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Energy Efficiency through Dynamic Packet Transmissions in Sensor Network

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ABSTRACT

The work presented in this study proposes an efficient mechanism to reduce the computational and communicational costs associated with sensor network models. Specifically, the study focuses on two different models or topologies, each consisting of three different methods of data transmission for the purpose of reducing the interaction among network nodes when data measured at some instant, t-1, is equal to the data sensed at later instant, t. In terms of the model configurations, the simulation-based approach used to validate our proposed technique indicates that scenarios where member nodes of a cluster was not needed for computation required for less resources for data transmission with increased energy consumption than scenarios that required both member nodes and cluster heads for computation.

Keywords: *Sensor Network; Packet transmission; Single-hop; Multi-hop; Energy Efficiency*.

1 INTRODUCTION

Sensors play an important role in many emerging technologies such as opportunistic networks, big data and vehicular ad hoc networks. Therefore, enhancing the efficiency of sensor networks in terms of computation and energy consumption is integral for ubiquity of smart and efficient technologies. Consequently, a lot of studies have been devoted to the design of efficient routing protocols, network topologies, data aggregation, localization and many other approaches for sensor networks. Notwithstanding the progress recorded in these directions, the need to improve the computational costs required for sensors to transmit data directly to the cluster head (CH) or multi-hop through other nodes is still an open question. More so, since there is need to curtail the transmission of redundant data to the CH using either single- or multi-hop communication, thereby enhancing the computational efficiency of network infrastructure.

The study presented in this work is primarily aimed at contributing to similar efforts by undertaking a comparative analysis of the computational requirements needed for single and multi-hop communication protocols between member nodes and CH of a cluster. Moreover, available literature [1-10] suggest that these protocols do not analyze cost if the computation is performed at the member nodes of a cluster, confined to the CH, both or none. Since most of these protocols are cluster-based, i.e., they utilize single hop communication between member nodes and CH, these algorithms do not consider comparisons between data from two consecutive timestamps. For instance, there is widespread use of LEACH [1-3], PEGASIS [4], DSC [5], TEEN [6-7], APTEEN [8], LESCS [9], advanced multi-hop LEACH [10], hybrid multi-hop LEACH [11] and zone-based routing protocol [12], which are mostly either proactive (transmit data periodically) or reactive (transmits data when sensor senses a certain value). Meanwhile, by using a uniform multi-hop clustering mechanism, the study in [13] reduces communication overhead while the efforts in [14-15] compare multi-hop routing protocols. Specifically, in [15], Singh et al. compared single-hop and multi-hop sensor communications in terms of energy efficiency and signal-to-noise-ratio without considering requirements for processing data at different nodes of the network.

Unlike the protocols highlighted above (all of which rely on computation at the CH level), the technique proposed in this study presents two sensor network models (single-hop and multi-hop), each assessed along three computational scenarios in terms of resources for data transmission and energy cost. The three computational scenarios are: Scenario 1 where computation is confined to the sink node, i.e., without using the sensor or CH;

Scenario 2 where computation takes place in the sensors but not at the CH level; and Scenario 3 where computation is executed at both sensor and CH levels. These scenarios provide the framework to validate the performance of our proposed technique and our simulation-based assessment. Simulation results suggest that computational costs of the multi-hop transmission is almost five times more than that of the single-hop transmission. Moreover, Scenario 3 was found to have the least energy consumption for data transmission in both models.

The remainder of the paper is outlined as follows. In Section 2, an overview of the proposed sensor network models including the three computational Scenarios used to assess them is presented. Following this, in Section 3, a detailed evaluation of the proposed technique is undertaken and its performance in terms of network energy consumption and resources needed for data transmission is reported. Section 4 presents a few concluding remarks as well as insights into possible improvements to the proposed technique.

2 PROPOSED NETWORK MODELS AND APPROACHES

This study presents three different Scenarios on sensors data computation and transmission from data collecting sensor nodes to the sink node. The Scenarios include: Scenario 1: where neither the sensor nor the CH is used for computation instead these nodes will only transmit data to the sink once they sense and receive data from other nodes. Hence, there is no cost (in terms of consumption or computation) in those nodes for processing data. In other words, in this Scenario, only the sink node is utilized to perform the required computation. Scenario 2 – where data collecting sensors are only used to sense and transmit data to the CH but not for computation. The CH performs some computation (i.e., data aggregation) and then the processed data is sent to the sink. The computation undertaken at the CH includes checks to ascertain whether data received by it at the current instant is identical to data received at some previous instant. When the data received at the consecutive time instant differentiates by a factor, the CH will transmit to the sink; otherwise, the CH will drop the packet. In Scenario 3, both data collecting sensors and CH perform computations as Scenario 2. After this sensors transmit partially processed data to the CH, which transmits processed data to the sink. Data will be processed only if data received at the current time instant varies from the previous time instant by a substantial factor.

Each of the three computational Scenarios will be applied to the two sensor network models or topologies, i.e., Model 1 (the single-hop model) comprising of a number of clusters with each node transmitting directly to the CH and Model 2 (the multi-hop model) where a single cluster comprising of a number of nodes that transmit data to the CH via other nodes or directly. Another objective of this study is identify optimal models in terms of energy dissipation and resource needed for data transmission in two consecutive instants.

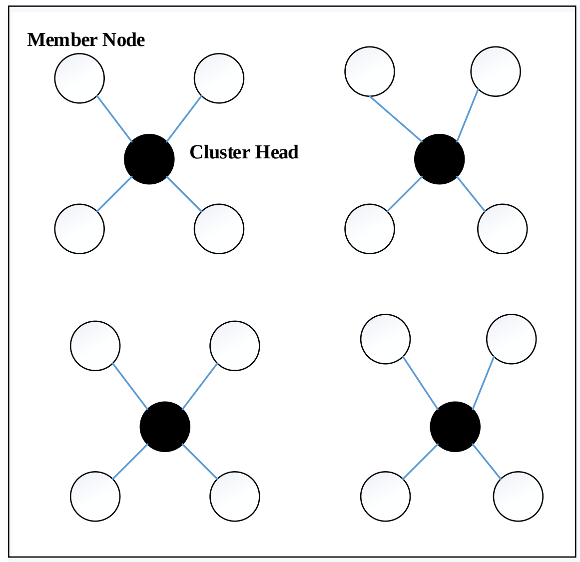

Fig. 1. Single Hop Topology

Figure 1 illustrates the single-hop topology (or model) with n = 4 clusters (each member node is one-hop away from the CH) and m = 4 nodes per cluster. In this model a base station (BS) randomly selects a number of nodes as CHs and then other nodes connect to the closest cluster of a CH as member nodes.

Figure 2 illustrates the multi-hop topology with a single cluster with m_1 = 4 single-hop nodes to CH and m_2 = 8 multi-hops nodes to CH. In this model, BS randomly selects only one CH. Other nodes are connected to CH directly or through other member nodes based on their distance.

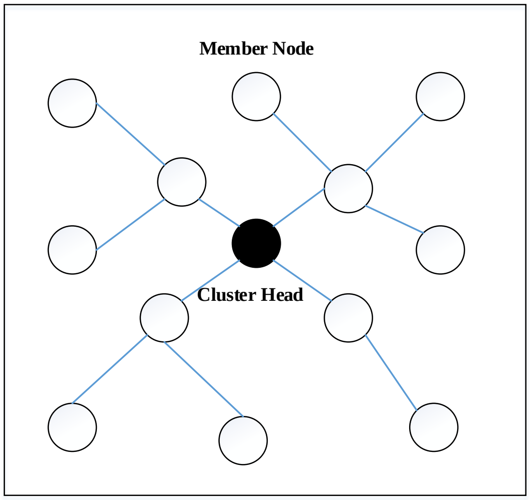

Fig. 2. Multi-hop Topology

2.1 Computational Models

Here, we present the computational cost of the sensor network topologies or models presented and three approaches in each model. The symbols used and their corresponding meaning of each symbol is presented in Table 1.

Table 1: Parameters and their corresponding symbols

Parameter Name	**Symbol**
Energy consumptions for data sensing	E_s
Energy consumption for data computation	E_c
Energy consumption for transmitting data	E_{TX}
Energy consumption for receiving data	E_{RX}
Probability that the data transmitted at time instant *t*-1 is different from the data measured at time instant *t*	p
The number of iterations	i
Number of nodes having one-hop to CH (model 2)	m_1
Number of nodes having two-hops to CH (model 2)	m_2
Number of nodes with one-hop to CH in model 1	m
Number of bits in each transmission	b
Number of clusters	n

2.2 Sensor Network Models

The sensor network models and three computational Scenarios on which the proposed technique is built are presented in the next Section.

2.2.1 Model 1 - Topology 1 (Single Hop to CH and Multiple-Cluster)

Scenario 1

In this Scenario, no nodes in the cluster will perform any computation. *m* member nodes and CH of a cluster performs data sensing and transmissions. If the experiment is run for *n* times or iterations, *m* cluster heads in the network receive data from its member nodes and then transmit to the sink. If the size of a data packet is b bytes the total computational cost will be given as:

$$C = i \times n \times \left((m+1)(E_s + b \times E_{TX}) + m(E_{TX} + E_{RX}) \times b \right) \quad (1)$$

Scenario 2

In this Scenario, member nodes do not perform any computation only the cluster head performs the computation. The computational cost associated with this model at the initial time instant is given as:

$$C_0 = i \times n \times \left(\begin{array}{l} (m+1)(E_s + E_c) + b \sum_{k=1}^{m} (E_{TX} + E_{RX}) \\ + b \sum_{k=1}^{m+1} E_{TX} \end{array} \right) \quad (2)$$

If the probability that the data transmitted at instant *t*-1 is different from the data measured at instant *t* the computational cost of this model at second and all subsequent time instant is given as:

$$C = i \times n \times \left(\begin{array}{l} (m+1)(E_s + E_c) + b \sum_{k=1}^{m} (E_{TX} + E_{RX}) \\ + b \sum_{k=1}^{m+1} p \times E_{TX} \end{array} \right) \quad (3)$$

Scenario 3

In this Scenario, both member nodes and cluster head perform computation. Computation cost at the initial time instant is denoted as:

$$C_0 = i \times n \times \left(\begin{array}{l} (m+1)(E_s + E_c) + b \times \sum_{k=1}^{m} (2E_{TX} + E_{RX}) \\ + b \sum_{k=1}^{n} E_{TX} \end{array} \right) \quad (4)$$

Similarly, computational cost at the subsequent time instants is denoted as:

$$C = i \times n \times \begin{pmatrix} (m+1)(E_s + E_c) + b \times \sum_{k=1}^{m} (2E_{TX} + E_{RX}) \\ + b \sum_{k=1}^{n} p \times E_{TX} \end{pmatrix} \quad (5)$$

2.2.2 Model 2 – Topology 2 (Single Cluster, Multiple-hop to CH)

Computational costs for three different methods in this model are represented as follows.

Scenario 1 (No computation)

$$C = i \times n \times \begin{pmatrix} (m_1 + m_2 + 1)E_s + (2m_2 + m_1 +)(E_{TX} + E_{RX}) \times b \\ + (2m_2 + m_1 + 1) \times E_{TX} \times b \end{pmatrix} \quad (6)$$

Scenario 2 (Computation only by CH)

This Scenario requires more message transmission and reception by CH as compared to method 1.

The computational cost at the initial time instant is denoted as:

$$C_0 = i \times n \times \begin{pmatrix} (m_1 + m_2 + 1)E_s + (2m_2 + m_1 +)(E_{TX} + E_{RX}) \times b \\ + \sum_{k=1}^{m_1 + m_2 + 1} b \times E_{TX} \end{pmatrix} \quad (7)$$

The computational cost for subsequent time instants is denoted as:

$$C = i \times n \times \begin{pmatrix} (m_1 + m_2 + 1)E_s + (2m_2 + m_1 +)(E_{TX} + E_{RX}) \times b \\ + \sum_{k=1}^{m_1 + m_2 + 1} p \times b \times E_{TX} \end{pmatrix} \quad (8)$$

Scenario 3 (Computation both at member nodes and CH)

This Scenario is expected to have more message transmissions and computations by both CH and member nodes as compared to other two methods. The computational cost at the initial time instant is denoted as:

$$C_0 = i \times n \times \begin{pmatrix} (m_1 + m_2 + 1)(E_s + E_c) + b \times \sum_{k=1}^{m_2} (3E_{TX} + 2E_{RX}) \\ + b \times \sum_{k=1}^{m_1} (2E_{TX} + E_{RX}) + b \times E_{TX} \end{pmatrix} \quad (9)$$

The computational cost for the subsequent time instants is denoted as:

$$C = i \times n \times \begin{pmatrix} (m_1 + m_2 + 1)(E_s + E_c) + b \times p \times \sum_{k=1}^{m_2} (3E_{TX} + 2E_{RX}) \\ + b \times p \times \sum_{k=1}^{m_1} (2E_{TX} + E_{RX}) + b \times p \times E_{TX} \end{pmatrix} \quad (10)$$

3 SIMULATION RESULTS

The results of the simulation-based evaluation of the proposed technique were carried out using MATLAB. In this simulation, parameter values and descriptions as summarized in Table 2 were used. Similarly, computational models described in earlier sections of the paper (Equations 1-10) were used to compute relevant parameters. Furthermore, the simulation-based results were obtained by presetting number of clusters as 1 and 4 for models 1 and 2, respectively. A maximum of 1440 iterations were run and the results obtained are presented in Figures. 3 - 6.

Table 2: Simulation parameters and their respective values

Parameter Name	**Symbol**	**Value**
Energy consumptions for data sensing	E_s	10^{-9} *Joule*
Energy consumption for data computation	E_c	10^{-12} *Joule*
Energy consumption for transmitting data	E_{TX}	4×10^{-6} *Joule*
Energy consumption for receiving data	E_{RX}	2×10^{-6} *Joule*
Probability that the data transmitted at instant *t*-1 is different from the data measured at instant *t*	p	$0 \le p \le 1$
The number of iterations (every minute in 24 hours)	*i*	Max. 1440
Number of nodes having one-hop to CH (model 2)	m_1	4 – 12
Number of nodes having two-hops to CH (model 2)	m_2	8 – 24
Number of nodes with one hop to CH in model 1	*M*	4 – 12
Number of bits in each transmission	*b*	64
Number of clusters	*n*	4

Figure 3 illustrates the number of message transmissions in Model 1 (multiple clusters, single-hop nodes) for varying number of nodes. Here, we observe that number of message transmission is less in Scenario 1 as compared to other two Scenarios where there is no computations at the member nodes and CH in Scenario 1. Hence, no message is transmitted between nodes in Scenario 1 whereas other two Scenarios require transmitting messages among member nodes and CH to perform computations. Similarly, Figure 4 illustrates that the network energy consumption of different scenarios in Model 1. Here, we observe that the network energy consumption is less in Scenario 1 as compared to other two Scenarios for similar reasons stated above.

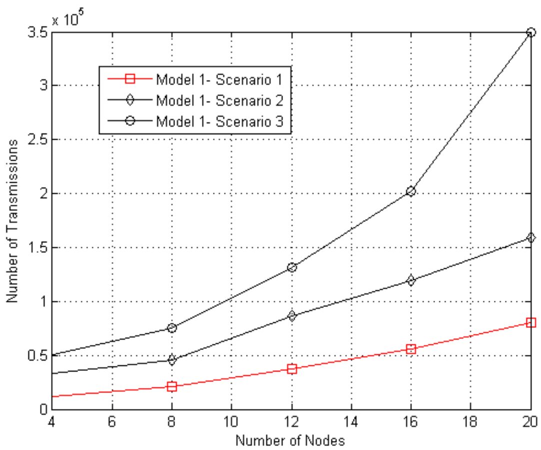

Fig. 3. Number of transmissions varying the number of nodes for Scenarios of Model 1

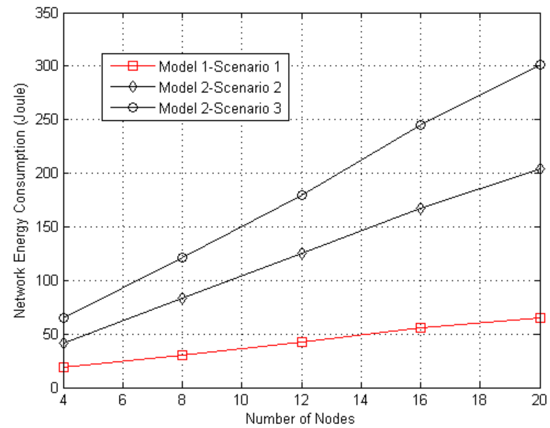

Fig. 4. Variation of network energy consumption with the number of nodes for different Scenarios of Model 1.

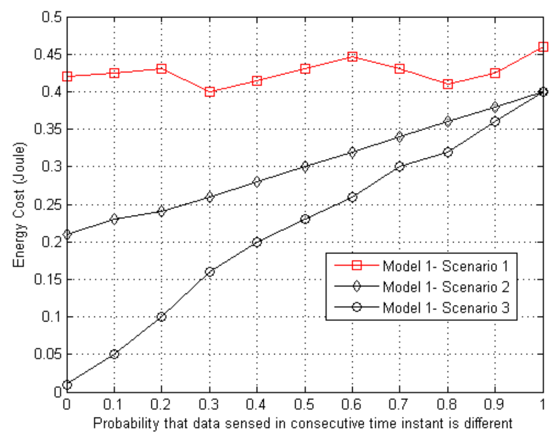

Fig. 5. Energy consumptions of different approaches in model 1 varying probability p

Figure 5 illustrates the network energy consumption of the different Scenarios in model 1 showing variation in the probability *p*, which represents the probability that the data sensed by a sensor nodes at the time instant *t* is different than the data that was sensed at the time instant $t - 1$. The energy consumption of Scenarios 2 and 3 increases if the probability increases at two consecutive time instant (i.e., data sensed that time instant *t* is more likely to be different than data sensed at time instant *t*-1). However, probability in Scenario 1 will not have much impact on energy consumption as neither member nodes of a cluster nor CH performs any data computation in Scenario

On the other hand, the network energy consumption in model 2 (multi-hop, single cluster) will be much more than that in model 1 varying the probability *p* (as illustrated in Figure 6) because the average distance that a packet travels to reach to the destination will exceed those in model 2.

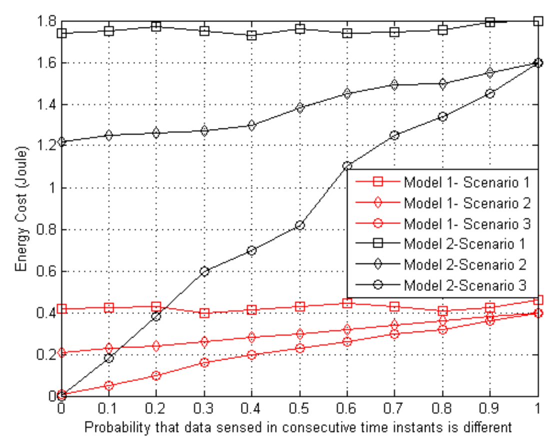

Fig. 6. Comparison of energy consumptions of models 1 and 2 varying probability p

4 CONCLUSION

This paper presented two sensor network models or topologies and three routing/data transmission

Scenarios. These models include single-hop and multi-hop data transmission between member nodes and cluster head of a cluster in a sensor network. Then, each model is assessed along three computational scenarios in terms of resources for data transmission and energy cost. The three computational scenarios include Scenario 1: data computation is confined to only the sink node, Scenario 2: computation takes place in the sensors but not at the CH level and Scenario 3: computation is performed at both sensor and CH levels. Then, a simulation was conducted to measure the performance of these models with their different Scenarios in terms of energy cost and number of data transmissions. The network model that used single hop data transmission between sensor nodes and cluster head where both member nodes of a cluster and cluster head process data before transmitting to the sink node is considered to be the best model. In future, we plan to compare these approaches in terms of packet loss ratio and other relevant performance metrics.

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