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Inspired Energy Efficient Data Delivery Based on Redundant Data Elimination using Discrete Cuckoo Search Optimization

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Abstract

Data aggregation in wireless sensor network is the process of aggregating the data from multiple sensors to eliminate redundant transmissions. Data aggregation still suffers from some defects like network congestion or contention, sensor power consumption in transmission of redundant data packets due to spatio-time correlation of the neighbor sensors, and false data aggregation resulted from outlier data. To overcome these defects, we propose a data packet delivery approach from a reliable sensor to the cluster head when an event is occurred in the field of interest. We take advantage of cuckoo search (CS) algorithm as a nature-inspired metaheuristic algorithm to implement Single Node Selection (SNS) scenario for data packet delivery and we show the influence of data delivery mechanism of this scenario on the life time of the network. In Single Node Selection (SNS), cuckoo search optimization is used to find the sensor that is relatively close to the event to send a data packet holding the sensed raw data (without any modification) to the cluster head. Optimum data delivery route involves a single sensor that is relatively close to the event to send the recorded data. A comparison is made with respect to LEACH, E-LEACH protocols that show a superior advance of our approach over LEACH and E-LEACH protocols in energy consumption, network lifetime, and network throughput.

Keywords: *Wireless sensor networks, Data aggregation, Cuckoo search optimization, Hierarchical clustering protocols, Energy efficiency*

1. Introduction

Wireless Sensor Networks (WSNs) consist of hundreds of small, inexpensive, low energy and computational power sensor nodes that deployed randomly and in unattended environment. WSNs and have achieved a widespread applicability in many applications such as object tracking, environment monitoring, military affairs, and medical care. The lifetime of a sensor node is determined by its power supply which is significantly affected by the communication among nodes. A salient feature of sensor networks is that neighboring sensor nodes may collect similar data and carry redundant information due to the spatio-temporal correlation characteristics of the physical medium being sensed [1-2]. Data aggregation [3] is an essential paradigm for wireless routing in sensor networks used for merge messages data in-network while traversing through network it is also termed as data fusion. In common scenario of sensor network, is to combine the data that coming from different sources, eliminate redundancy, minimize the number of transmissions and thus save the energy. In this paper we designed a single node selection (SNS) scenario using discrete cuckoo search (DCS) algorithm to find the best route to deliver the recorded data to the cluster head when an event is detected in the field of interest. We present node selection rules integrated with best route selection to maintain balance

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energy consumption between WSN nodes. We have compared this algorithm with the conventional aggregation algorithms in terms of network lifetime, energy consumption, and network throughput.

The rest of the paper is organized as follows: Section 2 shows some of the previous work in the related area. Data aggregation problems is presented in Section 3. Cuckoo Inspired Algorithm is presented in Section 4. Section 5 discusses proposed single node selection using discrete cuckoo searching optimization. Section 6 presents the simulation results. Finally we conclude our research work in Section 7.

2. Related Work

In [4] Slepian–Wolf coding was used that eliminates data redundancy caused by spatial correlation with no need for inter sensor communication.

In [5] clustered AGgregation (CAG) is proposed, that creates clusters of nodes that monitor similar values and allows transmission only from one node in every cluster.

In [6] Low Energy Adaptive Clustering Hierarchy (LEACH) and [7] Energy-Low Energy Adaptive Clustering Hierarchical protocol (E-LEACH) protocol, the cluster head (CH) allocates the TDMA slot for all its cluster members to avoid the collision. On the reception of TDMA all cluster members identify their time slot. At the located TDMA slot, all cluster members sends the monitored information to its cluster head (CH). Each cluster head (CH) waits for one TDMA frame to collect the information from its member nodes. After each TDMA frame, cluster head (CH) aggregates the received information and forwards the aggregated data directly to the base station, hence the error rate for the cluster heads over 4 hop distance are high. In LEACH the cluster head (CH) may die during the period it collects the data from its cluster members so it elects new cluster head but the previous cluster head data are lost. That information is not included with new cluster head (CH) aggregation so the data error is increased in LEACH and E-LEACH.

In [8] Kalpakis *et al*. study the maximum lifetime data aggregation (MLDA) problem. The objective is to find a set of data gathering schedules to maximize the system lifetime a schedule is defined as a collection of directed spanning trees rooted at the sink node.

[9] Studied efficient approximation algorithms for the optimal aggregation problem extensively. The optimization problem is modeled as a combinatorial optimization problem which can be solved using a population based meta-heuristic approach. In addition, energy balanced and efficient network routing protocol is critical to prolonged network lifetime.

3. Data Aggregation Problems

Data aggregation is defined as the process of aggregating the data from multiple sensors to eliminate redundant transmission. In WSNs the sensed information is collected in a single point (sink), when the sink queries the sensors to report the physical conditions from the area of interest. The follow of information in WSN is many to one that results high contention and congestion at nodes which are located closer to the sink as compared with nodes that are located away from the sink [10]. When the contention and congestion increased the probability of packet loss increased because the nodes that are close to the sink consume more higher energy due to heavy packets delivery traffic that results loss residual energy earlier and the sink maybe disconnected from the rest of the network.

The data aggregation still suffers from some obstacles, due to dissimilarity in the nature of the individual sensor node, and the network of sensor nodes raises some challenges:

- The low reliability of a sensor node. When sensors are deployed in an unfamiliar environment, the sensed values are unpredictable and unknown. It is, therefore, extremely difficult to distinguish between normal and abnormal sensor readings, identify an anomalous node is important but tricky.

- Network level problem, sensors have limited memory, processing capacity and limited battery life. The processing techniques and communication protocols must be able to adapt to individual node failures, adjust to changing environment, check sensor data integrity, extract useful information by aggregating spatial-temporal data with limited resources, and communicate as less as possible to preserve the nodes[11-12].
- Tackle abnormality and noise in the sensed data.
- The information must be send at a resolution as per the query requirements from the sink.
- In wireless sensor networks, the minimum data aggregation time problem was proved NP-hard [13].
- Node scheduling algorithm is key challenging in WSNs to reduce energy consumption [14]. Communication is a dominant source of energy consumption (80% of power consumed in each sensor node is used for data transmission) [15], while data aggregation requires substantial energy consumption because each sensor node has to report every reading to the base station.

4. Cuckoo Inspired Algorithm

Cuckoo Searching (CS) [16] is inspired by the parasitism of some cuckoo bird species. These birds aggressively reproduce and then abandon their eggs in the nests of other host bird species. Some host birds behave aggressively and then throw away the alien eggs upon discovering an intrusion. Others simply leave their nests and build new nests elsewhere. Xin-She Yang and Suash Deb in 2009 uses the following representations: Each egg in a nest represents a solution, and a cuckoo egg represents a new solution. The aim is to use the new and potentially better solutions (cuckoos) to replace a not so good solution in the nest. In the simplest form, each nest has one egg. The algorithm can be extended to more complicated cases in which each nest has multiple eggs representing a set of solutions. CS is based on three idealized rules:

1) Each bird lays one egg at a time. The egg gets placed randomly among the host bird nests.
2) The nest with the highest fitness value will get carried over to the next generation.
3) The number of host bird nests is fixed. The probability of a host bird discovering an intrusion is set at a constant value of $pa \in [0, 1]$. In this case, the host bird can either throw the egg away or abandon the nest so as to build a completely new nest in a new location.

In generating of a new solution, the random-walk is best performed in using levy flights. The levy flight of cuckoo *i* is performed using

$$x_i^{(t+1)} = x_i^{(t)} + \alpha \oplus \text{lévy}\ (\lambda) \quad (1)$$

Where $\alpha > 0$ is the step size which should be related to the scales of the problem of interests and can be selected by the user. In most cases, $\alpha = O(1)$. The above equation is essentially the stochastic equation for random walk. In general, the random walk via L´evy flight is more efficient in exploring the search space as its step length is much longer in the long run, and the product $\oplus$ means entrywise multiplications [17]. The L´evy flight essentially provides a random walk while the random step length is drawn from L´evy distribution

$$\text{Levy} \sim u = t^{-\lambda}, \ (1 < \lambda \leq 3) \quad (2)$$

Which has an infinite variance with an infinite mean. Here the consecutive jumps/steps of a cuckoo essentially form a random walk process with a power-law step-length distribution with a heavy tail.

Based on [16] and [17], CS is very efficient in finding the global optima with high success rates.

5. Proposed Single Node Selection using Discrete Cuckoo Searching Algorithm

In the area of interest the sensors deployed randomly and when an event occurred many adjacent sensors record spatial correlated data and the aggregation points/ or cluster heads will receive duplicate data records about the same event which means that aggregation sensors /or cluster heads consume its precious power to receive a redundant data from its cluster members that consumes its energy to send/ receive duplicate data. Our contribution is to overcome this defect of data aggregation, by proposing Single Node Selection (SNS) using Discrete Cuckoo Searching (DCS) data delivery scenario and show its effect on the network behavior.

5.1. Single Node Selection (SNS)

In this scenario when an event occurs in the WSN field all the sensors in the cluster detect the event occurrence, record the data, and all of them can send their data to the aggregation sensors/ or cluster head, but we propose to select just one sensor to deliver the recorded data packet to the cluster head. We adopt a discrete cuckoo search optimization (DCSO) algorithm to find the best sensor (*B_Sens*) (relatively close to the event in the field of interest and can deliver precise quality data to the cluster head with minimum energy consumption). As shown in Figure1, when an event take place all sensors in the cluster detect the event, but we will give attention just to s_1, s_2, s_3, and s_4 because they are close to the event and can record accurate readings. The power consumption of s_1, s_2, and s_4 to deliver data packet is relatively higher than power consumption of s_3 (s_3 is closest to the cluster head), hence just s_3 will be the best sensor (*B_Sens*) that will send its data report to cluster head and the cluster head will receive the data packet just from s_3 and transmit it to the sink with the following tuple: R = <*B_Sens ID*, *CH ID*>.

When s_3 take the role of data packet delivery, the delivery power consumption is drown from s_3 as a transmission power consumption (T_x), and from the cluster head as receiving power consumption (R_x) that means just two sensors (s_3, CH) lost some of their power, this scenario will preserve the sensors power and prolong the network life time.

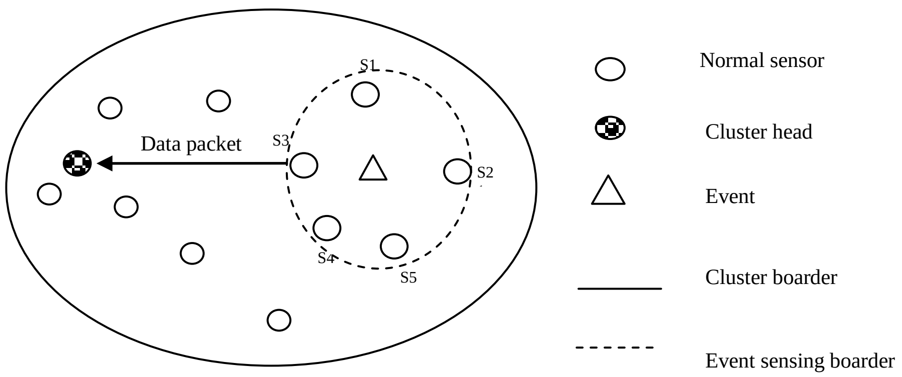

Figure 1. SNS for Packet Data Delivery

5.2. Nest Building

Our WSN nests represent by a square array of size ‘L’ where L is number of clusters. For example

WSN with 10 clusters will has 10 nests, each nest with 10 sensors. When an event take place in cluster ’i’, the ith nest will be the active nest. From Figure2 if an event occurs in cluster no. 5, then *NEST 5* will be the active nest, and we are randomly will select 10 sensors from cluster number 5 sensor list. This nest will undergo cuckoo search for further optimization to give the best solution.

Sensor ID / *Nest No.*	S_1	S_2	S_3	….	S_5	….	S_{10}
NEST 1	11	24	83	….	99	….	100
NEST 2				….		….	
….				….		….	
NEST 5	25	18	3	….	31	….	1
….				….		….	
NEST 10				….		….	

Figure 2. Nest Representation of WSN with 10 Clusters

If for jth generation, cuckoo search fitness function for s_k is the minimum, s_k will not be replaced and will passed to (j+1)th generation.

5.3 Discrete Step Size and Updating Scheme

In continuous optimization problem [18], the step size is related to the scales of the problem of interests and can be selected by the user. In most cases, $\alpha = 1$. For (DCS) step size for cuckoo can be defined as:

$$\text{Step size} = \varepsilon \quad \text{where} \quad 1 \leq \varepsilon \leq n \tag{3}$$

The diversity of ε as a random number allow to move in the search space in variable step size to cover the search space of our problem that facilitate the convergence of the best solution rapidly.

In our approach, we use no Lévy flight (Lévy flight=1). The exploitation around the best solutions is performed by using a local random walk, and express uniform distribution which become a standard random walk:

$$x_i^{(t+1)} = x_i^{(t)} + \varepsilon \tag{4}$$

This random walk may become too aggressive which makes new solutions jump outside of the design domain and thus wasting evaluations. Now the actual random walks or flights:

$$x_i^{(t+1)} = (x_i^{(t)} + \varepsilon) \text{ modulo } n \tag{5}$$

5.4 Discrete Fitness Function

Our fitness function is to minimize the power consumption of sensor (s_i) to transmit a data packet to the cluster head, the fitness function given by:

$$F=\begin{cases} 1*10^{10} & if\ dist \geq Event\_threshold \\ ETx*Packet_{length}+Efs*dist_1^2*packet_{length} & if\ dist_1 < d_0 \\ ETx*Packet_{length}+E_{mp}*dist_1^4*packet_{length} & if\ dist_1 \geq d_0 \end{cases} \quad (6)$$

Where *dist* is the distance (Event, s_i), and $dist_1$ is the distance (s_i, Cluster head).

Thus the fitness function is compound from two related parameters the distance and energy. On minimizing this function the total communication gets reduced and the route with minimum power consumption is resulted. Thus the lifetime of WSN gets increased.

5.5. Single Node Selection (SNS) Algorithm

In this section we will present single node selection (SNS) for optimum route data delivery in wireless sensor network using discrete cuckoo search (DCSO) algorithm. The input parameter is the set of all sensors in the cluster, and the output is the best route (sensor with minimum power consumption on data delivery from the event to the cluster head).

Algorithm *Single Node Selection (SNS)*

Input : *S1* = {s_1, s_2, …, s_n}, n is the number of sensors in the cluster

Output: R_{min} The best sensor for optimum route

1. Generate a host nest *xi* (i=1, 2, 3, ,L) ; *L is number of clusters*
2. Repeat
   Get a sensor randomly (say k);
   Evaluate its quality/ fitness F_k;
   Choose a sensor among n (say k1) randomly;
   If ($F_k < F_{k1}$),
     Substitute by the new solution (sensor);
   endif
   Replace a fraction (pa) of worse sensors by new sensors;
   Keep the best solution;
   Rank the solutions and store the present best solution in an array *best_route(i)*
   Until stop criterion true
3. Rank the array *beast_route* and return the best sensor (minimum power consumption)
4. End

6. Single Node Selection (SNS) Simulation

6.1 Energy Consumption Model

According to energy model proposed in [2], when sending m bit data over a distance d, the total energy consumed by a node is given by:

$$E_{Tx}(m,d) = E_{elec} * m + \varepsilon_{amp} * m \quad (7)$$

$$E_{Rx}(m) = E_{elec} * m \quad (8)$$

Where $E_{Tx}(m,d)$ and $E_{Rx}(m)$ are the energy consumption of transmitter, and receiver respectively. E_{elec} is the energy consumption of electronics per bit in the transmitter and receiver sensor nodes. ε_{amp} is the energy consumption of amplifier in transmitter sensor nodes, which can be calculated by:

$$\varepsilon_{amp} = \begin{cases} \varepsilon_{fs} * d^2, \text{ when} & d<d_0 \\ \varepsilon_{mp} * d^4, \text{ when} & d\geq d_0 \end{cases} \quad (9)$$

Where d_0 is the threshold distance, ε_{fs} is the free space communication energy parameter, and ε_{mp} is the multipath communication energy parameter. The radio energy dissipation model is shown in Figure 3.

For a normal node the residual energy after sending m data bits to its cluster head is:

$$E_{res\text{-}N} = E_{ini} - E_{Tx}(m,d_{N,CH}) \quad (10)$$

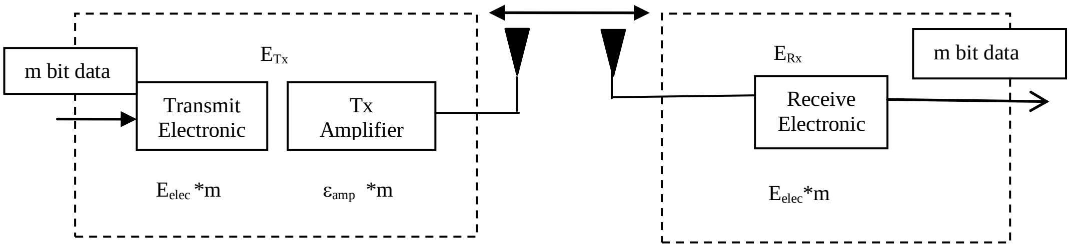

Figure 3. Radio Dissipation Energy Model

Where E_{ini} is the initial energy, and $d_{N,CH}$ is the distance from the normal node to its cluster head.

While in the classical data aggregation, for a cluster head node the residual energy is:

$$E_{res\text{-}C} = E_{ini} - E_{rx}(m) - E_{DA} - E_{Tx}(m,d_{C,BS}) \quad (11)$$

Where E_{DA} is energy for data aggregation, and $d_{C,BS}$ is the distance from cluster head node to the base station. While for our proposed system there is no data aggregation operation, so there is no energy consumption for data aggregation and the cluster head residual energy is:

$$E_{res\text{-}C} = E_{ini} - E_{rx}(m) - E_{Tx}(m,d_{C,BS}) \quad (12)$$

6.2 Simulation Parameters and Results

The proposed algorithm was simulated using Matlab, and a comparison was made with respect to LEACH, and E-LEACH clustering protocols by using the same simulation parameters. The network model is based on the following assumptions:

1. N sensors are randomly dispersed within a field of interest in area A=M*M. The Base station is positioned in the center of the squared region.
2. Each sensor node knows its position using one of localization services.
3. The sensor nodes and the base station are stationary. The location of the base station is known by each node. Each sensor with enough energy can communicate with the base station directly.
4. All nodes are homogeneous, have the same capabilities.

The parameters assumptions for our simulation model are shown in Table 1.

Table 1. Parameters Used in the Simulation Model

Parameter	Value
Sensing area (M*M)	200*200 m^2
Number of nodes (N)	500
Initial energy of nodes (E_0)	0.1joules
Electronics energy (E_{elec})	$5*10^{-8}$joules
Position of BS	100,100
Packet size	4600 bits
Amplification energy for free space model (ε_{fs})	10^{-11}joules
Amplification energy for multipath model (ε_{mp})	$13*10^{-17}$ joules
Threshold distance (d_0)	87m
Event threshold (*Event_threshold*)	20 m

Our proposed data delivery procedure can be implemented on any cluster-based protocol. The simulation program starts with 500 sensors deployed randomly in a field of 200*200 m^2. The network sensors arranged in 6 clusters and discrete cuckoo search optimization (DCSO) procedure will be used for Single Node Selection (SNS) scenario, while events take place randomly across the network. A comparison is made between data delivery power consumption in LEACH, E-LEACH protocols and SNS scenario to express the behavior of DCSO according to the simulation results.

An event take place in a cluster consist of 108 sensors, when applying DCSO procedure, it will return the best route (minimum energy consumption and reliable data quality) for data packet delivery from the sensor that enabled to sense the event in the field of interest and report it to the cluster head.

Figure 4 shows that an event take place in a cluster and all sensors hear the event, while single node selection (SNS) generations are proceed and sensors are randomly selected by discrete cuckoo search (DCS) algorithm and the fitness function for these sensors are calculated. When the stop criteria is met (minimum fitness), SNS algorithm return the best single sensor that is relatively close to the event. Just one sensor will involve to deliver the sensed data from event zone to the cluster head and the consumption power of data packet transmission (E_{Tx}) will affect just the transmitting sensor and the cluster head.

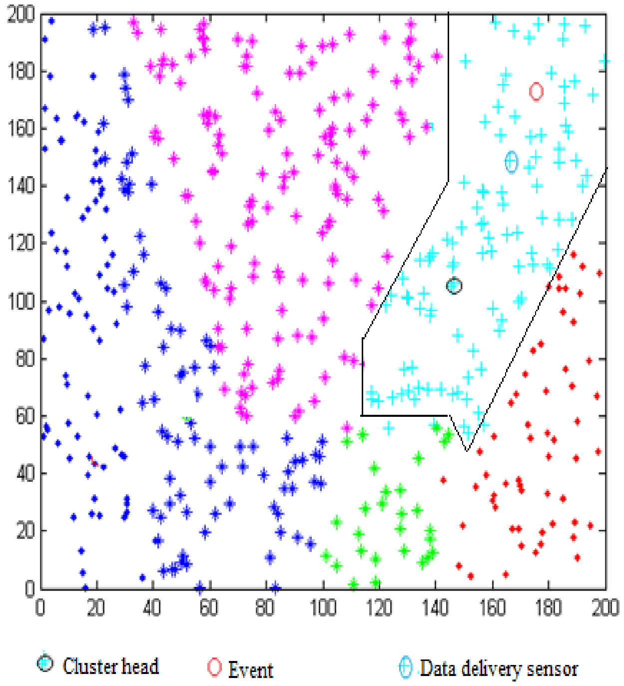

Figure 4. SNS Scenario One Sensor will Route the Network to Deliver the Data Packet to the Cluster Head

Single Node Selection (SNS), is evaluated to study the important performance measures of data delivery approaches include energy consumption, network lifetime, network throughput.

Figure 5 shows the time period between the start of network and the death of the first sensor (as settle down period) and the time period between the death of the first sensor and the death of the last sensor (as unsettle time period) for LEACH, E-LEACH, and SNS in seconds are 200,410, and 640 respectively that is reflected on the lifetime of the network.

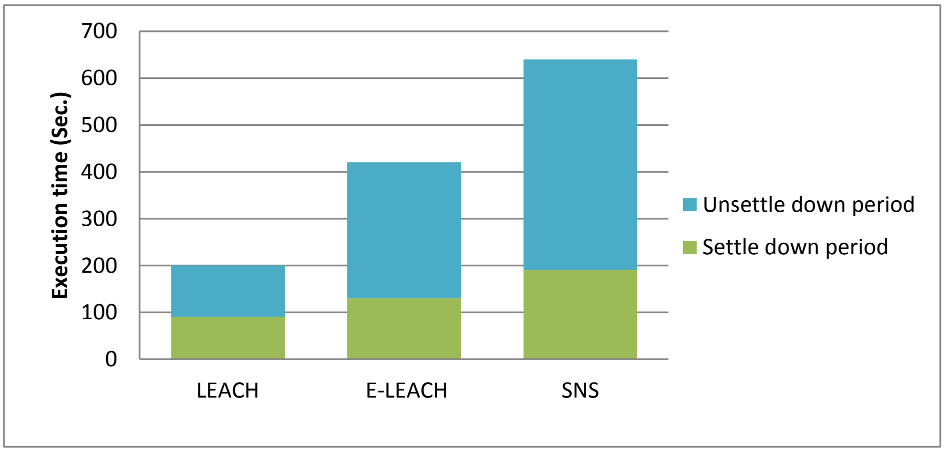

Figure 5. Network Working Time

The network lifetime metric which represents as the number of alive nodes for the three scenarios are presented in Figure 6, and it's clear that after round 1300 for LEACH, all nodes are dead, in E-LEACH after 2400 rounds all the sensors lost their energy, while in

SNS after rounds 7900 there are still alive sensors due to exclusive the data delivery on a single sensor instead of participating all sensors in the cluster.

Figure 7 presents another factor, the total network energy consumption which indicates that for data aggregation of LEACH, E-LEACH protocols the network lost its power early, while for our SNS scenario the network preserve its energy and still works for another thousands rounds.

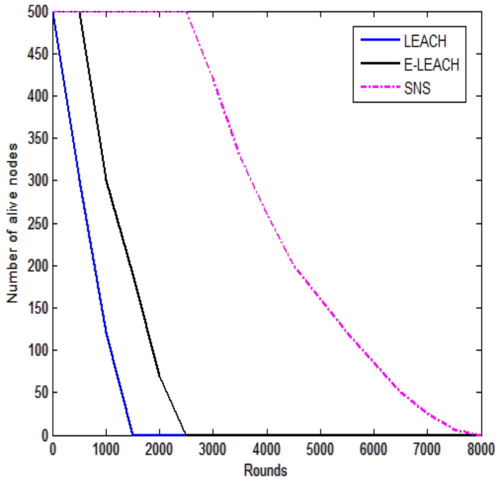

Figure 6. Number of Alive Nodes

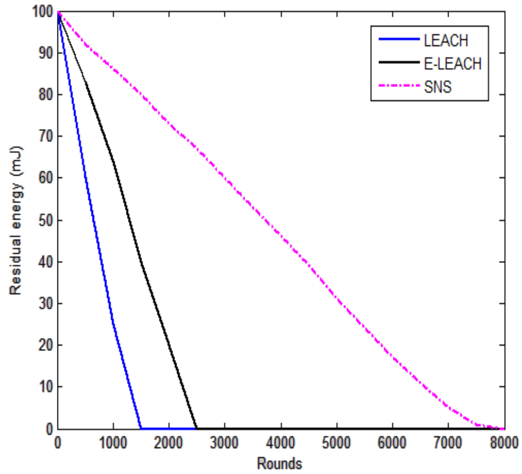

Figure 7. Network Energy Consumption

The last comparison of performance measurement is presented in Figure 8. It shows the overall throughput (the total packets sent from normal nodes to cluster heads and from cluster heads to the sink). The overall throughput for SNS scenario is larger than that of LEACH, E-LEACH because the network working time for SNS is longer than that for LEACH, and E-LEACH that improve packet transmission inside the wireless network.

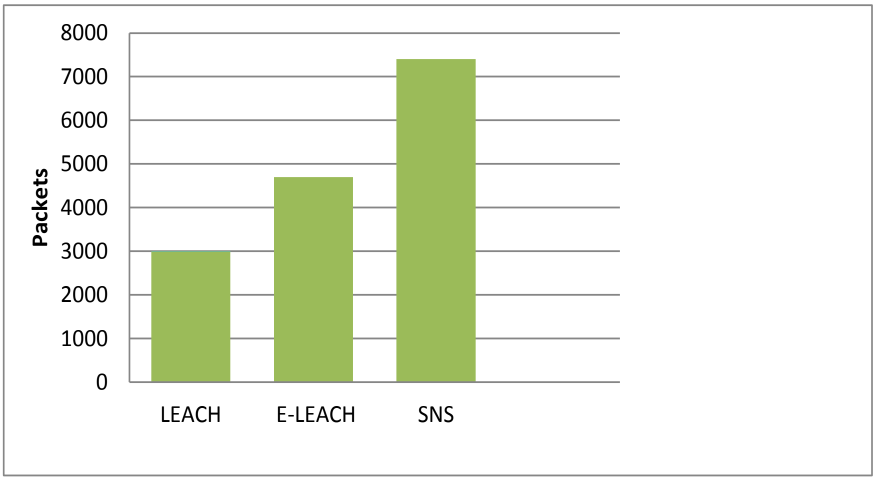

Figure 8. Network Throughput for LEACH, E-LEACH, and SNS

7. Conclusion

In WSN the information about the physical phenomenon are correlated in space and time. If nodes are located close to each other, the correlation is so high and these nodes may send identical packets to the aggregation point. The data aggregation requires substantial energy consumption because each sensor node has to report every reading to the base station. Optimum routing problems are usually considered to be the core of wireless sensor network design. Therefore, a good routing protocol should be able to select the routes that consume minimal global energy. To save energy, we proposed a new scheme Single Node Selection (SNS) that is instead of sending a data packet from all nodes in the cluster, a single sensor is selected to represent these groups of sensors and deliver its recorded data packet to the cluster head, and we utilizing discrete cuckoo search (DCS) algorithm to find this optimum sensor (minimum power consumption). For application specific WSN, this single node selection (SNS) scheme which selects the best route for data delivery will preserve the network energy and extend network lifetime.

The performance measurements of our proposed simulation show better robustness against LEACH, E-LEACH protocols in terms of settle down period, unsettle down period, network life metrics, energy consumption, and throughput.

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