An Efficient-Energy Model for Mobile Target Tracking in Wireless Sensor Networks

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Abstract

In this paper, an improved energy efficient target tracking protocol using mobile agents' method was suggested. In fact, many target tracking protocols have been recently proposed to handle resource limitations of tiny wireless sensor nodes. Some of these limitations include limited energy resources, limited communication and sensing ranges, limited processing and storage capacities, working in inhospitable and hostile regions, employing in large numbers, distributed and cooperative nature or work among sensors,…etc. Considered as the backbone for the emerging Internet of Things (IoT), Wireless Sensor Networks (WSN) still have many issues that are facing researchers working in this field. We propose two solutions to get rid of redundant communications among sensor nodes used for detecting a target. First, we provide an effective scheme between the received signal strength (RSS) indicator and a predefined RSS threshold which is called (TTP-RSS), in order to ensure preventing farther sensor nodes from participating in tracking the detected target. Second, when the identifications (ID) of the control messages are also re-encoded in order to achieve low energy consumption per each sensor, then another improvement can be introduced as TTP-MESS.

Keywords: Algorithms, Management, Measurement, Performance, Design, Wireless sensor networks, mobile target tracking, lifetime, energy consumption.

1. Introduction

In the WSNs, the power consumption is very important issue in many mobile target tracking applications because sensor nodes are usually operated on limited batteries [11]. Accordingly, well- designed transmission power control algorithms are required to reduce the energy consumption and improve the channel capacity.

Since WSNs are typically used for monitoring the physical world, one of the fundamental issues is the location tracking problem, where the goal is to trace the roaming paths of moving objects in the network area [2, 3, and 10]. Based on the fact that tracking can be defined as localization in time [7] and the fact that we can locate an object in 2D plane if we know its distance from at least three non linear points (trilateration principle) [12], we will use the received signal strength indicator (RSSI) to indicate the relationship between RSS from the object to the sensor and the distance between them. The previous will certainly make us use of triangular deployment of sensors in the monitored environment. Once the object is detected, a mobile agent will be initiated to track the roaming path of the object. The agent is mobile since it will choose the senor closest to the object to stay. In fact, the agent will follow the object by hopping from sensor to sensor. The agent may invite some nearby slave sensors to cooperatively position the object and inhibit other irrelevant (i.e., farther) sensors from tracking the object. There are two advantages in using mobile agents. First, the sensing, computing, and communication overheads can be greatly reduced. Secondly, on-site or follow-me services may be provided by mobile agents. Our prototyping of the location-tracking mobile agent based on MATLAB [14] simulation and performance comparison and evaluation show that our modifications on the base protocol [1] give improved energy consumption model and efficient communication procedure. We have increase network lifetime by reducing messages size and number of messages sent and received by all sensors participating in tracking operation, also developing new and efficient energy consumption model based on counting sensor node components energy consumption in both full operation state and idle state.

The rest of the paper is organized as follows: Related work and system model are the Section 2 and Section 3, respectively. Improvements are proposed in Section 4. Performance evaluations and Simulation results are defined in Section 5. Then, we conclude our paper in Section 6 with some future work ideas.

2. Related Work

Below are some of the techniques proposed in an attempt to solve the Target Tracking problem: The first technique has been proposed by Yu-Chee Tseng, Sheng-Po Kuo, Hung Wei Lee and Chi-Fu Huang [1]. As following: Whenever an object is detected, based on the distances of the sensor nodes from the object, three closest nodes are selected to monitor the movements of the object. At any time, these sensors monitor the movements of the object. These three agents (master and slaves) will perform the trilateration algorithm and calculate the (x, y) coordinates of the object. The sensors tracking the object keep changing as the object moves. The election process is constantly done based on the location of the object at different time instants. There is a certain signal strength threshold used to determine when to revoke/reassign a slave agent. The master may forward tracking histories to the location server (every 1-sec or before the agent move itself to another sensor).The paper has discussed the above technique with some constraints on the movements of the object. The object is assumed to be moving at a constant speed of 1-3 m/s and the sensors are not able to detect the object if it moves at a speed of more than 5 m/s(which is great constrain in military applications).

Another technique has been proposed by Asis Nasipuri and Kai Li [4]. The technique is as follows: Consider a network in which sensor nodes are scattered at random. These nodes track the object and relay the information to the Control Unit (end user computer or location server) as and when required. For various operations such as signal processing, data transmission, information gathering and communications the sensor nodes have a memory, a processor and supporting hardware. The sensor nodes have limited transmission range. They rely on store and forward multihop packet transmission to communicate. Each beacon signal is an RF signal of a separate frequency on a narrow directional beam with a constant angular speed of ώ degrees/s. Thus, the transmissions are distinguishable. The sensor nodes determine their angular bearings with respect to these signals. The supposition in this case is that transmission range is sufficient for the beacon nodes to be received by all sensor nodes in the network.

Data-centric and Location-centric approaches to the Target Tracking problem have been elaborated by R. R. Brooks, P. Ramanathan and A. M. Sayeed, [5].In the Data-centric approach, sensor nodes respond to particular requests. Whenever the nodes detect a request corresponding to the data they have, they transmit the data. Other nodes do not respond but take note for future use. Subscribed nodes receive data over the network. Diffusion routing is one of the solutions proposed to route data in the data-centric approach. Interests of particular nodes are disseminated and gradients set up within the network helping to pass the relevant data to the interested nodes. Paths are then reinforced and data flow takes place only along these specified paths. In the Location-centric approach, cells are created as per requests and tasked accordingly. The activities of the nodes in the cell are coordinated by a manager node. The occurrence of "events of interest" is collaboratively decided by all the nodes in the cell. If the object moves out of the current cell, the manager node has the responsibility of creating a new cell to track the object. The authors illustrate a location-centric approach developed at the University of Washington. In this case, a Route Request (RREQ) is needed to forward data from cell to cell unlike the creation of paths in diffusion routing. The cells are addressed by their geographic locations. As the RREQ propagates, state information is temporarily deposited in the network to identify an efficient route from the source to the destination. On receiving the RREQ, the node in the addressed cell responds with Request Reply (RREP) which is routed to the destination cell resulting in a single path from source to destination cell along which data is sent to all nodes in the latter by the manager node.

The other technique for location tracking was proposed by Saikat Ray, Rachanee Ungrangsi, Francesco De Pallegrini, Ari Trachtenberg and David Starobinski [6].explained as following: location tracking methodology based on radio waves. These employ received signal strength to calculate the location of an object. Their technique basically speaks about selecting a set of points and then based on the RF connectivity between these points; the transmitting sensors are placed only on a subset of these points. The sensors have a limited range of transmission and the observer would receive unique ID packets anywhere in this region. Since each point is served by a unique set of transmitters from which the location of the point can be known. Beyond the points incorporated into the graph model, this technique does not guarantee coverage. It has to rely on additional techniques for widespread coverage.

And finally yet another technique for location tracking keeping in view power considerations was put forward by Yi Zou and Krishnendu Chakrabarty [7]. In this paper, the authors talk about implementing a Virtual Force Algorithm for sensor deployment (which assumes a limited capability of movement to sensor nodes as one time movement to rearrange sensor nodes based on proposed locations by VFA). This is based on the proximity threshold between two neighboring sensors.

If the sensors are too close, they repel and if the distance between them falls below the threshold level, they attract. This leads to a uniform sensor deployment. Once the sensors have been deployed, a cluster head is chosen which is responsible for implementing the algorithm. In order to minimize traffic and conserve energy, a notification is sent by a sensor to the cluster-head whenever the object is tracked which then queries a subset of sensors to gather more detailed target information. These are intelligent queries based on the cluster-head generating a probability table for each grid point and then subsequent localization if a target is detected by one or more sensors.

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Some of the more recent works in this field includes [15] where they assume active sensors that are emitting energy and calculate the reflected amount of energy from the monitored targets. They propose an algorithm that guarantees collaboration among multiple sensors which increases the sensing area, allows tracking multiple targets simultanuosly and reduces each individual sensor power consumption. They also estimate the target velocity by using adaptive scheduling.

In [16], they also focus on energy efficiency in target tracking application of WSN by proposing a distributed, energy efficient, light weight framework for dynamic clustering of sensor nodes. Their aim is to reduce the number of messages and the message collisions (which produce more overhead because of the need for retransmission). One of their work features is the adaptivity to target change of velocity.

3. System Model

We consider a hexagonal sensor network, which consists of a set of sensor nodes placed in a 2D plane. Also we will assume a triangular network (to make use of the fact that if we know the distance from three points to an object, then we can locate that object, trilateration principle) as illustrated in Fig. (1).

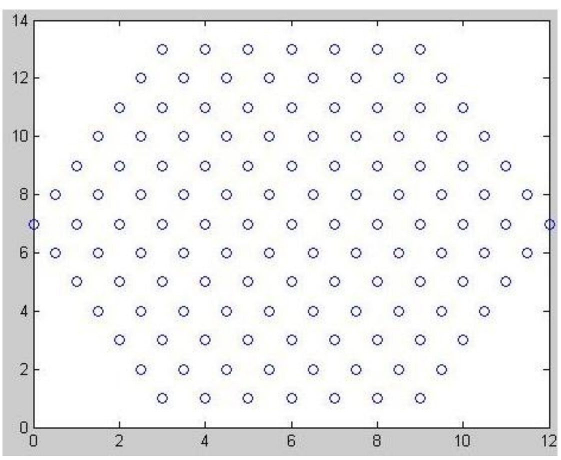

Fig. 1 2D Triangular network topology.

3-1 Target tracking protocol

In order to track objects' path, each sensor is aware of its physical location as well as the physical locations of its neighboring sensors (the matter that will be used mainly in specifying sensor node identification field in each message sent and received as will seen shortly)[8]. Each sensor has sensing capability as well as computing and communication capabilities, so as to execute protocols and exchange messages [1]. Each sensor is able to detect the existence of nearby moving objects. We assume that the sensing range is *r*, which is equal to the side length of the triangles-in trilateration technique- (so as to reduce intervention of neighboring nodes in tracking operation). Within the detectable distance (sensing range), a sensor is able to determine its distance to an object. This can be achieved either by the time of flight (TOF) or the signal strength indicator. We assume that three sensors are sufficient to determine the location of an object, which is the normal case in 2D planes [1, 8]. Specifically, suppose that an object resides within a triangle formed by three neighboring sensors S_1, S_2, and S_3 and that the distances to the object detected by these sensors are r_1, r_2, and r_3, respectively. As shown in Fig. 2, by the intersections of the circles centered at S_1 and S_2, two possible positions of the object can be determined. With the assistance of S_3, the precise position can be determined. (It should be noted that in practice errors may exist, and thus more sensors will be needed to improve the accuracy [12].)

The goal of this work is to determine the roaming path of a moving object in the sensor network. The trace of the object should be reported to a location server from time to time, depending on whether this is a real-time application or not. The intersection of the sensing scopes of three neighboring sensors is as shown in Fig. 3. We further divide the area into one *working area* A0 and three *backup areas* A1, A2, and A3. Intuitively, the working area defines the scope where these three sensors work normally, while the backup areas specify when "handover" should be taken.

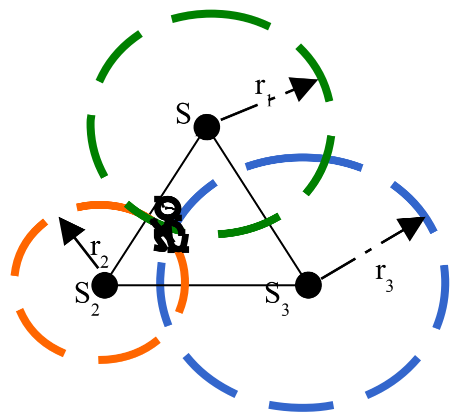

Fig 2 Trilateration Positioning example.

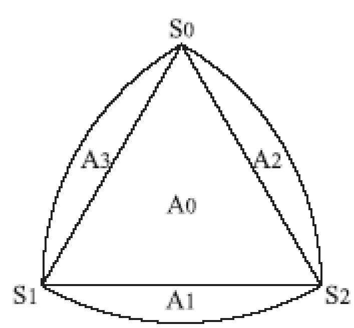

Fig 3 An example of working area layout (A0) and Backup Areas (A1, A2, A3).

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Our tracking protocol will go though the following state transition shown in Figure (4):

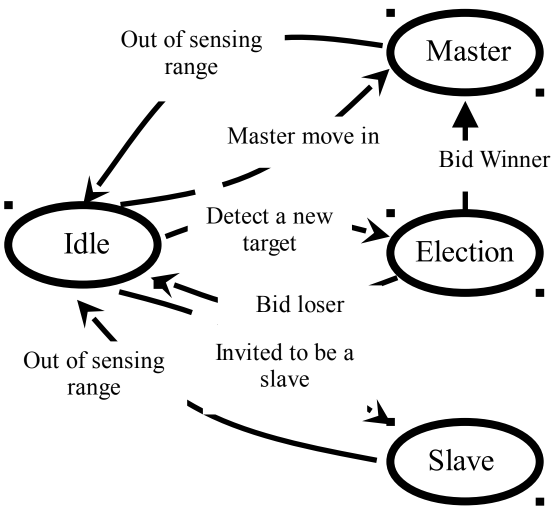

Fig 4 State Transition Diagram for sensor nodes.

Initially all sensor nodes are in idle state until one or more targets entering the monitored region. when the sensor nodes detecting the targets, their state will be election state to compete to be master node in tracking operation based on the strength of the received signal from the object (different sensor types deployed to detect and track different phenomena) and after determining master node from elected nodes (which will be responsible for collecting location information from slaves and determine the estimated location of the target based on these information) and specifying slaves from elected nodes, the master node go to master state and slave nodes are entering slave state and losing nodes are back to idle state. After the first tracking round (where master and two slaves are determined and estimate the target instant location) target may be out of master's range the matter that require moving the agent (master node) from the current out of range node to one of the current slaves based on proximity and RSSI and the replaced master will back to idle state after passing history information of each target (our protocol deals with multiple targets simultaneously) to newly elected master node. As in the master node slaves may be out of sensing range of the target(one slave or both of them) the matter that allow the master to invite one or two idle sensor nodes to be slaves for a specific target and the out of sensing range slave(s) will go back to idle state.

3-2 Energy consumption model

Typical sensor structure is as in figure (5)

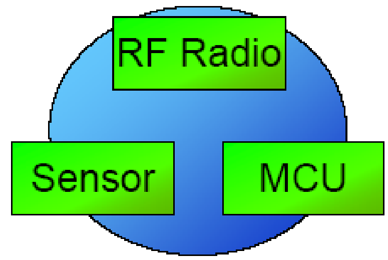

Fig 5 Typical sensor node structure.

So we base our energy consumption model on the following analysis of sensor, MCU, and RF transmitter, receiver components and their corresponding energy consumption:

1-Radio model: The radio module is responsible for wireless communication among nodes. A typical radio module used in wireless devices is shown in Figure 6. The *Transmit Electronics* represents electronics circuit performing signal modulation.

Tx Amplifier is used to amplify the modulated signal and output it to the antenna. The *Receive Electronics* is used to decode the modulated signal. *Eelec* is the energy needed for modulating or demodulating one bit of the circuits. *Єamp* is the energy for the amplifier circuit to transmit one bit to an area of radius d = 1 meter (i.e., πd^2). In a real device, the transmit module (*Transmit Electronics* and *Tx Amplifier*) normally stays in sleep mode. It only wakes up when there is any bit that needs to be sent. The receiver module (*Receive Electronics*) performs the reverse function. It needs to be ON when waiting to receive messages.

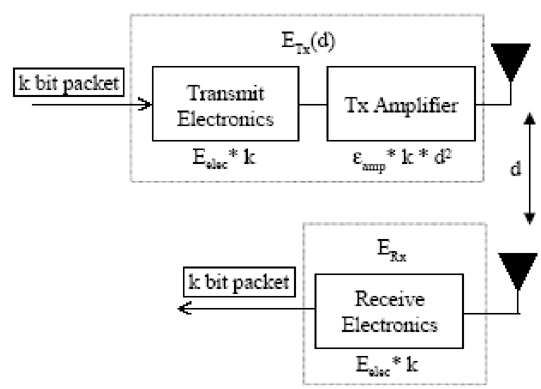

Fig 5 Radio Model for wireless devices.

The formula for sending K-bit message is as following:

$E_{TX}(k,d)=(Eelec*k)+(\epsilon_{amp}*k*d*d)$

Where: $E_{Tx}(k,d)$ represents the energy needed to spread k bits to an area of radius d, while $E_{Rx}(k)$ the energy needed to de-modulate k bits.

The formula for receiving K-bit message is as following:

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$E_{RX}(k)=Eelec*k$

2- *Sensor board, MCU (CPU board, Memory board), and Radio board of a sensor network*: These boards work in two modes: full action and sleep. In the sleep mode, the energy dissipation is almost zero. The full action mode consumes energy as shown in Table 1. In which, mA means milli-ampere, µA is micro-ampere.

Then we take typical values for our parameters as following:
-Eelec=50nJ/bit.
-Єamp=100pJ/bit/m^2.
-Data message size=16-bit (as in the base protocol [1]).
-Control message size=16-bit (as in the base protocol and then we modify (reduce control message size) to 8-bit).
-Distance between any two neighboring nodes is 80 m [1].
Our energy consumption model is based on the network performance analyses due to number of transmitted and received messages per tracking round, the size of each message, as well as the state of each sensor during transmission and reception as shown in Table(2).

Table 1: Current of boards in sensor node MICA2DOT (MPR 500).

SYSTEM SPECIFICATIONS		
Currents		**Example Duty Cycle**
Processor		
Current (full operation)	8 mA	1
Current sleep	8 µA	99
Radio		
Current in receive	8 mA	0.75
Current transmit	12 mA	0.25
Current sleep	2 µA	99
Logger Memory		
Write	15 mA	0
Read	4 mA	0
Sleep	2 µA	100
Sensor Board		
Current (full operation)	5 mA	1
Current sleep	5 µA	99

Table 2: Summary of sensor states in direct communication protocols [9].

Sensor board	Full operation
Radio board Sleep	wake up for transmitting only
MCU board Sleep	wake up for creating messages only

- We define the master node energy consumption per tracking round as:

$$E_M=(N_{TXM}\times E_{TXM})+(N_{TXM}\times E_{mcuM})+(N_{RXM}\times E_{RX}$$
$$+(N_{RXM}\times E_{radioM})+E_{sensorM}$$
(1)

- We define the slave node energy consumption per tracking round as:

$$E_S=(N_{TXS}\times E_{TXS})+(N_{TXS}\times E_{mcuS})+(N_{RXS}\times E_{RXS})$$
$$+(N_{RXS}\times E_{radioS})+E_{sensorS} \quad (2)$$

- Also we define the neighboring nodes energy consumption per tracking round as:

$$E_{Round}=E_{TX\_bid\_master}+E_{RX\_inhibit}+E_{RX\_bid\_master}$$
$$+E_{mcu}+E_{sensor}+E_{radio} \quad (3)$$

Where, N_{TXM} is the number of transmitted messages (data or control) by the master node per tracking round. E_{TXM} is the energy consumed for transmitting one message (data or control) by master node. N_{RXM} is the number of received messages (data or control) by master node per tracking round. E_{RXM} is the energy consumed for receiving one message (data or control) by the master node. E_{radioM} is the energy consumed by sensor board when it is in receiving or idle state, $E_{sensorM}$ is the energy consumed by sensor board in full operation mode, E_{mcuM} is the energy consumed by sensor to create one message, all for master node per tracking round.

And, N_{TXS} is the number of transmitted messages (data or control) by the slave node per tracking round. E_{TXS} is the energy consumed for transmitting one message (data or control) by slave node. N_{RXS} is the number of received messages (data or control) by slave node per tracking round. E_{RXS} is the energy consumed for receiving one message (data or control) by the slave node. E_{radioS} is the energy consumed by sensor board when it is in receiving or idle state, $E_{sensorS}$ is the energy consumed by sensor board in full operation mode, E_{mcuS} is the energy consumed by sensor to create one message, all for slave node per tracking round.

And, E_{Round} is the energy consumed by the neighboring nodes per tracking rounds, E_{radio} is the energy consumed by sensor board when it is in receiving or idle state, E_{sensor} is the energy consumed by sensor board in full operation mode, E_{mcu} is the energy consumed by sensor to create one message, $E_{TX\_bid\_master}$ is the energy consumed by radio to send *Bid_Master* message, $E_{RX\_bid\_master}$ is the energy consumed by radio board to receive *Bid_Master* message, and $E_{RX\_inhibit}$ is the energy consumed by radio board to receive inhibit message.

Note that the term (message) includes both data (location information) messages and control (networking control) messages. The same Equation (4) can be used for basic (idle), master and slave protocols with one difference in the number and type of messages in each case that is explained in details in the pseudo codes.

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-There are seven message types in the base protocol and only six of them will be used in our modified protocol as following [1]:

(1) ***bid_master(ID,sig):*** This is for a sensor to compete as a master for an object. Each object carries its own unique object identifier (ID) when there are multiple objects to be tracked and no inhibiting record has been created in the object list (OL) for that object ID. The parameter *sig* reflects the receive signal strength for this object which is useful for calculating the master from the three sensors participating in the current tracking operation.

(2) ***assign_slave(ID,s_i,t)****:* This is for a master to invite a nearby sensor si to serve as slave agent for object ID for an effective time interval of t.

(3) ***revoke_slave(*****si*****)****:* This is for a master to revoke its slave at sensor si.

(4) ***inhibit(ID)****:* This is a broadcast message for a master/slave to inhibit neighboring irrelevant sensors from tracking object ID. The effective time of the inhibiting message is defined by a system parameter Tinh.our modification will get rid of this message type.

(5) ***release(ID)****:* This is to invalidate an earlier inhibiting message.

(6) ***move_master(ID,si,hist)****:* A master uses this message to migrate itself from its current sensor to a nearby sensor si, where hist(stands for history) carries all relevant codes/data/roaming histories related to object ID.

(7) ***data(ID,sig,ts)****:* A slave uses this packet to report to its master the tracking results (sig =signal strength and ts = timestamp) for ID.

4- Proposed Improvements

Following are the improvements and modifications done on the base protocol to increase network lifetime and reduce energy consumption:

1- We make use of RSSI thresholds to prevent neighboring nodes from participating in tracking operation by adding the following modification for the election protocol such that (if any sensor node detect the target with RSS less than predefined threshold then it will not send any bid_master messages and as consequence of that, all the three active sensors (master and two slaves) will not need to send any inhibit messages which will reduce overall energy consumption per tracking round by reducing number of sent and received messages).

2- Another proposed improvement is to re-encoding the control messages such that the new size will be only one byte instead of two bytes (in the base protocol) but only with the limitation that each sensor (master or slave) can track up to four targets simultaneously (ID=00, 01, 10, 11) which is not great limitation compared with high energy consumption reduction, bellow is the proposed re-encoding order of protocol messages:

DATA message encoding:

110(message ID)	Target ID(2-bit)	Sig(11-bit)

Bid_Master message encoding:

000(message ID)	Target ID(2-bit)	Sig(3-bit)for bidding

Assign_skave message encoding:

001(message ID)	Target ID(2-bit)	Si(3-bit)

Revoke_slave message encoding:

010(message ID)	Si(3-bit)	Future use(2-bit)

Inhibit message encoding:

011(message ID)	Target ID(2-bit)	Future use(3-bit)

Release message encoding:

100(message ID)	Target ID(2-bit)	Future use(3-bit)

Move_Master message encoding:

101(message ID)	Target ID(2-bit)	Si(3-bit)

Where:

A- Message identifications:

code	Message type
000	Bid_master(ID,sig)
001	Assign_slave(ID,si,t)
010	Revoke_slave(si)
011	Inhibit(ID) :not needed in our modification
100	Release(ID)
101	Move_master(ID,si,hist)
110	Data(ID,sig,ts)
111	For future use

B-sensor identifications:

We know that each sensor has six neighbors and we assume in the beginning that each sensor is aware of its neighbor's location so (si) can be encoded using only 3-bits to identify up to 8 neighboring sensors (we have only six so even we use square topology 3-bits will be enough).

C-received signal strength (sig):

Encoding (sig) using only 3-bits (for bidding purposes only) reducing the likelihood of participating neighbors in tracking process to (0%) but for tracking accuracy it will be given 11 bits for representing received signal strength which will give error rate less than that of base protocol (+5% or -5%) which is inherited due to effects of outdoor environments (interference with other systems, wireless signal fading, obstacles in the signal ways,…etc.).So we will use (000-111) to represent (sig) with (010) as the threshold such that each sensor receive (sig) as (000 or 001 or 010) will stay in idle state (for bidding only and 11-bits for tracking).

D- (t) and(ts):

It will be 1-sec as default for all so there will be no need to send or receive (t) or (ts) by any sensor the matter that allow us to get rid of them in the data and control messages.

E- hist field:

Will be ignored by adding the following condition (each master send its history tracking information to location server before sending move_master message).

5- Performance evaluation

Below are some tracking accuracy examples which show that the error rates in tracking is similar to those of the base protocol.

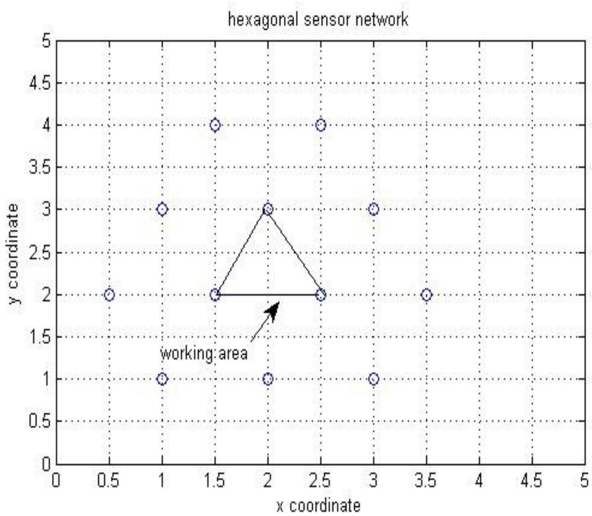

Fig 7 Working Area.

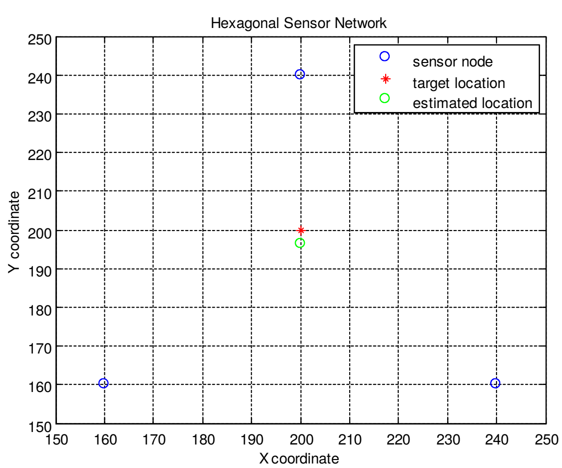

Fig 8 Localization example of one target appearance point.

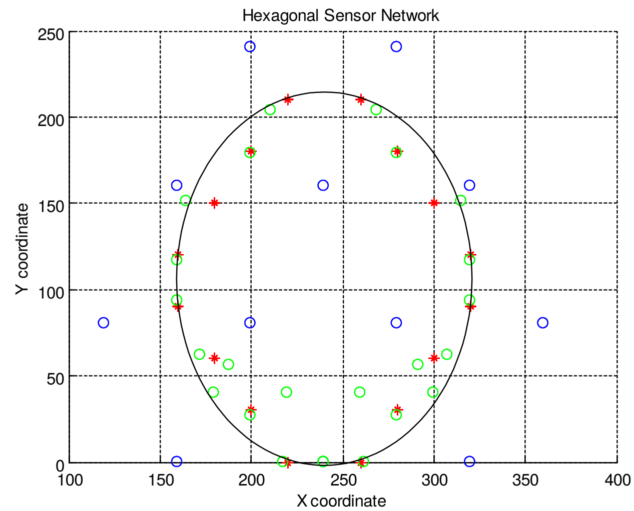

Fig 9 Localization in time (tracking) Zou et al. [7] with acceptable error rate (with respect to target rating speed=up to 33m/sec [8]).

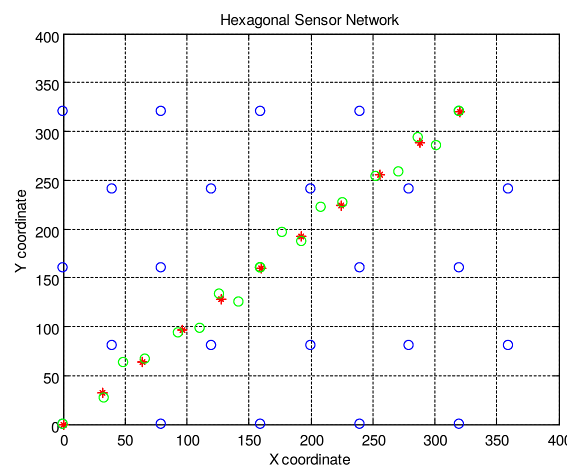

Fig 10 Another Tracking example using source localization protocol [13].

Then we show that energy consumption will be reduced by reducing control message size and preventing neighboring nodes from participating in tracking process as shown in figures (12),(13),(14) below, where (TTP-RSS) protocol energy consumption is compared with the base protocol energy consumption and then (TTP-MESS) energy consumption also compared with the base protocol energy consumption and finally the mixed protocol compared against the base protocol:

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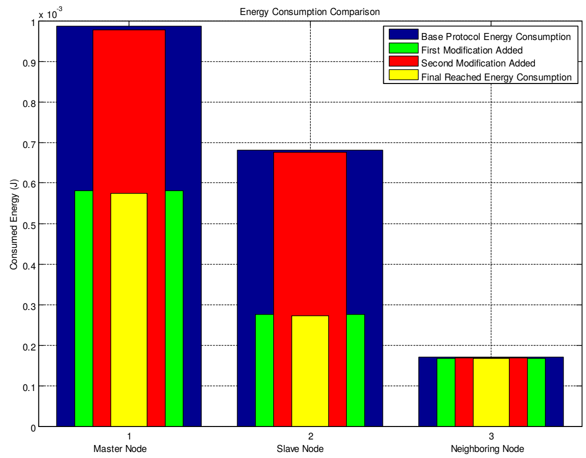
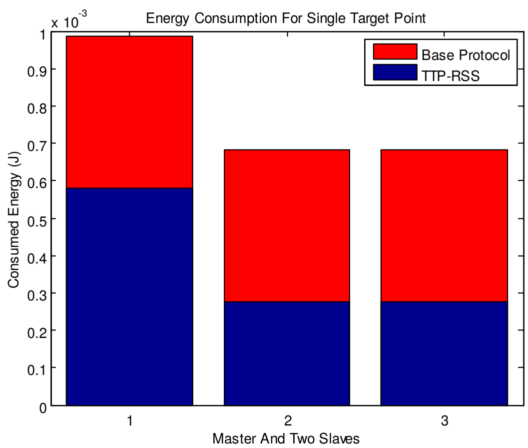
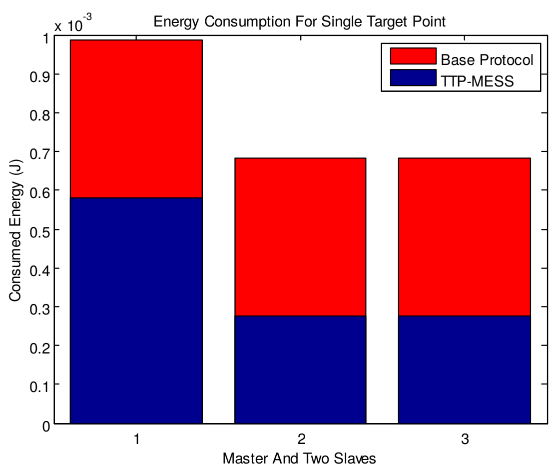


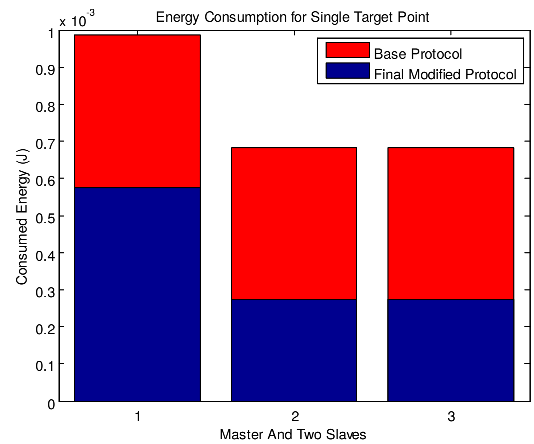
Fig 11 Energy Consumption by Master, Slave and Neighboring Nodes per Tracking Round



(a)

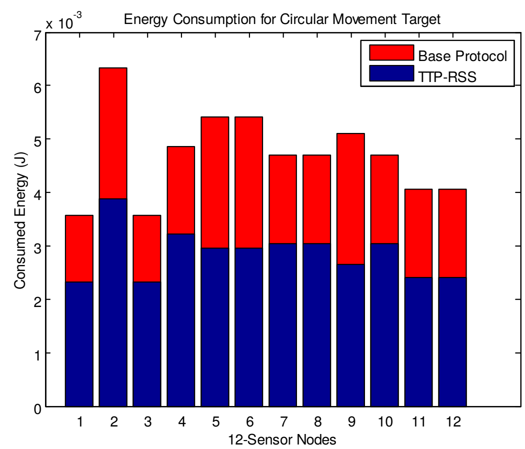


(b)

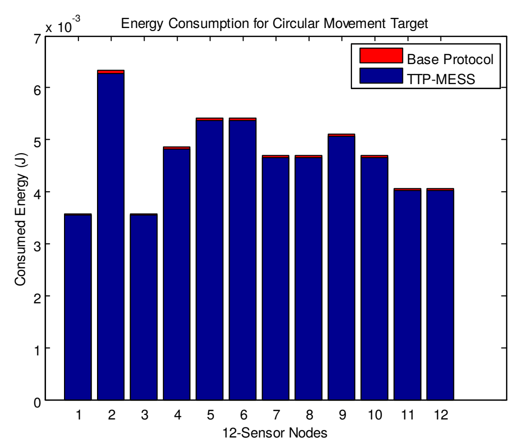


(c)

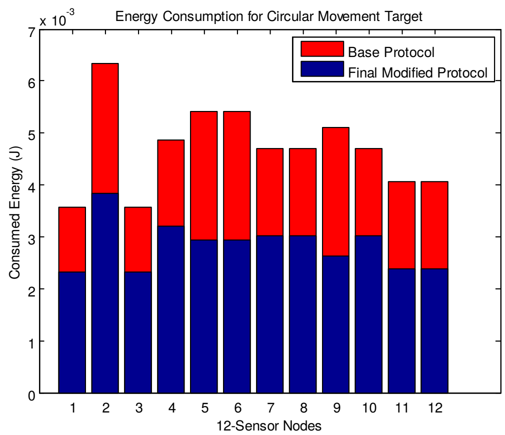
Fig 12 Energy Consumption Comparison corresponding to Fig 8 A single point target



(a)

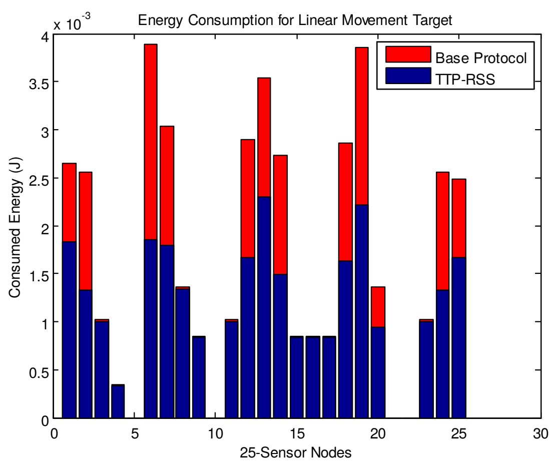


(b)

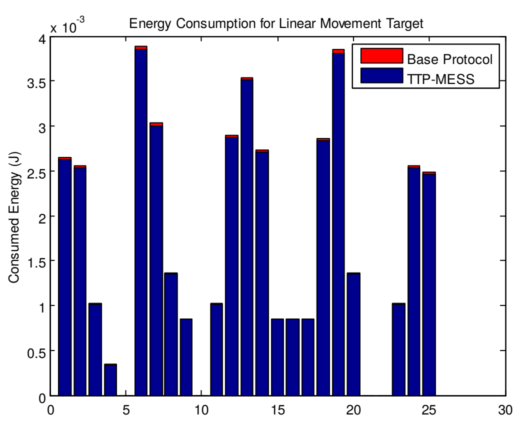


(c)

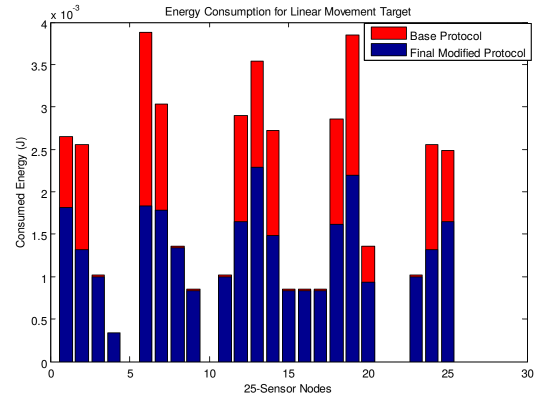
Fig 13 Energy Consumption Comparison corresponding to Fig 9 Circular movement



(a)



(b)



(c)

Fig 14 Energy Consumption Comparison corresponding to Fig 10 linear movement

6. Conclusion and Future Work

We take only one possible scenario of mobile target movement type (straight line movement) so our next step is to expand our protocol to deal with different types of target movement ways (zigzag, circular, random and even zero displacement movement). We conclude that any reduction in message size and number of messages sent or received without increasing error rate or reducing localization accuracy will improve network lifetime and reduce energy consumption per tracking round (which is the aim of many past, present and future researches). Future work will be on scaling the tracking and lifetime modeling network samples and tacking multiple clusters per target into account and applying our modifications on them.

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