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Enhancement of Network Lifetime Using Mobile Sink Node in Wireless Sensor Networks

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Abstract: - **Wireless Sensor Networks (WSNs) consist of a large number of sensor nodes deployed in a given region of interest to fulfil tasks such as area surveillance, biological detection, home care, object tracking, and sending information to sink nodes via multihop communication. The data collection from sensor nodes using mobile sink has been studied in Energy Harvesting Wireless Sensor Networks (EH-WSNs) with most focus on throughput maximization. The existing system used a Mixed Integer Linear Programming (MILP) Optimization model is introduced for energy harvesting based data collection and also designed two efficient algorithms namely Optimal Distance per Slot Allocation Algorithm (ODSAA) and Optimal Distance Allocation Algorithm (ODAA) for two practically implementable scenarios with fixed sink mobility model. However, high delay and packet loss incurred due to the fixed sink mobility model. The proposed system used a Particle Swarm Optimization (PSO) model based two efficient algorithms namely ODSAA and ODAA with Destination Sequence Distance Vector Routing Protocol. This system reduces the delay and packet loss by varying the sink mobility model using Sink Speed Allocation Algorithm and increases the Network Lifetime and Throughput. Another thing is Trust Values or Threshold Values are calculated based on the node behavior reported by their neighbors. The simulations are done by using network simulator and the parameter such as lifetime; total data collected by sink node, packet loss, delay, trust values are analyzed.**

Keywords **– Energy Harvesting Wireless Sensor Networks (EH-WSNs), Mobile Sink, Network Lifetime, Throughput Maximization.**

I. INTRODUCTION

A Wireless Sensor Network (WSN) is a wireless network consisting of spatially distributed autonomous devices which use the sensors in the network to monitor the physical and the environmental conditions. A WSN system uses a gateway that provides the wireless connection to the wired network and the nodes in the network [1]. WSN is one of the most standard and important services employed in both the commercial and the industrial applications, due to its technical development in a node, network, processor, communication, and low-power usage of embedded computing devices. The WSN is the combination of several nodes that are used to observe the surroundings like temperature, humidity, pressure, position, vibration, sound etc. The nodes in the WSN can be used in various real-time applications to perform various tasks like smart detecting, a discovery of neighbor node, trust value calculation, data processing, data storage, data collection, target tracking, monitor and controlling, synchronization, node localization, and effective routing between the source node and the base station [4]. WSNs are beginning to be organized in an enhanced or developed step. It is not awkward to expect that in 12 to 15 years that the world will be protected with WSNs with entree to them through the Internet. This beginning can be measured as the Internet becoming a physical network. This technology has an infinite potential for many application areas like engineering, medical, environmental, transportation, military, entertainment, homeland defense, crisis management and smart spaces.

A WSN is one kind of wireless network which includes large number of moving, roaming, circulating, self-directed, minute, low powered devices named sensor nodes called motes. These motes networks cover a large number of spatially distributed, little, small, battery-operated, embedded devices that are networked to collect the data, process the data, and transfer the data to the operators, and it has controlled the capabilities of computing and processing the data. Nodes are the small computers, which work together to form the networks in the WSN [13], [2]. The sensor node in the WSN is a multi-functional, energy efficient wireless device. The applications of motes in industries are huge. A collection or the group of sensor nodes in WSN collects the data from the surroundings to achieve the required or the specific application objectives.

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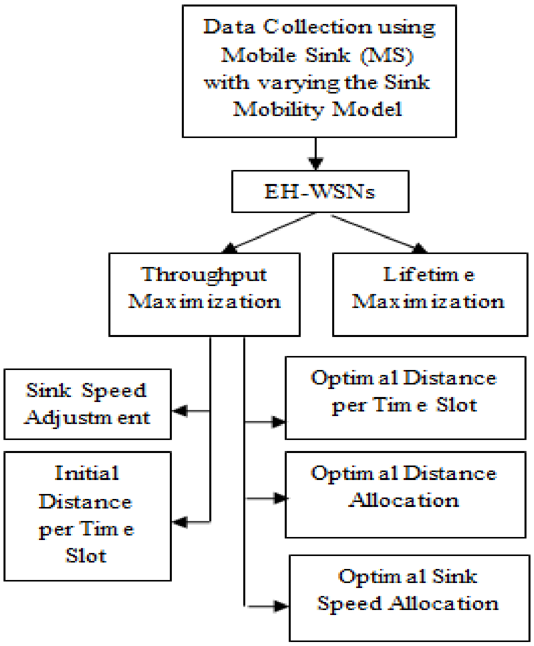

Fig. 1 Data collection in WSNs

Fig. 1 describes about the data collection in WSNs using Mobile Sink (MS) with varying the mobility pattern under different objectives. Data Collection is carried out by using MS with varying the Sink Mobility Model. It is used to collect the data from the source node and reaches the destination. The existing System uses the fixed Sink Mobility Model. There are many advantages in the fixed mobility model; however, high delay and packet loss are occurred due to the fixed Sink Mobility Model [1]. Furthermore, the motion of sink with a constant speed throughout the process can unnecessarily waste its energy. Static and Mobility based sink placement schemes are used to handle the data collection process. Mobile sinks are used to increase the network lifetime with delay constraints. Random mobility and Controlled mobility models are the different types of mobile sinks. In random mobility the sinks are moved randomly anywhere within the network. The mobile sinks are deterministically moved across the network is referred to as controlled mobility [1], [4]. The network lifetime is calculated with the number of nodes and delay values.

Energy harvesting in WSN which is also known as power harvesting or energy scavenging or ambient power is the process by which energy is derived from external sources for example solar power, thermal energy, wind energy, salinity gradients, and kinetic energy, also known as ambient energy, captured, and stored for small, wireless autonomous devices, like those used in wearable electronics, electrical and wireless sensor networks. For Energy Harvesting the Energy harvesters provide a very small or little amount of energy for low-power or low-energy electronics. While the input fuel to some large-scale generation costs resources that are oil, coal, etc., the energy source for energy harvesters in WSN is present as ambient background. For example, temperature gradients exist from the operation of a combustion engine and in urban or rural areas; there is a large amount of electromagnetic energy in the environment because of radio and television broadcasting due to the satellite in the Wireless Communication [1], [11], [13].

The data collection from the source nodes are carried out by EH-WSNs which most focus on throughput maximization. If throughput is maximized means altogether Network lifetime also improved. Here Optimal Distance per Time Slot algorithm is used to find an optimal distance that sink travels in the network. According to the distance the Optimal Distance Allocation is calculated which is used to allocate the shortest path for better transmission. Finally Optimal Sink Speed Allocation is calculated for allocating the speed for the MS. This allocation is not permanent which changes for every slot that is for every different transmission. By varying the mobile sink speed, different distances for time slots subsequently determine the time duration of time slots which their values vary depending on the optimal distance of each slot.

II. RELATED WORKS

Due to the development in WSNs architecture based on the mobile sinks, the data collection using a mobile sink has been extensively studied by several researchers [1], [2], [5], [11]. Fig. 1. shows a classification of works on data collection in WSNs using a sink with varying the mobility pattern under different problem objectives. Francesco et al. [2] survey thoroughly the data collection and energy harvesting works in WSNs using the mobile sinks. From the prospective of sink mobility, the Fixed Sink Mobility pattern where the mobile sink moves on a path-constrained trajectory has found many research attentions due to its wide range of applications [4], [5], [6]. Using a path-constrained sink for data collection and energy harvesting from one-hop sensor nodes not only improves the network throughput [7] but also reduces the data delivery latency [8].

On the other side, due to the recent advancement in energy harvesting wireless sensor networks, the sensor nodes can harvest energy periodically from the resources in their surroundings such as wind, solar or vibrations [8], [15], [4]. EH-WSNs, the data collection scheme follows two objectives: Throughput Maximization, Network Lifetime Maximization. Due to the constrained imposed on the

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energy of sensor nodes in EH-WSNs, the authors in [6], [13] introduce the problem of data collection from far away wireless sensors using relay nodes close to the trajectory of mobile sink with the objective of maximizing overall network lifetime. [13] Introduce the problem of collecting data from sensor nodes with the objective of maximizing throughput and network lifetime under the constraint that data delivery delay must satisfy the network deadline. Therefore, the data collection algorithms in EH-WSNs do not take into account the throughput and the lifetime maximization as long as the wireless sensors have the possibility of energy replenishment. Ren and Liang [6] investigate the problem of data collection from the energy harvesting nodes using a mobile sink under the constraint that the overall data delivery latency must meet the network deadline. Basically, most of the works on data gathering using a mobile sink node in EH-WSNs are defined with the objective of network throughput and lifetime maximization [5], [8], [3]. Due to the fixed mobility model there occur some problem the main disadvantage is the NTM problem in an EH-WSNs using a path constrained mobile sink [1] and in order to improve the network throughput, the authors in [8] propose a condition on a fixed distance travelled by mobile sink at all time slots. Motivated by the disadvantage of considering fixed mobility model travelled by sink and its constant speed in [1], [3] the proposed system consider a mobile sink by varying its sink speed per time slots. Altogether the trust values or the threshold values for each node has to be calculated, here in the proposed system the trust values are set in-between 0 to 1. Trust value means it a value which is calculated based on the node behavior reported by their neighbors. Threshold value is 0.5 the node having above 0.5 acts as good trusted nodes and below 0.5 is act as selfish node.

A. Contributions

The following are our main contributions in our paper:

A Particle Swarm Optimization model is a computational method which is used to detect the problem by repeatedly trying to improve a solution that is the candidate solution with regard to a given measure of quality. This PSO is used with two efficient algorithms namely ODSAA and ODAA with the Destination Sequence Distance Vector Routing Protocol this helps to maximize the Network Lifetime and Throughput using Mobile Sink Nodes in Wireless Sensor Networks.

To improve the data collection rate Optimal Distance per Slot Allocation Algorithm (ODSAA) is used to allocate the shortest path for each and every time slots and Optimal Distance Allocation Algorithm for calculate the distance from the source node to the base station (ODAA). This system reduces the delay and packet loss by varying the sink mobility model using Sink Speed Allocation Algorithm.

Trust Values are calculated based on the node behaviour reported by their neighbours. Trust values or Threshold values means it a value which is calculated based on the node behavior reported by their neighbors that is the neighbor node. Trust values or Threshold values is 0.5 the node having above 0.5 acts as good trusted nodes and below 0.5 is act as selfish node.

Furthermore, the energy harvesting distribution, we find out an analytical threshold on the battery capacity such that the capacity exceeds that trust value, the network throughput is calculated. As an advantage, these EH-WSNs are help to minimize the cost of energy harvesting resources in practical data collection scenarios.

III. DATA COLLECTION AND ENERGY HARVESTING MODELS

Mobile sink node is used for data collection and energy harvesting. It can collect data anytime and anywhere in the WSN. Therefore, the research on data collection methods is becoming increasingly very important. To overcome the challenges of Data gathering and enhancement of lifetime of mobile nodes the system propose a new data gathering technique with mobile sinks based on PSO technique. Particle changes its condition according to the following three principles in the PSO algorithm: (1) to keep its inertia (2) to change the condition by its most optimist position (3) to change the condition according to the swarm is the most optimist position.

In Mobile sink wireless sensor networks (MSWSN) Sensor nodes are low cost devices with limited storage, computational capability and power. Mobile sink has no resource limitation. It has a wide range of application in the real world problem like military and civilian domain etc. The nodes in the WSN are unattended and unprotected so energy efficient and security are two major issues of sensor network. The sensors have limited battery power and low computational capability, requires a security mechanism that must be energy efficient. In this proposed system model mobile sink traverse the network to collect the data. Here we proposed energy efficient secure data collection techniques with mobile sink wireless sensor networks. In proposed data collection technique mobile sink traverse network and collect data from one hop neighbors.

The sensors are remained stationary during the data collection. A mobile sink with large data buffer size moves on the path as its trajectory to collect data from the nodes in one-hop of its transmission range along the path. The total time duration of one round path traversal by sink is divided into several consecutive time slots. Due to the physical interference between nodes transmitting simultaneously, the mobile sink receives data successfully from at most one

sensor node for the whole transmission period of node at each time slot [9], [13], [6]. Furthermore, for initiating the data collection process and in order to localize the duration of message exchange between the sink and sensor nodes, following the work in [13], we consider the continues duration of every two consecutive time slots as one time interval. Based on the sensors' information which is provided to the sink through message passing at the beginning of each time interval, the sink makes decision on which nodes must send their data at the current time interval.
The amount of harvested energy varies at different time intervals therefore is non-deterministic. The amount of harvested energy by nodes at the beginning of each time interval which for the sake of simplicity, the system assume that follows a uniform distribution in this work is provided to the mobile sink through message passing when sink is located at the beginning of interval. Following the widely adopted energy model [9], the worst case is when the energy consumption rate of node is more than its energy harvesting rate. Therefore, the sensors must preserve their harvested energy during each time interval.

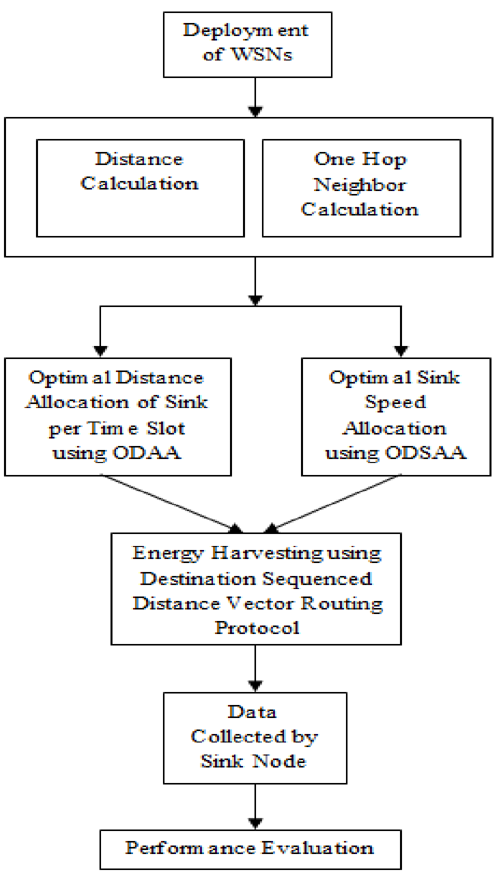

Fig. 2 System Architecture

Fig. 2 explains about the System Architecture. In EH-WSNs, maximizing the data collection throughput is one of the most challenging issues. In this paper, we consider the problem of data collection on a pre-specified path using a mobile sink which has a fixed-mobility pattern. As a generalization of the previous works, we propose an optimization model for the problem which incorporates the effective and heterogeneous duration of sensors' transmission in each time slot. To improve the network throughput, a simple condition is proposed which determines the maximum number of available time slots to each sensor node. Accordingly, the proposed condition specifies the constant velocity of the mobile sink. The NP-Hardness of the problem under the proposed condition is proved and an online centralized algorithm with less complexity is designed to handle the problem. Its complexity is in polynomial order and is easily scalable to the networks with large number of sensor nodes. Furthermore, we address the effect of increase in time slot period on the total amount of collected data which has not been yet exploited well. Finally, through extensive simulations on different set of deployed nodes, we observe that the proposed algorithm significantly increases the network throughput when the travelled distance by sink per time slot is reduced down to the adjusted point.

IV. PROBLEM STATEMENT

We consider a Wireless Sensor Network with large amount of sensor nodes including one sink node. Each nodes in the network are supplied by energy whether mobile sink nodes large amount of energy. The Sink node can also harvest energy from the nodes which are stable in the wireless network for future use. As typically assumed [5], [2], the sink node is powered by unconstrained power source and each sensor node harvests less energy than what it consumes. Nodes can transmit their data to the sink node through the links in a multi-hop manner. The Sink node collects data from the source and delivers the data to the destination. The data collection and energy harvesting models is defined as the problem of allocating time slots to the nodes considering their energy budget such that the total collected data by sink is maximized. Let dij denote the data transmission rate of node ni at time slot tj. Variable vij is used to denote the time duration in which the mobile sink can collect the data from the node ni at time slot tj. Corresponding to this time period, the mobile sink travels a distance dij on the path within the coverage range of ni at the time slot tj. Note that the node ni can have three possible deployed locations for its (xi,yi) coordinate at time slot tj which are when its communication covers two consecutive time slots tj-1,tj,only time slot tj or two consecutive slots tj,tj+1. With fixed value of l, it is straightforward to see that

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the value of dij, $1 \leq i \leq |V|$, $1 \leq j \leq |T|$, in all three deployed locations is obtained from the following relation:

$$d_{ij} = \begin{cases} Max\left\{\left\{Min\left(l_j, x_{end}\right) - Max\left(l_{(j-1)}, x_{start}\right)\right\}, 0\right\} & r_i > y_i \\ 0, & r_i \leq y_i \end{cases}.$$

Where xstart and xend are respectively the starting and ending intersection points of node's projection with the path. Furthermore, the binary variable aij is defined to indicates the allocation of time slot tj to sensor node si such that aij ¼ 1 if time slot tj is allocated to sensor node si and aij ¼ 0, otherwise.

TABLE 1
The List of Defined Parameters in Network Throughput Maximization

System Parameter	Parameter Description
|V|,|T|	The number of nodes and time slots
L,l	Fixed path length and fixed distance travelled by sink at all time slots
v_m	Constant speed of the sink
D_{ij}	Data transmission rate of node
n_i	Nodes
t_j	Time slot
y_{ij}	Time duration in which the mobile sink can collect data from the sensor
d_{ij}	The mobile sink travels a distance on the path within the coverage range
(x_i, y_i)	Cartesian deployed location of nodes s_i
x_{start},x_{end}	The Starting and Ending intersection points of nodes

A. Network Formation

Network Formation is the first step in the Wireless Sensor Networks. There are 85 nodes are randomly deployed with an area of 1500 x 1500 in the network animator. The nodes are having the uniform energy of 300J. The mobile sink and base station is deployed in this network. The mobile sink is deployed with the energy of 500J. Here the nodes are transferring the information between neighbor nodes about their location, id and neighbor nodes list. Here node 84 is mobile sink and node 85 is base station.

B. Optimal Distance per Time Slot

The objective of this module is to find an optimal distance that sink travels all time slots for that distance such that the network throughput is maximized assuming that sink maintains a constant speed during its trajectory on the path. Since the time duration of each time slot is not known in advance, with constant sink speed, the optimal distance subsequently determines the time duration and the number of time slots for the trajectory of sink on the path. Considering l here as a real decision variable which its value determines the distance for which sink travels all time slots, the first constraint of this problem scenario is Max {Ri, $1 \leq i \leq |V|$} $\leq l \leq L$. This condition implies that each sensor node has maximum two available time slots for data transmission to the sink.

C. Optimal Distance Allocation

Assuming that the mobile sink maintains a constant speed during whole of its trajectory on the path, the objective is to determine different optimal distances for time slots in order to further improve the network throughput. Note that under this scenario, the total number of time slots is fixed at |T| and the time duration of time slots are not known in advance. With constant sink speed, different distances for time slots subsequently determine the time duration of time slots which their values vary depending on the optimal distance of each slot. Denoting lj, $1 \leq j \leq |T|$ as the distance considered for time slot tj, the objective is to find the optimal distance vector lv = {l1, l2, . . . ; l |T|} for which the network throughput is maximized.

D. Optimal Sink Speed Allocation

For the third scenario, with total number of |T| slots and assuming the fixed distance l considered for all time slots, the objective is to determine the optimal sink speed vj for each time slot tj, $1 \leq j \leq |T|$ in order to achieve the maximum throughput. Since the distance is fixed for all time slots, the optimal speed at each time slot subsequently determines the time duration that sink must spend at that slot. With the aforementioned notations, the problem of optimal sink speed allocation with the objective of maximizing the network throughput (NTM-OSS) can be formulated as the following mixed integer nonlinear programming (MINLP) optimization model. Note that parameters Tdeadline, vmin and vmax are used to denote respectively the data delivery deadline, the minimum and the maximum speeds which can be allocated to sink at all time slots.

E. Energy harvesting using Destination Sequenced Distance Vector Routing Protocol

Destination-Sequenced Distance-Vector Routing (DSDV) is a table-driven routing scheme for ad hoc mobile networks based on the Bellman–Ford algorithm. The main contribution of the algorithm was to solve the routing loop problem. Each entry in the routing table contains a sequence number, the sequence numbers are generally even if a link is present; else, an odd number is used. The number is generated by the destination, and the emitter needs to send out the next update with this number. Routing information is distributed between nodes by sending full dumps infrequently and smaller incremental updates more frequently. If a router receives new information, then it uses the latest sequence number. If the sequence number is the same as the one already in the table, the route with the better metric is used. Stale entries are those entries that have not been updated for a while. Such entries as well as the routes using those nodes as next hops are deleted.

F. Trust Value Calculation

The proposed baseline trust protocol uses beta (α, β) distribution modelling in which a trust value is in the range of [0, 1] as a random variable where α and β represent the amounts of positive service evidence and negative service evidence respectively, such that the estimated mean trust value of a node is α/(α+β). A node uses the mean of Beta (α, β) distribution as the trust value it has toward another node. When a task which a node participated in is executed successfully (unsuccessfully), this node's α is incremented by $\Delta\alpha$ (β is incremented by $\Delta\beta$ correspondingly). For severely punishing the malicious behaviour, set $\Delta\beta \gg \Delta\alpha$. A "penalty severity" parameter is denoted by $\Delta\beta{:}\Delta\alpha$ to analyze its effect of trust penalty severity on our trust protocol performance. For all nodes, the initial α and β values are 1, representing ignorance with the initial trust value of 0.5.

V. PROBLEMS APPROACH

The proposed optimization models belong to the combination of branch and bound with linear programming relaxation can be applied to achieve the optimal solution of MILP models [5]. However, the computational complexity of the branch and bound significantly grows when the number of sensors or time slots increases. As another approach, one may apply the exhaustive method for searching one candidate for real decision variable from its domain for which the linear programming relaxation on its corresponding ILP sub problem results in the best upper bound. However, there is no guarantee on the optimality of the candidate value for real decision variable since there is no theoretically proven approximation factor for the relaxation technique.

Greedy Allocation Heuristic (GAH)

Input: |T|: Number of Time slots, |V| : number of sensors

Output: Allocation of |T| time slots to $|V|$sensor nodes

1: **for** each time slot 1 ≤ t ≤ |T| **do**

2: Neighbor(t) ←The set of nodes whose their transmission range covers the sink trajectory at t

3: for each sensor *s* ε Neighbor(t) **do**

4: energyBudget(*s*)←energyBudget(*s*)+harvestedEnergy

5: **end for**

6: eligibleNodes(t) ← The set of nodes from Neighbor(t) which satisfy constraint;

7: **for** each sensor *s*\` ε eligibleNodes(t) **do Compute** Throughput(*s*\`)

8: **end for**

9: *Sselect* ←*arg* $\max_{¥s€eligible\ Nodes(t)} \{Throughput(s)\}$

10: **Allocate** timeslot *t* to S*select*

11: **Update** energy budget of S*select*

12: overallThroughput ← overallThroughput + Throughput(S*select*)

13: **end for**

14: **return** overallThroughput

A greedy algorithm is an algorithmic paradigm that follows the problem solving heuristic of making the locally optimal choice at each stage with the hope of finding a global optimum. In many problems, a greedy strategy does not in general produce an optimal solution, but nonetheless a greedy heuristic may yield locally optimal solutions that approximate a global optimal solution in a reasonable time. For example, a greedy strategy for the traveling salesman problem (which is of a high computational complexity) is the following heuristic: "At each stage visit an unvisited city nearest to the current city". This heuristic need not find a best solution, but terminates in a reasonable number of steps; finding an optimal solution typically requires unreasonably many steps. In mathematical optimization, greedy algorithms solve combinatorial problem shaving the properties of mastoids.

VI. PROPOSED ALGORITHGMS

Algorithm 1. Optimal Distance per Slot Allocation Algorithm (ODSAA)

Input: Initial distance per time slot

l= Max (R_i, l≤ i≤ $|v|$)

Output: Optimal Distance per time slot

1: Throughput ← solution of GAH for subproblem ILP-ODTS(l,{a_{ij}})

2: **while** Throughput is increasing **do**

3: l← l + Δl

4: Throughput ← solution of GAH for subproblrm ILP-ODTS(l,{a_{ij}})

5: **end while**

6: **return** l, Throughput;

The greedy algorithm is run for the first round and the average of throughput at each time slot is obtained. Within a number of iterations equal to the number of time slots, the algorithm slightly updates the distance that sink must traverse at each time slot based on the amount of available data. More precisely, if the available data in the current time slot is below the average value, the algorithm decreases the distance at that time slot proportional to the difference between the average and available throughput at that time

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slot. Obviously, more available data to be collected less reduction in distance. The reverse operation is per-formed by the algorithm if the throughput at the current time slot is above the average. As a constraint, this updating process must satisfy the feasibility of distance vector. In other words, both constraints [4] and [6] must be satisfied during the updating process. The constraint (15) can be simply checked by performing two comparisons to ensure that the updated distance falls within the allowed range. To satisfy constraint [3] at each iteration, after updating the distance of the beginning time slots, the remaining slots are allocated with a distance which is the average of difference between the path length and residual distance. Two further conditions guarantee the validity of the allocated distance to the remaining time slots.

Algorithm 2. Optimal Distance Allocation (ODAA)
Input: Initial distance vector $l_v = \{l_1, l_2, \ldots l_{|T|}\}$ where $lv(k) = Max(Ri, l \leq i \leq |V|), €1 \leq k \leq |T|$
Output: Optimal distance vector and optimal throughput

```
overallThroughput ← solution of GAH for
        subproblem ILP-ODA (l_v,{a_ij})
optThroughput ← overallThroughput, optDVector ← l_v
for each l ≤ iteration ≤ |T| do
  aveThr ← overallThroughput / |T|
  for each 1≤ t ≤ iteration do
    l_r(t) = l_v(t) +
        (Throughput(t) – aveThr) / aveThr
    if l_v(t) < l_min OR l_v(t) > l_max then
      lv(t) = lv(t) +
        (aveThr – throughput(t)) / aveThr
    end if
  end for
  sumofDistance ← Σ_{t=1}^{iteration} l_v(t)
  aveDistance ← (L – sumofDistance) / (|T| - iteration)
  if aveDistance < l_min then
    lv(t) = lv(t) –
      ((lmin – aveDistance) ∗ (|T| - iteration)) / iteration
        £1≤ t ≤ iteration
  end if
  if aveDistance > l_max then
    l^v(t) = l_v(t) +
      ((aveDistance – l_max) ∗ (|T| – iteration)) / iteration
        £1≤ t ≤ iteration
  end if
  sumofDistance ← Σ_{t=1}^{iteration} l_v(t)
  aveDistance ← sumofDistance / (|T| - iteration)
  l_v(t) ← aveDistance, €iteration + 1 ≤ t ≤ |T|
  overallThroughput ← solution of GAH for
  subproblem ILP – ODA(l_v,{a_ij})
  if overallThroughput > optThroughput then
    optThroughput ← overallThroughput
    optDvector ← l_v
  end if
end for
return optDVector , optThroughput
```

The greedy allocation heuristic is run on the updated distance vector and the obtained throughput is compared with the best one found yet. The algorithm finally returns the optimal distance vector along with the maximum achievable throughput after the completion of all iterations. Since at each iteration, the distance of all time slots from the beginning up to the current iteration is updated based on the throughput achieved in the previous round, therefore, the convergence of the best solution returned by algorithm which as we show later provides the desired approximation factor is guaranteed. The body of the proposed algorithm called Optimal Distance Allocation Algorithm (ODAA) has been summarized in Algorithm 2.

VII. ENERGY HARVESTING THRESHOLD

One important factor which affects the network throughput is the amount of harvested energy by sensor nodes at each time interval. Although increasing the amount of harvested energy causes the increase in throughput, there is a threshold on the harvested energy such that the network throughput becomes saturated when the sensors harvest energy more than the threshold. The reason is due to the selection of at most one eligible sensor at each time slot by the mobile sink. The increase in harvested energy yields the increase in throughput until in all time slots, the energy consumption of the sensor node with maximum available data falls below its energy budget. Obviously, after this point, by increasing the harvested energy, no more data can be collected by the sink. Having the system parameters, we are interested here to find the above-mentioned threshold. We note that since from the data collection model, the sensors send data with fixed transmission rate and for whole of the period that cover the sink's trajectory on the path and also sink has large data buffer size, therefore, the parameters such as sink's buffer size or the data size in sensor's queue have no effect on the threshold on energy harvesting. However, the battery capacity of nodes as a realistic parameter is considered in the derivation of this threshold.

In the following derivations, we assume the uniform distributions for the amount of harvested energy by nodes, the transmission range, the transmission rate and initial energy level of nodes denoted by random variables h, R, r and I, respectively. For each of the above-mentioned variables, the corresponding minimum and maximum values are considered for the uniform distribution and, therefore,

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the middle point of min and max is the average value of that random variable. Furthermore, the variable C is defined as a random variable to indicate the energy consumption of an eligible node for data transmission to sink within a time interval. We note that since the amount of harvested energy by nodes changes within a uniform interval, therefore, we are motivated to find out the analytical threshold on the energy harvesting mean.

$$\text{Thresholdh} \approx \begin{cases} \frac{3B+pK-3I}{3+p}, & B \leq k \\ \frac{(3+p)K-3I}{3+p}, & B > K \end{cases}$$

A. Battery Capacity Threshold

Another important factor which affects the network throughput is the battery capacity of sensor nodes. The experiment shows that although the increase in battery capacity causes the increase in throughput but after a thresh-old point, the network throughput becomes saturated by increasing the capacity. The reason is that initially, the harvested energy by nodes is bounded by the low battery capacity and therefore increases in the capacity leads to the increase in throughput. But this increase is up to the point when the capacity of nodes has enough space to accommodate the initial and available energy for harvesting. Although after this threshold sensors have enough battery capacity, there is no more energy to be harvested and therefore the throughput becomes stable. We are here interested to find out theoretically the threshold on battery capacity when the mean of energy harvesting distribution is given.

In the following, we denote B as the identical battery capacity of all sensor nodes. As it is seen from comparing the average energy budget of nodes in both Cases 1 and 2 in Theorem 4, for every eligible node si 2 S, the battery capacity must be at least:

$$B \geq \max\{I_i + h_i, I_i + h_i - C_i, I_i + 2h_i - C_i, I_i + 2h_i\} = I_i + 2h_i$$

Since the above inequality must be satisfied for all eligible sensor nodes, therefore, we get the following result for the threshold on bttery capacity of nodes.

VIII. EXPERIMENTAL RESULTS

In this section, we evaluate the performance of three data collection algorithms ODSAA, ODAA, proposed in this work, and Adjustment Based-Allocation [11] in terms of network throughput, energy efficiency and computational complexity.

A. Simulation Setup

In the Simulation setup for the system parameters and its corresponding value the number of sensor nodes are 85 the path length is around 1500 * 1500. The Sink speed is 7.5 m/s and the Sensors Transmission Range is Uniform and the Sensors Transmission Rate is also Uniform and the Energy Harvesting Distribution is also Uniform. The Battery Capacity of nodes is also uniform the nodes energy rate is 300 joule and the sink energy rate is 500 joule. The Battery Capacity is 4500 joule. The Probability of Battery Failure is 0.05. The Time Slot period for ODSAA is a Variable and the Time Slot for ODAA is also a Variable. The Adjustment Based Allocation is 2 Seconds.

TABLE 2
The List of System Parameters and their Corresponding Values used in the Simulations

<table>
<tr><th>System Parameter</th><th colspan="3">Corresponding Value (ODSAA, ODAA, Adjustment based Allocation)</th></tr>
<tr><td>Number of Sensor Nodes</td><td colspan="3">85</td></tr>
<tr><td>Path Length</td><td colspan="3">1500 * 1500</td></tr>
<tr><td>Sink Speed</td><td colspan="3">7.5 m/s</td></tr>
<tr><td>Nodes Energy Rate</td><td colspan="3">300 Joule</td></tr>
<tr><td>Sink Energy Rate</td><td colspan="3">500 Joule</td></tr>
<tr><td>Sensors Transmission Range</td><td colspan="3">Uniform</td></tr>
<tr><td>Sensors Transmission Rate</td><td colspan="3">Uniform</td></tr>
<tr><td>Energy Harvesting Distribution</td><td colspan="3">Uniform</td></tr>
<tr><td>Battery Capacity of nodes</td><td colspan="3">4500 Joule</td></tr>
<tr><td>Probability of Battery Failure (P_f)</td><td colspan="3">0.05</td></tr>
<tr><td rowspan="2">Time Slot Period</td><td>ODSAA</td><td>ODAA</td><td>Adjustment Based Allocation</td></tr>
<tr><td>Variable</td><td>Variable</td><td>2 Sec</td></tr>
</table>

B. Performance Evaluation

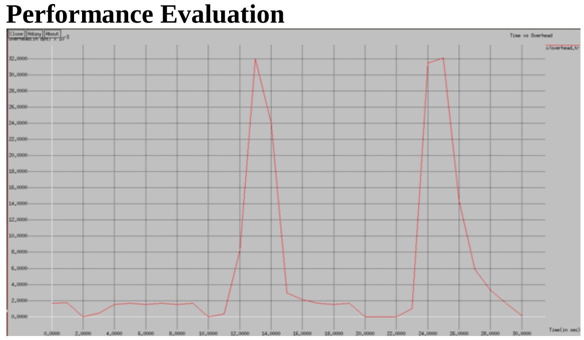

Fig. 3 Overhead

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Fig. 3 shows the snapshot of overhead graph. The overhead of a network is the utilization of extra resources for data transmission.

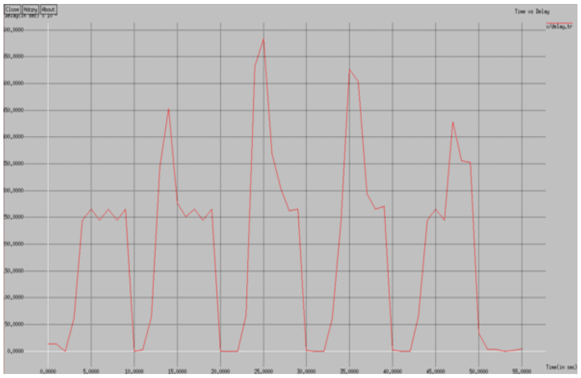

Fig. 4 Delay

Fig. 4 shows the snapshot of delay. Delay represents the time taken for data transmission to destination from source node. Here the simulation time is 55 sec. Each second some data is transferred from one to another node. This graph shows the time taken for data transmission at each time.

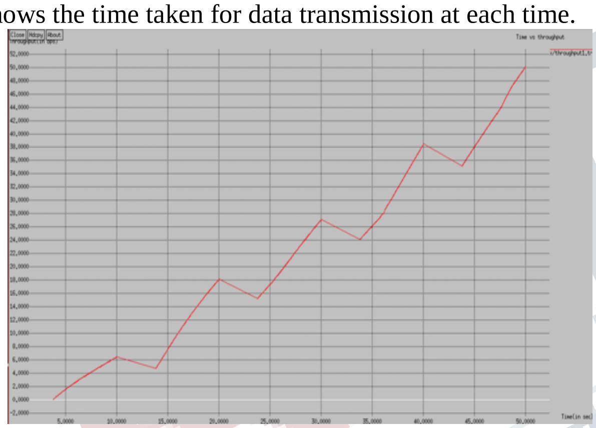

Fig. 5 Throughput

Fig. 5 shows that throughput graph. Throughput is number of bits received at destination graph is plotted between time versus throughput. Each time the number of bits transferred at destination is recorded and plotted as graph.

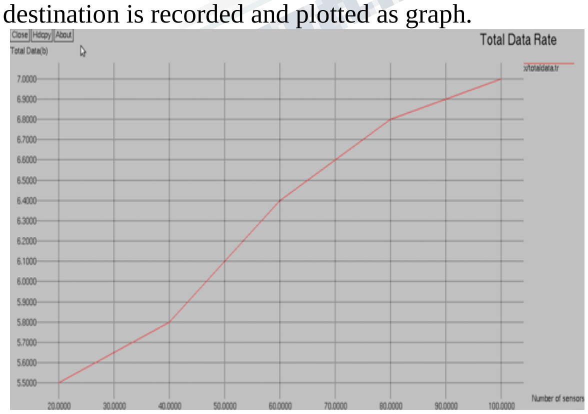

Fig. 6 Total data rate

Fig. 6 shows the snapshot of total data rate. The graph is plotted between no. of sensor nodes vs total data rate. The number of sensor node increases the total data rate will be increased.

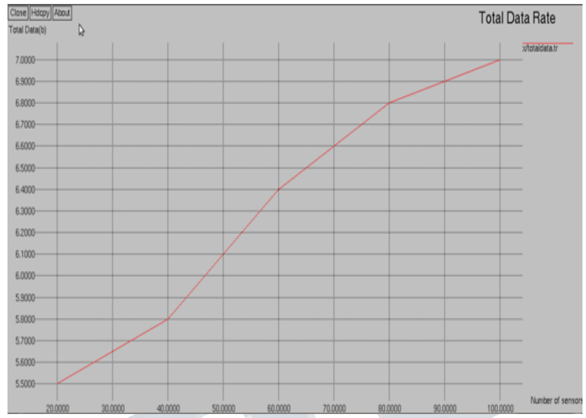

Fig. 7 Energy consumption

Fig. 7 shows the graph of energy consumption. The energy consumption of nodes is plotted between no. of sensor nodes versus energy in percentage. Here the maximum energy consumption is around 26% of initial energy.

IX. CONCLUSION

Mobile Sink Node in Wireless Sensor Networks for data transmission reduces the delay and packet loss and increases the Network Throughput and Lifetime. The simulations are done by using network simulator and the parameter such as lifetime; total data collected by sink node, packet loss, delay, trust values are analyzed.

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