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Channel Assignment in Multi-interface Multi-channel Wireless Networks

By
Muhammad Ejaz Ahmed
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Supervisor
Dr. Adeel Baig
NUST-SEECS

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National University of Sciences and Technology (NUST),
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Abstract

Channel assignment plays an important role in the performance of multi-channel multi radio wireless networks. Throughput and network connectivity being the very important performance metrics are severely degraded by the interference in these networks. Due to the dynamic and time varying nature of these networks, predicting channel quality and deciding the best channel becomes challenging. Channel quality is the function of interference caused by the transmissions in the neighbourhood nodes communicating on same channel, while connectivity depends on the number of channel and node density. Single channel provides ideal connectivity (network is fully connected), but on the other hand, it limits the overall throughput of the network. This results in connectivity-throughput trade-off. In this thesis, we propose a channel assignment algorithm that is meant to maximize connectivity and throughput at a certain level. In the proposed approach, channel assignments to the interfaces on each node depend upon the quality of a channel. Our algorithm is distributed in nature and becomes stable after few iterations of channel assignment. Our contributions in this work are to ensure connectivity and to maximize network throughput. Simulation results from ns-2 and empirical modeling show that our approach achieves better results compared to other approaches like common channel assignment (CCA) and optimization based approaches.

Certificate of Originality

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person nor material which to a substantial extent has been accepted for the award of any degree or diploma at SEECS or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom I have worked at SEECS or elsewhere, is explicitly acknowledged in the thesis.

I also declare that the intellectual content of this thesis is the product of my own work, except for the assistance from others in the project's design and conception or in style, presentation and linguistics which has been acknowledged.

Author Name: **Muhammad Ejaz Ahmed**

Signature: ________________

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Chapter 1

Introduction

1.1 Abstract

In this chapter we will present the basic concept of wireless networks. In the introduction section wireless background study including basic concept of channel allocation are discussed. Further, this chapter explains parameters used to perform channel allocation in order to gain throughput. Capacity problem arises in wireless networks due to interference. Interference causes significant throughput degradation of wireless networks. This chapter further covers significance of channel allocation in wireless networks.

1.2 Introduction

A multi-hop wireless network with multiple transceivers and channels increases capacity. Multiple transceivers are aimed to provide capacity gains in terms of higher bit rates. Two wireless nodes can communicate successfully with each other, if the receiving node is within the transmission range of a sending node and both nodes are tuned on the same channel. For capacity gains, connectivity must be ensured for data transmission. We define connectivity as, there must be at-least one path between any pair of wireless nodes in the network. As the number of channels and interfaces increases on a wireless node, one must take care of channel assignment on each interface on that particular node. Simultaneous transmissions on the same channel from two or more nodes being in interference range of each other cause interference. Hence the main goal is to reduce interference and increase capacity gain. Channel assignment in traditional multi-channel multi radio wireless networks is based on greedy approach, where a channel with best channel quality for a given transmission is selected [3],[4]. Best channel can be defined as the channel with highest bit rate. The use of multiple channels in multi-channel multi radio wireless networks provide performance gains and reduces loss due to collisions. Our goal is to improve network aggregate throughput and maintain connectivity. We propose channel allocation algorithm that performs channel assignment on each node depending upon the success delivery ratio as the parameter for channel quality, while maintaining connectivity among the networks.

Traditional wireless networks are characterized by fixed spectrum assignment policy where a new approach is cognitive radio networks. In a cognitive radio paradigm we opportunistically sense the spectrum and utilize the part of the spectrum which is available. however with the new paradigm of cognitive radio wireless networks we can use spectrum depending upon the licensed user spectrum usage. To utilize the white spaces (the band of frequency, which is not used by a licensed user at particular instance, space) we need to impart cognition to cognitive nodes. In the paradigm of cognitive radio networks the heterogeneity plays the main role. Due to the heterogeneous characteristics of spectrum in cognitive radio networks, efficient channel assignment becomes a challenge. This is because these channels have different ranges, data rates and interference parameter in time and space. We discuss different approaches that cater for

the channel assignment problem.
Channel switching in traditional wireless networks is different from channel switching in cognitive radio networks (CRN). Firstly, in traditional multichannel wireless schemes there is fixed number of channels available that can be used but in case of cognitive radio networks (CRN) the number of channels available at particular instance is not known in advance. In CRNs channel availability varies in time, space and frequency depending upon traffic demands from licensed users. The primary user has the exclusive right to use its licensed band anytime it wants and can come back to channel anytime. So, secondary users have to vacate the band for primary user. Secondly, the deafness and multi channel hidden (explained in the following sections) node problems of a node also arises in the traditional wireless and CRN's.
Cognitive radio supports the capability to select the best available channel. There are four main functions that cognitive radio network must handle:

- Spectrum sensing: Detecting idle spectrum and sharing the spectrum without any harmful interference effects with primary users.

- Spectrum management: To pick the best available channel in terms of bandwidth and interference level to meet the user requirements.

- Spectrum mobility: To be able to switch to the new spectrum (white hole) in case of the primary users comes back. Secondary user may switch to a better spectrum (having good channel conditions like less interference or noise).

- Spectrum sharing: To provides the fair spectrum scheduling among the secondary users who want to use the spectrum.

1.3 Aims and Objectives

The most important objective is to increase capacity and decrease interference among different radios. Increase in capacity is achieved by assigning channels in such a way that interference is reduced. Decrease in interference will increase performance and capacity is improved. Our objective is to investigate and explore channel assignment by doing following tasks:

- To know about the number of interfering nodes on a particular channel. The number of interfering nodes on a channel help us to estimate interference. Estimating interference is of vital importance because due to interference the performance of a system may degrade.

- Traffic awareness among the nodes tuned on a particular channel. Channel is assigned to know the traffic pattern of each interfering node because there may be n, number of interfering nodes but all nodes are silent and only one node is potentially interfering node which is transmitting most of the time. So while assigning channel we must have knowledge of traffic patterns of each interfering nodes.

- Topology awareness plays an important role in channel assignment. Maintaining connectivity and topology is challenging task. Change in topology due to multi channels having heterogeneous characteristics, may give rise suboptimal paths having higher number of intermediate nodes. So maintaining a given topology is important metric for performance gains.

- Channel capacity must be known before we assign channels. Due to channel heterogeneity in cognitive radio wireless networks we must know rate/range in advance before we assign channels. Heterogeneous channels are assigned to reduce interference. Interference is reduce if the number of nodes blocked from transmission is lesser as compared to selecting a channel which encompass larger number of nodes.

- Channel quality can be estimated from :
  a. SINR which leads us to find BER (bit error rate)
  b. Link layer delay
  c. Monitoring queue length on each node can give us intuition about channel conditions

1.4 Research Gap

In [2], author assigned channels depending upon traffic flows and distance parameters while without keeping in view the interference parameters. Interference has an important impact on the performance of the networks, so we cant overlook interference parameters. While in [2], author took SINR as the metric to estimate the distance of sending and receiving node, while we can not take this metric to find the distance between two communicating nodes because if the SINR value is high than we can get intuition that receiving node is near but in case if low SINR value we can not say that the node is far from us. In [5], channels are assigned depending upon interference parameters. While in the context of cognitive radio networks we not not sure about the availability of a particular channel. In [5], author worked for the wireless mesh networks in which fixed number of channels are always available while in cognitive radio networks we are not sure about the availability of any channels at any particular time. In [7], channel opportunities are explored depending upon the activity factor of a particular channels. In [7], author reduced channel switching latency depending upon the usage of a particular channel. Channel sensing is of great importance in cognitive radio. There is sensing/throughput trade-off. In [7], main task of the paper was to increase channel opportunities and reduce channel switching latency. After the channel was available it is assigned to a particular flow. Channel assignment is done without considering the interference, traffic impacts on performance in [7-11]. In [12], vulnerable period is reduced by using hybrid carrier sensing (physical carrier sensing, virtual carrier sensing). Vulnerable periods are those time periods that can cause interference due to hidden node and exposed node. so we need to be traffic-aware along with interference-aware so that we assign channel in a way to optimize performance (throughput) of the networks.

1.5 Research Contributions

Channel Assignment plays an important role for better performance. In our work, we emphasized to maintain connectivity and throughput. Since, there is trade-off between throughput and connectivity. Connectivity can be defined as: there must be at-least one path between any two nodes in the network'. We introduce connectivity by taking into account the 2-hop neighbours on any particular node. Critical links in the network is given more weight in channel assignment. so our approach go for the prioritized channel assignment.
Channel conditions are taken into account for channel assignment. As channel conditions go worse, our algorithm trigger channel assignment while maintaining channel connectivity. Our work mainly focus on 2-interfaces at each node.

Chapter 2

Current Channel Assignment Techniques in Literature

2.1 Abstract

In this chapter we will discuss recent approaches in channel allocation algorithm. As we know interference plays vital role in wireless networks, we will discuss interference modeling done in recent approaches. Channel assignment can be categorised in different types depending upon the dynamical behaviour of network. We have explained different types of channel assignment that are static, dynamic and hybrid channel assignment algorithms.

This portion will explain types of channel assignment and brief description of the recently proposed schemes in the literature till now. It will also explain parameters that are used in to quantify channel conditions parameter. Pros and cons of each algorithm will be discussed in detail too.

2.2 Channel Assignment and Types of Channel Assignment

Channel Assignment is the process of assignment of radios on each interface on node. Different approaches are proposed in literature for channel assignment nodes having Multi-Interface and Multi-Channel.
Bong-Jun Ko et al. [2] proposed distributed channel assignment algorithm for wireless mesh networks. In their channel assignment algorithm, they assumed non orthogonal channel. Channels are assigned to nodes only if the channel reduces overall interference in the network with the help of cost function. They assumed that each node knows the exact number of nodes in their interference range and their channel conditions (cost function). This assumption is not practical, because predicting channel quality of the neighbors in interference range is difficult due to varying channel conditions. In contrast, our algorithm-based channel assignment is performed by keeping in view success delivery ratio and connectivity. Raniwala et al. [3] proposed distributed channel assignment for multi radio wireless mesh networks. Their proposed channel assignment scheme was only for wireless mesh networks. They proposed channel assignment scheme in which assignment to higher nodes in the tree could affect the channel assignment to nodes that are in the lower hierarchy of the tree. In [4], Li et al. proposed hybrid channel assignment scheme. In this approach, each node has multiple interfaces, one interface is set fixed on a channel for longer time while other interface is switchable. If a node wants to communicate with a particular node in its transmission range, it switches its switchable interface to the fixed channel of the destination and starts communication. Ma et al. [5] proposed channel assignment technique for cognitive radio networks, where channel heterogeneity characteristics were incorporated in their work.

Spectrum utilization of the wireless band was maximized and solved as an optimization problem. Following constraint was formulated in their work.

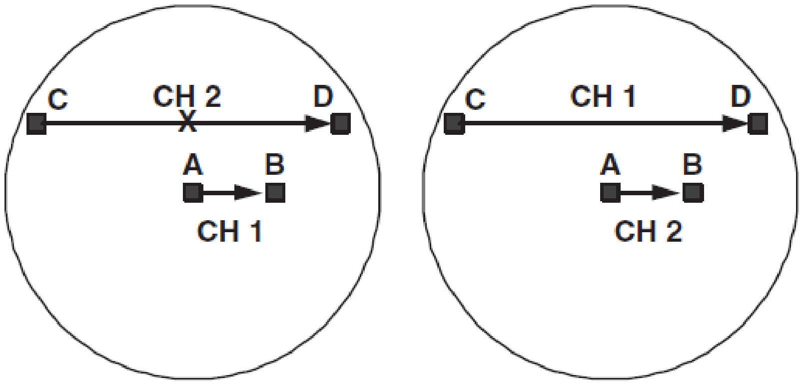
$$x^m\_e + x^m\_e' \leq 1(e \in E, e' \in I^m\_e, m \in (C\_e \cap C\_e'), e \neq e')$$

In the above equation x^m_e is decision variable that is equal to 1, if on link e, channel m is tuned. From the above equation, m is channel from the set of available channels C, e is link from the set of links E. While e' is set of interfering link of the link e.

2.2.1 Load-aware Channel Assignment

Load-aware channel assignment schemes use traffic load as a metric to calculate traffic on each channel. This load parameter is used to quantify the interference on a particular channel. As load increases from a certain limit on a particular channel, channel change process is initiated. In the following, we will explain techniques used to describe channel assignment.

Haythem Bany Salameh et al [2] proposed channel assignment algorithm which was made to increase simultaneous transmissions based on SINR values. The channel assignment [2], may be suboptimal but the main goal is to increase simultaneous transmissions. In this approach the dependence between signal attenuation model and transmission distance is exploited. In this paper author used SINR values to assign channels. In this approach author exploited the distance to assign channels. By doing so they increased the number of simultaneous transmissions. Channels assignment approaches in traditional multi-channel wireless networks typically try to select the best set of channels for a given transmission [2]. In the above figure in PRN1 (primary radio network) is on ch 1 and PRN 2 is on the ch 2. Ch 1 has low frequency and ch2 has higher frequency. But ch2 has higher interference. So in the above fig according



(a) BMC channel assignment

(b) Distance-dependent channel assignment

Figure 2.1: Channel Assignment [2]

to BMC Ch 1 is assigned between a and b similarly channel Ch 2 is assigned between and d. Since ch2 will require higher power to transmit to D due to its high frequency. So that may cause the interference to the PR users. So to avoid that CD transmission is not allowed. But we can do alternative in the sense that we assign channel 1 to CD and channel 2 to AB. In this case simultaneous transmissions are allowed and throughput can be achieved. This problem is addressed by the paper. Consider two PRNs and one CRN in the above figure. PRN1 operates on low frequency band (ch1) while PRN 2 operates on high frequency band (ch2). Let suppose we have four cognitive radio nodes (A,B,C,D). A and C wants to send data to B and D respectively. The channel ch1 has higher SINR value than the channel ch2. Ch2 has lower SINR due to interference factors. The distance between A and B is less than the distance between C and D. now while assigning channel, best channel (ch1) is assigned between A and B. now we also have power constraint

on cognitive node so that primary users are protected from interference. Now the problem arises when ch1 is assigned and we are left with only ch2. Since ch2 is having not higher range so it cant work between C and D. while on the other hand we also have power constraint. Due to optimal channel assignment the throughput of the overall network is increased. While at the same time blocking due to unavailability of the channel is decreased. The distance and traffic aware makes this approach more optimal because simultaneous transmissions are possible now. Such simultaneous transmissions increases throughput of the system. Under medium and high traffic load this approach performs good.
While there are some drawbacks is this approach.

- Under low traffic loads or conditions the performance of this channel assignment degrades because suboptimal channel are assignment.
- SINR is not a good metric to estimate the distance of destination node from the source node. Because due to interference the SINR value may get lower but at the same time the destination node may be nearer to source node.
- There is fairness issue in this approach because according to this scheme near node is assigned suboptimal channel while far node that is with in transmission range us assigned good channel.

2.2.2 Interference-aware Channel Assignment

Interference-aware channel assignment take into account the link quality or channel conditions. As channel conditions deteriorate, the channel change mechanism is initiated. Ramachanran proposed centralized algorithm for wireless mesh networks, that considers interference on a particular channel to model interference.

The main theme of that approach is to reduce interference and gain capacity. Krishna et al [5] proposed channels assignment based on the interference. In this paper centralized server is used to assign channels to links. The server CAS (channel assignment server) is used to accept information from all the nodes and than reply by assigning channels to the links. Krishna et al [5] used extended conflict graph approach to multi radio conflict graph. In this scheme each router have at least one radio. Router have at least one radio with default channel, same channel to which all nodes are tuned to. This constraint is implemented so that change in topology has no effect on the flows. When there is some flow on a particular node n, after channel changed on that node block the way of flow. To prevent this blocking there is a default radio on which the flow is carried out without any interruption. The main goal of the paper is :

- minimize interference between routers in mesh
- minimize interference between mesh network and wireless networks co-located with mesh

2.2.3 Default channel selection

Default channel is selected depending upon the rank of a particular channel. The default channel is the channel having least interference on all the routers. Rank for all channels on all routers is calculated and the least value is taken that corresponds to a particular channel and that channel is selected as default channel.

2.2.4 Non default channel selection

Non default channel is selected by CAS server that uses multi radio conflict graph. All nodes share there channel information and in the reply CAS assigns channels to all links.

2.2.5 Interference estimation method

Krishna et al[5] estimated the interference on a particular channel by Rfmon Mode. In this mode management as well as data frames are captured. From the management packets one can know size of the packet and rate at which the data is transmitted. From these two parameters we can estimate interference on a particular channel. By sniffing packets with unique MAC addresses we can know how much interfering radios are there. By sniffing management packets and getting packet size and rate we can estimate how much of the bandwidth is utilized from which radio.

2.2.6 Link delay estimation

Link delay estimation is a function of link bandwidth and loss rate at that particular channel. Link delay is calculated from expected transmission Time (ETT). ETT of a link is given by (etx * s/b) where etx is the expected number of transmissions required to transmit a packet, s is the size of packet and b, is the bandwidth of link.

2.3 Channel assignment in Cognitive Radio Networks

Cognitive radio is the new standard introduced recently by IEEE as 802.22. This is a hot topic for research. Cognitive radio differs from traditional wireless networks in some aspects. Channels heterogeneity, channel availability, data rates variability are some of the factors that we have to cater in cognitive radio. In cognitive radio networks secondary users (unlicensed user) share spectrum from primary user (licensed user) due to scarcity of spectrum. Usually the usage of the spectrum is about from 15% to 85% [1] that vary with time and space. So the licensed bands that are utilized by the primary users may not utilize the spectrum most of the time. While due to big demands from other users in recent time it is necessary to share the band of the primary users with secondary users (unlicensed user). This new networking paradigm is called next generation or cognitive radio networks. The spectrum utilization of the primary users can be depicted by the figure :1

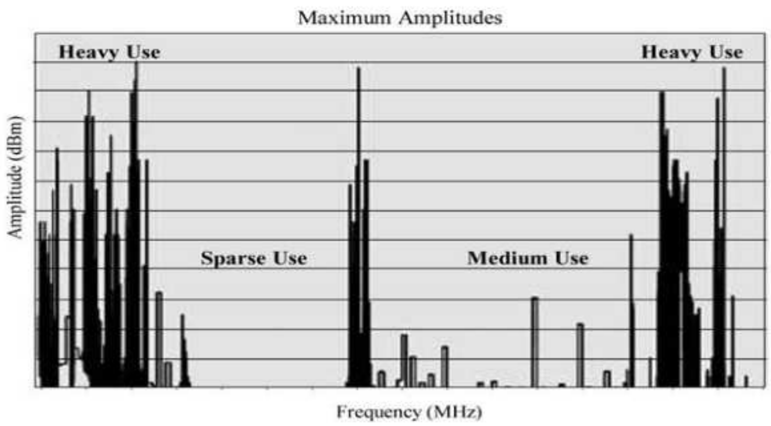


Figure 2.2: Spectrum Usage [1]

2.3.1 Main Components of Cognitive Radio Networks

Due to limited spectrum utilization we need another paradigm for the efficient use of spectrum. Cognitive radio supports the capability to select the best available channel. There are four main functions that cognitive radio node must handle [6]:

- Spectrum sensing: Detecting unused spectrum and sharing the spectrum without harmful interference with other primary users.
- Spectrum management: Picking the best available channel in terms of bandwidth and interference to meet the user requirements.
- Spectrum mobility: Switch to the new spectrum in case of the primary users comes back or to switch to a better spectrum.
- Spectrum sharing: Providing fair spectrum scheduling among the secondary users who want to use the spectrum.

Channel assignment is not trivial task in cognitive radio networks. Our purpose is to ensure channel assignment to reduce the interference and increase throughput of the system. Traditional wireless networks are characterized by a fixed spectrum assignment policy but in cognitive radio paradigm we need dynamic one because channels in cognitive radio available at a particular time may not be available at next moment. So it's the bigger challenge to assign channels in such a way that interruption is minimized.

2.4 Hybrid Channel Assignment in Multi-interface Multi-channel Nodes

In Hybrid Multichannel Protocol (HMCP) each node has two interfaces one fixed and other switchable. The main design issue is that the switchable channel period shall be carefully handled because it may increase switching overhead. To explain this point we have :

- Smaller time period to switch to different channel may increase the overhead of switching which decreases throughput. While larger time period may starve other channels.
- If waiting time is too long it decreases interface utilization.

In hybrid Multichannel multi interface (HMCMP[4]) the rendezvous problem is solved by the use of fixed interface of each node is used for data communication. All nodes in network know about the channel on fixed interface of other node in this way the rendezvous problem is tackled. So the common channel saturation problem was solved which results in high contention and reduced throughput. The common control channel results as bottleneck when the number of channels increases. In HMCMP[4], the problems of HMCP was solved by introducing the dynamic channel waiting time assignment depending upon the filled queue size. So each channel is assigned the dynamic channel duration time according to the weight of the queue.
There are two time periods assigned for each channel dynamic duration:

- Fixed staying time (to reduce channel switching frequency that reduces throughput)
- Dynamic staying time (depends upon traffic loadwhich is different for different for different channels)

2.4.1 Dynamic waiting time assignment for reducing sensing overhead

In order to solve multi channel hidden node problem a node waits for certain time before starting the communication on the newly switched channel. This waiting time is a back-off time period. This waiting time (back off period) reduces the collision

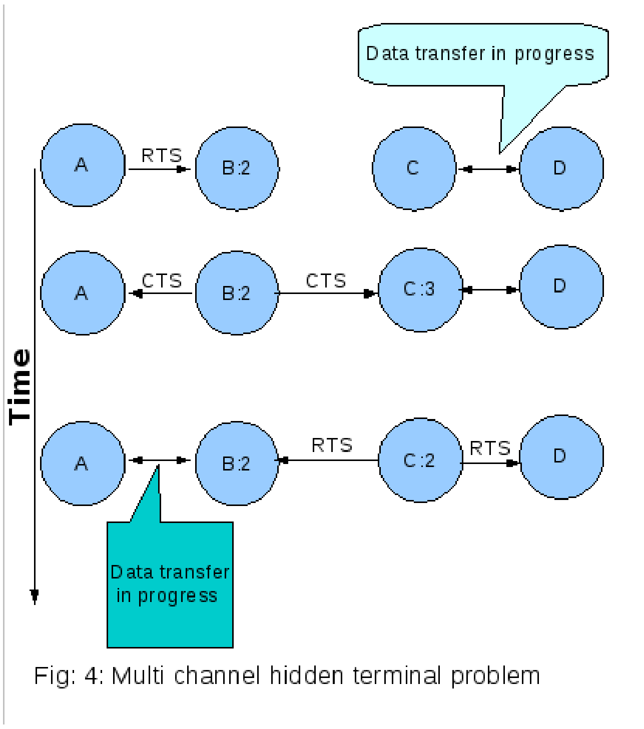


Figure 2.3: Channel Assignment [2]

problem. So the waiting time is the function of the number of nodes contending for the same channel on the switchable interface of the node. Based on the simulation results Chi-Yu et-al [4] has found the optimal waiting time values for the waiting time on which the throughput is maximum.

The problem with Chi-Yu [4] is the assumption that each packet of the fixed sized in the queue. Packet sizes may vary. In the future we can use the varying size packets to find the dynamic channel assignment time for each channel.

In [3], the scheme proposed is based on the 802.11 DCF to make

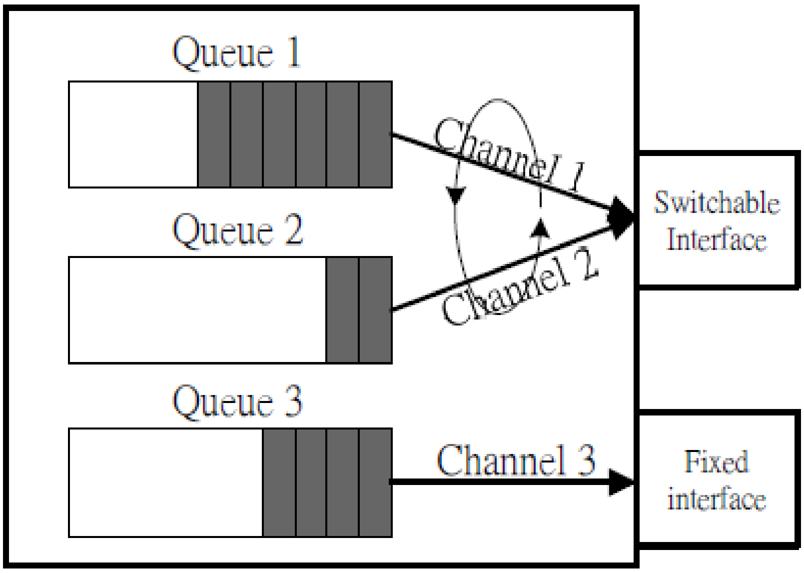


Figure 2.4: Queues at interfaces [4]

it compatible with in CRN paradigm. Cheng et-al[3] used the channel assignment scheme which balances the overhead caused by the broadcast of RREQ and gain obtained from multi channel. Cheng et-al [3] also addressed the problem of deafness (explained below) among the nodes. In this scheme one channel was used to transmit data using 802.11 DCF.

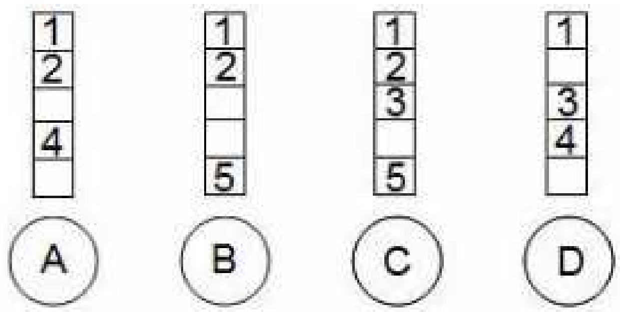
2.5 Synchronized MAC Protocol For Multi-hop Cognitive Radio Networks

In [3], author solved some problems pertinent to multi-channel wireless networks (common control channel problems, multi channel hidden node problem). In this approach the author went for distributed approach to communicate with other nodes instead of centralized common control channel. The paper contributions are to avoid the use of CCC (common control channel)

- Waste of channel resources
- CCC gets saturated as the number of users increases
- Prone to DOS (denial of service attack)

2.5.1 Contributions

The other contribution of the thesis was to mitigate multi-channel hidden node problem. Fig below represents 4 nodes with their respective channel sets. Suppose that only adjacent nodes are in transmitting range. Since channel 1 is available to all nodes, suppose that channel 1 is chosen as the control channel and that node C and D are already communicating using channel 3.



Four nodes with respective available channels

When node A wants to transmit a packet to node B in channel 2, it sends an RTS to B on the control channel (channel 1 in this case). B sends a CTS proposing channel 2 for data communication. Node A sends a confirmation message to B and to its neighbors that channel 2 is reserved for data communication.

But since C was communicating in channel 3, it did not receive the CTS from B. So C assumes that channel 2 is free and might initiate a communication with node B in channel 2 resulting in a collision. This is called the multi-channel hidden terminal problem. Though, the problem is solved successfully using this method, a CCC is still used for control signal exchange.
They proposes SYN MAC having:

- each node has 2 nodes, one for control information exchange and other for data transfer
- N channels are available but each node has different number of available channels

In MHCRN[12] the author addresses same issue for cognitive radio environment . in cognitive paradigm the availability of channel is not sure. While we know every channel have different ranges and bandwidth. So in MHCRN[12] in the network initialization state, the first node divides time into N number of equal time slots of fixed duration Tc, since there are N possible channels. Each time slot is dedicated to one channel for control signal exchange. The node then beacons in all its available channels at the beginning of the corresponding time slots. The following nodes choose one of the channels and listen for beacon messages to synchronize their listening radios. Since the first node broadcasts in all its available channels, the following nodes can choose any channel and be sure to receive a beacon message within NTc seconds. After it receives a message, the nodes exchange information about their channel sets. If it did not receive a beacon, then it is considered to be the first node.

In MHCRN[12] when a node wants to start a communication, it should exchange the required control signals. To exchange the control signals it chooses one of the channels common between itself and its neighbor. It then waits for the time slot which represents the chosen channel. Since all nodes will be listening to that channel in that slot duration, it will start exchanging its control signals with its neighbor. The flow of the channel sensing is given in the following figure below:

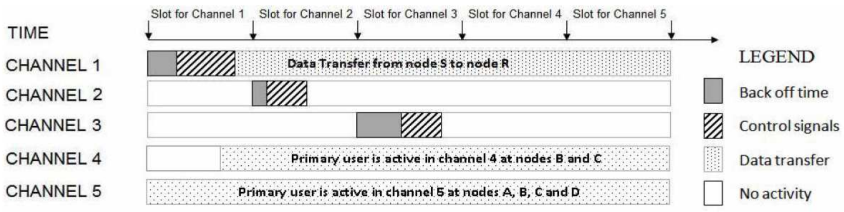


Figure 2.5: Protocol description [4]

2.6 Distributed Interference-aware Channel Assignment

In [15], distributed channel assignment algorithm is introduced. In [15] non orthogonal channels are considered and channel assignment is done depending on the channel whose interference is minimum with all other channels. Main goal of the work is to maximize channel utilization. In this approach following are the number of inputs given to algorithm: number of nodes in interference range, node i current channel, and channel on each node in the interference range of a node i. As it is already mentioned that this approach takes into account overlapping channel. Each node selects the channel by comparing each available channel with all channels tuned in the neighbourhood, and selects the one with having minimum cost function. Connectivity issue still remains in this approach. The algorithm proposed in [15] was stable in a sense that the over-all interference decreased after channel assignment.

In this algorithm the decision depends upon the information

available in the local domain. That is, each neighbour node tuned on a particular channel. This algorithm needs complete information of the nodes with in the interference range of a node i, however, this assumption is not very much practical. Information about the nodes with in interference range may not be correctly received.
In [14], capacity problem due to wireless interference has been catered. In [14], efficient heuristic algorithm is introduced, that is distributed greedy algorithm. This algorithm takes interface constraints from the start and assign channel based on the number of interfaces available with nodes. Conflict graph based approach is used to model the interference in this approach. Initially colours all the nodes in the conflict graph with same colour. In each iteration choose the node-colour pair that minimizes interference (not violating the interface constraint) the most and change the colour. The process is repeated until the interference decreases monotonically. In [14], they formulated channel assignment problem to minimize interference.

In [17], distributed and localized interference-aware channel assignment technique is introduced for cognitive radio networks. In [17], novel interference estimation technique is used using conflict graphs at each interface to model interference. In this work, multiple channels and multiple interfaces are utilized to reduce interference and increase aggregate throughput of the network.

2.7 Summary

The literature relating channel assignment schemes shows that the existing schemes use one of the following metrics for quantification of interference: traffic load, channel utilization and number of interfering interfaces. These metrics do not accurately

capture the impact of interference on throughput of wireless networks. The schemes relying on these metrics and the interference estimation mechanisms lead to suboptimal throughput of WMN.
All existing channel assignment schemes implicitly construct the network topology during the process of channel assignment. Most of the existing channel assignment schemes do not consider the trade-off between network connectivity and throughput of the network. Consequently, the achievable throughput is indirectly affected.

Chapter 3

Proposed Algorithm

3.1 Abstract

This chapter of thesis will explain the problem formulation and the proposed algorithm. All steps of the algorithm are discussed in detail. Further channel assignment scenarios are discussed with random topologies and channel assignment. This chapter also explains the channel assignment in random topologies with different number of nodes, channels, and interfaces. The results of channel assignment tells about the connectivity of topologies and the channel usage reuse in topology. Different scenarios will be discussed in detail about the channel assignment.

The average of success delivery ratios to each neighbour on a particular interface is called channel quality. We call it channel quality. Stability of channel assignment algorithm is very important and mandatory in wireless domain. An algorithm is said to be stable if channel change by that algorithm do not increase overall interference level of the network.

3.2 Proposed Algorithm for Channel Assignment

3.2.1 Assumptions

- It is assumed that each node has information about the number of neighbors.
- Success delivery ratio with a particular neighbour node on an interface is the ratio of number of successful packets transmitted to the over-all packets sent to that neighbour node.
- It is assumed that channel conditions are static that is success delivery ratio at particular interface do not change.
- Each node shares its channel quality (aggregate channel delivery, explained in next portion for calculation) with all its neighbours.
- There is single control channel available for the exchange of control information.

3.2.2 Network Model

We consider network with randomly distributed nodes in area A. Each nodes is having I number of interfaces. Let C be the set of channels in the network. We have k non overlapping channels that can be used to assign to each radio at node. In the network N is the set of nodes randomly placed in area A. In our scenarios we placed nodes in the area randomly and than ran channel assignment algorithm.

3.2.3 Problem Statement

Given number of nodes N, each node with I number of interfaces and C number of channels, keeping in view channel quality in terms of aggregate delivery ratio of each channel, number of neighbours at each interface of node , we have to assign channels on each interface of all the nodes in such a way that throughput is increased while maintaining connectivity.

3.3 Algorithm and Description

3.3.1 Algorithm steps and Explanation

In our algorithm each node exchange the information with their neighbours. It is assumed that each node have information about channel tuned by other nodes in its interference range. In our algorithm, each node calculates aggregate success delivery ratio to every neighbour on each interface. Aggregate success delivery ratio is the average of the success delivery ratio of a node to all of its neighbors on a particular interface. In our approach, each node share aggregate delivery ratio to its neighbors.

The major steps of the algorithm are summarized below:

Step 1: As we have already assumed that each node has information about success delivery ratio (ratio of total number of ACKs received to total number of packets sent to a particular neighbour on interface i) to all of its neighbours on a particular interface. In the next step, decision is made for the channels on that channel quality parameter.

Step 2: If on a node i, the channel quality on interface k degrades from a certain threshold then node i counts the number of neighbours having the channel quality less than threshold. Each node shares its channel quality (aggregate success delivery ratio) with it neighbours. So, each nodes has information about

its neighbours and their aggregate success delivery ratio. The number of neighbours having channel quality (a.k.a aggregate success delivery ratio) less than threshold is normalized with total number neighbours of node i on interface k. The normalized value gives us the information about the number of neighbours of node i, on interface k, having channel quality (aggregate success delivery ratio) less than threshold.
Step 3: In this step the normalized channel quality calculated in step 2, is used to decide for the channel change at node i and interface k. If the value of normalized channel quality of node i on channel j exceeds threshold then channel change decision is carried out. The normalized channel quality metric quantifies the number of neighbours of node i on channel j, that are having channel quality less than threshold.
Step 4: When the node decides channel change, it take into account all the nodes in the transmission range and prioritization is done. By prioritizing, we means that weights are assigned to each neighbour in the transmission range. Weights are calculated with respective to each neighbour node to maintain connectivity. The equation given below will depict, how weights are calculated:

$$weights(i,k) = common\_nodes(k) + (total\_nodes(k)/N)$$

In the above equation weights(i,k) means weight of neighbour k of node i. Common_nodes(k) means the number common neighbours between node i and node k (where node k is the neighbour of node i). total_nodes(k) represents the total number of neighbours of node k (where k is the neighbours of node i) and N is the total number of nodes in the network.
Step 5: In this step all neighbours of node i are sorted in descending order depending on their weights. The node with highest weights is selected and channel on node i is tuned according

the selected node.

Once the channel decision is taken by the node, all the nodes with in transmission range having channel quality less than the threshold are change channel. This can be explained, let node i on interface k has normalized channel quality less than threshold and now node i has to change channel. Node i selects channel having better success delivery rate and inform other nodes to tune on the channel selected by node i. In this way, the connectivity is ensured up to certain level among the nodes. Dictating neighbour nodes having channel quality less than threshold, to change to channel selected by node i have following advantages.

- All nodes in the neighbourhood having channel quality less than threshold are changed to same channel, so connectivity is achieved up to certain level.
- The remaining nodes (from above point) having channel quality greater than threshold remains on the same channel. This divides the nodes in two channels instead of one that were previously tuned on,so it adds in the throughput.

3.3.2 Algorithm Code

In this section, we explain the algorithm code and the symbols used to explain algorithm steps.

3.4 Summary

Proposed channel assignment algorithm contributes with aggregate throughput gains and connectivity. Most of the work discussed in literature address one of the challenge either throughput or connectivity. Our approach address both of the challenges. Proposed scheme allocates channels on the channel qual-

Algorithm 1: Channel Assignment Algorithm

Input: Channels C, Number of Interfaces I, Success Delivery Ratio with all neighbors of node i on interface k , and number of nodes N.
Output: Channel assignment at interface at I

```
begin
    AggregateDeliveryRatio ← Avg(SuccessDeliveryRatio of node i, with each neighbor on interface k);
    if Node i's AggregateDeliveryRatio on interface k ≤ Threshold then
        TotalNeighborsDegraded (i,k) ← count(neighbors of i on interface k having AggregateDeliveryRatio < Threshold); /* i is node and k is interface */
        DegradedNodes ← TotalNeighborsDegraded / TotalNeighbors;
        if DegradedNodes ≥ 0.5 then
            TotalNodes ←Total nodes in transmission range of node i, on interface k;
            if length.TotalNodes==1&AggregateDeliveryRatio at neighbor≥ Threshold then
                Select channel on node i that is common with TotalNodes(1);
                if length.TotalNodes > 1 then
                    foreach (Node k in length.TotalNodes) do
                        Set neighbors (k) ←neighbors of node(k) on interface j;
                        TotalNodes(k)←Total nodes in transmission range of node i, on interface k;
                        CommonNodes=intersect(TotalNodes(i),TotalNodes(k));
                        Weights(i,k) = CommonNodes(k) + (TotalNodes(k) / N);
                    end
                    if isempty(CommonNodes(k)) then
                        Weights(1,k)= Max(Weights)+1;
                    end
                end
            end
            Nodes ←sort weights(i,k) in descending order
            channels ←channels at nodes(1);
            channel ←channel at interfaces of Nodes(1) having AggregateDeliveryRatio > Threshold
            set Channel channel at interface(k) of node(i);
        end
    end
end
```

ity (aggregate success delivery ratio). As discussed in previous section that aggregate success delivery ratio is a good metric to quantify interference on a particular interface tuned on a particular channel. The main advantage of using this metric, as discussed previously is that, it provides channel conditions on both sides (sender and receiver).

Connectivity is ensured in proposed algorithm by incorporating 2-hop neighbours of a node. The final decision is taken by weights assigned to each neighbours on a node to maintain connectivity. Simulation results show total connectivity in the network.

Chapter 4

Topologies and Channel Assignment Results

4.1 Abstract

This Chapter will explain the problem formulation and the proposed algorithm. All steps of the algorithm are discussed in detail. Further channel assignment scenarios are discussed with random topologies and channel assignment. This chapter also explains the channel assignment in random topologies with different number of nodes, channels, and interfaces. The results of channel assignment tells about the connectivity of topologies and the channel usage reuse in topology. Different scenarios will be discussed in detail about the channel assignment. Stability of channel assignment algorithm is very important and mandatory in wireless domain. An algorithm is said to be stable if channel change by that algorithm do not increase overall interference level of the network. In this chapter stability of proposed algorithm with mathematical modeling and results of about the stability of proposed scheme.

4.2 Network model in Matlab

The network model that is considered for our simulation consists of N nodes that are randomly distributed in area A. Each node has I interfaces. There are total C channels in the network. Every channel has different success delivery ratio. In our scenario we have distributed nodes randomly with in area A. Each node is assigned channels with CCA (common channel assignment). Every node has some success delivery ratio on each channel. That delivery ratio for the start are taken randomly. Depending on the success delivery ratio channel assignment is done to optimize the network performance in terms of throughput and connectivity. Our approach is novel in the sense that connectivity is also maintained besides capacity. Following parameters are plug into ns2 for results.

- number of nodes
- x and y coordinates from matlab for each node
- channel success delivery ratios for each channel
- channel assignment on each node

4.3 Topologies with channel assignment

We performed simulations on random topology. We get random topology from Matlab and performed channel assignment. The topologies and channel assignment are given in the figure below. Figure shows the nodes placement. In the first portion of the figure the network topology is shown under single channel. Our approach ensures connectivity. While in the second portion of the figure , connectivity graph is shown along with channel assignment. Topology clearly shows that our channel assignment connects the whole network completely. Our algorithm exploits channel assignment and connectivity. The scenario in Fig:5 has 5 nodes, each node has 2 interfaces and each channel has transmission range of 250 m. Number of available channels at each node is 3.

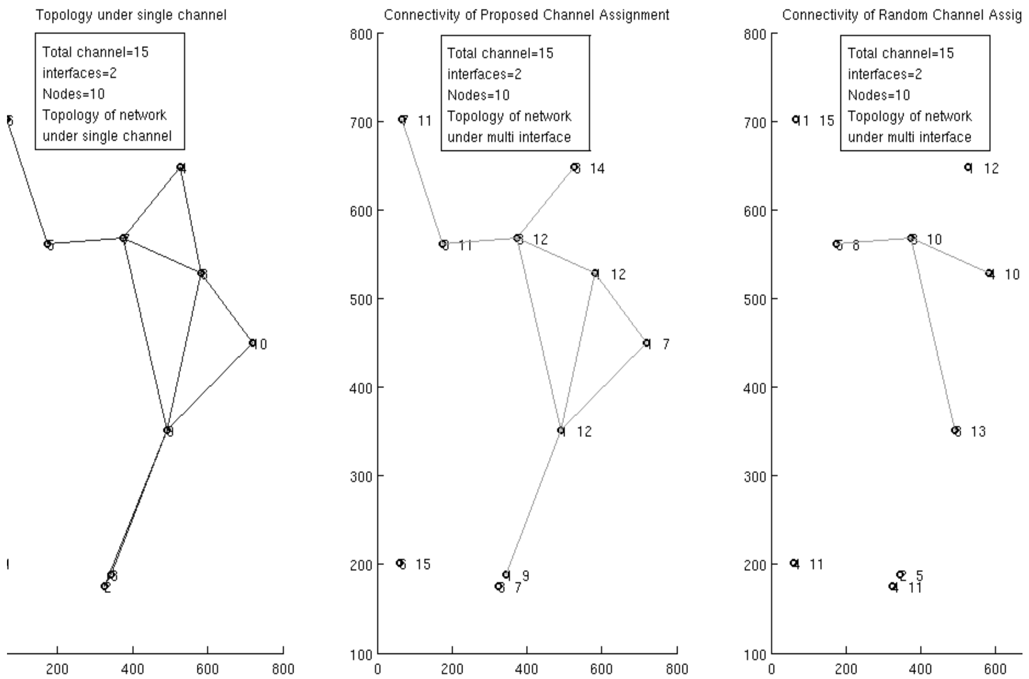


Figure 4.1: Example scenario for channel assignment

The links in topology graph shows the connectivity. We define connectivity as If a pair of node is in transmission range and tuned on the same channel, we call this node pair as connected. Each node is numbered in topology graph. While in the connectivity graph, we have nodes with channel assignment on each interface. The links connecting other nodes shows the channel on which that node is connected to other node in the topology. The scenario above shows that network is totally connected. In the second scenario we take number of nodes 10, number of channels are 5 with transmission range 250 m over

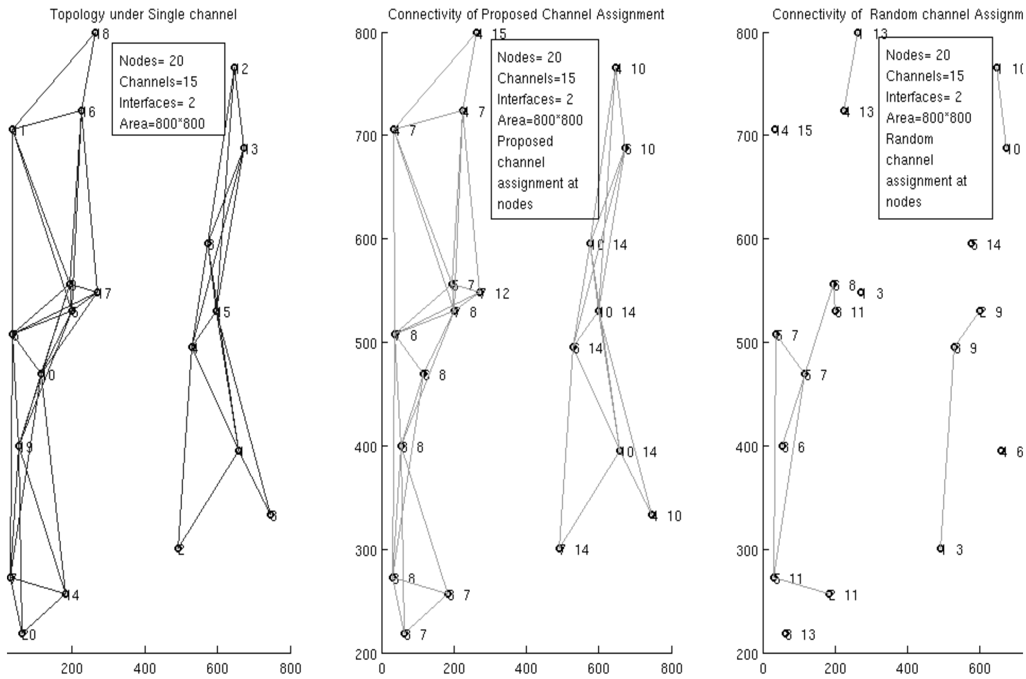


Figure 4.2: Example scenario for channel assignment

area 1200*1200m^2. Random topology is being generated from Matlab. From the channel assignment in the below figure we can observe that on each interface, in most of the nodes distinct channels are assigned which adds in throughput, while maintaining the overall connectivity of the network. Links with different color shows that different channel is tuned on that particular node. In the Fig:4.2 , we have 20 nodes each with 2 interfaces and number of channels are 15 with 800*800m^2 area. From Fig:4.2, we can see the total connectivity is maintained while exploiting the distinct channel assignment.

4.4 Connectivity Results

The results of our proposed algorithm shows that it provides good connectivity as compared to Best Quality Channel Assignment (BQCA), in BQCA each node selects the channel having maximum success delivery ratio.

Results generated from our algorithm shows that with increase

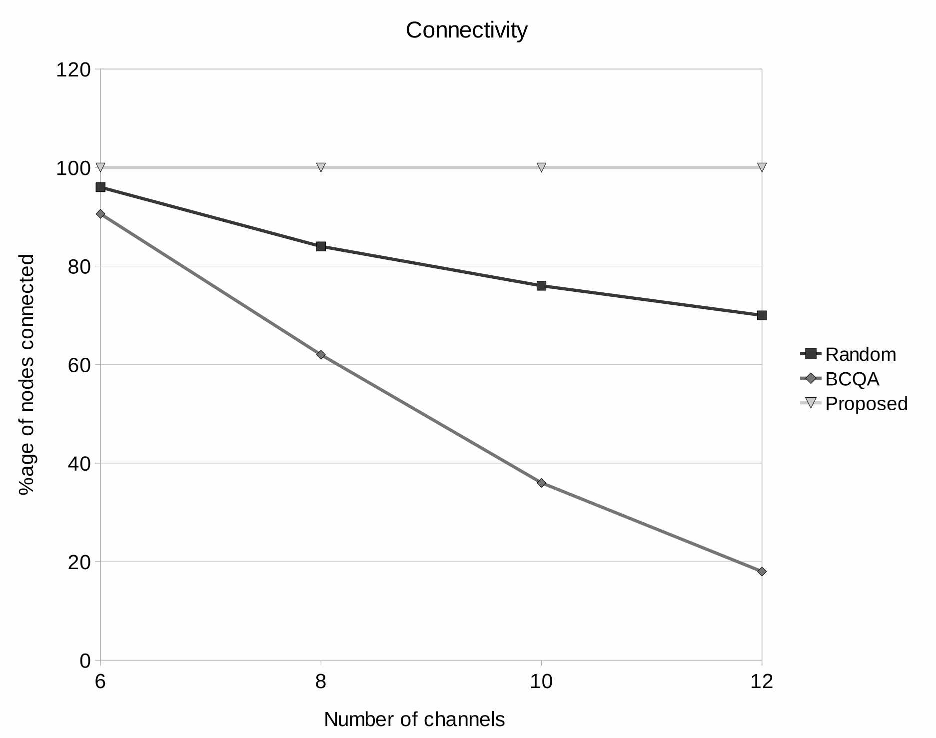


Figure 4.3: Comparison Results

in number of channels our algorithm maintains connectivity up to 70% of overall the network. While other approach (BQCA) connectivity decreases sharply with the increase in number of channels. We have compared our approach with ideal environment in which all nodes are tuned on single channel. Hence we are close to the single channel ideal scheme. Fig 4.4 shows the results for number of interfaces set to 2 and total nodes are 10.

Ma[8], approach perform channel assignment using optimization problem. but according to Ma[8], approach only one channel is assigned to a link with in its interference range. The channel assigned can be reused outside its interference range. This constraint limits re-assignment of channel and effects connectivity of the network. Due to constraint on channel re-assignment the network suffers from connectivity issues.

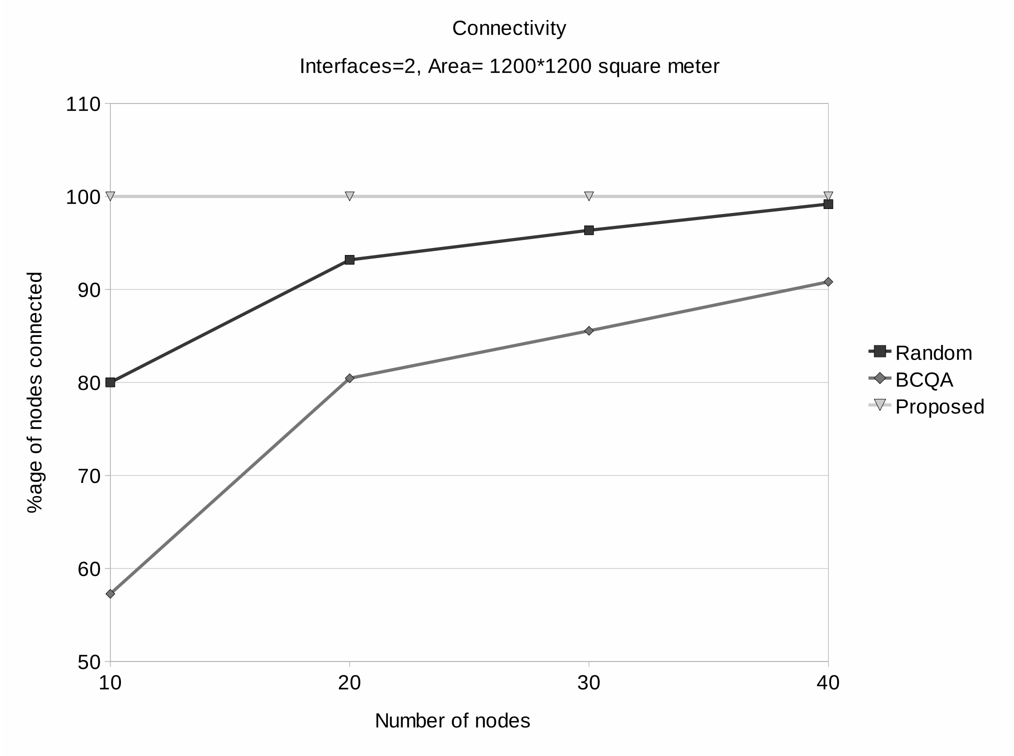


Figure 4.4: Comparison Results

4.5 Summary

Proposed channel assignment algorithm contributes with aggregate throughput gains and connectivity. Most of the work discussed in literature address one of the challenge either throughput or connectivity. Our approach address both of the challenges. Proposed scheme allocates channels on the channel quality (success delivery ratio). As discussed in previous section that success delivery ratio is a good metric to quantify interference on a channel. The main advantage of using this metric as discussed previously is that it provides channel conditions on both sides (sender and receiver). In this chapter we shown that how proposed algorithm maintains topology. Topologies drawn randomly shows channel assignment. Extensive simulations for random topologies shows that connectivity is maintained. Scenarios shown presents how channels are assigned, results shows connectivity is maintained. Connectivity is ensured in proposed algorithm by tuning all nodes having channel quality less than threshold on same channel. Simulation results show total connectivity in the network. Dictating other nodes to tune on the same channel having good delivery ratio improves connectivity. Stability of channel assignment algorithm plays important role in network throughput.Simulation results show that our algorithm is stable and converges after few channel changes. Less number of channels are affected from our channel assignment algorithm. Stability plays vital role in the efficiency of algorithm. Efficiency is measured in terms of throughput.

Chapter 5

Throughput Results

5.1 Abstract

In this chapter detailed simulation results of proposed algorithm is presented. This chapter will also present the results of connectivity and throughput analysis, and the comparison with different approaches. This will further explain how over algorithm will perform better as compared to other schemes. It further explains connectivity among nodes by proposed algorithm with results. Throughput results are investigated with different approaches and comparison between proposed and other approaches are presented in this chapter.

5.2 Model and parameters taken from Matlab

In our simulations we plug in values from the model produced by matlab into ns2 for results of our approach. The x y coordinates , channels success delivery ratios (normalized into according to ns2 parameters) ,channel assignment at each node's interface,number of nodes and the topology from matlab is plug into ns2.
We extended ns2 to support multi-channel multi-interface [7].

We set ns2 wireless parameters for MAC as 802.11, data rate to 1 Mbps, two way ground model, enabled multiple interfaces, omni directional antennas. Tcp traffic generator is used with each packet of size 512 bytes.

5.3 Throughput

Channel assignment algorithm takes into account connectivity and throughput. Our objective is to assign channels in such a way that connectivity and throughput is maximized. There is trade-off between connectivity and throughput, our contribution is to keep this trade-off at certain level. In our approach, we have compared our approach with [1], common channel assignment, single channel assignment. Simulations are carried out in ns-2

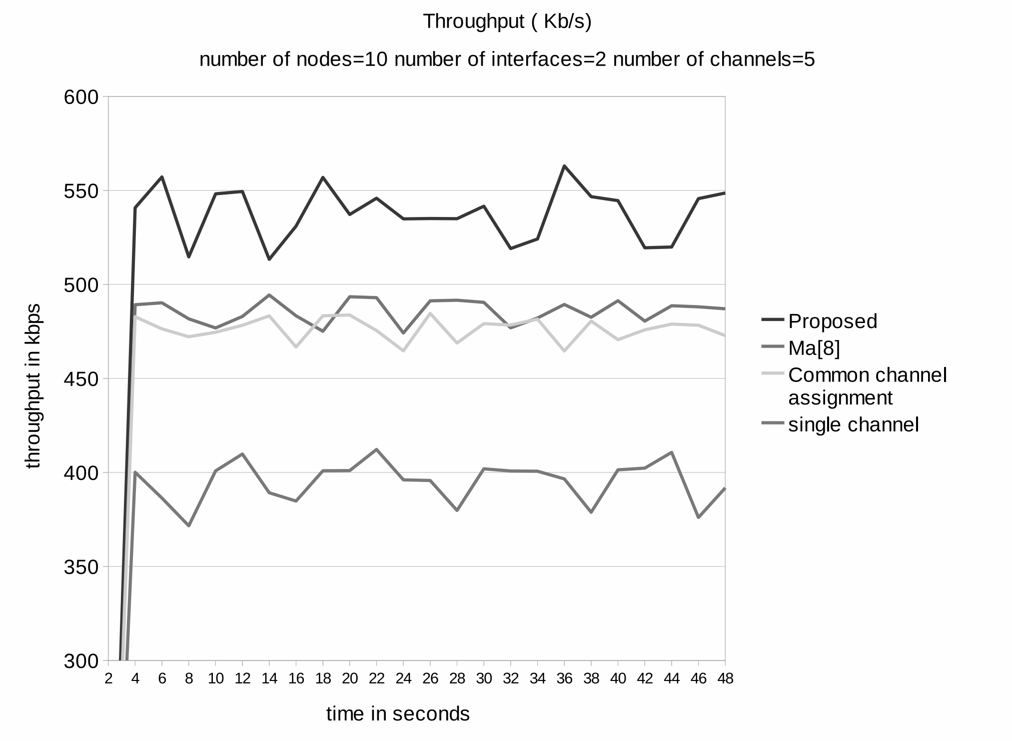


Figure 5.1: Instantaneous Throughput

with multichannel extension. Simulation results shows that our approach performs better in terms of throughput, packet drops, and latency as compared to other approaches.
Simulation results with our channel assignment scheme with different time periods suggests instantaneous throughput in the Fig: 5.1. The results are for 2 number of interfaces, 5 number of channels and 10 number of nodes. We carried out simulations for random network topology. We compared our approach with common channel assignment, in this approach common channel is tuned on each interface. We can observe that channel quality based channel assignment is performing well as compared to other approaches. This better throughput gain is due to quality aware channel assignment and exploiting the availability of channels.

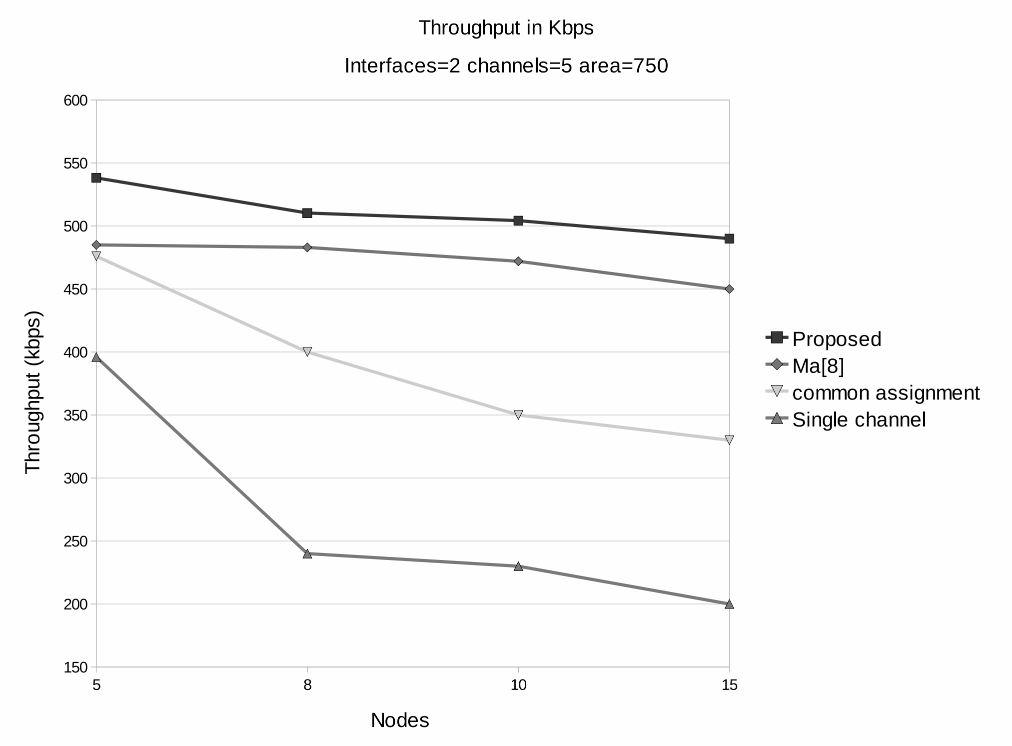


Figure 5.2: Throughput Vs Nodes

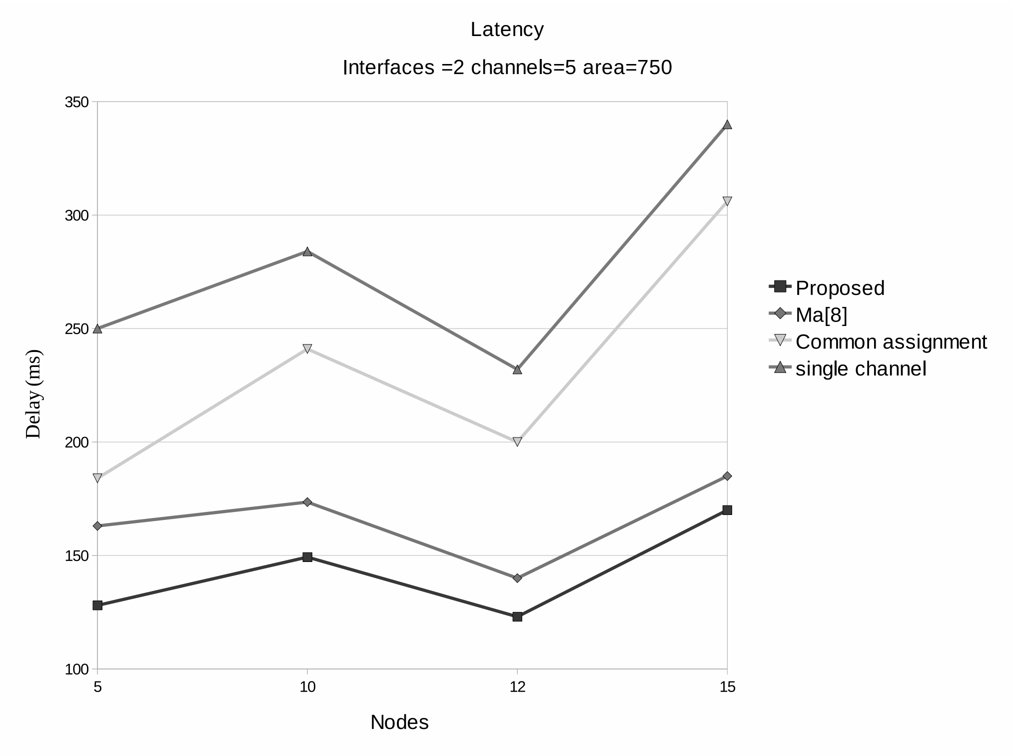


Figure 5.3: Throughput Vs Delay

In the Fig 5.1, throughput for 10 number of nodes with 2 interfaces is given. The above graph shows that throughput normally remains above 500 kbps, and we can call it being stable under fixed number of nodes. In the Fig 5.2, as the number of nodes increases throughput decreases linearly.

5.4 Latency and Packet Drops

Latency is the end to end delay from source to destination. Beside other factors latency depends upon the connectivity among the nodes. If the network is connected in such a way that one message is received by many receivers on a single channel than it means we can reach to farthest node in less time as compared to if the network is not highly connected. Simulation results show that our algorithm takes less time than other approaches to reach farthest nodes in the network. Following Fig:5.4, shows the simulation results for latency.

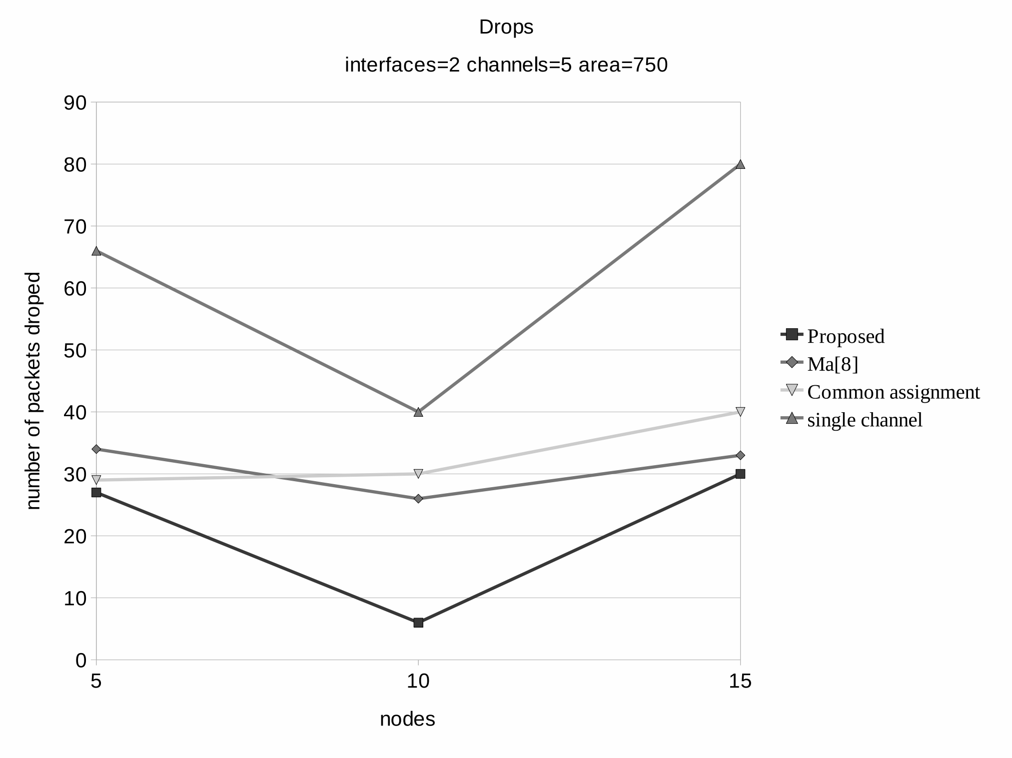


Figure 5.4: Throughput Vs Packet Drops

Throughput and connectivity plays an important role in network performance. Our objective in this research was to maximize throughput and connectivity. From our approach, we do the channel assignment in order to maintain connectivity keeping in view the quality of the channel being used. So this channel quality and connectivity gives us better results.

5.5 Summary

Simulation results show that our our algorithm preforms better than CCA and optimization based algorithms. In terms of connectivity our algorithm performs total connectivity (all nodes are connected). According to our algorithm, dictating other nodes to same channel induces connectivity in proposed algorithm. This feature provides the connectivity among all nodes in the network. Throughput increases as we select channel having success delivery ratio maximum. This will increase aggregate throughput in the network. Switching to the channel having maximum success delivery ratio will gain throughput. Simulation results show that our approach performs better then other approaches in literature.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

In this thesis, we have explored the possibility of improving the performance of multi-channel multi radio wireless networks by using efficient channel assignment. By gaining throughput and maintaining the connectivity we have shown that significant performance gain can be achieved. In this approach, we do the channel assignment in such a way that connectivity is maintained keeping in view the quality of the channel parameters. Our results demonstrate that the quality based channel assignment performs well, compared to recently proposed approaches in the literature. In this thesis, we also advocate that this algorithm is stable in the long run, which as a result improves the performance of the whole network. Our ongoing work includes modeling the power and rate adaptation to maximize aggregate throughput of the network.

6.2 Future Work

In this thesis, we have explored the possibility of improving throughput and maintaining connectivity under single data rate. While, other possibilities, how to maintain connectivity under

different IEEE802.11 data rates. We know, that at low rate maximum nodes are covered in uniform node distribution while at higher rate less number of nodes can be covered in uniform distribution. Future investigation may include, how to maximize performance by maintaining connectivity among nodes.
One can check, the effect of power adaptation on performance, interference and connectivity among nodes in the network. Efficient power adaptation algorithm will reduce interference and can improve performance.

Appendix A

Matlab code

```
function[]=channel_assignment(N,A,I,IR,C)
dist = zeros(N,N);
channel_neighbors= zeros(N,C);
random_assignment=zeros(N,C);
neighbors= zeros(N,N);
N_C = zeros(N,C);
SINR= zeros(N,C);
ch_success_rate= rand(N,C);
channel_traffic= rand(N,C);
sucess_rate=zeros(N,C);
channel_quality= zeros(N,C);
link_quality= zeros(N,C);
pos=A*rand(N,2);
lessthanthreshold=zeros(N,C);
neighbors=topology(N,A,IR,pos);
display(neighbors);
channel_neighbors=Random(N,I,C,random_assignment);
display(channel_neighbors);
random=Random(N,I,C,random_assignment);
N_C= find_channel_neighbors(N,channel_neighbors,neighbors,C);
display(N_C);
C_L=quality_channel(N,C,channel_neighbors,N_C);
```

```
for i=1 :N
for k=1: I
X= find(neighbors(i,:));
p=find(channel_neighbors(i,:));
a=0;
if(C_L(i,p(k))¡0.5)
a=a+1;
for j=1 : N_C(i)
if(C_L(X(j),p(k))¡0.5)
a=a+1;
end
end
end
N_N(i,k)=a/(N_C(i)+1);
end
end
display(N_N);
display(channel_neighbors);
channel_neighbors=proposed_assignment2(N,I,N_N,neighbors,
channel_neighbors,C_L,C,N_C);
display(C_L);
display(N_N);
subplot(1,3,2);
hold on;
title('Connectivity');
for i=1 : N
a=find(channel_neighbors(i,:));
n=find(neighbors(i,:));
if(isempty(n))
hold on;
plot(pos(i,1),pos(i,2),'o','LineWidth',2,'MarkerEdgeColor','k');
end;
plot(pos(i,1),pos(i,2),'o','LineWidth',2,'MarkerEdgeColor','k');
```

```
for j=1 : length(a)
for k=1 :length(n)
c=find(channel_neighbors(n(k),:));
if(find(a(j)==c))
plot([pos(i,1) pos(n(k),1)],[pos(i,2) pos(n(k),2)],'color','g');
end
end
end
text(pos(i,1),pos(i,2), num2str(a));
end
display(channel_neighbors);
BCQA(N,I,C,neighbors,C_L,random,pos);
```

Appendix A

NS2 Simulation Set-up

```
set val(chan) Channel/WirelessChannel ; #Channel Type
set val(prop) Propagation/TwoRayGround ; #Radio propagation model
set val(netif) Phy/WirelessPhy ; #Network interface type
set val(ant) Antenna/OmniAntenna ; #Antenna model
set val(rp) AODV ;#Routing Protocol
set val(ifq) Queue/DropTail/PriQueue ;# interface queue type
set val(ifqlen) 50 ;# max packet in ifq
set val(mac) Mac/802_11 ;# MAC type
set val(ll) LL ;# link layer type
set val(nn) 12 ;# number of mobilenodes
set val(ni) 2 ;# number of interfaces
set val(channum) 5 ;# number of channels per radio
#set val(cp) ./random.tcl ; # topology traffic file
set val(stop) 50 ;# simulation time
===========================================
# Main Program
===========================================

   # Initialize Global Variables
set ns_ [new Simulator]
set tracefd [open ./Proposed.tr w]
```

$ns_trace - all$tracefd

set up topography object
set topo [new Topography]
$topoload_flatgrid$10001000

#create nam
set namtrace [open ./test.nam w]
$ns_namtrace - all - wireless$namtrace 1000 1000

Create God
set god_ [create-god $val(nn)$]

$ns\_use - newtrace$

configure node
$ns_node{-}config{-}adhocRouting$val(rp) -llType $val(ll){-}macType$val(mac) -ifqType $val(ifq){-}ifqLen$val(ifqlen) -antType $val(ant){-}propType$val(prop) -phyType $val(netif){-}topoInstance$topo -agentTrace ON -routerTrace ON -macTrace ON -movementTrace ON

for set i 1 i <=val(channum) incr i
set chan_$(i)[new$val(chan)]

#configure for interface and channel
$ns_node - config - ifNum$val(ni)

proc UniformErr1
set err [new ErrorModel]
$errunitpacket$
err set rate_ 0.04
return err

$procUniformErr2seterr[newErrorModel]$err unit packet
$errsetrate\_0.02$
$return$err

proc UniformErr3
set err [new ErrorModel]
$errunitpacket$
err set rate_ 0.02
return err

$procUniformErr4seterr[newErrorModel]$err unit packet
$errsetrate\_0.03$
$return$err

proc UniformErr5
set err [new ErrorModel]
$errunitpacket$
err set rate_ 0.04
return err

$procUniformErr6seterr[newErrorModel]$err unit packet
$errsetrate\_0.04$
$return$err

proc UniformErr7
set err [new ErrorModel]
$errunitpacket$
err set rate_ 0.04
return err

$procUniformErr8seterr[newErrorModel]$err unit packet
$errsetrate\_0.03$

$return$err

proc UniformErr9
set err [new ErrorModel]
$errunitpacket$
err set rate_ 0.03
return err

$procUniformErr10seterr[newErrorModel]$err unit packet
$errsetrate\_0.07$
$return$err

#for set i 0 i <val(ni) incr i
$ns_add - channel$i $chan\_$(i)
#

$ns\_node - config - OutgoingErrProcUniformErr1$
ns_ add-channel 0 $chan\_$(1)
ns_ add-channel 1 $chan\_$(2)
$setnode\_$(0)[ns_ node]
$node\_(0)random - motion0$
node_(0) set recordIfall 1

channel seting at node 1
$ns\_node - config - OutgoingErrProcUniformErr2$
ns_ add-channel 0 $chan\_$(1)
ns_ add-channel 1 $chan\_$(2)
$setnode\_$(1)[ns_ node]
$node\_(1)random - motion0$
node_(1) set recordIfall 1

channel seting at node 2
$ns\_node - config - OutgoingErrProcUniformErr3$

ns_ add-channel 0 $chan\_(1)$
ns_ add-channel 1 $chan\_(3)$
$setnode\_(2)$[ns_ node]
$node\_(2) random - motion 0$
node_(2) set recordIfall 1

channel seting at node 3
$ns\_node - config - Outgoing Err Proc Uniform Err 4$
ns_ add-channel 0 $chan\_(1)$
ns_ add-channel 1 $chan\_(4)$
$setnode\_(3)$[ns_ node]
$node\_(3) random - motion 0$
node_(3) set recordIfall 1

channel seting at node 4
$ns\_node - config - Outgoing Err Proc Uniform Err 5$
ns_ add-channel 0 $chan\_(1)$
ns_ add-channel 1 $chan\_(2)$
$setnode\_(4)$[ns_ node]
$node\_(4) random - motion 0$
node_(4) set recordIfall 1

channel seting at node 5
$ns\_node - config - Outgoing Err Proc Uniform Err 6$
ns_ add-channel 0 $chan\_(3)$
ns_ add-channel 1 $chan\_(4)$
$setnode\_(5)$[ns_ node]
$node\_(5) random - motion 0$
node_(5) set recordIfall 1

channel seting at node 6
$\# ns\_node - config - Outgoing Err Proc Uniform Err 7$
ns_ add-channel 0 $chan\_(2)$

ns_ add-channel 1 *chan_*(4)
*setnode_*(6)[ns_ node]
*node_*(6)$random - motion0$
node_(6) set recordIfall 1

channel seting at node 7
$\#ns\_node - config - OutgoingErrProcUniformErr8$
ns_ add-channel 0 *chan_*(1)
ns_ add-channel 1 *chan_*(3)
*setnode_*(7)[ns_ node]
*node_*(7)$random - motion0$
node_(7) set recordIfall 1

channel seting at node 7
$\#ns\_node - config - OutgoingErrProcUniformErr8$
ns_ add-channel 0 *chan_*(2)
ns_ add-channel 1 *chan_*(4)
*setnode_*(8)[ns_ node]
*node_*(8)$random - motion0$
node_(8) set recordIfall 1

channel seting at node 7
$ns\_node - config - OutgoingErrProcUniformErr8$
ns_ add-channel 0 *chan_*(1)
ns_ add-channel 1 *chan_*(2)
*setnode_*(9)[ns_ node]
*node_*(9)$random - motion0$
node_(9) set recordIfall 1

channel seting at node 7
$ns\_node - config - OutgoingErrProcUniformErr8$
ns_ add-channel 0 *chan_*(1)
ns_ add-channel 1 *chan_*(2)

*setnode_*(10)[ns_ node]
*node_*(10)*random − motion*0
node_(10) set recordIfall 1

\# channel seting at node 11
*ns_node − config − OutgoingErrProcUniformErr*8
ns_ add-channel 0 *chan_*(3)
ns_ add-channel 1 *chan_*(5)
*setnode_*(11)[ns_ node]
*node_*(11)*random − motion*0
node_(11) set recordIfall 1
\#for set i 0 *i* <val(nn) incr i
\# set node_(*i*)[ns_ node]
\# *node_*(i) set recordIfall 1
\# *node_*(i) random-motion 0 ;# disable random motion
\# #*god_new_node*node_(*i*)
\#
node_(0) set X_ 272.9176
*node_*(0)*setY_*111.0535
node_(0) set Z_ 0.000000000000
*node_*(1)*setX_*375.2667
node_(1) set Y_ 392.2988
*node_*(1)*setZ_*0.000000000000
node_(2) set X_ 307.2494
*node_*(2)*setY_*374.6278
node_(2) set Z_ 0.000000000000
*node_*(3)*setX_*531.3849
node_(3) set Y_ 514.1406
*node_*(3)*setZ_*0.000000000000
node_(4) set X_ 798.7889
*node_*(4)*setY_*107.1711
node_(4) set Z_ 0.000000000000
*node_*(5)*setX_*243.386

node_(5) set Y_ 509.8109
$node_(5)setZ_$0.000000000000
node_(6) set X_ 207.2272
$node_(6)setY_$112.0190
node_(6) set Z_ 0.000000000000
$node_(7)setX_$782.0463
node_(7) set Y_ 98.2759
$node_(7)setZ_$0.000000000000
node_(8) set X_ 787.0463
$node_(8)setY_$374.2759
node_(8) set Z_ 0.000000000000
$node_(9)setX_$263.0463
node_(9) set Y_ 230.2759
$node_(9)setZ_$0.000000000000
node_(10) set X_ 65.0463
$node_(10)setY_$802.2759
node_(10) set Z_ 0.000000000000
$node_(11)setX_$663.0463
node_(11) set Y_ 439.2759
$node_(11)setZ_$0.000000000000

set tcp_(1) [$ns_create - connectionTCP$node_(2) TCPSink $node\_(1)0$]
tcp_(1) set window_ 32
$tcp\_(1)setfid\_1$
tcp_(1) set packetSize_ 512
set ftp_(1) [$tcp\_(1)attach - sourceFTP$]
ns_ at 2.333118917575632 "$ftp\_(1)start$"

4 connecting to 6 at time 146.96568928983328 # set tcp_(3) [$ns_create - connectionTCP$node_(6) TCPSink $node\_(3)0$]
tcp_(3) set window_ 32
$tcp\_(3)setfid\_0$

tcp_(3) set packetSize_ 512
set ftp_(3) [$tcp\_(3) attach-source FTP$]
ns_ at 1.634230382570173 "$ftp\_(3) start$"
$\#4 connecting to 6 at time 146.96568928983328$
$\#set tcp\_(3)$[ns_ create-connection TCP $node\_(7) TCPSink$ node_(3)
0]
$tcp\_(3) set window\_ 32$
tcp_(3) set fid_ 0
$tcp\_(3) set packetSize\_ 512$
$set ftp\_(3)$[tcp_(3) attach-source FTP]
$ns\_ at$ 1.634230382570173"ftp_(3) start"

set tcp_(5) [$ns\_create - connection TCP$ node_(1) TCPSink
$node\_(4)$ 0]
tcp_(5) set window_ 32
$tcp\_(5) set fid\_ 1$
tcp_(5) set packetSize_ 512
set ftp_(5) [$tcp\_(5) attach - source FTP$]
ns_ at 10.546173154165118 "$ftp\_(5) start$"

#for set i 0 $i < 10 incr i$ #god_ is_neighbor 0 i
#

Tell nodes when the simulation ends
for set i 0 i <val(nn) incr i
ns_at val(stop).0 "$node\_$(i) reset";

ns_at val(stop).0002 "puts N̈S EXITING...;̈ ns_halt"
$proc stop global ns\_ tracefd$ ns_ flush-trace
close $tracefd$
$exec nam ./test.nam$
$exit$ 0

$puts$"$StartingSimulation...$"
ns_ run

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