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Adaptive Route Design for Wireless Sensor Networks with Multiple Mobile Sink in Delay Tolerant Mobile Applications

Gunjan madaan*
Department of Computer Science,
Maharishi Markandeshwar
University, India

Dr. Devendra Prasad
Department of Information Technology,
Maharishi Markandeshwar
University, India

Abstract— Wireless Sensor Network has specific characteristics and requirements that are unique. The fundamental function of Wireless Sensor Network is the gathering of information from a covered area. Information thus gathered by the Sensor Nodes deployed in the network is processed by sink nodes according to the applications. Motivated by their tremendous potential in civil and military applications, Wireless Sensor Network raised tremendous research interests in recent years. One of the most active research areas in wireless sensor networks is to establish the route to deliver the information gathered by Sensor Nodes deployed in the deployment area. Here a scheme is proposed to establish route in delay tolerant application. In the proposed scheme within a prescribed delay tolerance level, nodes need not to send the data immediately as they become available. Instead, the nodes store the data temporarily and transmit them when the mobile sink is at the most favourable location for achieving the longest WSN lifetime. We also develop an algorithm that decides the criteria with which the mobile sink visits the subset of nodes. To find the best solution we formulate optimization problems that maximize the lifetime of the WSN subject to the delay bound constraints, node energy constraints and flow conservation constraints. Extensive computational experiments are conducted on the optimization problems and the lifetime can be increased significantly as compared to not only the stationary sink model but also more traditional mobile sink models.

Keywords- Wireless sensor networks, static sink, mobile sink

I. INTRODUCTION

Wireless Sensor Networks (WSNs) consist of small nodes with sensing, computation, and wireless communications capabilities. Many routing, power management, and data dissemination protocols have been specifically designed for WSNs where energy awareness is an essential design issue.

A Wireless Sensor Network (WSN) is consisting of spatially distributed autonomous devices using sensors which enable pervasive, ubiquitous, and seamless communication with the physical world. A few common applications are military, security, habitat monitoring, industrial automation, and agriculture, environmental observation and forecasting. WSN comprises numerous sensor devices, which can contain several sensors to monitor the physical entities such as temperature, contains 2 hundreds or thousands of sensor nodes communicate either among each other or directly to the base station (BS). A BS is a fixed PE or mobile PE that is capable (SNs)/Processing Element (PE) that have the ability to of connecting the sensor network to an existing communication infrastructure or to the Internet. One of the most important requirements of WSN is to reduce the energy consumption. There is a need for energy efficient communication and routing techniques that will increase the network life time [4]. However, due to limited computing and storage resources, the sensors are not equipped with an enriched operating system that can provide energy efficient resource management; thus, the application developers are responsible to incorporate energy efficient communication and routing strategies [5-6, 7-8].

Although WSNs are similar to traditional mobile ad hoc networks (MANETs), there exist some fundamental differences between them [2].The focus, however, has been given to the routing protocols which might differ depending on the application and network infrastructure. In this paper, a route is established to deliver the information gathered by Sensor Nodes deployed in the deployment area. A scheme has been proposed to establish route in delay tolerant application. In the proposed scheme within a prescribed delay tolerance level, nodes need not to send the data immediately as they become available. Instead, the nodes store the data temporarily and transmit them when the mobile sink is at the most favourable location for achieving the longest WSN lifetime. An algorithm is also developed that decides the criteria with which the mobile sink visits the subset of nodes. To find the best solution optimization problems are formulated that maximize the lifetime of the WSN subject to the delay bound constraints, node energy constraints and flow conservation constraints. Extensive computational experiments are conducted on the optimization problems and the lifetime can be increased significantly as compared to not only the stationary sink model but also more traditional mobile sink models.

II. RELATED WORK

The aim of any route design scheme is to establish path among the sensor nodes with minimum energy consumption and improve network lifetime. In [9], the authors formulated a linear programming problem to maximize the lifetime of a WSN where the sensor nodes are deployed in a grid pattern and the sink can move to a subset of the grid points. When the location of the mobile sink is known to the sensor nodes, each node can identify the minimum hop-count paths to the sink. The nodes distribute the data evenly onto these paths.

Luo and Hubaux [10] further investigated a joint mobility and routing algorithm with mobile relays to prolong the lifetime of WSNs. They showed that showed that the network lifetime can be extended significantly if the mobile sink moves around the periphery of the WSN. They assumed that, if the mobile sink can balance the traffic load of the nodes, the lifetime of the network can increase. Therefore, they proposed an optimization problem for choosing a mobility strategy that minimizes the maximum traffic load of the nodes. However, they assumed the shortest path routing, which, in general, does not produce the best lifetime. Gu *et al.* [11] proposed a partitioning-based algorithm to schedule the movement of mobile elements, which minimizes the required moving speed and eliminates buffer overflow. Their solution was customized for an "Eye" topology, where the events are concentrated at certain locations. Solutions for sensor networks with general distributions remain to be explored.

Somasundara *et al.* [12] further formulated the problem of scheduling the mobile element with deadlines and presented earliest deadline- and minimum-weight-based heuristics. Recently, mobile elements have been suggested for assisting data delivery in diverse wireless networks. Pathirana *et al.* [13] examined the location estimation and trajectory predication for mobile base stations with a focus on cellular networks. Our analysis demonstrated that our algorithm can successfully track the mobile users with less system complexity, as it requires measurements from only one or two closest mobile base stations. Further, the technique is robust against system uncertainties caused by the inherent deterministic nature of the mobility model**.** Zhao *et al.* [14] proposed a message ferrying approach to address the network partition problem in sparse ad hoc networks. The MF design exploits mobility to improve data delivery performance and reduce energy consumption in nodes. For sensor networks, Shah *et al.* [15] presented an architecture using moving entities (*data mules*) to collect sensing data. They have presented architecture to connect sparse sensor networks at the cost of higher latencies. The main idea is to utilize the motion of the entities that are already present in an environment to provide a low-power transport medium for sensor data. There have also been studies on mobile sinks with predictable and controllable movement patterns. In [16] authors explored a novel avenue of saving power in sensor networks based on predictable mobility of the observer (or data sink). Predictable mobility is a good model for public transportation vehicles (buses, shuttles and trains), which can act as mobile observers in wide area sensor networks.

In [17] researchers have proposed methods by which the network can take advantage of mobile components. We exploit mobility to develop a fluid infrastructure where mobile components are deliberately built into the system infrastructure for enabling specific functionality that is very hard to achieve using other methods. Built-in intelligence helps our system adapt to run time dynamics when pursuing pre-defined performance objectives. The prototype system has clearly established the feasibility of using a mobile networking device for data gathering.

Recently, Bisnik *et al.* [18] studied the problem of providing quality coverage using mobile sensors and analyzed the effect of controlled mobility on the fraction of events captured. Their focus, however, is not on the route design.

Our work is motivated by the above studies. The key difference is that focus is laid on adaptive and distributed route design for multiple mobile elements in WSANs, specifically, actuators moving along independent routes. Also, the non uniform weights of the static sensors with a novel probabilistic solution is addressed.

III. SYSTEM MODEL

One of the most active research areas in wireless sensor networks is the coverage. Coverage is usually interpreted as how well a sensor network will monitor a field of interest. Coverage can be measured in different ways depending on the applications. In addition to coverage it is important for a sensor network to maintain connectivity. Connectivity can be defined as the ability of a sensor node to reach the data sink. If there is no available route from a sensor node to the data sink then the data collected by that node can't be processed. Each node has a communication range which defines the area in which another node can be located in order to receive data. This is separate from the sensing range which defines the area a node can observe. The two ranges may be equal but are often different.

In this section, a scheme is proposed for route design in WSNs in delay tolerant applications by using a mobile sink when the underlying applications tolerate delayed information delivery to the sink so as to maximize the lifetime of WSNs.

Existing mechanism to prolong the network life of energy-constrained wireless sensor networks incurs an additional delay for packet delivery when each node needs to wait for its next-hop relay node to wake up, which could be unacceptable for delay-sensitive applications. Prior work in the literature has proposed to reduce this delay using any cast, where each node opportunistically selects the first neighbouring node that wakes up among multiple candidate nodes. Joint control problem of how to optimally control the sleep-wake schedule, the any cast candidate set of next-hop neighbours, and any cast priorities, to maximize the network lifetime subject to a constraint on the expected end-to-end delay. Here an efficient solution is given to this joint control problem. Our numerical results indicate that the proposed solution can substantially outperform prior heuristic solutions in the literature, especially under the practical scenarios where there are obstructions in the coverage area of the wireless sensor network.

Secondly, the communications in the WSN has the many-to-one property in that data from a large number of sensor nodes tend to be concentrated into a few sinks. Since multi-hop routing is generally needed for distant sensor nodes from the sinks to save energy, the nodes near a sink can be burdened with relaying a large amount of traffic from other nodes. This phenomenon is sometimes called the "crowded centre effect" or the "energy whole problem".

It results in energy depletion at the nodes near the sink too soon, leading to the separation of the sink from the rest of nodes that still have plenty of energy.

A. *Related lifetime maximization problems:-*

In this section, related lifetime maximization problems are being discussed and later their performance is compared with new proposal.

Let the set of sensor nodes be denoted by N or experimental convenience, we suppose they are uniformly randomly deployed into a circular area with radius R. Let the centre of the disk be the origin. Each node i is assumed to generate data at a constant rate of d_i during its life span and the initial energy of i is denoted by E_i. Furthermore, the nodes have the ability of adjusting their transmission power level to match the transmission distance. Similar to [30], the energy required per unit of time to transmit data at the rate of xij from node i to j can be determined as follows.

$$E_{ij}=C_{ij} \cdot x_{ij} \quad \text{......(1)}$$

Where C_{ij} is the required energy for transmitting one unit of data from node i to j and it can be modeled as follows [31].

$$C_{ij} = \alpha + \beta \cdot d(i, j)^{e} \quad \text{......(2)}$$

Where d(i, j) is the Euclidean distance between node i and j, α and β are nonnegative constants, and e is the path loss exponent. Typically, e is in the range of 2 to depending on the environment. Here, the energy cost per unit of data does not depend on the link rate, and this is valid for the low rate regime. Hence, we need to assume that the traffic rate x_{ij} is sufficiently small compared to the capacity of the wireless link.

The energy consumed at node i per unit of time for receiving data from node k is given by [30]

$$E_{ki} = \gamma \cdot x_{ki} \quad \text{......(3)}$$

where γ is a given constant. Hence the total energy consumption per unit time at node i is

$$E_{ij} + E_{ki} = C_{ij} \cdot x_{ij} + \gamma \cdot x_{ki} \quad \text{......(4)}$$

B *Problem formulation:-*

Interested is laid on maximizing the delay lifetime of event-driven wireless sensor networks, for which events occur infrequently. Any cast forwarding schemes is optimized for minimizing the expected packet-delivery delays from the sensor nodes to the sink. Based on this result, a solution is provided to the joint control problem of how to optimally control the system parameters of the mobile sink model scheduling (MSM) protocol and the any cast packet-forwarding protocol to maximize the network lifetime, subject to a constraint on the expected end to end packet-delivery delay.

Any cast packet-forwarding scheme is developed to reduce the event-reporting delay and to prolong the lifetime of wireless sensor networks employing asynchronous sleep-wake scheduling. Specifically, two optimization problems are studied. First, when the wake-up rates of the sensor nodes are given, an efficient and distributed algorithm is developed to maximize the expected event-reporting delay from all sensor nodes to the sink. Second, using a specific definition of the network lifetime, lifetime-maximization problems are studied to optimally control the sleep-wake scheduling policy and the any cast policy, in order to maximize the network lifetime subject to a upper limit on the expected end-to-end delay. Our numerical results suggest that the proposed solution can substantially outperform prior heuristic solutions in the literature under practical scenarios where there are obstructions in the coverage area of the wireless sensor network.

C *Network Setup:-*

In the *mobile sink model* (MSM), sink moves around within the sensor field and stop at certain locations to gather the data from the sensor nodes. The traveling time of the sink is ignored between nodes. Our aim is to maximize the network life in applications that can tolerate a certain amount of delay. Each node postpones the transmission of data until the sink is not at the favourable location (sink stop) for extending the network life. This way, the nodes can collectively achieve a longer network life.

The nodes do not always participate in the communication for all the sink stops; they each wait until the sink's location is most favourable for energy saving, and then send data at the higher rate. Recall that we have assumed that the traffic rate is sufficiently small compared to the capacity of the wireless link, and hence, sending data a higher rate does not alter the per-bit energy consumption.

Figure 1 shows the proposed model where the mobile sink visits all the nodes in order to collect the data in order to achieve maximum lifetime and maintain energy efficiency.

a) ***Phase 1:-*** A scheme is proposed and formulated optimization problems that maximize the lifetime of the WSN subject to the delay bound constraints, node energy constraints and flow conservation constraints. Extensive computational experiments are conducted on the optimization problems and the lifetime can be increased significantly as compared to not only the stationary sink model but also more traditional mobile sink models. Also, the delay tolerance level does not affect the maximum lifetime of the WSN.

b) ***Phase 2*** **Sub-Flow-Based Model:-** In the *sub-flow-based model*, the nodes in the current coverage are not allowed to buffer the relayed traffic from other nodes; as soon as a node in receives the data from other nodes, it immediately forwards the data to its neighboring nodes. To model this constraint at each node i, we need to differentiate the data generated by node i itself and the data originally generated by other nodes but forwarded to node i. The data generated by the same source is sometimes called a *commodity* or a *sub-flow model.*

c) Phase 2 **Queue-Based Model:-** In the *queue-based model*, the sensor node can buffer the commodities or sub-flows of all nodes. The energy constraints can be expressed in the same way as in the MSM or sub-flow based MSM

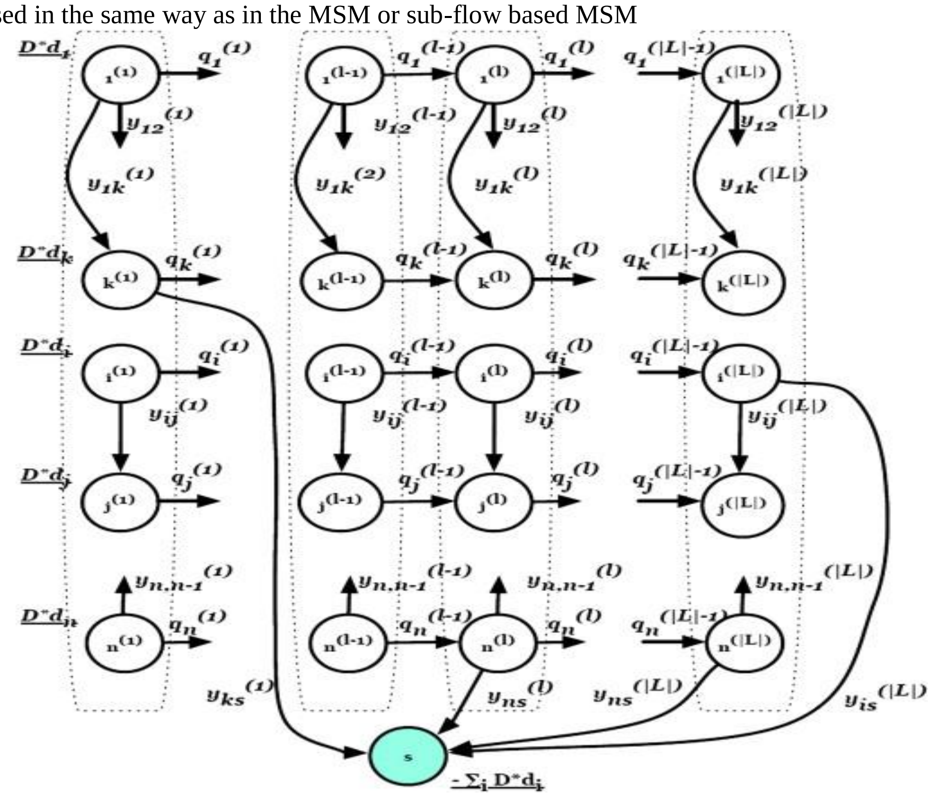

Fig. 1 Network setup under proposed scheme

In both sub-flow-based model and queue-based model, the coverage of the sink location is a very important factor for the lifetime of the WSN. Consider the optimization problem formulated for the sub-flow-based model. Depending on the radius of coverage, we may obtain different instances of the optimization problem. This observation is also valid in the queue-based model.

IV. RESULTS AND DISCUSSION

The following values of various parameters are considered during the simulation of the presented scheme.

- Number of sensor nodes deployed in the sensor field can be 100 or 200
- Number of possible sink locations i.e. distance of various nodes from sink at (in m) can have values as {5,6,7,8,9,10,15,20,30,40}
- Possible values of path loss component(e) as mentioned in section 3.1 are {2.0,3.0}
- Transmission range between a pair of nodes can have values (in m) : {5,6,7,8,9,10,15,20,30,40,50}
- Constant α as mentioned in section 3.1 has value $10pJ/bit/m^2$
- Constant β as mentioned in section 3.1 has value $0.0013pJ/bit/m^4$
- Initial energy(E_i) of the mobile sink is 500J
- Data generation rate(d_i) of the sensor nodes is 500bps

A. *Modules:-*

a) Random deployment of nodes:-This module creates the nodes (sensors) according to the network capacity. Here it will show in a draw panel. While the creation itself, all the nodes shows their associated calls and initially it will be zero.

b) Connection establishment:-After the creation of the nodes, connection between the nodes will establish. Connections are based on two conditions, by finding nearest neighbours and by connecting to the isolated nodes.

c) Communication messages:-Each node should connect to the calls made by the devices, according to the node capacity and call duration. If network capacity is less, there will be failed calls. User can see the list of total calls made.

d) Graphs:-Graph module is the important one to see the network capacity and to know what the network condition is. Graph draws according to the average number of hops and number of completed calls. This also shows which nodes are currently in the sleep state

B. *Figures and Tables:-*

Specifically, for a wireless sensor network where each node is provisioned with an initial energy all nodes are required to live up to a certain lifetime criterion. Since the objective of maximizing the sum of rates of all the nodes in the network can lead to a severe bias in rate allocation among the nodes, we advocate the use of lexicographical max-min (LMM) rate allocation.

To calculate the LMM rate allocation vector, we develop a polynomial-time algorithm by exploiting the parametric analysis (PA) technique from linear program (LP), which we call serial LP with Parametric Analysis (SLP-PA). We show that the SLP-PA can be also employed to address the LMM node lifetime problem much more efficiently than a state-of-the-art algorithm proposed in the literature. More important, we show that there exists an elegant duality relationship between the LMM rate allocation problem and the LMM node lifetime problem.

Our focus is on the communication energy consumption. A naive approach to the LMM rate allocation problem would be formulated to apply a max-min-like iterative procedure. Under this approach, successive LPs are employed to calculate the maximum rate at each level based on the available energy for the remaining nodes, until all nodes use up their energy. As it turns out, for the LMM rate allocation problem, any iterative rate allocation approach that requires energy reservation at each iteration is incorrect the LMM rate allocation problem, there usually exist non-unique flow routing solutions corresponding to the same rate allocation at each level. Consequently, each of these flow routing solutions will yield different available energy levels on the remaining nodes for future iterations and so forth, leading to a different rate allocation vector, which usually does not coincide with the optimal LMM rate allocation vector.

We develop an efficient polynomial-time algorithm to solve the LMM rate allocation problem. We exploit the so-called parametric analysis (PA) technique at each rate level to determine the minimum set of nodes that must deplete their energy. We call this approach serial LP with PA (SLP-PA). In most cases when the problem is non-degenerate, the SLP-PA algorithm is extremely efficient and only requires time complexity to determine whether or not a node is in the minimum node set for each rate level. Even for the rare case when the problem is degenerate, the SLP-PA algorithm is still much more efficient than the state-of-the-art slack variable (SV)-based approach proposed in, due to fewer numbers of LPs involved at each rate level. Calculate the LMM-optimal rate vector; we developed a polynomial-time algorithm by exploiting the parametric analysis (PA) technique from linear programming (LP), which we called serial LP with Parametric Analysis (SLP-PA). Furthermore, we showed that the SLP-PA algorithm can also be employed to address the maximum node lifetime curve problem and that the SLP-PA algorithm is much more efficient than a state-of the-art algorithm.

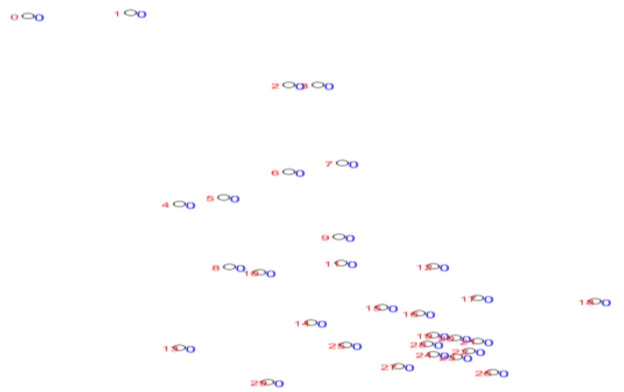

Fig. 2: Random deployment of MSNs

Figure 2 shows the random deployment of nodes on the rate allocation simulator on the basis of parametric analysis (PA) technique by maintaining the mode and simulation speed.

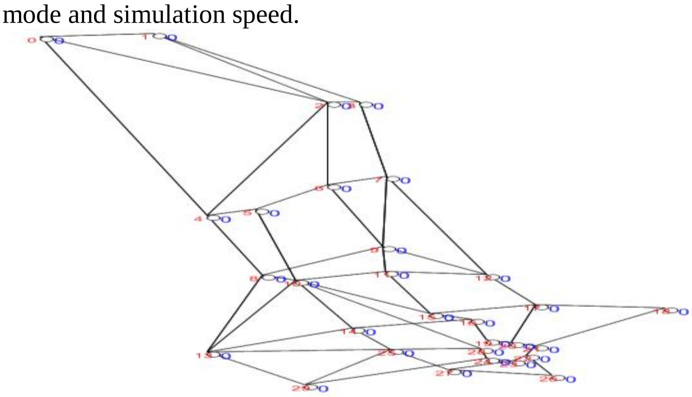

Fig. 3: Connection establishment

Figure 3 shows the connection made by the nodes on the basis of parameters by selecting a random function. The connection is usually made by selecting a shortest path for routing of data from source to sink. Here we can easily calculate total calls, concurrent calls and call duration on the basis of SLP-PA algorithm. Hence, SLP-PA algorithm can also be employed to address the maximum node lifetime curve problem and that the SLP-PA algorithm is much more efficient than a state-of the-art algorithm.

C. *Simulation results:-*

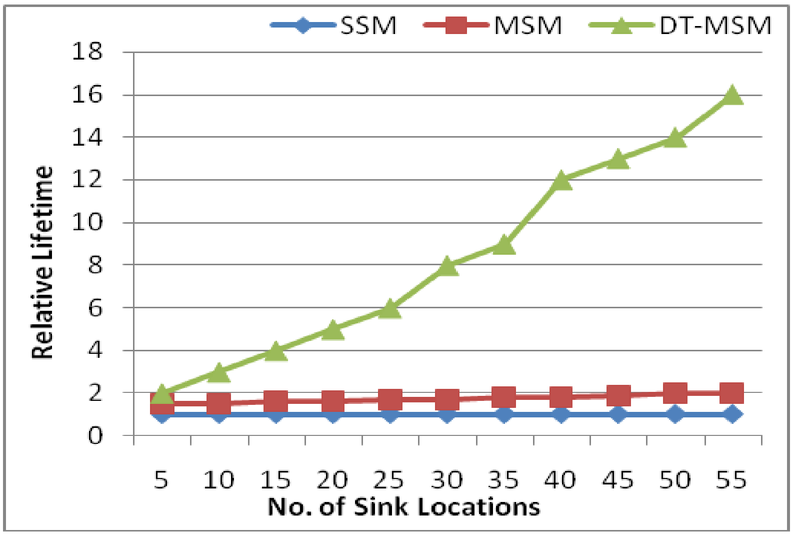

Fig. 4: Lifetime against the number of sink locations; maximum coverage; e =2.

Figure 4 shows the comparison between different mobile models with the proposed scheme. As the number of sink locations increases relative lifetime also increases. For SSM this remains constant. For MSM there is a little increase in lifetime. But our proposed scheme shows a rate of increase in lifetime as the number of sink locations increases.

The number of nodes is set to 100 or 200, the path loss exponent e is 2.0, and the coverage is as large as possible. We ran the experiment 100 times for each configuration. As shown in Figure 4.17, the lifetime of the MSM is about 100% greater than that of the SSM. However, the proposed scheme is 200% better than the SSM. Moreover, the curves all look linear; the performance gap can grow even larger with more sink locations.

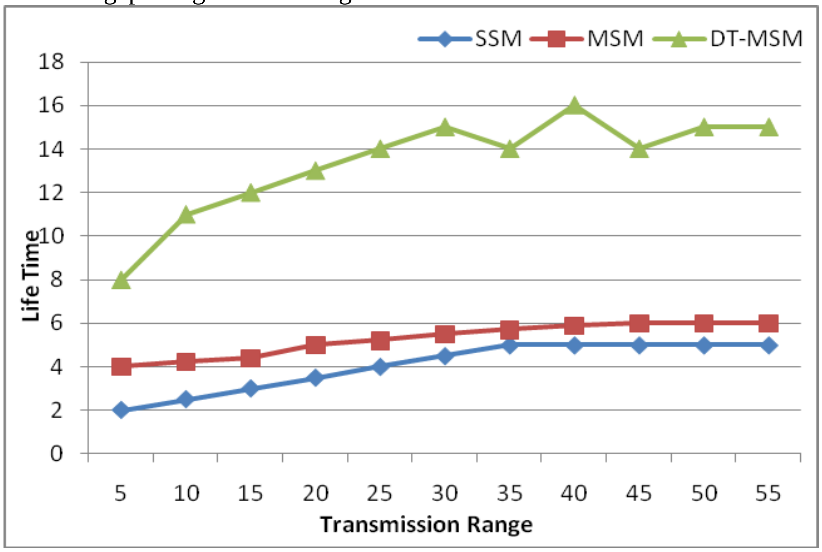

Fig.5: Lifetime versus transmission range: |N| = 200 |L| = 20, e = 2.0

Figure 5 shows the comparison of different system models with the proposed scheme. As the transmission range increases lifetime also increases but there is a high rate of increase for the proposed scheme.

We have experimented with different parameters extensively, such as the number of nodes, the number of possible sink locations and the parameters for the energy consumption model. We conducted similar experiments with the same configuration but minimum coverage. Although the slope of lifetime increases for the DT-MSM is lowered when compared to the maximum coverage case, the increase pattern is similar. Although a larger set of sink locations increases the network lifetime, it can be undesirable if the sink travel time. Both the MSM and the DT-MSM exhibit a sharp lifetime increase when the transmission range is small but increasing. However, the transmission range becomes large; the lifetime increase comes to a stop for all 3 models. The result implies that long-distance wireless links are not beneficial for improving the system lifetime and energy consumption.

V. CONCLUSION

We proposed a scheme to improve the network life. The proposed scheme is useful in applications that can tolerate a certain amount of delay in data delivery. We presented mathematical formulation for optimizing the network life. We identified several properties that our scheme possesses. In particular, we showed that the delay tolerance level does not affect the system life. We conducted extensive experiments and found that the proposed scheme is better than some existing schemes. The gain in the network life by the proposed scheme is significant when compared to other schemes. Furthermore, as the distance of sink locations increases, the optimal network life increases substantially. The scheme can be applied to practical situations and can be used as benchmarks for studying energy-efficient network design.

As a future work the presented scheme may be compared with some existing schemes on the basis of various parameters like the average movement required by the MSNs to fix themselves to the preferred location, time taken by the scheme to come to the stable state (convergence time), effect of density of MSNs on network setup time, effect of communication range and sensing range on network life.

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