

Chapter 11

Model and Simulation of Data Aggregation Based on Voronoi Diagram in Hierarchical Sensor Network

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Abstract A hierarchical wireless sensor network is proposed which separates the sensing ability and routing ability at different layer respectively. It cannot only simplify the hardware design but also can reduce wireless node cost. Also, a mathematical model of data fusion based on hierarchical architecture and Voronoi diagram is given to make sure the connectivity of stochastic sensor nodes and can be more energy efficient. The simulation shows, network communication traffic are cut down sharply, which can reduce nodes energy cost and prolong the lifetime of the sensor network.

Keywords Wireless sensor network • Stochastic connectivity • Mathematical model • Data fusion

11.1 Introduction

With the development of micro-electro-mechanism system and communication technology, the tiny sensors can have the capability of sensing, wireless communication, memory and processing. Sensors cannot only sense the change of the objects, but also collect data from an appointed environment. These data can be processed and sent to the base station. Due to the trait of the sensor networks, it can be applied in two special fields:

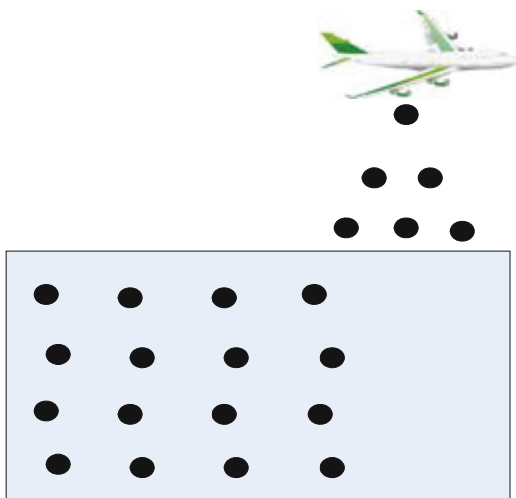
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Fig. 11.1 Stochastic distribution of sensor nodes



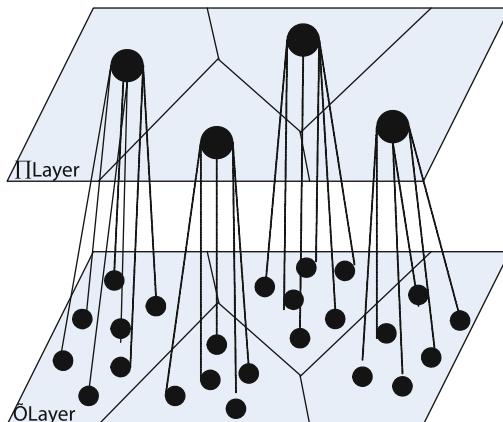
Military affairs. Sensor network [1–4] will be an important part in C4ISRT system. C4ISRT system is to provide a battlefield chain of command integrated command, control, communication, computing, intelligence, surveillance, reconnaissance and targeting for future war using high-tech. Wireless sensor network can be used to find out the state of the war and the accomplished task. Soldiers and weapons can be equipped with sensors to cooperate with each other in the war.

Emergency and temporary Environment. When fire, flood or earthquake happened, the fixed communication establishments are all destroyed or can't work well, and they can't be repaired in a short time. At that time, wireless network can be used because it is in a self-organizing way without relying on any established infrastructure and can be settled up soon. To some remote area, for example virgin forest, wireless network can be used to monitor the fire.

Due to the particularity of the two fields, for example in the battlefield and the worst-hit area, engineers can't set up the sensor network in workplace directly, the sensor nodes have to be spread by airplane or other tools just as Fig. 11.1. Because the spreading of the nodes is stochastic, so how to make sure the connectivity of the wireless sensor nodes is the first key problem. And the energy in the sensor nodes is limited and can't be recharged, so an efficient energy scheme of wireless sensor network is another key problem which can reduce the node energy cost and prolong the lifetime of the sensor network.

There some researches focuses on the connectivity and energy conservation of wireless sensor network now [5–8], but few is about stochastic distribution sensor networks. A Hierarchical Sensor network Based on Voronoi Graph is proposed in this chapter, which can make sure the connectivity of the stochastic distribution sensor network and reduce the traffic flow by data fusion.

Fig. 11.2 The hierarchical architecture of sensor network



11.2 Hierarchical Wireless Sensor Network

Now the research of sensor network is limited to the isomorphic network, every node in the network is same, i.e. the nodes have the same sensor range, the same propagation power and the same battery, and the node integrated the capacity of sensing and routing into itself, which makes the function of sensor nodes too miscellaneous. So we proposed an isomeric sensor network. There are two kinds of nodes in this sensor network: type A and type B. The nodes of A type is the normal nodes in the network, they only have the capacity of sensing and propagation for little range and don't have the ability of routing. The nodes of B type can route and transfer but can't sense, they have a high propagation power and more battery storage to send data to the remote base station. To be robust, a high nodes density (it can be 20 nodes/m^3 [9]) is needed in sensor network, so the high nodes density will bring some redundant data that will burden to the limited bandwidth, the limited processing and communication capabilities of sensor network. Thus we should adopt some way to reduce the redundancy, and B type nodes in the sensor network proposed by us can do this work. The structure of A type nodes and B type nodes makes the function of nodes simpler and reduces the equipment cost.

B type nodes can be looked as the backbone of the sensor network. They should be connected to communicate with each other. B type nodes can transmit the data that A type nodes collected to the sink node. In this way, the sensor network can form two-layer architecture. In Fig. 11.2, layer I is the A type nodes that answer for collecting data from its monitoring area; layer II is the backbone network (B type nodes) that makes sure the connectivity, reduces the redundancy, aggregates data and transfers the data to base station by one or more hop.

11.2.1 Formation of Layer II network

Layer II nodes have high propagation power, more battery storage and a longer propagation range than layer I nodes. Layer I nodes can only collect data and can't route data, so layer II nodes must be connected to make the whole network can communicate and the data can be sent to the base station. To make the layer II nodes to be connected is not a difficult problem, [10] had proved that the connectivity of network can be assured by adjusting the propagation range: There are n nodes in a two-dimensional plane and the nodes distribute in Poisson distribution. If the sensing area of every node satisfies the expression $\pi r^2 = (\log n + c(n))/n$ (r is the sensing range), the network of n nodes will be connected with probability 1 if and only if $c(n) \rightarrow +\infty$. Feng Xue and Kumar [11] indicated to assure the network connectivity by adjusting the number of node's neighbors: n nodes distribute in a two-dimensional plane randomly, if the number of node's neighbors is less than $0.074 \log n$, the network will be disconnected with probability 1 when n increases, at that time, there are some isolated nodes in the network; if the number of node's neighbors is more than $5.1774 \log n$, the network will be connected with probability 1 when n increases. We can use the two ways to assure the connectivity of layer II nodes.

11.2.2 Partition Based on Voronoi Diagram

According to the hierarchical architecture of sensor network, layer II nodes collect data from the monitored area, and send to the nodes of backbone network (layer I nodes). This is related to the partition of layer II nodes, i.e. an appointed node of layer II needs to aggregate which area of nodes. To save the energy of layer II nodes, the appointed node of layer II should be in the center of the monitored area. Voronoi Diagram can solve this problem well.

11.2.3 Voronoi Diagram

$V = \{v_1, v_2, \dots, v_i, \dots, v_n\}$ is a node set in two-dimensional Euclidean plane. Voronoi Diagram is to distribute the n nodes into n area $\{p_1, p_2, \dots, p_i, \dots, p_n\}$, and every area p_i ($1 \leq i \leq n$) only has one node v_i . The distance between every point in area p_i and v_i is less than the distance between any other point in area p_i and v_i . So $p_i = \{x : |v_i - x| \leq |v_j - x|, \forall j \neq i\}$, this can form a Voronoi Diagram.

We bring the Voronoi Diagram in the sensor network. Layer II nodes are partitioned based on Voronoi Diagram, every node of layer II is in charge of collecting the data for layer I nodes that are in the its Voronoi area, reducing the redundant data and aggregating data.

11.3 The Mathematics Model of Data Fusion for Hierarchical Sensor Network

11.3.1 The Ration of Data Fusion

In Fig. 11.3, there are N sensor nodes in a square area. C^1, C^2 and C^n are the sensing area of the sensor node 1, node 2 and node n respectively. When some of the sensor nodes have overlap area, the event is the overlap area can be sensed by the crossed nodes. So the transmitted data can be fusion to reduce the repetitive event by abandoning the overlapping area. The available sensing area of all n nodes in Fig. 11.3 is $\sum_{i=1}^n C^i - \sum_{i=1}^n \sum_{j=i+1}^n (C^i \cap C^j)$, $C^i \cap C^j$ is the overlapping area of node i and node j. So the data fusion ratio can be defined to $\left(\sum_{i=1}^n C^i - \sum_{i=1}^n \sum_{j=i+1}^n (C^i \cap C^j) \right) / \sum_{i=1}^n C^i$.

11.3.2 Mathematical Model of Data Fusion

To adapt to the hierarchical sensor network, we proposed simple mathematics model of data fusion. Assumption that layerInodes and layerII nodes are two independent Poisson distribution and in a square area, their intensity are λ_1 and λ_2 . So every node of layerII has wireless links with λ_1/λ_2 nodes of layerI averagely, i.e. in every Voronoi partition area there are λ_1/λ_2 nodes of layerI sending data to the node of layerII. If the range of node is r , we need nodes of layerI to cover the square area; we have known in 3.1 that if there are n nodes of layer I in the square, the data fusion ratio is $(n\pi r^2 - \sum_{i=1}^n \sum_{j=i+1}^n (C^i \cap C^j)) / (n\pi r^2)$.

If a node of layer I send x data packages to a node of layerII at one time, v_i will receive $x \lambda_1/\lambda_2$ data packages averagely in its Voronoi partition area p_i , so the number of data packages after data fusion is $x \lambda_1 (n\pi r^2 - \sum_{i=1}^n \sum_{j=i+1}^n (C^i \cap C^j)) / (\lambda_2 n\pi r^2)$.

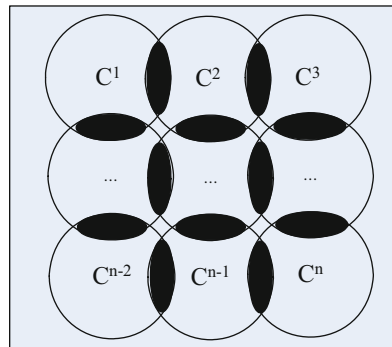


Fig. 11.3 The definition of data fusion ratio

So the nodes of layerII can distinguish some related data packages that the nodes of layerI had send to them, and integrate these data packages into one package, which reduce the data bulk and relief the limited bandwidth and energy in sensor network.

11.4 Simulation

We complemented the hierarchical sensor network in NS2. The sensor nodes of two groups Poisson distribution that the intensities are λ_1 and λ_2 respectively are spread randomly in a square area (the length and width are both 100 m). In the center, there is a base station. The nodes that intensity is λ_1 are in layer I and the nodes that intensity is λ_2 are in layerII. The layerII nodes are partitioned based on Voronoi graph. The nodes all use omnidirectional antennas and MAC protocol is DCF of 802.11 wireless local area networks. In every Voronoi partition area, the layer nodes use CBR traffic flow that sends 4 traffic data packages per second, and every data package is 512 bit. We use $N = x\lambda_1(n\pi r^2 - \sum_{i=1}^n \sum_{j=i+1}^n (C^i \cap C^j)) / (\lambda_2 n\pi r^2)$ to record the traffic data packages of layerII, and the traffic flow can be calculated by $512\lambda_1(n\pi r^2 - \sum_{i=1}^n \sum_{j=i+1}^n (C^i \cap C^j)) / (\lambda_2 n\pi r^2)$. Calculating the traffic flow at $\lambda_1/\lambda_2 = 1, 2, \dots, 10$ respectively.

As in Fig. 11.4, the traffic flow is obviously reduced after reducing redundancy and fusion data. And we find that the traffic flow has a big increment when the nodes of layerII changes from 1 to 10, but if more than 5, the traffic flow is always about 2,700 bit. It shows this Voronoi partition area can be covered by 5 nodes of layerII, if more than 5 nodes, the nodes of layerII can reduce the redundancy, then reduce the traffic flow. This coincides with the real condition and shows that our model is correct.

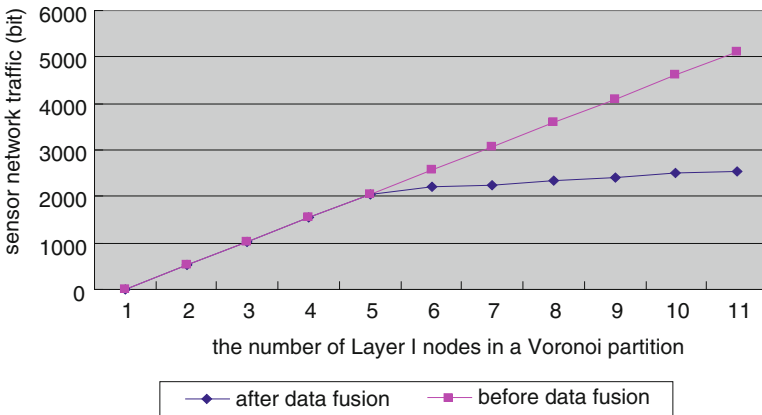


Fig. 11.4 Comparison of sensor network traffic

11.5 Conclusion

In this chapter, a hierarchical sensor network is proposed which place the sensing capacity and routing capacity at different layer nodes respectively. It cannot only simplify the hardware design but also reduce cost. Adopting Voronoi diagram to the partition of backbone network, a mathematical model of data fusion based on hierarchical architecture is given. The simulation shows, the number of transmission data packages is cut down sharply, which can reduce nodes energy cost and prolong the lifetime of the sensor network.

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