Performance Analysis of Wireless Sensor Network Using Localization Combined With MAC Protocol

Suman Pandey*, Member, IEEE

Kamla Nehru Institute of Technology, Sultanpur, Uttar Pradesh, India

***Abstract*: -The efficient localization complementing the services of wireless sensor networks holds promises of diverse application domains each with competing requirements. The resource constraints of WSN necessitate the efficient localization algorithm which optimizes the resource utilization at various network operation levels like data link layer, routing etc. Energy is scarcest reserve of low power sensing devices in WSNs.**

The existing localization algorithms might perform efficiently in smaller networks comprising of one or two hop networks but its performance degrades in multihop sensor networks. Towards improving the performance of WSN the localization algorithm is integrated with media access control (MAC) protocol of data link control of network operation.

In this paper the localization algorithm is seamlessly combined with MAC protocol to optimize the performance of WSNs. The MAC scheme is basically targeted towards achieving load balancing, throughput and energy optimization. A detailed analysis of performances of a ranged based localization algorithm with various MAC standards was performed on the simulator tool NS-2 with varying application scenarios. With the observed data this is concluded that localization algorithm combined with MAC protocol performs more efficiently in terms of energy usage and positioning accuracy in comparison to localization algorithm without MAC. Thus a MAC protocol is instrumental to improve localization along with conserving the energy usage. The observed data further adds that the MAC protocol may also be utilized to enhance coverage and scalability of WSN localization.

***General Terms:* Algorithms, Performance.**

***Keywords:* WSN, Sensor networks, Anchors, MAC, Adhoc, SMAC, localization, mobile.**

I. INTRODUCTION

In recent times localization is most important and integral service of a wireless sensor network which needs be efficiently processed and optimized. The vitality of large number of sensor applications along with some network operation such as tracking the significant events, intruders, estimating the coverage area of WSNs, position based network routing aiming at reducing energy consumption and geo-casting[1-2] is hinged on position estimation capacity.

A sensor network is defined as an adhoc network of sensor nodes encompassing the transducer, microcomputer, transceiver and a power source all in a very small casing are randomly scattered over a region of interest to detect, identify and track targets in order to provide situation awareness, agility of network and predicts the survival of WSN. In most of the applications, sensors are deployed at static place whereas some applications like habitat monitoring as in the ZebraNet [3] sensors are basically connected to live zebras to collect information from their moving patterns and behaviour. In some cases, sensors are mounted on mobile phones to measure the quality of the signals [4] received. With rapid and easy deployment with increasingly low cost of embedded computing power the wireless sensor network has opened vast horizons of new applications. The endurance of sensor applications such as monitoring and surveillance mainly depend on efficient usage of unattended sensors.

Efficiency of the functionality of sensor network is augmented by its localization capability which is used to identify, detect and record the occurring of events with their positional information, transferring packets using position based routing [5]. The manual calculation of location estimation is not workable for large-scale networks and mobile networks. Providing external module (hardware) for localization as GPS [6] is too costlier in terms of energy and cost.

Coverage and life time are the two burgeoning issues of WSN. So developing an efficient localization algorithm is main focus of this work. Following optimization strategies are employed at various design levels of WSN's protocols.

1. At architecture level, it determines appropriate topology by optimizing number of sensor nodes and its distribution over the deployed area and also the placement of base station.
2. At component level tuning of voltage and frequency of processor, sensing frequency are adjusted to get optimized performance.
3. Data Link level employs various strategies for load-balancing, throughput management and controlling the usage of resources of sensor nodes mainly the energy resource.
4. The network level adopts energy efficient routing, query dissemination and data aggregation by resource adaptive and dynamic network reprogramming.

5. Operating system implements event driven and time driven task, dynamic power management and fault tolerance.

This work is focused on the localization algorithm combined with MAC to improve the accuracy of positioning and the other performances as well. The applications of resource constrained WSN necessitates collaboration among algorithms implemented at different layers to conserve various resources.

The basic idea behind this collaboration is as:

- Localization – an inherent service module required mostly in all of WSN applications.
- MAC – providing quality of service by effective and efficient utilization of accute constrained resources in WSN as directly utilizing the service of physical layer.
- Localization Combined with MAC – A basis of localized algorithms which are currently inevitable for scalability, coverage and reliability of WSN application.

Holding the above opinion of collaboration to optimize the wireless adhoc sensor network here a range-based localization algorithm is integrated with a specific MAC protocol and analysed the scope for better positioning accuracy, enhanced scalability and reduced energy consumption. To study the effect of MAC protocol firstly, the proposed model of a range based localization algorithm without a MAC protocol is analysed and then its performance is compared by integrating the localization module with some standards of MAC protocol such as IEEE 802.11 and SMAC. This analysis concludes that energy utilization is conserved with enhancement in the positioning accuracy also and advocates for an efficient localization algorithm combined with optimized MAC protocol.

The organization of paper is as follows. In section 2 the relevant work on localization problem is reviewed to study the perspective view of localization in WSN. The section 3 defines proposed model of localization algorithm and also discusses requirements of MAC schemes. The Section 4 presents simulation of the proposed model with comparative analysis of performance of localization algorithm combined with and without MAC protocols. In final section 5, the work is concluded with mentioning relevant future scope.

II. RELATED WORK

The thorough study of the relevant articles available in literature reveals that most of the localization algorithm is for static sensor networks while very few aims at mobile sensor networks. Future researchers are advised to study [7-8] for a comprehensive literature review. The collection of localization algorithms available are broadly grouped into two groups as briefly discussed in following section.

2.1 The Range Based Localization Schemes:

This group of localization algorithm needs distance or range measurements between pair of nodes for estimating the positioning of an unknown node. To estimate range between the anchor and unknown sensor nodes, it requires additional hardware. Different techniques to measure the range measurements from the target node to anchor node are defined as Time of Arrival (ToA), Angle of Arrival (AoA), time difference of arrival (TDoA), Received Signal Strength Indicator (RSSI) of the received signal ranging techniques.. For example the techniques proposed by Bischoff *et al.* [9] and Bahl*et al.* [10] use received signal strength (RSSI) to estimate distance between two sensor nodes. In the proposal of Ward *et al.* [11] time of arrival of signals is used to measure the range while Niculescu and Nath [12] exploit angle of arrival of signals.

2.2 The Range-Free Localization Schemes:

Under this category of localization the connectivity information such as number of hops between the nodes to localize the unknown nodes of wireless sensor network are used. In most basic localization algorithm APIT [13] every possible triangle of the anchors are formed surrounding the unknown node whose position needs to be estimated. The intersection or common region of all triangles is anticipated to be position of that unknown node. A gradient algorithm [14] similar to distance vector routing technique also estimates distance between a pair of nodes in number of hops. The DV-Hop proposed by N. and Nath [15] is almost similar to Gradient methodology and this also measures the average distance of a hop. Similarly, Sextant [16] developed a distributed positioning technique using B`ezier curves to measure the possible positioning of the unknown nodes. Recently, the radio interferometric approach is a new addition to this range free category of localization. In the approach of range-free methods the distance between nodes are approximated by multiplying hop counts by the average distance of a hop.

For most part and inclusive comparison, the positioning obtained of range-based localization are always more accurate than range-free methods. But none of the above mentioned algorithms were careful to bring down the energy losses caused in localization process. With in-depth analysis of relevant literature, it is worth mentioning here that a localization algorithm generally involves trade-offs between energy consumption and performance in terms of accuracy, coverage and life time of sensor network but this proposal tries to conserve energy along with improved positioning accuracy. A localization scheme integrated with a MAC scheme optimizes ad hoc sensor network as MAC is instrumental in controlling the resource usage in WSN.

This proposal improves the performance in following ways.

- In the localization method the usage of radio channel is controlled by a MAC scheme and may be tuned with the specific requirement by adjusting various parameters such as duty cycle, dynamic contention window size or synchronization period.
- Generally, existing localization schemes perform satisfactorily in smaller network of single hop or two hops but in multihop networks its performance increasingly goes down. With characterizing feature of MAC the scalability and coverage of sensor network within specified threshold is achieved by restricting anchors (on the basis of their remaining energy) contributing in estimating the positioning of an unknown node.

This analysis illustrates the trade offs between achieved accuracy and localization time. In future, different MAC parameters and communication structures can be optimized to improve overall performance.

2.3 Performance of Localization Techniques available in Literature

The following table shown as Table 1 represents the collection of performance (in terms of positioning accuracy with coverage) proposed or available in literature and table 2 shows the average energy consumption by a sensor node in energy efficient localization of a wireless sensor network.

Table 1 Performance of Localization Techniques available in Literature

Sl. no	**Size of Network(m^2) / Radio Range(R)/ Ratio of Anchors to Node / Localization Algorithm**	**Positioning Accuracy in Average Mean Error (in % of radio-range) / Coverage**
1	100m x100m /10m /10% to 30%/ Fine Grained and Dynamic Localization [17]	From 2m to 4m /100%
2	6Rx6R / R /10% to 25% / Structuring a Global Coordinate System using Local Information [18]	0.2R to 0.4R /100%
3	9x9/ R /40 unknown sensor nodes and 4 anchor nodes were deployed / Relative Location Estimation [19]	1.23m in TOA and 2.18m in RSS case / 100%
4	Not defined/ R/ 200 node with fine grained deployment in such a way that at least 9 neighbours are placed in radio range of a sensor node/ Distance Vector Based Positioning Algorithm [20]	< 1- hop (in uniformly distributed deployment case) otherwise > 1-hop but not more than two hops /100%
5	20x20 /R/ the N cols. and N rows with N^2 sensor and 4 anchors/ With Cooperative localization [21]	error Upto 3m that is Upper Bound on rms error /100%
6	10mx10m / sensors of varying range of 1.1m to 1.9m / 200 sensor nodes / 10% / Localization based on Simulated Annealing [22]	Upto 1% error when radio range is 1.8m
7	100x100 /25m / 25/ Using Cooperative Range Based and Mobility Assisted Localization Technique [23]	0.45R / Localization Coverage Upto 90%
8	50x50/ 10m/ 5% to 30%/ With Improved DV-Hop Range Free Localization Algorithm [24]	0.45R to 0.75R /100% coverage
9	10x10/ Not defined/ 48 nodes and 5 to 25 anchors/ Localization algorithms based on RSSI measurements in Indoor WSN[26]	(In RSSI Based ranging) From 2.2 to 4.5 m
10	100mx100m/ 25m / Upto 30% / Localization based on Cooperative Algorithms for Zigbee and 802.15.4a in PAN [26]	0.4R in RSSI Based Ranging and 0.2R in ToA Based
11	100mx100m / 20meter/ Upto 30% of sensors are anchors/ A localization algorithm using Cross Entropy Method [27]	0.4R / 100% Nodes (if number rounds in localization process is increased)

From the data of above table it is clearly observed that obtained positioning accuracy is different for different setup of wireless sensor network and lies in range from 0.2R to 0.5R.

Table 2 Average Energy Consumption by A Sensor Node in Localization of A WSN

Sl. No.	Energy Efficient Localization Algorithm (proposed or available in literature)	Network Description	Average Energy Consumed(in Joule)
1.	Anchor-guiding mechanism for beacon-assisted localization in wireless sensor networks[28]	300x300 $units^2$/ 100 sensors deployed randomly in the grid/ transmission range of 10 meter	12
2.	Energy-Efficient Opportunistic Localization with Indoor Wireless Sensor Networks[29]	100x100$units^2$ /100 sensors deployed/ range of 20 meters	1.5 to 2.0
3.	Range-free Localization Approach for M2M Communication System using Mobile Anchor Nodes[30]	100x100 $units^2$ / 100 sensors deployed / range of 10 meters	0.2 to 0.3

Our work also results in this localization accuracy range but with better performance in terms of energy usage (from .02J to .06J) and scalability and coverage.

III. THE PROPOSED MODEL OF LOCALIZATION WITH MAC SCHEMES

The issues of real-time environment are significantly varies from one domain to another. Moreover, the design and analysis processes involve certain assumptions which constrain the achieved performance in real time sensor application.

3.1 General Assumptions about the WSN

1. Radio links or channels are stable over time and symmetric and follows a radial pattern.
2. A radio transceiver is in one of the states of transmitting, receiving or powered off.
3. It is very common assumption that the medium is free means no other node in the network tries to acquire the network.

3.2 Optimization Model of a Range Based Localization in WSN

Here a weighted graph as triple G (S,E,W) is used to simulate a wireless sensor network where S defines a set of vertices representing sensor nodes and E represents a set of edges connecting any two sensor nodes while W: E $\rightarrow \mathbf{R}$ where $\mathbf{R}$ denotes a set of real numbers used to represent the weight in terms of distance or energy residue of connecting nodes:

- $S = \{S_1, S_2, S_3, \ldots\ldots\ldots\ldots S_n\}$.
- A set E of edges e_{ij} represents a link between node S_i and S_j and $e_{ij} \in E$ iff communication range of S_i and S_j overlaps.
- Energy level of a link e_{ij} is expressed as a weight $w_{ij} \in W$.

Let a network is formed with n sensor nodes scattered over 2-D plane wherein m anchor nodes with known position are also deployed in such a fashion that at least three of them are neighbours. Certain sensor nodes (n-m) in network need their positions be estimated. Before developing analytical model of localization, the symbols and notations used in the work are defined. Symbols that are in bold upper case denote matrices and lowercase bold symbols are used for vectors.

We use $\{\cdot\}^0$ to represent the absolute value while its estimate is represented with $\{\cdot\}$. The $\mathbf{I}_n \in \mathbf{R}^{n\times n}$ defines an identity matrix and $\mathbf{0}_{m\times n} \in \mathbf{R}^{\mathbf{m}\times n}$ and $\mathbf{0}_n \in \mathbf{R}^{n\times n}$ represent zero matrices. If two symmetric matrices $\mathbf{A}$ and $\mathbf{B}$ are such that $\mathbf{A} \succeq \mathbf{B}$ then it is expressed as $\mathbf{A} - \mathbf{B} \succeq \mathbf{0}$ and this represents a positive semi-definite matrix for which all the eigenvalues are positive. The $^{-1}$ and ^{T} represent matrix inverse and transpose operators respectively. The 2-norm of a vector θ is represented through $\|\theta\|_2$ which represents a point in 2-D space [x, y] in Euclidean $\succeq$ space $\mathbf{R}^2$, the length or magnitude of the vector θ is evaluated by the formula $\sqrt[2]{x^2+y^2} = (\theta^T, \theta)^{1/2}$ gives the ordinary distance from the origin to the point as vector θ, a consequence of the Pythagorean theorem.

Let the true or actual positions of sensor nodes are defined using the notation $\theta_i^0 = [x_i, y_i]^T$ for i=1 to n in the wireless sensor network. So positions of m anchors are expressed by θ_1^0, $\theta_2^0, \ldots \theta_m^0$ and θ_{m+1}^0, $\theta_{m+2}^0, \ldots \theta_n^0$ are the positions of unknown sensors. The objective is to estimate θ^0 a vector of true positions of sensor nodes $\theta^0 = [\theta_{m+1}^0, \theta_{m+2}^0, \ldots \theta_n^0] \in \mathbf{R}^{\mathbf{2xk}}$ m<k ≤ (n-m).

Let symbol d_{ij} represents the distance between node (i) and node (j) where i, j = 1, 2, ・・・, n. Without range measurement error, this can be calculated with a mathematical relation

$$d_{ij}^0 = d_{ji}^0 = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (1)$$

$$= \|\theta_i^0 - \theta_j^0\|_2$$

where i,j = 1, 2, . . . ,n

But observed positions are erroneous due to path loss of signals propagating into medium so measured distance between i^th and j^th sensor node here are represented through d_{ij} where $d_{ji} = d_{ij}^0 + \epsilon_{ij}$ i≠j = 1, 2, . . . n. The errors in distance measurement $\epsilon_{ij} \in \mathbf{R}^{1xn}$ can be equated to variances α_{ij}^2 and covariance matrices $C_i \in \mathbf{R}^{\mathbf{2x2}}$ of a Gaussian processes. The energy of the link between i^th and j^th sensor at the time t, is represented by $w_{ij_t} \in \mathbf{R}$ and that is the weight of edge e_{ij} at time t. This decreases with time and defines the life of sensor node. This is observed at the time t, the distance set $\{d_{ij}\}_t$ which is incomplete and varies with time due to limited communication range and exhausted energy level of some nodes .

Let θ be the variable matrix for θ^0 and defined as follows:

$$\theta = [\theta_1, \theta_2, \theta_3 \ldots\ldots \theta_k],\ m < k \le (n\text{-}m).$$

Expressing the error as Gaussian noise the MLE (maximum likelihood expectation) for θ^0, first we use joint density function for all n observations and is equated to

$$\prod_{i=j=1}^{n} f(\{d_{ij}\}|\theta)$$

Here $f(d_{ij}|\theta)$ is pdf, a probability distribution function, θ is unknown parameter that is to be estimated and observed. The d_{ij} is dependent upon signal strength w_{ij}. The maximum likelihood expectation for θ is given by a function $L(\theta|\{d_{ij}\})$ and it can be achieved by maximizing the probability of function $f(\{d_{ij}\}|\theta)$ and it is supposed as P_r.

$$P_r = f(\{d_{ij}\}|\theta)$$

Taking log of it as it always gives monotonically increasing value of the maximum likelihood function $L(\theta|\{d_{ij}\})$ and that is equated to

$$\text{Log} \prod_{i=j=1}^{n} f(\{d_{ij}\}|\theta) \quad (2)$$

$$\sum_{i=j=1}^{n} \log f(\{d_{ij}\}|\theta)$$

With the error ϵ_{ij} in estimation of d_{ij}, the probability P_r can be converted into nonlinear least square problem.

Thus localization problem is expressed as maximizing the (2) and that can be equated to an objective function as a non linear least square problem.

$$\text{Min } \sum_{m+1}^{n} \sum_{j=1}^{n} | d_{ij} - ||\theta_i - \theta_j||_2|^2 \frac{w_{ij_t}}{\alpha_{ij}^2}$$

$$\text{s.t. } w_{ij_t} \geq e_{th}$$

$$d_{ij} \leq r_i$$

w_{ij_t} is equated to 1 if is greater than e_{th} that is minimum threshold value of energy, a sensor is required to have for any transmission and expresses that distance measurements are available otherwise it is kept at 0.

For a scenario suppose i^{th} sensor has transmitted signal with a power P_{ti} to j^{th} sensor that receives signal with strength of P_{rj} or vice-versa then according to Friss equation [31] the following relation exists.

$$P_{ri}-P_{ti}+G_{ti}+G_{ri}+20*\log10(\lambda/4\pi) = 20\log10(d_{ij}) \quad (3)$$

between node(i) and node(j) there is a minimum value of P_{ri} that is dependent upon the power transmitted P_{ti} by the sender and puts a constraint for reliable transmission. G_{ti} and G_{rj} represent the transmission and reception antenna gains respectively. The d_{ij} represents the measured distance for a pair of nodes (i,j).

In this model of localization it is considered that the energy possessed by the node affects the performance of positioning. Our work is to conserve or reduce the loss of energy of a sensor node by adapting a MAC protocol in localization.

3.3 Integrating MAC Performance with Localization of WSN

For a WSN designing an efficient algorithm is really a critical task. The functional model of efficient localization scheme is simulated and analysed including constraints of energy, variance in delay (in reception of data) and the error associated with distance or range measurement data. Radio communication is major energy consumer of any sensor application. A wireless medium works on broadcast principle and shares radio with other transmission which is prone to have interferences. This is ground reasons for MAC to be optimized for localization. Basically, MAC coordinates and controls usage of channel amongst neighbouring nodes. The [32] explains that energy required in sleeping mode is almost negligible in comparison to the energy consumed in awakened mode.

From design perspective, a MAC for WSN is different from the MAC of traditional ad hoc network. The sensor networks differ in operational environment also. In the sensor node's operating network protocol the upper layer are defined with abstract concept of real viable channels whereas MAC directly sitting over physical layer controls the traffic produced by the network layer. The patterns of communication differ in sensor network which monitors the specific environmental status eventually or periodically and send perceived data to a base station. Following section explains other features considered in designing a MAC for localization purpose.

Firstly, the traffic pattern must be exclusively analysed as this is handled truly by a MAC algorithm. The individual node produces data of small payloads periodically and also shows high spatial correlation that increases the protocol overhead. Thus, number of sensor nodes and anchors are to be exclusively restricted for positioning using MAC.

Secondly, the resource constrained sensor nodes also need an optimized MAC to control radio usage to conserve energy.

Thirdly, achieving synchronization is also an issue of sensor networks which necessitates low-cost devices so MAC needing low synchronization is preferred.

Generally, the sensor adhoc networks are deployed with many sensor nodes from hundreds to thousands (in number), so algorithms based on centralized approach do not perform efficiently due to incurred overhead in exchange of information. In contrast, the distributed algorithms, even not the optimal ones, their functionality conform to sensor networks need of efficient channel utilization. Other important design attributes adapt to changes in topology, node density and network size vary with application.

3.3.1 A General MAC Overview

Generally, variable performance of MAC is based on the network-size, capability of interconnecting devices, and requirements of algorithms running in upper layers of sensor network. Still, most of the MAC protocols share some common functions. The MAC regulates the access by defining variable status of sensor node as receiving, sending or sleeping. As radio, while transmitting or listening consumes relatively more power, MAC is efficient way to control usage of channel. Through MAC protocol controlling active and sleep state of WSN node can easily be optimized. Reducing radio consumption means reduction in energy wastages. One of major causes of energy losses is collisions where more than one node tries to access the radio at the same time. The idle listening also causes energy losses means watching channel for no traffic. The overhearing, capturing others' traffic reasons for energy waste. The other significant issue is control packet overhead (packets other than data to schedule and control the traffic) which involves extra consumption of energy. More over variation in consumption of energy, where some nodes closer to sink (base station) need more energy than nodes far from the sink and die out earlier.

3.3.2 Requirements on MAC Scheme for Localization

The basic task of a ranged based localization algorithm comprises of three phases. In first phase, unknown nodes collect range data of their neighbouring anchors. In the second phase the unknown nodes, with the gathered data evaluate their position using some positioning method and finally the whole algorithm is iterated number of times to refine its positioning by neighbour learning process. The whole process involves data communication, data processing and then disseminating the data to base station.

The major energy consumption lies in data communication process involving transmission and reception of range data. Data processing also consumes significant amount of energy in computation and fusion of data. As detailed in [33] the data communication consumes more energy than data processing. If major energy wastage is avoided and data processing is optimized with dynamic load balancing it helps achieve enhanced life of sensor network. Thus MAC adapted to localization is a strong basis to optimize wireless ad hoc sensor network.

Our work is targeted to utilize the duty cycle controlled radio in localization process of WSNs. The localization process integrated with MAC scheme, additionally, requires two measures. Firstly, it needs broadcasting of ranging probes to the anchors to send their position information and secondly, it demands for data processing required to estimate position of the node. To implement the first, MAC should be able to perform even in cases where frequent topology changes occur due to mobility or death of sensor nodes.

1. It requires scheduling of broadcast of ranging control packets in a fixed time period. To achieve, a level of synchronization is needed within a reasonable time (not beyond a value that also varies with application). This time limit should be controlled by the underlying MAC protocol. The loosely synchronized network may create large inaccuracy and lead to energy wastage.
2. To achieve reliability, upon receiving the request packet the anchor nodes must unicast their position data to the requesting node and should be free from any acknowledgements. To implement this idea data exchanges are required to be collected from anchors in assigned duration. This duration must be learnt from the application scenario as it should be of long enough to collect data from neighbouring anchors.
3. The estimation of positioning depends upon basic geometrical method as lateraion, bound box or min max.
4. Allowable latency in positioning varies with size and density of the network and affects the size of location database required for positioning.

The above requirements vary with application scenario and also to the extent of accuracy desired by application. To estimate positioning in real time, MAC integrated with upper layer also must reduce the delay caused to route through the sensor network and reach to the base station. For small sized networks centralized computation might be successful but larger networks need distributed computation schemes.

3.3.3 Basic Standards of MAC Schemes Considered for localization

To develop a localization algorithm to optimize a WSN is target of this study which analyses impact of MAC on the proposed energy constrained model for localization. From the literature, the rulings of MAC schemes caring for energy consumption are considered. It is very difficult to develop efficient schedules with high degree of channel reuse. The other issues of clock synchronization or the varying channel conditions also hamper the benefits realized of WSN.

The carrier sense multiple access policy of MAC protocol is the basic requirement for distributed network topology and non periodic transmission. With large overheads due to increasing network size it becomes a negative factor. So, developing a localization algorithm for WSN approaches for a hybrid MAC scheme based on CSMA principle and also implements TDMA functionality. The MAC schemes conforming to these requirements are considered in this work. In direction to the development of MAC optimizing the localization we considered following MAC schemes:

- *IEEE 802.11*

The media access scheme IEEE 802.11 [34] is basically based on contention and employs carrier sensing and avoid collisions of the data packets using randomized back-offs periods. The power saving mode (PSM) defined in IEEE 802.11 MAC protocol further saves energy by reducing the period of idle listening by going into the sleeping status. This PSM efficiently works in single-hop network as achieving synchronization among neighbours is easily processed. But it becomes quite complex process for multihop networks where problems of neighbour discovery, achieving clock synchronization and network partitioning exist. Despite the issues, this scheme puts efficient energy usage control on designing the architecture of communication, protocols, the topology and the operational environment of network.

- *Sensor MAC*

The sensor S-MAC [35], a modified form of IEEE 802.11 protocol also uses contention to access the channel and was specifically, developed for wireless sensor network. The sensor nodes change the state of listening and sleeping periodically. The time period of SMAC frame is partitioned into two states listening state (transceiver is made ON) and sleeping state (transceiver is made OFF). In a listen period, sensor nodes listen to other nodes using some control packets like Request to Send (RTS), SYNC, ACK (Acknowledgement), Clear to Send (CTS) and unicast DATA packets. The neighbouring nodes synchronize themselves using SYNC packets. The exchange of RTS/CTS between the two nodes facilitates for collision free communication. In this method, energy is conserved using low duty cycle, i.e., the ratio of listen time to a sleep time in a cycle. By putting sensors into sleep state, energy wastage can be controlled and which prolong the lifetime of a sensor network. But this policy also enhances the complexity on the design construct of the architecture of communication and protocols resulting into increased latency.

3.3.4 Modified MAC Frames for Localization

Some important frames are needed to avoid collision in channel access and they are RTS and CTS frames which need to be modified for localization combined with media access control protocols for WSNs. In this work the MAC protocols IEEE802.11 and S-MAC considered and integrated with proposed localization model.

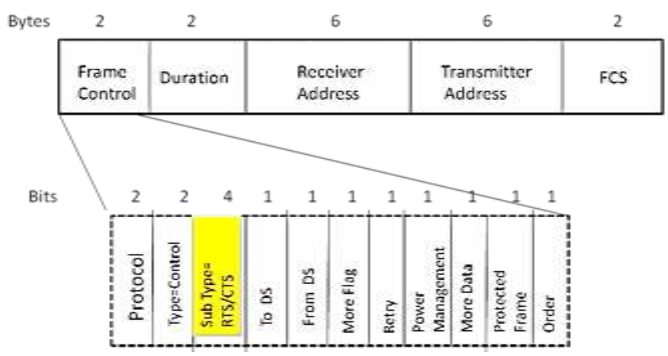

Figure 1 MAC Frame Header of IEEE802.11 and SMAC Protocol

The Figure 1 (above) shows a MAC header for control packets. The control frames, the clear to send (CTS) and request to send (RTS) are modified which improve the performance of the CSMA/CA technique. Two different ways are proposed to implement the MAC's performance in collecting the location information from the anchors. To support localization two types of modifications are made in MAC frames. There is added one more type in sub Type field of MAC frame and assigned a code 0001 (from reserved codes from 0000–1001 existing for this sub type field). Not changing the external frame so same RTS as shown in Figure 2 shown below has been utilized. Similarly for CTS packet two fields Ax and Ay of 1 byte each which are optional fields to collect ranging data are proposed to be added. The Ax and Ay denote the x and y coordinate of anchor node A. The size of Ax and Ay depends upon the size of network which employs number of anchor nodes.

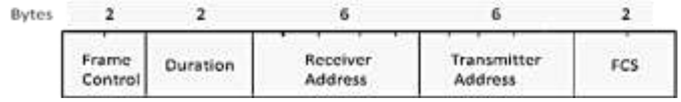

Figure 2 RTS Packet for Localization

Upon receiving the location requests the receiving anchor prepares the CTS packet (CTS for localization purpose) as shown in Figure 3 (below) and by filing the Ax and Ay fields with its position it sends to node who has requested.

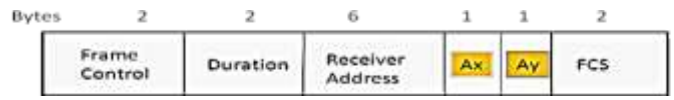

Figure 3 CTS Packet for Localization

Thus RTS and CTS packets are exclusively used to collect location information at the time location data is needed. In this implementation the existing RTS and CTS packets are slightly modified for localization. This consumes very little additional time and energy comparatively.

The other way is to add one more flag in frame control as localization flag for the scenarios where continuous location information is needed for network specific application like routing and coverage. Upon receiving the RTS with localization flag set to '1' the location information is piggybacked to the data frame during data transmission. If time is a factor in real time localization application the exclusive CTS packets can be sent. In this implementation there is no requirement of ACK packet in any case.

Restricting the number of anchors has been implemented in following way. Let the range of an arbitrary sensor is r and it is fact that the anchors nodes lying on the boundary may suffer from more environmental path loss and well as interferences from other nodes. But the nodes nearer to unknown nodes suffer lesser in comparison to anchors lying on the boundary and this also can be estimated about the loss of energy or equivalent distance of anchors from which location data is received. This way it puts a bound on numbers of anchors if unknown node is receiving location data from more than sufficient number of anchors to obtain optimum latency and accuracy desired by the application and this is also implemented at MAC layer checking.

For reducing losses of control packets and its retransmissions request and response packets of MAC frames are basically modified to collect localization data in efficient way. To achieve the MAC performance the neighboring nodes are synchronized using various timers for reducing collision from the other nodes communicating simultaneously. Rest of the S-MAC and IEEE802.11 are kept same.

IV. PERFORMANCE ANALYSIS

The proposed localization model integrated with different standards of MAC protocols was simulated to analyse the performance of WSN over very popular NS-2 tool [36]. In addition to different modules of topography, radio channel and sensor node etc. available in simulator, some modules such as mobility and energy modules were added. Thus the performance of a defined wireless sensor network was analysed and presented using various graphical charts. The topographic area of 100*100 m^2 was considered where in 30 nodes to 80 sensor nodes were scaterred randomly . It was considered that area should not be densly populated as it requires energy in achieving synchronization. So, with ground reasons 30 nodes (as below this number anchors were not able to completely localize the whole area with random deployment) were initialy considered and increased in step of 10 to minutely observe the performance of WSN. Increasing the number of nodes means more data and range probes exchanges i.e. needing more energy. Beyond 80 nodes performance was not improving appreciably but requiring more energy.

4.1 The Localization Accuracy

Here, localization accuracy is normalized with respect to its transmission range so that performance can be predicted for different sizes of networks and for varying transmission ranges of sensor nodes also. The average of mean errors is computed by averaging the errors occurred in positioning at different nodes of WSN application. This way average mean error was estimated and it was compared for localization without a MAC scheme and also with some standards MAC like IEEE802.11 and SMAC. Beyond certain density such as more than 80 nodes in above described scenario it was observed that sensor nodes were depleted early of their energy reserves with very little improvments in the positioning accuracy. Thus it was decided not to increase it further.

In simulation anhor-to-node percentage was was kept at 25%. The increasing number of anchors betters the performance but to find optimum number of sensor nodes required to localize defined deployed area with acceptable positioning accuracy. In the analysis a threshold of node density is obtained which localize the network with acceptable positioning accuracy.

From the Figure 4. it is concluded that the positioning accuracy obtained without a MAC protocol follows an uncertain path and is also not bounded by an upper limit which makes confidence interval undefined.This is important parameter for reliabilty of the localization of WSN. For localization with MAC schemes it is concluded that with increase in node density curve is approaching a deterministic path and upper bound is found at 0.35 R. With SMAC protocol the Figure 4. exhibits a path which is concave downwards. The localization algorithm combined with standards of SMAC protocol give better positioning accuracy by tuning various characterizing parameters of MAC protocol.

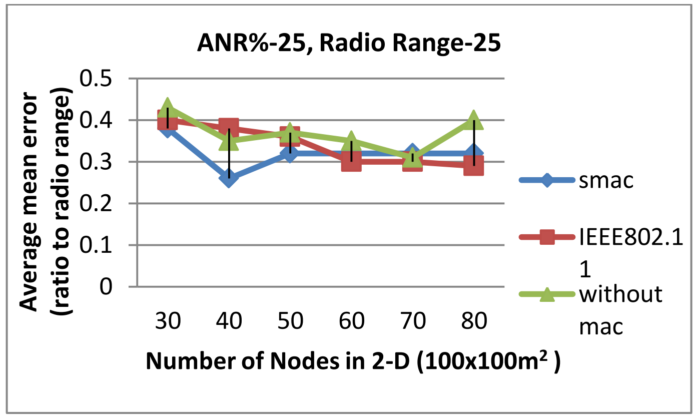

Figure 4. Average Mean Error Versus Number of Nodes

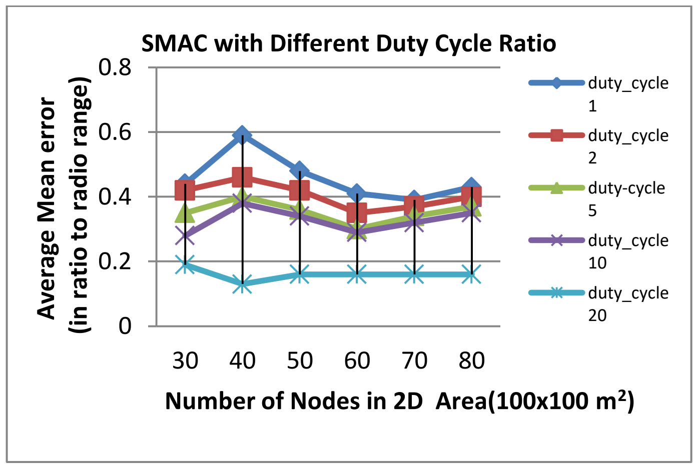

Figure 5. Average Mean Error Versus Number of Nodes with varied Duty_Cycle of SMAC.

The Figure 5. shows that the positioning accuracy also changes with change in duty_cycle of SMAC. So duty cycle can be conformed to the application requirement.The above analysis considers the duty cycle from 1% to 20%. The average mean error is reduced significantly with a slight increase in the duty cycle of MAC protocol. So duty_cycle can be adjusted to give optimum positioning accuracy in a application.

Conclusion:

The above analysis shows that localization algorithm combined with MAC protocols, the obtained positioning accuracy may be achieved upto desired extent of the application by adjusting the various characterizing parameters of MAC.

4.2 Scalability and Coverage:

Enhancing the scalability of network owes to following reasons:

- To enhance the coverage of localization to 100% i.e. whole network (here 100% coverage means that all nodes whose positions are not known must be estimated by the proposed method). If it does not cover the whole network then number of sensors (anchor nodes) must be increased so that localization can cover or localize the whole network.
- The second reason of enhancing the scalability is to enlarge the coverage of deployed network to cover more regions to capture or track the target data needed in monitoring and tracking applications. With the proposed localization module for a given specific deployed area the required node density can be calculated as shown in Figure 6. This also shows the average mean error (localization) which is estimated with required number of nodes in given specific area.

Scalability is easily handled by clustering as explained in above section. The following Figure 6. shows the analysis which is carried out to determine the average node density of deployed area for achieving accuracy in acceptable range. The simulation was started with initial network size of 50x50 m^2 and then the network size is increased in cluster of 25x25 $meter^2$.

The accomodation of more number of sensors do not degrade the positioning accuracy in a specific given area by the proposed localization module as it is clear from Figure 6. (below). The reason behind this improvement is the control of MAC protocol which has put control on number of anchors (participating in position estimation) on the criterion of remaining energy level. This can also be improved with selecting nearest neighbouring sensors. In the following Figure 6. different areas of deployment were taken as $50x50m^2$, $75x75m^2$ and $100x100m^2$ etc. and for each deployement area localization with and without MAC standards were implemented with varying node density from 30 to 80. This is observed and concluded that localization with a MAC scheme improves the positioning accuracy with certain threshold of number of sensor nodes.

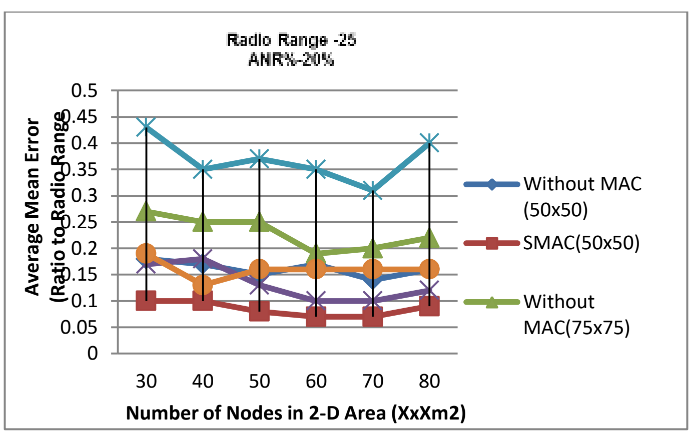

Figure 6. Average Mean Error versus Number of Nodes in 2-D Area (XxX m^2)

Similarly, to anlyze the coverage of localization with and without MAC scheme, different area of deployment (clustered) were simulated and analysis is represented through following Figure 7. The result shows that clustered network with MAC scheme enhances the coverage area of localization within acceptable performance i.e. now larger area is localized with reduced error of positioning in comparison to without MAC scheme.

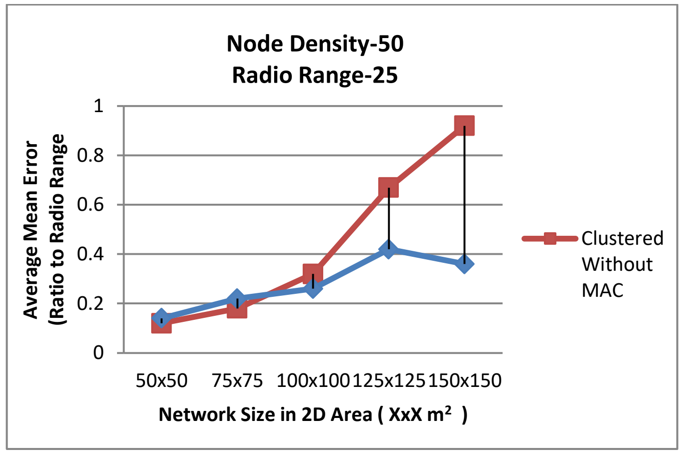

Figure 7. Average Mean Error versus Network Size

4.3 The Average Energy Consumption

The Figure 8. shows average energy consumption by a sensor node in localization model integrated with a MAC scheme and without MAC protocol. From observed performance, it is obvious that using MAC scheme the energy consumption may be controlled significantly. With the needs and operational environment, the energy wastages can be controlled upto a significant extent. In the scenario same as above, the initial energy of a sensor node was assumed to be 5 joule. The average energy consumed by a sensor node in localization is from 0.01 joule to 0.2 joule with node density from 30 nodes to 80 nodes respectively without MAC protocol.

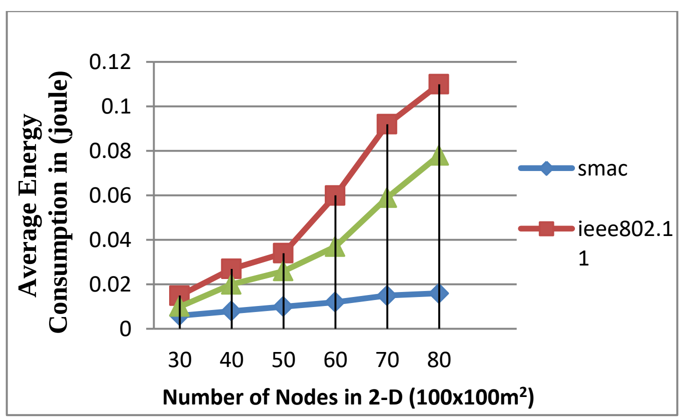

Figure 8. Average Energy Consumption (in joule) Versus Number of Nodes

With the simulation carried with different MAC schemes, the observation shown in Figure 8. concludes that energy consumption may be reduced upto significant amount. The case of SMAC reduces the energy consumption from 0.20 joule to 0.05 joule in case of 80 nodes in same network. The case of IEEE802.11 MAC protocol also reduces the consumption of energy for coarse network in comparison to without MAC protocol but for dense network it is not preferrable as more collisions results into more energy wastage.

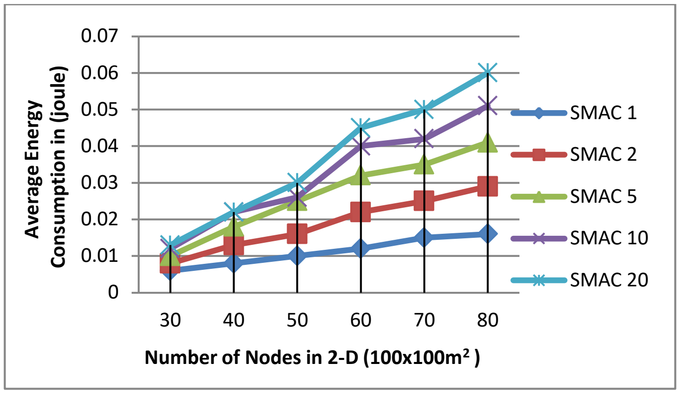

Figure 9. Average Energy Consumption Versus Duty Cycle of SMAC

The above Figure 9. shows the analysis of consumption of energy by a sensor node which varies with varying duty cycle of sensor-MAC protocol. The analysis considered duty-cycle of SMAC from 1% to 20%.

Conclusion:

By optimizing senstivity of tansmitters and receivers energy consumption can be conserved. In the above analysis it is also observed that energy consumption is very sensitive to the parameters of MAC protocols. The values chosen for various interframe spaces such as difs, sifs, guard time also affects the energy consumption. So it must be adjusted to realize the optimum performamce. The duty-cycle of SMAC is very effective parameter to control the dissipation of energy in synchronization, idle listening etc.

V. CONCLUSION AND FUTURE SCOPE

In this work a range based localization model is enhanced for better positioning and performance of wireless sensor network. This proposed model of localization is basically integrated with a media access control algorithm which results into better performance of a sensor network. The simulation study shows that values of various characterizing parameters of the MAC protocol conforming to specific application improves the performance of WSN and also reduces energy dissipation in wireless sensor network which contribute significantly in enhancing the life of sensor network. This way a multi hop wireless sensor networks necessitates usage of a MAC as it is instrumental to optimize the resource utilization of a constrained resources of a sensor node. In future, an optimized media access control protocol must be designed for localization of a WSN to realize better positioning accuracy with optimization of resources of wireless sensor network.

REFERENCES

[1]. T. He, C. Huang, B.M. Blum, J.A. Stankovic, and T. Abdelzher,“Range-Free Localization Schemes for Large Scale Sensor Networks”, Proc. ACM MobiCom ’03, pp81-95, Sept. 2003.
[2]. J.-P. Sheu, S.C. Tu, and C.-H. Yu, “A Distributed Query Protocol in Wireless Sensor Networks”, Wireless Personal Comm., vol. 41, no. 4, pp 449-464, June 2007.
[3]. P. Juang, H. Oki, Y. Wang, M. Martonosi, L. S. Peh, and D. Rubenstein, “Energy-Efficient Computing for Wildlife Tracking: Design Tradeoffs and Early Experiences with Zebranet”, In Proceedings of ASPLOS, pp 96–107, 2002.
[4]. S. Tilak, V. Kolar, N. B. Abu-Ghazaleh, and K. D. Kang, “Dynamic Localization Control for Mobile Sensor Networks” in 24th IEEE International Performance, Computing, and Communications Conference (IPCCC), pp 587–592, 2005.
[5]. B. Karp and H. T. Kung, “GPSR: Greedy Perimeter Stateless Routing for Wireless Networks”, in Proceedings of the Sixth Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom), pp 243–254, 2000.
[6]. B. Hofmann, H. Lichtenegger, andJ. Collins,“Global Positioning System, Theory andPractice” Springer-Verlag, 1993.
[7]. J. Bachrach, C. Taylor and I. Stojmenovic, “ Handbook of Sensor Networks: Algorithms and Architectures, :Wiley”, 2005
[8]. A. Savvides, C.. Han, and M. B. Strivastava,“Dynamic Fine-Grained Localization in Ad-hoc Networks of Sensors”, in Proceedings of the 7th Annual International Conference on Mobile Computing and Networking (MobiCom), pp 166–179, 2001.
[9]. U. Bischoff, M. Strohbach, M. Hazas, and G. Kortuem,“Constraint-Based Distance Estimation in Ad-hoc Wireless Sensor Networks”, in Proceedings of theThird European Workshop on Wireless Sensor Networks (EWSN), pp54–68, 2006.
[10]. P. Bahl and V. Padmanabhan, “RADAR: AnIn-Building RF-Based User Location and Tracking System” in Proceedings of INFOCOM, pp 775–784,2000.
[11]. A. Ward, A. Jones, and A. Hopper, “A New Location Technique for the Active Office”, IEEE Personal Communications, 4(5):42–47, 1997.
[12]. D. Niculescu and B. Nath, “Ad hoc Positioning System (APS) Using AoA”in Proceedings of INFOCOM, pp1734–1743, 2003.
[13]. T. He, C. Huang, B.M. Blum, J.A. Stankovic, and T. Abdelzher, “Range-Free Localization Schemes for Large Scale Sensor Networks,” Proc. ACM MobiCom ’03, pp 81-95, Sept. 2003.
[14]. R. Nagpal, H. Shrobe, and J. Bachrach,“Organizing a Global Coordinate System from Local Information on An Ad hoc Sensor Network”, in Second International Workshop on Information Processing in Sensor Networks (IPSN), pp333–348, 2003.
[15]. D. Niculescu, B. Nath,“Ad hoc Positioning System (APS)” in Proceedings of GLOBECOM, pp 2926–293, 2001.
[16]. S. Guha, R. Murty, and E. Sirer, “Sextant: A Unified Node and Event Localization Framework Using Non-Convex Constraints”, In ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc), pp 205–216, 2005.
[17]. A. Savvides, C. Han, and M. B. Strivastava, "Dynamic Fine-Grained Localization in an Ad-hoc Networks of Sensors", in Proceedings of ACM MobiCom, pp 166- 179, 2001.
[18]. R. Nagpal, H. Shrobe, and J. Bachrach, “Organizing a Global Coordinate System from Local Information on an Adhoc Sensor Network”, Proc. of IPSN, LNCS 2634, Springer , pp 333-348, 2003.
[19]. N. Patwari, A. O. Hero, M. Perkins, N. S. Correal, and J. Robert, “ Relative Location Estimation in Wireless Sensor Networks”,

Signal Processing, IEEE Transactions, vol. 51 , no.8 , pp 2137-2148, 2003.

[20]. D. Niculescu and B. Nath, "DV Based Positioning in Adhoc Networks", Journal of Telecommunication Systems, 22(1-4), pp 267-280, 2003.

[21]. N. Patwari, J. N. Ash, S. Kyperountas, A. O. Hero III, R. L. Moses, and N. S. Correal, "Locating the Nodes: Cooperative Localization in Wireless Sensor Networks", IEEE Signal Process.Mag., pp 54–69, 2005.

[22]. A. A. Kannan, G. Mao and B.Vucetic, "Simulated Annealing Based Localization in WSN", Journal of Computers, vol. 1, no. 2, pp 15-22, 2006.

[23]. H. Chen, P. Huang, H.C. So, X. Luo, and P. Deng, "Mobility-Assisted Cooperative Localization Scheme for Wireless Sensor Networks", In Proc. Military Communications Conference MILCOM'08, pp 1-7, 2008.

[24]. H. Chen, K. Sezaki, P. Deng and H.C.So, "An Improved DV-Hop Localization Algorithm for Wireless Sensor Networks", Proc. IEEE Conference on Industrial Electronics and Applications, pp 1557-1561, 2008.

[25]. G. Zanca, F. Zorzi, A. Zanella and M. Zorzi, "RSSI Based Localization Algorithms for Indoor Wireless Sensor Networks", REALWSN'08, pp 1-8, 2008.

[26]. A. Moragrega, and C. Ibars, "Performance Analysis of Cooperative and Range Based Localization Algorithms for Zigbee and 802.15.4a Wireless Sensor Networks", Proc. IEEE Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), pp 1996- 2001, 2010.

[27]. M. A. Azim, Z. Aung, W. Xiao, and V. Khadkikar, "Localization in Wireless Sensor Networks by Cross Entropy Method", in Proc. International Conference on Adhoc Networks, pp 103-118, 2012.

[28]. C.-T. Chang, C.-Y. Chang, and C.-Y. Lin, "Anchor-Guiding Mechanism for Beacon-Assisted Localization in Wireless Sensor Networks," Sensors Journal, IEEE, vol. 12, no. 5, pp 1098–1111, 2012.

[29]. F. Xia1, X. Yang, H. Liu, D. Zhang and W. Zhao, " Energy-Efficient Opportunistic Localization with Indoor Wireless Sensor Networks" in ComSIS Vol. 8, No. 4, Special Issue, October 2011, DOI: 10.2298/CSIS110406063X.

[30]. L. Karim, N. Nasser, Qusay, H. Mahmoud, A. Anpalagan,and T. Salti, "Range-free Localization Approach for M2M Communication System using Mobile Anchor Nodes" in Journal of Network and Computer Applications 47 · August 2014

[31]. H.T. Friis, "A Note on a Simple Transmission Formula", Proc. IRE, vol. 34, no. 5, pp 254–256, 1946.

[32]. A.Bachir, M.Dohler, T.Watteyne and K.K.Leung, "MAC Essentials for Wireless Sensor Networks" Vol.12 , Issue: 2,Communication and Survey Tutorials, IEEE pp 222 – 248, 2010

[33]. R.Yadav, S.Varma, and N. Malaviya, "A Survey OF MAC Protocols For Wireless Sensor Networks", UbiCC Journal, Volume 4, Number 3, pp827-33, 2009.

[34]. IEEE Standard 802.11. Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications (1999).

[35]. W. Ye and J. Heidemann, "An Energy-Efficient MAC Protocol for Wireless Sensor Networks", IEEE Infocom, pp 1567-1576,June 2002.

[36]. Patrik Moravek, "NS2 Simulator Capabilities In Nodes Localization in Wireless Networks", A research Work Was Supported by the Czech Science Foundation - Project No. 102/07/1012.