Signal Strength based Communication in Wireless Sensor Networks

Imran S. Ansari

December 10, 2009

EE 242 Digital Communications and Coding (Fall 2009)
Project Report

Department of Electrical Engineering
Division of Physical Science and Engineering
King Abdullah University of Science and Technology

Abstract

Wireless Sensor Networks (WSNs) are employed to sense a required measurement to its maximum accuracy. WSNs contain multiple sensors for the same task and forward their sensed values to the Base Station/Fusion Center (BS). Although, this gives accuracy in our measurements but there are many issues that arise during this process. There are issues like battery power of the sensors among others that are to be looked upon. Hence, to tackle such issues, this report proposes an optimal design that shall reduce the computations to the minimum at the sensor's level while allowing for accurate measurements simultaneously at the BS using signal strength's between the sensor nodes and the BS as the basic criterion.

Contents

1 Introduction

Wireless Sensor Networks have become an essential part of Communications in present age. Data has started moving at very high speeds. The frequency of data testing in different fields has increased exponentially and so has the requirement of having accurate measurements has raised quite high. In this regards, having a single device at the receiver's end to detect the required data might not satisfy the present requirements. Hence, researchers have been working on WSNs lately wherein many devices i.e. nodes in our case are employed for the same task to achieve accuracy.

These WSNs have several different characteristics that can be handled for achieving different results based on the requirement of the user. For instance, there is a factor of spatial-correlation between the sensor nodes or there is proximity of the sensor nodes with the event source among others. In this paper, the strength of the sensor nodes in terms of their respective transmission to the Base Station (BS) is measured and then BS then sets a threshold for the sensor nodes. This allows for only a certain number of nodes transmitting rather all.

The nodes are tried to be reduced as the objective of this design because it has been learned from previous work that after a certain no. of nodes, the network performance does not gets affected i.e. does not gets better.[3] Hence, this motivated the proposed design. Keeping the above in mind, the paper proceeds with discussing previous work, the proposed design including the objective, Experimental Setup and Implementation Model followed by the algorithm and lastly conclusion.

2 Related Work

Wireless Sensor Networks or in general Sensor Networks are basically composed of Base Station/Fusion Center (BS), and Sensor nodes apart from the event source. Power and Bandwidth Limitations are applied as the data is compressed and communicated through the channel. It has been reported that each sensor node encodes its observations before transmitting the data.[1]

The performance criteria applied in WSNs is usually Mean Square Error (MSE) [1]. Also, the channels between the sensor nodes used to be orthogonal though studies have proved that coherent channels are much more efficient [2]. Hence, MAC is also coherent [1].

Scalars are employed at very initial stages of the experiment though the real testing is done while employing vectors and hence, in case of vectors, both Bandwidth and Power constraints play role giving much better understanding of the network.[1]

It was mentioned in [1] that sensor statistics are studied using Gaussian waveforms. Also, it must be understood that not having orthogonal channels allows for interference and hence even better analysis of the sensor network [1].

In addition, it is good to learn that orthogonal MAC occupies a complete channel even if the channel is not being used and hence wasting the resources of the network whereas coherent MAC is void of this wastage. Lastly, it is interesting to know that both these types of MACs have the same noise power.[2]

As mentioned earlier in the introduction, there is a threshold to the number of sensor nodes required at a time for successful measurement at the BS. This was proved in [3] with the help of spatial correlations between the nodes. It was concluded that in dense node network, nodes away from each other though close to the event source shall transmit only and the rest shall keep silent increasing the efficiency of the network.[3]

3 Proposed Design

It was required to design and implement an efficient wireless sensor network that will allow for an easy procedure to attain the output with maximum accuracy.

3.1 Setup

The setup of our wireless sensor network includes an event (source), sensors around the event/source, some in close proximity; some little distant though all in accessible region. These sensors run on battery. Hence, these sensors must not be required to do any rigorous or complex computations. They must be as simple as possible to allow for long battery life.

The sensors amount to n sensors. These sensors sense some quantity like temperature or its likes that change or fluctuate on a very low frequency. They sense through wireless medium. Although this will definitely have some effect on the measurements sensed, but these are ignored in this model for the time being. These effects include noise among others. It may also include the correlation between the measurements being sensed by the sensors placed quite close to each other.

There are M channels in this network. These M channels are present in between the sensor nodes described earlier and the Base Station/Fusion Center (BS). This BS will be described and discussed following these channels description. The channels mentioned above are coherent and not orthogonal. It was choosen so, as it has been proved in previous work that coherent performs much better than orthogonal [1]. Also, its sensible and logical as orthogonal reserves a complete channel for a sensor even if its not being used leading to wastage of Bandwidth (BW) whereas in coherent case, each sensor node will be able to use each of the present M channels.

These channels can lead to many sorts of effects on the message or measurements, in current case, being transmitted from sensor nodes to the BS. But for the time being the only case considered is where noise is added to the transmitted message and ignore the rest of the effects. Lastly, there is the BS, where the final value of the measurements is expected.

This is the final destination of this network and this is it where maximum number of computations shall take place rather at the sensor nodes to allow for a

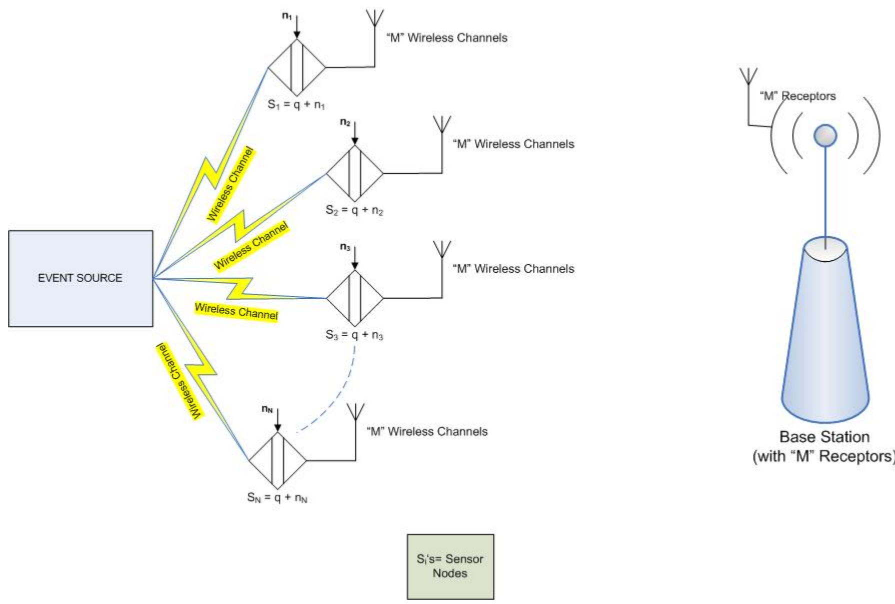

Figure 1: The wireless sensor network mode.

longer battery life at the sensor nodes. This BS will have M receptors/antennas corresponding to the M channels between the sensor nodes and itself.

The setup is shown pictorially as in Figure 1.

3.2 Implementation

In our network system, the event source is continually getting changed in one of its parameters like temperature for instance. But the change is not on a very frequent basis. The sensor nodes sense the value of the parameter after every time t intervals. On sensing, they just amplify-and-forward the measured/sensed value to the BS over the M channels. Hence, each sensor detects a measurement q (for instance in our case) and then sends it over the channel getting an additive noise attached to its transmitted signal leading to following:

Initially at event source $\rightarrow q$

Sensor nodes detect $\rightarrow q$

Sensor nodes amplify and forward getting noise added over the channel $\rightarrow q + n_i$; where $1 \leq i \leq N$

Hence, the received signals S_i's at the BS are $\rightarrow S_i = q+n_i$; where $1 \leq i \leq N$.

Now in our case, we would like to implement that instead of all N sensor nodes transmitting their sensed/detected q's, only those in very close proximity of the event source will be transmitting their detected values (q's). This will allow for more efficient use of the network for longer time and simultaneously also getting the job done.

So, originally we have following: (for each received signal on each channel)

$$
\begin{aligned}
y_1 &= \alpha_{11}S_1 + \alpha_{12}S_2 + \cdots + \alpha_{1N}S_N \\
y_2 &= \alpha_{21}S_1 + \alpha_{22}S_2 + \cdots + \alpha_{2N}S_N \\
&\vdots \\
y_M &= \alpha_{M1}S_1 + \alpha_{M2}S_2 + \cdots + \alpha_{MN}S_N
\end{aligned}
$$

In vector form:

$$
\begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_M \end{pmatrix} = \begin{pmatrix} \alpha_{11} & \cdots & \alpha_{1N} \\ \vdots & \ddots & \vdots \\ \alpha_{M1} & \cdots & \alpha_{MN} \end{pmatrix} \begin{pmatrix} S_1 \\ S_2 \\ \vdots \\ S_N \end{pmatrix} \tag{1}
$$

Now, we want to change the above into only X nodes. This could be done by requesting each sensor node to send a pilot signal to the BS. On doing so, the BS can learn the strength of each node and set a threshold, only above which, the sensor nodes must transmit to the BS. This will allow for $X < N$ nodes transmitting only.

Alternatively, Compressive Sensing might be applied to the original vector/matrix representation allowing for reduction in nodes actually transmitting. Hence, this reduction will lead to the following new vector/matrix representation

$$
\begin{aligned}
y_1 &= \alpha_{11}S_1 + \alpha_{12}S_2 + \cdots + \alpha_{1X}S_X \\
y_2 &= \alpha_{21}S_1 + \alpha_{22}S_2 + \cdots + \alpha_{2X}S_X \\
&\vdots \\
y_M &= \alpha_{M1}S_1 + \alpha_{M2}S_2 + \cdots + \alpha_{MX}S_X
\end{aligned}
$$

In vector form:

$$
\begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_M \end{pmatrix} = \begin{pmatrix} \alpha_{11} & \cdots & \alpha_{1X} \\ \vdots & \ddots & \vdots \\ \alpha_{M1} & \cdots & \alpha_{MX} \end{pmatrix} \begin{pmatrix} S_1 \\ S_2 \\ \vdots \\ S_X \end{pmatrix} \tag{2}
$$

Therefore, the important effects of this reduction will be:

1. At the sensor nodes, there will be only single check for the threshold value set by the BS and rest would be to only forward the detected value.

2. Whereas, at the BS, the complexity and computation increases. The BS has to initially set the threshold. Then, it also has to come to final result of the detection based on the upcoming procedure.

Now for the main computation at the BS for the actual value detection, the vector/matrix representation in Eq. 2 can be reduced to the following.

$$\begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_M \end{pmatrix} = \begin{pmatrix} b_1 \\ b_2 \\ \vdots \\ b_M \end{pmatrix} q + N' \tag{3}$$

Where,

$$\begin{aligned} b_1 &= \alpha_{11}S_1 + \alpha_{12}S_2 + \cdots + \alpha_{1X}S_X \\ b_2 &= \alpha_{21}S_1 + \alpha_{22}S_2 + \cdots + \alpha_{2X}S_X \\ &\vdots \\ b_M &= \alpha_{M1}S_1 + \alpha_{M2}S_2 + \cdots + \alpha_{MX}S_X \end{aligned}$$

And we know that $S_i = q + n_i$.

Since

$$\begin{aligned} y_j = &\quad S_i & 1 \leq j \leq M, 1 \leq i \leq X \\ y_j = &\quad Aq + An_i & 1 \leq j \leq M, 1 \leq i \leq X \end{aligned}$$

Where, A is the main α_{ji} matrix in Eq. 2. Also, the An_i's can be considered as combined noise $\rightarrow N'$.

Now, since the noise component can be learned from the channel and hence ignored from the vector/matrix representation in Eq. 3 i.e. N can be ignored. This will allow us to get our required value.

Each $y_j = b_j q \rightarrow q = y_j / b_j$.

Therefore, the q_{avg} can be calculated as,

$$q_{\text{avg}} = \frac{\frac{y_1}{b_1} + \frac{y_2}{b_2} + \cdots + \frac{y_M}{b_M}}{M} \tag{4}$$

Above all, one of the important points to note is that, after certain elapsed time interval, the BS will re-evaluate the eligibility of sensor nodes by learning the pilot signals and assigning a new threshold. This is so because; the sensor nodes might not be fixed or stationary instead in random and possibly continuous movement.

To conclude, this proposed design is a very simple design and on its successful implementation, this design can further be made complex and much more efficient. This can be done by considering more sources of message distortion between the nodes and the BS, by considering disturbances in channel from the event source nodes.

4 Algorithm

- We have an event source.
- There are N sensor nodes.
  - After every certain time interval T
    - They send a pilot signal to the BS;
    - Receive a threshold check value;
    - Each sensor node compares its corresponding level with the threshold
      - If greater than the threshold then declares itself as switched ON and eligible for the transmissions;
      - Else does not sends and Switches OFF for this session or goes to standby state;
    - After every certain time interval t // ($t << T$)
      - The eligible X sensor nodes detect q and transmit their detected measurements; //$(X < N)$
- At BS (Has M Receptors)
  - After every certain time interval T
    - Requests and receives pilot signals from the sensor nodes and learns the strength of each of those and by using compressive sensing, defines a threshold level for the sensor nodes and returns back to the sensor nodes;
    - It also learns the noise level of the channel(s) $\rightarrow N$;
    - After every certain time intervals t //$(t << T)$
      - Received y_j's from X eligible nodes; //$(X < N)$
      - It then forms the vector/matrix representation as displayed in Eq. 2;
      - Then performs calculations and modifications as shown in Eq. 3 and Eq. 4 to obtain the final result q in terms of q_{avg};
      - So, it forms vectors of all received signals;
      - Then, reduces the coefficient matrix to a column vector matrix;
      - Then, splits the actual measurement part and the noise part;
      - It then ignores the noise component and computes the average of the q;
      - Displays the final obtained/detected result;

5 Result Analysis

The above described algorithm in Section 3 was implemented using MATLAB. The equations employed for signal estimation ($\hat{S}_{XM}$) and distortion (D_X) calculation, as shown below, were based on [3].

$$\hat{S}_{XM} = \frac{1}{M} \frac{Y\sigma_q^2 \sum_{i=1}^{X} \sum_{j=1}^{M} \alpha_{ji}}{\sigma_S^2 \sum_{i=1}^{X} \sum_{j=1}^{M} \alpha_{ji}^2}$$

$$D_X = \sigma_q^2 - \frac{\sigma_q^4 \left(\sum_{i=1}^{X} \sum_{j=1}^{M} \alpha_{ji} \right)^2}{\sigma_S^2 \sum_{i=1}^{X} \sum_{j=1}^{M} \alpha_{ji}^2 + 1}$$

The results were relatively satisfactory and as seen in Figure 2, the simulation also conformed with the previous work in [2] & [3] that after a certain number of nodes, the performance does not gets affected much.

Hence, the proposed design yielded the expected results.

6 Conclusion

Consequently, it can be successfully stated that, the performance of a WSN can be improved using the proposed design as it will reduce the maximum number of nodes transmitting at a time and hence increasing the efficiency of the network. It is so as it will reduce the power consumption of the sensor nodes among others.

Furthermore, the efficiency of the network is also increased due to the fact that the computations at the sensor level are reduced to almost null and almost all the computations taking place at the BS. Hence, the proposed design increases the efficiency of the WSN.

7 Future Work

The proposed design in this report has to be learned with practical modeling apart from what follows. In general, the WSNs can further be tested with more complex assumptions and analyzing much more rigorously allowing for more parameters and their solution towards a more efficient WSN. Spatial Correlation between the sensor nodes and also between the different channels between the sensor node and the BS can be appended to the proposed design and analyzed for its efficiency.

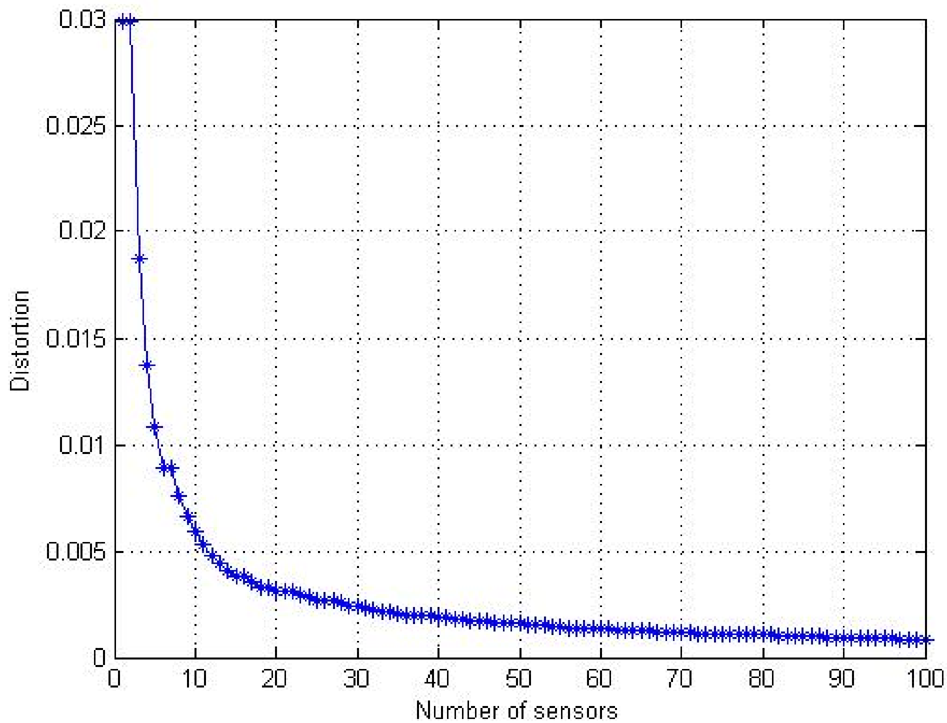

Figure 2: Average distortion for varying number of sensor nodes.

References

[1] J.-J. Xiao, S. Cui, Z.-Q. Luo, and A. J. Goldsmith, "Linear Coherent Decentralized Estimation", *IEEE Global Conference on Communications*, November 2006.

[2] M. C. Vuran and I. F. Akyildiz, "Spatial Correlation-Based Collaborative Medium Access Control in Wireless Sensor Networks", *IEEE/ACM Transactions on Networking*, February 2005.

[3] T. Murad, "Untitled/Unpublished Paper".