An Algorithm for Alleviating the Effect of Hotspot on Throughput in Wireless Sensor Networks

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***Abstract*—Multilayer Clustered Designing Algorithm is exploited to present MCDA - Hot Spot algorithm; a technique to increase the network throughput by alleviating the impact of hotspot issue on network lifetime. The network nodes in the hot spot region are in a flat layer form in contrast to rest of the network nodes that are grouped into clusters. This design substantially helps in achieving goal above. This claim is proved by making its simulation-based comparison with other competing algorithms on various performance evaluation parameters.**

***Index Terms*— Hotspot; MCDA; Cluster; Throughput; Energy.**

I. INTRODUCTION

The characterization of multi-hop wireless sensor networks by many-to-one traffic (i.e. converge cast) leads towards the imbalance of energy among deployed sensor nodes. This energy imbalance is more severe in some areas of network especially around the sink node\base station named as a hotspot. The sensor nodes that are in the hotspot area forward the excessive amount of data that results in quickly decomposition of energy and ultimately the nodes die quickly. It is of prime importance since it causes the sink node to be isolated from the network and hence rest of the network will be rendered useless. This scenario is called as network partitioning. In this case, even the network is rich in high energy carrying nodes, but that is of no use as the transmitted data is not approaching to the sink.

Intending to improve the network lifetime in such scenario, various solutions were proposed specifically by exploiting the architecture of clustered network [1]. The use of intelligent transmission control schemes is used to balance the energy usage by each sensor node [2]. Other schemes like data sink movement or data aggregation are also used in an energy-efficient way to handle this issue [3]. Given the fact that data sink movement and aggregator node deployment can be expensive enough than that of an ordinary micro sensor deployment. So, there must be a tradeoff between different types of cost among these approaches [4].

In this underlying research work, we have exploited our prior work; Multilayer Clustered Designing Algorithm (MCDA) [5] to improve the network throughput by alleviating the impact of the hotspot on network lifetime. The network nodes in the hot spot region are in flat layer form and are not grouped into clusters. While the deployed nodes in rest of the network are grouped into clusters. So, the work load is distributed among selected forwarding nodes around the BS. Their status is rotated to other optimal nodes in the same region around the BS.

Rest of the paper is organized as follows: Literature survey is presented in section II followed by the energy consumption analysis of hotspot region in clustered network in section III. Proposed scheme is discussed in detail in section IV. Section V presents results and a brief discussion thereon. The conclusion is given in section VI proceeded by an acknowledgment in section VII. References are provided in the last section.

II. LITERATURE SURVEY

This section presents the efforts of mitigating the hotspot issue in wireless sensor networks and its causes. The effort of solving the matter through uneven nodes' deployment is proposed by Y. Gu *et al.* [3] with the name CRAUND (a clustering routing algorithm based on uneven node deployment). The nodes are deployed unevenly in the concentric ring-shaped monitoring area, and the Base Station is placed at the center.

Perillo *et al.* have investigated the performance of optimal transmission range distribution on alleviating the hotspot problem. It was found that even extensive transmission ranges alone cannot resolve this issue [6]. Since the nodes' density is in increasing order from outer to the inner annulus, so the more nodes are there in the hotspot region to share the communication load.

Another Unequal Cluster based Routing (UCR) protocol is proposed by G. Chen *et al.* [7] for resolving the same issue. The clusters nearer to Base Station (BS) are denser with nodes in comparison to the clusters that are farther from BS. Hence, there are more transient nodes at the hotspot region to better handle the load and hence increasing the network lifetime and throughput as well.

Ahmed *et al.* [8] have proposed a scheme to address hot spot issue. This scheme is a hybrid approach combining flat multi-hop routing and hierarchical multi-hop routing. The former minimizes the total power consumption in the network, while the latter decreases the amount of traffic by applying the data

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compression technique.

A distributed algorithm; Minimum Hotspot Query Trees for WSN is proposed by G. Chatzimilioudis *et al.* [2]. Their technique has significantly reduced overhead for constructing a tree. The designated tree deviates far less from the optimally balanced tree when compared to competing algorithms as they showed in experimentation.

R. Balamurali *et al.* have proposed a quantification algorithm by following the similar idea of unequal clustering as in [9] and increasing the order of nodes from outer to inner annulus as in [6]. This quantification algorithm decides the number of nodes in each tier to mitigate the hot-spot problem.

TLPER [10] by Jabbar *et al.* have taken the nodal density and geographical location of nodes to decide centrally at the BS about the cluster heads and distributed selection of cluster members. Their proposed design has involvement of assistant cluster heads with LBT (Load Balancing Threshold) and RTT (Role Transfer Threshold) techniques. On approaching LBT, a node having the highest energy level in the cluster called Assistant Cluster Head (ACH) is selected to share the load of CH. CH uses this ACH as its forwarding node rather than directly sending the data to CH of next cluster. This assisting role of nodes helps in mitigating the hotspot influence on throughput and supports in increasing the network lifetime.

Another proposed Mechanism; Energy-Aware Distributed Unequal Clustering (EADUC) by Yu *et al.* [11] is an energy aware routing algorithm for cluster-based wireless sensor networks. They introduced unequal sized clusters for the remedy of hot spot issue that results in better network lifetime. A competition radius determines the size of the cluster that is based on the proximity to the BS. This fashion of cluster designing is assisted in managing the hotspot problem and hence in increasing the throughput.

III. Energy consumption analysis of hotspot region in clustered network

Hotspot in the network causes the nodes to drain out their energies quickly. The nodes at this critical region work both as sensor and relay nodes. The power consumption in the first case is almost insignificant compared to the second instance based on well-known fact in WSN that transmission of one bit to a distance of 100 meters is 1000 times expensive in energy consumption compared to sensing one simple event. This simple event is in relaying data that is flowing into the hotspot region from outside. A significant energy is consumed that results in network partitioning and hence decrease the network life. Following is the mathematical formulation of power consumption at the hotspot region.

Let, to reach the data of volume M to sink node flowing from outside hotspot region, it needs to relay through λ an average number of hops and for which for the transmission of a unit of data over a distance is $Energy_{(dist)}$. This relationship comes up with Equation 1.

$$Energy_{hotspot} = Hops_{avg} \times Energy_{(dist)} \times Data_{vol} \quad (1)$$

Where

$$\mathrm{Hops}_{Avg} = \frac{\mathrm{Radios}_{hotspot}}{\mathrm{Tx}_{just}} \quad (2)$$

Hops_{Avg} that the data has to be relayed through in hotspot to reach the BS is equal to the radius of hotspot region ($\mathrm{Radios}_{hotspot}$) divided by the average transmission distance (Tx_{just})

And

$$Energy_{(dist)} - (\epsilon_1 + \epsilon_1) \times Sqr_{dist}(Node_{tx}, BS) \quad (3)$$

$\mathrm{Enenergy}_{(dist)}$ is equal to the multiplication of sum of constant parameters of transmitting and receiving circuitry of sensor node's characteristics to the square of the distance between the transmitting node and the BS.

Moreover,

$$M = Msg_{size} \times N_{(clusters)}(1 - \frac{\pi r^2}{4l^2}) \quad (4)$$

The volume of data is equal to the size of the message in bits multiplied by the number of clusters in the network. Resultant is multiplied further with $(1 - \frac{\pi r^2}{4l^2})$. Combining equations from 1 to 4, we come up with the following;

$$Energy_{hotspot} = \frac{Radius_{hotspot}}{Tx_{dist}} \times (\epsilon_1 + \epsilon_1) \times Sqr_{dist} \times Msg_{size} \times Node_{cnt}(1 - \frac{\pi r^2}{4l^2}) \quad (5)$$

Equation 5 can also be written as

$$Energy_{hotspot} = \frac{r}{d} \times \epsilon_1 \times d^2 \times m \times Node_{(clusters)}(1 - \frac{\pi r^2}{4l^2}) \quad (6)$$

Short form of Equation 8 can be as follows;

$$E_{hotspot} = \epsilon_1 mrd N_c (1 - \frac{\pi r^2}{4l^2}) \quad (7)$$

Equation 5 represents a framework that gives the hotspot energy consumption specifically for clustered network. To make it generic, $\mathrm{N_c}$ (number of clusters in the network) is to be replaced with the number of nodes in the network. Since in the first case, data is aggregated at cluster head (CH) that is forwarded to BS while in the second case, the network is flat instead of clustered network. Here nodes communicate their data directly to BS through transient nodes if there is no allocation of any aggregation point.

IV. Proposed scheme

In this section, we are presenting the analysis of the base architecture of MCDA [5] for its exploitation in the typical scenario of hotspot issue. First, we give a summary on working of MCDA and later a sub-section is dedicated to hotspot resolution in MCDA.

A. Multilayer Cluster Designing Algorithm

Multilayer Cluster Designing Algorithm for lifetime improvement of wireless sensor network; MCDA by Jabbar *et al.* [5] is a hybrid approach in its communication architecture perspective and architectural design perspective. MCDA uses multilayered approach comprising of the first flat layer in the footprint of the base station and the subsequently clustered layers. Designing of the former layer is initiated centrally while distributed fashion is applied in the designing of later. The deployed nodes in the flat layer are termed as first layer nodes $(Node_{L_1})$. Authors' started the network clustering from 2nd layer up to network boundary. The cluster heads in the 2nd layer are selected by the elected decision maker nodes of the first layer. Neighbor counter (for preferring one node over others for selection of various positions i.e. decision maker, cluster head at various steps), decision maker Node (nodes for selection of cluster heads from the subsequent layer) and packet sequence ID with postfix counter i.e. packet ID are the key factors in designing the clusters. 2nd layer nodes $(Node_{L_2})$ elect the node with highest node density as their decision maker node $(Node_{(dm)})$ i.e. $Cnt_{n_i} > Cnt_{n_j} \forall_i$ *and* $j = 1,2,3,\dots,n$ and n is equal to all nodes with the same sequence no i.e. belongs to the same group. 2nd layer nodes $(Node_{L_2})$ communicate their nodal density (Cnt_{n_i}) on their turn to their $Node_{(dm)}$ to take part in the competition of becoming CH. Time slots the are assigned to these nodes based on TDMA technique. When the first node of $Node_{L_2}$ communicates its nodal density (Cnt_{n_1}) to $Node_{(dm)}$ it assigns sequence number $(Pkt_{(Seq\_no)})$ with postfix counter '0' to this packets. All the recipient nodes of $Node_{L_2}$ saves this $Pkt_{(Seq\_no)}$ and become the part of the same group. All the nodes having a packet with same $Pkt_{(Seq\_no)}$ are included in the same group. Only those nodes of a group communicate their Cnt_{n_i} *to* $Node_{(dm)}$ which have highest nodal density than their previous nodes. These nodes increment the postfix counter giving two fold advantages; i) to let the other member nodes of the same group to know about their Cnt_{n_i} ii) to let the non-member nodes to know that neither they should continue this postfix counting nor they should save any info of other group's member nodes.

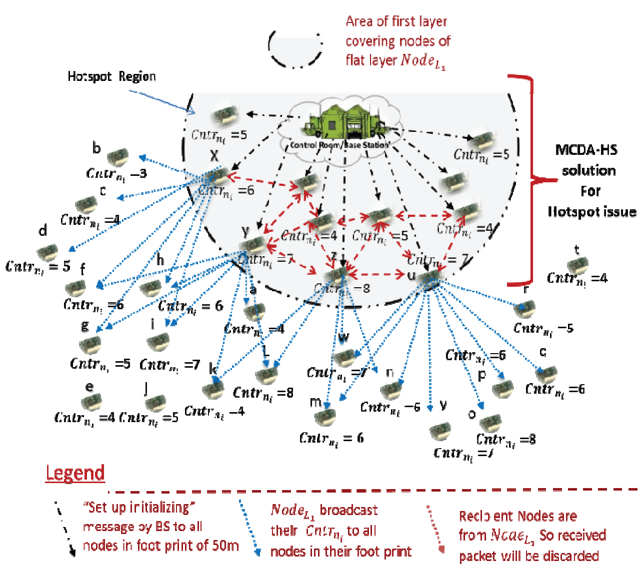

Fig. 1: Working of MCDA and its Hotspot Exploitation (MCDA-HS) to resolve this issue

This postfix counter assists the $Pkt_{(Seq_{n.o})}$ in separating the members of one group from other. The node right after the last member of the first group communicates to its $Node_{(dm)}$ and assigns the new $Pkt_{(Seq_{no})}$ with postfix counter '0'. After collecting the nodal density of 2nd layer's selected nodes, the decision maker nodes elect the CH having highest nodal density among its 2nd layer's addressed nodes. The elected cluster heads broadcast *"Join Request"* packets. This is to inform other sensor nodes of its availability as CH. Recipient nodes send their consent message in the form of *"join accept"* message to become the cluster members. If *"Join Request"* message is received from more than one CHs, then the decision of membership is based on the current load on CH i.e. CH having less number of member nodes is preferred to be attached to it.

B. Hotspot resolution in MCDA (MCDA-HS)

Cluster member nodes communicate their collected data to the cluster head. Like all other nodes of the underlying layer, under discussion, CH also has forwarding node table having node IDs of its decision maker nodes (DM_{Node}) in the precedence level of their node degree. The node at the top of the list is selected as the forwarding node (FN). If this FN is not the CH then it directs the data to its CH. In another case, CH sends the collected data to the '*highest node degree carrying value node*' from its neighbor table. The nodes at the second layer whose next most appropriate node is of the first layer send their data to them. Here all the nodes have their direct access to BS. Once the nodes of this layer have their energy near to some defined threshold, then their energy status is communicated to second layer nodes and the communication is switched to second highest energy carrying node in the neighbor table. This style decreases the burden over the neighboring region of BS and removes the threat of network partitioning. Hence the lifetime of the network is improved which comes up with a better throughput of the network as is depicted from Fig. 2 to Fig. 5 and the discussion thereon in Section V. Exploitation of MCDA for resolving the issue of the hotspot in MCDA-HS are depicted graphically in Fig. 1.

V. RESULT AND DISCUSSION

In MCDA-HS, the first layer that covers about 50m – 70m area does not have a cluster(s). In the remaining area, there is not much difference in cluster size. In the case of TLPER, the size of the cluster is determined by the proximity of nodes to CH that is based on RSSI. While in the case of EADUC, cluster size is directly related to proximity to BS. Lesser the distance of cluster to BS, smaller is its size and vice versa. Based on the above discussion, the highest number of clusters in EADUC compared to TLPER and MCDA-HS is logical (Fig. 2). This scenario forms the base for analyzing the hotspot resolution and its impact on throughput in algorithms.

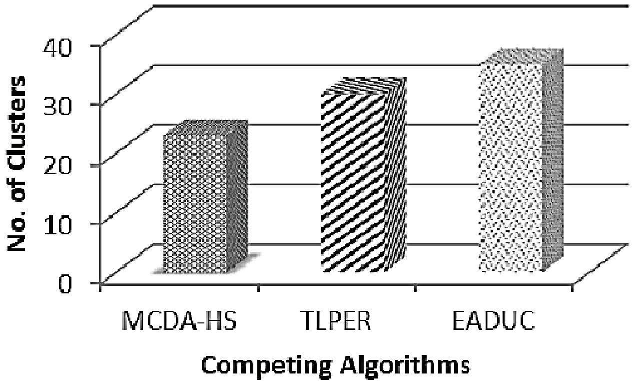

Fig. 2: No. of Designed Clusters

This difference in a number of clusters construes that number of clusters may mean number of end to end hops. At every transient node, each arriving packet must face delay due to a number of indispensable factors like queuing delay, processing delay, etc. Also, there needs to do the calculation for decision making of forwarding the received packet on the way to BS. This further aggregately reflects more End to End (E2E) delay due to the aforementioned reasons. Thus, there is more energy consumption for communicating the data from source to destination. MCDA-HS removes this effect with the following measures:

- Less number of clusters (Fig. 2)
- No cluster in the neighbor of BS (Fig. 1)

While, in the case of TLPER and EADUC, this comes up with severe effect on energy consumption. Fig. 3 demonstrates this effect in the form of average energy consumption for one packet from end to end. In this figure, MCDA-HS consumes the least amount of energy. Which shows MCDA-HS outperforms the competing algorithms i.e. TLPER and EADUC.

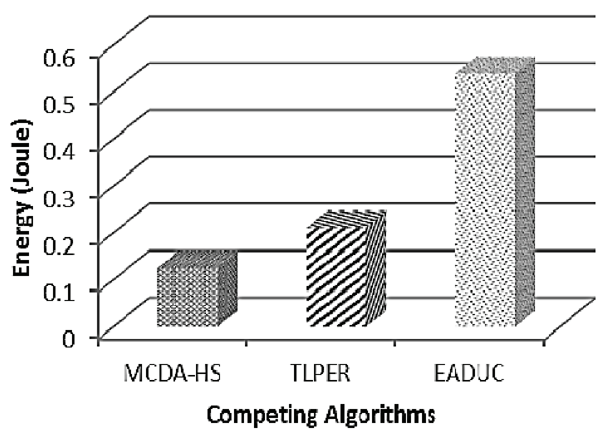

Fig. 3 Avg. Eng. Consumption for 1 Packet from E2E

For this evaluation parameter, the performance efficiency [$\xi = \left(1 - \frac{\text{Result of 1st Algo}}{\text{Result of 2nd Algo}}\right) \times 100$] of MCDA-HS over TLPER is 40% and in comparison to EADUC, it is 77%. This performance ultimately comes with better throughput.

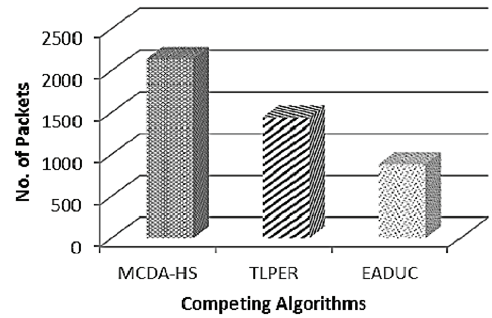

Fig. 4 Throughput in first 300 Seconds

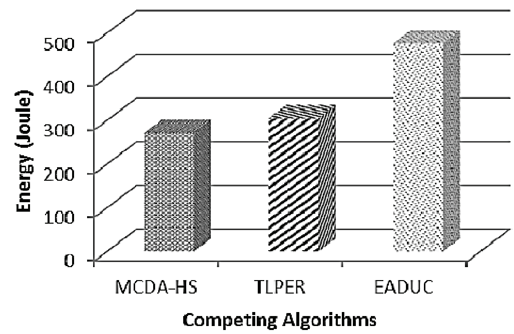

Fig. 5 Total Energy Consumption for Throughput in 300 Seconds

Fig. 4 shows the throughput of competing algorithms in first 300 seconds. Similarly, its extension to resultant effect of throughput due to improved performance in energy consumption in first 300 seconds is shown in Fig. 5. For this evaluation parameter, the performance efficiency [$\xi = \left(1 - \frac{\text{Result of 1st Algo}}{\text{Result of 2nd Algo}}\right) \times 100$] of MCDA-HS over TLPER is 11% and in comparison, to EADUC, it is 43%.

VI. CONCLUSION

From the empirical results, it is intuited that flat layer about base station and the better management of nodes therein and the rotation of their roles gives a better solution for resolving the hotspot issue compared to the solution proposed in TLPER and EADUC. Though the size of clusters based on the proximity to BS also leaves a beneficial effect on network performance, yet it increases the End to End delay and decreases the throughput. It also causes the increased frequency of cluster head rotation but on this aspect, we did not take into consideration in the presentation of results.

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