An Evaluation of Segregate Networks Compared to GRID Technology.

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Abstract- **In this paper we focus on Ad-Hoc networks, deployed in a mesh network topology utilising multi-channel technology. Our target is to investigate the performance of the location-aware channel assignment protocol named GRID compared to a segregated multi-channel mesh network. The term segregated means that the network is divided into smaller areas/teams 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. Both networks have been assigned with the same number of channels and used as a variable the number of the nodes within the simulated area. As we have seen from the results, we have managed to keep the average delay of the whole network low and sometimes lower than the delay in the GRID topology. The effect of single channel interference has been minimised and the throughput of the network has been increased.**

I. INTRODUCTION

Ad-hoc wireless networks provide a mean of networking together groups of computing devices without the need for any existing infrastructure. Devices which can be found in the text as nodes automatically form a network when within range of another and act as a router by forwarding any packets for other nodes. This permits nodes to communicate further than their transmit power allows them but also a more optimal use of the radio spectrum.

Since the first appearance of wireless networks, the traffic demands of the modern networks have been 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 of wireless networks are *interference*, *multipath* and *attenuation*. All these prevent the wireless networks from performing of 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 focus on Ad-Hoc networks, deployed in a mesh network topology utilizing multi-channel technology. The target is to investigate the performance of the GRID channel assignment protocol compared to segregated multi-channel mesh network. The term segregated means that the network is divided into smaller subnetworks and each one operates a single channel. The results of the tests have shown that segregated networks could improve delay, throughput and network reliability in a more simple and straightforward way as explained below.

II. LITERATURE REVIEW

All these years there are many proposed solutions for the MAC layer and the network, new routing algorithms but also existing algorithms improved through their routing decisions.

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, should be taken into great 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 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 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.

III. 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 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:

- 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.

In this paper are presented two different approached to avoid these problems.

GRID proposed by Tseng et al [11] a location-aware routing and channel protocol that enables each node to be aware of its position, through a GPS device attached on each node, at any time as it moves around and it uses the appropriate channel according to its position. In our case we leave out the mobility and use only fixed nodes. Our proposed approach is to divide the whole network into subnetworks, where each subnetwork uses only one particular frequency channel. This frequency is different than the rest frequencies already deployed into other subnetworks.

In both technologies mentioned above, there are a number of characteristics that need definition. Within a multi-channel environment the two main issues that should be addressed are: *channel assignment* and *medium access*. The first is to decide the node in which channel it should use to communicate with the other nodes. The other issue is to resolve the collision/contention problem using a particular channel. GRID is using the location information of the nodes to solve the channel allocation problem. It is the only location-aware protocol that has been proposed in a MANET environment focusing on the allocation subject. The term channel can be a frequency band, either FDMA or CDMA. The way to access multiple channels is mainly technology dependent. Disregarding technology dependences, the channel access capability is categorized into the following:

- *Single-transceiver*: The wireless node can access only one channel at a time either in simplex or duplex mode.
- *Multiple-transceiver*: Multiple channels can be access simultaneously in simplex or duplex mode.
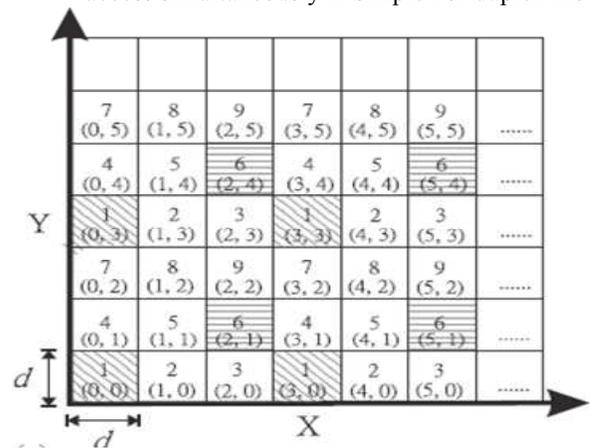

Fig. 1 Assigning channels to grids. Number of channels n=9. In each grid the top number is the channel number and the ones in the bottom are the grid co-ordinates.

The GRID is a multi-channel MAC protocol able to access multiple nodes increasing the available bandwidth within the wireless network and also reducing the possibilities of contention/collision. The idea of GRID is first of all to divide the physical area of the wireless network into smaller squares called grids, something similar to the cellular structure in GSM communications. The number of channels used within the network, depend on the number of grids. The example in figure (2) above has 6 grids for axis X and 6 grids for axis Y and totally there are 36 grids. The network uses 9 so the first 3 grids in both axes use the 9 channels and afterwards the pattern is being repeated. To summarize, the initial grids $g1$ on X axis and $g2$ on the Y axis, give the total number of channels k.

$$k = g1 \ x \ g2 \qquad (1)$$

As shown in figure (2), each grid is assigned a default frequency channel for the nodes to operate in. Every node that is within this grid uses this single channel. Since the node facilitates a GPS device on it, is able to be aware of its position and assign its channel according to the principles of the grid. There might more than one node within each grid. According to this pattern there is no possibility that a node will have a neighboring grid operating at the same channel, thus reducing interference.

On the other hand we propose a wireless network configuration which aims to increase the throughput of the network, minimize the effect of interference. At the moment we do not propose a new routing protocol as our target is to find the drawbacks of our approach and after the recommended analysis to create a new protocol that will fit best to the proposed network configuration. The configuration is called *Segregate* wireless networks and has an analogous approach as the GRID one. The nodes are fixed and spread around the physical area randomly and they are not location aware as the GRID ones. The network is divided, segregated, into smaller sub-networks where each subnetwork operates into a different frequency channel than the rest. Since we reduce the number of channels that operate at the same channel, the interference generated would be much smaller than if we had all the nodes listening to the same channel. Also there is no communication between them and the target of the network is to transfer data from one side of the network to the other. There are usually two *edge* nodes that are responsible for the data transfer. These nodes are multi-channel enabled and can switch from one channel to the other in order to achieve communication with all the sub-networks. Data is traveling from one side to the other following any of the available routes through the subnetworks, almost at the same. We say almost as the transfers cannot be really simultaneous, due to the channel switching delay of the side nodes. This delay is calculated about 80miliseconds. That way, it is possible to minimize the effect of collision/contention and at the same time to increase the throughput of the network.
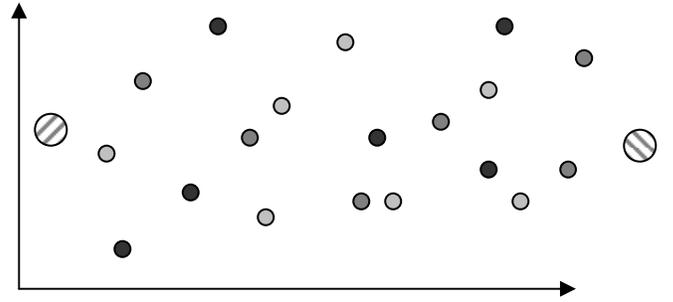

Fig.2 A segregate network of 21 nodes. The side (purple) nodes operate in all the three channels available. All the rest nodes operate in different channels as separated from their colors.

After the general description of the systems architectures that have been taken into consideration, the next chapter moves on to the detailed description of the testing and simulation that took place. All the set up details and ideas that were implemented to compare those two different network architectures.

IV. SYSTEMS EVALUATION

Both networks have been designed carefully to meet the requirements and the specifications that they were designed for. This way only it is possible to get the most accurate results from our simulations. First to attempt was the GRID network

A. GRID Network

The area simulated is an area of 200 meters by 200 meters, with a variable number of nodes. We decided the size of the grids to be so that we will not have to use many channels. This way we keep the number of channels low and at the same time make our testing easier since we don't have to utilize a large number of subnetworks within the segregated network. The number of nodes n takes values of:

$$20 \le n \le 105 \qquad (2)$$

On the other hand the grid size was given two different values. Testing has been implemented for grid size of $t1 = 10$ and $t2 = 40$ meters, keeping the same total area dimension a, and channels k.

Four frequency channels, $k=4$, were deployed inside the networks in both scenarios. In the case of GRID, for $t1$ we had $g1=2$ and for $t2$ again $g2=2$. In GRID technology the number of grids and the number of channels used are relevant and depended from each other. In both networks, GRID and Segregated, we kept the same density b which is given from the following equation:

$$b = n \ / \ a \qquad (3)$$

One more thing that should be taken into consideration is the transmission power and the range d of each node. Range of

each node is relevant to the transmission power Pt the receiver power Pr and is given from the equation:

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

During the simulations all the nodes were placed randomly inside the area *a*, trying to give a more real world sense to the network. The GRID protocol divided the area into smaller grids and placed the nodes randomly. Some of the grids might have more than one node inside and other might be empty. Increasing *n* more grids were occupied by at least one or more nodes. During the simulations we had to change the transmission power of the nodes when *n* had a small value as it was impossible for the nodes to communicate with each other. For large values of *n* we had to reduce *Pt*.

B. Segregate Network

In this scenario we deploy always the corresponding number of nodes as the GRID and we keep the same physical characteristics of the simulated area. The difference of with the GRID is that the nods are divided into groups depending the number of nodes and the number channels used. Since the *k* is constant in both scenarios the only thing that changes is the number of nodes within each segregate sub-network. Each sub-network operates in a single channel which is different from the rest. This ensures that there is no communication between the rests of the segregated parts of the whole network. There is no possibility that there will be a second sub-network operating at the same frequency.

All the network characteristics of the GRID network are adopted in our approach and the only difference is the way that channels are allocated to the nodes. In GRID channels are allocated according to the location of each node and we do not know how many nodes operate at particular channels. Inside the segregate network, channels are assigned according to the total number of nodes. For example when we have *n*=42 and the number of subnetworks *s*=4 we set 10 inside each subnetwork plus the two side nodes of the network which don't belong to any subnetwork. If we had totally 40 nodes, two out of the four subnetworks would have one node less than the rest. The maximum difference for any *n* between them is one node. It is a random technique which just ensures that each sub-network has the same number of nodes as the rest. This is done mainly to keep a balance for each sub-network.

The side nodes mentioned above, as in the GRID network, are responsible for the traffic generation. The target remains the same, to 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 sub-network. When data leaves from the transmitter, it has the option to choose more than one route. Actually it has 4 different routes to choose from. The channel allocation is clearly decided by the routing protocol used and in our case it is AODV [12] multichannel

enabled [13]. More than one node of each sub-network is able to listen to the side nodes, reducing the effects of broken links. Every time a side node tries to send data, selects the channel randomly without satisfying any criteria as soon as the other nodes are not busy. A route might be maintained for some time as long as it is needed. Graphical representation of simulations showed that during transmissions more than one route was set up. Figure (3) shows a representation of a segregate network with 24 nodes and how segregation is performed. Although it should be noticed that usually the nodes with same channel are mixed up with rest
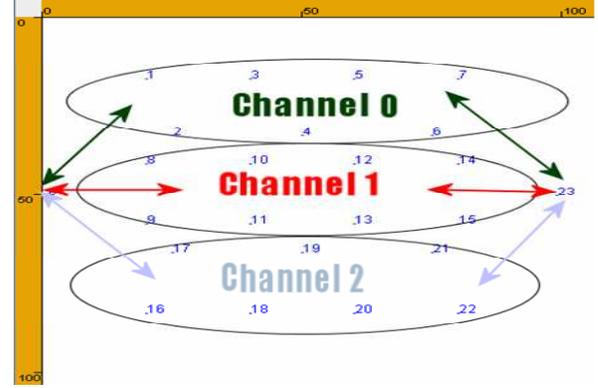

Fig. 3   A segregated network, using three channels. Side nodes are able to communicate with all the three sub-networks.

The main advantage of this approach is the increase at the total bandwidth available of the network. Each segregate network provides a different route utilizing the maximum bandwidth someone can transmit on a single channel. This way transmitting almost simultaneously through more than one path results in an increased bandwidth. As mentioned before the transmission power of the nodes Pt takes variable values according to the number of nodes in the network. In order for the network to be operable, Pt is adjusted accordingly. For example when n=25, the transmission power is Pt=-4 dB. To sum up the values that it can get are:

$$-2dB \leq Pt \leq -6dB \qquad (5)$$

This way the range of nodes is achieves to have a better coverage of the physical area. Mobile nodes are taken into consideration and they are able to move easily within the area and achieve better connections with the fixed nodes/access points.

V. 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 [14], 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. The next table shows the general network configuration used for the simulations.

TABLE I

SIMULATION PARAMETERS

Parameter	Value	Parameter	Value
Terrain	200x200 m	Nodes	20→105
Propagation	Two-ray	Channels	4
Pt	-2dB ≤ Pt ≤ -6dB	Duration	15 minutes
Mobility	None	Protocol	IEEE 802.11
Rate	11Mbps	Segregates	4
No Grids	5 & 400	Traffic	CBR

VI. RESULTS

The following graphs present the results acquired from the comparison of the two different technologies that have been explained above. The two side nodes at the two opposite sites of the physical area are responsible for the traffic generation. Because of the restrictions of GlomoSim for traffic generation, in order to increase the traffic and the load of the network, we assigned the two side nodes to send data one to the other at the same time, the same load, starting at the same time and ending at the same time also.. The application to generate the traffic is a constant bit ratio generator who sends data during the simulation time. The parameters of the network that are compared are the average delay, the average throughput and the delivery ratio of the data within the network. The following figures were gathered from the simulations and with the maximum possible accuracy.
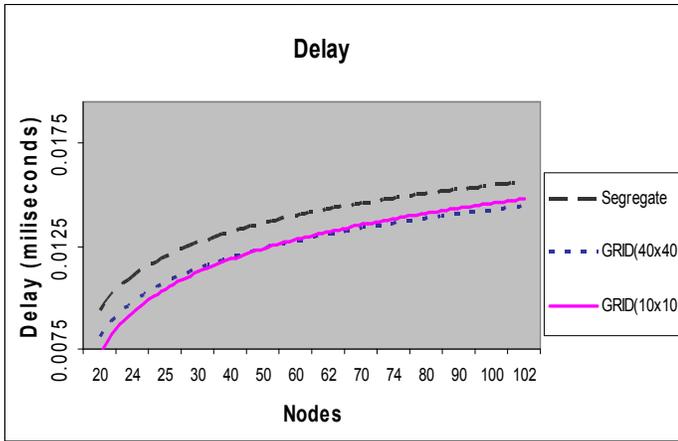

Fig. 4   The average delay of the networks for a variable number of nodes.

As we can see from figure (4), the average delay of the segregate network is slightly higher than the GRID technology. This is mainly due to the lack of an appropriate routing protocol. Although AODV does perform pretty well within a single-receiver node network, in a multichannel segregate network its performance is not the best possible. That's why there are currently many proposals from other researchers about routing protocols in such environments. The results indicate that the difference is really small, about couple of milliseconds. This difference was something expected as our

network configuration is pretty basic without any mechanisms to improve the QoS.

Since the data has to go through many routes, in case of congestion in one route there is no way for the route to be relayed to another sub-network where the load is quite lower. In this case the AODV is not very suitable for the current segregate approach. The network might function better if there was a more appropriate routing technique. Nevertheless even at the current form the results are quite promising regarding the delay parameter.
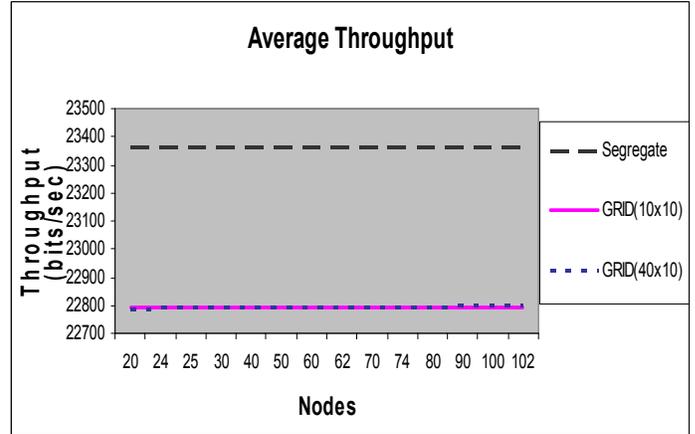

Fig. 5   The average throughput of the networks for variable number of nodes.

As shown in figure (5), one of the main advantages and capabilities is the increase of the throughput within the network during transmission. According to our requirements, the segregate network provides an increased throughput for the same sending/receiving configuration. This happens mainly because the multiple routes provided by the sub-networks but also the side nodes can switch within the different frequency channels with minimum delay. Apart from that, since a packet enters a particular subnetwork, all the nodes inside already know the path that it should follow. Only in case of a link failure AODV has to find an alternative route. It should be noticed that we are not able to define a maximum load overflow which would result in routing the data through another path. If we were able to set a load overflow and start routing data through less congested sub-networks, then we could see a slight increase to the throughput having a better utilization of the different sub-networks and possibly a decrease to the delay.
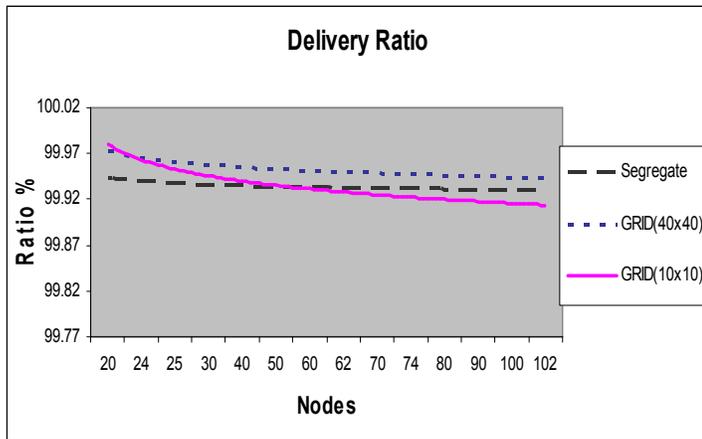
Fig. 6 The delivery ratio of the networks for variable number of nodes

In figure (6) we see the reliability of the segregate network compared to the GRID by comparing the delivery ratio. Delivery ratio is the sent/received ratio during the simulation process. It indicates the number of packets that were transmitted and did not require a retransmission because of collision or high interference. As it is shown above, the ratio of the segregate network is quite constant and does not have big deviation as the nodes increase. GRID watches its reliability to fall as nodes increase. The reason can found to the channel allocation being used and the small number of channels that we use. In case we used more channels, reliability would increase. Interference seems to affect seriously the network when there are 40-50 nodes deployed. The ratio of the segregate network exceeds the GRID network when it is being divided into many smaller grids.

VII. CONCLUSION AND FUTURE WORK

In this paper we evaluated two different network architectures, the Segregate and the GRID. Both are multi-channel enabled technologies used to transfer data within an industrial environment. From the results we can see that the general performance of our proposal is very satisfactory as it provides a higher throughput within the network and a better stability regarding the delivery ratio of the data packets.

This paper is a sequel of our previous publication [15], where we compared the segregate network with a uniform multi-channel network.

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