Achieving 802.11 Wireless Networks Deployment in Noisy Environments

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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 traditional cables. Our attempt is based on this concept and we propose solutions which manage 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 gives adequate results when tested inside a harsh-industrial- environment. One the main advantage 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.*

Keywords: Wireless networks, ad-hoc, multi-channel communication, harsh environments, segregate networks, modulo.

1 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 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 at different frequencies than the rest. 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.

2 Literature Review

Node placement and deployment play a crucial role to the network stability and performance. During node placement, variable environment characteristics such as sources of interference and area morphology like physical obstacles and constructions should be taken seriously into consideration. This way it is easier to adjust the deployed wireless network to those needs, achieving maximum operability and performance.

To reduce interference, neighbouring 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 to interfere with each other. During our testing we used the multi-hop infrastructure which has been proved [2] to overcome many problems of the single-hop networks.

In the multi-hop infrastructure, a node may find many routes to access 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 to select and the appropriate channel for the communication. An approach is the use of single Network Interface Card (NIC) and trying to find a way for appropriately managing the multiple channels in use. The NIC should be able to change from one channel to another every time the node should communicate with a node without at the same time to interfere with the node next to it Kyasamur and Vaidya So et al. [3] proposed a routing and channel assignment protocol which is was based on traffic load information. The proposed protocol successfully adapted to changing traffic conditions and improved performance over a single-channel protocol and one with random channel assignment.

Bahl et al. [4] 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. Both of these approaches have been proved insufficient by the following approaches. A different approach was to install multiple NICs and each one to operate in different channel, the multi-radios technique. This way each node has to establish first of all a connection with the other node and after to decide to talk in a common channel from the variety of the available ones.

In this category falls the suggestion that has been made by Raniwala et al. [5] by developing 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. Apart from that, there are other proposals [6] and [7] which in fact require proprietary MAC protocols. They propose something like a packet-by-packet channel switching which resulted in an increased time per transmission. More MAC modifications were proposed in [8] to support beamforming, whereas [9] and [10] required a separate radio to communicate firstly with the neighbors and then start transmission. These approaches are under utilizing a channel just for configuration set up whereas it could be used in a more efficient and useful way.

3 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.

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 high speed and robust wireless network. The main problem to face in such network is the interference between the nodes that operate on the same channel. 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 firstly the 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 and secondly the 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.

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 numbers.

Channel assignment between the nodes now follows a more complex pattern called modulo, described in the next chapter.

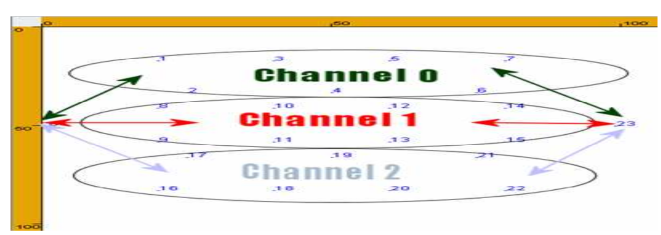

Fig. 1 A sample of a 24 node segregate network using three different channels.

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 technologies.

4 Systems Evaluation

The network was tested for a variable number of nodes, starting from 50 and reaching to 130 regarding the delay utilizing modulo. 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 [11], 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. 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..

4.1 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 the Ad hoc On-Demand Distance Vector (AODV) [12] in a standard mode, no multichannel enabled.

4.2 Segregate channel 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 placed in a random way.

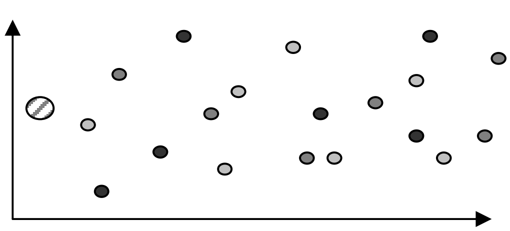

Fig. 2 A segregate network of 21 nodes. The side nodes operate in all the three channels available. All the rest nodes operate in different channels as separated from their colors.

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 [13] 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.

4.3 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 ...kn}* differ from the frequencies operating in the other *{k2, k4, k6 ...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 [14] 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:

$$f n = (n+k) \bmod c \quad (1)$$

A graphical representation of the modulo technique is shown next.

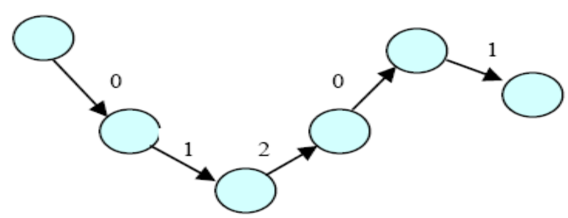

Fig. 3 Modulo channel allocation using three frequency channels.

The initiative behind modulo is that it decreases the effect of interference as the gap between nodes that use the same channel is large enough. Initially modulo targeted on nodes that were placed into a chain topology and not randomly. In our case placing 50, 90 or even 130 nodes into a chain topology is almost impossible and time consuming. For this reason a slight change should be made to modulo to adopt it into a segregated wireless network. 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.

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

We kept the general idea of the *(k+1)* hopping but changed the channel allocation scheme as the number of subnetworks 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 following example gives an idea of the algorithm used for a network with 2 subnetworks, $g=2$, and 2 channel $k=2$ utilized inside each one.

```
If NodesAddress(a) >= n(1) and NodeAddress(a) =<n(1+x)
then they belong to subnetwork g(0)
        If ReceiveChannel(k)
          then TransmitChannel (k+1)
        else if ReceiveChannel (k+1)
          then TransmitChannel (k)
Else if NodesAddress(a) >= n(x+2) and NodeAddress(a) =<n(x+y)
then they belong to subnetwork g(1)
      If ReceiveChannel (k+2)
        then TransmitChannel (k+3)
      else if ReceiveChannel (k+3)
        then TransmitChannel (k+2)
```

When modulo was initially proposed, five channels across a line of nodes where enough to reach the network to its maximum performance. In this paper we try to investigate if the same happens in a more complex network where all the nodes are not in a straight line.

4.4 Noisy Environment

The GlomoSim simulator that was used to perform the testing gives the user the option to increase or decrease the noise figure m of the environment. Noise is calculated as the sum of all the signals on the channel other than the one being received by the radio plus the thermal (receiver) noise. The resulting power is used as the base of SNR (Signal to Noise Ratio), which determines the probability of successful signal reception for a given frame. For a given SNR value, two signal reception models are commonly used in GlomoSim, the SNR threshold based and BER (Bit Error Rate) based. The SNR threshold based model uses the SNR value directly by comparing it with an SNR threshold (SNRT), and accepts only signals whose SNR values have been above SNRT at any time during reception. By increasing the noise/interference factor significantly increases the data packet drops as the accumulated power of interference signals and noise can increase the probability of frame drop including MAC control frames. Generally noise may have a greater impact on the operation of the routing protocols. In our case, the initial noise figure started from value $m=6$ and was increased up to 18, using the SNR model. The impact of the noise increase is clearly shown in the results section.

5 Methodology

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 [15], 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 provided by Parsec.

6 Results

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. Next follow the results that show the benefits of network segregation as the noise figure is increasing related to the delay. Apart from the network performance based upon network delay, we also 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.

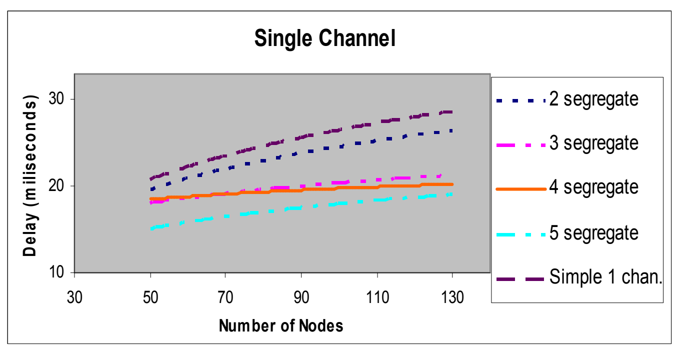

Fig. 4 The average delay of the networks for a variable number of nodes.

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 luck of multiple routes increases the delay. This first, figure (5), is the base for the comparisons for the segregate network using modulo.

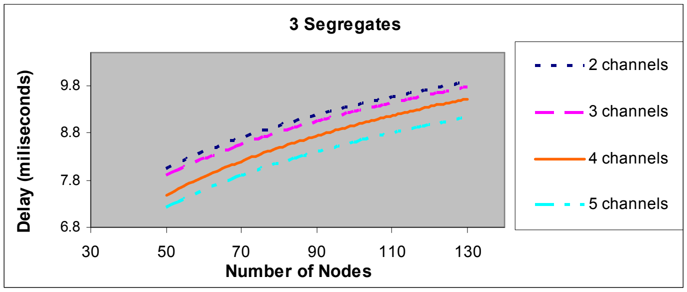

Fig. 5 The average delay in milliseconds of a 2 part segregated network utilizing two ore more channels.

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)

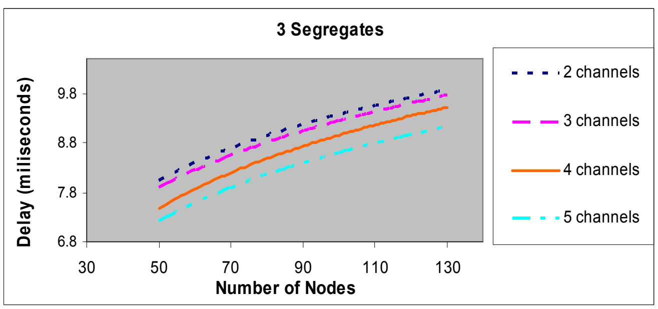

Fig. 7 The average delay in milliseconds of a 3 part segregated network utilizing two ore more channels.

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).

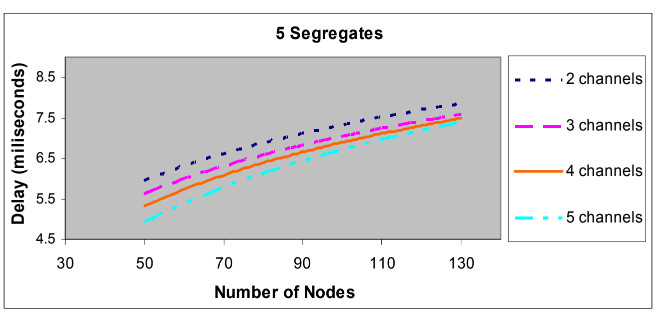

Fig. 6 A The average delay in milliseconds of a 4 part segregated network utilizing two ore more channels.

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 how close the values for the five segregated network are. This is because the provided available routes using five subnetworks are already enough. Another thing to worth to mention is that for S (5,1) up to S (5,5) the delay is decreased slightly and some might think that the gain is very small as we are talking about couple milliseconds. In our case, because limitations of the simulator, the traffic generated is around 4 KB and the network load is not that great. In a real life scenario the traffic would be much more and the final gain on the network's performance would differ significantly.

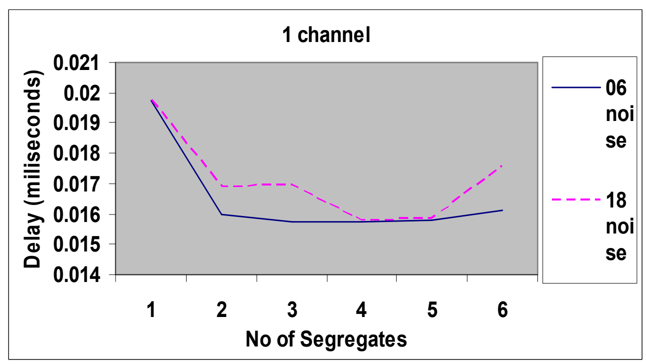

Fig. 7 The average delay in milliseconds of a 2 part segregated network utilizing two ore more channels.

In figure (7) we examine the drop of the delay as we divide the network into subnetworks and at the same time the noise figure is increased. Actually from the minimum value of 6 is noise is increased to value 18. Modulo is not deployed in the network and there is only one channel operating within each subnetwork. The delay is benefited from the network segregation although the noise increases. It should be noted that for more than 6 subnetworks, delay starts to increase again. This happens because of the low density of each subnetwork.

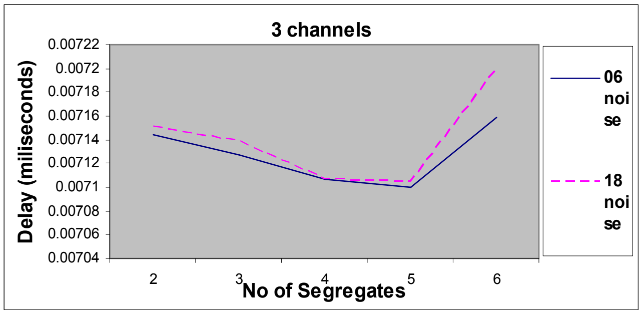

Fig. 8 The average delay in milliseconds of a 3 channel segregated network over noise increase

Again in this case, figure (8) we examine the drop of the delay as we divide the network into subnetworks and at the same time the noise figure is increased. The difference from the previous scenario is that we now utilize 3 channels inside each subnetwork and they are unique for each one. Once more the delay is benefits over the segregation and of course is reduced in value compared to figure (7).

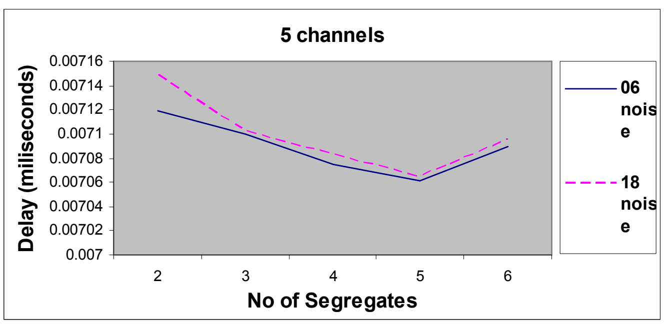

Fig. 9 The average delay in milliseconds of a 5 channel segregated network over noise increase

As shown in figure (9), we manage to achieve better results for the delay when the network is segregated into 5 subnetworks. The results follow the same pattern as previously. The number of nodes is 90.

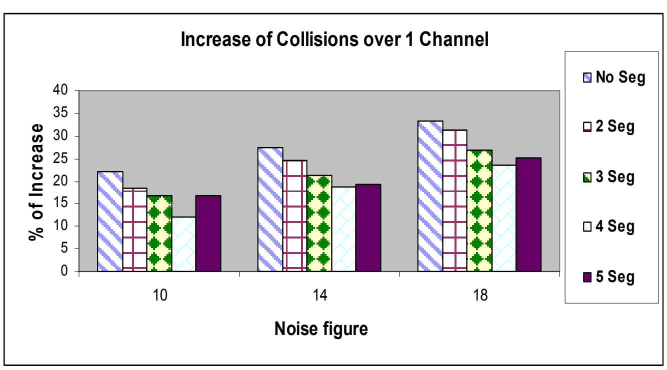

Fig. 10 Collision increase over noise for 1 channel.

In this category of results we examine the percentage of increase in number of collisions that take place during the simulation for 90 nodes. Noise is increase as the number of subnetworks does. It is evident that the network with no segregation shows the higher percentage of increase. On the other hand as the network is segregated the rate of increase lowers.

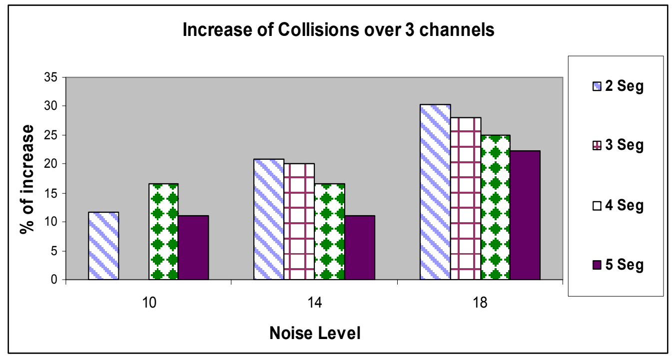

Fig. 11 Collision increases over noise for 3 channels

In figure (11) is presented the percentage of collision increase as noise level is increasing. From the graph is visible 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. At the moment only 3 channels are deployed within each segregate network.

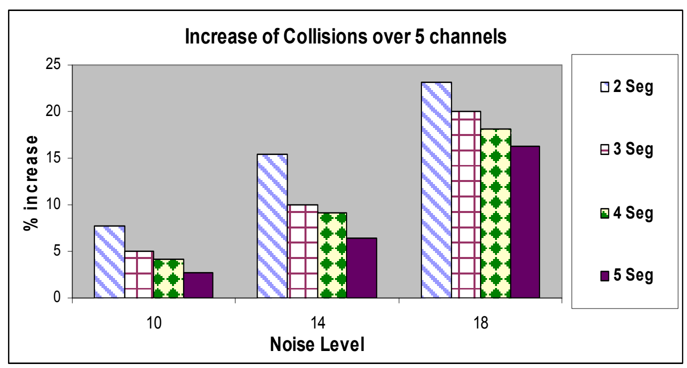

Fig. 12 Collision increases over noise for 5 channels

In the last figure, figure (12), 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.

7 Conclusion and Future Work

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. The difference from S (5,4) is not big and this makes us to suggest that we can get 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. We then moved on and started dividing the network into subnetworks, using a different channel for each one. We didn't include any results for S (1,2) up to S (1,5) as there is already work done on this aspect and the results can be found in our previous publication [11].

The next step was to identify if the reduction to the delay was happening because only of the utilization of modulo or the network segregation was also contributing. Inside a noisy environment, we checked how the delay was affected for different values of the noise figure and by increasing the number of segregated networks. It was shown that despite the noise increase, if we segregate the network, the delay kept dropping.

The last attempt had to do with the calculation of the total number of collisions that occur during the transmission. The results presented come in accordance with the delay results utilizing modulo. As g and k increase, network faces fewer collisions and the reliability of the network is increased.

This paper is a sequel of previous publication where we compared the segregate network idea with a uniform [16] multichannel network and also against GRID, a location aware protocol [17]. Target is to prove that simplicity can sometimes perform better than other expensive and complex techniques.

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