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Energy efficient data gathering using compressive sensing in wireless sensor networks

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ABSTRACT : *Wireless sensor networks are autonomous distributed networks which consist of a collection of wireless nodes deployed to sense a field of interest. To achieve energy efficient data gathering from a sensor network we are proposing an innovative concept of compressive sensing for the collection of data from individual nodes to the Base Station. Compressive sensing exploits the spatio-temporal correlation of data samples. The results are analyzed with the synthetic data model in which the correlation is already created. This model is also verified against real data sets and we intend to prove that it is accurate in recreating the statistical characteristics of the signal of interest.*

Keywords - Sensor networks; Data gathering; Compressive sensing; Nesta algorithm.

1. Introduction

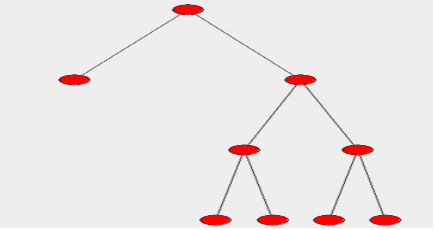
Data gathering is an important function of wireless sensor networks, i.e., the collection of sensed data from each and every node to Base Station. A large number of networking protocols are used for the aggregation, compression and recovery in WSN's. They utilize the spatio-temporal characteristics of real world signals. But most of them fail to provide good performance in terms of energy savings and signal reconstruction accuracy. The amount of data acquired from each and every node used in the sensor network will be enormous, which will indirectly affect the energy efficiency of the network. In order to minimize the cost of energy, the complexity of the data gathering process is minimized by including the nodes which have significant information. This process is named as Compressive sensing. The selection of the significant nodes in the sensor field is based on the knowledge of correlation among the data samples. In this paper we are estimating the correlation structure of the signal and it is exploited at the sink node. This paper is structured in such a way that, introduction section followed by section 2 which deals with a survey on data gathering protocols, Section 3 describes existing data gathering protocols and Section 4 deals with an example of data gathering operation. Section 5 explains solution to overcome the existing limitations using the method of compressive sensing followed by the conclusion Section.

2. Data Gathering Protocols- A Survey

Energy aware routing protocol is indispensible for the networks operating in isolated and unreachable places where recharging of batteries is not possible. So in order to extend the lifetime of the network, the protocol should perform well in decision making to suit the dynamic behavior of the network. A wireless sensor network is subjected to rapid topological changes due to node mobility and failure. Hence the optimization of the network behavior is a challenging process. A major portion of energy is drained during the repeated rounds of data gathering. The data gathering protocols are mainly classified based on data centric, hierarchical, location based, topology control etc.

2.1 Data Centric Protocols

2.1.1 Flooding: In this protocol every node is free to broadcast the packet received, ref Fig 1 .This method does not require specific route discovery algorithms. The disadvantage of this method is that each node may receive the copy of same message which it has already received.



1. Fig 1 – **F**looding Protocol [9]

2.1.2 Direct Diffusion: In this protocol each sensor node generates requests for receiving the data sensed by all the other nodes in the network as shown in Fig 2. The destination for these data requests can be either the Base Station or a network node itself.

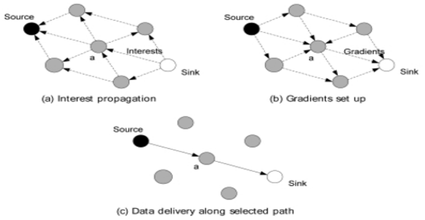


Fig 2- Direct Diffusion Protocol [11]

2.1.3 SPIN: Sensor Protocols for Information via Negotiation. This protocol uses a negotiation technique for routing. SPIN produces three types of messages ADV, REQ and DATA. A sensor node will broadcast an ADV message which consists of the actual information. If the receiving node is interested in that information, it sends an REQ message. Then the sensor node sends the actual DATA to that particular neighbor. The neighbor again sends ADV to its neighbors and this process is repeated to propagate the data within the whole network.

2.2 Hierarchical Routing Protocols

2.2.1 Leach: It's a clustering based protocol. Operation of this protocol depends on the spatial density of the sensor network. The protocol randomly elects nodes as cluster heads, sends the fused data to the destination and performs periodic re-election of cluster head nodes. These cluster head nodes can be advanced nodes i.e. nodes that are equipped with an additional amount of energy.

2.2.2 PEGASIS: Power efficient gathering for Sensor Information systems. In this protocol it is assumed that each node knows the current location of every other node in the network.

2.3 Topology control protocol

2.3.1 GAF: In this protocol the total sensor field is divided into a grid. All nodes in the grid will be able to communicate with each other. The size of the grid needs to be calculated.

2.3.2 STEM: STEM stands for Sparse Topology and Energy Management. This protocol uses two channels, a wake up channel and a data channel. Wake up channel is used to inform the receiver that a transmitter wants to transmit data to it. STEM protocol is applicable where the nodes have two states, a monitor state where the nodes monitor and no event takes place, and a transfer state where an event is detected and data has to be transmitted. On the Wake up channel the total time is divided into a sleep period and a listen period which together constitutes the wake up period as shown in Fig 3.

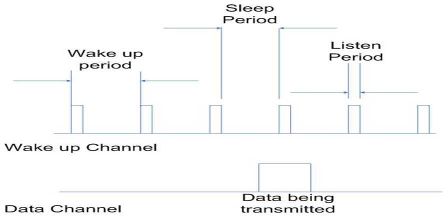


Fig 3-Stem Protocol [13]

3. Simulation of some existing data gathering protocols

3.1 Direct Transmission Protocol

In this protocol all nodes in the network directly transmit their data to the base station. Some nodes may be too far away from the base station and they get drained off very soon. These nodes waits for its turn to transmit to the base station to avoid collision and this would create a lot of propagation delay in the network and hence the performance of this scheme is poor in terms of energy X delay metric. Fig 4 shows the ns2 simulation of direct transmission protocol.

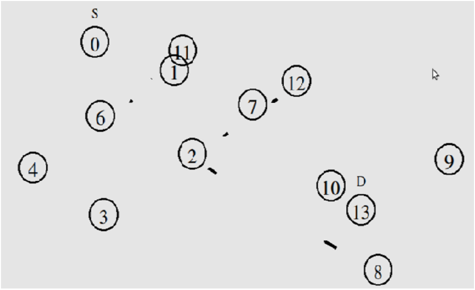


Fig 4-Direct transmission protocol

3.2 Adhoc on Demand Distance Vector Routing Protocol

AODV protocol utilizes only symmetric links between the neighboring nodes. The unicast and multicast route tables have to be updated after each and every topological change in the network. In this protocol the network remains silent until the connection is required. Whenever a network node needs a connection it broadcasts a route request to its neighboring nodes. Other AODV nodes forward this message and replies back with cached routes in their route replies. If the reply comprises of the needed route the node can forward the packet through that particular path. When a link fails, a routing error is passed back to a transmitting node. AODV requires more time to establish a connection.

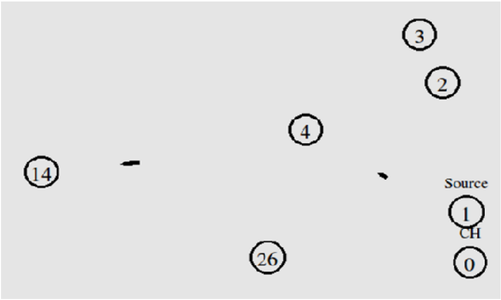


Fig 5-Simulation of AODV protocol

3.3 Leach

Leach is a hierarchical routing protocol. The operation is based on the concept that the energy used by every node in the network is equal compared to overall energy of the system. The working of this protocol is split into two phases i.e. set-up-phase and steady phase. This protocol ensures that every node in the network will become the cluster head once in every $1/p_{optm\ rounds}$, where p_{optm} is the optimal probability for the election of cluster heads. Its optimum value is 0.05. During the set up phase each node chooses a random number between 0 & 1and if it is lower than the node threshold T(s) that node would become the cluster head.

$$T(s) = poptm / [1- p_{op\ tm} (r \bmod (1/ p_{op\ tm}))] \qquad (1)$$

During the steady phase, the cluster heads perform data aggregation and transmit the fused data. But the main limitation of leach protocol is network instability

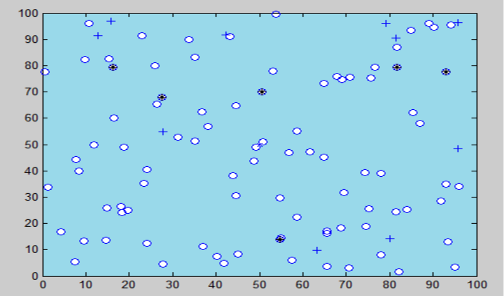


Fig 6-Leach protocol simulation showing the normal nodes and cluster heads (black dots)

As the number of nodes decreases the number of cluster heads per round becomes unstable and as a result the total sensing of the field becomes poor.

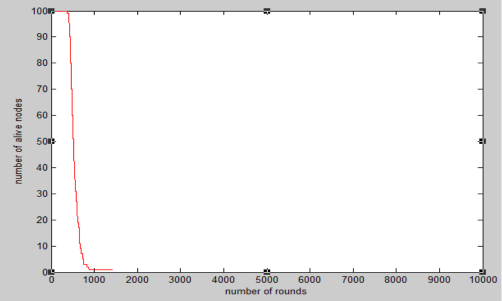


Fig 7-number of alive nodes in a homogeneous network

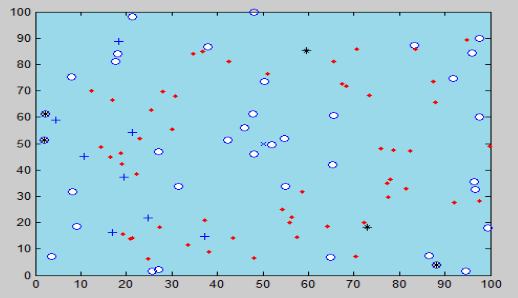


Fig 8-Dead node formation

So in the heterogeneity case the total instability in the network will be more between the first dead node and the last dead sensor node. This is the major drawback of Leach protocol.

3.4 Stable Election Protocol

This protocol is able to overcome the disadvantage of leach because each node is equipped with an additional amount of energy. SEP modifies the network by introducing normal nodes and advanced nodes to it. The advanced nodes have more energy factor α than the normal nodes. The probability of election as cluster heads is more for advanced nodes than normal nodes.

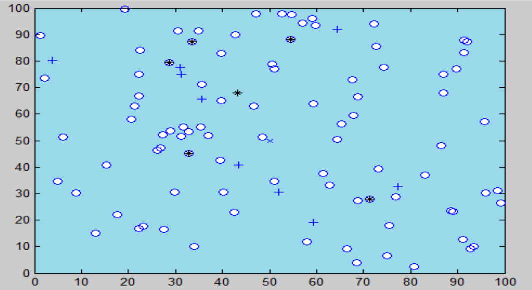


Fig 9-Simulation of Stable Election Protocol

The protocol will take the full advantage of node heterogeneity and the network throughput is considerably more than the leach protocol. The stable region is increased by 3% than that of leach protocol. Sep protocol uses a two tier node setting.

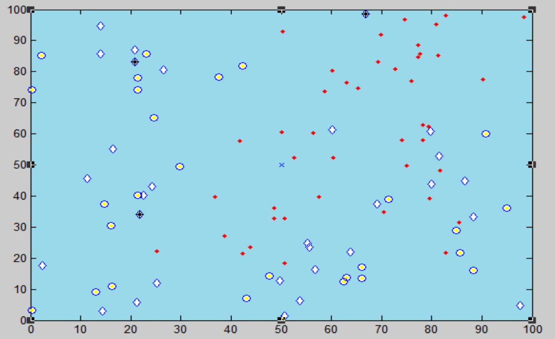


Fig 10-Dead node formation

I have observed that the time of first dead node has been extended in SEP rather than in leach protocol. The number of cluster heads is more and also the advanced nodes are elected as cluster heads.

3.4 Improvement to Stable Election Protocol

An improvement to this protocol is introduced by replacing its two tier hierarchy level using a three tier model. They are the intermediate nodes which have an energy level between the normal nodes and advanced nodes. As an impact of this approach the stable region of the network is further increased as the node can exploit three energy levels.

3.5 Imperfections of existing schemes.

These methods consume much amount of energy and perform poor in the case of non stationary signals. The unnecessary information gathered would result in a high communication load. Collecting data from a large sensor network involves large scale data aggregation and integration and hence quickly consume the energy of the sensor nodes. These protocols fail to solve the funnel shaped problem. To increase the lifetime of the network the sensed data should be aggregated and transmitted in a lightweight manner.

4. An example for data gathering operation

A heat sensing environment is simulated with the sources, and the mobility of the sources may vary from 0 to 50. The simulated environment is shown in the figure 11 and 12.

Three heat sources are kept and they randomly changes fifty positions within the network.
Sensor position= matrix (no. of sensors)*2 which gives the X and Y co-ordinates of sensors in environment.
Sensor data = matrix of sensors*(time instant/position).
Heat position X and Y= matrix of position*heat sources.

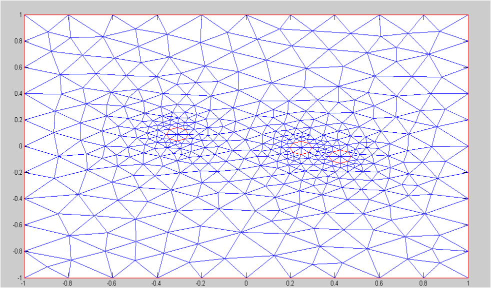


Fig 11-Simulation of heat sensing of an environment

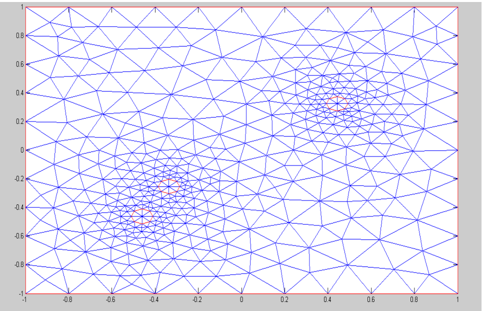


Fig 12-Simulation of heat sensing with new position of heat sources

5. Solution to these limitations using compressive sensing

Compressive sensing addresses these limitations by directly acquiring a compressed or incomplete signal representation without collecting all the signal samples. Traditional approach of gathering data was to uniformly sample the data and send it to a fusion centre. Since the transmitted data consists of a large number of redundant information this approach proved to be inefficient in terms of energy efficiency. According to compressive sensing theory an ‘N’ dimensional signal is considered. It is represented as a column vector $x^k \in R^N$. This is the tuple representation of the vector or matrix. Each element of x^k is the value measured by one of the N sensors collected according to a fixed sampling rate. The signal is reconstructed from the random projections of

x^k. It is represented as $y^k \square R^L$. In actual WSN scenario, principal component analysis [pca] is used to represent the best M term by exploiting the knowledge of correlation among the data samples of the signal.

While using pca the mean covariance matrix of the signal of interest is estimated. The method used in pca is also called as eigen analysis. The eigen vector associated with the largest eigen value holds the direction of the first principal component. Each principal component is a linear transformation of the entire data set.

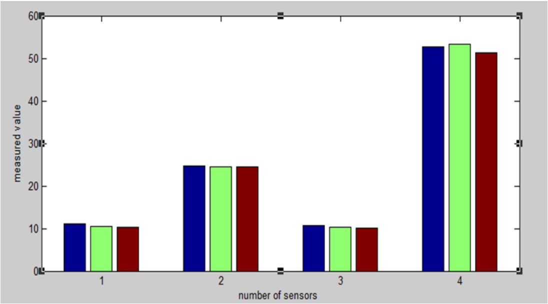


Fig 13-Real world data simulation

Figure 14 shows a real world data set simulation. Here I have taken the data measured by four different sensors for three different time instants.

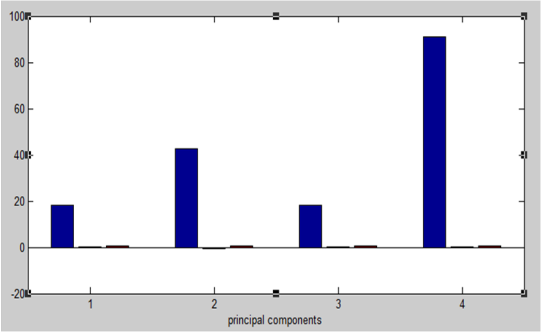


Fig 14-Principal components of real data

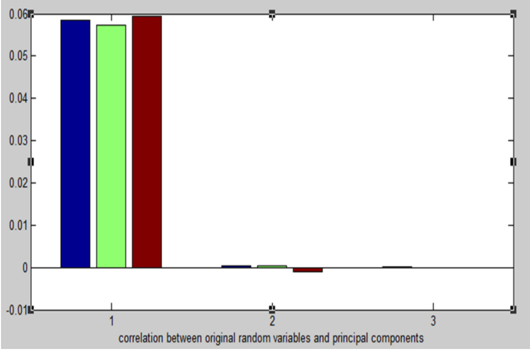


Fig 15- Correlation between the original variables and the principal components

5.1 Nesta Optimization Algorithm

NESTA is the short form of Nesterov's algorithm. This algorithm is efficient in solving large scale compressed sensing reconstruction problems through a lesser number of iterations. While applying nesta to solve compressive sensing related problems we try to solve the quadratically constrained l1 minimization problem i.e. Minimize ll x ll l1   Subject to ll b- Axll l2 $\leq \varepsilon$ The main parameters that control the convergence of nesta are μ and δ where, μ is a smoothing parameter and δ controls the convergence of algorithm. The algorithm converges for $\Delta f\mu < \delta$ for some $\delta>0$, possible values of δ are $\{10^{-5}, 10^{-6}, 10^{-7}, 10^{-8}\}$ and it is related to the accuracy required.

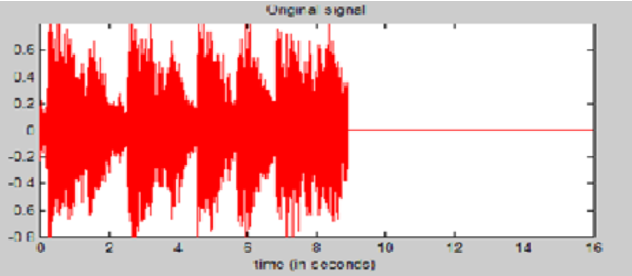


Fig 16-Original signal used for reconstruction using Nesta algorithm

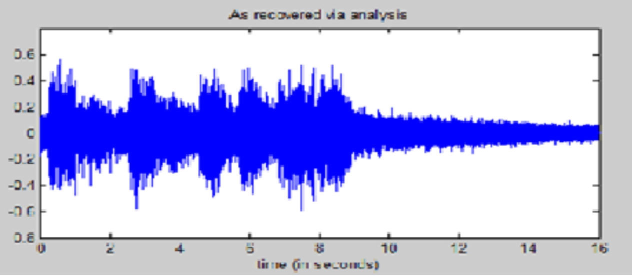


Fig 17-Reconstructed signal

6. Conclusion

In wireless sensor networks it is very important to increase the lifetime of the network so that large amount of data can be aggregated at the sink. In this paper the different existing data gathering schemes have been reviewed, and their performance is evaluated in terms of energy efficiency and a new method of compressive sensing using Nesta algorithm is introduced to optimize the energy efficiency of a WSN. The algorithm ensures that signals with more irregular and quickly varying statistics can also be recovered. In this approach, from small amount of compressed data a large distributed network is recreated with better accuracy.

7. Future work

The future work includes the generation of a mathematical model to study the performance of different data gathering protocols. The model can capture correlation in data irrespective of node density, topology etc. The physical sensor gathered data will be spatially correlated which is best fitted to the synthetic generated models and a synthetic signal having the same correlation features of the real signal is created on a suitable grid. Both the synthetic as well as real signal is reconstructed using Nesta optimization algorithm. The effectiveness of the recovery algorithm is checked in terms of number of transmissions versus reconstruction error, which is tried to both synthetic as well as real data. This innovation is not only limited to wireless sensor networks but also can be applied to other type of network infrastructures.

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