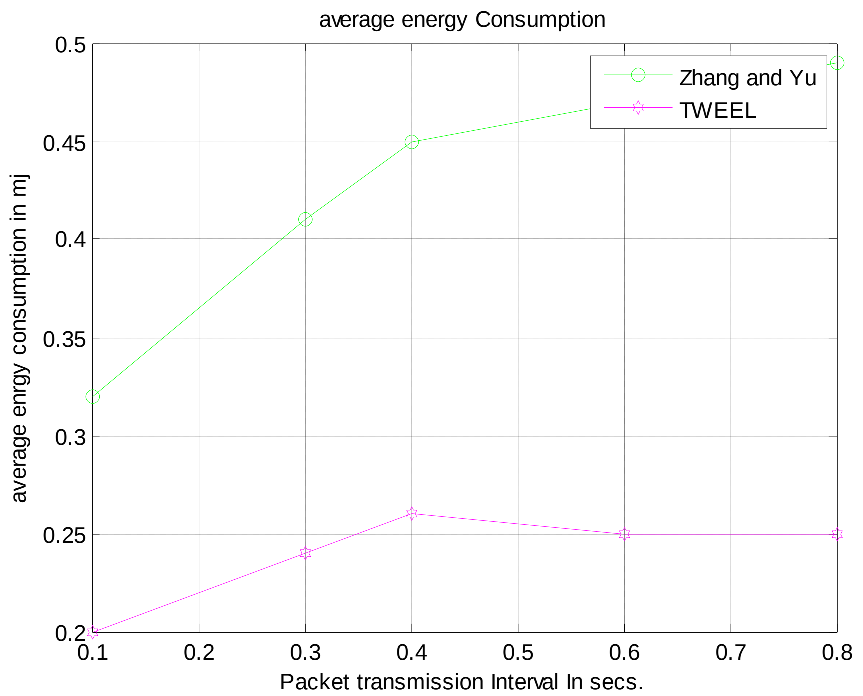

Figure 7 Average Energy Consumption

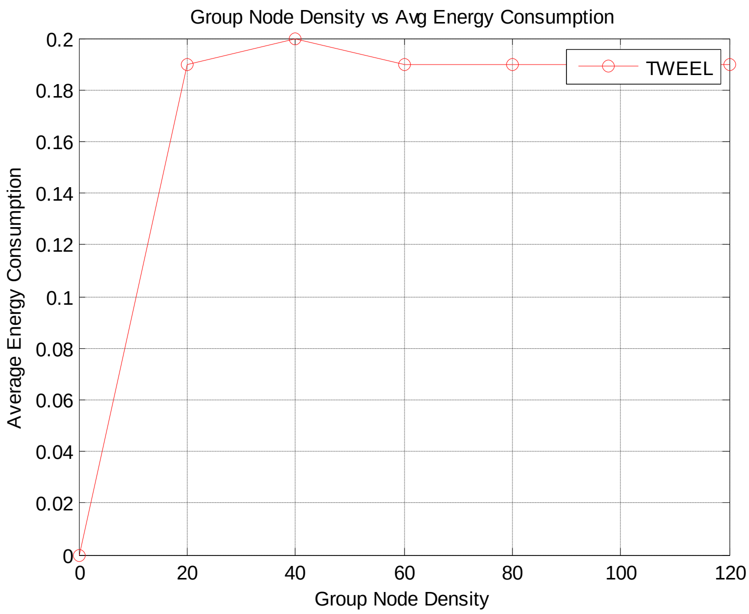

Figure 8 Group Node Density vs Average Localization Error

Effect of Group Node density on Average Energy Consumption

If ρ_G increases then the average energy consumption decreases up to a saturation point. Thereafter we observe a constant trend in average energy consumption curve. This can be observed by Figure 9.

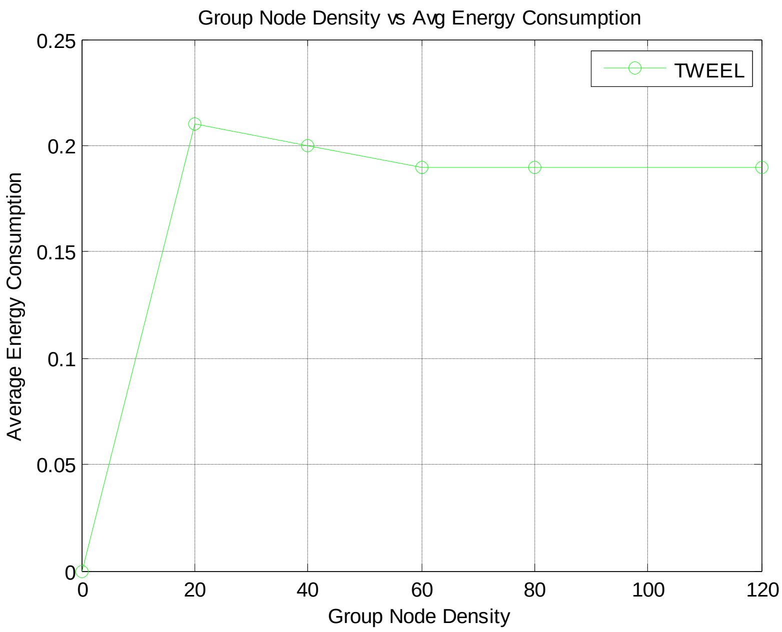

Figure 9. Group Node Density vs Energy Consumption

This behaviour matches with basic assumptions for the trend in energy consumption through computing as energy consumed in computing decreases with the number of nodes where as energy consumed in transceiver remains constant as the messages are broadcasted. Therefore we see a saturation point and a constant trend because energy consumed in transceiver takes on energy consumed in computing.

V. CONCLUSION

TWEEL found the locations of moving sensor nodes without providing a GPS system to the sensor nodes, it also coordinates the movement of the mobile sensor nodes to achieve single and common target. In TWEEL accuracy is achieved using 2-way localization with the help of horizontal and vertical anchor points provided by two mobile anchor nodes. These sensor nodes are not energy constrained as they are equipped with energy harvesting capability, so sensor nodes are able to work in hostile environment for long time. If sensor nodes get destroyed in the battlefield they can be replaced easily as their primary function is to provide location information, which will be continued by the new node, thus hazards can also be handled easily. Energy efficiency is achieved by ruling out the calculation for all the nodes in the group.

VI. FUTURE WORK

Since the location of all members are keep on changing with time and a fraudulent anchor point can creep in the system and provide the mischievous locations, in future TWEEL will be enhanced to address the issue of security, which requires a great overhead to provide authentication and authorization to the mobile anchor node before entering in the questioned sensor field. Most of the current protocols are highly applications dependent hence a generic model for the WSN needs to be developed that can cover a wider range of applications.

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