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Use of Mobile Relay in Data-Intensive Wireless Sensor Networks

Jyothi B[1], G. Srinivasachar[2]

M.Tech Student, Department of CSE, Atria Institute of Technology, Bangalore, India

Assistant Professor, Department of CSE, Atria Institute of Technology, Bangalore, India

Abstract: ***WSN are increasingly used in different types of data-intensive applications scenarios such as micro-climate monitoring, precision agriculture, and audio/video surveillance. The sensor nodes are tiny and limited in power. Sensor types vary according to the application of WSN. Whatever be the application the key challenge is to transmit all the data generated within an application's lifetime to the base station despite the fact that sensor nodes have limited power supplies. The concept of mobile relay is that the mobile nodes change their locations so as to minimize the total energy consumed by both wireless transmission and locomotion. The conventional methods, however, do not take into account the energy level, and as a result they do not always prolong the network lifetime.***

Keywords: Data intensive; Energy; Relay; Routing tree; WSN

1. Introduction

Sensors have the capabilities of doing sensing, data processing, and wirelessly transmitting collected data back to base stations by way of multiple-hop relay. Sensor itself supplies necessary operation with limited battery energy. Those operations that consume energy are transmitting and receiving data, running applications, measuring power, and even staying in standby mode. Among others, data transmission consumes the most energy.A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound , vibration , pressure , humidity, motion or pollutants and to cooperatively pass their data through the network to a main location[1,2]. The more modern networks are bi-directional, also enabling control of sensor activity. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so on. Figure 1 shows an example of a wireless sensor network.

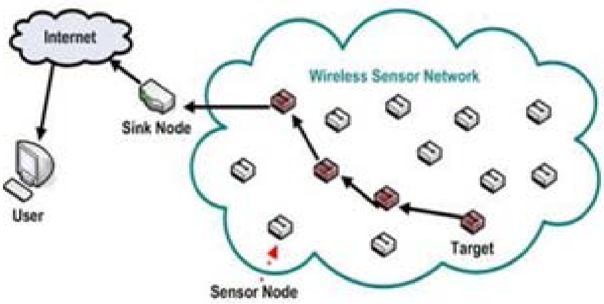

Figure 1: An example of Wireless Sensor Network

Recent advancement in mobile sensor platform technology has been taken into attention that mobile elements are utilized to improve the WSN's performances such as coverage, connectivity, reliability and energy efficiency. The concept of mobile relay is that the mobile nodes change their locations so as to minimize the total energy consumed by both wireless transmission and locomotion. The conventional methods, however, do not take into account the energy level, and as a result they do not always prolong the network lifetime.

2. Related Work

Analyzing the three different approaches: Mobile base stations, data mules and mobile relays. All the three approaches use mobility to reduce energy consumption in wireless sensor networks.

A. Mobile Base Station

A mobile base station is a sensor node collects the data by moving around the network from the nodes [4]. In some work, in order to balance the transmission load, all nodes are performing multiple hop transmissions to the base station. The goal is to rotate the nodes which are close to the base station. Before the nodes suffer buffer overflows, the base station computes the mobility path to collect data from the visited nodes. Several rendezvous based data collection algorithms are proposed, where the mobile base station only visits a selected set of nodes referred to as rendezvous points within a deadline and the rendezvous points buffer the data from sources. High data traffic towards the base station is always a threat to the networks life time [5]. The battery life of the base station gets depleted very quickly due to the sensor nodes which are located near to the base station relay data for large part of the network. The proposed solution includes the mobility of the base station such that nodes located near base station changes over time. All the above approaches incur high latency due to the low to moderate speed of mobile base stations. Figure 2 shows Mobile base station

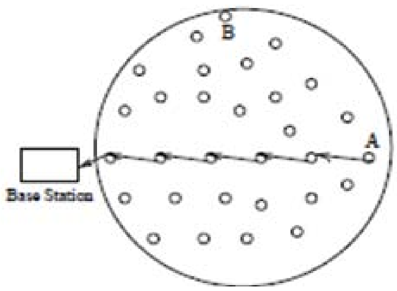

Figure 2: Mobile base station

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B. Data Mules

Data mules are another form of base stations. They gather data from the sensors and carry it to the sink. The data mule collects the data by visiting all the sources and then transmits it to the static base station through the network. In order to minimize the communication and mobility energy consumption the mobility paths are determined. In paper [6] the author analyses an architecture based on mobility to address the energy efficient data collection problem in a sensor network. This approach utilizes the mobile nodes as forwarding agents. As a mobile node moves in close propinquity to sensors, data is transmitted to the mobile node for later dumps at the destination. In the MULE architecture sensors transmit data only over a short range that requires less transmission power. However, latency is increased because a sensor has to wait for a mule before its data can be delivered. Figure 3. The three tiers of the MULE architecture. The Mule architecture has high latency and this limits its applicability to real time applications (although this can be mitigated by collapsing the MULE and access point tiers). The system requires sufficient mobility. For example, mules may not arrive at a sensor or after picking the data may not reach near an access-point to deliver it. Also, data may be lost because of radio-communication errors or mules crashing. To improve data delivery, higher-level protocols need to be incorporated in the MULE architecture. Data mules also introduce large delays like base stations since sensors have to wait for a mule to pass by before initiating their transmission.

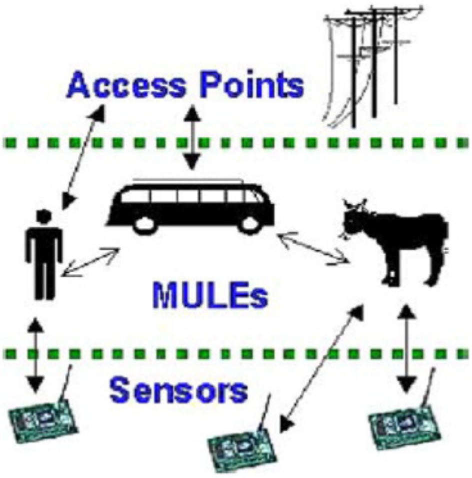

Figure 3: The three tiers of the MULE architecture

C. Mobile Relay

In this approach, the network consists of three nodes such as mobile relay nodes along with static base station and data sources. To reduce the transmission cost relay nodes do not transport data rather it will move to different locations. We use the mobile relay approach in this work. In [7] author showed that an iterative mobility algorithm where each relay node moves to the midpoint of its neighbors converges on the optimal solution for a single routing path This paper presents mobility control scheme for improving communication performance in WSN. The objectives of the paper [7] are 1) Analyse when controlled mobility can improve fundamental networking performance metrics such as power efficiency and robustness of communications 2) Provide initial design for such networks. Mobile nodes move to midpoint of the neighbours only when movement is beneficial [8]. Unlike mobile base stations and data mules, our approach reduces the energy consumption of both mobility and transmission. Our approach also relocates each mobile relay only once immediately after deployment. The paper study the energy optimization problem that accounts for energy costs associated with both communication and physical node movement. Unlike previous mobile relay schemes the proposed solution consider all possible locations as possible target locations for a mobile node instead of just the midpoint of its neighbors.

3. Proprosed work

We use low-cost disposable mobile relays to reduce the total energy consumption of dataintensive WSNs. Different from mobile base station or data mules, mobile relays do not transport data; instead, they move to different locations and then remain stationary to forward data along the paths from the sources to the base station. Thus, the communication delays can be significantly reduced compared with using mobile sinks or data mules. Moreover, each mobile node performs a single relocation unlike other approaches which require repeated relocations. Figure 4 shows Proposed Network.

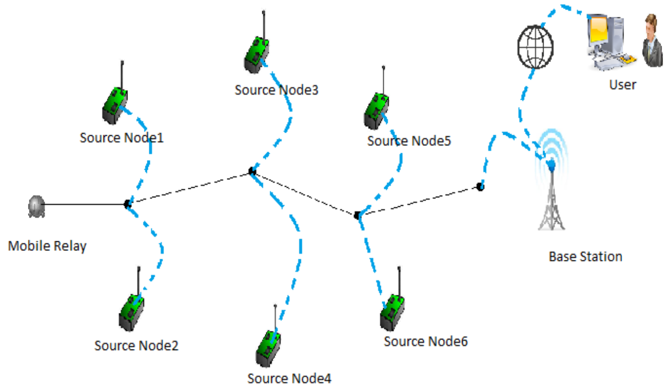

Figure4: Proposed Network

The network consists of mobile relay nodes along with static base station and data sources. Relay nodes do not transport data; instead, they move to different locations to decrease the transmission costs. We use the mobile relay approach in this work. Goldenberg et al. [13] showed that an iterative mobility algorithm where each relay node moves to the midpoint of its neighbors converges on the optimal solution for a single routing path. However, they do not account for the cost of moving the relay nodes. In mobile nodes decide to move only when moving is beneficial, but the only position considered is the midpoint of neighbors.

The sink is the point of contact for users of the sensor network. Each time the sink receives a question from a user, it first translates the question into multiple queries and then disseminates the queries to the corresponding mobile relay, which process the queries based on their data and return the query results to the sink. The sink unifies the query results from multiple storage nodes into the final answer and sends it back to the user.

The source nodes in our problem formulation serve as *storage points* which cache the data gathered by other nodes and periodically transmit to the sink, in response to user queries. Such a network architecture is consistent with the design of storagecentric sensor networks [38]. Our problem formulation also considers the initial positions of nodes and the amount of data that needs to be transmitted from each storage node to the sink.

we consider the subproblem of finding the optimal positions of relay nodes for a routing tree given that the topology is fixed. We assume the topology is a directed tree in which the leaves are sources and the root is the sink. We also assume that separate messages cannot be compressed or merged; that is, if two distinct messages of lengths m1 and m2 use the same link (si, sj) on the path from a source to a sink, the total number of bits that must traverse link (si, sj) is m1 + m2.

a) Energy Optimization Framework

In this section, we formulate the problem of Optimal Mobile Relay Configuration (OMRC) in data-intensive WSNs. Unlike mobile base stations and data mules, our OMRC problem considers the energy consumption of both mobility and transmission. The Optimal Mobile Relay Configuration (OMRC) problem is challenging because of the dependence of the solution on multiple factors such as the routing tree topology and the amount of data transferred through each link. For example, when transferring little data, the optimal configuration is to use only some relay nodes at their original positions.

Assume the network consists of one source s_{i-1}, one mobile relay node si and one sink s_{i+1}. Let the original position of a node s_j be $o_j = (p_j , q_j)$, and let $u_j = (x_j , y_j)$ its final position in configuration U. According to our energy models, the total transmission and movement energy cost incurred by the mobile relay node s_i is

$$c_i(U) = k\| u_i - o_i \| + am + b\| u_{i+1} - u_i \|^2 m$$

Now We need to compute a position u_i for s_i that minimizes $C_i(U)$ assuming that $u_{i-1} = o_{i-1}$ and $u_{i+1} = o_{i+1}$; that is, node s_i's neighbors remain at the same positions in the final configuration U. We calculate position $u_i = (x_i, y_i)$ for node s_i by finding the values for x_i and y_i where the partial derivatives of the cost function $C_i(U)$ with respect to x_i and yi become zero. Position ui will be toward the midpoint of positions u_{i-1} and u_{i+1}. The partial derivatives at x_i and y_i, respectively are defined as follows:

$$\frac{\delta C_i(U)}{\delta x_i} = -2bm(x_{i+1} - x_i) + 2bm(x_i - x_{i-1}) + k\frac{(x_i - p_i)}{\sqrt{(x_i - p_i)^2 + (y_i - q_i)^2}}$$

$$\frac{\delta C_i(U)}{\delta y_i} = -2bm(y_{i+1} - y_i) + 2bm(y_i - y_{i-1}) + k\frac{(y_i - q_i)}{\sqrt{(x_i - p_i)^2 + (y_i - q_i)^2}}$$

and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

b) Static Tree Construction

We construct the tree for our starting configuration using a shortest path strategy. We first define a weight function w specific to our communication energy model. For each pair of nodes s_i and s_j in the network, we define the weight of edge s_is_j as: $w(s_i, s_j) = a + b\|o_i - o_j\|^2$ where o_i and o_j are the original positions of nodes s_i and s_j and a and b are the energy parameters. We observe that using this weight function, the optimal tree in a static environment coincides with the shortest path tree rooted at the sink. So we apply Dijkstra's shortest path algorithm starting at the sink to all the source nodes to obtain our initial topology.

We improve the routing tree by greedily adding nodes to the routing tree exploiting the mobility of the inserted nodes. For each node s_{out} that is not in the tree and each tree edge s_is_j , we compute the reduction (or increase) in the total cost along with the optimal position of s_{out} if s_{out} joins the tree such that data is routed from s_i to sout to s_j instead of directly from s_i to s_j using the LocalPos algorithm described in algorithm 1. We repeatedly insert the outside node with the highest reduction value modifying the topology to include the selected node at its optimal position, though the node will not actually move until the completion of the tree optimization phase. After each node insertion occurs, we compute the reduction in total cost and optimal position for each remaining outside node for the two newly added edges (and remove this information for the edge that no longer exists in the tree). At the end of this step, the topology of the routing tree is fixed and its mobile nodes can start the tree optimization phase to relocate to their optimal positions.

Algorithm 1

function LOCALPOS($o_i, u_i, u_{i-1}, u_{i+1}$)
⊳ *Consider case* s_i *moves right*
valid ← FALSE;
$x_i \leftarrow \frac{1}{2}(x_{i-1} + x_{i+1}) - Y_i$;
if $x_i > p_i$ **then**
valid ← TRUE;
else
⊳ *Consider case* s_i *moves left*
$x_i \leftarrow \frac{1}{2}(x_{i-1} + x_{i+1}) + Y_i$;
if $x_i < p_i$ **then**
valid ← TRUE;
end if
end if
⊳ *Record if new position is different from previous one*
if valid **then**
$y_i \leftarrow \frac{(x_{i-1}+x_{i+1}-2p_i)}{(y_{i-1}+y_{i+1}-2q_i)}(x_i - p_i) + q_i$;
$u' = (x_i, y_i)$;
if $\| u'_i - u_i \|$ > threshold **then**
return (u_i, TRUE);
end if
end if
⊳ *not beneficial to move, stay at original position*
return (o_i, FALSE);
end function

c) Tree Optimization Algorithm

In this section, we consider the subproblem of finding the optimal positions of relay nodes for a routing tree given that the topology is fixed. We assume the topology is a directed tree in which the leaves are sources and the root is the sink. We also assume that separate messages cannot be compressed or merged; that is, if two distinct messages of lengths m1 and m2 use the same link (si, sj) on the path from a source to a sink, the total number of bits that must traverse link (si, sj) is m1 + m2. Let the network consists of multiple sources, one relay node and one sink such that data is transmitted from each source to the relay node and then to the sink. We modify our solution as follows. Let si be the mobile relay node, S(si) the set of source nodes transmitting to si and sdi the sink collecting nodes from si. The cost incurred by si in this configuration U is:

$$c_i(U) = k\|u_i - o_i\| + am_i + bm_i\|u_{i+1} - u_i\|^2$$

Now we obtain the following positions:

$$x_i = p_i + \frac{-B_x(\sqrt{pB^2_x + B^2_y} \pm k)}{A\sqrt{pB^2_x + B^2_y}}$$

$$y_i = q_i + \frac{-B_y(\sqrt{pB^2_x + B^2_y} \pm k)}{A\sqrt{pB^2_x + B^2_y}}$$

Where

$$A = m_i + \sum_{sl \in S(s_i)} m_l,$$

$$B_x = m_i x_d + \sum_{sl \in S(s_i)} m_l x_l + Ap_i,$$

$$B_y = m_i y_d + \sum_{sl \in S(s_i)} m_l y_l + Aq_i.$$

We note that these values correspond to two candidate points moving in each direction (left/right). The optimal position is the valid value yielding the minimum cost.

Our algorithm starts by an odd/even labeling step followed by a weighting step. To obtain consistent labels for nodes, we start the labeling process from the root using a breadth first traversal of the tree. The root gets labeled as even. Each of its children gets labeled as odd. Each subsequent child is then given the opposite label of its parent. We define mi, the weight of a node s_i, to be the sum of message lengths over all paths passing through s_i. This computation starts from the sources or leaves of our routing tree. Initially, we know $m_i = M_i$ for each source leaf node s_i. For each intermediate node s_i, we compute its weight as the sum of the weights of its children. Once each node gets a weight and a label, we start our iterative scheme. In odd iterations j, the algorithm computes a position uj i for each odd-labeled node si that minimizes $C_i(U^j)$ assuming that $u^j_{i-1} = u^{j-1i}_{-1}$ and $u^j_{i+1} = u^{j-1}_{i+1}$; that is, node s_i's even numbered neighboring nodes remain in place in configuration U_j. In even-numbered iterations, the controller does the same for even-labeled nodes. The algorithm behaves this way because the optimization of u^j_i requires a fixed location for the child nodes and the parent of s_i. By alternating between optimizing for odd and even labeled nodes, the algorithm guarantees that the node s_i is always making progress towards the optimal position u_i. Our iterative algorithm is shown in algorithm 2.

Algorithm 2
procedure OPTIMALPOSITIONS(U^0)
converged ← false;
j ← 0;
repeat
anymove ← false;
j ← j + 1;
⊳ *Start an even iteration followed by an odd iteration*
for idx = 2 to 3 **do**
for i = idx to n by 2 **do**
(u^j_i ,moved) ← LOCALPOS(o_i, $S(s_i)$, s^d_i);
anymove ← anymove OR moved
end for
end for
converged ← NOT anymove
until converged
end procedure

4. Conclusion

The main objective of this paper is energy conservation which is holistic in that the total energy consumed by both mobility of relays and wireless transmissions is minimized, which is in contrast to existing mobility approaches that only minimize the transmission energy consumption. The tradeoff in energy consumption between mobility and transmission is exploited by configuring the positions of mobile relays. We develop two algorithms that iteratively refine the configuration of mobile relays. The first improves the tree topology by adding new nodes. It is not guaranteed to find the optimal topology. The second improves the routing tree by relocating nodes without changing the tree topology. It converges to the optimal node positions for the given topology. Our algorithms have efficient distributed implementations that require only limited, localized synchronization.

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Author Profile

Jyothi B received the BE degree in computer science from Visvesvaraya Technological University of Belgaum in 2011.She is working toward the M tech degree at Visvesvaraya Technological University of Belgaum. Her research interests include algorithms and wireless sensor networks.

G Srinivasachar received M.S. in CSE from IIT Madras and M. Sc (Physics)from Mysore University. He is currently an assistant professor with Department of computer science and Engineering , Atria Institute of Technology Bangalore. His areas of interests are Algorithms, Architecture, Web applications.