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GTSH: A New Channel Assignment Algorithm in Multi-Radio Multi-channel Wireless Mesh Networks

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ABSTRACT
One of the complexities in a wireless mesh networks is its low throughput. For this reason and due to the fact that throughput is highly reduced by increased number of nodes, it is difficult to extend such networks. Therefore, providing a high throughput in these networks is an essential goal. The main lowering cause of efficiency of such networks is interference between wireless links. A high interference leads to a reduced throughput. In this research, two channel assignment methods were presented using genetic and tabu search algorithms and their advantages and disadvantages were assessed. Finally, a new method combining the advantages of both methods was proposed. With the help of NS2 network simulator, our work was simulated and the combination results of the two methods were compared. The results were indicative of the better performance of the hybrid method and significant increase of throughput in the network.
***Keywords*:** interference, multi-channel, multi-radio, channel assignment, Throughput

I. INTRODUCTION

With the growth of communication technology and the need of permanent, high-speed connectivity to global networks and information exchange in every time and place, the need to develop wireless networks capable of connecting users to the Internet easily in any locations becomes more evident day by day. Generally, due to their specific capabilities and features, wireless mesh networks have been proposed as a novel growing and promising technology to promote next-generation wireless networks [1].

Wireless mesh networks consist of the two parts of mesh router and mesh client. A mesh router is assumed to be fixed and equipped with one or more wireless interfaces called gateways. These interfaces are directly connected to the Internet, while mesh routers provide coverage between the neighboring clients. They also connect with each other to form a multi-backbone wireless network to be able to create network traffic between mesh routers or between mesh routers and Internet through gateways. On the other hand, mesh clients can be fixed or mobile and connect to the network through mesh routers.

A major problem facing a wireless mesh network is reducing the backbone network capacity caused by wireless interference. using multiple channels can solve this problem since the links can transmit their data simultaneously on different channels. Therefore, many studies have been conducted on multi-radio multi-channel wireless mesh network [2]. A major problem faced by these networks is reducing capacity caused by interference between simultaneous transmissions. To solve this problem, the router is equipped with a radio interface and set on different channels to enhance network throughput [3].

By setting different radios on non-overlapping channels, mesh routers can simultaneously send and receive in a neighborhood. Therefore, using multiple radios and channels lead to spectral efficiency and augmented actual bandwidth available on the network [4].

A key aspect of the architecture of a multi-radio multi-channel wireless mesh network is channel assignment, including assignment of each radio to a channel in a way that to achieve suitable efficiencies of the existing channels. In particular, the objective of channel assignment in multi-step communications is minimizing interference on each given channel [5]. 802.11 b/g and 802.11 a standards provide 3 and 12 non-overlapping (non-interfered) channels, respectively. Although number of channels in 802.11 a standard is greater than that of 802.11 b/g standard, 802.11 b/g standard is used because of providing a higher transmission range and cheaper interface [6].

II. CHANNEL ASSIGNMENT

Channel assignment is an NP-hard optimization problem which different algorithms try to solve using heuristic methods [7]. Channel assignment, several conditions must be met that are described below:

1. There are a limited number of radio interfaces of each node, which are often less than the available channels. **2.** Ensuring topology preservation.
Therefore, a balance should occur between maximizing connection and minimizing interference. Fig.1 shows 3 states of the mentioned balance. A depicts a network communication when a channel is used. In this case, if a node is located within the transmission distance, it can create an communication. This would establish maximum communication in case of using a channel. B and C are 4 separate channels for an available connection. Each node is also equipped with 2 network cards acting on different radio frequencies. In B, assignment of a channel to a radio creates a maximum communication. However, this condition is fulfilled by choosing at most 3 from 4 channels.

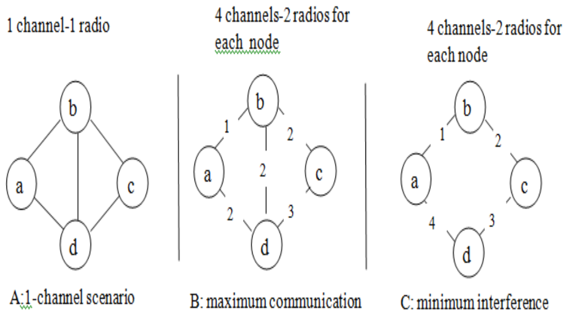


Fig.1: balance between connections and interference

For example, suppose that there is a direct connection between each pair of nodes. Yet, all these interfaces cannot be active at the same time because of the existence of interference on Channel 2. Nevertheless, C demonstrates how the interference between connections can be eliminated so that all of them are active concurrently though they cannot create a direct connection between b and d neighbors.
Channel assignment process can be considered to assign different colors for interference graph nodes. Each color represents an orthogonal channel. Thus, any monochromatic edges in the graph display a pair of interfering links that cannot be active simultaneously. A number of monochromatic edges would reflect a number of interfering link pairs that can be used to assess the network performance [2].
Classification of channel assignment has been generally shown in Fig.2. Our proposed algorithm is a sub-category of all-directional antennas of a static type.

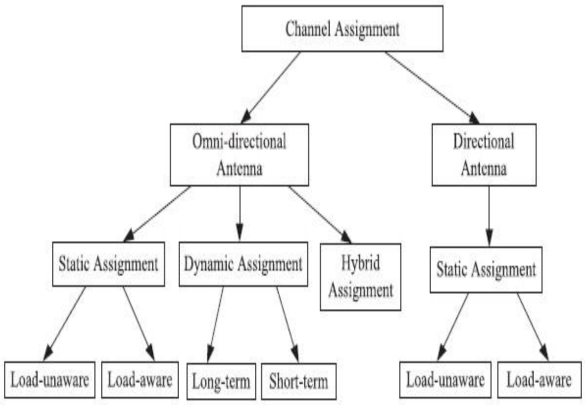


Fig.2:Categorization of channel assignment algorithms

There are 3 ways to assign a channel: 1) dynamic assignment; 2) pseudo-dynamic/static assignment; and 3) hybrid assignment [8].
1. Dynamic assignment: This method allows each interface to be set on each channel, while the interfaces can change frequently from one channel to another. The discussion on the synchronization between the nodes to communicate data and the issue of what channel should be selected for each interface will be of the existing challenges. The delay for switching a channel in an interface will be to the extent that might be unacceptable in some cases [9].
2. Static/pseudo-dynamic channel assignment: In this method, the channels are assigned to interfaces permanently or for a long time. The static methods are appropriate when the delay caused by changes in the interface is great. In addition, if the number of available channels is equal to the number of interfaces, the problem of channel assignment would be a simple one. Methods of static assignment do not require any special coordination for data communication between the nodes since the channels have already been assigned so as to readily transfer data. This is often simpler than other approaches since it does not consider changes such as those of traffic patterns or external interferences. A static channel assignment leads to a stable network topology, thus preventing the problems of network fragmentation and non-convergence behavior [10].
3. Hybrid approach: This method utilizes a combination of static and dynamic assignments. It employs the static channel assignment for some interfaces, while the other interfaces are assigned frequently to other channels.

III. Definitions used in this Research

3.1 Connectivity graph

To solve the problem of channel assignment, a network is considered to be a graph which is called a connectivity graph. The purpose is to assignment channels to the wireless links between the mesh routers. In these networks, a transmission range of R_t is considered for each router node. Depending on R_t value, a link is placed between the two nodes of less distance than R_t in a connectivity graph. A graph is defined as $G = (V, E)$, where V shows the vertices of the graph, actually acting as router nodes and E portrays the graph edges to represent the links between the routers.

3.2 Interference

After establishing a connectivity graph, the interference present in the network is calculated. To calculate the interference in the graph, an interference model is needed besides a transmission model for each node, which is defined as an interference range (R_i). When two nodes in the network occur within the same range of interference and use a shared frequency channel to transmit data, interference happens. There are two different interference models defined as follows:

1. Protocol model: This model indicates a transfer of Node A to node B would be successful if:

• A link used for transmission exists between them in the network topology.

• Each node C, in which $D_{CB} \leq R$, is not transferred on a channel utilized by A and B, where D_{CB} represents the distance between nodes C and B, and R shows the interference range, which is considered identical for all nodes for simplicity. In this model, to avoid collisions, RTS/CTS mechanism is applied.

2. Physical model: This model indicates a transfer of node A to node B would be successful if:

• SNIR (Signal-Noise-Interference Ratio) received at the receiver node is defined to be greater than the threshold.

• Noise power and receiver interference include the noise created by other transfers and the limited noise on the network.

Due to the complexity of physical models, applications of channel allocations mostly use protocol models.

3.3 Interference graph

An interference graph is defined as $G_c = (V_c, E_c)$, where V_c is corresponding to the links present within the connectivity graph and $\mathbf{E_c}$ shows the edge between two vertices, provided that the vertices in graph $\mathbf{G_c}$ (in fact, the edges in the connectivity graph) are interfering. According to R_t value and the interference model presented, the favorite network interference graph is created. For instance, Fig.3 displays an interference graph when transmission and interference ranges are identical.

As it can be seen, each edge is regarded as a vertex, between each pair of which a link is created.

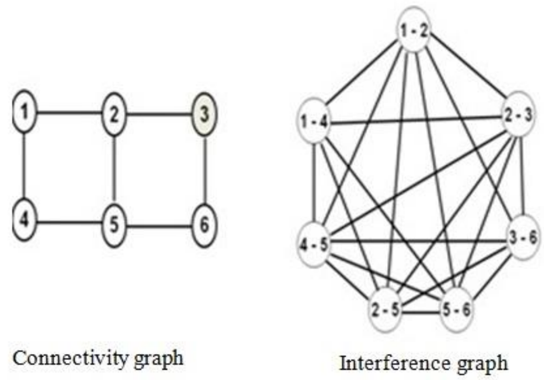


Fig.3: A view of a connectivity graph and its relevant interference graph

4.3 Fitness function

Another problem involved in algorithms is the method of evaluating how well the solutions are obtained by an algorithm. For this purpose, a fitness function is utilized. Fitness function must consider two issues. An optimal answer is an answer that: (1) minimizes interference; and (2) eliminates all restrictions. Fitness function is defined as follows:

$$\text{Fitness Function} = \text{Total interference} + k_1 * \text{MN} + \text{K}_2 * \text{LN} \quad (1)$$

Total interference: this quantity indicates the degree of interference on the network after channel assignment. any answer with less interference has a lower value of objective function and is thus more appropriate.

MoreNum (MN): It is the number of nodes of any solution not complied with the limited number of channels. MN quantity should be zero in the result obtained as the ultimate answer at the final step so as to demonstrate compliance with all restrictions

LessNum (LN): This quantity shows the nodes to which the number of assigned channels is less than their number of radio interfaces. It is not necessary for all nodes to use all their allowed number of channels; yet, if a node is to use all its channels, a greater reduction of interference would certainly occur.

IV. Related Works

In [7], Ananad has designed a centralized algorithm based on tabu search and a distributed greedy algorithm. In both algorithms, frequency channels are assigned to the radio interfaces of nodes to minimize interference. In [11], Wei Wang employed a genetic algorithm to solve the problem of a static channel assignment. The network is intended as a graph. At first, a few random solutions are generated and evaluated and then better solutions will be selected from among them. At this part, new solutions arise from the selected solutions. This process is repeated several times depending on the problem size. In [12], a new genetic algorithm based on tabu algorithm has been introduced. The purpose of this algorithm is to maximize the number of active links in a network, for which the idea of a maximal independent set is employed.

V. The algorithms used in this research

5.1 Genetic algorithm

The general steps of a genetic algorithm are as follows:

1) Generation of a random population of n chromosomes
2) Evaluation of the fitness function of each chromosome in the population
3) Creation of a new population by repeating the following steps:
• Selection of a few pairs of parent chromosomes of a population based on their degree of desirability
• Application of a crossover operator on a selected pairs of chromosomes and generation of two new offspring from each pair of chromosomes
• Calculation of a mutation probability for each offspring and changing the existing genes in the offspring based on the comparison of their mutation probabilities and the overall mutation probability
4) Utilization of the new population for the next iterations of the algorithm
5) Stopping the algorithm process in case of observing stop conditions and returning the best response
6) Going to step 2

The various components of the genetic algorithm for channel assignment are as follows:

Chromosome: In fact, each chromosome represents one of the solutions. each chromosome can indicate the channel assigned to each link. Chromosomes are composed of a number of genes. The number of genes in each chromosome is equal to the number of links present in a network and a gene value demonstrates an assigned channel. An example of chromosomes can be seen in Fig.4.

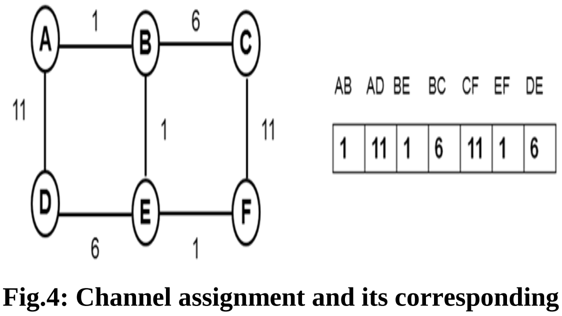


Fig.4: Channel assignment and its corresponding chromosome

As it can be seen, the left-side figure displays a connectivity graph and assigned channels to links with IEEE 802.11 b standard (Channel 11,6,1) and the right-side figure indicates the corresponding chromosome of this assignment.

Population: The different states of channel assignment to links create various chromosomes, which form a population. The population size (number of chromosomes) in each iteration depends on the problem size (number of nodes). In the beginning, the initial population is randomly generated (by selecting a random channel for each gene in a chromosome).

Fitness function: Fitness function was discussed in 4.3. Based on a chromosome fitness function, the present solutions in a population are evaluated.

Selection function for a crossover operation: Of the existing solutions in a population, selection function selects several solutions to create new ones. After calculation of the fitness of the present chromosomes, the chromosomes are sorted in an ascending or descending order on a list based on the fitness function value. Then, the list is divided into two better and worse halves. In 40% of choices, 2 parents are randomly selected from among the better half and combined together, but in the remaining 60%, one parent is randomly selected from among the better half and another parent from among the worse half. The aim is to utilize the solutions with a low fitness function since it is possible to arrive at good results by combining them with good answers.

Crossover function: The selected solutions are combined in pairs to create new solutions. The number of pairs selected is the same size as half of the population. The method used to combine the solutions is called a 1-point crossover function that can be seen in Fig.5.

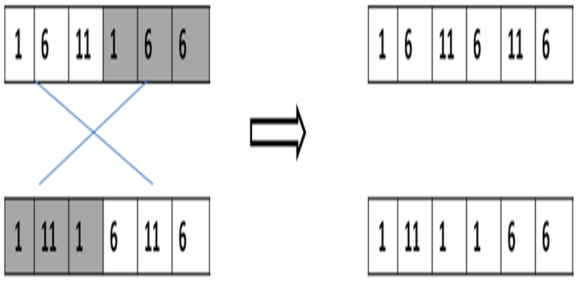


Fig.5: Method of a 1-point crossover operator

Mutation function: after the combination of two parent chromosomes and generation of a new chromosome, the value of a gene on the chromosome may change. a random number is produced for each chromosome. Also, a mutation probability is defined as desired. If the random number selected for each chromosome is less than that of a mutation probability, a genetic mutation occurs in that chromosome. The value of a chromosome selected for a mutation changes to a value other than the current value. For example, if the value is 1 and 3 channels exist (1-6-11), its value can change to 6 or 11 (Fig. 6).

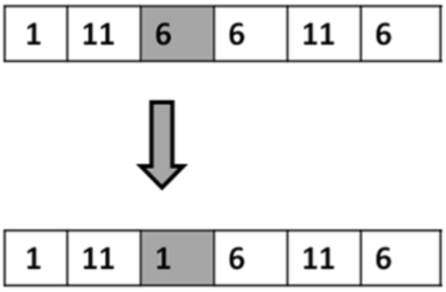


Fig.6: Method of mutation operator

Population selection for each next step: the beginning of each step of a GA, the present population is kept in memory. After creating a new population at the end of each step of the algorithm, the existing solutions in the new population are fitted and compared with the population in the memory. From among the answers, the best chromosomes are selected and then sent to the next step as a population. The advantage of this method is that the best solutions are always retained.

End: Genetic algorithm ends when no improvement is attained in the fitness function at a specified period. in some cases, it is seen that the results obtained are not observing all the constraints and in fact, the answer falls in a local minimum.

VI. Tabu search algorithm

Similarly, network topology is considered as a graph in this algorithm. Each solution is in a way that is regarded as a one-dimensional array corresponding to the links in the network and the channels assigned to them as it can be seen in Fig.7.

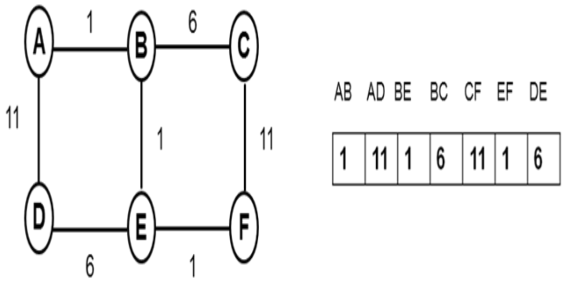


Fig. 7 Channel assignment and the corresponding arrangement

At first, a random solution is created. Then, this solution is assayed by the fitness function and is considered as its best value (F_{best}). This value and its corresponding solution are kept in memory. Afterwards, several new solutions are created from the current solution, each of which is called a neighboring solution. The method of generating a neighboring solution is selecting a link and giving it a new value other than its own. For example, in the figure above, channel 2 can be replaced by link 2 (frequency channel 6) and thus a new solution can be created. The fitness function value of this solution is compared with the best value (F_{best}) in the memory. If it is less, it will be taken as a new value and the value in memory is subsequently replaced by its corresponding solution which is selected as the best value. Otherwise, the best value does not change. The solution selected in this step is then used as the basis for the next step. The neighboring solutions are created from this solution in the next step. This process continues until no improvement in the fitness function is achieved at the specified time. The number of the neighboring solutions produced in each step is the same as the number of links in the network topology. Fig.8 displays the creation of 4 neighboring solutions from 1 solution. The fitness function for each of the 4 solutions is calculated and the solution with the best fitness function (lowest value) is applied as the basic solution for the next step.

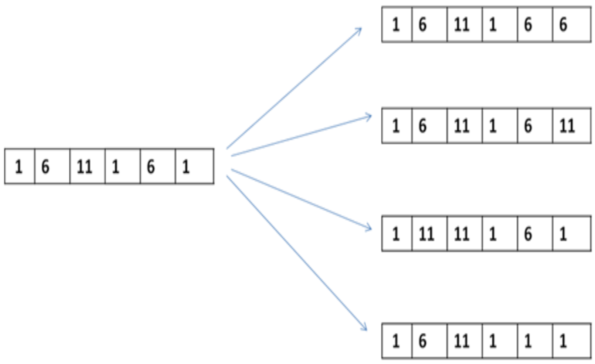


Fig. 8 creation of neighboring solutions from the current solution

Tabu List: To prevent a loop and quick convergence to a solution in tabu algorithms, creation of repeated solutions is prevented. For this purpose, a tabu list is employed. In each iteration, when a neighboring solution is chosen as the best solution, its corresponding change is recorded on the list. For example, if the solution is selected with a new channel assignment c_1 to link u, pair (u, c_1) will be recorded on the tabu list. If these changes are reselected in the later steps, their presence or absence on the tabu list is checked and they will be applied if absent. The values do not remain on the tabu list permanently and they are thus removed from the list after a specified time interval (after a certain number of running steps). For example, if in the second iteration of the algorithm, the value (u, c_1) is recorded on the list and the lasting time is 10 iterations, then, the value 10 is given to pair (u, c_1) on the tabu list. Figure 9 represents an example of a tabu list implemented by a table, the rows and columns of which demonstrate the links and channels, respectively.

	c_1	c_2	c_2
u	10		
v			7

Fig.9: A view of a tabu list

After the end of the algorithm, the best value stored is selected as the optimal solution. However, all restrictions are not usually observed by this solution. It means that several nodes in the network are seen to have utilized more channels than their corresponding interfaces in the end. Therefore, this algorithm requires a second phase by which the nodes not having observed the limits are identified and the number of their channels is reduced to the number of their radio interfaces.

5.2 Advantages and disadvantages of the two algorithms

• ***Genetic Algorithm (GA):*** As the search space of a genetic algorithm is a global space, i.e. it uses a global search, it is possible for one of the answers to approach the objective solution. the initial results are scattered at different points, each of which is improved until one ultimately reaches a general minimum value (objective). The main problem of a genetic algorithm related to the issue of channel assignment is its slow convergence to an optimal solution. According to what was said, a crossover function is used for the production of new offspring. This function selects a random point, on which two parent chromosomes are combined together in a crossover form. Since the crossover point is selected randomly and is not done intelligently, combining of two solutions sometimes provide solutions worse than the existing ones.

• ***Tabu algorithm:*** A tabu method starts from a random point in the search space and tries to find an optimal solution in its neighborhood. In fact, a tabu algorithm performs a local search around that very initial result. Arriving at an optimal solution in a tabu algorithm depends on the initial selected solution to a large degree. The results of this study revealed that a tabu algorithm mostly occurs in a local minimum and an optimal solution cannot be achieved, i.e. all limits are not observed in the final answer obtained and a number of nodes will possess a greater number of channels than their interfaces. A tabu algorithm has the advantage of a rapid convergence to an answer. Since it uses a local search mostly around a point, it quickly reaches a minimum response close to that point, especially when the initial point is made near to the minimum objective.

VII. Hybrid algorithm (GTSH)

The advantage of a genetic algorithm is its global search and the use of multiple solutions scattered in the search space simultaneously. Tabu algorithm advantage relates to the rapid convergence of each solution to a near optimal solution. Combination of these two solutions produces a new hybrid algorithm called GTSH. The main structure of this algorithm is like the genetic algorithm. It utilizes both the property of a global search and multiple solutions at each step. Nevertheless, it does not use crossover and mutation functions to create new solutions at each step. Its method of generating offspring is based on a tabu algorithm. Several random solutions are generated in the first step, each of which is improved in parallel using the tabu algorithm. Since the solutions are scattered in the search space, it is possible that at least one solution approaches the minimum objective solution. This solution is improved until it reaches the objective solution and then the algorithm ends at this point. The process of producing the solution is shown in fig.10.

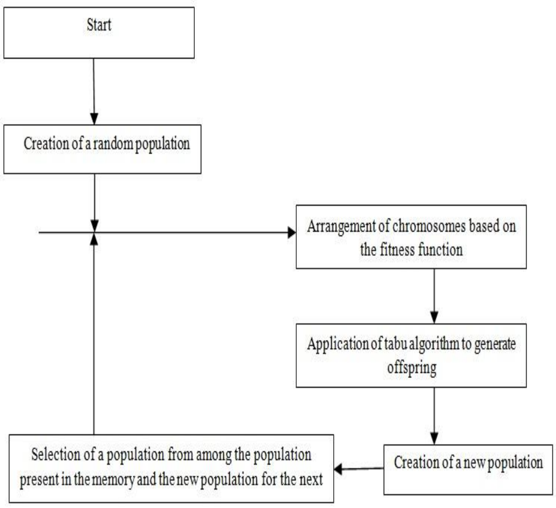


Fig.10: An overview of the steps in a hybrid function

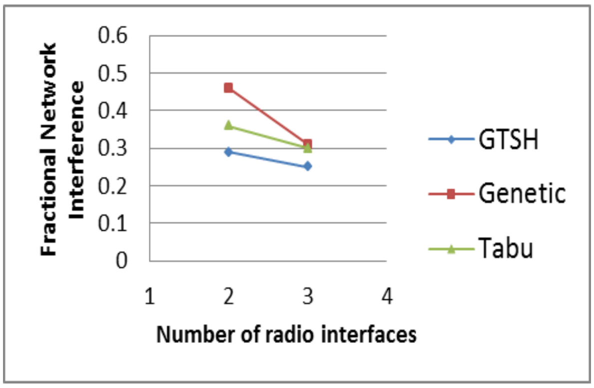
VIII. Simulation

To evaluate the proposed algorithm, a relative interference criterion was used. Relative interference is defined as the ratio of the number of interfering links after channel assignment to their number before channel assignment. At first, using the connectivity and interference graphs, the interference was calculated before channel assignment. After assignment of the channels, using the 3 genetic, tabu search, and hybrid algorithms, the degree of interference was calculated in the network.

The criterion for relative interference was a number smaller than 1. The more this number is closer to zero, the method used to assign the channels is more appropriate.

Simulation parameters: After creation of a random network, 50 nodes with a dimension of 800 × 800 m^2 were distributed. The degree of each node was 5, i.e. it was associated with 5 other nodes. Transmission and interference ranges were assumed to be equal for all the nodes. These ranges were considered to be 150 m and 300 m (double the transmission range), respectively. No two nodes could send their data within their own interference ranges simultaneously. Calculations were done based on IEEE 802.11b/g standard. In this standard, 3 orthogonal frequency channels existed. The coefficient values of k_1 and k_2 in the fitness function were set to 1000 and 1, respectively. The population size and mutation probability rate in GA were assumed to be 500 chromosomes and 0.01, respectively, the lasting time on the tabu list was set to 16 steps, and the number of neighboring solutions was regarded equal to the number of links at each step. These values were experimentally obtained using trial-and-error tests.

MAC protocol used in NS-2 was based on CSMA/CA, which employed RTS/CTS mechanism and the routing protocol utilized was AODV protocol.



Graph.1: Diagram of relative interference in a 3-channel mode

IX. Conclusion and suggestions

In this research, Genetic and Tabu Search Algorithms were assessed. These algorithms are from among centralized algorithms dealing with channel assignment in a static way. They employ random search methods to find optimal solutions. Genetic and tabu algorithms utilize population-based and local search methods, respectively. They greatly reduce the overall interference between wireless links within a mesh network, while this increases the end-to-end throughput of a network. The common problem with these two algorithms is their inabilities to find the main optimum solution and thus they do not often produce the desired result. Therefore, in this project, after careful consideration of these two algorithms, a new hybrid algorithm was presented, which tries to utilize their advantages and provide a better performance.

In this research, interference was only considered as a factor affecting the throughput and reducing it was thus the aim of the selected algorithms. To this goal, it was assumed that the traffic load is equally distributed in all parts of the network, i.e. the traffic conditions are assimilated all over the network. Nonetheless, it is not mostly the case and the traffic conditions are not the same everywhere in the network. In addition to interference, the traffic load present at different parts of the network should be considered in channel assignment and in fact, a load-aware channel assignment should take place so as to attempt to further reduce interference at points with a more traffic load than any other parts in the network. This requires combining the two layers of MAC and routing to allow the algorithms to work on them together.

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