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Deploying a LEACH Data Aggregation Technique for Air Quality Monitoring in Wireless Sensor Network

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Abstract

The aim of this paper is to develop an effective aggregation technique for wireless sensor networks that is mainly designed to suit air quality monitoring application. The solution is based on LEACH by Heinzelman*et al.*; a well known data aggregation technique for wireless sensor networks. Experimental results show the effectiveness of our solution in extending the network lifetime, while efficiently monitoring air quality.

Keywords: Wireless Sensor Networks; Data Aggregation; Data Streams; Air Quality Monitoring; Air Pollution Monitoring; LEACH

1. Introduction

Wireless sensor networks (WSNs) have many applications such as environmental monitoring, flood detection, and home automation. Since sensors have limited power capabilities, the need for developing algorithm to aggregate sensors' data forms an important concern in the area of WSNs.

The goal of data aggregation algorithms for WSN is to develop techniques that minimize the data transmission within the network in order to save energy, since the energy consumption is mainly affected by the data transmission. Minimizing the data transmission can be reached either by reducing the size of the data that is transmitted or reducing the number of transmissions.

There are many data aggregation algorithms in the literature, some of which are cluster-based algorithms[1,2,3,4,5,6,7,8,9], while others are based on different ways of routing. We only consider the cluster-based routing algorithms, which group nearby sensors into a number of clusters. Each cluster is, then, assigned a representative sensor called the cluster head (CH), which is responsible for collecting data records from its cluster members and sending them to the base station. This reduces power consumption in the network because only the CH is sending the data to the base station. One well known cluster-based algorithm is the Low Energy Adaptive Clustering Hierarchy Aggregation (LEACH) algorithm by Heinzelman *et al.* [2].

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In this paper, we target one important application of WSNs, that is the air pollution monitoring application due to its importance on human health. To the best of our knowledge, only a limited number of studies on WSN in air pollution manner exists in the literature[10,11,12,13,14,15].

We develop a solution for air quality monitoring applications in wireless sensor networks using a LEACH-based aggregation algorithm in order to effectively save energy and extend the network lifetime. As the solution is mainly designed for air quality monitoring, the idea behind it is that when the air is in good quality then less data is sent, while more data must be sent if the air quality gets worse in order to have more accurate monitoring results and raise any danger alarm if needed. For deciding the level of air quality, we refer to the USA international air quality indexes[16]. Experimental results show that our algorithm is promising in the field of air quality monitoring.

The remainder of the paper is organized as follows: Section 2 states the background. Section 3 proposes our solution. Section 4 states experimental settings. Section 5 shows experimental results. Finally, Section 6 draws our conclusions.

2. Background

2.1. LEACH algorithm

Low Energy Adaptive Clustering Hierarchy Aggregation (LEACH) algorithm by Heinzelman *et al.*[2] is a data aggregation algorithm based on cluster routing. The algorithm works in rounds such that each round has two phases namely, a setup phase and a steady state phase.

In the setup phase, $p\%$ of n sensors are uniformly randomly chosen to be cluster heads (CHs) based on a threshold

$$T(n) = \begin{cases} \frac{p}{1-p(t \ mod \frac{1}{p})}, & \text{if } n \in G \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

where p is the desired number of CHs, t is the current round, and G is the set of nodes that have not been CHs in the last $\frac{1}{p}$ rounds. This ensures that a sensor that is chosen to be CH is not chosen in the next rounds until all other sensors in the network become CHs. After all CHs are chosen, clusters are dynamically defined such that each non-CH becomes a member of the cluster with the nearest CH.

In the steady state phase, each CH collects data from all sensors in its cluster based on Time Division Multiple Access. CHs, then, compress the collected data and send it to the base station.

2.2. Air Quality Index

The air quality index (AQI) is an index for reporting daily air quality based on the values of specific air pollutants at some time. AQI is different for different countries. Each country defines the pollutants that are to be included in calculating the values of AQI as well the number of pollutant concentration levels and how severe each level is on the human health. We consider the United States AQI defined by the United States Environmental Protection Agency (EPA)[16]. EPA calculates the AQI for five major air pollutants; ground-level ozone, particle pollution (also known as particulate matter), carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2). EPA defines six air quality levels, namely, good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous.

3. Proposed solution: Air Quality Monitoring LEACH

We propose an air quality monitoring LEACH algorithm (*AQM-LEACH*) to monitor the quality of the air using wireless sensor network. Unlike LEACH, where data is sent to base station at every round, AQM-LEACH tents to save energy by not sending data unless its important to do so. Deciding the level of importance to send the data is based on the AQI values, which are calculated based on the data that are sensed by the sensors in the networks.

If the AQI is in good level then less data should be sent since no harm on human health is expected, and hence, no alarms are needed to be raised. Whenever the AQI values are higher and mapped to be in levels with more effect on human health, then more data must be collected as the situation is considered unusual and need to be precisely addressed. The main goal of collecting more data is to reflect the exact air quality situation. The frequency of collecting data reaches its maximum when the air is in hazardous level. Using this strategy, the power consumption in the network is clearly reduced due to the fact that the network has low data transmission since the normal case for air quality is having most of the readings in good/moderate status. The network lifetime is, therefore, increased.

3.1. AQM-LEACH details

The idea of the proposed aggregation can be explained as follows: we assume that once the AQI value is in good level, then it is safe to maximize the time periods between the rounds of sending data. The period between sending data is derived from a data sending frequency parameter F; a proposed variable with real values such that $0 < F \leq 1$. F calculates the frequency of sending the data through the network based on the calculated AQI values.

We define an *event* in the network as the change in the level of the AQI reading for one or more sensors. Whenever at least one sensor records an event, then more data should be collected to keep track of the new changes in the air quality. The number of data to be collected when the status changes depends on how severe the change is. F reaches its maximum value when the AQI readings are in hazardous level, hence, the situation is severe and more data must be collected, whereas it is at its minimum value when the AQI readings are in good level and less data is to be collected.

We come up with a plausible general solution to define F in order to reflect the above mentioned explanation:

$$F = \begin{cases} (c_{max}/C) * \alpha, & \text{if } c_{max} < C \\ 1, & \text{otherwise: } c_{max} = C \end{cases} \quad (2)$$

where C is the total number of air quality levels of the AQI that is used ($C = 6$ for the USA AQI), c_{max} is the maximum AQI reading that is recorded during this specific round through all sensors (ranges from 1 to 6 for the USA AQI), and α is a tuning factor, such that $0 < \alpha \leq 1$.

The tuning factor α is a user defined variable whose value can be defined based on the application. If it is safe to collect less data α can be minimized, while its maximized to 1 for more sensitive applications. Note that for hazardous AQI levels, the effect of α is neglected and the sampling frequency F is forced to be set to 1, which means that data is collected at every round. This is the case where LEACH and AQM-LEACH perform the same.

4. Implementation and Experimental Settings

We simulate both LEACH and AQM-LEACH in order to compare their performances. We assume that all sensors can reach each others and reach the base station directly. All our simulations are based on C-Language.

4.1. Testing Criteria

The criteria by which we evaluate our work are:

- *First node dies, last node dies, and average sensor lifetime:* obtain the rounds at which the first sensor in the network dies and the last sensor in the network dies, as well as the average of lifetimes for sensors in number of rounds.
- *Number of alive sensors:* obtain the number of sensors that are still alive at each round.
- *Remaining energy:* compute the total remaining energy for the network per round.
- *Sampling Frequency:* show the rounds at which the sensors are active for both LEACH and AQM-LEACH, and that AQM-LEACH responds efficiently to the of raise in AQI values.

Results for all criteria are averages over 20 runs, while randomly selecting CHs/sending sensors for each run.

4.2. Simulation Settings

4.2.1. Parameters settings

We base our energy calculations on the energy settings by LEACH[2]. The probability of selecting the maximum number of cluster heads p is set to 15%. Whereas the tuning factor α is set to three different values for upcoming results, except for sampling frequency results where α is set to 1. The values we use for α are 1, 0.75, and 0.5.

4.2.2. Network structure

The network that we use is taken from from EPA; United States Environmental Protection Agency[16]. The number of sensors in the network is 23. Sensor locations haven been mapped to a 50 x 50 network to result into a network shown in Figure 1.

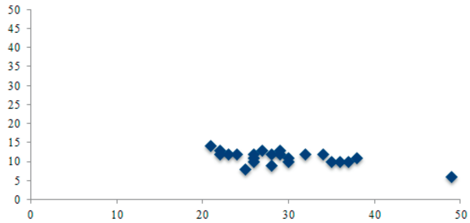

Fig. 1. Network structure

4.2.3. Data sets

We use real data from EPA United States Environmental Protection Agency[16]. Data files contain AQI values for the gases CO, NO_2, $and SO_2$ with time stamps that defines the time at which they were recorded. Since original AQI values are in good and moderate AQI levels only, we add synthetic larger AQI values to represent pollution events. Events have been inserted for every Gas (CO, NO2, SO2) as follows:

1. choose 12 random time stamps in the data file
2. for every time stamp, randomly select a close by group of sensors and apply the event block as follows:

    (a) generate 5 random readings in good level
    (b) for every remaining level, generate 10 random readings until the level is hazardous, then generate 10 readings again for each level till the level is back to moderate.
    (c) generate 5 random readings in good level to end the events block.

A total of 129 events have been inserted to the data files for different gasses and different sensors. Note that events for different gasses can overlap at the same times.

5. Results and Discussions

5.1. First node dies, last node dies, and average sensor lifetime

Figure 2 represents the number of rounds at which the first node dies and last node dies. It also shows the average lifetime of sensors for both LEACH and AQM-LEACH.

As it is shown from the figure, AQM-LEACH extends LEACH in terms of the first node dies, the last nodes dies, and the average lifetime. The increment is more than 100% for the first node dies, and about 200% for the last node dies and the average lifetime for the sensors for $\alpha = 1$ (highest sampling frequency). Whereas its even extremely more for $\alpha = 0.75$ and $\alpha = 0.5$.

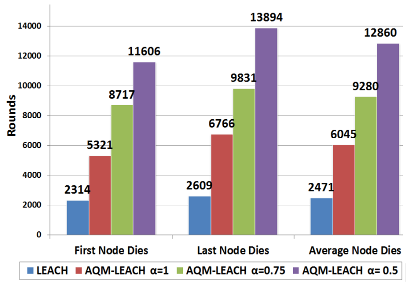

Fig. 2. First node dies, last node dies, and average lifetime for LEACH and AQM-LEACH

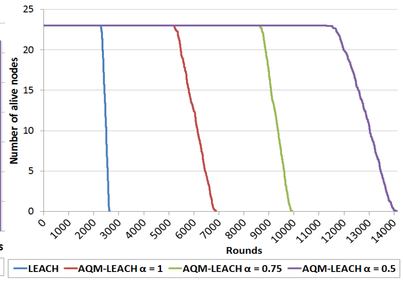

Fig. 3. Number of alive sensors versus rounds for LEACH and AQM-LEACH

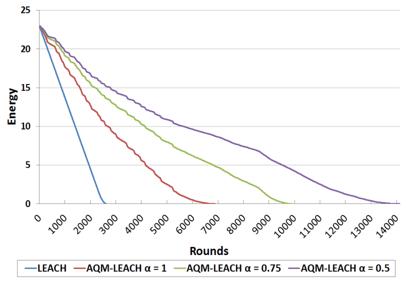

Fig. 4. Remaining energy versus rounds for LEACH and AQM-LEACH

5.2. *Number of alive sensors*

Figure 3 demonstrates the number of alive sensors versus the number of rounds for LEACH and AQM-LEACH for the three different values of α. In the case of $\alpha = 1$, the figure shows that AQM-LEACH extends the network lifetime by about 4200 rounds having all the sensors alive until about 5300 rounds which represents about 80% of the total network lifetime. This insures that the network is fully monitored for 80% of the network lifetime. For lower values of α, the network stays alive for more than 7000 rounds for $\alpha = 0.75$ and more than 11000 rounds for $\alpha = 0.5$.

5.3. *Remaining Energy*

Figure 4 presents the total remaining energy of the network with respect to the number of rounds for LEACH and AQM-LEACH. The figure clearly shows that there is an extreme save of energy when AQM-LEACH is applied on our air monitoring network. The less the value of α, the more the save in energy. These results complement the results shown in Figure 3.

5.4. *Sampling Frequency F*

Figures 5, 6, and 7 show the sampling frequency F for three random events appearing in CO readings, NO_2 readings, and SO_2 readings respectively. The results represent the algorithm reaction in change in sampling frequency to the maximum recorded AQI value in the network for a specific gas at a specific round. The background colors are standard colors by EPA, which show the different levels of the USA AQI readings. Note that the dashed line represents F of LEACH which is = 1 for all time as its displayed during all rounds. Whereas if the black line (that represents AQM-LEACH) is continuous, then the F is maximum and equals to 1, while F is less for the case where the dots are displayed. The dots show that for this specific round, the sensors are activated and sending data.

It can be clearly shown from the figures that during the events, the AQM-LEACH sampling frequency is increased till it reaches the maximum (sample every round as in LEACH) for hazardous levels. It can also be noticed that at some readings in CO and SO_2 the sampling frequency is maximum although the level of AQI readings is not hazardous. This is due to the fact that there is another event that is taking place in another gas which gives the maximum reading c_{max} in hazardous level, and therefore, all the network sensors are at their highest sampling frequency. The figurers confirm that AQM-LEACH reacts efficiently to events by being able to capture the change in AQI level and increase the sampling frequency accordingly.

6. Conclusion

This paper have proposed an air quality monitoring LEACH-based data aggregation algorithm (AQM-LEACH). The key feature of AQM-LEACH is that; data is not sent unless its necessary. The frequency of sending the sensed data is, therefore, minimized when the air is in high quality. This feature results in having more sleep times and,

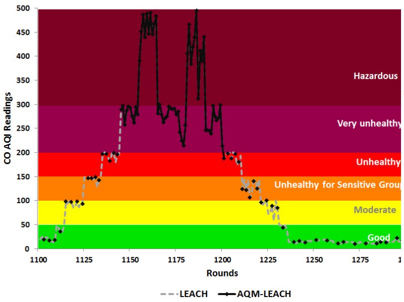

Fig. 5. Sampling frequency for an event in CO readings

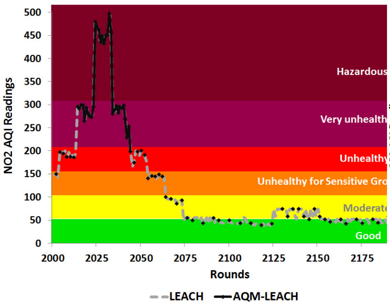

Fig. 6. Sampling frequency for an event in NO_2 readings

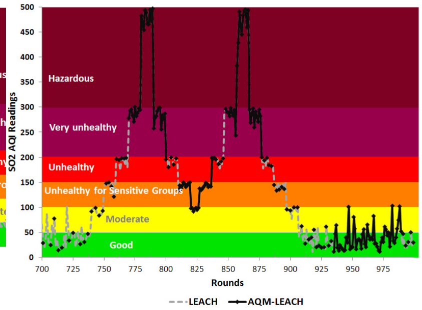

Fig. 7. Sampling frequency for an event in SO_2 readings

hence, the network lifetime is extended. Whenever the air quality gets worse, more data is sent to make sure not to miss any severe information. Simulation results show that the network life time is extended, The results also show that the proposed solution reacts well to any event in the network by changing the data sending frequency accordingly.

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