Energy Efficiency in Wireless Sensor Networks Using Data Aggregation

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***Abstract*—Communication systems have been marching towards rapid developments due to the advancements in science and technology. Wireless Sensor Networks (WSNs) have been gaining importance recently due to the development of low-cost nodes and electronics. But WSNs always come with certain constraints like battery power, resources etc. In order to extend the network lifetime and to minimize the energy consumption, it is essential to propose techniques that will serve the purpose. In clustered Sensor networks Cooperative Multiple-Input-Multiple-Output (CMIMO) can be used to bring in diversity among the different nodes in the cluster. By doing so, all the nodes in the cluster will cooperatively transmit the sensed data to the sink or access point (AP). Data aggregation is one more technique which can be combined with CMIMO to reduce the number of bits present in the data that is transmitted to the destination or AP. In any communication ninety percent of the energy is spent in transmission of the data. So it is essential to compress the data before transmission. In terms of clustered WSNs, nodes that are spatially close to each other will sense more or less the same information like, for example, temperature, pressure, humidity etc. As a result there is redundant data and this redundancy should be removed to enable energy-efficient transmission. The technique combining CMIMO and Data Aggregation is named as CMIMO-A.**

***Index Terms*— Wireless Sensor Networks, Energy Efficiency, CMIMO, Data Aggregation, Spatial Correlation**

I. INTRODUCTION

In Wireless Sensor Networks, the nodes are powered using non-rechargeable batteries. In some remote applications it is even impossible to replace the batteries. So it is crucial to minimize the consumption of battery power by the nodes for various operations like sensing, processing, transmitting, receiving, analog-to-digital conversion etc. The sensor node is made of four important components, namely: a sensing unit, a processing unit, a transceiver unit and a power unit [1]. The power unit plays a major role as it decides the network life-time.

In a clustered Wireless Sensor Network the total energy consumed for a transmission is made up of two components. One is called the Local Communication or Intra-Cluster Communication and the other is called the Long-Haul Communication or Inter-Cluster Communication. The communication that takes place between the nodes in the same cluster is called Local communication. The communication that takes place between a node in one cluster and a node in another cluster is called Long-Haul Communication [2]. The scenario used in the analysis is shown in figure 1. In this scenario, the network is clustered with uniform distribution of nodes in each cluster. For simplicity, the case of multi-hop transmission is neglected. The destination or Access Point (AP) is placed on top of the network. The AP flies over the cluster from which it is going to receive data. It is assumed that the distance from every node in a cluster to the AP is fixed.

II. COOPERATIVE MULTIPLE-INPUT-MULTIPLE-OUTPUT (CMIMO)

CMIMO is used to bring in cooperation among the various nodes in the cluster. CMIMO is used to cooperatively transmit the sensed data from the cluster to the AP. In sensor networks, CMIMO is again used to reduce the transmission energy as sensor networks consists of nodes that are powered using batteries. In a clustered sensor network, the nodes within a cluster participate in cooperation to reduce energy consumption in the so-called long-haul transmission.

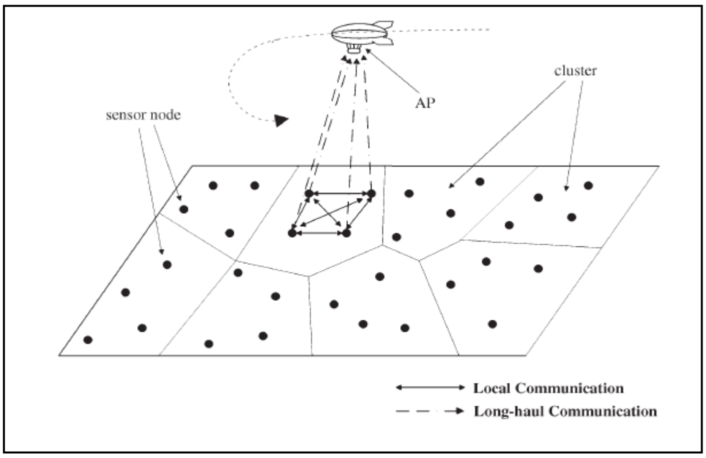

Figure 1: Network Scenario

III. DATA AGGREGATION

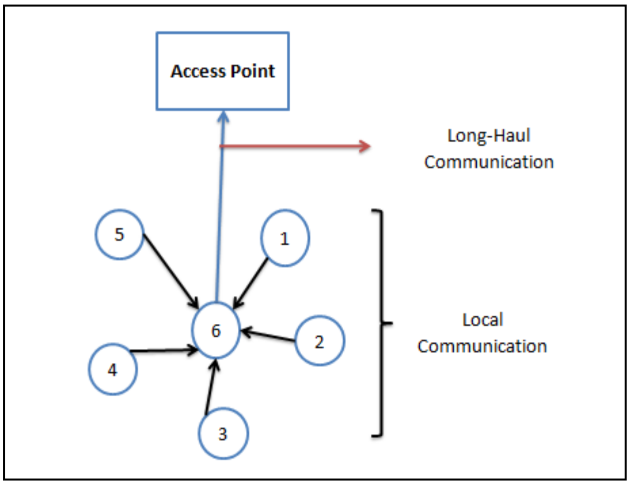

Figure 2: Mechanism of CAS

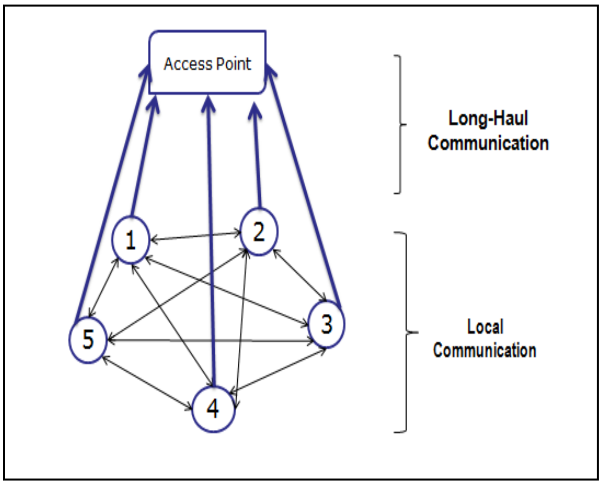

Figure 3: Mechanism of DAS

It is well known that nodes that are placed close to each other sense data that is highly correlated. Due to this spatial correlation there is redundancy in the data that has to be transmitted to the destination. Data Aggregation is one technique that is applied to remove the redundancy that is present. There are two aggregation schemes called the Centralized Aggregation Scheme (CAS) and the Distributed Aggregation Scheme (DAS) [2]. In CAS, redundancy removal in local communication takes place in three phases as follows:

- *Gathering phase*: In this phase, the central node of the cluster is chosen as the cluster head. All the other nodes in the cluster transmit the sensed data, at a particular rate, to the cluster head. This is called gathering and certain amount of energy is utilized for this purpose.
- *Compressing phase*: The data sensed by different sensor nodes within a cluster are correlated due to their spatial arrangement. As a result some redundancy can be taken off from them through compression at the central node. The degree of correlation in the data from different nodes is a function of the distance between them. Also, the size of the cluster has an impact on the compression efficiency of the cluster.
- *Broadcasting phase:* The central node now contains the compressed data and broadcasts the compressed and integrated data to other nodes within the same cluster at the same data rate that was used in the gathering phase. All the nodes in the cluster receive the compressed data. Thus the total energy spent in local communication is given by equation (1).

$$E_{Local\text{-}CAS} = E_{Gathering} + E_{Compression} + E_{Broadcasting} \quad (1)$$

The node numbered '6' in the figure 2 is the cluster head. In long-haul communication, the cluster head transmits the compressed data to the access point. Since data aggregation removes the unwanted bits, the amount of energy spent in long-haul communication is minimized. Thus data aggregation can be said to be an effective technique for collecting and compressing the data sensed by the sensor nodes. The total energy spent in one transmission can be visualized as the sum of the energy spent in local communication and the energy spent in long-haul communication and is given by equation (2).

$$E_{Total} = E_{Local} + E_{Lh} \quad (2)$$

There is yet another aggregation scheme called the Distributed Aggregation Scheme (DAS). DAS has two phases, gathering and compression and it is explained below:

- *Gathering phase*. Each node in a cluster exchanges its sensed data with all other nodes in that cluster by using different time slots to broadcast. Thus each node in the cluster will have a copy of data sensed by all the nodes in the cluster.
- *Compressing phase*. Each node separately collects and compresses the data gathered from the gathering phase and this compressed data is used in long-haul communication.

$$E_{Local\text{-}DAS} = E_{Gathering} + E_{Compression} \quad (3)$$

The mechanism of DAS is shown in figure 3. In DAS, since every node in the cluster performs the compression operation more energy is consumed whereas in CAS only the cluster head performs compression. But DAS also carries the advantage that when the degree of spatial correlation is less, it is more energy efficient than CAS.

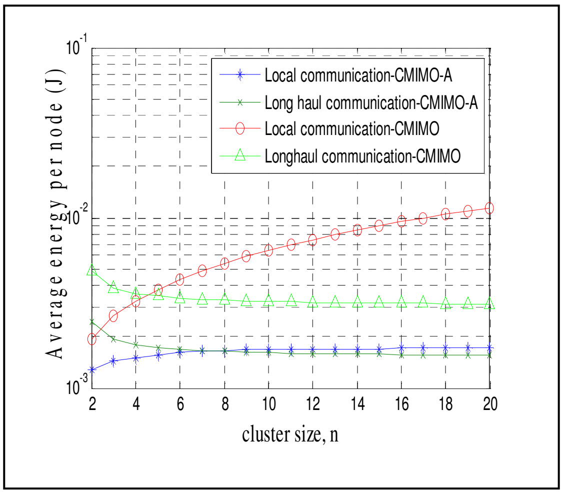

Figure 4: Comparison between CMIMO and CMIMO-A

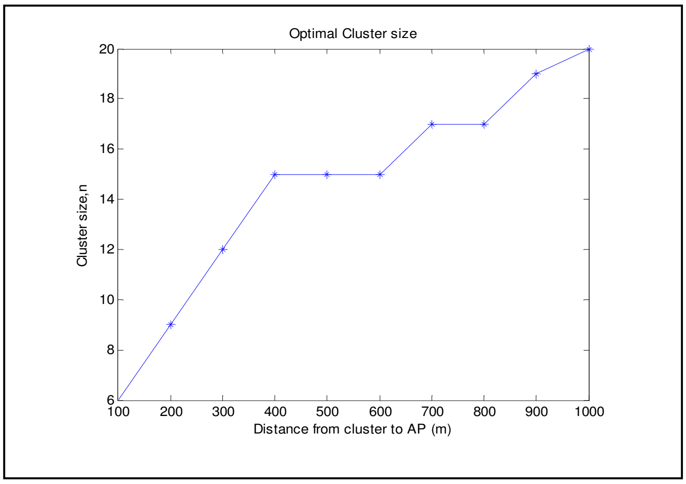

Figure 5: Optimal Cluster Size

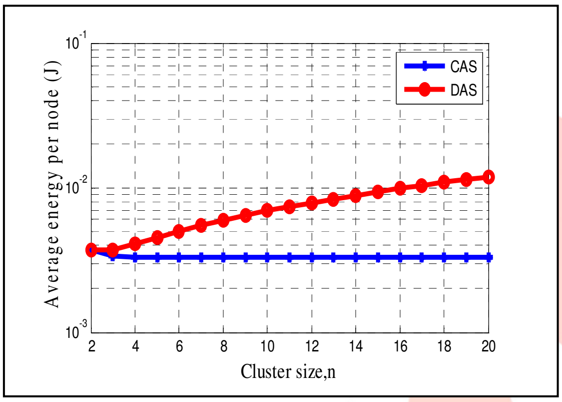

Figure 6: Comparison between CAS and DAS

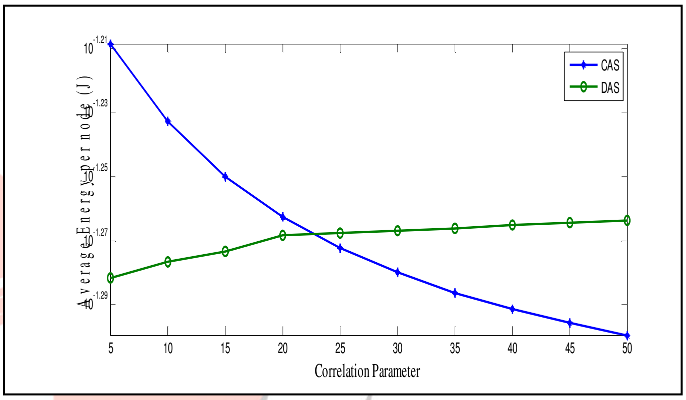

Figure 7: CAS and DAS with respect to Correlation Parameter

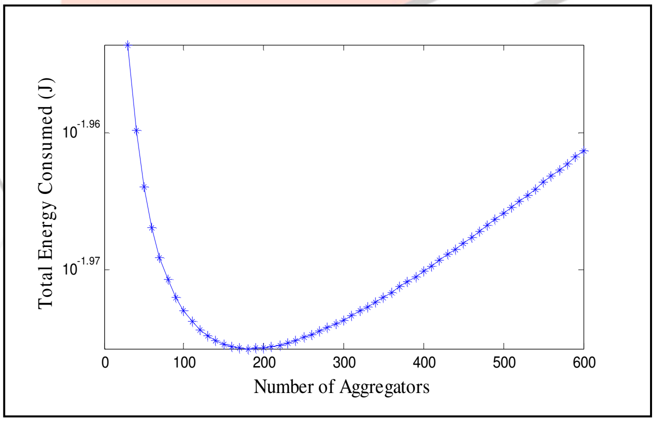

Figure 8: Optimal Number of Aggregators

IV. ENERGY MODEL AND SIMULATION RESULTS

The most prominent disadvantage of a WSN being its power constraint, many techniques have been introduced in literature to reduce the amount of battery power consumed by each node in the network. In most of the cases CMIMO-A has been proved to be a better technique in terms of power consumption and efficiency.

The scenario considered in this case is shown in figure 1. The network is divided into clusters with uniform distribution of nodes. Each node in the center of a cluster is chosen as the cluster head. The destination is named as the Access Point (AP). In this case it is assumed that the AP flies over the network. It is also assumed that the distance from each node in the cluster to the AP is fixed [2].

From figure 4, the performance difference between CMIMO-A and CMIMO for different cluster sizes can be understood. The two components of energy consumption (local and long-haul communication) are plotted. It is seen that the energy consumed by these components is less in CMIMO-A compared to CMIMO due to the aggregation and compression of data. Thus it is concluded that CMIMO-A is a better technique in terms of energy efficiency.

Optimal cluster size is the cluster size for which there is minimum average energy consumption per node for CMIMO-A. This corresponds to changing a number of parameters given in equation (2). Thus the optimal cluster size is based on the following optimization problem:

$$\min_{n} E_{node}^{CMIMO\text{-}A} \quad \text{Subject to: } n \text{ is integer, } n \geq 1 \tag{4}$$

The optimization process is conducted by allowing the cluster size *n* to vary and fixing other parameters in equation (2). Also the distance from the cluster to the access point (D) can also be used as a parameter for finding the optimal cluster size. The graph in figure 5 shows the optimal cluster sizes for different distances from cluster to AP. A detailed study of the formulae for the energy consumed in different phases of local communication and long-haul communication is given in [2].

The total energy consumed by a node, in transmission from the cluster to the access point, is the sum of the energy spent for local communication and the energy spent for long-haul communication. Thus the overall energy spent by a node in CAS and DAS is plotted in figure 6. It is seen that DAS consumes more energy than CAS. This is due to the fact that in DAS all nodes compress the sensed data in order to remove the redundancy, whereas in CAS only the cluster head performs compression. The energy consumed for long-haul communication is the same for both CAS and DAS. This is due to the fact that, the increasing number of nodes in the cluster affects only local communication and does not affect long-haul transmission.

A detailed analysis of energy consumption based on the correlation parameter is given in [2]. The correlation parameter gives the degree of spatial correlation that exists between closely placed sensor nodes. It is seen from figure 7 that when spatial correlation is less DAS is an energy-efficient scheme and when spatial correlation is high CAS proves to be a better technique. The formula that is used to calculate the number of bits after aggregation is as follows:

$$I_i = I_{i-1} + [1 - 1/(d_i/c + 1)]L \tag{5}$$

where I_i is the number of bits in the data after aggregation and compression. Here 'c' denotes the degree of spatial correlation and d_i is the radius of the cluster.

Figure 8 shows the optimal number of aggregators that can be used for minimum energy consumption. Aggregators are nothing but the cluster heads. It is also important to plan the number of aggregators that can be used based on the power available and the application used. Figure 8 shows the optimal number of aggregators for single level aggregation. This can be extended to a hierarchy as given in [3].

V. CONCLUSION AND FUTURE WORK

As a result of the various performance and energy analysis performed, it can be concluded that Cooperative Multiple-Input-Multiple-Output with Aggregation (CMIMO-A) is the technique which saves the power of nodes by reducing the transmission energy in the long-haul communication. CMIMO exploits the single antennas present on each node and makes the nodes to cooperate in order to avoid redundant transmissions and also increase the throughput of the system by making it spectrum-efficient. As a consequence, transmission energy is reduced reasonably when compared to one-to-one transmission.

Data aggregation, on the other hand, reduces the amount of data that is exchanged in the network. It is believed that data sensed by nodes that are placed close to each other are correlated due to the spatial impact. Therefore the data are spatial correlated and are more likely to contain redundant data. Thus aggregation techniques will gather these data, remove redundant information from the data, and provides an overall summary of the gathered information. This compressed information is then transmitted from the cluster of nodes to the access point. As a result the amount of data is reduced and the amount of energy spent for long-haul communication is also reduced. To highlight the advantage of CMIMO-A, it has been compared with other techniques like CMIMO, DATAG, and the traditional SISO system. But it is seen that when the cluster size is very big, in the order of thousands, CMIMO-A is no better than the other techniques.

This work can be extended further for finding an effective data aggregation technique, which consumes very less battery power and can compress the data even further without compromising the security and integrity of the data. When the cluster size is big (>1000), CMIMO-A is no more an energy-efficient technique. Therefore some amount of research can be done to address this problem.

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