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A QoS based Heuristics for Clustering in Two-Tier Sensor Networks

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Abstract: Once sensors detect an event they always have to route the data to base station where the data is processed. Since sensors usually have concerns regarding coverage, energy, processing power and memory, etc achieving Quality of Service is hard in sensor networks. Therefore to deal with such issues of sensors and to maximize the Quality of Service, initially the two tiers Heterogeneous Sensor Networks approach is used to route the data. Second, the sensors are partitioned into clusters to increase the network coverage and to reduce transportation costs and energy utilization. Voronoi clustering and Tabu search meta-heuristics have been used for making such clusters. An Improved Tree Routing technique is applied to two-tier Heterogeneous Sensor Networks to route the data through cluster heads. This approach largely increases the performance of sensor networks. Through simulation results, we show that the Voronoi-Tabu based clustering technique when added to Improved Tree Routing has better Quality of Service than Directed Diffusion and Low Energy Adaptive Clustering Hierarchy routing protocols. Furthermore, empirical evaluations show that Voronoi-Tabu based clustering increases the throughput of the network, in addition to decreasing the energy utilization and network delays.

Keywords: Heterogeneous sensor networks; Voronoi; Tabu; Clustering; Routing

I. INTRODUCTION AND RELATED WORK

The sensors are becoming cheaper as the technology is advancing; furthermore a number of functions can be embedded in one sensor and it still uses less power. In the last fifteen to sixteen years a lot of research has been done on the important functions in sensor networks such as clustering, routing, and security.

In sensor networks the two tiers cluster based routing has benefits of network scalability, effective communication, and energy efficient routing [16]. Two tier routing is a hierarchical routing with two layers where at one layer low end nodes route their data to cluster heads (CH) and at the second layer cluster heads route the data to Base Station (BS). The low end nodes have less processing power, low energy and are cheap and CHs have more processing power, higher energy and are costly.

What matters when routing should be based on Quality of Service (QoS)? When a routing protocol should route data based on Quality of Service then the sensor network has to balance the energy utilization and the quality of the data. Specifically, the given sensor network should fulfill some of the QoS metrics when routing data to the base station. The metrics are network delays, utilization of energy, available bandwidth, etc.

Hence, to fulfill above mentioned QoS metrics we should follow some advice from the previous research on sensor networks. Several researchers have shown that two-tier clustering improves the energy efficiency and coverage of sensors [6], [7], [8], [10]. Packet collision is escaped in clustered sensors networks because only high end (HE) or cluster head nodes route data from its cluster. Nevertheless, cluster heads use more energy for sending the data [5], [11], [12]. The proposed approach, TabuVoronoi-Improved Tree Routing (TV-ITR), reduces the energy used by the sensors.

In our approach, we are using two-tier Heterogeneous Sensor Networks (HSNs). There are two types of nodes: low and high end. The high end nodes are fewer in number than low end nodes and have more processing power, transmitting range, bandwidth availability and memory. Each low end node is a member of a cluster, and the data collected by the low end nodes is routed to their respective high end node, or cluster head. After accumulating data, a CH can potentially process the data to produce valuable information before forwarding it to the base station. The low end nodes do not process the data due to their limitations in transmission range, processing power and memory. This two tier strategy conserves the energy resources of the low end nodes but does require multi-hop routing for data to reach the base stations.

The overall strategy that we employ to conserve network energy with fewer network delays to achieve QoS for the sensor networks is summarized as follows:

1. Initially the given approach uses Voronoi clustering to partition the sensors in the given area. Voronoi uses Euclidian distance to make clusters but sensors use multi-hops for routing so a new Tabu heuristic is applied to adjust the nodes on or near the boundaries. Thus, to achieve QoS, some threshold transmission range for low and high end nodes is set.
2. Once low end sensors detect some event, they gather data and send it to CHs using Improved Tree Routing.
3. Before forwarding data to BS, aggregate data at every CH so that useless data does not get through.
4. Use Improved Tree Routing for intra and inter cluster routing.

5. Simulation results show the new Tabu-Voronoi based ITR routing approach is performing better than Directed Diffusion (DD) and Low Energy Adaptive Clustering Hierarchy (LEACH) protocols.

The Directed Diffusion and Low Energy Adaptive Clustering Hierarchy protocols have been chosen for comparison since these two protocols share a number of similarities with the developed TabuVoronoi-ImprovedTreeRouting (TV-ITR) approach. Following we have given a brief description of some characteristics of DD and LEACH protocols. Table 1 outlines comparisons of some of the characteristics of these three protocols.

Directed Diffusion [3] protocol is a data-centric approach. The sensor nodes generate data and that is named as attribute-value pairs. Since the protocol is query driven, the data is requested by a sensor node by conveying interests for the named data. The data that match the given interest is forwarded or drawn towards the requesting node. The intermediate sensor nodes may cache that data, could convert that data, and may even send their own interests according to the cached data up to that time. The Directed diffusion protocol is not an IP-style protocol. In IP-style protocols the nodes are recognized by their end points and the communication among nodes is based on an end-to-end distribution of data service provided in a given network. With directed diffusion routing, the sensor nodes are application-aware. The directed diffusion protocol could cache and process the data (aggregation) at intermediate nodes and use multi path delivery of data, thus leading to less energy usage.

Table 1: Comparison of the characteristics of three protocols: TV-ITR, LEACH, DD

	TV-ITR	LEACH	DD
Classification	Hierarchical	Hierarchical	Flat
Mobility	Fixed BS	Fixed BS	Limited
Position Awareness	Yes	No	No
Power Usage	Limited	Maximum	Limited
Negotiation based	No	No	Yes
Data Aggregation	Yes	Yes	Yes
Localization	Yes	Yes	Yes
QoS	Yes	No	No
State Complexity	CHs	CHs	Low
Scalability	Very Good	Good	Limited
Multipath	No	No	Yes
Query based	No	No	Yes

Heinzelman, et. al. [5] came up with a new protocol for sensor networks known as Low Energy Adaptive Clustering Hierarchy. LEACH is a hierarchical clustering algorithm. The LEACH protocol forms distribute clusters and randomly choose some sensor nodes as the cluster heads for the given cluster. For distributing the energy load in the network, the function of cluster head rotates among different sensor nodes. Functioning of LEACH protocol is divided into two phases: setup phase and steady phase. The clusters are formed and the cluster head is chosen in the setup phase. Data routing from sensor nodes to base station takes place in steady state phase.

The paper is organized as follows. The introduction section discusses Quality of Service as important for routing the data in sensor nets. It also describes the TV-ITR approach used to route the data and the main characteristics of DD, LEACH and TV-ITR protocols. Section II discusses the Voronoi clustering and the new Tabu heuristics used. Section III describes implementation specifications of the Improved Tree Routing technique. Section IV explains simulation environment and evaluation of the simulation outcomes. Section V concludes the paper.

II. CLUSTERING

When Voronoi algorithm runs on 2D plane the clusters are formed using Euclidean distance as shown in Fig. 1. Because sensor nets use hops instead of distance for data routing, in a 2D finite plane it may suffer with wrap around regions, some nodes could be lying on or near the boundary, and density of nodes in different clusters also becomes an issue for properly covering the complete network. It has been shown that Tabu search is a successful approach to solve such problems, and it could be applied to clustering problems [1], [2], [9], [11], [13]. Hence we use Tabu search to overcome distance vs. hops problem to balance the Voronoi clusters.

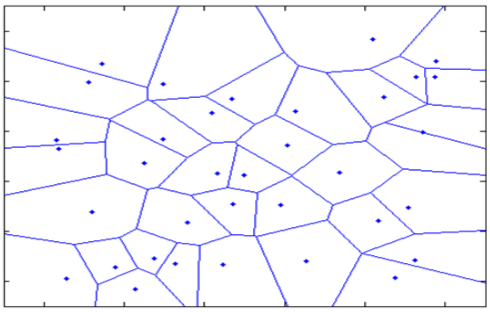

Figure 1. Cluster heads are shown as dots in the above shown Voronoi clusters

Being Tabu search a meta-heuristic approach, it is effective in modifying local solutions in combinatorial problems [9]. In our approach, the new Tabu heuristics is reassigning the nodes to different clusters so that it can deal with the problems of voronoi clusters for QoS routing. During tabu search some nodes are reassigned to another cluster, then those nodes are released from their existing cluster. Recursively, all the nodes chosen by tabu search to be reassigned are freed from their present clusters. With the advancement of tabu search, the approach changes the neighborhood structure for every one solution. Tabu search retains a Tabu list to avoid reversal of region examination moves.

The key steps used for tabu search are as follows:

1. **Reassignment**: The Tabu reassigns/reallocates nodes to different cluster. Reassignment is done in the intensification phase. We have considered three different types of moves. First, the nodes near or on the boundaries are exchanged between clusters. Second, the cyclic transfer moves on nodes in different clusters as shown in Fig. 2. Finally, pair wise exchange of nodes between two clusters. All these moves reduce the hop count along Improved Tree Routing to minimize the hop count to the base station from any sensor node.

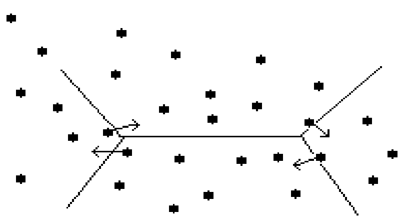

Figure 2. Cyclic transfer moves

2. **Aspiration condition:** The aspiration condition is set to f_{min} >f(a), where a is the solution. The tabu list deletes the given move if the minimum objective function exceeds the given objective function.
3. **Stopping criteria:** How long the steps will be repeated depends on the number of nodes in the network and different number of clusters respectively.
4. **Release of a node by cluster:** In the diversification phase releasing of nodes from the given clusters takes place. To reduce memory usage, we are releasing each node after it is reassigned to some cluster in respective iteration.

Following are a few assumptions used for simulation setup:

1. All the sensor nodes have a distinctive binary identification number (explained in Section III) and location, where both IDs and locations are known to its CH, BS and node itself.
2. All low-end and CH nodes sense with their specific carrier sense threshold frequency, such as CSThresh1 for low end and CSThresh2 for CHs. The nodes also receive at receiving threshold setting; for example for low end it is RXThresh1 and for CHs it is RXThresh2. Basically, the carrier sense for all nodes, CSThresh_, is set less than receiving threshold RXThresh_ else the data packets cannot be routed up to network layer from physical layer.
3. The BS has unlimited resources and CHs are robust to tempering.

To set up the above mentioned 2nd assumption the following theory has been taken into account. The signal strength from the source to receiver reduces to $1/d^2$ when they are d distance apart. When the distance between them doubles the received signal strength would be $1/d^4$ from the source as is shown in fig 3.

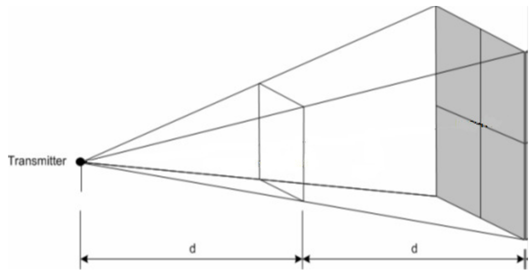

Figure 3. Signal strength vs. distance from source to receiver

Therefore it is a good idea to limit the relay signal strength. Hence, the relay signal strength of nodes is adjusted such that low end sensors can reach their neighbors and cluster head only and cluster heads can contact other cluster heads and the base station. Setting the threshold signal strength ensures decreased information leakage and reduced energy utilization [5], [7], [14]. We also minimize the energy utilization of the network by using ITR routing scheme, as energy dissipated in hopping is a considerable portion.

Algorithm for the Tabu heuristics is as follows:

1. Tabu search starts with the given Voronoi clusters for the given area of interest.
2. During intensification stage of the Tabu search:

   2.1: First we consider nodes on or near the already established voronoi cluster boundaries (as shown in fig. 4 a low end node is placed in C1' cluster, but if we use tabu search then this node could be placed in C2 cluster) and measure the hop count from the adjacent cluster heads with respect to the low end nodes and high end nodes transmission ranges. If the hop count for the low end node along the shortest path tree is less with adjacent cluster head then it is reassigned to adjacent cluster.

   2.2: Second we consider pair wise exchange of nodes between two clusters. If the hop count of low end nodes of two adjacent clusters along the shortest path tree is less toward its adjacent cluster head then these two nodes are reassigned to respective cluster heads.

   2.3: Finally, we consider the cyclic transfer moves among clusters as illustrated in Fig. 2. If the hop count for the low end node along the shortest path tree is less with adjacent cluster head for more than two clusters, those are reassigned to adjacent clusters in a cyclic manner.
3. Once the node arrangement is redefined, it is evaluated with the value of the best solution established thus far concluded over the entire search

process. Next those reassignments of low end nodes to cluster heads are allowed and the nodes are released from their present clusters at respective iteration. (Note: Thus to improve the solution space search using less memory, our approach has applied a strategy of releasing one such link during reallocation procedure at respective iteration. Therefore, the reallocation process shrinks the solution space as this strategy follows the diversification approach and is relatively expanded by the releasing process.) The aspiration condition is reevaluated. Then go to step 2 until all the clusters are considered.

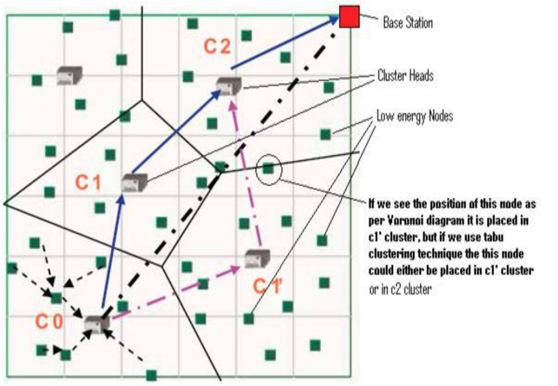

Figure 4. Tabu heuristics applied to Voronoi clusters

4. The tabu search stops after 50000/(2*((n+1)/(C+1))) number of iterations.

III. ROUTING

The Improved Tree Routing (ITR) [6] approach reduces the number of hop counts. The complete description of ITR is available in paper [6]. The ITR scheme generates a distinctive tree, where each node could have only three offspring. All the nodes are assigned only binary addresses. Upon deployment these sensors gather details of their parent and child nodes and set up parent child links. They also gather information about all of their neighbors and store that in their neighbor table. A node uses this neighbor table to find alternative paths to reduce the hop count. The central thought for such a tree is that it could use different paths having lesser hops for proficient routing. The spanning tree is not capable of forwarding data in case of node failure [12], [15]. Such situations are handled very well by ITR scheme, since it explores its neighbor table to select a different node to send the data packets.

The binary addressing scheme of ITR is as follows. Only the BS has binary address 0, being the root of tree topology. All other IDs for the nodes are calculated in a specific way. The next binary address, 01, is for the first child. The binary address 10 is for the second child and 11 for the third child. The 11 in binary is 3 in integer. This parent child addressing scheme adds 2 bits to its ancestor address. For example, the node has binary address 10, so its first child address will prefix 01 to its address; second and third will prefix 10 and 11 respectively. Therefore, the address of the first child of node ID 10 will be 0110 where its integer value is 6. The second child will have address 1010 with integer value 10. The last and third child will have address 1110, having integer value 14. This pattern of addressing saves significant amount of energy for the network.

Suppose the sender node S and receiving node D does not have any grandparent, sibling or grandchild association and there exists some neighbor node n, that has parent or child association with receiving node D [6]. The ITRAgent (program written in C++ for ITR routing in NS-2) picks that neighbor node n to route the data to the receiving node by making a temporary link. For example, in Fig 5, if we choose to route data using the shortest path tree then the route is S->c->b->a->D, with hop count 4 (H_{SP} = 4). However, node n sounds promising to be chosen as neighbor node to route instead S->n->D, having hop count 2 (H_{ITR}= 2). Therefore, if $H_{SP} - H_{ITR} > 0$ then $H_{ITR} < H_{SP}$ and is given as $H_{SP} - H_{ITR} = \Delta$. If Δ is positive or greater than zero, this means it should use neighbor n to route the data.

Hence, if some neighbor node, n, could be found having no association of a sibling / grandparent / grandchild with the sending node, S, it could be used to route the data [6].

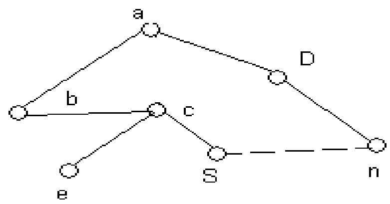

Figure 5: No parent-child relation between sending and receiving nodes [6]

On the other hand, if sending and receiving nodes do share such (parent-child) association then selecting a neighbor node would not reduce the hop count as is shown in Fig 6. Therefore, ITR works only when sender and receiver do not share parent-child association [6], [7], [8].

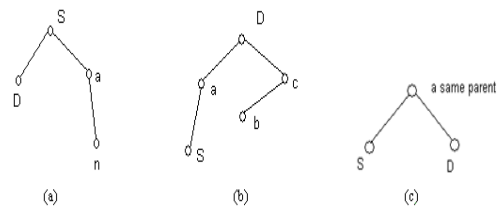

Figure 6: Receiver (D) and Sender (S) nodes having a) child-parent association b) grandchild-grandparent association c) sibling association [6]

Tabu-Voronoi clustered ITR routing algorithm is implemented in NS-2 network simulator. Primarily, two different agents are implemented first for dividing the complete network into Tabu-Voronoi clusters named TabuVoronoiClusteringAgent and second for routing named ITRAgent. The clusters generated by TabuVoronoiClusteringAgent are used as input to

ITRAgent. The routing initially uses the shortest path tree to setup the path. Then nodes look in the neighbor table for a possible neighbor to reduce the hop counts. If it finds such a neighbor, it uses the neighbor to route the data instead of shortest path tree. In the simulation, the Improved Tree Routing first executes for intra cluster for low end nodes, afterwards it executes for inter-cluster routing for CHs. When a node in the network gets disabled, the ITR algorithm discovers another route so is resilient.

IV. EVALUATION

The empirical evaluation of TabuVoronoi-ImprovedTreeRouting (TV-ITR), DD and LEACH algorithms is done on NS-2 [4]. TV-ITR algorithm is compared with Directed Diffusion and LEACH algorithms.

A. Simulation Environment

The sensor nodes are arranged in a 650m x 650m area. There is just one BS so all other nodes are either sender or receiver nodes. At the Media Access Control (MAC) layer the IEEE 802.11 protocol is executed. In TV-ITR, the Tabu-Voronoi clustering of nodes takes place at physical layer and ITR runs at the network layer. The size of packets is 40 bytes. The simulation start time is 0.1seconds and it runs for 150 simulated seconds. Omni-directional radio range is in use for all the nodes. The data sharing interface for the BS is Direct Sequenced Spread Spectrum (DSSS) Wave LAN. The high end sensors initial energy is 100.0J and of the low ends is 10.0J. The Carrier sense threshold of high end nodes is 220m and of low ends is 65m. 10.0MHz and 3.0 MHz is the receiving frequency for high end and low end nodes respectively. 914 KHz and 9140 Hz is the radio range for high end and low end sensors. Five different topologies are averaged to obtain the results. For uniformity, the given dimensions, variables, and the energy model are kept the same for all three simulated TV-ITR, DD and LEACH protocols.

B. Performance Analysis

Typically following characters were considered for comparison on NS-2:

1. **Throughput**: The throughput is the measure of number of bytes received in one second by the recipient. From Fig. 7 we can observe that TV-ITR is performing better than LEACH and DD. This could be because the LEACH uses broadcast advertisements so much of the slow data is in the network; moreover, it also floats extra data in the network for dynamic clustering. On the other hand, in Directed Diffusion Publish, Subscribe API is used; DD also uses flooding that produces lower network throughput whereas TV-ITR is using Tabu heuristic to reduce the hop counts for the data to travel in the network.

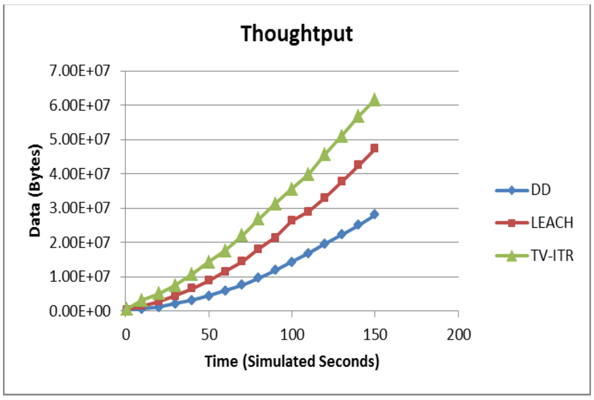

Figure 7. **Throughput**

2. **Energy Utilization**: With the passage of time all protocols are dissipating energy. We can observe from Fig. 8 that TV-ITR uses the least energy of all three protocols. This is because TV-ITR is almost connected and properly covered and also using less hops so it saves a lot of network energy whereas LEACH and DD retain less energy for the network. The TV-ITR is using two types of nodes, low end and high end nodes, whereas LEACH and DD both are using one type of node. In LEACH some nodes start acting as CHs, thus using more of the node energy to work and involving extra overhead to become CHs and for advertisements etc. However, the LEACH protocol also assumes that all the sensor nodes in the network start with the equal quantity of energy in every election round. This is not right since as a cluster head the node uses more energy than other nodes in the network. Both TV-ITR and LEACH use clustering but DD does not form cluster for routing the data so it is using more energy to route the data.

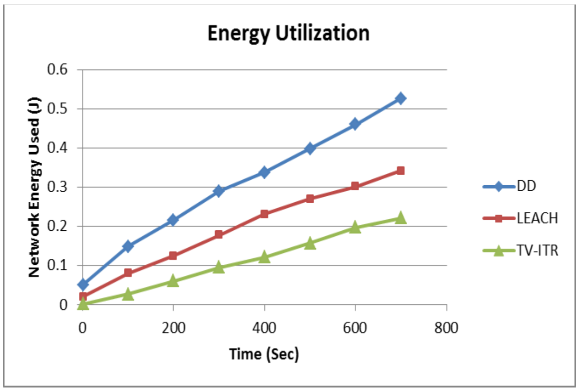

Figure 8. **Energy Utilization**

3. **Network Delay**: The average end to end time required for the data to reach the recipient from the sender is called network delay. The queuing time and propagation time also add to total network delay. We can observe from Fig. 9 that TV-ITR has fewer delays than LEACH and DD. In LEACH protocol the CHs make transmission and sleep schedules. If a node is a CH once, it cannot be CH next time. Performing a lot of calculations leads to added delays and energy usage in

the network. Similarly, DD is using flooding for routing adding to network delays. Moreover, in DD protocol intermediate nodes cache the data to process it (aggregation) and even use multi path delivery of data, thus leading to network delays.

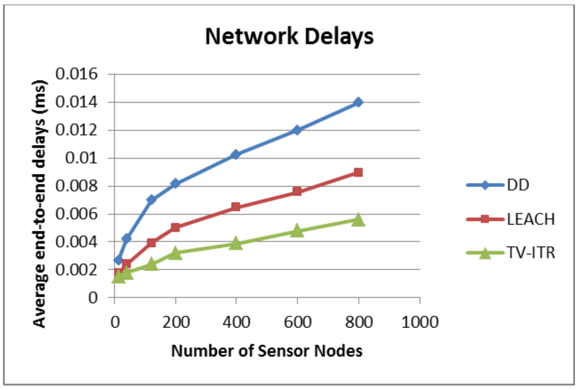

Figure 9. **Network Delay**

The following table 2 briefly represents the Quality of Service differences among TV-ITR, LEACH and DD.

Table 2: QoS comparison among TV-ITR, LEACH and DD

	TV-ITR	LEACH	DD
Route Optimality	Yes	No	Yes
Lifetime of the Network	Very Good	Good	Good
Resource Awareness	Yes	Yes	Yes
Meta-Data Usage	Yes	No	Yes
Clustering	Yes	Yes	No

V. CONCLUSION

In this paper, we have come up with a new approach of TabuVoronoi-ImprovedTreeRouting (TV-ITR) for the sensor networks. A new Tabu heuristic has been used to adjust the nodes in the Voronoi clusters to reduce the hop counts and increase the Quality of Service for data to travel in the Improved Tree Routing protocol. Using simulations, we have found that TV-ITR algorithm is performing better than LEACH and DD. The empirical evolution shows that TV-ITR dissipates less energy and faces less network delays so improves the QoS for the data. The TV-ITR has more throughput than LEACH and DD protocols. The TV-ITR is more effective and efficient because the Tabu is using hop parameter for routing the data whereas Voronoi is using distance as parameter. Moreover, Tabu removes the wrap around regions and nodes on or near the Voronoi clustered boundaries problems and balances the Voronoi clusters, making the network more covered.

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