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Design of a Communication Strategy for Wireless Sensors in Non-Deterministic Environments using Mobile Agents

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Abstract
The premise of this paper is to propose and implement an energy efficient communication strategy for WSNs which specifically caters the needs of non-deterministic fields. The authors have thus proposed an integrated approach which performs the task of energy efficient communication, clustering, filtering and fusion in an intelligent manner. Another unique contribution of this work is the application of Extended Kalman Filter for filtering the noise/unwanted data from data detected by the sensors. A case study to filter unwanted data from air pollutants has also been carried out and significant results thus obtained have been presented. The authors have also exploited mobile software agents to perform the task of clustering, fusion and negotiation in particular among clusters for transmitting the data on demand. The results obtained are comparable with other existing protocols.

Keywords: software agents ,RCNTEP, residual energy, data fusion, Kalman Filter

Introduction

Although extensive research has been done in the field of deterministic WSN, there is a considerable scope of improvement in the case of non-deterministic environment. In this domain, there are several challenges to be dealt with like improving the lifetime of network, energy efficient node deployment, efficient clustering techniques, coverage, sink hole problem etc. In addition to the various challenges listed above, one of the major challenge is to find an energy efficient alternative to the conventional routing paradigm involving the client server approach.
The literature review [1,2,3] done till the time of listing reveals that, practically there exist no integrated approach which can ensure efficient communication among the sensors, cluster them as well process the information to be transmitted to the sink. The above listed technical challenges and the requirement of an integrated intelligent strategy thus lay the foundation of our work. This research work proposes a **M**obility **C**ontrolled **C**ommunication taking advantage of **C**lustering, **F**usion and **F**iltering (MC3F2) also and henceforth is referred to as MC3F2 in all upcoming sections.
The rest of the paper is organized as follows. Section 2discusses the works of eminent researchers in the related field highlighting the need for a new technical solution. Section 3 describes the unique contribution of this work and section 4 finally concludes throwing some light on future work.

Related Work

A lot of research has been carried out to find the feasibility of implementing the idea under focus. It is evident in order to overcome the constraints such as lifetime of network, deployment strategy, communication protocols, just to list a few, various mechanisms have already been proposed and implemented ranging from initial deployment to finally processing the information received. For instance, RWP(Random Waypoint Model) [4-8] is one of the most common mobility model being used. Though this basic model works well in most of the situations, results get fluctuated when the distance between two nodes and the speed at which the nodes move do not match with each other. Further, clustering has proved to be advantageous while contributing to increase the lifetime of the network. While summarizing some of the important clustering protocols HEED[9], LCA[10],RCC [12], multitier clustering scheme [11], FLOC [13], LEACH[15], just to list a few, it was discovered that all these algorithms are able to cater the need of clustering in one way or another. Further, a variation of LEACH known as Mobile Agent Based LEACH in WSN[14] has also been proposed in practical which exploits the autonomy and intelligence features of software agents to sense and disseminate data to the sink node. Though it results in conserving the energy of sensor nodes, agents by no means contribute for the task of clustering in this work. It is worth noticing that mostly all of the above listed protocols do not make use of mobile agents for carrying out clustering and hence these appeared to be unsuitable for our proposed integrated approach. Further none of the works available above talks about the reliability of software agents used for clustering.

Now turning our attention to information processing, fusing the filtered information contributes two major challenges. Actually, the data being sensed by the sensors (in a clustered or flat network) comprises of outliers and is also fluctuating. In addition the data being transmitted can be faulty. Transmission of such data to the sink may lead to unnecessary consumption of bandwidth of the network. Amongst various available filtering tools [16,17], use of Kalman Filter as one of the possible and a novel tool for information processing is still in its infancy. The authors thus aim to explore this naïve area. The requirement of fusing the filtered information has been apparent since ages due to the demands of high network life time. Basically, data fusion deals with combining data from multiple sources and gather this information in order to achieve inferences, which will be more efficient and potentially more accurate than if they could be achieved by means of a single source.[data fusion 1.pdf of dimple]. Works given in [18,19,20] have elaborately discussed the need of data fusion in WSN and the various ways in which it can be achieved. Further, deployment of software agents for fusion [21,22,23] could also be traced in literature and the need of an energy efficient approach which caters mobility in a more intelligent manner could be felt.

In the light of above stated facts, the authors aim to develop an integrated approach which can provide a more cost-effective and dynamic method for communication as well as information processing in a non-determinstic environment. The proposed protocol MC3F2 operates in four phases described in the upcoming section.

The MC3F2 Protocol

This section proposes a novel approach beginning from the energy efficient communication to information filtering and fusion in WSN in an energy efficient manner. The proposed protocol is a reliable, energy efficient event-driven approach which performs clustering, filtering and fusion each time an event occurs and also allows the movement of agents at random times rather than at constant intervals. It is worth mentioning that filtering is performed at the source nodes so that noise can be filtered periodically consuming the energy in transmitting the relevant information only. The filtered and fused information is then transferred to sink for onward transmission to scientific community for visualizing and analyzing the real time results. The work is designed for improving the performance of the hierarchical protocol AERDP **[25]**. The proposed protocol executes in four phases as depicted in figure 1:

Phase I: Mobility Controlled Communication : First phase deals with the major challenge of putting forward an energy efficient means for communication among the randomly deployed sensors in the non-deterministic area. While deploying the sensors in an unattended environment, an underlying network model is considered and various assumptions pertaining to the same are listed as follows:

- Sensor nodes are heterogeneous

- The energy consumption is not uniform for all the nodes.
- All the links are symmetric
- Nodes are not uniformly distributed and remain unattended once they have been deployed

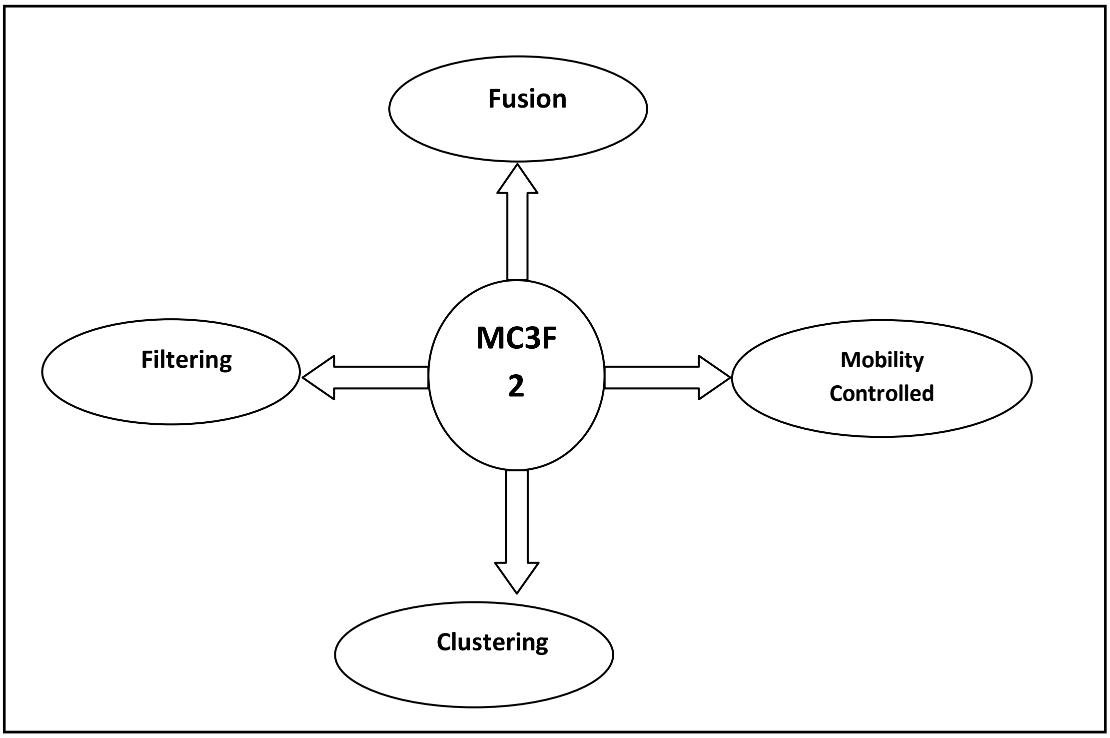


Fig 1 : Four Phases of the Proposed Work

On the basis of above assumptions, initially nodes are being deployed using random way point mobility model. The basic model of RWP assumes that the sensor nodes are mobile and they either move individually or in groups. In either of the cases, their constant pause time becomes the major bottleneck in the practical implementation of the existing model. In light of this limitation, the authors have proposed that the mobile nodes shall function as almost static sensor nodes by making the pause time between the sensors random instead of constant. It is noteworthy that during the practical implementation of the work, the interval of random pause time is found to be greater than constant pause time. Further, the task of mobility is achieved with the help of mobile agents embedded within them. The work thereafter simulates the aforesaid proposition in matlab. The network topology generated using random pause time is given in figure 2.

A comparison of both existing and new deployment strategy revealed that significant energy could be conserved by avoiding unnecessary movements of mobile nodes and also, since mobile agents also traveled less frequently(random pause time is greater than constant pause time), a lot of energy could be saved as observed from results shown in figure 3(a) and 3(b) respectively.

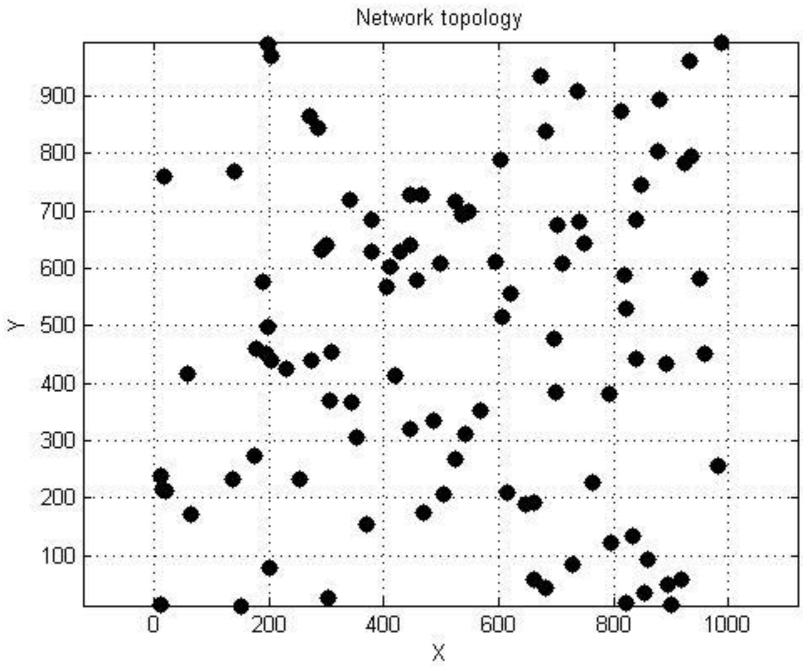
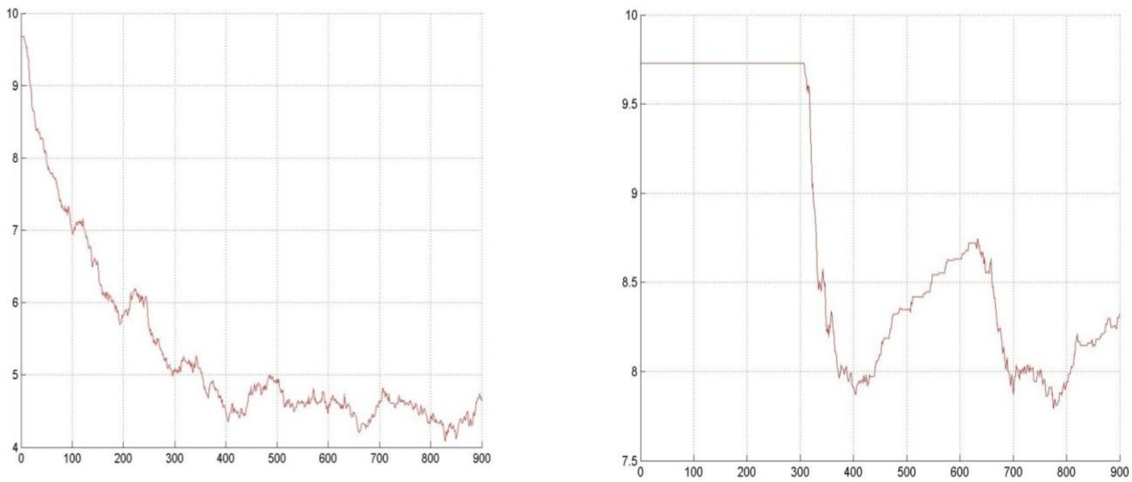


Fig 2 : Network Topology as a Result of MC3 Phase



(a) (b)

Fig 3 (a) : Rate of Energy Consumption using existing RWP Model of constant pause time

(b) : Rate of Energy Consumption using modified RWP Model of random pause time

Phase II: Clustering : After the deployment of the sensors in the given field, a strong need for clustering is apparent. Therefore, the focus of this phase is to distribute all scattered sensor nodes into an optimal set of clusters and each cluster would be required to elect a cluster head. Formation of clusters may appear to be a straightforward task, but during the practical implementation, the clustering phase encountered the design challenges listed below.

Design Challenges

- Mapping of all nodes to atleast one cluster is a sufficient condition. Although, cluster head is only responsible for upward transmission of information but there may exist nodes which do not belong to any cluster and intend to transmit the information.
- Mapping of each node with atmost one cluster head is a necessary and sufficient condition. Handling the redundant links will remain one of the primary challenges.
- In order to have efficient clustering strategy, it should be distributed and energy efficient.
- Designing a clustering approach with limited complexity and less intercommunication cost is another design challenge in existing clustering approaches.
- Since AERDP is an agent based approach, hence adding more functionality to the same may increase the complexity of the overall network.

Therefore, requirement is to maintain the existing complexity of AERDP by proposing an efficient clustering strategy which not only reduces the interagent communication cost but also the processing times at each node.Now, since, AERDP is already employing mobile agents for collecting and transmitting the information, the clustering would also be carried out by mobile agents, thereby alleviating the sensors from the burden of processing. In fact, since the proposed clustering approach is an addition in the basic AERDP, therefore it is also event-driven.

Flow diagram and the working algorithm for cluster formation

Figure 4(a) lists the algorithm for the proposed protocol and figure (b) depicts the action execution in clustering phase with the help of flow diagram :

```
Algorithm :Form_clusters()

Input :

n : no. of nodes in the network
Eresidual[1.....n] : Residual energies of all the nodes in the network
RVagent[1……....n] : Reiability value of the software agents of  all the sensors in the network
Output : A Clustered Network

Begin

Detect the event
For ( i=1; i<=n; i++)   // n is the no. of sensors which detected the event
Sensor_Agent[i] = Tentative CH
Sensor_Agent[i] broadcasts its sensing range(r) value to rest of the n-1 sensors in the network and ask for their
Eresidual value based on the equation : c = 2r
Sensor_Agent[i] also asks for Reliability value of the agent of each responding sensor
Log in the incoming Eresidual value and Reliability Value of the sensors (say j sensors) and compare it with the
Eresidual values of the parent/receiver sensor
For ( j=1; k<=j; k++)
            If any(Eresidual (j)) >Eresidual (parent sensor)

cluster_head = j

else        if    Eresidual (j) <Eresidual (parent sensor)

cluster_head = i

else        if    Eresidual (j) = Eresidual (parent sensor) = Emax

thencluster_head = sensor whose agent has max(RV)

EXIT();
```

Fig 4(a) : Working Algorithm of Clustering Phase

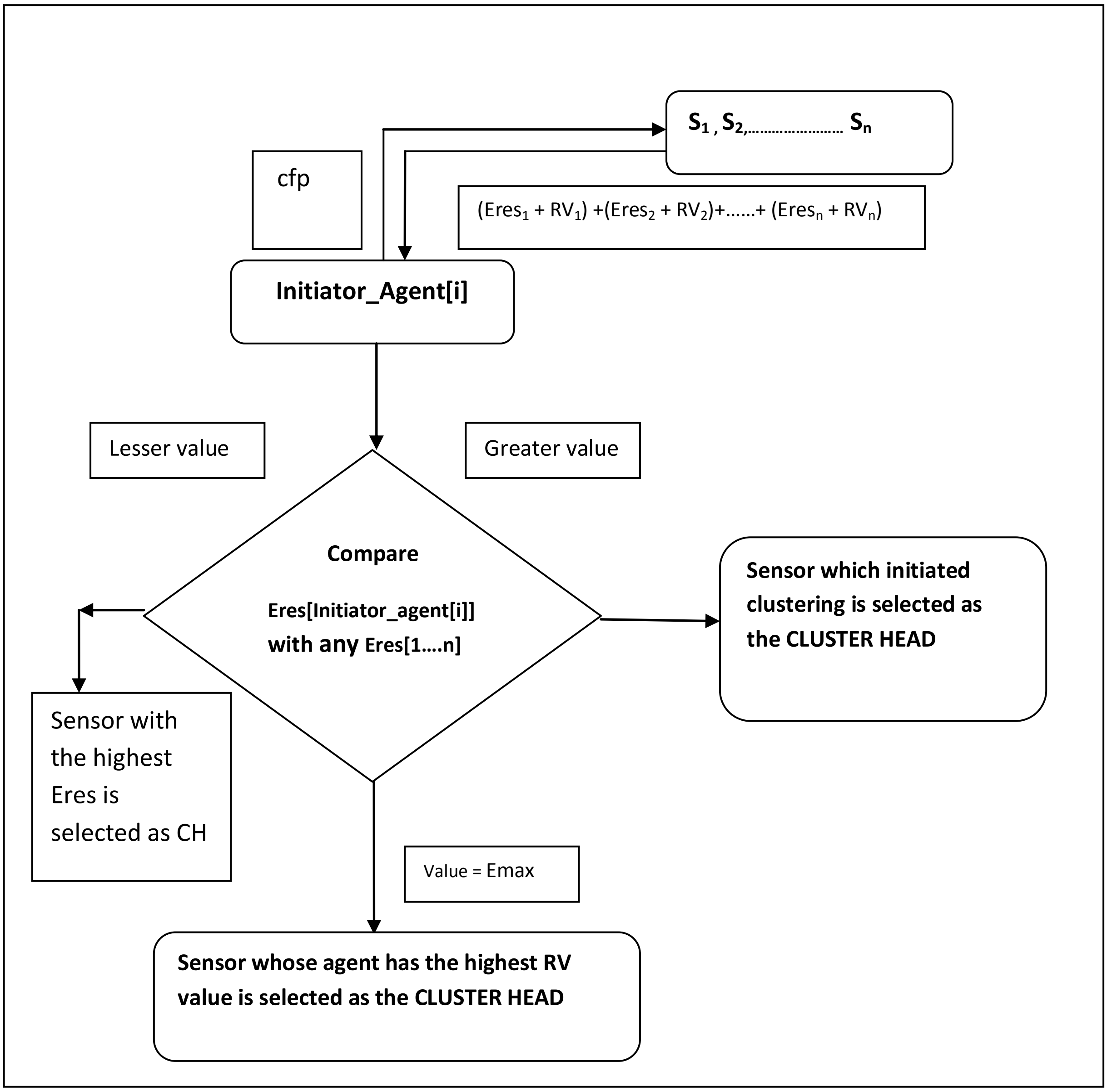


Fig 4(b) : State Diagram of Clustering Phase

As mentioned in the algorithm above, once a sensor detects an event, it initiates its corresponding agent to form clusters. This agent(termed as initiator agent) considering itself to be a tentative cluster head generates a call for proposal(cfp) for all the sensors which are within its communication range of its sensor. The communication range of a particular sensor is calculated using the formula:

$$\mathbf{c = 2*r} \tag{1}$$

where c = communication range of a sensor
r = sensing range of a sensor

Each of the receiving sensor responds with its residual energy and reliability value through its agent. The residual energy at any interval(say t) is given by the equation:

$$E_{residual} = E_{max} - (E_{sensing} + E_{processing} + E_{communication}) \qquad 2)$$

The reliability value(RV) of an agent refers to its credibility to perform an assigned task. When two or more agents compete for a similar task, the one with the higher RV value is chosen to perform that specific task. The RV value of an agent can be calculated using [24].

The initiator agent logs both these values from every responding sensor and compares its residual energy with each of the incoming residual energy values($E_{residual[1.......n]}$). Three possibilities arise:

a) The residual energy value of the initiator agent is greater than any of the respondent's residual energy. In such a case, the initiator agent considers its sensor to be a **Cluster Head** and broadcasts an ***electionwon*** message to all the neighbours for which it generated a cfp.

b) The residual energy value of the initiator agent is less than any of the respondent's residual energy. In such a case, the initiator agent determines the sensor with the maximum energy and communicates it to carry out the task of clustering and generate a cfp for the same.

c) The residual energy value of the initiator agent is equal to any of the respondent's residual energy. This situation normally arises when clustering is being carried out for the first time in the network. In such a case, each of the sensor has maximum energy. (i.e. $E_{residual} = E_{max}$). The initiator agent in this case thus uses the RV value of an agent to determine the cluster head.

The snapshots of the simulation of agent based clustering is shown in figure 5(a) and figure 5(b).

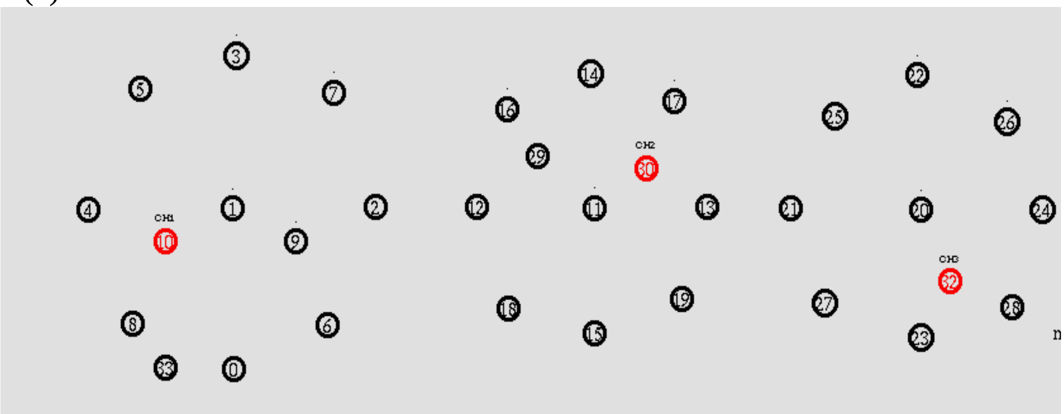


Fig 5(a) : Randomly Deployed Clusters with Elected Cluster Heads

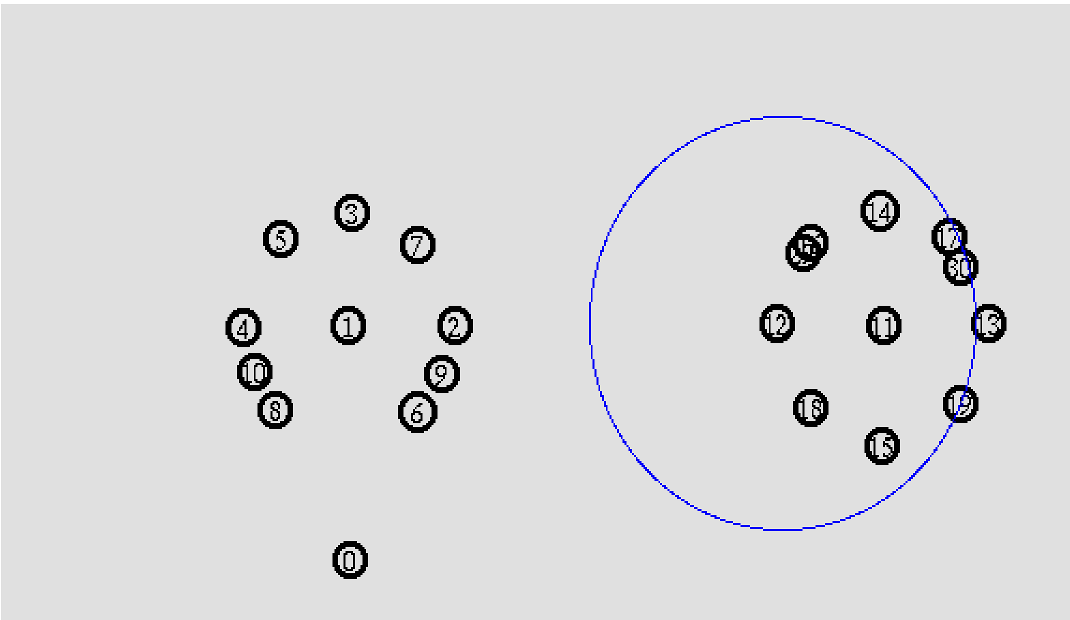


Fig 5(b) : Intermediate Phase of Clustering

Phase III: Filtering The third phase i.e. the filtering phase has been motivated by the fact that although lot of data is being sensed but it comes with lots of noise resulting into very less useful information. For instance, data sensed by various pollution measuring sensors is often corrupted and contains ambiguous information. Additionally, lot of energy of sensors is being used in transmitting this data which actually is of no use directly unless filtered. Also, in order to conserve the energy of sensors and increase the lifetime of network, the requirement to filter the sensed data at source level is highly desired. In order to execute this phase efficiently, study was carried out and it was discovered that Extended KalmanFilter (EKF) [] is the most suitable tool to filter the sensed data. In fact, EKF filter has always served as an important tool when it comes to modeling a system with unknown precise nature especially to model a non-linear environment. It can be used to estimate the state of system efficiently with minimum mean of the squared error.The prime intent of this phase is to develop a mathematical model using EKF for filtering the data sensed by pollution sensors, in particular. The mathematical model presented below has been tested and simulated and resulted obtained have shown remarkable gap between actually measured values and transmitted values.

Problem Statement and Proposed Mathematical Model The problem of air pollution is not confined to one particular locality or region but is a world wide spread problem. The section aims to initially present the existing approach for measuring pollution in air and later proposes the filtering model(based on Kalman Filter) to filter the noise so as to get accurate information. As concluded from the literature review, the ***five*** main air pollutants that are usually estimated are Sulphur Dioxide, Carbon Monoxide, Oxides of nitrogen and Oxidants. Further, it is stated that methods for sampling and measuring air pollution should be chosen carefully. However, all methods including very sensitive ones are prone to measuring noise. Therefore filtering of this undesired information is strongly desired.

Since measuring all pollutants and further filtering is out of scope of this paper, therefore the current work only considers estimating suspended particulates in air. Suspended particulates are a composite group of substances i.e. liquids or solids which are dispersed in the atmosphere. These substances can have severe effect on an individual's health and vision.At present, the gravimetric principles are used which involves selection of suspended particulate matter often for a period of 24 hours. Analytically, equation (3) is used to compute the mass concentration of suspended particulate:

$$sp = \frac{(w_f - w_i)}{v_m} \times 10^6 \qquad (3)$$

Where,

$$sp = mass\ concentration\ of\ suspended\ particulates\ in\ \mu\frac{\mathrm{g}}{\mathrm{ms}}$$

$w_f = final\ weight\ of\ filters\ in\ gms$

$w_i = initial\ weight\ of\ filters\ in\ gms$

$v_m = total\ volume\ of\ air\ sampled\ in\ ms$

At any time interval $i+1$, sp_{i+1} represents the mass concentration of suspended particulates measured w.r.t.sp_i measured at time i. In fact, equation (4)represent the difference equation while equation (5) is known as measurement error as specified on the basis of EKF for representing a non-linear state of a system:

$$sp_{i+1} = Asp_i + Bu_i + w_i \qquad (4)$$

$$y_i = Csp_i + z_i \qquad (5)$$

Here,

$w_i = process\ sampling\ error$

$$u_i = \frac{w_f - w_i}{v_m}\ Input\ to\ the\ System$$

$z_i = measurement\ error$

$A = n \times n$ *matrix that relates the state of* sp_i *at the previous time step i to the state at the current step* sp_{i+1}, *i+1, in the absence of either a driving function or process noise.*

$B = n \text{ x} l matrix\ that\ relates\ the\ optional\ control\ input\ u\ to\ the\ state$

$C = m\ xn$ *matrix in the measurement equation relates the state to the measurement* y_i.

$y_i = the\ measured\ oputput$

Similarly, standard air volume or air volume at standard conditions is given by equation (6):

$$v_s = v_m \left(\frac{p_a - p_m}{760}\ X\ \frac{298}{t_a} \right) \tag{6}$$

Here,

$v_s = air\ volume\ at\ std\ conditions$

$v_m = air\ volume\ being\ measured$

$p_a = pressure\ drop\ at\ inlet\ of\ positive\ displacement\ mtr$

$p_m = barometric\ pressure\ at\ atmospheric\ conditions$

$t_a = absolute\ temperature\ of\ ambient\ air$

Similar to equation (4) and equation (5), equation (6) can be represented by equation (7) and equation (8) given as follows:

$$v_{s_{i+1}} = Av_{s_i} + BI_i + \widetilde{v_{s_i}} \tag{7}$$

$$y_i = Cv_{s_i} + z_i \tag{8}$$

Here ,I_i is the known input to the equipment measured in terms of air volume, pressure and absolute temperature. $\widetilde{v_{s_i}}$is the process error.

This system has the capability to measure and filter information about various hazardous substances but measuring and using all of them could increase the complexity of the problem under focus. Therefore the scope of work has been limited to suspended particulates. Above proposed environment was simulated and the results produced are shown in figures 6(a) and figure 6(b).

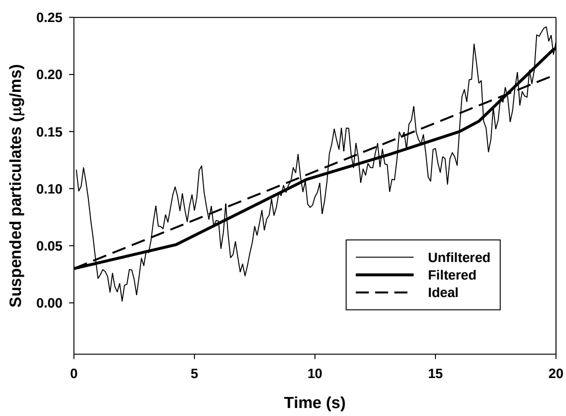


Fig 6(a) : Variation of Measured Suspended Particulates with time

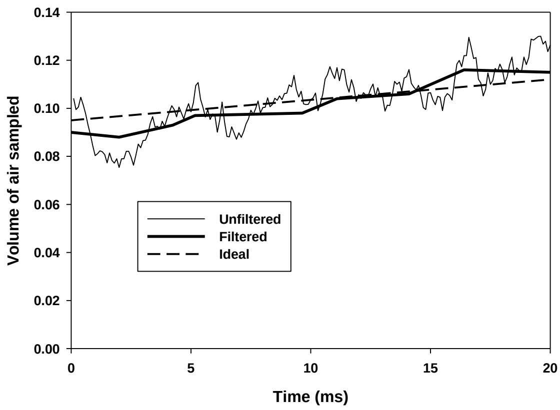


Fig 6(b) : Variation of Air Volume Measured at standard conditions with time

Phase IV: Fusion This is the final phase of the MCFF protocol. Once the filtered data is available with the sensors, it is ready to be submitted to the sink for further analysis. However, this data is raw and redundant as in a dense network, the clusters usually contain sensors deployed in close vicinity. Transmission of such redundant data is futile at the cost of bandwidth of the network. Meticulous study done in this area reveals that till the time of listing no agent based solution has been proposed to the above stated setback. For that reason, the authors have come up with a novel approach of fusing the data at intermediate nodes using mobile agents.This phase intelligently fuses the data within the cluster once an event is detected by the cluster. For performing the task of fusion, the cluster head which detects the event of interest initially time-stamps itself and the event and then immediately sends a replica of its own with a message '*call for any event*' to the immediate neighbours**[10]**.This originating master agent i.e. the one with the oldest timestamp acts as the root and is responsible for sending the data to sink node. The listening nodes i.e. master agents of neighbouring clusters further generate a similar message for their next immediate neighbours. Within a particular periphery, each master agent fuses the data received from its child agents and other neighbouring master agents and forwards the same to the ancestor master agent who had actually originated the call.

Once an event is detected and the cluster heads of respective heads initialised, the task of fusion (more specifically intra cluster fusion) is performed in parallel at each cluster where an event is detected. After time-stamping the event, the cluster head at each cluster replicates a mobile agent which visits the sensors in a specific order. At each sensor, it compares the incoming valuewith the ones which are previously stored in its data buffer. Only the ones which are most recent and are non-redundant are considered, rest are rejected. The recency of a data value is compared on the basis of timestamp. Similarly the redundancy of a data value is compared on the basis sensing range. Only valid data is thereafter added to the data buffer and is submitted to the corresponding cluster head which forwards it to initiator cluster head or the sink as the case may be.

```
AERDP()
{
MasterAgentObservation()
{Timestamp ts;
Action: EventbyOtherAgent, SenseFromEnviornment,Sleep;
If (Action=SenseFromEnvironment)
Activate MasterAgent;
Ts=GetTimeStamp(Event);
CallForEvent();
If (EventbyOtherAgent!={})
EventsSensed=EventbyOtherAgent□SenseFromEnvironment;
MatchEventName(EventsSensed);
If (EventbyOtherAgent□SenseFromEnvironment!={})
AggregatedData=DataAggregation();
FusedData=DataFusion(AggregatedData);
ForwardtoSink(FusedData);
Sleep;
}
```

Fig 7: Working Algorithm of AERDP

The algorithm given in figure 7 presents the high level view of the working of intra cluster fusion. The task of fusion(more specifically intra cluster fusion) is then performed in parallel at each cluster where an event is detected.In each cluster, the filtered data is being incrementally and intelligently fused into the data buffer of the initiator agent. As described in [ISCON 13], the incoming data from various sensors is first compared to consider only the recent most value and the non-redundant value. This data is then fused using value fusion[] and is submitted to the corresponding cluster head which forwards it to initiator cluster head or the sink as the case may be. The pseudocode for this intelligent data fusion is given in figure 8.

```
Aggregation_agent()
node[1…n] = A cluster of WSN consisting of n nodes
Ts = Time at which the master agent sensed the event
EvaluateTimestamp()
{ ActivateChildAgent // the child node is chosen randomly from n nodes using local tuple space
Ts1 = GetTimeStamp(Event_of_ChildAgent)
return Ts1
}
MasterAgentNegotiation()
{
Ts2= CallEvaluateTimestamp()
If (Ts2>Ts) // event being sensed is a previous one
Action = InformationDiscarded
Else
Action = Add_Data_to_Buffer(Data)
For ( i =2; i<=x; i++) // x<=n .It is the number of the sensor node which is visited by the master
agent till it ends its itinerary.
{
Ts3=CallEvauluateTimeStamp()
If(Ts3>Ts)
Action = InformationDiscarded
Else
Action = CompareDataBits() // data is rejected if it is redundant or else added to buffer
AggregatedData = DataAggregation()
Add_Data_to_Buffer(AggregatedData)
}
}// end Aggregation_Agent()
```

Figure 8: Working Algorithm of Aggregating Agent

Conclusion

The work proposed a four tier protocol beginning from energy efficient mobility of deployed sensors to their clustering, filtering and finally fusion of information. The data thus delivered to sink shall be of high utility to scientific community and can be analyzed for future predictions. The proposed protocol has not only resulted into an efficient deployment but also since it final delivers filtered and fused information i.e. only relevant information without noise, it owes an edge over existing protocols. A case study as an application of current work has been presented which could prove the protocol worthy. Though the approach proves to be leverage over conventional protocols in terms of energy efficiency and latency, it has its own limitations. For instance, although security of sensor may not be of high concern here but the security of data transmitted is a desirable feature. Therefore, another phase addressing the security concern may be extended in future. The authors also aim to negotiate the data between the clusters so that it can only be transferred on demand thereby contributing to save the bandwidth of the network.

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