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Chain-Chain Based Routing Protocol

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Abstract

Wireless sensor network (WSN) is an emerging technology for monitoring physical world.

WSNs consist of large numbers of sensor nodes operated by battery mostly in harsh environment. Thus energy conservation is a primary issue for organization of these sensor nodes. Another crucial issue is the data delivery time by sensor nodes to the sink node, especially in Military, medical fields, and security monitoring systems where minimum delay is desirable.

Number of protocols has been proposed in the literature for routing. One of such protocols is the cluster based routing protocol LEACH (low energy adaptive clustering hierarchy). LEACH protocol organizes WSN into a set of clusters and a periodic voting for cluster head is performed in order to be evenly distributed among all the sensors of the WSN. This periodical cluster head voting in LEACH, however, consumes an amount of non-negligible energy and other resources. For energy conservation, PEGASIS (power efficient gathering in sensor information systems) a near optimal chain-based protocol has been proposed, however, it is faced with the challenge of long delay for the transmitted data. Another routing protocol called CCM (Chain-Cluster based Mixed routing), which is mainly a hybrid of LEACH and PEGASIS is proposed, the consumed energy increases as network size increases.

In this paper, we propose an efficient routing protocol called CCBRP (Chain-Chain based routing protocol), it achieves both minimum energy consumption and minimum delay. The CCBRP protocol mainly divides a WSN into a number of chains (Greedy algorithm is used to form each chain as in PEGSIS protocol) and runs in two phases. In the first phase, sensor nodes in each chain transmit data to their chain leader nodes in parallel. In the second phase, all chain leader nodes form a chain (also, using Greedy algorithm) and choose randomly a leader node then all chain leader nodes send their data to this chosen leader node. This chosen leader node fuses the data and forwards it to the Base Station, BS. Experimental results demonstrate that the proposed CCBRP outperforms LEACH, PEGASIS and CCM with respect to the product of the energy consumed and the experienced delay.

Keywords: *Wireless Sensor Network, LEACH, PEGASIS, CCM, CCBRP, Routing Protocols.*

1. Introduction

Wireless sensor networks (WSNs) consist of a large number of small, inexpensive, battery-powered Communication devices densely deployed throughout a physical space. These WSNs can be used in a various applications such as disaster management, Military field reconnaissance, border protection and security surveillance. Due to their features, these applications need data delivery without delay and the energy consumed by them must be small. Since, WSNs are deploy in harsh physical environment it is impossible to charge or replace the batteries of these sensor nodes. Therefore it is desirable to design communication network protocol such that energy source is used efficiently and with minimum delay, for these purposes many routing protocols have been proposed.

LEACH (low energy adaptive clustering hierarchy) [1][8][9] is the first hierarchical cluster-based routing protocol for WSN. LEACH protocol partitions the sensor nodes of WSN into clusters; each cluster has cluster nodes (CNs) and cluster head (CH). CH receives data from CNs in their cluster, aggregates the data, and forwards them to the sink. LEACH protocol achieves even energy dissipation by randomly re-choosing CH at regular intervals. It leads to an eight times improvement compared to the direct transmission protocol.

CALS(Efficient Clustering Protocol in the Large-scale WSN) [5] is self-organizing and adaptive multi-hop clustering protocol that uses efficient MAC to distribute the energy load evenly and guarantee minimum energy consumption for large scale WSNs and the ones that deployed in frequently idle environments due to low data occurrence.

PEGASIS (Power-Efficient gathering in Sensor Information Systems) [2][10][11], which is a near optimal protocol for high rate data gathering applications in sensor networks. The key idea of the PEGASIS protocol is the formation of a chain among the sensor nodes so that each node will receive from and transmit to a close neighbor. Gathered data moves from node to node, get fused, and eventually a designated node transmits it to the BS. The PEGASIS protocol achieves improvement varies between 100 to 300% when 1%, 20%, 50% and 100% of nodes die in the deployed field compared to the LEACH protocol.

CBERP (Cluster Based Energy Efficient Routing Protocol for Wireless Sensor Network) [4] is a hybrid

protocol of LEACH and PEGASIS. CBERP combines the clustering mechanism of LEACH and the chaining mechanism of PEGASIS. More specifically, it organizes the clusters using the same mechanism of LEACH-C with the exception that each of the header nodes is not permitted to transmit data directly to BS; it sends its data through a chain to reduce the energy consumption as in PEGASIS protocol.
CCM (Chain-Cluster based Mixed routing) protocol [3] makes full use of the advantages of LEACH and PEGASIS, and provides improved performance over both of them. CCM protocol mainly divides a WSN into a number of chains and runs in two phases. In the first phase, sensor nodes in each chain transmit data to their own chain head nodes in parallel, using an improved chain routing protocol. In the second phase, all chain head nodes grouped as a cluster in a self organized manner, where they transmit fused data to a voted cluster head using the cluster based routing.
In this paper we present a new efficient routing protocol called CCBRP (Chain-Chain based routing protocol). The proposed CCBRP divides a WSN into a number of chains and runs in two phases. The CCBRP utilizes Greedy algorithm to form each of the chains. In the first phase, sensor nodes in each chain transmit their data to their chain leader nodes in parallel. In the second phase, all chain leader nodes form a chain (also using Greedy algorithm) and then all the leader nodes send their data to a randomly chosen leader node. This chosen leader node fuses its data with the received data and sends to the BS. Experimental results demonstrate that the proposed CCBRP outperforms each of LEACH, PEGASIS and CCM with respect to the product of the consumed energy and delay.
The paper is organized as follows. Section 2 presents the PEGASIS protocol which is the proposed CCBRP based upon. In section 3, the proposed CCBRP is presented. Experimental results of the proposed CCBRP are given in section 4. Section 5 presents the conclusions and future works. The references are given in section 6.

2. PEGASIS (power-efficient gathering in sensor information system)

PEGASIS is a near optimal chain-based routing protocol. The basic purpose of this protocol is the extension of the WSN lifetime. In PEGASIS protocol all the WSN nodes communicate only with their closest neighbors and continue communicating in their turns until the aggregated data reaches the BS. This method of communication reduces the power consumption required to transmit data per round. Thus PEGASIS protocol achieves a factor of two improvements in energy consummation over the LEACH protocol [2]. PEGASIS protocol starts forming a chain using Greedy algorithm then randomly selects a leader for the formed chain after that data transmutation takes place.

2.1 Chain Formation

To construct the chain PEGASIS protocol starts from the furthest node from the BS and uses Greedy algorithm to form a chain. The main idea here is that each sensor node communicates only with its closest two neighbors in order to minimize the power consumption.

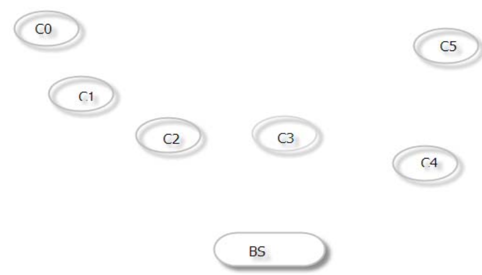

Fig. 1 Chain formation in PEGASIS using Greedy algorithm

In Fig.1 node C0 lies the furthest from the base station so the chain construction starts from C0 which is connected to node C1, C1 is connected to node C2, and so on till C5 [6].

2.2 Leader Selection

At the beginning of each round, a chain leader is selected randomly. This way of selection is easy and fast since no extra computation is performed. Moreover, the random selection has the benefit that as it is more likely for nodes to die at random locations thus providing robust network.
After the leader has been selected it passes a token message to initiate a data gathering process. Passing a token also consumes energy however; the cost of passing a token is very small since the size of the token message is very small.

2.3 Data Transmission

Gathering the data in each round, each node receives data from one neighbor, fuses its own data with it, and transmits it to the other neighbor on the chain until the whole chain data reaches the chain leader. Finally, the chain leader sends this data to the BS.
Fig.-2 shows a simple example for data transmission in PEGASIS protocol. First the chosen leader C3 sends a token to all the nodes in the chain. Immediately after the chain nodes receive the token both nodes C0 and C5 (the two ends of the chain) start sending their data to C1and C4 respectively and fuse their data with the received data to C2 and C3 respectively. Then in turn, C2 fuses its data with C1's data and sends it to C3. After that Leader node C3 fuses its data with the data received from both C2 and C4 and sends it to the BS.

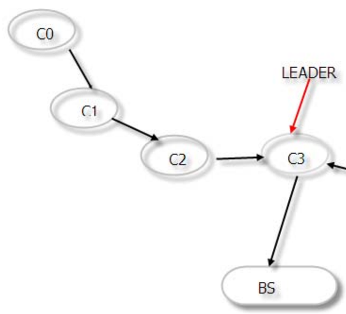

Fig. 2 Data transmission

3. The Proposed CCBRP

In this section, we present the new efficient CCBRP that achieves both minimum energy consummation and minimum delay. CCBRP divides the WSN into a number of chains; Greedy algorithm is used to construct each of the chains as in PEGASIS [2]. Each chain contains a number of sensor nodes, the number of chains and the number of sensor nodes in each chain depend on the number of sensor nodes in the WSN under consideration.

To illustrate the proposed CCBRP let us consider an WSN with N sensor nodes distributed in a 2-dimension area having a size of L(m)×L(m). If N is equal to hundred nodes and let us assume for now that the number of chains is equal to ten percent of N, then there are ten chains each of which contains ten sensor nodes as show in Fig. 3.

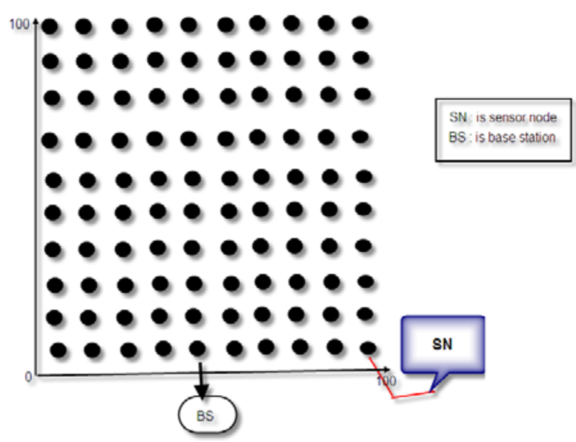

Fig. 3 100 Sensor nodes WSNs, divided into 10 chains each chain contains 10 sensor nodes.

The proposed CCBRP forms each of the partitioned chains using Greedy algorithm and runs in two phases. The first phase starts by randomly selecting a leader for each chain, and then each chain leader sends a token message to the two ends of its chain to notify them. After that each of the two end nodes of each chain simultaneously starts sending its data to its closet neighbor node, the neighboring nodes receive the data and fuse its data along with the received data and send to the next node in the chain and so on. This process is repeated till the data has reached all the chain leader nodes. Fig. 4a presents a pseudo code for the first phase of the proposed CCBRP.

The second phase of CCBRP starts after all the chain leader nodes have received all the data from their chain nodes. These chain leader nodes form a chain (using Greedy algorithm) and randomly choose a chain leader for the newly formed chain. Then the randomly chosen leader sends a token message to the two ends of the newly formed chain. Thereafter, each of the two nodes at the two ends of the formed chain of leaders simultaneously starts sending its data to its closest neighboring node. The neighboring nodes receive the sent data and fuse their data with the received data and send to the next neighboring nodes and so on. This process of sending data is repeated till all the data of the WSN under consideration has reached the leader node of the chain of leader nodes. After the node leader of leaders has received this data it is fused with its own data and sent to the BS. Fig. 4b presents a pseudo code for the second phase of the proposed CCBRP. Fig. 5 illustrates the data transmission for the proposed CCBRP.

Partition the N nodes of the given WNS into n chains (C_0 to C_{n-1}), and let y (y=N/n) be the number of nodes in each chain C_i
For i= 0 to n-1 do
{Select a chain leader L_i randomly
Case CL_i:
C_i (1): the first node of C_i
{ CL_i sends a token message to C_i(y) the end of this chain
C_i(y) sends its data (i ,y) to C_i(y-1);
While y >j
C_i(y-1) fuses its own data (i, y-1) and received data (i , y)
C_i(y-1) sends the fused data to its neighbor C_i(y-2);
y=y-1}
C_i(N/n): the last node of C_i
{ x=1;
CLi sends a token message to C_i(x)
C_i(x) sends its data (i ,x) to C_i(x+1);
While x<j
C_i(x+1) fuses its own data (i, x+1) and received data (i , x)
C_i(x+1) transmits the fused data to its neighbor Ci(x+2);
x=x+1}
C_i(2.. N/n - 1): all the intermediate nodes of C_i
{x=1, y=N/n;

CL_i sends a token message to $C_i(x)$;
If(x<j) then
{ $C_i(x)$ sends its data(i ,x) to $C_i(x+1)$;
While x<j
$C_i(x+1)$ fuses its own data (i, x+1) and received data (i , x)
$C_i(x+1)$ transmits the fused data to its neighbor $C_i(x+2)$;
x=x+1; }
CL_i sends a token message to $C_i(y)$;
If(y>j)
{$C_i(y)$ sends its data (i ,y) to $C_i(y-1)$;
While y >j
$C_i(y-1)$ fuses its own data (i, y-1) and received data (i , y) ;
$C_i(y-1)$ transmits the fused data to its neighbor Ci(y-2);
y=y-1 ;}
}
CL_i fuses its data (i ,j) with the data received from $C_i(j+1)$ and data received from $C_i(j-1)$;

Fig. 4a a *pseudo code for the first phase of the CCBRP*

Constitute a new chain from the chain leaders Li (i= 0..n-1) using Greedy algorithm as in PEGASIS[1]
Randomly select the main leader ML.
Let x=1 and y=n, j index of ML in CLs;
Case ML:
CLs (0); the first node of CLs
{ML sends a token message to CLs(y) end of chain
CLs (y) sends its fused_ data(y) to CLs (y-1);
While y >j
CLs (y-1) fuses its own fused_ data(y-1) and received fused_ data(y)
CLs (y-1) sends the fused data to its neighbor CLs (y-2);
y=y-1; }
CL_s (n-1); the last element of CLs
{Let x=1;
ML sends a token message to CLs (x)
CLs (x) sends its fused_ data(x) to CLs (x+1);
While x<j
CLs (x+1) fuses its own fused_ data(x+1) and received fused_ data(x)
CLs (x+1) sends the fused data to its neighbor CLs (x+2);
x=x+1 ;}
CL_s (1 .. n); intermediate node in CL_s
{Let x=1, y=n;
ML sends a token message to CL_s (x);
CL_s (x) sends its fused_ data(x) to CL_s (x+1);
If(x<j)
{
While x<j
CL_s (x+1) fuses its own fused_ data(x+1) and the received fused_ data(x)
CL_s (x+1) sends the fused data to its neighbor CL_s (x+2);
x=x+1;
}
L_i sends a token message to CL_s (y)
If(y>j)
{
CL_s (y) sends its fused_ data(y) to CL_s (y-1);
While y >j
CL_s (y-1) fuses its own fused_ data(y-1) and received fused_ data(y) ;
CL_s (y-1) sends the fused data to its neighboring s CL_s (y-2);
y=y-1;
}
}
ML fuses its data with data from $CL_s(j+1)$ and $CL_s(j-1)$ and sends it to the BS;

Fig. 4b a pseudo *code for the second phase of the CCBRP*

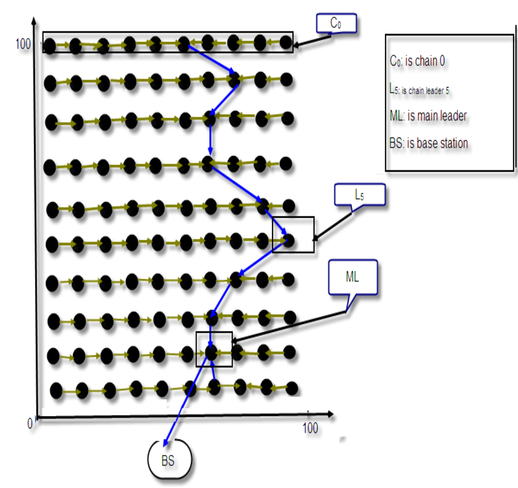

Fig. 5 Data transmission for CCBRP protocol

4. Experimental Results

To evaluate the performance of the proposed CCBRP we have developed a simulation program written in Java. For our simulation we have chosen the WSN sizes of 100m x100m and 50mx50m in order to be able to compare the results of the proposed CCBRP with the simulation results available in the literature [1][2][3][4][5].

4.1 Simulation Results for 100 x 100 Network

We have simulated the proposed CCBRP in a self organized network of 100-node in a 100m x 100m field; the BS is located at (50,300). The size of each packet was set to 2 k bits. The time for transmitting such a packet is considered to be one unit time delay.

4.1.1 Energy × Delay metrics

We have claimed that the proposed CCBRP achieves minimum Energy × Delay metrics. Next, the experimental results verify this claim. The average energy consumption per round can be estimated as:

$$E = \sum_{i=1}^{N} E_i(r)/r \qquad (1)$$

Where N is the number of sensor nodes in the considered WSN, and r is the number of rounds**.** Fig. -6 show the performance evaluation comparison among LEACH, PEGASIS, CCM and the proposed CCBRP. For this test of performance the sensor nodes of the considered WSN were evenly distributed within a 100m×100m area. It is clear from Fig. -6 a that the energy consumption of the proposed CCBRP is almost the same as PEGASIS, but 60% less than LEACH and 10% less than CCM. Moreover, the simulations result shown in Fig. -6 b indicates that the delay of the proposed CCBRP is the same as of LEACH and CCM but 75% less than of PEGASIS. Furthermore, Fig. -6 c presents the energy × delay metrics, which clearly illustrates that the proposed CCBRP has the best energy × delay metrics in comparison with all the protocols available to us in the literature [1][2][3][4][5].

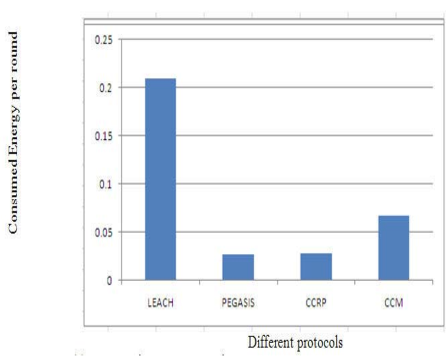

Fig. 6.a Consumed energy per round

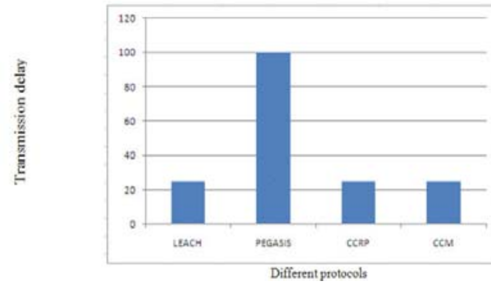

Fig. 6.b Transmission delay

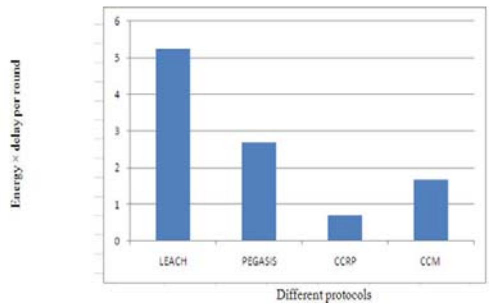

Fig. 6.c Energy × delay during a round

Fig. 6 Performance evaluation and comparison among LEACH, PEGASIS, CCM, and CCBRP for 100x100 WSN

4.1.2 Optimal Number of chains

The number of the partitioned chains in the proposed CCBRP is a critical design issue because it affects both the energy consumed and the delay. Thus our quest here is to find the number of chains that achieves the minimum delay*energy metrics. Fig.-7 draws the delay*energy metric as a function of the number of chains.

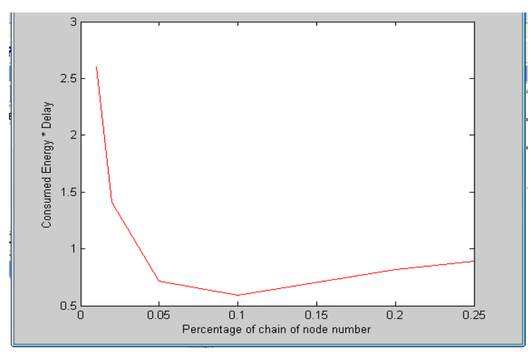

Fig. 7 the delay*energy metric as a function of the number of chains for 100x100 WSN

As it is clear from Fig. 7, as the number of the partitioned chains increases the product of the delay and the energy consumed decreases up to a point and then the reverse happens. This is logical and expected; if the number of partitioned chains is small the consumed energy will be small but the delay will be very high. On other hand if the number of partitioned chains is big the delay will be small but the consumed energy will be very high. Thus a number in between has to be found to obtain the best value for the product of the energy consumed and the delay experienced for a given size of WSN. Fig.7 indicates that the size of chain that achieves best product of energy consumed and delay experienced (i.e., lowest value) is around ten percent of the number of nodes in the WSN.

4.1.3 Energy Efficiency

PEGASIS is a near optimal protocol in energy consumption, but it suffers from high delay. However, the proposed CCBRP achieves minimum product of delay and energy consumed since the consumed energy by CCBRP is very close to the energy consumed by PEGASIS. Fig. -8 shows the energy consumed per node as a function of the number of rounds. From Fig. 8, it is clear that the proposed CCBRP consumes less energy than the consumed energy by all the other protocols except PEGASIS. More specifically, the proposed CCBRP consumed 70% less than consumed by LEACH 1% in ‘first 750 rounds less than CALS and 2% for more than 750 rounds in CALS.

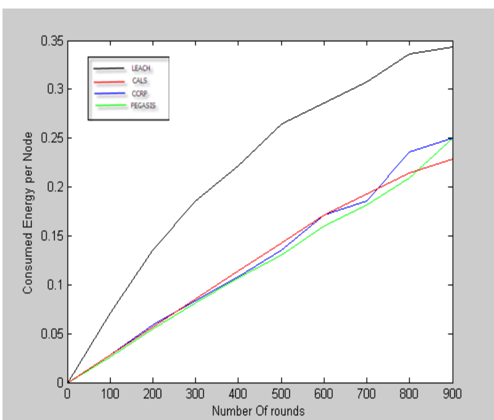

Fig. 8 The Energy consumed per node as a function of the number of rounds for 100x100 WSN

4.2 Simulation Results for 50 x 50 Network

Also, we have performed simulation for the proposed CCBRP in a self organized network of 100-node in a 50m x 50m field; the BS is located at (50,300). The size of each packet was set to be 2 k bits. The time for transmitting such a packet is considered as one unit of delay.

4.2.1 Energy × Delay metrics

Fig. 9 shows performance evaluation and comparison among LEACH, PEGASIS, CCM and the proposed CCBRP. For this test of performance the sensor nodes of the considered WSN were evenly distributed within a 50m×50m area. It is clear from Fig. -10 a that the energy consumption of the proposed CCBRP is almost the same as PEGASIS, but 60% less than LEACH and 1% less than CCM. Fig. -9 b presents the energy × delay metrics, the proposed CCBRP achieved better energy × delay metrics compared to all the other protocols.

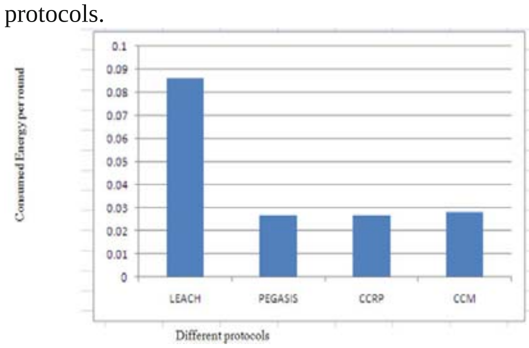

Fig. 9.a Consumed energy per round

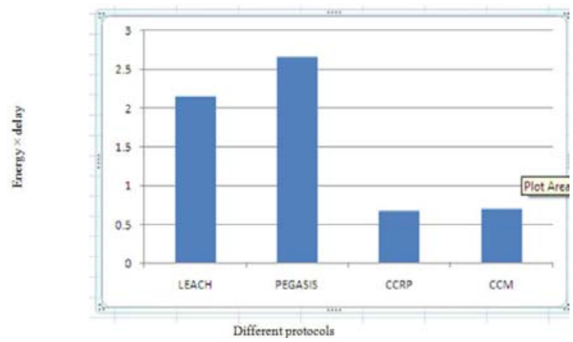

Fig. 9.b Energy × delay during a round
Fig. 9 Performance evaluation and comparison among LEACH, PEGASIS, CCM and CCBRP for 50x50 WSN

4.2.2 Optimal Number of Chains

The number of the partitioned chains in the proposed CCBRP is a critical design issue because it affects both the energy consumed and the experienced delay. Thus our quest is to find the number of chains that achieves the minimum delay*energy metrics. Fig.10 draws the delay*energy metric as a function of the number of chains.

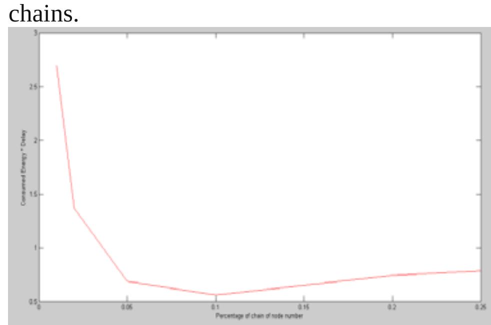

Fig. 10 The delay*energy metric as a function of the number of chains for 50x50 WSN

As it is clear from Fig. 10 that as the number of the partitioned chains increases the product of the delay and the energy consumed decreases up to a point and then the reverse happens. This is logical and to be expected; when the number of partitioned chains is small the consumed energy will be small but the delay will be very high. On other hand when the number of partitioned chains became big the delay will be small but the consumed energy will be very high. Thus a number in between has to be found to obtain the best value for the product of the energy consumed and the delay experienced for a given size of WSN. Fig.10 indicates that the size of chain which achieves best product of energy consumed and delay experienced (i.e., lowest value) is around ten percent of the number of nodes in the WSN.

5. Conclusions And Future Work

In this paper a Chain-Chain based routing protocol, CCBRP has been presented. The proposed CCBRP achieves both minimum energy consumption and minimum experienced delay. The CCBRP mainly divides a WSN into a number of chains and runs in two phases. In the first phase, sensor nodes in each chain transmit data to their chain leader nodes in parallel. In the second phase, all chain leader nodes form a chain (using Greedy algorithm) and randomly choose a new leader then all leader nodes send their data to the new chosen leader. The new chosen leader fuses all the data and forwards it to the Base Station. Experimental results demonstrate that the energy consumption of the proposed CCBRP is almost as same as for PEGASIS and 60% less than LEACH and 10% less than CCM for WSN with hundred nodes distributed in 100m x 100m area. The delay of the proposed CCBRP is the same as of LEACH and CCM but 75% less than of PEGASIS. The proposed CCBRP outperforms LEACH, PEGASIS and CCM with respect to the product of energy consumed and experienced delay.

Experimental results demonstrate that as the WSN size increases the difference between the energy consumption of the proposed CCBRP and the energy consumption of PEGASIS remains the same. However, the reverse is true for CCM protocol; the difference between the energy consumption of CCM and the energy consumption of PEGASIS increases with the increase in the size of the WSN.

As part of our future work, we are planning to investigate how to optimize the procedure of chain leader selection by using different leader selection strategies [6], to enhance the performance of the proposed CCBRP.

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