Mobility Adaptive Clustering Algorithm for Wireless Sensor Networks with Mobile Nodes

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Abstract—**In this study, the authors propose a mobility adaptive clustering algorithm for wireless sensor networks with mobile nodes . In the proposed algorithm, a sensor node selects itself as a cluster head based on a Single Point Predictor for the combined criterion prediction. Here, as a combined criterion predicting proposed comprising parameters as connectivity, coverage, mobility and residual energy consumption of all the nodes (Distributed Clustering Algorithm). A non-cluster-head nodes declare themselves as members of the cluster based on a new value , that value is related to each cluster head , which is used to indicate its suitability for connecting this cluster head or other (Mobility-Based Clustering protocol). We found in the Distributed Clustering Algorithm the Mechanism to elect the head of the cluster and in the Mobility-Based Clustering protocol the mechanism for engagement a non-cluster head nodes to a specific cluster.**

Thus, the combination of them together provides a significant increase in the network life-time, availability, stability period of wireless sensor networks and reduction of packet loss in the cluster formed by a simple point predictor for combined criterion prediction and stability value.

Keywords— **Mobile wireless sensor networks, Single Point Predictor, Combined criteria, The stability value, Network life-time.**

I. Introduction

Wireless Sensor Networks (WSNs) are self-organizing networks consisting of multiple wireless sensor nodes deployed over a geographic area known as the sensors field and designed for monitoring the characteristics of the environment or objects. Actually wireless sensor nodes are tiny devices with limited resources: battery power, memory, computational power, very low data rates, low bandwidth processing, variable link quality..etc [1]. However, combining a large number of these elements in the network provides the possibility of obtaining a realistic picture of what is happening in the field of sensing [2]. Wireless sensor nodes can collect information about the observed phenomena and pass it on for processing and analysis. Examples of information collected may be data on temperature, humidity, lighting conditions, seismic activity, etc. Such data can be used to detect any events and to manage them [3]. Network lifetime has become the key characteristic for evaluating sensor networks in an application specific way [4]. Especially the availability of nodes, the sensor coverage, connectivity and the mobility have been included in discussions on network lifetime. Even quality of service measures can be reduced to lifetime considerations. A great number of algorithms and methods were proposed to increase the lifetime of a sensor network- while their evaluations were always based on a particular definition of network lifetime [5].

In recent years, a new type of sensor networks has been appeared - Mobile Sensor Networks (MSN). These networks have retained all the features of wireless sensor networks WSN and these features have been added mobility. Cluster architecture has been applied in WSN, so search for the best options for the cluster and select the cluster head for MSN is now an urgent task [6].

In this paper, we propose a Mobility Adaptive Clustering Algorithm (MACA) for wireless sensor networks with mobile nodes. Here the cluster formed by a simple point predictor for combined criterion prediction and stability value.

The rest of this paper is structured as follows. In section 2, the related work is discussed. The network model, together with mobility model and radio model are described in Section 3. Section 4 exhibits the criteria and the Single Point Predictor (SPP) for the combined criterion prediction .The details of our approach are introduced in Section 5. In Section 6, the performance of our approach is evaluated through simulation results and compare the results with DCA and LEACH-M. Finally conclusions of this paper with plans for future work are presented in Section 7.

II. Related work

Recently, several researchers show their enormous interest in clustering wireless sensor networks with mobile nodes. They try to improve the efficiency, stability and prolong the life of the sensor network. The best part of clustering protocols proposed for WSNs assume that the nodes are stationary LEACH [7], LEACH-C [8], HEED [9], TEEN [10]. The operation is divided into rounds. Each round contains two states: Setup phase and Steady-State phase. In the setup phase the nodes are organized themselves into local clusters. In the Steady-State phase each non-CH node sends data in the time slot allocated to CH. The CH aggregates the data and sends it to the BS.

Nevertheless, the assumption of the mobility of sensor nodes makes those clustering mechanisms invalid, because mobility has a negative effect on the quality of the wireless communication where the relative movement between nodes creates or breaks wireless connections and changes the network topology. This mobility influences the performance of the network and also invokes protocol mechanisms to react to such dynamics. Nevertheless, it has been shown that mobility can enhance the functionality of the network (deployment, coverage and connectivity…) by exploiting the movement patterns of mobile nodes [11].

An improved algorithm LEACH-M (LEACH-mobile) [12] is presented to manage such routing problem in mobile network by adding its membership declaration to the LEACH protocol. The idea behind this membership declaration is to confirm the inclusion of sensor nodes in a particular cluster in the steady-state phase. If the mobile sensor node does not receive a request from its cluster head within two consecutive frames, can also recognize that it has moved out of the cluster, and thus it will broadcast a cluster joint request message in order to join in a new cluster by receiving cluster join-ask messages back from specific cluster heads. LEACH-mobile protocol increases the successful packet, however in this protocol, transmission overhead is increased to send a message because of membership declaration.

In [13] authors proposed a Distributed Clustering Algorithm (DCA) which is based on the use of predicted combined criteria metric. In DCA algorithm, the sensor calculates its combined criteria metric according to connectivity, coverage, mobility and residual energy, after that each sensor node uses its history combined criteria information to predict the current combined criteria based on heuristic predictors. The sensor with the highest Predicted combined criteria in its r- hop neighbourhood will become the cluster head. They introduce a parameter termed as cluster-hop, r-hop. Cluster-hop is defined as the maximum number of direct hops between a cluster head node and nodes at the cluster periphery. This dynamic parameter determines the dimensions of the clusters formed by the algorithm and serves as an input for the cluster formation process.

In [14] authors proposed Group Mobility Adaptive Clustering scheme (GMAC) for mobile WSN based on a new group mobility metric which use network topology information and a position predictor to determine if nodes move together or separately. In GMAC, the area of interest is divided in equal zones (to fix the number of clusters), and each sensor calculates its weight based on Mobility Group and residual energy. The sensor node with the greatest weight in its zone will become the cluster-head. In spite of this protocol provides an efficient method to the construction, it suppose all nodes moving in group.

Samer et al. [15] proposed a cluster-Based Routing (CBR) protocol .In the CBR protocol, a cluster-head receives data not only from its member during the allocated TDMA timeslot, but also from other sensor nodes that just enter the cluster when it has a free timeslot. The CBR protocol changes TDMA scheduling adaptively according to the dynamic traffic and mobility conditions in the network.

In [16] authors proposed a mobility-based clustering (MBC) protocol for wireless sensor networks with mobile nodes. In the proposed clustering protocol, a sensor node elects itself as a cluster-head based on its residual energy and mobility. A non-cluster-head node aims at its link stability with a cluster head during clustering according to the estimated connection time and the distance from a cluster head, and the residual energy and node degree of the cluster head, which can guarantee a stable link with a cluster head and thus increase the successful packet delivery rate, and reduce the control overhead and energy consumption because of the less frequent membership changes.

We found in the DCA algorithm a mechanism to elect the head of the cluster and in the MBC protocol the mechanism for affiliation(for engagement) a non-cluster head nodes to a specific cluster. We combined them together and modified multiple hops to one sequential jump.

III. MACA ALGORITHM

In this section, we present our proposed algorithm that enables to generate steady and balanced clusters and improve the efficiency, stability and prolong the life of the wireless sensor network with mobile nodes. We will first introduce the network model under study, and the mobility model and radio model used in the study, and then we will describe the characteristics and procedures of the protocol.

A. The network model

For our proposed model, we adopt a few reasonable assumptions of the network model as follows:

- Sensor nodes are deployed densely and randomly in sensor field.
- The network topology can be changed and the sensor nodes can move at a speed of 0 to 2 m / s.
- Sensor nodes carry out their activity without centralized management.
- Each sensor node has a capability to transmit data to any other sensor node or directly to the base station using power control.
- There is mobility in sensor nodes.
- The most efficiency of this protocol can be achieved when the number of nodes moving out their cluster is equal the number of nodes getting in the cluster.
- The radio channel is symmetric.

B. Random waypoint model

Mobility models have a great impact on the performance of routing protocols in wireless networks. Many standard mobility models, like random waypoint, random walk, and random direction, do not generate random movement since their behaviour is strongly affected by their configuration and the shape of the used scenario [17].

The most substantial argument against the usage of the standard mobility models is that these models do not reflect typical movement of humans, which brings us back to the question of the previous sub section. The best counter question is, what is typical movement and how would you define it? Obviously, typical movement is not reflected by a particular scenario e.g. movement of students on a campus, cars on the road, or customers in a shopping mall.

The nodes are distributed by the random walk mobility model.

The algorithm can be dived into the following five steps.

1. Select a random speed (uniform distributed)
2. Select a random direction (uniform distributed)
3. Move into that direction
   a. for a predefined amount of time
   b. for a certain distance
   c. if the border of the scenario is reached, select a new direction (Bouncing rule)
4. Wait some time.
5. Go back to step one.

C. Channel propagation model(path loss and distance calculations)

The electromagnetic wave propagation is a power law function of the distance between the transmitter and receiver. Without considering the shadowing losses in our simulation, we use the same radio energy dissipation model in [18] as the radio model.

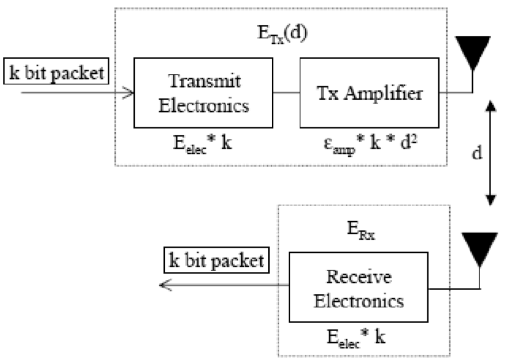


Figure 1. Radio model

The costs for transmitting and receiving a k-bit message through a distance d between a transmitter and a receiver can be calculated as:

Transmitting:

$$E_{tran}(\mathrm{k,d}) = \mathrm{E}_{elec} * k + e_{amp} * k * d^{n} \quad (1)$$

Receiving:

$$E_{rece}(\mathrm{k}) = \mathrm{E}_{elec} * k \quad (2)$$

Where :

$E_{tran}(\mathrm{k,d})$ and $E_{rece}(\mathrm{k})$ are the transmitting cost and receiving cost, respectively, E_{elec} is the energy dissipation to run the transmitter or receiver circuitry, e_{amp} is the energy dissipation for the transmission amplifier. The propagation exponent n can be from 2 (LOS) to 4 (NLOS) depending on the transmission condition between the transmitter and receiver.

IV. PREDICTED COMBINED CRITERION METRIC

In this section we proposed the combined criterion predicting as comprising parameters as connectivity, coverage, mobility and residual energy consumption of all the nodes, then we introduce the Single Point Predictor (SPP) which is used to predict the combined criterion metric. The DCA(Distributed Clustering Algorithm) calculate the Combined Criterion $CC(s_i)$ for node s_i ; at any time t by the following formula:

$$\begin{aligned} CC(s_i) &= \alpha \times ConC(s_i) + \beta \times CovC(s_i) \\ &+ \gamma / (1 + MC(s_i)) + \xi \times RECC(s_i) \end{aligned} \quad (3)$$

In equation (3) $\alpha + \beta + \gamma + \zeta = 1$

In [13] authors outline three heuristic predictors which are used in their work: Single Point Predictor(SPP), Linear Extrapolation Predictor(LEP) and Hybrid Predictor(HP). Searching have shown that simple point SPP provides the greatest predictor for the duration of the life cycle of networks. The Combined Criterion (CC) mentioned above will be predicted at a current time t ; according to historical combined criterion.

$$HCC = [(CC_1, \mathrm{t}_1), (CC_2, \mathrm{t}_2), ..., (CC_n, \mathrm{t}_n)$$

where:

$$\mathrm{t}_1 < \mathrm{t}_2 < ..... < \mathrm{t}_n$$

SPP (Single Point Predictor) always predicts the next value as the previous value of HCC:

$$PCC = SPP(t_c) = CC_n \quad (4)$$

V. MACA DESCRIPTION

Our proposed MACA algorithm divided into two phases: the set-up phase when a set of clusters are organized and a TDMA schedule is created, followed by a steady-state phase when data are delivered to the base station.

A. Phase 1:The set-up phase

•***The Cluster Head Election:*** At the beginning of each round each node calculates its PCC according to a Simple point predictor then, by the distributed method in the algorithm each node broadcast the PCC value in it is 1-hop neighbourhood. The CH node of the cluster selected by the maximum PCC.

•***The Cluster Formation:*** Cluster formation consists of the following three phases:.

1) Cluster Head Advertisement: After a cluster head is selected, it broadcasts an advertisement message as well as its location, velocity to the sensor nodes within its transmission range, In this phase, non-cluster-head sensor nodes must keep their receivers ON in order to receive the messages from the cluster heads.

*2) **Cluster Join Request:*** Just like the MBC protocol [16] in order to enhance the stability period of wireless sensor networks., each member node is assigned a value related to a cluster head that is used to indicate its suitability to connect such cluster head. This value is determined based on a generalized formula that takes into account the estimated connection time, together with the residual energy and node degree of the cluster head, and the distance between the sensor node and the cluster head, a non-cluster-head sensor node chooses a cluster head with the maximum stability value to join.

Thus, the value can be formulated as:

$$W_{ij} = a * \frac{E_{j\text{-current}}}{E_{max} \cdot N_{j\text{-current}}} + b * (1 - \frac{d_{ij}}{R_{tran}}) + c * \frac{\Delta t_{ij}}{t_{frame}} \qquad (5)$$

where:

w_{ij} -the stability value assigned to sensor node i ,which indicates its suitability for connection with cluster head j, $E_{j-current}$ -is the current energy of cluster head j, $N_{j-current}$ -the number of members of cluster j after node i joins in, d_{ij} -the distance between sensor node i and cluster head j , Δt_{ij} -the estimated connection time between node i and j, t_{frame} -is the expected duration of a data frame.

In equation (5) $a + b + c = 1$ constant coefficients a, b and c between 0 and 1 and represent the significance of each factor.

*3) **Cluster Head Acknowledgement:*** After receiving a cluster join request, the cluster head sends an acknowledgement to the sensor node confirming that the sensor node is now a part of its cluster, then the cluster head creates a TDMA schedule based on the number of nodes and assigns each node a time slot of when it can transmit. This schedule is broadcasted to all the sensor nodes in the cluster.

B. Phase2: The steady-state phase:

During the steady state phase, the sensor nodes collect data from their surroundings and then send it to their respective cluster heads according to their time slot in the TDMA schedule. The CHs compresses and transmit data to the base station which located out of the network. Finally a new round begins from the first step. Both the cluster-head and the non-cluster head sensor node maintain the information on the estimated connection time, both of them can check whether a sensor node is going to remain in the cluster when its next timeslot comes at the end of the transmission. If the sensor node is not going to remain in the cluster, it will broadcast a request message to join a new cluster and avoid more packet loss before it loses connection with the cluster head. On the other hand, the cluster head will remove the sensor node's membership.

Figure 2. illustrates the process when the sensor node leaves the old cluster and join a new one. It broadcasts a joint request message in order to reduce the packet loss because of the disconnection between a cluster head and a non-cluster-head node (when the connection time is over). It chooses a new cluster based on a value related to each cluster head.

Node 11 joins the cluster 1, while leaving the cluster node 4. The cluster head of the cluster 1 deletes the node 4 of TDMA schedules and adds a node 11 in schedule TDMA. TDMA schedule is adjusted based on the estimated time Δt connection between cluster member node and the head node in ascending order [16].

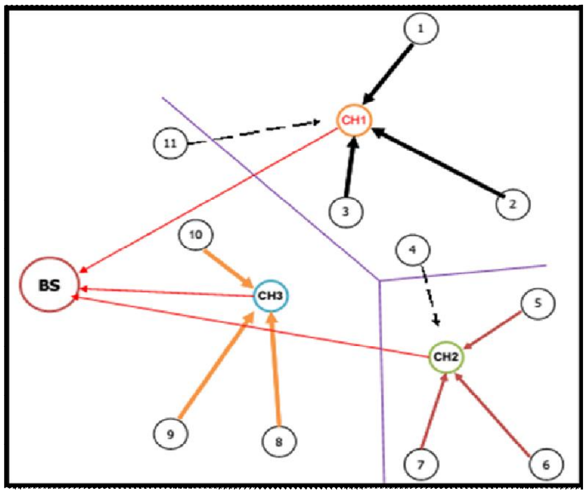
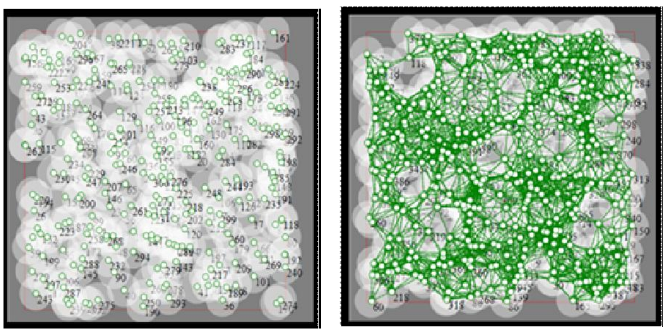


Figure 2. Mobile nodes leave the old cluster and join a new one

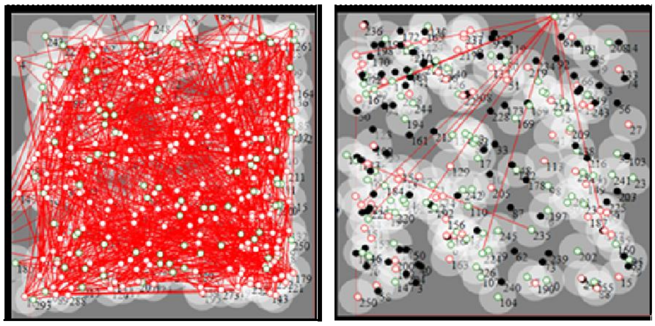
VI. SIMULATION RESULTS

In this section, For evaluation, the performance of our proposed clustering algorithm through simulation results using c#.NET, we (compared) simulated the MACA, DCA algorithm and LEACH-mobile protocol for different number of nodes with random topology and 400m*400m network region, with the parameters shown in Table 1, in terms of the network life time , stability period and throughput(the quantity data packets that are successful in reaching the base station from cluster heads).

Figure 3 shows snapshots of the MACA simulation.



(a) Random deployment *(b)Connectivity and broadcasting PCC*



(c) Clustering *(d) After a certain time of work*

Figure 3. Display Model on the screen

TABLE 1. SIMULATION PARAMETERS

Parameter	Acronym	Value
Electronics energy	*E*	*2j*
Tx/Rx	E_{elec}	*50 nj/bit*
Free space constant	e_{fs}	$10\ pj/bit/m^2$
Multipath constant	e_{fs}	$0.0013\ pj/bit/m^4$
Distance Threshold	$\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$	*87*
Sensing Range	*r*	*25m*
Transmission Range	*R*	*2r*
Cluster Hop	$1-hop$	*2r*
Bit Rate	9600	*bps*
Communication Range	$2r$	*50m*
Network Size	$400*400$	*m^2*

A. Network Life-time

Lifetime of a sensor network is defined as the time after which certain fraction of sensor nodes run out of their batteries so that the network cannot work well [19]. In this case the life time for the network estimated after 40% nodes of the full size of the network die.

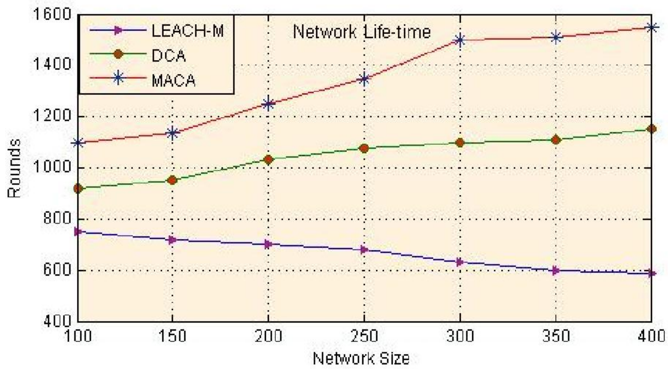


Figure 4. Network lifetime using MACA , DCA and LEACH-M

The line graph illustrates the network life-time of three protocols dealing with mobile wireless sensor networks (MWSN) in rounds among different size of network from 100 to 400 nodes with increment of 50. Overall, it can be figured out that network life-time for MACA protocol is higher than DCA algorithm and LEACH Mobile protocol.

B. The stability period

The stable period of a sensor network is the time from the beginning of the network operation until first node dies (FND).

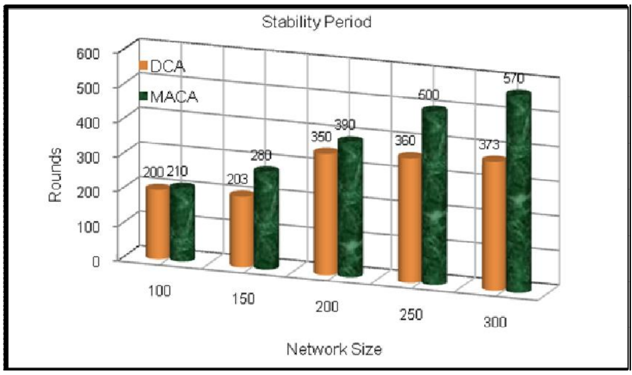


Figure 5. Stability period using MACA vs. DCA

It is clear from the simulation results shown in Fig. 5 that the stability period of the new progressive clustering protocol is longer than that of the DCA protocol. The Figure also illustrates that the stable period of both protocols increases with the increasing in the network size. of 50. Overall, it can be figured out that network life-time for MACA protocol is higher than DCA algorithm and LEACH Mobile protocol.

C. Throughput

Improvement in the overall throughput (data messages sent to the Base Station) is another major goal of sensor network protocols and is measured by the total data sent by all nodes in the lifetime of the network.

Figure.6 shows the total number of packets received successfully as the number of sensor nodes is increased.

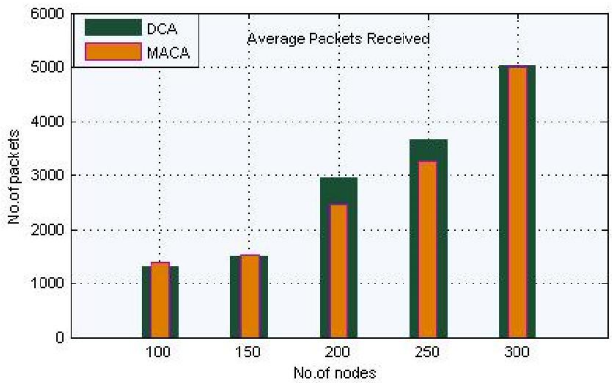


Figure 6. Average packets received for MACA and DCA

From the graph it can be seen that ,the data transferred with the new protocol is approximately the same amount that could be transferred by DCA algorithm over its lifetime.

VII. CONCLUSIONS

In this paper, we have proposed an approach for adaptive mobility clustering protocol. In our approach, we found in the DCA algorithm a mechanism to elect the head of the cluster and in the MBC protocol the mechanism for engagement a non-cluster head nodes to a specific cluster. We combined them together. The simulation results show that the MACA protocol provides a significant increase in the network life-time comparing with DCA and LEACH-mobile protocol in terms of the network lifetime. It is also show that the stability period of the new progressive clustering protocol is longer than that of the DCA protocol, But the data transferred with the new protocol is approximately the same amount that could be transferred by DCA algorithm over its lifetime.

FUTURE WORK

In the future we will improve MACA for three-dimensional geometric WSNs.

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