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Information-aware collaborative routing in wireless sensor network

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ABSTRACT

In this paper, we propose a new approach to routing protocol called information-aware collaborative routing for wireless sensor networks. Clustering and local data aggregation schemes have been developed to reduce the energy for transmitting redundant data in the wireless sensor network. Most existing approaches have been developed for the cases when there is direct communication between cluster head and base station. Even though these schemes are able to reduce data redundancy to be transmitted from the cluster heads to the base station, they have not exploited the data redundancy between neighboring clusters. In this research, we study a more general case when there are multi-hop communications from cluster heads to the base station. To exploit the potential redundancy between neighboring clusters, we propose to develop a routing protocol architecture that combines multi-hop routing with information-aware clustering based on the correlation of sensor data. The information-aware collaborative routing includes the re-clustering based on data correlation as well as the central-controlled clustering and cluster heads rotation to evenly distribute the energy load in the entire network. Extensive simulations show that the proposed information-aware collaborative routing can achieve better performance in terms of longer network lifetime and less energy dissipation comparing with the existing cluster-based routing.

Keywords: clustering, collaborative clustering, data correlation, information-aware, energy efficiency, meta-data

1. INTRODUCTION

Wireless sensor networks are capable of monitoring a wide variety of ambient conditions such as: temperature, pressure, motion etc. Most sensors are constrained by on-board energy supply and battery replenishment is often not practical once the sensors are deployed. Therefore, energy is a very limited resource for such sensor networks and has to be managed wisely in order to extend the network lifetime. Energy efficiency is of prime importance and is a key design objective in most research related to wireless sensor networks [8]. Almost every technical issues in the wireless sensor networks is related to energy efficiency, including routing, media access control (MAC), local computation, and data gathering schemes [1], [9], [10], [11].

In order to maximize the lifetime of the wireless sensor networks, optimal energy efficient operation and well organized power management in the wireless sensor network is necessary. Among existing energy efficient routing schemes developed recently, the clustering-based routing has been proved to perform better than many others schemes [1]. A cluster-based routing can take advantage of in-network data aggregation within a cluster and enables the cluster head node to transmit the aggregated data to the base station (BS). The cluster head-based transmission and local data aggregation can more efficient in reducing the transmission latency and the energy dissipation than a routing protocol without cluster formation and local computation. Also, clustering based scheme enables the bandwidth reuse, a better resource allocation, and the power management [6].

Another strategy for energy efficient routing is to select multi-hop communication for routing the sensor data to the base station. Multi-hop communication mode can be applied to node to node data communications. It can also be applied to cluster to cluster communication to route the aggregated data from cluster head nodes to BS [6]. The multi-hop

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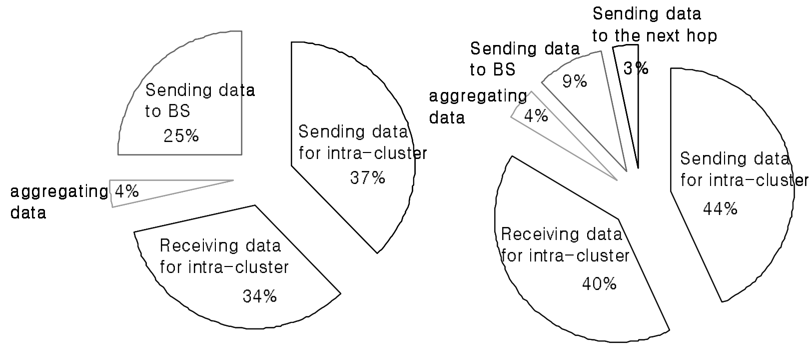


Fig. 1: Distribution of total energy dissipation per cluster per round: (a) for cluster-based routing (b) cluster-based routing with multihop for inter-cluster. This graph shows that the transmitting and receiving energy dissipation in intra-cluster is occupied more than 71%. Even though the multihop routing can reduce the energy dissipation for transmitting in the inter-cluster communication, it is unable to reduce the energy dissipation for intra cluster communication, 84%. The experiment condition is same as the simulation condition presented later in this paper.

communication mode usually can achieve better performance, but it may depend on some network environmental settings and parameters. In some cases, the energy consumed by transmitter and receiver electronics is comparable to the energy consumed by the power amplifier. However, when a sensor network is deployed over a large region, the energy consumed by the power amplifier may dominate over the energy consumed by transmitter and receiver electronics to such an extent that multi-hop mode is always more energy efficient than the single hop mode [6].

Sensor data draw from nodes that are adjacent to each other usually are highly correlated since the physical object or environment under monitoring will not change dramatically both spatially and temporally. If the distance between nodes within a cluster is small compared with the distance from which events or objects can be sensed, there is a high probability that the nodes will be sensing the same event or object. Therefore, in-network data aggregation is desired in order to avoid the transmission of the redundant data from cluster head to the base station. Local data computation generally results in the saving of transmission energy but also there are multiple tradeoffs in overall resource utilization, transmission latency, and reliability requirement.

The clustering-based routing, multi-hop routing, and local data aggregation all contribute to exploiting sensor data correlation and therefore reducing the energy dissipation to transmit data to the BS. However, existing schemes for energy efficient data collection only result in an improved data transmission from the cluster head nodes to the base station. There has been no attempt or strategy to exploit the potential redundancy in sensor data within each cluster that will also cause energy waste when the sensor data are transmitted from sensor nodes to their cluster head node. In other words, existing energy efficient technique has not been able to reduce the energy dissipation in the intra-cluster transmission at all.

We have conducted some simple experiments to demonstrate that intra-cluster communications consume significant portion of the total energy for sensor networks. Fig. 1 shows that the total energy dissipation used for transmitting and receiving sensor data for intra-cluster communications may account for about 71% of total energy dissipation per cluster and per round for the clustering-based routing with local computation. If we apply the multi-hop mode to the transmission between cluster heads, we can reduce the energy dissipation for sending data to the next hop and the BS, the percentage of energy dissipation for transmitting and receiving data in intra-cluster transmission become more significant.

Therefore, it is also crucial to avoid sending redundant sensor data to cluster head if we are able to determine whether or not the sensor data from a particular node is indeed redundant. This may not be accomplished easily if the cluster head communication with the base station directly. However, in the case when the cluster head communicate with base station via multi-hop mode, the aggregated data a particular cluster head received from its neighboring cluster may be highly correlated with some of its own sensor nodes that are deployed next to its neighboring cluster. If we can recognize which sensor nodes whose data is highly correlated with information from its neighboring cluster, intra-cluster communication can be reduced by not sending the correlated data to their cluster head. This shall result in additional energy saving for clustering based sensor data collection.

In our study of routing protocol for wireless sensor networks, we aim at developing an energy efficient routing by exploiting the intrinsic sensor data correlation between neighboring clusters. We propose a novel approach for routing protocol called information-aware collaborative routing (IACR), a protocol architecture that combines the clustering-based multi-hop routing for inter-cluster transmission and the information-aware collaborative clustering. In the existing cluster-based schemes, sensor nodes are clustered based only on the location of the sensors and their receiving signal strength. Therefore, there exist some data redundancies between sensor nodes that are spatially close to each other but belong to different clusters. In our research, we will reexamine the clusters based on information content of the data currently received from previous hops to exploit the potential correlation of the sensor data between two neighboring clusters.

The rest of this paper is organized as follows. In Section 2, we review related existing scheme for the clustering-based hierarchical routing protocols. In Section 3, we shall describe in detail the proposed information-aware collaborative routing. In Section 4, we present the simulation condition and results. Finally we conclude the paper in Section 5.

2. RELATED WORK

Recently, Heinzelman *et al.* developed an elegant scheme called low-energy adaptive clustering hierarchy (LEACH), a protocol architecture in which computation is performed locally to reduce the amount of transmitted data and the corresponding routing protocols enable low-energy networking [1]. In LEACH, the nodes organize themselves into local clusters, with one node acting as the cluster head. All non-cluster head nodes transmit their data to the cluster head, while the cluster head node receives data from all the cluster members, performs data aggregation, and transmits aggregated data to the remote BS. Moreover, it incorporates randomized rotation of the high-energy cluster head position among the sensors to evenly distribute the extra energy load of being a cluster head among the sensor nodes.

The cluster head nodes will let all other nodes in the network know that they have chosen this role for the current round. Each non-cluster head node determines its cluster by choosing the cluster head that requires the minimum communication energy, based on the received signal strength of the advertisement from each cluster head.

The cluster heads in LEACH act as local control centers to coordinate the data transmissions within their clusters. A cluster head node sets up a TDMA schedule and transmits this schedule to the nodes in the cluster. After the TDMA schedule is known by all nodes in the cluster, the set-up phase is complete and the steady-state operation (data transmission) can begin.

The steady-state operation is broken into frames, where nodes send their data to the cluster head at most once per frame during their allocated transmission slot. To save energy, the radio of each non-cluster head node is turned off until its allocated transmission time.

The cluster head must be awake to receive all the data from the nodes in the cluster. Once the cluster head receives all the data, it performs data aggregation to enhance the signals and combine the data into a single representative signal with perfect correlation. The resultant data are sent from the cluster head to the BS.

They also propose LEACH-centralized (LEACH-C) using a central control algorithm to form better clusters by dispersing the cluster head nodes throughout the network. During the set-up phase of LEACH-C, each node sends information about its current location and energy level to the BS. In addition to determining good clusters, the BS needs to ensure that the energy load is evenly distributed among all the nodes. To do this, the BS computes the average node energy, and whichever nodes that have energy below this average shall not serve as cluster heads for the current round.

They used the network simulator, ns-2, to evaluate LEACH and LEACH-C, and compare it to other protocols, i.e. a minimum transmission energy (MTE) routing, and static clustering, in terms of system lifetime, energy dissipation, amount of data transfer, and latency.

They showed that LEACH distributes an order of magnitude more data per unit energy than MTE routing, LEACH-C delivers 40% more data per unit energy than LEACH, and static clustering does not perform well when the nodes have limited energy. They also showed that LEACH can deliver ten times the amount of effective data to the BS as the MTE routing for the same number of node deaths. The benefit of rotating cluster heads in LEACH is clearly seen by comparing the number of nodes alive in LEACH and static clustering.

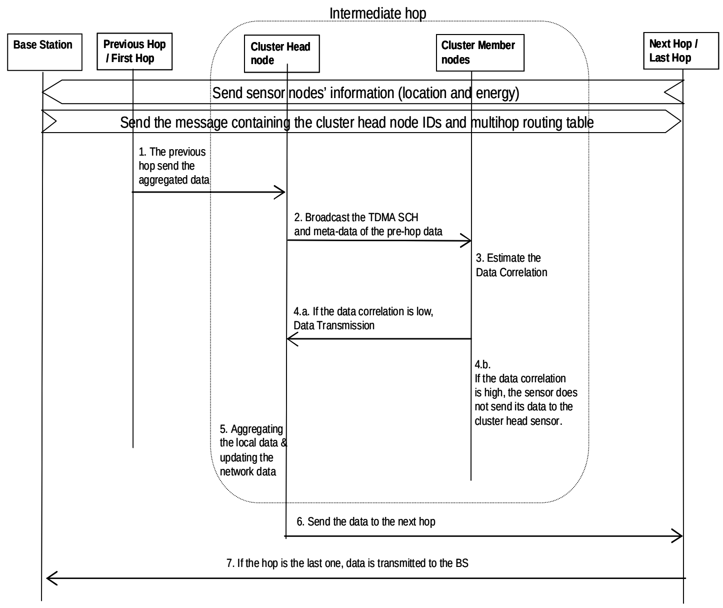


Fig. 2. The message flow of information-aware collaborative routing.

3. INFORMATION-AWARE COLLABORATIVE ROUTING

In order to reduce the redundancy in sensor data, data aggregation schemes have been proposed for wireless sensor network [2]. Data aggregation is to combine the data coming from different nodes in order to eliminate potential redundancy, minimize the amount of data transmissions, and save the energy consumption.

In the clustering-based schemes, local data aggregation is performed per cluster. Typically, sensor nodes are clustered based on their location, i.e. the distances to cluster head node. In an adaptive clustering, while the cluster sensor nodes send the advertising join request message after they self-elected with the remained energy level, the other sensor nodes recognize the message and calculate received signal strength when there are multiple join request messages. Each sensor node can send the acknowledgement message to its cluster head node with the strongest received signal strength. Or, in central-controlled clustering, the base station elects the cluster head nodes based on their energy level and ensures that the cluster head nodes are dispersedly located in the entire network. In this case, the base station determines the membership of individual cluster nodes for each cluster head node, based on the distance between the cluster head node and other nodes. The base station assumes that the most appropriate cluster for a sensor node is the one with the smallest distance from the cluster head.

Even in the central-controlled clustering or the adaptive clustering, the cluster formation is determined only based on the location of the sensor nodes, which can guarantee that the sensor nodes have the shortest distance to the cluster head node among other head nodes and that the energy for transmission and reception in intra-cluster communication with the cluster head node is the least

However, since these clustering schemes are based on only location, not information correlation, there exist certain data redundancies among neighboring clusters. Obviously, there is no need to transmit the redundant data to the cluster head if the same data have already been collected by other neighboring cluster heads. If we do, then, there is will be a waste of transmission energy since there is no information gain in collecting the redundant data at the base station. It is desired for clustering-based routing to be able to recognize such redundancy before the data are transmitted to the cluster head

We propose in this paper a novel information-aware collaborative routing scheme in order to reduce the data correlation between nodes from neighboring clusters and to save energy for transmitting redundant data from sensor nodes to cluster head nodes

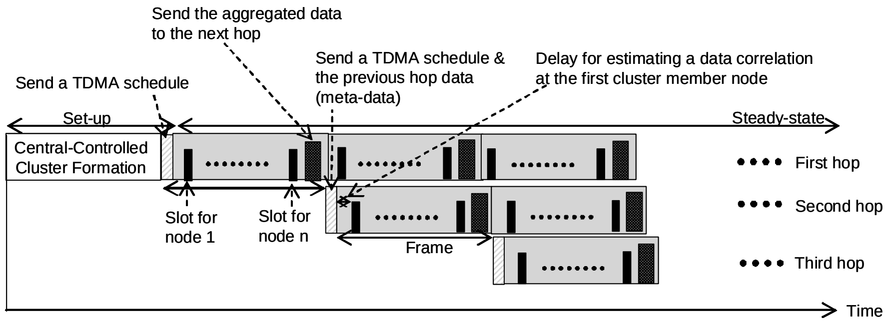


Fig. 3: The information-aware collaborative routing operation. The set-up phase is separated by two phases. The central-controlled cluster formation is done during set-up phase I, and TDMA slot and the previous hop data, if available, are transmitted during set-up phase II. Then, data collection and transfer to the next hop occur during the steady-state phase.

The information-aware collaborative routing adopts clustering-based routing and the multi-hop mode for the inter-cluster transmission. Therefore, the cluster head node at current hop transmits the data aggregated up to this cluster to the next hop cluster head node. The cluster head node which receives the previous hop data collects data from its own cluster member nodes, aggregates them with the previous hop data into a single packet, and then sent it to the next hop data. It assumes to update the network data by fusing data sent from the previous hop with the current hop data. The sensor data finally reach the BS in a hop-by-hop fashion.

In the proposed routing protocol, the cluster head node that receives the previous hop data shall broadcast the data to its current cluster member nodes. Upon receiving the data, the sensor nodes estimate the data correlation between their sensed information and the broadcast data. If the estimation shows high data correlation, the member nodes shall not send their sensed data to the cluster head node. This means that same or similar data have already been collected by the cluster head node of previous hop within its cluster. Since the information has already been included in the data that are transmitted towards the base station, there is no need to send the sensor data from sensor nodes to their cluster head. If the estimation shows low data correlation, the sensor node will send its data to the cluster head node in order to update the information to be forwarded to base station. In other words, at the current hop, only the data with low correlation shall be transmitted to the cluster head node.

Since some cluster member nodes with high data correlation with the previous hop data shall not transmit their sensed data to the cluster head node, the network overall shall save some energy that would otherwise be used for intra-cluster communication, that is, transmitting data at the cluster member nodes and receiving data at cluster head node.

Even though some energy is dissipated when the cluster head node broadcasts the data received from the previous hop to the cluster member nodes in order to estimate their data correlation, we adopt the meta-data format that is much smaller in data size than the data to be transmitted and received during the normal intra-cluster communication. The broadcast of previous hop data is scheduled at a pre-defined time interval.

Since we consider the data correlation between the nodes from neighboring clusters in the information-aware collaborative routing, we can effectively reduce data redundancy among clusters and save additional amount of energy for transmitting and receiving the cluster member nodes' data during intra-cluster communication.

In the existing schemes, the cluster formations are performed based on sensor nodes' location and energy to minimize overall transmission energy. These schemes works fine when there is no correlation between sensor nodes of different clusters. However, since the clusters are formed without respect to data correlation in cluster member nodes, some information may be redundant among nodes between two neighboring clusters. The proposed information-aware collaborative routing scheme is able to re-organize the nodes within a cluster to determine whether or not they join the current round of data collection based on the estimated data correlation. This is equivalent to re-clustering sensor nodes based on information content and collaboration between two neighboring clusters. The end result of such routing scheme is a reduced data transmission and therefore overall reduced energy dissipation for the wireless sensor network.

With such an information aware collaborative routing, the total amount of data received at the BS should be smaller

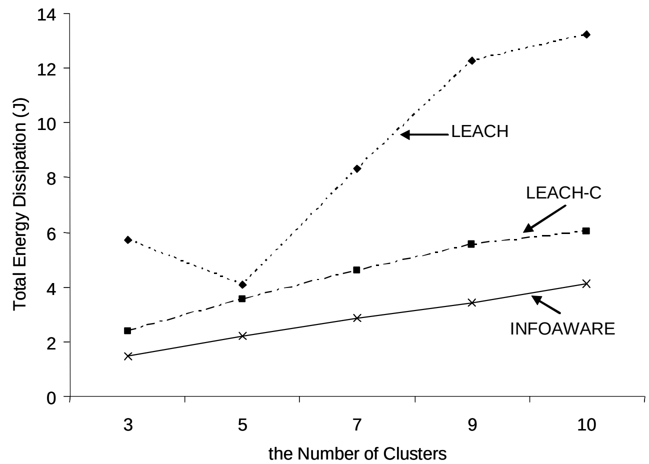


Fig. 4: The average energy dissipation per round. The information-aware collaborative routing with data correlation 0.5 shows the better performance on the average energy dissipation than LEACH and LEACH-C.

than the existing clustering-based routing, i.e., LEACH and LEACH-C. This is because in the proposed information-aware collaborative routing, certain amount of the highly correlated data is not transmitted to the cluster head node and eventually to the BS. However, in the LEACH and LEACH-C, sensor data from all sensor nodes will be transmitted to the cluster head and to the BS. This includes those sensor data that are highly correlated with their neighboring cluster and have been collected by neighboring cluster head. Through careful design of correlation estimation algorithm, we assume that in the information-aware collaborative routing, the data that received at the BS are sufficient enough to represent the entire network information.

3.1. Central-Controlled Cluster Formation

At the initial stage of time interval, all live sensor nodes in the wireless sensor network send their location and energy information to the BS (See Fig. 2). The base station determines the cluster head nodes among the sensor nodes and let them know with which order they can communicate to other cluster head nodes in multi-hop mode for inter-cluster transmission and which sensor nodes are assigned as their member nodes. As proposed in [1], the BS can select sensor nodes as cluster head nodes from those nodes whose energy is above the average node energy.

Once the cluster heads and associated clusters are determined, the base station broadcasts a message that contains the cluster head ID for each node and multi-hop routing table that contains multi-hop routing order, the next cluster head ID, and the transmission distance up to next cluster head node in order to adjust signal strength. If one's node ID is contained in the multi-hop order table, the node becomes a cluster head; otherwise, the node is waiting for the message from its own cluster head node.

The first cluster head node triggers the steady-state data transmission by sending a TDMA schedule for its cluster member nodes (See Fig. 3). And the other cluster head nodes store the message with the cluster head IDs and multi-hop table received from the BS until when the previous hop data is transmitted. From the second hop, as soon as the cluster head nodes get the previous hop data, they can start the steady-state phase to transmit its TDMA schedule and a meta-data of the previous hop data to their member sensor nodes in order to estimate their data correlation.

Since the data transmission in the inter-cluster communication is relayed hop-by-hop, the TDMA schedule is set up after the previous hop data is received at this cluster head node. Once the TDMA schedule of sensor nodes in the entire network nodes is set up, the radio components of each non-cluster head nodes can be turned off at all times except during their transmit sensors.

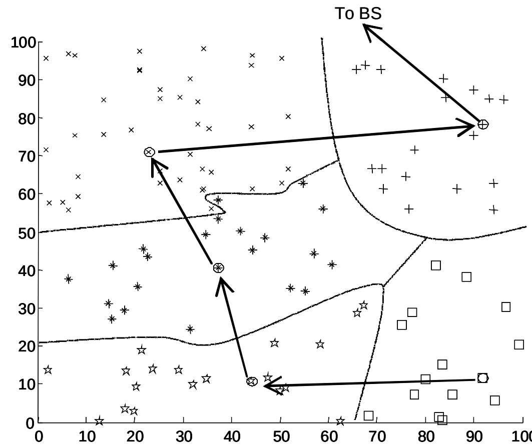


Fig. 5: Clusters and multi-hop mode for inter-cluster communication centrally controlled and formed by the base station. Nodes in the same cluster are marked with same symbol and the cluster head node is marked with a circle. And arrows show that the multi-hop routing path.

3.2. Steady-State Phase

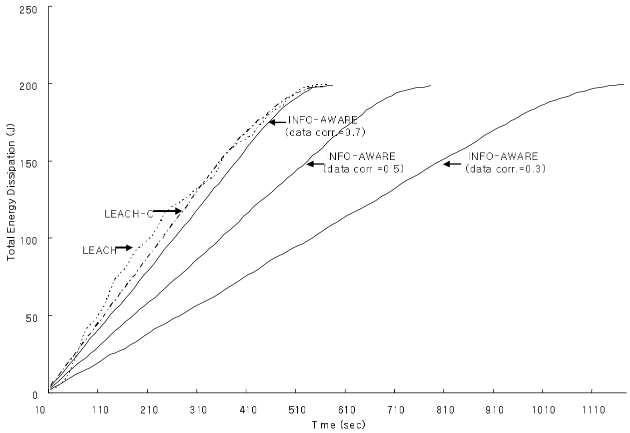
At first, the steady-state phase can be triggered by the cluster head node with the first order in the multi-hop table. The first cluster head node sends the TDMA schedule to its member sensor nodes. The member nodes sent the data to their cluster head node at its TDMA time slot. Also, to reduce energy dissipation, each cluster member node uses power control to set the amount of transmitting power based on the received strength of the cluster head message. Furthermore, the radio of each cluster member node is turned off until its allocated transmission time. The cluster head must be awake to receive the data from the nodes in the cluster.

Once the cluster head receives all the data, it performs data aggregation to reduce the redundant data among the member sensor nodes. For local data aggregation, we assume that all individual sensor data can be combined into a single representative data. The resultant data are sent from the current cluster head to the cluster head node at the next hop. The current cluster head node already knows which node is the next hop cluster head node and where the next cluster head node is located. Thus, it can adjust the transmit power up to the next cluster head node in order to reduce unreasonable energy dissipation. For inter-cluster communication, we assume that the cluster head nodes can communicate each other.

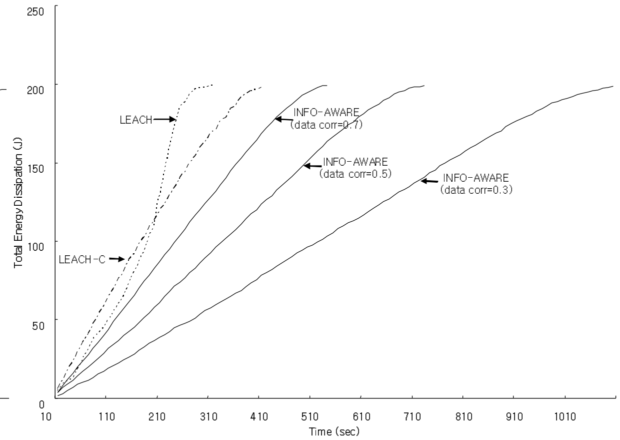
When the cluster head node receives the data from the previous hop, it sends the TDMA schedule and the meta-data of the previous hop data to cluster member nodes. Each cluster member node estimates the data correlation between its own sensed data and the aggregated data from previous hop. If the data correlation is high, the member node would not send its own data to the cluster head. If not, it sends its own data to the cluster head since the data will contain new information for its current round of data aggregation. If a cluster head node is the last hop according to the multi-hop table, it will send the data to the BS after the operations as outlined above.

The first cluster head node triggered this entire process of multi-hop communication of cluster heads. TDMA schedule and aggregated data from previous hop shall be transmitted at time segment I. The cluster member nodes estimate their data correlation based on the previous hop data per the time segment. We assume that the time segment is sufficiently small so that the environments under monitoring remain relatively changed. Also, during time segment II, all live sensor nodes send their information, i.e. location and energy, to the base station, in order for new round of cluster head nodes election.

In this information-aware collaborative routing, the latency can be happened because the transmission of previous hop data occurs in order to trigger the data collection in this current cluster and because the cluster member nodes have to estimate the data correlation before transmitting their data to the cluster head node.



(a)



(b)

Fig. 6: The total energy dissipation over the simulation time (a) The total energy dissipation when the base station is located on (50, 175). (b) The total energy dissipation when the base station is located at (50, 300). These graph shows that the Information-aware collaborative routing (data correlation = 0.5) keeps alive longer by 34% than LEACH-C. Also, the information-aware collaborative routing shows much better performance when the base station is located at the remoter place, thank to multihop mode for inter-cluster communication.

4. ANALYSIS AND SIMULATION OF INFORMATION-AWARE COLLABORATIVE ROUTING

4.1. Experiment Setup

In this research, we also adopt the simple radio hardware energy dissipation model as proposed in [1]. The energy consumption modes for the radio hardware are assumed as follows. The transmitter dissipates energy, $E_{Tx}(l,d)$, to run the radio electronics, $E_{Tx\text{-}elec}(l)$, and the power amplifier $E_{Tx\text{-}amp}(l,d)$. The receiver dissipates energy, $E_{Rx}(l)$, to run the radio electronics, $E_{Rx\text{-}elec}(l)$. For the experiments described in this paper, both the free space and the multi-path fading channel modes are used, depending on the distance between the transmitter and receiver. If the distance is less than a threshold, $d_o=85m$, the free space (fs) model is used. Otherwise, the multi-path (mp) model is used. Thus, to transmit an l-bit message a distance d, the radio expends

$$E_{Tx}(l,d) = E_{Tx-elec}(l) + E_{Tx-amp}(l,d)$$
$$= \begin{cases} lE_{elec} + l\varepsilon_{fs}d^2, & d < d_o \\ lE_{elec} + l\varepsilon_{mp}d^4, & d \geq d_o \end{cases} \quad (1)$$

$$E_{Rx}(l) = E_{Rx-elec}(l) = lE_{elec} \quad (2)$$

For the simulations described in this paper, the communication energy parameters are set as follows:

The electronics energy, E_{elec} = 50nJ/bit, the amplifier energy, ε_{fs} = 10pJ/bit/m^2 & ε_{fs} = 0.0013pJ/bit/m^4, and the energy for data aggregation, E_{DA} = 5nJ/bit/signal

We consider a sensor network of 100 nodes where sensor nodes were randomly distributed between (x=0, y=0) and (x=100, y=100). And we locate the BS at two locations, i.e. (x=50, y=175) and (x=50, y=300). The bandwidth of the channel was set to 1 Mb/s, each data message was 500 bytes long, and the packet header for each type of packet was 25 bytes long. And for the information-aware collaborative routing, the meta-data was 16 bytes long.

The operation round is set up to 20 second in LEACH and LEACH-C, while 10 second in the information-aware collaborative routing because it needs to transmit the previous hop data, if available, as well as the TDMA schedule.

Fig. 4 shows that the LEACH achieves the best performance on the average energy dissipation per round with the five

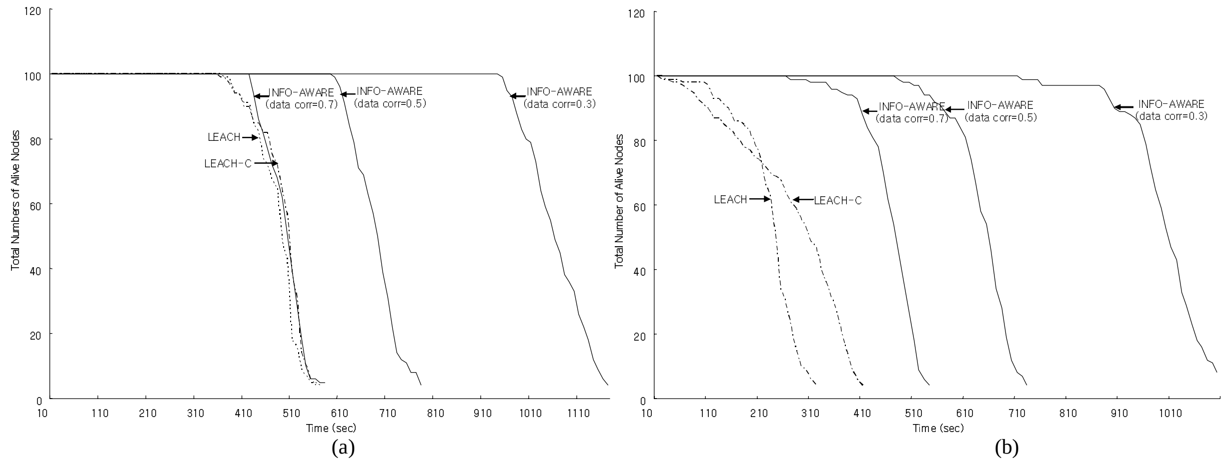


Fig. 7: The number of nodes that remain alive over the given simulation time. (a) The number of nodes that remain alive over the simulation time when the base station is located at (50, 175) (b) The number of nodes that remain alive over the simulation time when the base station is located at (50, 300). These graphs show that in the information-aware collaborative routing the sensor nodes can remain alive longer than LEACH and LEACH-C. Even when the base station is located at the remoter place, the information-aware collaborative routing shows the better performance, thank to the multihop mode for inter-cluster communication.

cluster head nodes. From this graph, the average energy dissipation in the information-aware collaborative routing is calculated per two rounds, i.e. 20 second. It is why we set the number of clusters to five for the following simulation.

Fig. 5 shows an example of the central-controlled cluster formation with 100 nodes and 5 cluster head nodes and the multi-hop inter-cluster transmission route for the cluster head nodes.

4.2. Results

Each node begins with 2J of energy. Each node senses the environment, gathers information, and transfers the data until the initial energy is completely exhausted. When the nodes use up their limited energy during the course of the simulation, they can no longer transmit or receive data. Then, the new cluster head nodes are elected by the base station every 20 seconds and the cluster head node transmit the previous hop data to member nodes per 10s. We tracked the total energy dissipation and the number of nodes alive over the entire simulation process.

The value of data correlation used in information-aware collaborative routing means how many sensor nodes within a cluster participate in transmission of data. Therefore, the less the value of data correlation the less sensor nodes transmit their data to the cluster head node, and the more data correlation is observed among neighboring clusters.

Fig. 6 shows the total energy dissipation over the simulation time. From these graphs, we can extract the network lifetime of the information-aware collaborative routing with several different settings of data correlation and corresponding comparisons with the LEACH and LEACH-C schemes. Fig. 6 (a) shows the total energy dissipation over the simulation time when the base station is located at (50, 175). The network lifetime of the information-aware collaborative routing with 0.5 data correlation is extended much longer by 34% and 39% than the LEACH and LEACH-C schemes, respectively. Also, the network lifetime of the information-aware collaborative routing with 0.3 data correlation is about twice as long comparing with LEACH and LEACH-C schemes. This is because, for the information-aware collaborative routing, the cluster member node sends its own information to cluster head node only if the information is not correlated with previously collected data and can contribute new information to the network data. The reduced data transmission is able to save the energy for transmitting and receiving data during the intra-cluster communication. In LEACH and LEACH-C, sensor data will always be transmitted to cluster head node irrespective of whether or not the sensor data are correlated with data collected at the previous neighboring clusters. However, the information-aware collaborative routing with 0.7 data correlation shows the similar results to LEACH and LEACH-C. This is because the additional messaging, i.e. transmitting the meta-data, will consume additional energy for information-aware collaborative routing.

When we move the base station further away to the location at (50, 300) (See Fig. 6 (b)), the total energy dissipation over the simulation time for LEACH and LEACH-C has been decreased by 44% and 27%, respectively, comparing to previous simulation as shown Fig.6 (a). However, for information-aware collaborative routing, the network lifetime is only slightly decreased by about 3% comparing to the previous simulation with BS located at (50, 175). This is because for the proposed information-aware collaborative routing, the data at a cluster head node are transmitted hop-by-hop with the multi-hop mode for inter-cluster communications. Even though the transmission distance to the BS becomes longer, the multi-hop mode results in better performance on total energy dissipation. It is because, for the information-aware collaborative routing, the aggregated data at the cluster head is transmitted in a much shorter distance to the next hop of cluster head, while for the LEACH and LEACH-C schemes, the data at each cluster head shall be directly transmitted to the BS that is located far way from the sensor networks.

Fig. 7 shows that the total number of nodes that remain alive over the simulation time. The sensor nodes in the information-aware collaborative routing with 0.5 and 0.3 data correlation can be alive much longer by 34% and 105% respectively than LEACH-C scheme. In LEACH and LEACH-C, the every non-cluster head node shall transmit their sensed information to cluster head nodes, regardless of spatial and temporal information correlation of the sensed data. This causes the rapidly drainage of the energy for sensor nodes in the entire network.

If we once again move the base station further away at the location (50, 300), as shown in Fig. 7 (b), the total numbers of nodes that remain alive over the simulation time for LEACH and LEACH-C are decreased by 40% and 26%, respectively, than the results in Fig. 7 (a). However, in the case of information-aware collaborative routing, the number of sensor nodes alive is virtually not affected by the longer transmission distance to the BS. The improvement also caused by the multi-hop mode for the inter-cluster transmission adopted in the proposed information-aware collaborative routing.

5. CONCLUSION

This research shows that the information-aware collaborative routing can significantly reduce the energy dissipation in the entire network and extend the sensor network's lifetime. The proposed scheme exploits the data correlation between the neighboring clusters and reduces the energy consumption in the intra-cluster transmission. This information-aware collaborative routing saves energy by excluding some sensor nodes with high data correlation between clusters from transmitting their information to the cluster head nodes. This is in contrast to the existing cluster-based routing schemes in which all sensor nodes send their information to the cluster head node regardless of spatial and temporal correlation of their collected data. The information-aware collaborative scheme is able to decrease the number of cluster member nodes to participate in updating the network data and reduce the energy consumption used for transmitting and receiving data in the intra-cluster communication. Even though the existing clustering based technique can reduce the data size to be transmitted from the cluster head node to the BS, the proposed scheme is able to exploit the data correlation and to reduce further the energy dissipation in the intra-cluster transmission.

Furthermore, the multi-hop mode for inter-cluster communication in the information-aware collaborative routing provides additional energy efficiency when the base station is located at remote location or when the sensor nodes are dispersed in the large area.

This routing is very much applicable to tracking, especially for the information-driven tracking tasks. This is because the cluster nodes would share the previous hop data for information update as they anticipate the next moving direction and speed.

For the next research, we can improve the performance in reducing the data size to be transmitted from cluster member nodes to cluster head node with the distributed source coding. This is because once the cluster member nodes receive the correlated data from the previous hop meta-data, they can carry out the distributed source coding using the correlated data as side information for distributed coding. Those cluster member nodes with high data correlation may be excluded to transmit their information to cluster head. However, with distributed source coding, other sensor nodes below the threshold of data correlation can still transmit reduced size information data resulting from the distributed source coding.

We expect the information-aware collaborative scheme, after integration with distributed source coding, will further improve both the efficiency of energy dissipation within the intra-cluster and the accuracy of data acquisition.

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