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A Solution for Local Channel Collisions in Sensor Networks

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Abstract

The energy performance of sensor nodes which are deployed in arbitrary regions in sensor networks is an important issue. Clustering of the network is a method to make nodes to groups based on geographical position. Nodes on the clustering sensor networks can reduces the communication traffics of inter-node communications and raises energy efficiency by transmitting the collected data to the cluster head for sending finally to the sink. Nevertheless, due to radio channels used on clusters, interference and collision of frequency can occur between neighboring clusters. The channel collision increases energy consumption due to waste of communications. The occurring of frequency interference and channel collisions among neighbor clusters can be resolved by assigning non-overlapping channels among neighbor clusters. In this study, a channel allocation algorithm based on the four-channels is proposed. It allocates exclusive channels among neighbor clusters those implicate various polygonal shapes. Allocating channels in complicate clustering topologies, a local hole which is surrounded by four different channels can be appeared. To solve this local problem, an algorithm which has main and local parts is proposed. The proposed algorithm is applied to a complicate network. The result of experiment shows that the proposed method assigns successfully exclusive channels among neighbors using only four-channels in sensor networks.

Keywords*: Clustering sensor networks, channel collisions, exclusive allocation, four-channels*

Introduction

Wireless Sensor Networks collect data for the surrounding environment and can be applied to a variety of purposes such as intrusion detection in military areas, area security, home automation, smart factory and environmental monitoring. Sensor nodes try to aware of the resulting symptoms of surrounding and transmit the measured data to a base station which in turn analyzes the collected data. Sensor networks consist of thousands of low cost sensor nodes, deployed via individual installation or random scattering. The usual sensor nodes are power-constrained and have limited computational ability and resources. Many studies on the efficient use of energy have been conducted to overcome some resource constrained problems [1-7].

Typically, neighboring sensor nodes in a small area collect similar information, which lead to large energy wastage because of unnecessary transmission of similar information. Consequently, many clustering methods on sensor networks have been studied. A sensor network which is divided into non-overlapping groups of sensor nodes is called as clustering. Clustering is an effective method for achieving high levels of energy efficiency and scalability. In clustering, each node belongs to a local cluster and the cluster head integrates the data collected from the cluster members, and then transmits the integrated

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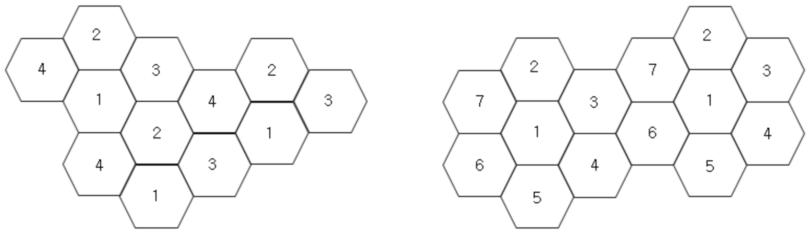
data to a sink node. This procedure prevents duplicated transmission of similar information and gives low-power consumption networking in sensor networks [5-7].

Transmission synchronization of wireless channels among neighbor clusters can achieve through the assignment of different resources between adjacent clusters. Figure 1 shows examples of reuse rate 4 and reuse rate 7 when different channels among neighbor clusters are assigned [8-9].



A. Reuse rate 4 B. Reuse rate 7

Figure 1. Examples of Channel Reuse

In the Low-Energy Adaptive Clustering Hierarchy (LEACH)[1], a typical clustering protocol for sensor networks, cluster heads make the time division multiple access (TDMA) schedule for the cluster members. Each member of the cluster are scheduled communication chance by applying it. Because the TDMA scheduling of each cluster is working independently, some data transmissions of nodes located near the cluster boundary can meet collisions with the transmission of a neighboring cluster. Figure 2 shows that a transmission of a node which is located near the cluster boundaries can make a collision with data transmissions of the other clusters.

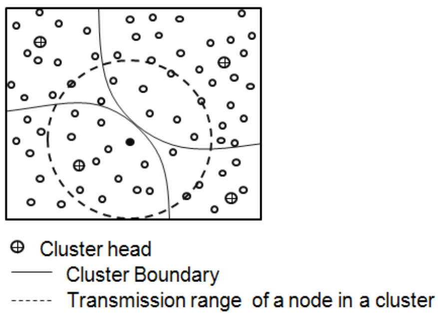


Figure 2. A Collision between Adjacent Clusters

To minimize collision interference, each cluster communicates using different code division multiple access (CDMA) codes in LEACH [1]. This is not a suitable solution for implementing CDMA code in sensor nodes for low cost.

TDMA-based Avoiding Collision (TAC)[10] solves this problem in the view of TDMA. Clusters exchange control messages for the allocation of non-overlapping group IDs among adjacent clusters based on hexagonal cluster model. In the Initial stage, a cluster broadcasts a group allocation message including its own group ID and the received clusters for allocating the group ID which isn't same group ID compared with that of the received message. This process is done gradually and repeatedly until all clusters have non-overlapping group IDs in the networks. This method requires the exchange of many messages and preprocess of time synchronization for all clusters in WSN.

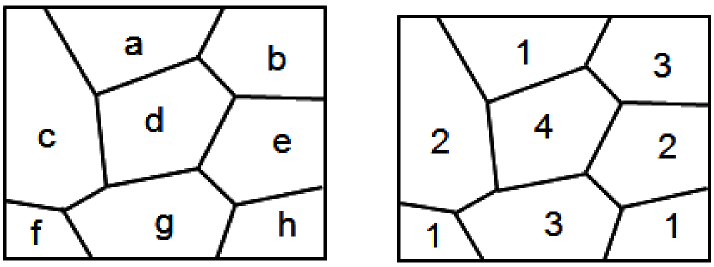
In the study of [11-12], a non-overlapping channel reuse method based on matrices is proposed. It assigns dynamically channels that do not overlap among adjacent clusters using the matrices, such as an adjacency matrix, a topology matrix and a resource allocation matrix. The complicate calculations which are required in this method are made by a gateway or a server with non-limited amount of memory, high power and high processing capability. Therefore, the method is well suited, when considering the efficient use of the energy of sensor nodes, because it doesn't require the exchange of many messages among sensor nodes. When cluster model is used a hexagonal, it doesn't completely solve the collisions among neighboring clusters in various cluster topologies.

A channel allocation algorithm [13] based on four-channels [14-18] is proposed. This method is very simple and is easy to apply as compared to the conventional methods which are based on the four-color theorem. But, we have found channel conflicts cases among neighbor clusters in complex cluster topologies.

A local channel allocation method can solve the channels confliction. The results of experiment show that the algorithm assigns successfully exclusive channels among neighbors in a very complicate cluster topology.

1. Related Studies

Based on the four-color theorem, the exclusive channel among adjacent clusters can be assigned by only using 4 channels in some form of topology. Figure 3(b) represents a result of the exclusive channel allocation using the four channel numbers 1,2,3,4 in the topology of figure 3(a).



(a) Cluster topology (b) Channel allocation

Figure 3. Cluster Topology and the Result of Exclusive Channel Allocation

For exclusive channel allocation in the cluster sensor network, the exclusive channel *EC* matrix presents the process of exclusive channel allocation[19].

(3) shows the initial *EC* matrix of the cluster topology of figure 3(a). In the initial *EC*, when two clusters are adjacent, the elements are represented by 'n' and are not adjacent the elements are represented by '0'[20].

$$Initial\quad EC = \begin{array}{c} \\ a\\ b\\ c\\ d\\ e\\ f\\ g\\ h \end{array}\!\!\begin{array}{c} \begin{array}{cccccccc} \mathrm{a} & \mathrm{b} & \mathrm{c} & \mathrm{d} & \mathrm{e} & \mathrm{f} & \mathrm{g} & \mathrm{h} \end{array} \\ \begin{bmatrix} \infty & n & n & n & 0 & 0 & 0 & 0 \\ n & \infty & 0 & n & n & 0 & 0 & 0 \\ n & 0 & \infty & n & 0 & n & n & 0 \\ n & n & n & \infty & n & 0 & n & 0 \\ 0 & n & 0 & n & \infty & 0 & n & n \\ 0 & 0 & n & 0 & 0 & \infty & n & 0 \\ 0 & 0 & n & n & n & n & \infty & n \\ 0 & 0 & 0 & 0 & n & 0 & n & \infty \end{bmatrix} \end{array} \qquad (3)$$

$$Final \quad EC = \begin{array}{c} \\ a \\ b \\ c \\ d \\ e \\ f \\ g \\ h \end{array} \begin{array}{c} \begin{array}{cccccccc} a & b & c & d & e & f & g & h \end{array} \\ \begin{bmatrix} \infty & 3 & 2 & 4 & 0 & 0 & 0 & 0 \\ 1 & \infty & 0 & 4 & 2 & 0 & 0 & 0 \\ 1 & 0 & \infty & 4 & 0 & 1 & 3 & 0 \\ 1 & 3 & 2 & \infty & 2 & 0 & 3 & 0 \\ 0 & 3 & 0 & 4 & \infty & 0 & 3 & 1 \\ 0 & 0 & 2 & 0 & 0 & \infty & 3 & 0 \\ 0 & 0 & 2 & 4 & 2 & 1 & \infty & 1 \\ 0 & 0 & 0 & 0 & 2 & 0 & 3 & \infty \end{bmatrix} \end{array}. \qquad (4)$$

(4) shows the result the result of execution of the exclusive channel allocation algorithm.

One of the clusters which have three neighbors is selected as an initial FR(First Reference) and one of the clusters which are the neighbors of the FR is selected as an initial SR(Second Reference). Exclusive channels are assigned to the FR and the SR. If there are columns which have the ‘n’ elements in the FR and SR rows of EC matrix, one of the columns is selected and the exclusive channel number is assigned to the selected column. And then, the cluster which is assigned a new channel becomes the new SR. If channels are assigned to the all neighbor clusters of FR, a new FR and a new SR are selected and the previous process is repeated.

2. Solving Algorithm for Local Channel Collision Holes

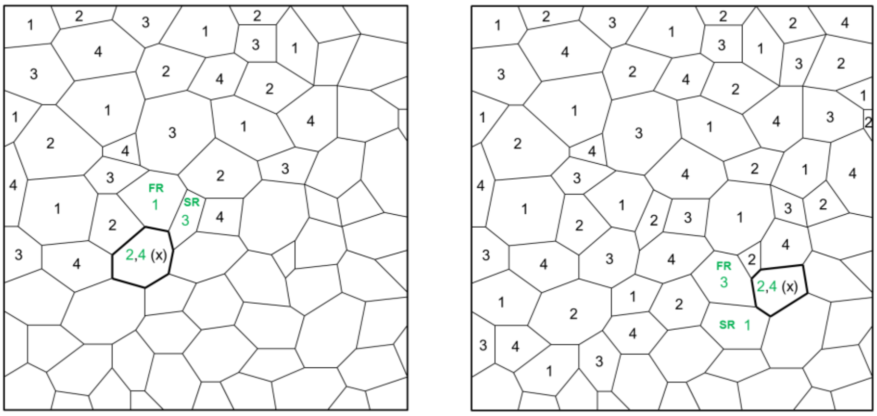
In this section, the phenomenon of channel collision is appeared locally during channel allocation and the algorithm to resolve this problem is shown.

2.1 Appearance of Channel Collision Holes

In the process of channel allocation based on the algorithm of the section 2[13], there are cases that all four channels are already assigned at neighbors.

In figure 4(a), the channel 2 or 4 is assigned to the neighbour of the FR and the SR. But, the channels, 2 and 4 are already assigned to the neighbour of the cluster.

In figure 4(b), the channel 2 or 4 is also assigned to the neighbour of the FR and the SR. But, the channels are already assigned to the neighbour of the cluster.



(a) Case 1 (b) Case **2**

Figure 4. The Examples of the Local Channel Collision

2. 2 Solving Algorithm for Channel Collisions

We propose the solving algorithm for channel collisions are appeared locally during channel allocation.

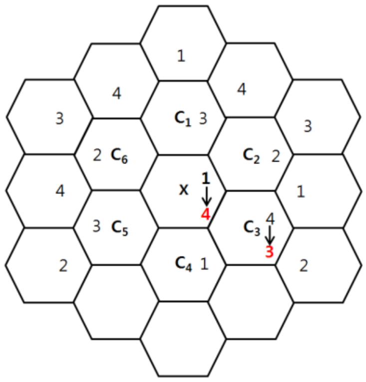


Figure 5. The Channel Reassignment Model of Cluster X

In the figure 5, the one-hop neighbors of a cluster x are marked : C_1, C_2, C_3,…,C_6. The channel of cluster x is overlapping to the channel of the cluster C_4.

To reassign an exclusive channel to the cluster x, the channels of C_1, C_2, C_3,…,C_6 are checked. Since the channel of C_3 may be reassigned, an available channel is reassigned to the C_3. Then, an exclusive channel can be reassigned to the cluster x. This process is expanded continuously to far neighbors until find a candidate.

The following is the one-hop solving algorithm for channel collision hols.

1) If it is possible to change the channel of C_i. ① An available channel is reassigned to it. ② An available channel is reassigned to the x. Else If there have not checked all the one-hop neighbor clusters of x. i is incremented by 1 and go to 1).

The following is the whole solving algorithm to avoid the collision of channels among clusters.

CN : The unassigned co-neighbor of FR and SR.
α: The first channel number by the channel allocation rule.
β : The second channel number by the channel allocation rule.
CCN_i : The collision neighbor of CN with i channel, where i= α, β.
N_i : An one-hop neighbor of i cluster, where i=a,b,c, …, k.
N(i) = { j | j is one-hop neighbor of i cluster, where i=a,b,c, …, k }.

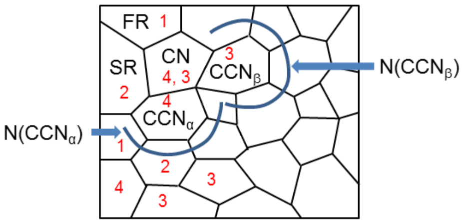


Figure 6. An Algorithm Indicator Model in the Clustered WSN

1. Checks the channel of SR and if it is possible to change the channel of the SR,
① An available channel is reassigned to it.
② A new channel is assigned to CN by the channel allocation rule.
③ Go to the main algorithm.

2. Checks $CCN_{\alpha}$and if it is possible to change it,
① An available channel is reassigned to it.
② $\alpha$is assigned to CN.
③ Go to the main algorithm.

3. Checks CCN_{β} and if it is possible to change it,
① An available channel is reassigned to it.
② β is assigned to CN.
③ Go to the main algorithm.

4. Selects one of N(SR),
① The reassignment algorithm.
② A new channel is assigned to CN.
③ Go to the main algorithm.

5. Selects one of $N(CCN_{\alpha})$,
① The reassignment algorithm.
② $\alpha$is assigned to CN.
③ Go to the main algorithm.

6. Selects one of $N(CCN_{\beta})$,
① The reassignment algorithm.
② β is assigned to CN.
③ Go to the main algorithm.

7. Selects one of the one-hop neighbors of N(SR),
① The reassignment algorithm.
② If the channel of the N_SR is not reassigned,
Selects one of the one-hop neighbors of the next N_SR and go to ①
③ An available channel is reassigned to the SR.
④ A new channel is assigned to CN.
⑤ Go to the main algorithm.

8. Selects one of the one-hop neighbors of $N(CCN_{\alpha})$,
① The reassignment algorithm.
② If the channel of the N_ $CCN_{\alpha}$is not reassigned,

Selects one of the one-hop neighbors of the next N_ CCN_α and go to ①
③ An available channel is reassigned to the CCN_α.
④ α is assigned to CN.
⑤ Go to the main algorithm.

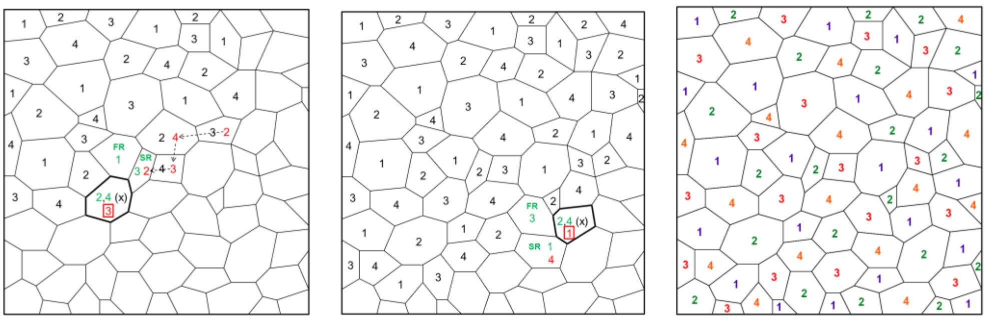
9. Selects one of the one-hop neighbors of $N(CCN_\beta)$,
① The reassignment algorithm.
② If the channel of the N_ CCN_β is not reassigned,
Selects one of the one-hop neighbors of the next N_ CCN_β and go to ①
③ An available channel is reassigned to the CCN_β.
④ β is assigned to CN.
⑤ Go to the main algorithm.

The figure 7(a) shows the result of applying the solving algorithm for the collision of figure 4(a). An exclusive channel is reassigned to the second level neighbor of the SR, other exclusive channels are reassigned to the first level neighbor of the SR, and then an exclusive channel is reassigned to the SR.

The figure 7(a) shows the result of applying the solving algorithm for the collision of figure 4(a). It is possible to change the second level neighbor of the SR. An available exclusive channel is reassigned to the second level neighbor of the SR, other exclusive channels are reassigned to the first level neighbor of the SR, and then an exclusive channel is reassigned to the SR.

The figure 7(b) shows the result of applying the solving algorithm for the collision of figure 4(b). It is possible to change the channel of the SR. An available exclusive channel, 4 is reassigned to the SR and then and exclusive channel, 1 is assigned to the neighbour of the FR and the SR in the fig 4(b).

Figure 7(c) shows the result that all conflicts are resolved and exclusive channels is assigned to all the clusters in the WSN.



(a) Case 1 (b) Case 2 (c) The whole sensor network

Figure 7. The Results of Applying the Solving Algorithm

3. Channel Allocation Procedure

The cluster head performs a central role such as synchronization, data collection, data transfer, so it consumes a lot of energy, compared to other nodes. The election of the new cluster header is needed before the energy depletion of a cluster header. Clustering is performed periodically or according to the amount of the residual energy of nodes.

The operation is divided into rounds, as in LEACH [1]. One round consists of cluster setup period, channels allocation period, data sensing & gathering period and transmission period in figure 8. The proposed channel allocation method is performed at the channel allocation period, after cluster topology is made at the cluster setup period.

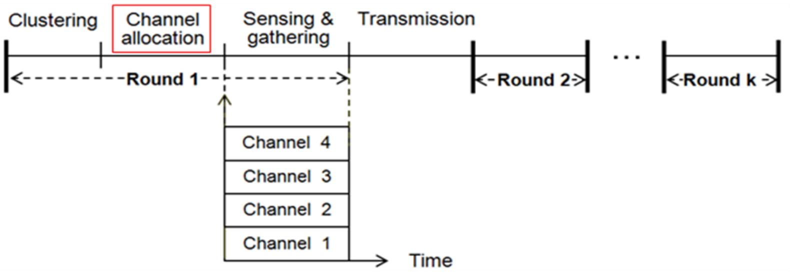
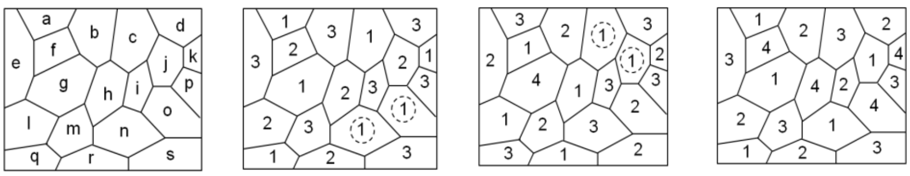


Figure 8. Rounds Including Clustering, Channel Allocation and Data Sensing & Gathering and Transmission

The proposed channel allocation algorithm is performed in a server or a gateway which is not constrained by the amount of memory, processing power, energy limit. During the channel allocation period, cluster heads broadcast a hello message including their cluster ID and TTL with value 1 by using non-persistent CSMA. The non-cluster heads which receive the message rebroadcast it and the cluster heads which receive it recognize the existence of adjacent clusters and decrease TTL value 1. The cluster heads make the list of their adjacent clusters and send it to the gateway. When the cluster heads transfer data to the gateway, it can be transferred directly or through the multi-hop. The routing method to minimize the overhead data transmission is very important in terms of the efficiency of sensor networks. This is beyond the scope of research. The gateway makes the adjacent matrix of the cluster topology based on the lists of the adjacent clusters of each cluster and performs the channel allocation algorithm for exclusive channel allocation. The result of exclusive channel allocation is transferred to the clusters in the WSN.

4. Simulation

The experiments for the performance of the exclusive channel allocation are performed. Figure 9(b-d) shows the results of channel allocations using the TAC algorithm, T and RA matrices, the four-color method based on the cluster topology fig.9(a). Figure 9(b) shows the results of TAC channel allocation. Cluster ‘n’, and cluster ‘o’ have the same channel number as ‘1’. Figure 9(c) shows the results of T matrix and RA matrix channel allocation. Cluster ‘c’, and cluster ‘j’ have the same channel number as ‘1’. The result of the figure 9(d) shows that every channel is exclusive among neighbors.



(a) Cluster topology

(b) The result of TAC method

(c) The result of T and RA matrices

(d) The result of exclusive channel allocation method

Figure 9. Comparison of Channel Allocation Methods

The experiment for the energy efficiency of channel allocation methods is performed. The efficiency of energy which is consumed in channel allocation processes is compared with the TAC method. The non-overlapping channel determination of our proposed channel allocation is processed by the server or the gateway which is not constrained by the amount of memory, processing power, energy limit based on a centralized manner. Energy consumption model [21-22] for the experiment of energy efficiency is shown by (5).

$$E_{Tx}(k,d) = \begin{cases} k*E_{elec} + k*\varepsilon_{fs}*d^2 & (d < d_0) \\ k*E_{elec} + k*\varepsilon_{mp}*d^4 & (d \geq d_0) \end{cases}$$

$$E_{Rx}(k) = E_{elec}*k \tag{5}$$

E_{Tx} is transmission energy. If distance is smaller than threshold d_0, free space model(d^2 : energy loss) is used, if distance d is larger than threshold d_0, multipath model(d^4 : energy loss) is used. k is the number of bits, E_{elec} is electron energy, ε_{fs}(free space) and ε_{mp}(multi-path) are amplification energy to maintain acceptable SNR. d is transmission distance, d_0 is calculated by $\sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$. E_{Rx} is receiving energy.

Table 1. Experimental Elements

Elements	Explanation	Value
k	The number of bits	512
d	The distance between cluster centers	20m
d_0	$\sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$	87m
E_{elec}	Electron energy	50 nJ/bit
ε_{fs}	Free space amplification energy	10 pj/bit/m^2
ε_{mp}	Multipath amplification energy	0.013 pj/bit/m^4

Figure 10 shows the results of an amount of the used energy for TAC method which is operated in a distributed manner and the four-color allocation method based on the increase of the number of sensor nodes. The result shows the four-color allocation method achieves up to 47% reduction in energy compared with TAC[10].

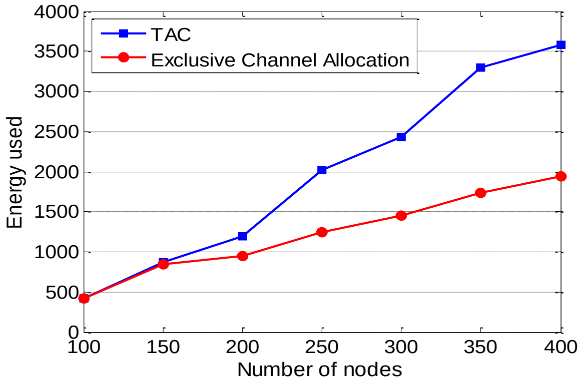


Figure 10. The Performance Simulation Based on the Energy Used

Figure 11 shows the result of our proposed four color channel allocation algorithm in the cluster topology which consists of 307 clusters. The enhanced algorithm successfully allocates non-overlapping channels by using four channels among adjacent clusters in a very complicate cluster topology.

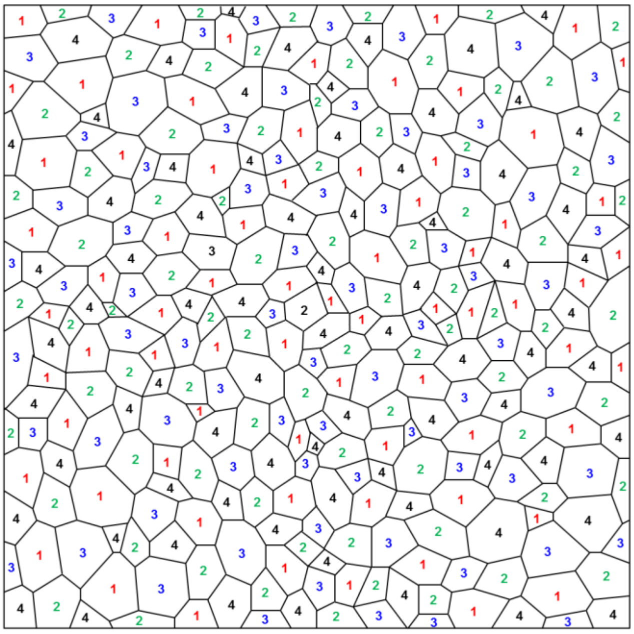


Figure 11. The Results of Our Proposed Four Color Channel Allocation Algorithm

5. Conclusions

The inter-cluster channel synchronization in the clustering sensor networks is important. To resolve the channel collisions during allocating channels by only four-channels, a main and a local algorithm are proposed. In the experiment, shape of the most complicate polygon used in a cluster is nonagon. A local algorithm for solving channel collision is proposed for during channel allocation in clusters.

Some experimental results of the proposed algorithm show that successful exclusive channel allocations among adjacent clusters in various and complex cluster topologies are succeeded. As the future research, a practical networking protocol and procedures that can be applied in a real cluster wireless network system must be studied.

Acknowledgements

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