Lifetime Enhancement in Wireless Sensor Networks through Selective Data Handover

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Abstract- **Wireless sensor nodes, being highly energy constrained, must function in an energy-efficient manner in order to enhance network lifetime. Thus suitable protocols must be defined in order to minimize the energy dissipated by the individual nodes in the network. The LEACH and PEGASIS protocols are elegant solutions to the problem. While the LEACH protocol randomizes cluster heads for equal energy dissemination, the PEGASIS protocol forms a chain of cluster heads taking rounds in transmitting to the base station. The binary hierarchical model also addresses this issue. In this paper we propose Data Handover Scheme (DHS) which enhances the performance of LEACH, PEGASIS and binary model in terms of network lifetime. The base station being located at variable distances from the individual nodes, in spite of randomization and chain formation, each node actually dissipates a different amount of energy during its turn of transmission to the base station. This energy difference increases quadratically as the base station is located further off from the sensed area and linearly with the number of cycles elapsed and the packet length. DHS eliminates this energy difference by data handover in specific cycles through suitable node pairing and partner swapping. Extensive simulations show that LEACH with DHS performs 16.66% better than LEACH alone, PEGASIS with DHS shows 12.93% improvement over PEGASIS alone and binary model with DHS performs 15% better than the binary model alone considering lifetime for an illustrative small scale network. A generalized mean transfer scheme is devised for large scale networks with significant (3 – 12%) lifetime increment. Furthermore PEGASIS with DHS shows that it attains almost a near optimal solution for the number of cycles endured by the network. As far as our knowledge goes, we are the first ones to address the problem of variable node distances from the Base Station and present a scheme which outperforms all existing schemes in terms of network lifetime.**

***Index Terms*—Wireless Sensor Networks, LEACH, PEGASIS, Binary hierarchical model, network lifetime.**

I. INTRODUCTION

RECENT advancements in the field of digital signal processors, short range radio electronics, MEMS based sensor technology and low power RF design have enabled the development of inexpensive low power sensors with significant computational capability [1-3]. Applications of sensor networks vary widely from climatic data gathering, seismic and acoustic underwater monitoring to surveillance and national security, military and health care. The sensor networks are required to transmit gathered data to the base station (BS) or sink. It is often undesirable or infeasible to replace or recharge sensors. Network lifetime thus becomes an important parameter for sensor network design and efficiency.

In case of WSNs, the definition of network lifetime is application specific [4]. It may be taken as the time from inception to the time when the network becomes non-functional. A network may become non-functional when a single node dies or when a particular percentage of nodes perishes depending on requirement. However, it is universally acknowledged that equal energy dissipation for equalizing the residual energy of the nodes is one of the keys for prolonging the lifetime of the network [4].

Sensor nodes are constrained by limited battery power. Each node is provided with transmit power control and omni-directional antenna and therefore can vary the area of its coverage [2,5]. Since communication requires significant amount of energy as compared to computations [1], sensor nodes must collaborate in an energy-efficient manner for transmitting and receiving data so that lifetime enhancement is achieved.

In this paper, we consider a wireless sensor network where the base station is fixed and located far off from the sensed area. Furthermore all the nodes are static, homogenous and energy constrained and capable of communicating with the BS. Communication between the nodes and the base station is expensive and the network being homogenous, no high energy node is available for data bypassing [1]. Moreover all nodes have information about their respective distances from the BS in the static environment as stated in [2]. Often, the sensor network is burdened with too much redundant data during the process of systematic data gathering from the field. One of the means to avoid energy loss by transmitting unreliable data to the distant base station is to accomplish data fusion [1] which packs the data into meaningful sets of information. Individual nodes thus take rounds in transmitting to the base station which also distributes the dissipated energy more or less uniformly amongst the nodes.

The LEACH protocol [1] presents an elegant solution to this energy utilization problem where nodes are randomly selected to collaborate to form small number of clusters and the cluster heads take turn in transmitting to the base station during a data gathering cycle. It improves energy cost per round by a factor of 4 for a 100 node network as compared to a direct approach where individual nodes transmit directly to the base station.

The PEGASIS protocol [2] is a further improvement upon the LEACH protocol where a chain of nodes is formed which take rounds in transmitting data to the base station. A further improvement is the binary hierarchical model proposed in [5]

978-1-4244-1878-7/07/$25.00 2007 IEEE

which reduces the energy*delay metric compared to all other protocols and thus is one of the most high performing protocols in the field. In case of chain based CDMA enabled nodes it performs 10 times better than PEGASIS in terms of energy*delay metric.

The DHS actually attacks an issue which has not been addressed in any of the protocols so far – the variable distance of the transmitting nodes from the base station. In spite of randomization and chain formation, every node will actually dissipate a different amount of energy during its turn of transmission to the BS thus violating the equal energy dissipation requirement for lifetime enhancement. This energy difference becomes significant as the BS is located far off from the play field and increases quadratically with distance from the BS and linearly with packet length and cycles elapsed. DHS eliminates this discrepancy by data handover of the low energy nodes which skips its turn of transmission to the BS to a suitable high energy partner which transmits the data packet to the BS on its behalf at the end of a specific cycle. This balances the energy of the two interacting nodes and partner swapping at the end of a specific number of cycles tend to bring all the nodes in the network on a uniform level in terms of energy dissipated.

The paper is arranged as follows: in section II, we detail the energy dissipation model followed in the scheme. Section III analyzes the elements responsible for non –uniform energy dissipation. Section IV illustrates the Data Handover Scheme and Section V details the Handover Table. In section VI, we present the simulation results and finally in Section VII, we conclude delineating the scopes for future improvements.

II. ENERGY DISSIPATION MODEL

We consider the first order radio model as discussed in [1,2,5] with identical parameter values. The energy per bit spent in transmission is given by

$$e_{tx}(d) = e_t + e_d{*}d^n \qquad (1)$$

where e_t is the energy dissipated per bit in the transmitter circuitry and $e_d{*}d^n$ is the energy dissipated for transmission of a single bit over a distance d, n being the path loss exponent (usually $2.0 \leq n \leq 4.0$). For a first order model we assume n=2 for simulation purposes. However as channel non-linearities increase and the value of n enhances, our model would then gain even greater relevance as BS transmission would then require greater energy dissemination.

Thus the total energy dissipated for transmitting a K-bit packet is

$$E_{tx}(K,d) = (e_t + e_d{*}d^2) * K \qquad (2)$$

If e_r be the energy required per bit for successful reception then the energy dissipated for receiving a K-bit packet is

$$E_{rx}(K) = e_r * K \qquad (3)$$

In our simulations we take e_t = 50 nJ/bit, e_d = 100 pJ/bit/m^2 and $e_r = e_t$ as mentioned in [5] with K = 2000 bits.

It is assumed that the channel is symmetric so that the energy spent in transmitting from node i to j is the same as that of transmitting from node j to i.

III. ELEMENTS RESPONSIBLE FOR NON-UNIFORM ENERGY DISSIPATION

The data handover scheme attempts to reduce the energy difference of the nodes acquired during BS transmission. All the protocols such as LEACH, PEGASIS and Binary hierarchical scheme might have been used to demonstrate this common drawback of the previous protocols. However, a simplistic network consisting of 4 nodes C_0, C_1, C_2, C_3 deployed in a 50m×50m playfield with the BS at (25m, 150m) employing the binary model for CDMA enabled nodes is considered here for the sake of illustration as shown in Fig. 1. This is the exact situation which has been considered for simulation in the previous protocols.

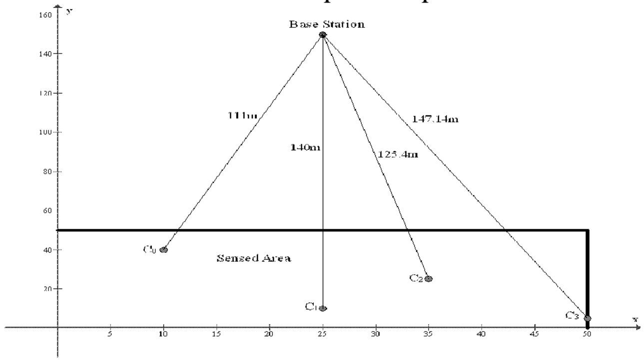


Fig. 1. 4 nodes placed at (10,40), (25,10), (35,25) and (50,5) in a playfield of 50m×50m with the BS at (25,150)

According to the previous protocols each node will take turns in transmitting to the BS. Here we define a cycle of transmission to be completed when a particular node transmits to the BS for a second successive time i.e. after each node has taken rounds in BS transmission. Thus in cycle 1 there will be 4 rounds of BS transmission by each of C_0, C_1, C_2, C_3 in the sample network.

A. *Energy profiles of nodes during a cycle*

In the first round of transmission when C_0 transmits to the BS following the binary scheme, the order of transmission is

BS
↑
Step 3 C_0

Step 2 $C_0 \leftarrow C_2$

Step 1 $C_0 \leftarrow C_1$ $C_2 \leftarrow C_3$

Fig. 2. Binary Hierarchical Scheme for illustrative network in Round 1

There will be 4 such rounds in the first cycle. Let d_{ij} denote the separation between the ith and the jth node and d_{Bi} denote the distance of the ith node from the BS. Then considering unity bit packet i.e. K=1, the energies dissipated by the various nodes in cycle 1 is illustrated in the following table

TABLE I
ENERGY DISSIPATED BY VARIOUS NODES IN A CYCLE

Energy dissipated in	C_0	C_1	C_2	C_3
Round 1	$2e_r + e_t+e_d*d_{B0}^2$	$e_t+e_d*d_{01}^2$	$e_r + e_t+e_d*d_{02}^2$	$e_t+e_d*d_{23}^2$
Round 2	$e_t+e_d*d_{01}^2$	$2e_r + e_t+e_d*d_{B1}^2$	$e_t+e_d*d_{23}^2$	$e_r + e_t+e_d*d_{13}^2$
Round 3	$e_r + e_t+e_d*d_{02}^2$	$e_t+e_d*d_{01}^2$	$2e_r + e_t+e_d*d_{B2}^2$	$e_t+e_d*d_{23}^2$
Round 4	$e_t+e_d*d_{01}^2$	$e_r + e_t+e_d*d_{13}^2$	$e_t+e_d*d_{23}^2$	$2e_r + e_t+e_d*d_{B3}^2$
Total energy dissipated in CYCLE 1	$3e_r + 4e_t + e_d*(2d_{01}^2+ d_{02}^2+ d_{B0}^2)$	$3e_r + 4e_t + e_d*(2d_{01}^2+ d_{13}^2+ d_{B1}^2)$	$3e_r + 4e_t + e_d*(2d_{23}^2+ d_{02}^2+ d_{B2}^2)$	$3e_r + 4e_t + e_d*(2d_{23}^2+ d_{13}^2+ d_{B3}^2)$

It is thus observed that over any cycle, the amount of energy dissipated a node in the network is variable only in terms of the internodal distance d_{ij} and the BS distance d_{Bi} but the energy spent in terms of fixed transmitter and receiver electronic costs is the same for every node. Again since for a wireless microsensor network $d_{Bi} >> d_{ij}$, the main contributor to the energy difference is the BS distance $d_{Bi.}$ For a K bit packet this energy difference per cycle is proportional to $K * e_d * d_{Bi}^2$. Thus neglecting internodal distances, a node located further away from the BS drains away faster than a node located closer resulting in a decreased network lifetime.

Contributions in this energy difference due to variable internodal distances will also come into play with an increasing node number. It will however be manifold times less than BS communication.

IV. Data Handover Scheme

The Data Handover Scheme (DHS) is now introduced which nullifies this energy difference amongst the nodes due to variable locations from the BS. This technique demands that the energy difference between two nodes aggregated during (N-1) cycles is nullified in the N^{th} cycle by data handover between compatible nodes and appropriate grouping. Thus after (N-1) cycles, a lower energy (LE) node finds a suitable higher energy (HE) partner to whom it transmits its data during its round in the N^{th} cycle and the HE node now transmits to the BS on behalf of the LE node. The partner selection criterion is such that after the N^{th} cycle, the HE-LE pair attains the same energy level. Let the i^{th} node be located further off from the BS compared to the j^{th} node and E_i and E_j denote the energies dissipated by the i^{th} and j^{th} nodes respectively after (N-1) cycles. If E_i' and E_j' denote the initial energies of the nodes, then at the outset $E_i' = E_j' = E_0$. As the i^{th} node is located further off from the BS,

$$(E_j' - E_j) > (E_i' - E_i) \tag{4}$$

The difference in energy dissipated by the 2 nodes after (N-1) cycles is

$$D_{ij} = E_i - E_j \tag{5}$$

Again as argued in section III,

$$D_{ij} = (N-1) * e_d * (d_{Bi}^2 – d_{Bj}^2) * K \tag{6}$$

DHS demands that in the N^{th} cycle, the i^{th} node hands over the data to the j^{th} node during its round of BS transmission and the two nodes become equivalent in terms of energy. Thus

$$(E_j' - E_j) – (e_r * K + e_t * K + e_d * d_{Bj}^2 *K) = (E_i' - E_i) – (e_t * K + e_d * d_{ij}^2 * K) \tag{7}$$

or, $$\Delta_{ij} + D_{ij} = \{ e_r + e_d * (d_{Bj}^2 – d_{ij}^2) \} * K \tag{8}$$

where $\Delta_{ij} = E_j' - E_i'$ = difference in initial energies of the nodes.

Combining (6) and (8) we get

$$N = 1 + \frac{Ke_r + Ke_d(d_{Bj}^2 - d_{ij}^2) - \Delta_{ij}}{Ke_d(d_{Bi}^2 - d_{Bj}^2)} \tag{9}$$

At the outset $\Delta_{ij} = 0$, hence

$$N = 1 + \frac{e_r + e_d(d_{Bj}^2 - d_{ij}^2)}{e_d(d_{Bi}^2 - d_{Bj}^2)} \tag{10}$$

V. Data Handover Table

Equations (9) and (10) form the basis of partner selection by an individual node. For this, in a network consisting of N′ nodes, at the outset, the i^{th} node computes the value of N or the number of cycles after which it has to participate in data handover vide equation (10) $\forall$ j ={1,2,3…,N′} except j = i. The number of possible node pair combinations is given by

$$P(i, j) = (N' - 1)(N' - 3)(N' - 5) \text{ ....} \tag{11}$$

while the number of handover periods is given by

$$H = (N' - 1) + (N' - 2) + ... + 1 = \frac{N'(N' - 1)}{2} \tag{12}$$

Now, depending on the scenario two policies may be adopted. If the nodes are provided with significant computational capabilities as stated in [1,2] each node can construct its own data handover table using (9), (10), (11) and (12) or in the other case, for nodes with limited computational capabilities, the BS might construct the handover table for every node and transmit the final pairing information to the individual nodes in the network. The energies dissipated in either case will be negligible for, as mentioned in [1], computational energy is negligible in comparison to communication and as stated in [6], the energy required to transmit or receive information by a sensor node is a mere fraction of the energy for transmitting sensed data to the BS or to the other nodes. The i^{th} node now constructs its own $N' \times N'$ data handover table with all the diagonal entries crossed out. The entries in the i^{th} row of the data handover table denotes the number of cycles after which data handover will establish energy equality of the node C_i with the node C_j for $j \neq i$.

The simplistic 4 node network, as mentioned in section III, is used to illustrate the handover table scheme. Thus for $N'=4$, by (11), the number of possible node pair combinations

$$P(i,j) = 3$$

namely (C_0-C_1 and C_2-C_3), (C_0-C_2 and C_1-C_3) and (C_0-C_3 and C_1-C_2).

By (12), the number of handover periods

$$H = 6$$

namely N_0-N_5 each of which is obtained by (10) rounded up to the nearest integer and denotes the number of cycles after which the LE node in the pair will handover its data to the HE node of the pair.

The handover table thus assumes the form

TABLE II
HANDOVER TABLE FOR ILLUSTRATIVE SIMPLISTIC NETWORK

	C_0	C_1	C_2	C_3
C_0	×	N_0	N_1	N_2
C_1	N_0	×	N_3	N_4
C_2	N_1	N_3	×	N_5
C_3	N_2	N_4	N_5	×

Once the handover table has been constructed each node now selects its partner depending on the network requirements via the three schemes addressed next.

Scheme A: Fixed Handover Table

This scheme performs best for small scale WSNs with nodes having limited computational capabilities. According to this scheme, once the handover table has been constructed initially, it is followed by the nodes without updating the present status of the other nodes in the network.

A. Partner Selection Criterion

The partner selection criterion is based upon the minimum L.C.M. principle. According to this principle, out of the possible number of combinations of P(i,j), that combination of nodes is selected which provides the minimum L.C.M. of the handover periods corresponding to that selection.

This criterion is illustrated through the simplistic 4 node network considering the handover table provided in TABLE II. In this case, as stated earlier P(i,j) = 3 giving rise to the combinations (C_0-C_1 and C_2-C_3), (C_0-C_2 and C_1-C_3) and (C_0-C_3 and C_1-C_2). From TABLE II, the corresponding handover periods are (N_0, N_5), (N_1, N_4) and (N_3, N_2). Now let

$$L.C.M.\{N_1,N_4\} < L.C.M.\{N_0,N_5\} < L.C.M.\{N_3,N_2\}$$

Then the partner selection criterion demands that the initial handover should occur between C_0-C_2 and C_1-C_3. This provides the minimum time after which the nodes will again attain equality in terms of the residual energy in groups of two. In case of equality of L.C.M., to resolve conflict, that combination is selected for which the node number of the partner corresponding to C_0 is minimum.

B. Partner Swapping

Data handover following Table II ensures that after the minimum L.C.M., the nodes become equivalent in terms of residual energy in groups of two. This means that while previously the network perished on the wake of the death of individual nodes, now the network will sustain till the first pair of nodes perish. This itself accounts for increased lifetime. However, lifetime may further be increased following the principle of partner swapping.

The principle of partner swapping demands that after each handover, all immediate previous partnerships will be invalid and the new partner selection will be based on the modified handover table following the principle of minimum L.C.M.

Partner swapping aims to eliminate the energy differences between the node-pairs after each handover and thereby attain a near uniform energy profile for the entire network after

$$\sum_{r=0}^{P(i,j)-1} L.C.M.\{N_r, N_{H-r-1}\}$$

cycles when all possible handovers have occurred and the initial handover table resurfaces.

To illustrate partner swapping we resort to the simplistic 4 node network where the initial handover takes place between C_0-C_2 and C_1-C_3 following the partner selection criterion. Thus after a time L.C.M.$\{N_1,N_4\}$ by the partner swapping criterion the handover table is modified as illustrated in Table III.

TABLE III
MODIFIED HANDOVER TABLE FOR ILLUSTRATIVE SIMPLISTIC NETWORK

	C_0	C_1	C_2	C_3
C_0	×	N_0	×	N_2
C_1	N_0	×	N_3	×
C_2	×	N_3	×	N_5
C_3	N_2	×	N_5	×

Now by the principle of minimum L.C.M., the next partners would be C_0-C_1 and C_2-C_3. This handover occurs after L.C.M.$\{N_0,N_5\}$ whereby the handover table is further modified to Table IV and the only possible remaining node pair combination is resorted to. Thus after $\sum_{r=0}^{3} L.C.M.\{N_r, N_{6-r-1}\}$ cycles, Table II resurfaces and the sequence repeats.

TABLE IV
MODIFIED HANDOVER TABLE FOR ILLUSTRATIVE SIMPLISTIC NETWORK

	C_0	C_1	C_2	C_3
C_0	×	×	×	N_2
C_1	×	×	N_3	×
C_2	×	N_3	×	×
C_3	N_2	×	×	×

Scheme B: Adaptive Handover Table

The adaptive handover table accounts for an increased lifetime in comparison to the fixed handover table and is applicable for a small scale network consisting of nodes with significant computational capabilities. It may also be applied for a network with nodes having limited computational capacity, but in that case the modified table has to be constructed by the BS and the relevant information transmitted to the individual nodes.

A. Partner Selection Criterion

In this scheme, equation (9) is followed for handover table construction and hence the initial handover tables for both schemes A and B are the same. Partner selection takes place following the principle of minimum L.C.M. as before.

B. Partner Swapping

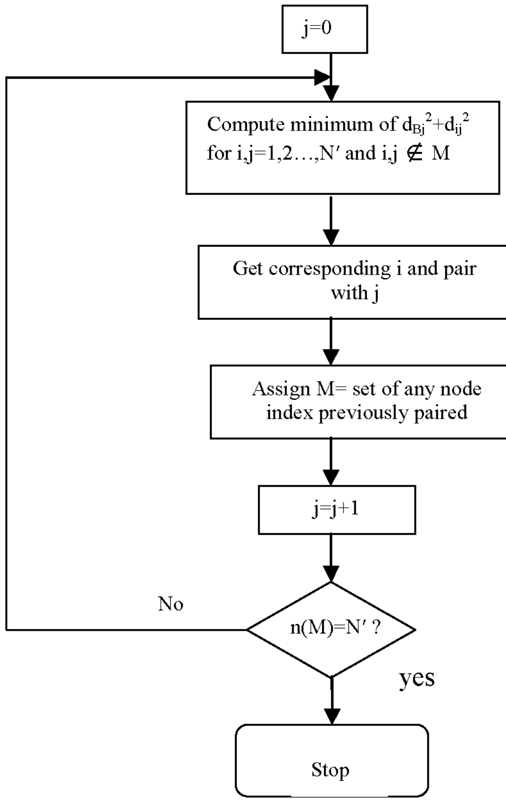
After each handover, following (9), the handover table is reconstructed based on the current energy profiles of the nodes and the principle of minimum L.C.M. is resorted to for partner selection. This may even allow immediate previous partners to pair up if permitted by their energy profiles. As a result, no sequence is maintained in data handover as in scheme A and no table ever resurfaces in the procedure. This accounts for even uniform energy dissipation.

Scheme C: Mean Handover Table

The previous two schemes, though theoretically efficient, suffer from the practical drawback that for a reasonable number of nodes of the order of 20, the L.C.M. of 10 numbers to be calculated may be quite large and may, in the worst case, exceed the number of cycles sustained by the network. Hence no special benefit is obtained by data handover. Scheme C then serves as a generalized formulation for application of DHS to a network consisting of any number of nodes. However for small scale networks, Schemes A and B are more efficient.

In the mean handover scheme, initially each node constructs the Data Handover Table (Table II) as before using (9). However partner selection is based upon the following flowchart eliminating the principle of minimum L.C.M.

A. Partner Selection Criterion



Here n(M) denotes the number of elements in M.

Once partner selection has been performed, the nodes now engage in data handover at the mean period which is defined as

$$\bar{N} = 2 * \left(\sum_{i=1}^{N'/2} N_i\right) / N' \qquad (13)$$

Now after N′ given by (13) the LE nodes hand over data to the HE nodes of the pair, thereby all nodes gradually approach a central energy value although equality is not established after each handover. After each handover following adaptive scheme, the handover table is reconstructed vide (9) and node pairing reorganizes.

VI. Simulation Results

For simulation E_0=100 J is considered as in [2,5] with other parameters as stated in sections II and III. Extensive simulations confirm that Direct approach, LEACH, PEGASIS and binary scheme perform far better with DHS.

Scheme A: Fixed Handover Table

TABLE V
LIFETIME COMPARISONS FOR DIFFERENT SCHEMES WITH N′=4 FOLLOWING FIXED HANDOVER TABLE

Scheme	Mean number of Cycles sustained	Mean Lifetime (sec.)
Direct	5637	90
Direct with DHS	6209	106
LEACH	13047	204
LEACH with DHS	16890	238
PEGASIS	19024	304
PEGASIS with DHS	20838	343
Binary Scheme	18489	221
Binary model + DHS	20588	254

Table V highlights that for the illustrative network, DHS outperforms other schemes.

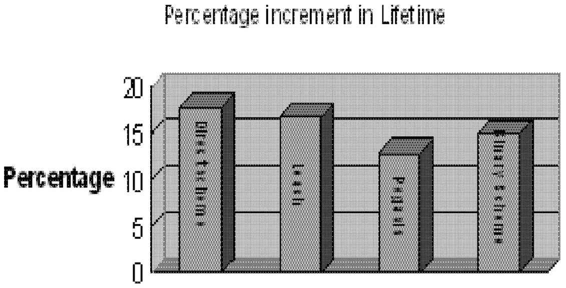


Fig. 2. Percentage increment in lifetime for different schemes with DHS following fixed handover table in illustrative network

Scheme B. Adaptive Handover Table

TABLE VI
LIFETIME COMPARISONS FOR DIFFERENT SCHEMES WITH N′=4 FOLLOWING ADAPTIVE HANDOVER TABLE

Scheme	Mean number of Cycles sustained	Mean Lifetime (sec.)
Direct	5637	90
Direct with DHS	6314	116
LEACH	13047	204
LEACH with DHS	17290	254
PEGASIS	19024	304
PEGASIS with DHS	21302	353
Binary Scheme	18489	221
Binary model + DHS	20970	265

It can be established that for the illustrative network the optimal lifetime accounting absolutely equal energy dissipation is approximately 22700 cycles. PEGASIS with DHS results in about 21300 cycles which thus presents a near optimal solution.

However, as mentioned in section IV, these schemes function exceptionally only in case of small scale networks as evidenced from Fig. 3.

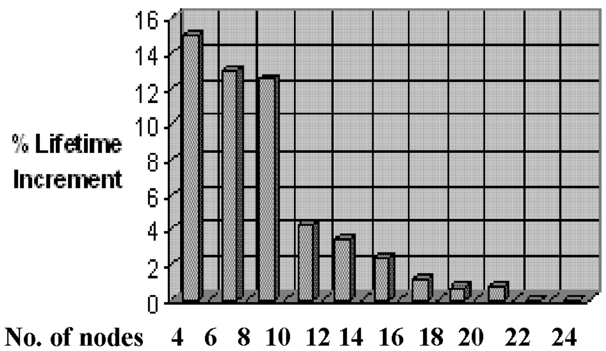


Fig. 3. Percentage increment in Lifetime with DHS following Binary Scheme with Adaptive Data Handover

Hence for N′≤16, schemes A and B perform exceptionally.

Scheme C. Mean Handover Table

Scheme C overcomes this limitation of node number to a certain extent by sacrificing efficiency for small scale networks

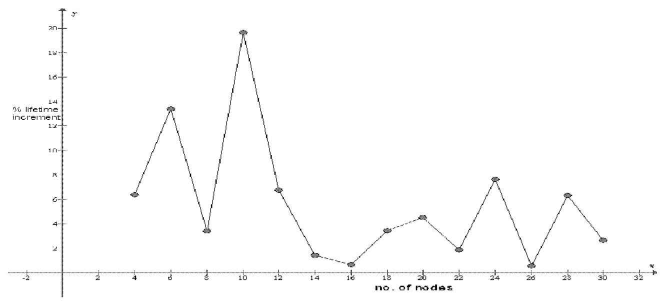


Fig. 4. Percentage increment in lifetime with DHS following binary scheme with Mean Adaptive Transfer for random node deployment

In this case the percentage increase in lifetime does not follow any fixed pattern and is dependent on node placement. It is seen that even with 28 nodes, there is a 6.32% increment in lifetime.

VII. Conclusion

It is thus evident that DHS when run along with any other existing scheme outperforms all other schemes in terms of network lifetime. As far as our knowledge goes, this is the first scheme which addresses variable BS distance in the network layer. From the extensive literature survey that we have conducted, this scheme provides the best field performance and network sustainability. PEGASIS along with DHS is a close approximation to the optimal solution for network lifetime. Three solution schemes have been proposed with two schemes highly efficient for small scale networks while the other one trades efficiency for large scale networks. The best scheme however remains elusive and presents a scope for further investigation and research.

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