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A Novel Approach for Sensory Data Collection in Wireless Sensor Networks with Mobile Sinks

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Abstract--- Recently, there has been a rapid growth in the wireless communication technique. Mobile sinks can be mounted upon urban vehicles with fixed trajectories provide the ideal infrastructure to effectively retrieve sensory data from such isolated WSN fields. Existing approaches uses either single-hop transfer of data from SNs that lie within the MS's range or heavy involvement of network periphery nodes in data retrieval, processing, buffering, and delivering tasks. Our proposed protocol aims at reducing the overall network overhead and energy expenditure associated with the multihop data retrieval process while also ensuring balanced energy consumption among SNs and prolonged network lifetime. This is achieved through building cluster structures consisted of member nodes that route their measured data to their assigned cluster head (CH). CHs perform data filtering upon raw data exploiting potential spatial-temporal data redundancy and forward the filtered information to appropriate end nodes with sufficient residual energy, located in proximity to the MS's trajectory. Simulation results indicate the superior performance of our proposed algorithm to strike the appropriate performance in the energy consumption and network lifetime for the wireless sensor networks.

***Index Terms*— Mobile Sinks, Wireless Sensor Networks, Information Retrieval, Clustering, Sensor Islands, Rendezvous Nodes.**

I. INTRODUCTION

A Wireless Sensor Network (WSN) is a collection of small, lightweight sensor nodes deployed in large numbers to monitor the ambient conditions. WSN have a numerous advantages, but the available energy at each sensor nodes are treated as a constraint. Hence energy consumption is a major criterion. Cluster is a collection of sensor nodes which are randomly deployed. Each cluster consists of one or more number of cluster heads. The cluster heads gathering all data from their cluster members. The collected information's are routed to the Base Station. The Base Station (BS) is a fixed node, which is capable to transmit and receive the data within the entire network. The number of cluster head selection varies depends on the number of sensor nodes. Energy consumption is efficiently controlled by selecting more than one cluster head for cluster containing more number of nodes in the network. Analysis of energy consumption is made depends on number of cluster heads are needed, when the number of nodes increased.

A main reason of energy spending in WSNs relates with communicating the sensor readings from the sensor nodes (SNs) to remote sinks. These readings are typically relayed using ad hoc multihop routes in the WSN. A side effect of this approach is that the SNs located close to the sink are heavily used to relay data from all network nodes; hence, their energy is consumed faster, leading to a no uniform depletion of energy in the WSN [2]. This results in network disconnections and limited network lifetime. Network lifetime can be extended if the energy spent in relaying data can be saved. Recent research work has proved the applicability of mobile elements (submarines, cars, mobile robots, etc.) for the retrieval of sensory data from smart dust motes [3] in comparison with multihop transfers to a centralized element. A mobile sink (MS) moving through the network deployment region can collect data from the static SNs over a single hop radio link when approaching within the radio range of the SNs or with limited hop transfers if the SNs are located further. This avoids long-hop relaying and reduces the energy consumption at SNs near the base station, prolonging the network lifetime. Large classes of monitoring applications involve a set of urban areas (e.g., urban parks or building blocks) that need to be monitored with respect to environmental parameters (e.g., temperature, moisture, pollution, and light intensity), surveillance, fire detection, etc. In these environments, individual monitored areas are typically covered by isolated "sensor islands," which makes data retrieval rather challenging since mobile nodes cannot move through but only approach the periphery of the network deployment region. In such cases, a number of representative nodes located in the periphery of the sensor field can be used as "rendezvous" points wherein sensory data from neighbor nodes may be collected and finally delivered to an MS when the latter approaches within radio range [24]. In this context, the specification of the appropriate number and locations of rendezvous nodes (RNs) is crucial. The number of RNs should be equivalent (neither small nor very large) to the deployment density of SNs.

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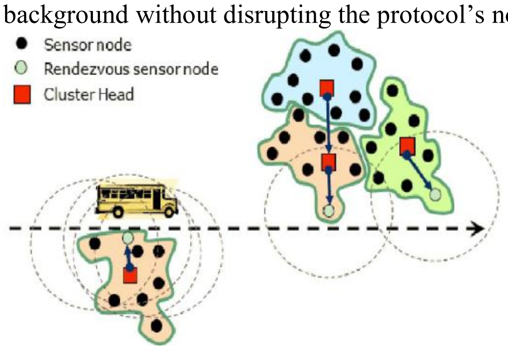
Herein, we investigate the use of MSs for efficient data collection from "sensor islands" spread throughout urban environments. We argue that the ideal carriers of such MSs are public surface transportation vehicles (e.g., buses) that repeatedly follow a predefined trajectory with a periodic schedule that may pass along the perimeter of the isolated sensor fields. Our proposed protocol called MobiCluster [1] aims at minimizing the overall network overhead and energy expenditure associated with the data retrieval process while also ensuring balanced energy consumption among SNs and prolonged network lifetime. This is achieved through building cluster structures consisted of member nodes that route their measured data to their assigned cluster head (CH). The CHs perform data filtering upon the raw data exploiting potential spatial-temporal data redundancy and forward the filtered information to their assigned RNs, typically located in proximity to the MS's trajectory. We also introduce a sophisticated method for enrolling appropriate nodes as RNs taking into account the deployment pattern and density of sensor nodes. Last, we propose methods for building adaptable intercluster overlay graphs and techniques for fairly distributing sensory data among RNs and delivering data to MSs in nonintersecting time windows.

II.THE MOBICUSTER PROTOCOL

In the proposed protocol, MSs are mounted upon public buses circulating within urban environments on fixed trajectories and near-periodic schedule. Namely, sinks motion is not controllable and their routes do not adapt upon specific WSN deployments. Our only assumption is that sensors are deployed in urban areas in proximity to public transportation vehicle routes. Also, an adequate number of nodes are enrolled as RNs as a fair compromise between a small number which results in their rapid energy depletion and a large number which results in reduced data throughput. Finally, SNs are grouped in separate clusters. Raw sensory data are filtered within individual clusters exploiting their inherent spatial-temporal redundancy. Thus, the overhead of multihop data relaying (intercluster-ing traffic) to the edge RNs is minimized as in Fig.1. Given that the communication cost is several orders of magnitude higher than the computation cost [34], in-cluster data aggregation can achieve significant energy savings.

A basic assumption in the design of MobiCluster protocol [1] is that SNs are location unaware, i.e., not equipped with GPS-capable antennae. Also, we assume that each node has a fixed number of transmission power levels. Finally, we assume the unit disk model, which is the most common assumption in sensor network literature. The underlying assumption in this model is that nodes which are closer than a certain distance (transmission range R) can always communicate. However, in practice, a message sent by a node is received by the receiver with only certain probability even if the distance of the two nodes is smaller than the transmission range [26].

In the following sections, the five phases of MobiCluster are described. The first three phases comprise the setup phase while the last two comprise the steady phase. The setup phase completes in a single MS trip and during this trip, the MS periodically broadcasts BEACON messages which are used by SNs for determining a number of parameters important for the protocol operation. In the steady phase, data from SNs are routinely gathered to RNs and then sent to MS. During the steady phase, reselection of RNs and/or local reclustering is performed in case of energy exhaustion of some critical nodes. Most importantly, these operations take place in the background without disrupting the protocol's normal operation.



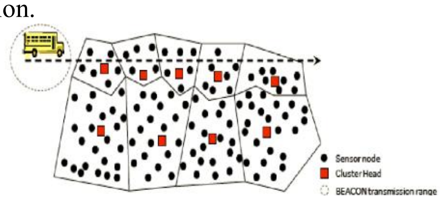


Fig.I. Rendezvous sensor nodes, cluster structure and data forwarding paths formation in MobiCluster.

Fig.II. Unequal cluster

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A. Phase 1: Clustering

The large-scale deployment of WSNs and the need for data aggregation necessitate efficient organization of the network topology for the purpose of balancing the load and prolonging the network lifetime. Clustering has proven to be an effective approach for organizing the network in the above context. Besides achieving energy efficiency, clustering also reduces channel contention and packet collisions, resulting in improved network throughput under high load. The clustering algorithm in [5] constructs a multisized cluster structure, where the size of each cluster decreases as the distance of its cluster head from the base station increases. We slightly modify the approach of [5] to build clusters of two different sizes depending on the distance of the CHs from the MS's trajectory. Specifically, SNs located near the MS trajectory are grouped in small sized clusters while SNs located farther away are grouped in clusters of larger size as in Fig. 2. The CHs near the MS trajectory are usually burdened with heavy relay traffic coming from other parts of the network. By maintaining the clusters of these CHs small, CHs near the MS trajectory are relatively relieved from intracluster processing and communication tasks and thus they can afford to spend more energy for relaying intercluster traffic to RNs.

During an initialization phase, the MS moves along its fixed trajectory broadcasting periodically a BEACON signal to all SNs at a fixed power level. All nodes near the MS trajectory receive the BEACON message and thus they know that the clusters in their region will be small sized. Then, these nodes flood the BEACON message to the rest of the network. A detailed description of the clustering algorithm (Algorithm CH_ELECTION) which is executed right after the MS completes its first trip. As soon as the clustering phase finalizes, each CH proceeds to the selection of the appropriate cluster member(s) to serve as RN(s). As discussed in the following section, not every CH can find such a set of RNs.

B. Phase 2: Rns Selection

RNs guarantee connectivity of sensor islands with MSs; hence, their selection largely determines network lifetime. RNs lie within the range of traveling sinks and their location depends on the position of the CH and the sensor field with respect to the sinks trajectory. Suitable RNs are those that remain within the MS's range for relatively long time, in relatively short distance from the sink's trajectory and have sufficient energy supplies. In practical deployments, the number of designated RNs introduces an interesting trade-off:

A large number of RNs implies that the latter will compete for the wireless channel contention as soon as the mobile robot appears in range, thereby resulting in low data throughput and frequent outages. A small number of RNs implies that each RN is associated with a large group of sensors. Hence, RNs will be heavily used during data relays, their energy will be consumed fast and they will be likely to experience buffer overflows.

To regulate the number of RNs and prevent either their rapid energy depletion or potential data losses, we propose a simple selection model whereby a set of cluster members (in vicinity to the MS's trajectory) from each cluster is enrolled as RNs. RN's role may be switched among cluster members when the energy level of a node currently serving as RN drops below a prespecified threshold. As mentioned earlier, MSs follow a fixed trajectory. We argue that the Euclidean distance among SNs and the MS should not be used as the only factor for selecting RNs. In addition to lying in a short distance from MS trajectories, the best candidates RNs are the SNs with sufficient residual energy that receive a relatively high number of BEACON packets. To count the number of received BEACON packets, when a SN v receives the ith BEACON, it increases a BEACON counter n_b by one, records the receipt timet_i, the signal strength s_i and restarts a "Connection Dropped Timer" set equal to 3. T_{beacon} (Which allows up to two BEACON packets lost due to channel error). The SN v also keeps record of the receipt time for the first and last received BEACON, $v.T_{first}$ and $v.T_{last}$.If a BEACON is received at time $t_{i+1} \approx t_i + 1$ the node assumes that n _ 1 BEACON packets have been lost due to channel error or MAC collision and increases nb by n. When the "Connection Dropped Timer" expires the node assumes that the MS has moved away and the BEACON counter value is finalized. Herein, we assume that when the sink moves away it does not return within the node's range during the same traversal. Then, the SN v calculates a competence value ($v.Comp_{val}$) based on its residual energy, the n_b value and the average signal strength of received BEACON messages (the latter reflects the average distance of the node from the MS's trajectory). Later on v announces its candidacy to be elected as RN sending to its assigned CH a RN_Cand_Msg (v.Node ID,$v.Comp_{val}$,$v.T_{first}$,$v.T_{last}$) containing its Node_ ID, competence value, Tfirst and Tlast. Nodes with relatively high competence values are likely to be elected as RNs.

C. Phase 3: Chs Attachment To Rns

CHs located far from the MS trajectories do not have any RNs within transmission range. An important condition for building intercluster overlay graphs is that CHs with no attached RNs, attach themselves to a CH u

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with nonempty R^u set so as to address their clusters' data to u. It is noted that our approach typically requires a single MS trip to collect (through the receipt of BEACON messages) the information needed to execute the setup phase. Clustering starts upon the completion of the first MS trip. The RNs' selection process commences immediately afterward (the information needed for the execution of this phase, i.e., the number of beacons, their receipt time, and signal strength is also collected during the first MS trip). All these phases complete in reasonably short period of time, typically within the time interval between two successive bus trips. As soon as the setup phase finalizes, sensory data collected at CHs from their attached cluster members are forwarded toward the RNs following an intercluster overlay graph. The selected transmission range among CHs may vary to ensure a certain degree of connectivity and to control interference.

D. Phase 4: Data Aggregation And Forwarding To The Rns

The steady phase of MobiCluster protocol starts with the periodic recording of environmental data from sensor nodes with a T_r period. The data accumulated at individual source nodes are sent to local CHs (intracluster communication) with a T_c period.CHs perform data processing to remove spatial-temporal data redundancy, which is likely to exist since cluster members are located maximum two hops away. CHs then forward filtered data toward remote CH they are attached to. Alongside the intercluster path, a second-level of data filtering may apply.

E. Phase 5: Communication Between Rns And Mobile Sinks

The delivery of data buffered to RNs to MSs. Data delivery occurs along an intermittently available link; hence, a key requirement is to determine when the connectivity between an RN and the MS is available. Communication should start when the connection is available and stop when the connection no longer exists, so that the RN does not continue to transmit data when the MS is no longer receiving it.

To address this issue, we use an acknowledgment-based protocol between RNs and MSs. The MS, in all subsequent path traversals after the setup phase, periodically broadcasts a POLL packet, announcing its presence and soliciting data as it proceeds along the path. The POLL is transmitted at fixed intervals T_{poll} (typically equal to T_{beacon}). This POLL packet is used by RNs to detect when the MS is within connectivity range. The RN receiving the POLL will start transmitting data packets to the MS. The MS acknowledges each received data packet to the RN so that the RN realizes that the connection is active and the data were reliably delivered. The acknowledged data packet can then be cleared from the RN's cache.

III.SIMULATION RESULTS

As MobiCluster assume that MS moves on a fixed trajectory, a fair comparison of this protocol with other proposals should only consider the efficiency of routing structures for transferring data from SNs to RNs. In the simulation tests, we compare our method with the solutions proposed in [24] and [20] which also assume fixed MS trajectory. In these tests, MobiCluster and the protocols in [20] and [24] have been extensively evaluated with respect to several performance parameters. First, the three protocols are compare in terms of the network lifetime, the average residual energy as well as the variance of this energy across the network. Then, the protocols are compared in terms of the overall number of outages, i.e., the number of data packets cached in RNs, yet, not delivered to the MS due to buffer overflows, packet collisions or the movement of the MS away of the RNs' transmission range. Finally, the third group of tests concerns the total generated traffic as well as the network throughput of these protocols, i.e., the packets delivered to the MS over those sent from the RNs.

Fig.III. illustrates the output screenshots of our simulator. The blue colour sensor nodes in Fig.III.(a) denote the cluster head and black sensor node represent nodes with high energy dissipation and green nodes are having less energy dissipation. The black squares represent packets lost during transmission from cluster head to base station. In Fig.III.(b) black nodes denote cluster heads and light green nodes denote rendezvous nodes. The small blue squares represent message packets.

In this section, the performance of EC is compared with LEACH and OCA. LEACH is a distributed clustering algorithm, where CHs relay data to a sink node via multihop routing. It has an iterative CH selection mechanism in which the probability for each node to become a CH depends on its residual energy. When a CH candidate is not selected as a CH node in a round, it double its probability of selection so that it will have a better chance in the next round. Although widely accepted as a major clustering algorithm, OCA does not address the hot-spots of the network; hence no lifetime equalization mechanism is involved.

Here, we compare our aggregation rate in LEACH and Optimal Clustering algorithm with a suggested method. We evaluate the performance of Mobile sink and Mobile clustering algorithm using Network simulator with the 100-node network in a play field of size 100m x 100m in Fig.IV. The base station is located at position (50,200)

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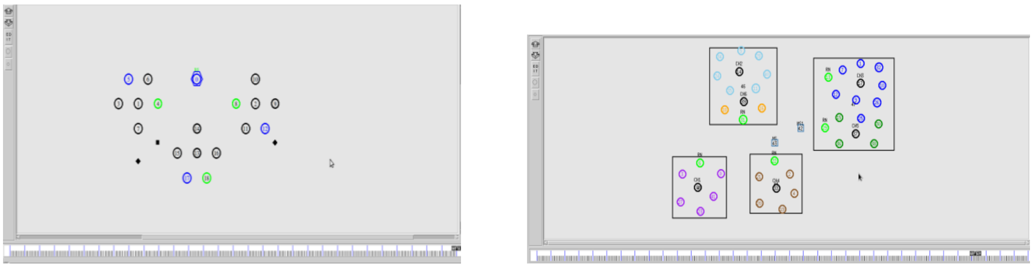
and the initial energy per node is the random number of [2J, 5J]. For simplicity, we assume the probability of signal collision and interference in the wireless channel is ignorable. We compare the performance of mobile clustering algorithm with three important clustering algorithms. Fig.5. shows the relationship between the number of node death and the network runtime (rounds). We see that, in addition to LEACH, the curve of the other three algorithms is gentle, which demonstrates their methods of cluster head selection enable the balanced energy dissipation among the sensor nodes. The other three algorithms, however, by using strategy of probabilistic based clustering, are prone to partition the adjacent nodes with similar sensed data into several clusters, thus increase the energy consumption of wasteful message transmission. We compare data aggregation rate of Mobile Clustering algorithm with the other two algorithms. It is obvious to see that Mobile based Clustering algorithm has the highest rate of data aggregation, which ensures the maximum reduction of the total amount of data received at the BS.



(a) (b)

Fig. III. Topologies derived from protocols (a) [5], (b) Mobicluster

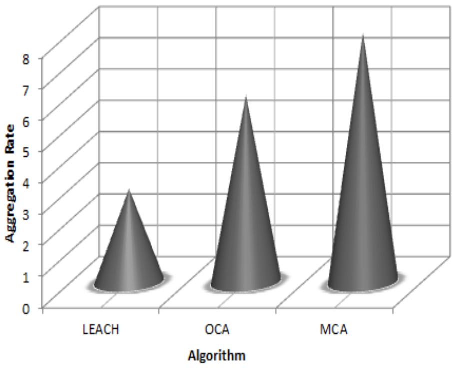


Fig . IV. Data Aggregation Rate

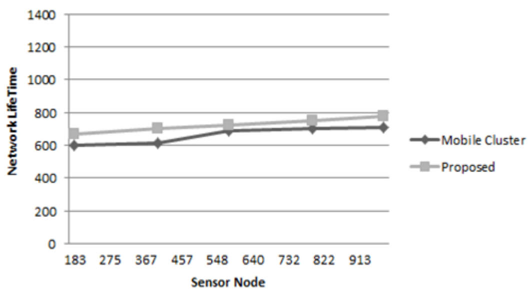


Fig .V. Network Life Time

IV.CONCLUSION

This paper introduced MobiCluster, a algorithm that proposes the use of urban buses to carry MSs that retrieve information from isolated parts of WSNs. MobiCluster mainly aims at maximizing connectivity, data throughput, and enabling reasonable energy expenditure among SNs.The connectivity idea is addressed by employing MSs to collect data from isolated urban sensor islands and also through prolonging the lifetime of selected peripheral RNs which lie within the range of ephemeral MSs and used to cache and deliver sensory data derived from remote source nodes. Increased data throughput is ensured by regulating the number of RNs for allowing sufficient time to deliver their buffered data and preventing data losses. Unlike further approaches, MobiCluster moves the processing and data transmission burden away from the vital periphery nodes (RNs) and enables balanced energy consumption across the WSN through building cluster structures that exploit the high redundancy of data collected from neighbor nodes and minimize intercluster data in the clouds. The performance gain of MobiCluster over different approaches has been validated by widespread simulation tests.

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