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An Adaptive Mixed Algorithm for Lifetime Optimization in Dense Wireless Sensor Network

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Abstract — **The problem of data collection in wireless sensor networks (WSNs) is becoming critical as larger networks are being deployed. Increasing network size possesses significant data collection challenges, which includes sensing, transmission coordination and sensor lifetime. To tackle these problems in-network compression techniques without centralized coordination are becoming important solutions. Data gathering and compressive sensing are the two approaches used earlier. To overcome the limitations of two aforementioned approaches, an adaptive mixed algorithm is used. An adaptive mixed algorithm is a combination of pack and forward (PF) and compressive sensing (CS). The proposed solution successfully minimizes the power consumption and the number of packets transmitted in the network. This approach is fully distributed in which each node autonomously takes a decision about the compression and forwarding scheme to minimize the number of packets to transmit. The method explained has been simulated using MATLAB and it has been established that an effective lifetime optimization could be achieved.**

Keywords – **Pack and Forward, Compressive Sensing, In-network Compression, Mixed Algorithm, Wireless Sensor Network.**

I. Introduction

Wireless sensor networks (WSNs) have a large number of sensor nodes with the ability to communicate among themselves and also to an external sink or a base-station. The sensors coordinate among themselves to form a communication network such as a single multi-hop network or a hierarchical organization with several clusters and cluster heads. The sensors periodically sense the data, process it, and transmit it to the base station [4]. Data gathering is one of the methods used here to increase the network lifetime. In order to monitor the sensor network a Zigbee manager is used here. This Zigbee monitors all the nodes in the network and deactivates the node which does not transmit or receive data's in the network.

Data Gathering is defined as the systematic collection of sensed data from multiple sensors to be eventually transmitted to the base station for processing. Since sensor nodes are energy constrained, it is inefficient for all the sensors to transmit the data directly to the base station. Data generated from neighboring sensors is often redundant and highly correlated. Hence, we need methods for combining data into high-quality information at the sensors or intermediate nodes which can reduce the number of packets transmitted to the base station resulting in conservation of energy and bandwidth, so that network lifetime is enhanced.

Compressive sampling is another method used in wireless sensor network to increase the network lifetime. The packet which is sent from each node is being compressed and it is sent to the sink node. During the compression of packets redundancy is being removed and the noise which is being added during transmission is also removed. Due to the compression the packets are sent efficiently and the power is consumed in all the nodes which lead to increase in lifetime of the network.

These two methods have some limitations, so we design a new mixed algorithm to get a better performance than the above two methods. The mixed algorithm is a combination of the above two methods.

This paper is structured as follows. Section II, describes data gathering in WSN, Section III, briefly explains about CS. A proposed mixed algorithm scheme is described in section IV. Section V deals with the advanced method of mixed algorithm called the modified mixed algorithm. The performance analysis for various parameters is discussed in Section VI. Finally, section VIIconcludes the work presented in this paper.

II. Data Gathering

It is one of the techniques used here to increase the network lifetime. It is defined as the systematic collection of sensed data from multiple sensors to be eventually transmitted to the base station for processing. A data gathering scheme in WSN is shown in fig 1. Since sensor nodes are energy constrained, it is inefficient for all the sensors to transmit the data directly to the base station. Data generated from neighboring sensors is often redundant and highly correlated. Hence, we need methods for combining data into high-quality information at the sensors or intermediate nodes which can reduce the number of packets transmitted to the base station resulting in conservation of energy and bandwidth. This can be accomplished by data aggregation [3].

Data aggregation is defined as the process of aggregating the data from multiple sensors to eliminate redundant transmission and provide fused information to the base station. Data aggregation usually involves the fusion of data from multiple sensors at intermediate nodes and transmission of the aggregated data to the base station (sink).

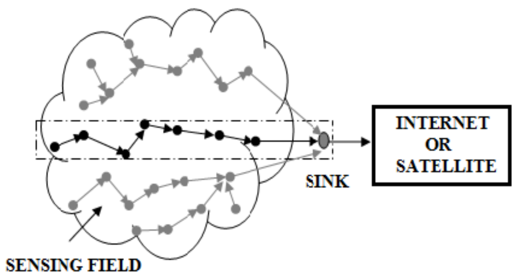

Fig.1. Data Gathering in sensor network

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In data gathering an algorithm is used to increase the network lifetime, PF is one of the algorithms used. PF refers pack and forward. It is an energy-safe strategy in which each node tries to encapsulate data in the most effective way by minimizing the number of packets.PF uses only fixed number of nodes in the network. The node before sending its own data to the next hop waits for the complete transmission of its children nodes [9].

A. Pack and Forward

It is an algorithm used in Data Gathering. PF is an energy-safe strategy in which each node tries to encapsulate data in the most efficient way, minimizing the number of outbound packets. This is a slightly modified version of the classical relay scheme usually adopted in WSNs in which each node on the path toward the sink forwards the incoming packets to the next hop according to its own routing table. If the network has just one aggregation point and the number of nodes is large, this technique turns out to be very energy unaware, wasting communication power proportionally to the number of packets to relay.

PF takes advantage of the fact that nodes in the network are fixed in space and, assuming that the routing tables are built during the network bootstrap, each node knows the number of children nodes. In this way, the node, before sending its own data to the next hop, waits for the complete transmission by its children nodes, computing an aggregated payload before sending out the final aggregated data. Since, in general, the size of transmitted data is smaller than the ZigBee payload, which is 127 bytes in size, the PF mechanism allows to pack several payloads within a single outbound packet.

The information the decoder requires to know for signal reconstruction is constituted by two fields: 1) the scalar sensor reading and 2) an identification ID. Indicating with B_{data} the number of bytes needed to encode the scalar reading and with B_{ID} the size in bytes of the identification field, the number of packets sent by the k^{th} node without fragmentation is,

$$P_k^{PF} = \left\lceil \left((N_{tch} + 1) \cdot (B_{ID} + B_{data}) \right) / B_{payload} \right\rceil \quad (1)$$

Where in case of ZigBee $B_{payload}$ = 127 bytes. N_{tch} is the number of nodes performing relay on the node.

III. Compressive Sensing

It is a data compression technique that does not require any prior information about original data. CS is the ability to reconstruct any sparse signal from a relatively small number of samples, even when the observer is corrupted by additive noise. It is shown in fig 2. The essential purpose of sensing and sampling systems is to accurately capture the salient information in a signal of interest. Generically, such systems can be viewed as having the following core components [5]. First, in a preconditioning step, the system introduces some form of sensing diversity, which gives each physically distinct signal from a specified class of candidates a distinct signature or fingerprint. Next, the "diversified" signal is sensed and recorded, and finally the system reconstructs the original signal from the sampled data. Because inadequate sampling of a signal can induce aliasing, meaning that the same set of samples may describe many different signals.

CS offers an alternative measurement approach that does not require any specific prior signal knowledge and is an effective (and efficient) strategy in each of the situations described above. The values of all nodes can be recovered from the compressed data y = Ax, provided its size k is proportional to the number of deviant nodes and y can be efficiently computed in a distributed manner, and by virtue of its small size, it is naturally easy to store and transmit. In fact, in certain wireless network applications, it is even possible to compute y in the air itself, rather than in silicon.

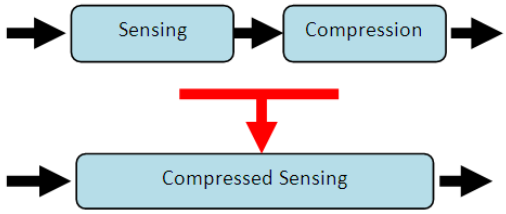

Fig.2 Compressive Sensing

Thus, CS offers two highly desirable features for networked data analysis. The method is decentralized, meaning that distributed data can be encoded without a central controller, and universal, in the sense that sampling does not require a priori knowledge or assumptions about the data. The theory of CS extends traditional sensing and sampling systems (designed with band limited signals in mind) to a much broader class of signals [8]. According to CS theory, any sufficiently compressible signal can be accurately recovered from a small number of non-adaptive, randomized linear projection samples.

B. CS in Wireless Sensor Networks

Sensor networking is an emerging technology that promises an unprecedented ability to monitor the physical world via a spatially distributed network of small, inexpensive wireless devices that have the ability to self-organize into a well-connected network. A typical wireless sensor network, as shown in Fig 3, consists of a large number of wireless sensor nodes, spatially distributed over a region of interest, that can sense (and potentially actuate) the physical environment in a variety of modalities, including acoustic, seismic, thermal, and infrared. A wide range of applications of sensor networks are being envisioned in a number of areas, including geographical monitoring, inventory management, homeland security, and health care.

The essential task in many applications of sensor networks is to extract some relevant information from distributed data and wirelessly deliver it to a distant destination, called the fusion center (FC). While this task can be accomplished in a number of ways, one particularly attractive technique leverages the theory of CS and corresponds to delivering random projections of the sensor network data to the FC by exploiting recent results on encoded (analog) coherent transmission schemes in wireless sensor networks. Transmission per random projection is based on the notion of so-called "matched source-channel communication". Here, the CS projection

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observations are simultaneously calculated (by the superposition of radio waves) and communicated using amplitude-modulated coherent transmissions of randomly weighted sensed values directly from the nodes in the network to the FC via the air interface. Algorithmically, sensor nodes sequentially perform the following steps in order to communicate k random projections of the sensor network data to the FC:

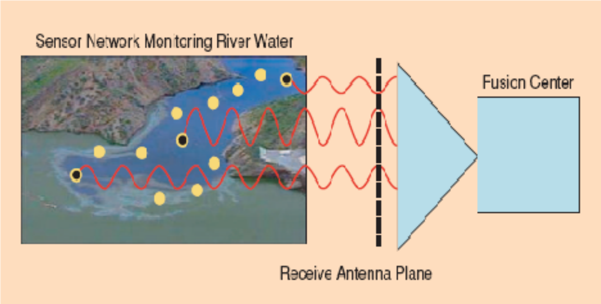

Fig.3. CS in Wireless Sensor Network

Step 1: Each of the n sensors locally draws k elements of the random projection vectors $\{A_{i,j}\}k_i$ =1 by using its network address as the seed of a pseudorandom number generator. Given the seed values and the addresses of the nodes in the network, the FC can also easily reconstruct the random vectors $\{A_{i,j}\}k_i$ =1 for each sensor j= 1, … , n.

Step 2: The sensor at location j multiplies its measurement xj with $\{A_{i,j}\}k_i$ =1 to obtain a k-tuple

$$V_j = (A_{1,j}x_j , \ldots , A_{k,j}x_j)^T , \quad j= 1, \ldots , n \qquad (2)$$

And all the nodes coherently transmit their respective v_{js} in an analog fashion over the network-to-FC air interface using k time slots (transmissions).

C. Distributed Compressive Sampling

When CS is used in WSN to achieve in-network compression of data, it is referred to as DCS. It is an algorithm used in Compressive Sampling [1]. This is a powerful approach to network data compression because it does not require any information about signal to compress (except the scarcity rate of the signal) and data encoding is performed jointly with routing in a distributed fashion.

CS compression is performed by each node in two steps:

Step 1: The node computes the M×1 random vector $Ø_j$ using its own ID as generator seed for the vector.

Step2: This vector is multiplied by the scalar reading x_j. Before sending out the result, it waits to receive data from all its children nodes to sum all together the intermediate results.

The generation of the random vector using the node ID is a requirement. During the reconstruction phase, the decoder must know the whole matrix Ø for the resolution of the optimization problem. In this way, the decoder is able to reconstruct the matrix for the reconstruction process from node ID (or address). The number of packets sent by a node performing CS is,

$$P_k^{CS} = \lceil (M \cdot B_{data}) / B_{payload} \rceil \qquad (3)$$

Differently from PF, the number of outbound packets is not a function of a geographic parameter, as N_{tch}, which depends on the position of the node within the network. In this case, each node in the network sends the same number of packets, independently from the position in the directed routing path from the node to the sink. P_k^{CS} is a function of M, which is depending on the network size N. The major drawback of this technique is that a slightly increasing in the value of M determines a huge increment in data circulating within the network.

IV. Mixed Algorithm

Since PF and DCS have some limitations we shift to a new algorithm is proposed called mixed algorithm. The main aim of this mixed algorithm is to increase the network lifetime. The PF performance is strictly related to the node position inside the routing path, whereas DCS is not suitable for big-sized networks due to its dependence on the parameter M. Therefore, neither PF nor DCS are suitable schemes to adopt in every condition and network topology. The contribution of this work is to provide a mixed algorithm assuming that each node has enough information to take a proper decision with the goal of reducing the outbound packets. Thus, a generic node can autonomously choose to adopt PF or DCS to save battery power.

The number of packets sent by a generic K node is,

$$P_k = \begin{cases} P_k^{CS}, & if\, P_k^{CS} \leq P_k^{PF} \\ P_k^{PF}, & if\, P_k^{CS} > P_k^{PF} \end{cases} \qquad (4)$$

Where, P_k is the number of packets actually sent by the node.

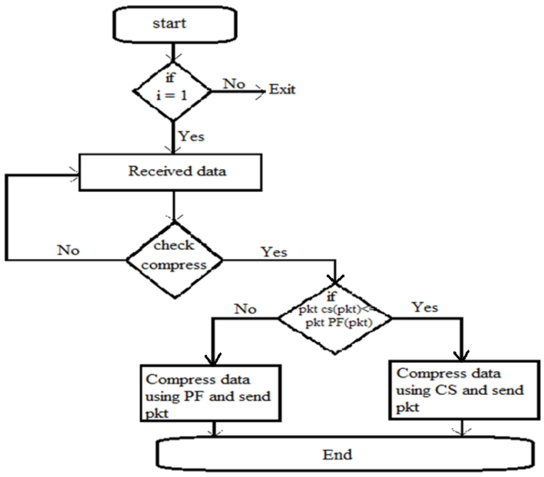

Fig.4. Mixed Algorithm

If a node receives packets coming from the children nodes encoded with different schemes (PF and DCS), the decision is narrowed by the fact that from a packet compressed with DCS it is not possible for the node going back to the original data.

Therefore, the mixed algorithm is composed of many steps:

Step 1: The cluster head node receives all the packets from the cluster nodes.

Step 2: The cluster head node checks whether the received packets are compressed using PF or CS.

Step 3: If the packets compressed with CS is less when compared to the packet compressed with PF, the node chooses to adopt CS aiming to send the lowest number of packets.

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Step 4: If the packets compressed with CS is greater when compared to the packet compressed with PF, the node chooses to adopt PF aiming to send the lowest number of packets.

Step 5: The lowest number of packets at the cluster head node is finally sent to the sink node.

These steps are being adopted to design a mixed algorithm. This increases the lifetime of the network.

V. Modified Mixed Algorithm

A modified mixed algorithm is proposed to increase the lifetime of the network. It gives better result when compared to the mixed algorithm scheme. In this modified mixed algorithm a certain value is given to increase the lifetime. The mixed algorithm minimizes the number of packet being transmitted and the modified version increases the number of transmissions in the network trying to obtain a better overall lifetime of the system reducing the energy used in compression by boundary nodes.

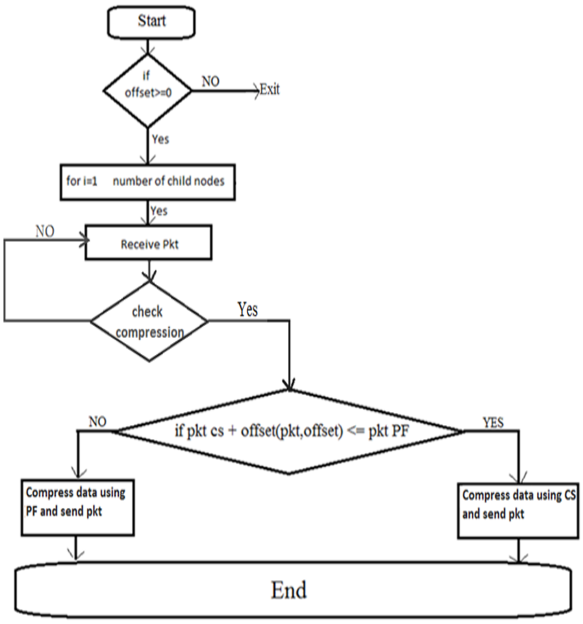

Fig.5. Modified Mixed Algorithm

In this modified mixed algorithm a term B_{off} is added to obtain an overall lifetime. B_{off} is a value assigned to take a decision about the mechanism to adopt.

The modified mixed algorithm is composed of the following steps:

Step 1: The cluster head node receives all the packets from the cluster nodes.

Step 2: The cluster head node checks whether the received packets are compressed using PF or DCS.

Step 3: If the packets compressed with CS plus the offset packets is less when compared to the packet compressed with PF, the node chooses to adopt CS aiming to send the lowest number of packets.

Step 4: If the packets compressed with CS plus the offset packets is greater when compared to the packet compressed with PF, the node chooses to adopt PF aiming to send the lowest number of packets.

Step 5: The lowest number of packets at the cluster head node is finally sent to the sink node.

VI. Performance Analysis

The performance of mixed algorithm for increasing the network lifetime is analyzed in this section. Simulation is performed using MATLAB R2011a. The parameters used in the simulation are given in table1. Simulation experiments were conducted to assess the performance of the network lifetime.

Table 1: Simulation Parameters

PARAMETERS	
B_{data}	Bytes needed to encode
B_{ID}	Size of the identification field
$B_{payload}$	Zigbee payload
B_{off}	Redundant bits
M	Matrix

Mixed algorithm achieves an increase in lifetime when compare to all other schemes. This is because mixed algorithm uses a mixed concept of both PF and DCS. Hence by using this power is consumed and in turn lifetime of the network is increased.

The NMSE (Normalized Mean Square Error) is the overall deviation between the predicted and measured values. It is defined as:

$$NMSE = \frac{\sum_{n-1}^{N}(x(n)-x\hat{}(n))^2}{\sum_{n-1}^{N} x(n)^2} \quad (5)$$

Where, x(n) is the original signal and x^(n) is its reconstructed signal.

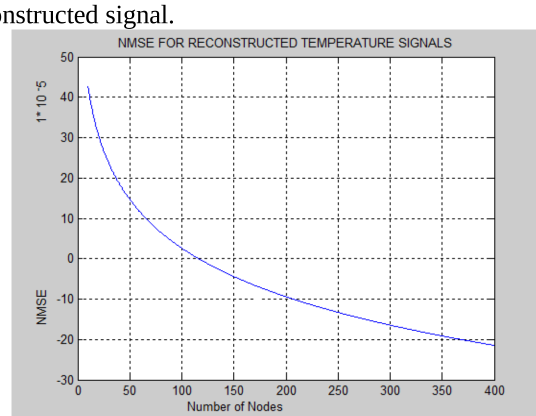

Fig.6. NMSE for reconstructed signal

Fig 6 shows the Normalized Mean Square Error gets decreased as the number of nodes gets increased. This is because, it is a dense Wireless Sensor Network, the sensor nodes are higher and in a particular network size the nodes are nearer and not far. Since the nodes are near, they transmit the data very faster and due to its short distance the error occurrence is also low.

In fig 7 a framework for optimization is done using all the nodes in dense wireless network. Optimization is done by selecting minimum number of nodes which has high energy. Here the minimum number of nodes is represented in dark black stars, which performs compressive sampling. While other nodes are represented in small circles performs classical PF.

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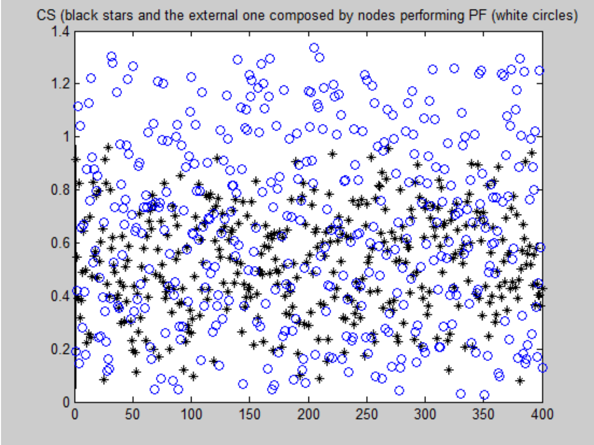

Fig.7. Framework for network with size N>Ncrit

In fig 8as the nodes increases the total number of transmission in the network is good for mixed algorithm when compared with other two algorithms. The data which is being sent by the node is compressed and it is sent to the base station. During the transmission data loss occurs and in addition some noises may also occur. In the receiver side the sent data are reconstructed and the original data is got back.

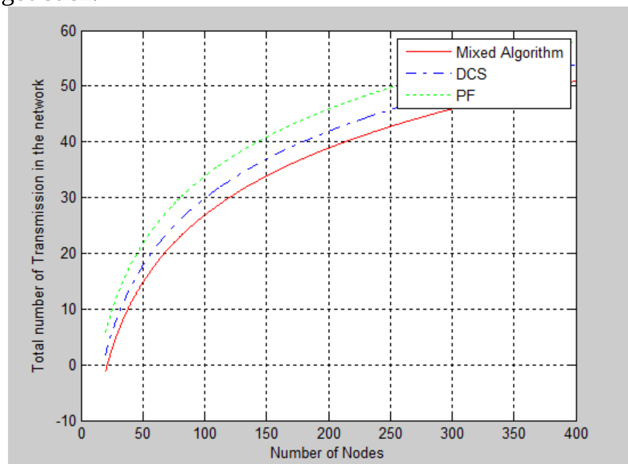

Fig.8. Transmission in the network

The plot shows, as the classical PF scheme presents, a slightly increasing trend with an increase in the network dimension. More interesting is the behavior of DCS. For a particular network dimension, the number of sent packets explodes, presenting a huge increment. This increment regards each single node within the network that has to send out two packets instead of one. Our algorithm performs better than the two previous schemes, presenting a number of sent packets that is always smaller than both PF and DCS. For small-sized networks, the proposed solution approaches DCS. This is why the number of packets sent with PF or DCS is the same. Therefore, according to the algorithm proposed, the node compresses data using CS.

In fig 9 the lifetime of the network is increased in our proposed algorithm, when compared with PF (Pack and Forward) and DCS (Distributed Compressive Sampling). Here the value of B_{ID} and B_{data} is kept constant and the performance is compared.

It is possible to identify two different parts in the plot:

Step 1: For small networks with N <N_{crit}, the algorithm is coincident with CS as also seen in Section 3.

Step 2: For N ~ N_{crit}, we have an abrupt decrement in lifetime.

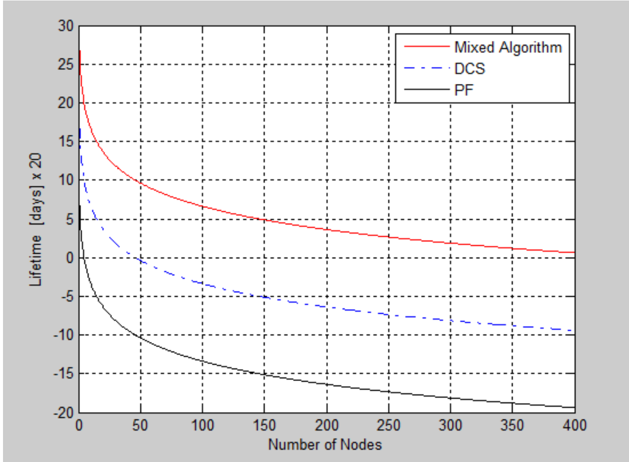

Fig.9. BID = 8 bytes and Bdata = 1 byte

Simulations mainly depend on two parameters: B_{ID} and B_{data}. B_{data} results to be the most critical one. Both PF and DCS depend on this parameter, but doubling the value has a deep impact mainly on DCS since each nodes within the network doubles the number of sent packets, whereas PF is only slightly affected since B_{data} is an additional contribution to the sum. The result of simulations when B_{data} is doubled is reported in Fig 10. In this B_{data} is varied and B_{ID} is set as 8 bytes. By varying B_{data} the performance of our proposed mixed algorithm is always greater and gives a better increase in lifetime.

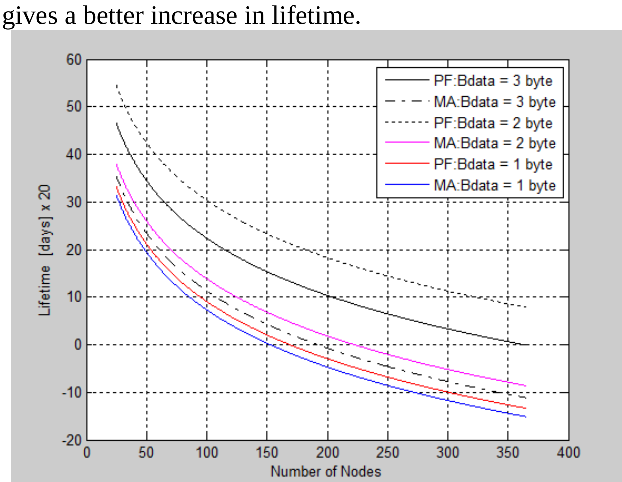

Fig.10. Varying Bdata(BID = 8bytes)

In fig 11when B_{ID} is varied from 2 to 8 bytes is reported. On the contrary, in this case, the increase in the dimension of the ID field of the ZigBee packet affects much more PF than the mixed algorithm. The increase in the number of bytes used for ID has the main effect to enlarge the central region for DCS since PF performs poorly when it has to manage too many bytes per node that is what happens within the network near the sink. Even if the influence of the parameter mainly affects the performance of the mixed algorithm, the lifetime is always better for our algorithm than classical PF scheme.

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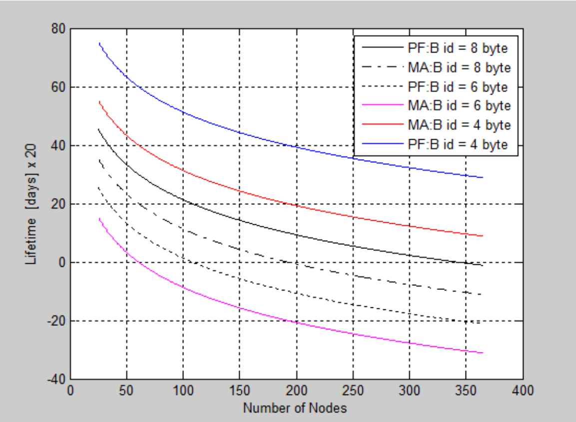

Fig.11. Varying BID (Bdata = 1 byte)

The following simulation results shows the increase in lifetime of the modified algorithm with respect to the Classical implementation of the mixed algorithm when different values for B_{off} are used in the simulation using the network size M as parameter in the plots. Modified mixed algorithm is used to obtain an overall lifetime. A value B_{off} is added and the transmission of the packets are increased to obtain a better lifetime. In fig 12 when B_{ID}= 0 bytes the transmission is ideal and the lifetime improvement is random.

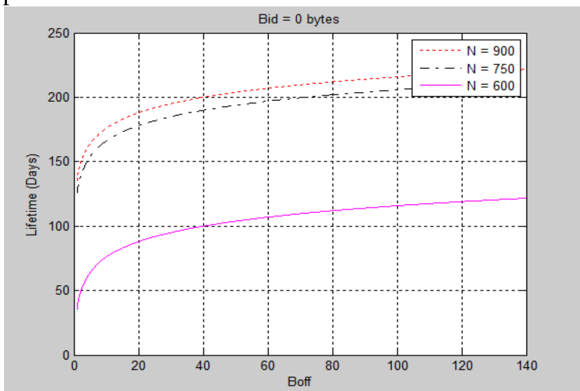

Fig.12. When BID = 0 bytes

In fig 13 when B_{ID} = 2bytes there is a overall good increase in lifetime when B_{off} is varied, the lifetime gets increase with increase in nodes. Here as the node increases the lifetime also gets increased. This is due to Dense Wireless Sensor Network. In Dense WSN the nodes are located nearer to each other. So that traffic and error will be low.

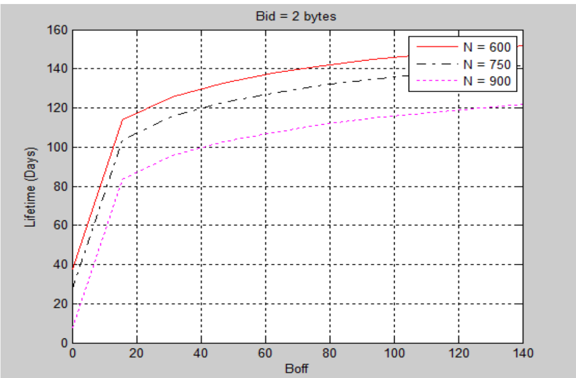

Fig.13. When BID = 2 bytes

In fig 14 when B_{ID} = 4bytes the lifetime is better when compared to B_{ID} = 2 and 0 bytes. By using this modified mixed the lifetime is maximized when B_{off} ranges from 60 to 100. As the nodes increases the lifetime is also increased.

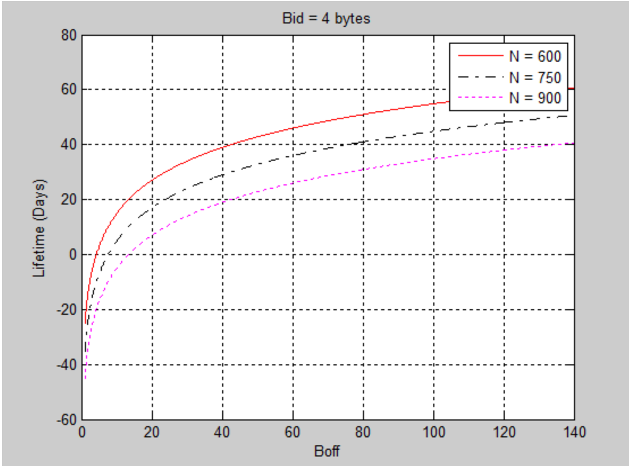

Fig.14. When BID = 4 bytes

In each graph, it is identified that, a general behavior for the network with increasing value of B_{off}. For small increasing values of B_{off}, the lifetime increases since the contribution of the energy spent in compression decreases although in the network expands the inner portion of nodes performing DCS, reducing the contribution of for each boundary node.

VII. Conclusion

The problem of power consumption can be minimized when a large-scale ZigBee is considered. A classical gathering scheme and DCS have been explained. This is not suitable when the network consists of a large number of nodes. A new adaptive mixed algorithm is proposed. which saves the communication power and prolongs the network lifetime. A modified version of the algorithm is also proposed to obtain a better overall behavior. Here CS can be a powerful tool for energy saving in WSN as long as network size and compression work are both taken into account. The proposed modified algorithm prolongs the lifetime of the network achieving a trade-off between traffic in the network and energy spent in compression.

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