

# **The Performance of Segregate WLAN inside a Noisy Industrial Environment.**

**Athanasios Paraskelidis, Dr Mo Adda**

School of Computing  
Parallel Systems and Networks Research Group  
University of Portsmouth)  
e-mail(s): {athanasios.paraskelidis, mo.adda}@port.ac.uk  
United Kingdom

## **Abstract**

Wireless networks have invaded into every aspect of our life, from small piconets to larger networks connecting big areas together. Industrial environments are not the exception, as primitive wireless devices have been used for a long time for machinery control. On the other hand, wireless data networks such as 802.11 networks, are rapidly taking their place inside such environments replacing the typical cables. The use of a WLAN in an area like this is not at all an easy issue. Initial attempts to deploy a WLAN in a factory/industry returned poor results. This way it was proven that more steps should be taken in order to satisfactorily deploy a WLAN.

Our attempt is based on this concept and we are proposing a network configuration which manages to reduce the effects of some of the common problems a WLAN has to face inside an industrial environment. Network segregation utilizing multichannel enabled nodes proves to give adequate results when tested inside a harsh-industrial- environment. Our designed WLAN is deployed inside a noisy industrial environment and its purpose is to transfer data from one side of the area to another as quickly as possible, with the minimum delay and failed transmissions. One of the main advantages of network segregation is the multiple paths that are created. Network performance is the primary key always in accordance of the noise level and the results from our simulations satisfy our expectations.

## **Introduction**

Ad-hoc wireless networks provide a means of networking together groups of computing devices without the need for any existing infrastructure. Devices automatically form a network when within range of each other, and also act as routing nodes by forwarding any packets not intended for them. This permits nodes to communicate further than their transmit power permits, and also allows and provides a more optimal use of the radio spectrum.

Since the first appearance of wireless networks, the traffic demands of the modern networks have increased rapidly. A single channel for transmission is

not always enough and in high traffic routes, a single channel device can create more problems than it can solve. Current applications require the transfer of large amounts of traffic such as bulk file transfers, video-conferencing and video surveillance.

Common problems with wireless networks are *interference*, *multipath* and *attenuation*. All these prevent the wireless networks from performing to their maximum capabilities. Places and environments, which accommodate all the above-mentioned problems, make the existence and deployment of wireless LANs highly restrictive.

In this paper we examine the impact of utilising multi-channel technology. Our target is to investigate the performance of segregated multi-channel mesh network and a simple, single channel wireless network - WLAN. The term segregated means that the network is divided into smaller areas/domain and each one operates only one radio. Each node is assigned one radio frequency but each segregate part has been assigned a different radio from the others. One of the advantages of this approach is that the effect of single channel interference has been minimised as each segregate network consisted of the least number of static nodes possible spreading randomly within the tested area. Apart from that, we were able to duplicate the data and send the same data through different segregate areas simultaneously, to overcome the interference in harsh environments.

## Literature Review

There are many proposed solutions for the MAC and the network layers, new routing algorithms as well as existing algorithms improved ones.

Node placement and deployment play a crucial role to the network stability and performance. When nodes are placed in a proper way taking into consideration other environment characteristics such as sources of interference and area morphology like physical obstacles and constructions it is easier to adjust the deployed wireless network to those needs to achieve maximum operability and performance.

To reduce interference, neighboring nodes should operate in different frequency channels. For example the IEEE 802.11b standard for wireless LANs can operate simultaneously in three non-overlapping channels (1, 6 and 11) [1] without each node interfering with each other. Each client inside the network should be within the range of the access point of the network in order to access the Internet, for instance. The access point is directly connected to the wired backbone network. There are many limitations to a single-hop wireless LAN. These can be limited load traffic management and the need for a large number of backbone nodes to relay the traffic to the main network, which in most cases is a wired one.

On the other hand, in the multi-hop multi-channel infrastructure, a node may find many routes to different access points, potentially operating on different channels. Thus each node must select the best route in order to achieve the best possible Quality of Service, QoS. Since each router is operating on different

channels, to select a route means first of all selecting an appropriate channel for the communication. To maximize channel utilization, the channels should be assigned according to the traffic load through the network accomplishing a balanced traffic flow.

One approach is to use a single Network Interface Card (NIC) and appropriately manage the channels in use. The NIC should switch from one channel to another every time the node initiates a communication by choosing a channel  $k$  from a pool of available channels, and hence avoiding interferences. Kyasamur and Vaidya [2], proposed a routing and channel assignment protocol, which is based on traffic load information. The proposed protocol successfully adapted to changing traffic conditions and improved performance over a single-channel protocol adopting random channel assignments. Bahl *et al.*, [3] suggested a link-layer protocol called SSCH that increases the capacity of an IEEE 802.11 network by utilizing frequency diversity. Nodes are aware of each other's channel hopping schedules and are also free to change their schedule.

Another approach of the multi-channel subject was to install multiple NICs with each one operating with different channels. This way each node has to establish first a connection with the other node and then communicate on a common channel. Based on that, Raniwala and Chiueh [4], suggested a development of a wireless mesh network architecture called Hyacinth. In this architecture each node is equipped with multiple IEEE 802.11a NICs supporting distributed channel assignment/routing to increase the overall throughput of the network.

## **Systems Architecture**

In the case of an industrial environment, the problems can be more persistent and result in really bad quality of service even of no service. The problem of broken links has been mainly encountered by the deployment of multi-channel networks.

In our case the networks that we test are placed inside an industrial area using fixed nodes and they are used to send, receive or relay information from other nodes. Information traveling through them is data from machinery sensors and which sensors monitor their functionality and also gather results from experiments that might take place. This means that the wireless nodes perform a very difficult and important task, as the data has to reach its destination as soon as possible without errors and delays. Such kind of environmental circumstances require a robust wireless network that provides a high speed and reliable transmission all the time utilizing a multi-path mesh wireless network. The problems to face are the interference between the nodes that operate on the same channel and also the interference from other sources. It is very common for the nodes to fail to transmit as their neighbors operate at the same frequency channel. The multi-channel approach solved partly this problem. At this point a new challenge was created. The ability of the wireless nodes to

manage efficiently their frequency channel decisions and avoid any interference problems. The two main problems about channel assignment are:

- Neighbor-to-interface binding, which means that the nodes should be aware of the channel that has to use in order to communicate with their neighbors.
- Interface-to-channel binding, which means in case of multiple NICs, every interface should be aware the channels that it should during any time point.

Within a single channel network a packet has to be transmitted from one node to another, but these nodes are out of reach from each others range. Thus the routing protocol initiates a series of steps and set-up a route to the destination. All the nodes operate in the same channel and this causes the problem that each time a single transmission can take place, otherwise there will be collisions during the relay of the data.

One first step was to enable in each node to operate into more than one channel. This would enable concurrent transmissions. Another approach was to divide the network into smaller parts, and assign different channels for each subnetwork. This would enable us to have all the benefits of a uniform multichannel network such as multiple transmissions simultaneously through different routes. Figure (1) represents a segregated wireless network using 3 channels and is divided theoretically into 3 subnetworks. We have two side nodes that are responsible for the data generation.

Each subnetwork makes use of only one channel and only the side nodes can utilize all the three channels. Simultaneous transmissions can take place as the side node can initially transmit at channel 1 and then switch to channel 2 for the next packet transmission. Although the channel hop is not packet by packet but each channel might be kept for a small some time, like seconds. This way, instead of having a large amount of nodes operating in the same frequency we only have less nodes and thus less interference between them. This network configuration aims to increase the throughput of the network, reduce the problems of contention/collision and the network can operate within normal delay figures.

Next step was to see the behavior of the network by using multiple channels inside each subnetwork instead of just only one. This would decrease further any existing interference from the other nodes that operated in the same frequency. Channel assignment between the nodes now follows a more complex pattern called modulo, described in the next chapter. Throughout the experiments that take place we assume that there is no limit to the number of channels that can be used. Although IEEE802.11 sets a limit to the available channels, in our case we emphasize on a more standard independent approach able to operate in all available current technologies.

## Architectures Evaluation

The network was tested for a variable number of nodes, starting from 50 and reaching to 130. Every time the nodes are located within a certain terrain with constant dimensions. The target is to evaluate the performance of the network by increasing the number of segregate networks and at the same time to increase the number of channels used within each one. In previous approach [5], we showed that by segregating a network we can achieve better network performance. Current target was to improve further by using more channels inside the segregated network and improve the network reliability. There are three main steps to achieve that. First was to simulate a single channel network, then to divide the network into a variable number of subnetworks and use one different channel for each subnetwork and finally the multichannel approach by using more than one channel within each subnetwork.

### *Single Channel Network*

This is the simplest form of a wireless network. A number of nodes able to relay data from one side to the other by using one channel only. This approach is used only for benchmark reasons in order to be able to decide if any improvement has been achieved. Routing protocol used is AODV [6] in a standard mode, no multichannel enabled.

### *Segregate Network using Single Channel*

The approach is the same as explained in figure (1) and figure (2). It should be made clear that nodes don't always follow the configuration given in figure (1) as they are usually randomly placed in the space area.

We start dividing the network into smaller and watch if there is improvement over this segregation. Channels are randomly chosen during transmission by the edge nodes, whilst inside each subnetwork since there is only one channel operating and the routing is done using AODV multichannel enabled [7] in both cases. The number of nodes included in each subnetwork is the same and is relevant to the number of channels we use. For example, when we have 42 nodes and 4 channels in use, there will be 4 subnetworks. Leaving out the side nodes as they do not belong to any subnetwork, we have 10 nodes inside each one. This way interference from surrounding nodes is reduced compared to the previous scenario. Reduced interference results to better performance and higher reliability.

### *Segregate Network using Modulo*

In this case, each subnetwork is operating into more than one frequency channel. Again the frequencies in one subnetwork  $\{k1, k3, k5 \dots kn\}$  differ from the frequencies operating in the other  $\{k2, k4, k6 \dots kn+1\}$ . Again, the number of channels existing in one subnetwork will be the same to all the rest.

According to the scenario, a slight change was made to the way the nodes switch channels during data transmission. The switching technique is based on modulo algorithm [8] shown in figure (3).

A node, upon receiving data packet on a channel  $k$ , transmits it on the next channel  $k+1$ , where  $k+1$  is next channel greater than the current one in rank. In general, the channel that is in use at hop  $h$ , given a starting channel  $k$  and  $e$  channels available can be expressed as:

$$f_{h+1} = (h+k) \bmod e \quad (1)$$

When a transmission initiates, a random channel  $k$  is selected to avoid any possibilities of other nodes selecting the same channel.

Modulo performs better when the nodes are placed in a chain topology. On any other topology its performance decreases as it experiences interference from intersecting and adjacent traffic flows. Until now modulo had only been tested in chain topology in its simplest form [8]. However, in the case of segregated networks these problems were eliminated. We managed to overcome the interference from intersecting traffic flows as each segregate network is operating on different frequency channels. Since AODV sets up a route until the transmission is finished, only one segregate network will be used to transfer the data. If another node tries to set up a transmission at the same time, AODV will establish a different route from the one already established, using a different subnetwork and since each subnetwork operates on different frequency channels, intersecting interference ceases to exist.

In all three scenarios, the side nodes mentioned above are responsible for the traffic generation. The target remains the same, to successfully transfer data from one side to the other enabling multiple routes through the segregated networks. The side nodes are multi-channel enabled which means that they can switch channels and transmit to each subnetwork at any time. When data leaves from the transmitter, it has the option to choose from more than one route. Alternatively, for high interference, duplicate of the same data might exist on different subnetworks to minimize the chances of data loss, and thus achieve a greater reliability.

Modulo is only responsible for the allocation of the channels between the nodes during the transmission. More than one node of each subnetwork is able to listen to the side nodes, reducing the chances for a broken link between them. Every time a side node sends data, it selects the channel randomly without satisfying any criteria as long as the other nodes are not busy. A graphical representation of a segregate network used can be seen in figure 3.

Generally the idea was to get a wireless network, divide it into smaller parts  $g$  and use more than one channel  $k$  inside each subnetwork by using the modulo. The question was if we could decrease the network delay and for which values of  $S$  as seen in (2), where  $g$  is the number of subnetworks and  $k$  the number of channels used inside each one. At the point where delay was the minimum possible then  $S$  would have its optimum value.

$$S(g, k) \quad (2)$$

We kept the general idea of the  $(k+1)$  hopping but changed the channel allocation scheme as the number of subnetworks  $g$  was changing and at the same time the number of nodes were changing also. Each subnetwork should use different channels as this the idea of a segregated network. For this reason the algorithm was changed accordingly. The main advantage of this approach is to increase the total bandwidth available of the network. Each segregate network provides a different route utilizing the maximum bandwidth. Another issue to taken into consideration is the transmission power of the nodes  $P_t$ . In order for the network to perform at its maximum, the transmission power is adjusted accordingly,  $-2\text{dB} \leq P_t \leq -6\text{dB}$ . For example when  $n = 25$ , the transmission power of  $-4$  dB that minimizes the delay. The range  $d$  of the nodes was taken into consideration and as it was related with the transmission power  $P_t$ , as seen in (3), the appropriate steps were taken to improve the network performance.

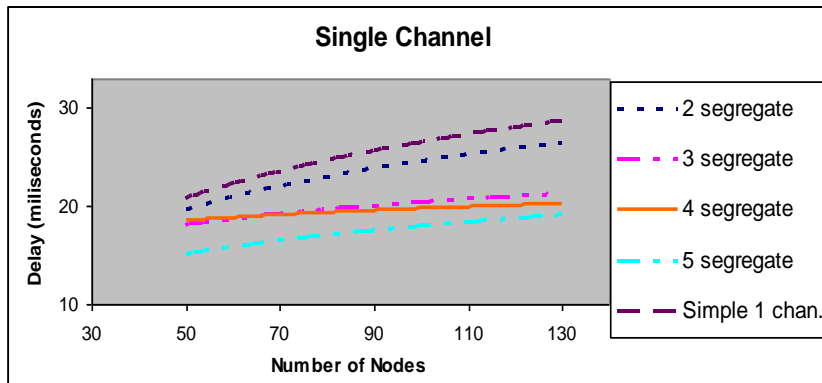
$$d = \frac{\sqrt{\frac{P_t}{P_r}} c^2}{4\pi f} \quad (3)$$

Mobile nodes are able to move easier within and achieve better connections with the fixed nodes/access points. Mobile nodes, such as laptops, are also taken into consideration since the simulated region is an industrial place and frequent checks from the employees to the machinery are very common.

## Results and Discussion

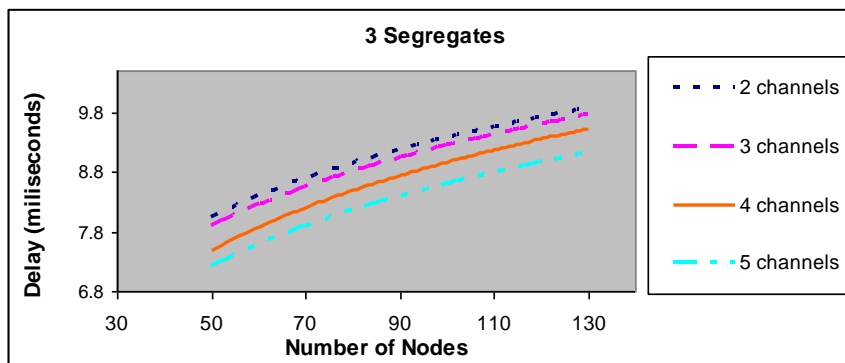
First of all we start with the simulation results of a wireless network using just one channel, the most basic form of a wireless network, without any segregation. It should be made clear that only delay is presented at the moment, due to the big variety of the scenarios. Network's available throughput and delivery ratio has also been measured and follow the same pattern as the delay. We had to test 5 different scenarios for a variable number of nodes in order to have the most possible accuracy to our results. Apart from the network performance based upon network delay, we examined the reliability of the network based on the number of collisions that took place during the transmission of data for a particular time period.

Scenarios like those presented and investigated in this paper are difficult to investigate and deploy in the real world, thus the best way to gather information is through simulations using one of the network simulators available. The simulator used is GlomoSim v2.03 [9], a well known widely used and free to use tool able to simulate wireless and wired networks systems. It has been designed using the parallel discrete-event simulating capability.



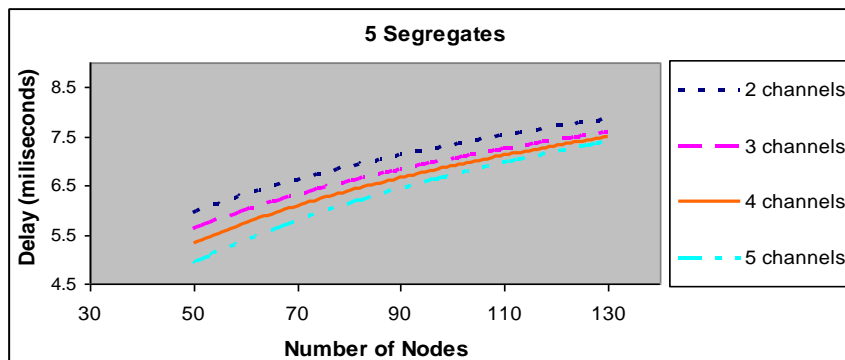
**Figure 4** The average delay for a variable number of nodes.

As we can see from figure (4), the segregate network operates quite well and overcomes in terms of delay the basic configuration. Something that was expected as it operates in a single channel, thus interference and the lack of multiple routes increases the delay. This first, figure (4), is the base for the comparisons for the segregate network using modulo.



**Figure 5** The average delay of a 3 - segregated network

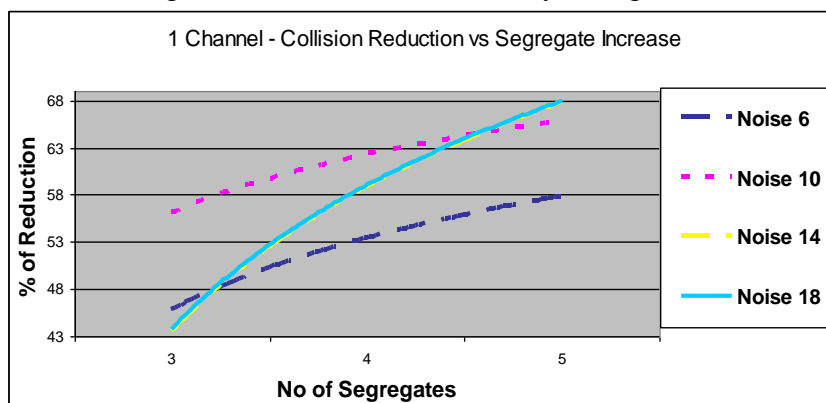
Here the network is divided into 3 parts and again we use modulo for the channel allocation. The delay is decreased even more and gets the value of 7.1ms. Of course as the number of nodes increase, the delay increases. It is clear that every time we use five channels within each subnetwork, the differences between the values get even smaller. At the moment equation (2) is minimized with values  $S(3, 5)$ .



**Figure 6** The average delay of a 5 – segregated network.

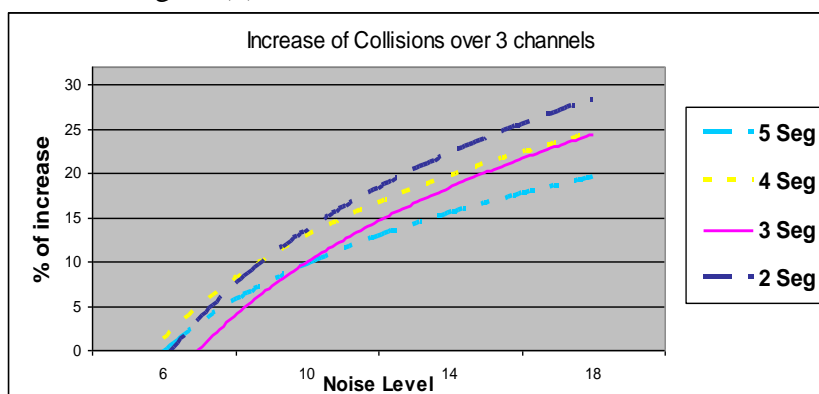


In figure (6) we got the best results regarding the delay inside the network having a value of 5ms. Even though the network gets the minimum delay for S (5,5), the difference from S (5,4) is quite minimal. An explanation is that, because modulo was designed for a row-of-nodes scenario but this has not been implemented to our network. Another explanation is that the volume of data sent through the network is not large enough in order to limit the network and the four channels can cope with it easily. In case we increased the load, five channels probably exceed in performance the four channels. It has been assumed [8] that if we use more than five channels results will not get any better so we give it a try. Another thing worth to mention is the how close are the values for the five segregated network. This is because the provided available routes using five subnetworks are already enough.



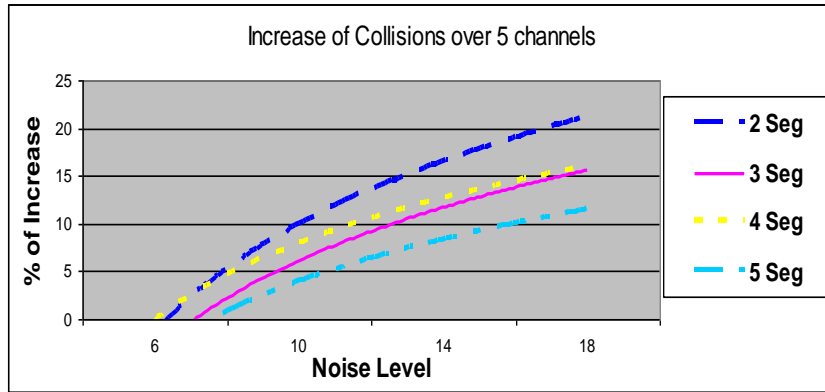
**Figure 7** Collision reductions over increase of segregate networks.

In figure (7) we calculated the percentage of collision reduction for four different values of noise  $m$  as the number of segregate networks  $g$  was increasing when just on channel  $k$  was deployed. For middle noise the reduction was average. On the other hand as the environment was getting harsher as the noise was increasing, network segregation was improving the reliability of the network and thus reducing more effectively the number of collisions that took place. This can be seen as the higher noise the improvement over collision reduction is steeper and can perfectly match the reduction of the delay as shown in figure (4).



**Figure 8** Collision increase over noise for three channels.

In figure (8) is presented the percentage of collision increase as noise level is increasing. From the graph it can be seen that the number of collisions has the minimum rate of increase when the network is divided into 5 subnetworks. Minimizing the rate of increase of collisions helps the network to improve its performance. This graph comes in accordance with figure (5). At the moment only 3 channels are deployed within each segregate network.



**Figure 9** Collision increase over noise for five channels.

In the last figure, figure (9), we see the ratio of collision increase while noise is increasing also. The graph shows that when we deploy five channels for a five segregated network, the collisions are increasing to the minimum possible ratio. Once more this graph comes to prove right figure (6) where we achieved the minimum possible delay for S (5, 5) network.

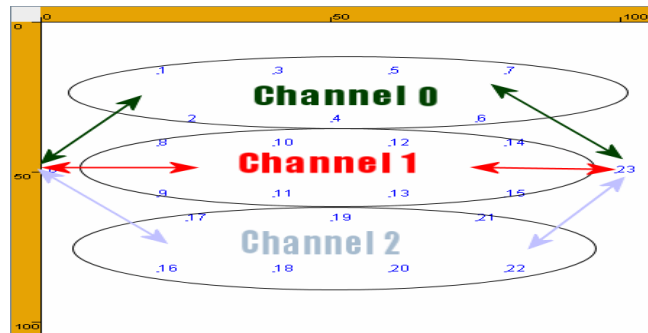
## Conclusion

In this paper we evaluated the performance of a wireless network that is divided into smaller subnetworks and these utilize a variable number of frequency channels. Target of the study is to get the best possible results according the variable as explained in (2). We find that when S (5, 5) we get the best possible results, dropping the delay of the network from roughly 16ms to 5ms. Apart from that, we showed that the performance improvement is result of the reliability improvement using as criteria the number of collisions during transmission. The difference from S (5, 4) is not big and this makes us to suggest that we can get a very decent delay within the network by using four channels. The use of four channels is more realistic as it requires less expensive and complex mechanisms for real world implementation. The base for the comparison was a simple wireless network using only one channel common for all its nodes. Modulo has been compared with other channel allocation as presented in [10].

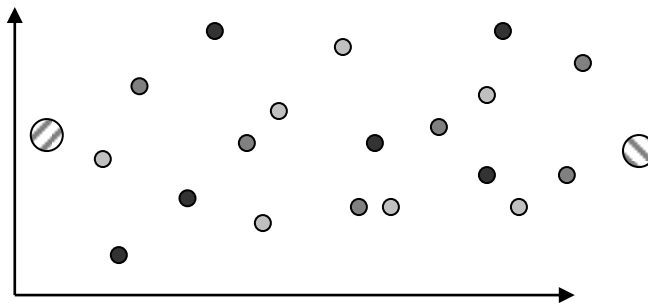
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**Figure 1** A sample of a 24 node segregate network using three different channels.



**Figure 2** A segregate network of 21 nodes. The side nodes operate in all the three channels available. All the rest nodes operate in different channels as separated from their colors.



**Figure 3** Modulo channel allocation algorithm

