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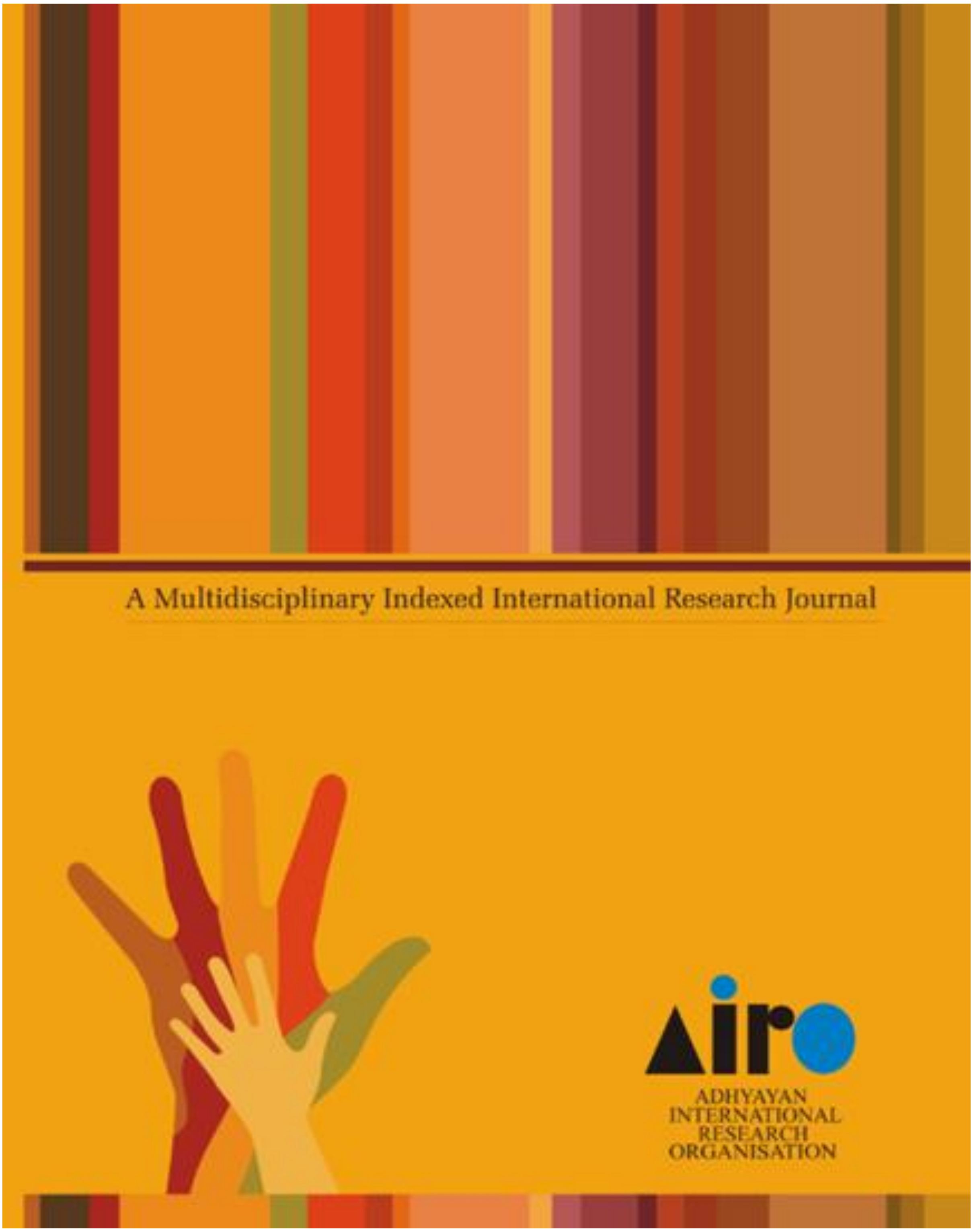

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# A STUDY OF QOS BASED JOINT CHANNEL ASSIGNMENT AND ROUTING IN WIRELESS MESH NETWORKS

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## *ABSTRACT*

*Wireless LAN standards allow multiple non-overlapping frequency channels to be used simultaneously to increase the aggregate bandwidth available to end-users. Such bandwidth aggregation capability is routinely used in infrastructure mode operation, where the traffic to and from wireless nodes is distributed among multiple interfaces of an access point or among multiple access points to balance the traffic load. However, bandwidth aggregation is rarely used in the context of multi-hop 802.11-based LANs that operate in the ad hoc mode. Most past research efforts that attempt to exploit multiple radio channels require modifications to the MAC protocol and therefore do not work with commodity 802.11 interface hardware. In this paper, we propose and evaluate one of the first multi-channel multi-hop wireless ad-hoc network architectures that can be built using standard 802.11 hardware by equipping each node with multiple network interface cards (NICs) operating on different channels. We focus our attention on wireless mesh networks that serve as the backbone for relaying end-user traffic from wireless access points to the wired network. The idea of exploiting multiple channels is particularly appealing in wireless mesh networks because of their high capacity requirements to support backbone traffic. To reap the full performance potential of this architecture, we develop a set of centralized channel assignment, bandwidth allocation, and routing algorithms for multi-channel wireless mesh network.*

**KEYWORDS:** Wireless LAN, multi-channel wireless mesh network, routing algorithms

## I. INTRODUCTION

Wireless Mesh Networks (WMNs) [1-4], a key technology in the wireless access, have emerged recently to provide on the go connectivity to the end users. WMNs are dynamic multi-hope networks having the self-organization and self-configuration capabilities. Conceptually, WMNs have been evolved from Mobile Ad-hoc Networks (MANETs) [2] and thus inherit the forwarding and self-configuration capabilities from there.

WMNs consist of two main components, i.e., Mesh Points (MPs) and Mesh Clients (MCs). While MPs are the wireless routers interconnected to one another in a multi-hop fashion to form what is called the mesh backbone, end users MCs typically consist of the client machines accessing the Internet through the mesh backbone with wired or wireless medium. Depending on the location and functionalities of MPs in WMNs, they are further divided into three categories [2]. Those mesh routers which give connectivity to the end users are called Mesh Access Points (MAPs) and are usually located at the user premises while the mesh routers inside the MCs data to/from the Internet, are called Mesh Points (MPs). There are some backbone routers, called Gateways, which provide connectivity between WMNs backhaul and the Internet through wired medium. WMNs are a promising technology to provide broadband wireless connectivity in the user premises [5] due to their rich resources and fixed wireless routers, having stable power supplies. The multi-hop capability results in a scalable solution for otherwise limited ranged networks. These networks are highly resilient as failure of some nodes has no effect on the connectivity of end users and overall network at large. The always connected and robust nature of WMNs qualifies it to be deployed as future broadband wireless solution in the user premises. Due to the advantages of WMNs, IEEE has established subgroups to include mesh capability in their existing standards like IEEE802.11s for Wireless Local Area Networks (WLANs), IEEE 802.15.5 for Wireless Personnel Area Networks (WPANs) and IEEE 802.16e for Wireless Metropolitan WMNs backbone, which are responsible for forwarding Area Networks (WMANs) [6, 7]. Many commercial products are also available in market for the deployment [8, 9] and vendors like Motorola, Nokia and Mesh Dynamics have implemented practical WMNs topologies [10-12].

The IEEE 802.11 based WMNs. The Multiple-Radio capability and their assignment to multiple non-overlapping channels, makes WMNs as one of the prime candidate to be deployed as the future wireless broadband access technology. However, WMNs are facing the same inherited problems of capacity limitations and interference being in the category of multi-hop wireless networks. First, the multi-hop nature of its routers put an upper bound on the end-to-end data rate achievements. Secondly, the interference phenomenon needs to be earnestly addressed while developing any protocol for such types of networks. Support for providing the Quality of Service (QoS) to the recent broadband applications like Voice over IP (VoIP), Video Conferencing and Online Gaming is one of the essential requirements from the access technologies. These QoS in the form of delays and bandwidth must not be compromised and should be guaranteed for the smooth functioning of the network. If channel assignment is one of the deterministic parameter in improving the capacity of the network by minimizing the interference and providing communication parallelism among the multiple radios of the neighboring nodes, routing, on the other hand, plays an equally important role by providing the guaranteed end-to-end path selection based on some required metric. Both these issues are interdependent and hence affect each other. the joint routing and channel assignment problem for the WMNs, where the channel assignment scheme tries to minimize the interference of the network while ensuring the connectivity. Routing, on the other hand, provides an end-to -end guaranteed path based on the end users' delay requirements. A MANET routing protocol, called Ad-hoc On Demand Distance Vector (AODV), has been extended to make it Multi-Radio Multi-Channel (MRMC) compatible and to provide an end-to-end path to the end users ensuring the maximum tolerable delays guarantees. The decision of end-to-end route selection between a pair of source-destination nodes is taken based on the end users requirements and the match of each individual link capabilities. Experimental results show that the proposed scheme achieves low network latency, high throughput and low routing overheads in the network.

## II. SYSTEM MODEL

An infrastructure based hierarchical WMN is considered where Mesh Clients, consisting of end users, access the Internet via Mesh Backbone. There is always some data at the Mesh Clients or at the server connected to the gateways, which have some QoS demands in terms of end-to-end network delays. The application scenarios of WMNs are always in the form of data travelling to or from the Mesh Clients towards the gateways. This means that the QoS provided on an end-to-end path must be bi-directional. For instance, consider the example given in Figure, where node A wants to send some data to node Bon path Pa-b. Let a-b be the maximum delay node A's data can tolerate, on-end-to end path Pa-b, where the total path delay is the cumulative delays of individual links. If a-b>=9 units, the path is feasible for the said application. However, delays on bi-directional links are not the same from both sides. For example, it is possible that node A`s data experiences one type of delay while sending it to node c; on the opposite, c might experience different delay when sending some data to node A on the same link. Generally, for a path Pa-b in the multi-hop network, the end-to-end delay is given by:

$$Path_{Delay} = \sum_{i=1}^{|l|} l^{i}delay$$

Where $l^{i}{}_{delay}$ in the Equation (1) is the delay associated with the i link across the path.

Let S={S ,S ,S ,….., S 123 |S|} be the set of source nodes requesting for some delay sensitive data like a request from the network to find a route to a video conferencing application or a VoIP server. Let D= {D, D , D , …., D 123 |D|} be the set of destination nodes in the network. In the case of WMNs, the (S, D ) is always the (end user nodes, i i gateways) or (gateways, end user nodes). Let each (S , D ) i i have some data to send across the WMNs backbone through a path P with the some delay constraint. Since S-D WMNs consist of multi-hop routers spreading across multiple collision domains and each router is equipped with multiple radios deployed to multiple channels, therefore, there are multiple possible routes for this data to transport from the source to the destination. The routing function is to select such a route across these multiple collision domains so that the delay constraint imposed by the (source, destination) is satisfied. A channel assignment scheme based on minimum interference is proposed to achieve the above objective. Secondly, a reactive routing protocol is extended for MRMC WMNs which achieves the minimum requirements set by the end users applications. Both routing and channel assignment are inter-dependent because a certain channel assignment strategy affects the routing decisions on each node whereas the load due to the already established connections by the routing decisions can trigger the channel re-assignment.

## III. QOS BASED CHANNEL ASSIGNMENT AND ROUTING

We consider an 802.11 based WMNs, where each mesh router is equipped with K multiple radios/IEEE 802.11 compatible network interfaces. The topology of the network is considered relatively static and only a few routers are able to move in the whole network. Multiple orthogonal channels, C, (12 or 3) are available to each node as according to the IEEE 8021.11 a/b/g standards. All the routers, afterwards called nodes, have equal transmission capabilities. This means that all the radios of the nodes belong to the same technology i.e., either IEEE 802.11a or IEEE 802.11 b/g. Similarly all the radios have the same transmission and interference ranges as defined in these standards. A node can assign only one radio to a specific channel. This is necessary because assigning the same channel to two different radios of a specific node causes co-channel interference [37]. The aim of the channel assignment scheme is to assign channels from the channel set C to each link connecting two radios of a pair of nodes in the mesh backbone such that the interference is minimized.

**Channel Assignment:** We follow the protocol model [38] for developing the proposed channel assignment and routing scheme. The channel assignment model consists of the following sub-modules, where the interference is minimized using a similar concept as in.

- Initialization and channel assignment
- Channel/link Assessment and Neighbors Monitoring
- Channel Re-Assignment

## IV. INITIALIZATION AND CHANNEL ASSIGNMENT

This module assigns multiple non-overlapping channels from the set C to the multiple radios set K of the nodes. The aim of channel assignment is to produce a network topology inside the WMNs backbone so that each link gets a channel causing minimum interference and the backbone is highly connected. In this work, it is assumed for simulation purposes that the channel assignment process is initiated at the gateways. Our assumption is based on one of the basic characteristic of WMNs data traffic which travels from MAPs all the way towards the gateways. This assumption is made in all gateways oriented channel assignment protocols. However, the algorithm is flexible enough that the starting point can be any mesh router in the mesh backbone. It is assumed that there is no prior channel assignment inside the backbone and all the radio of all nodes listen to arbitrary channels for broadcast messages. Broadcast messages are special type of messages as defined in IEEE 802.11 standard, where the destination address is set to all 1's. Any node N in the WMNs backbone can initiate the channel assignment process by sending a special channel assignment request in the form of CH frame. The first Req field of this frame is set to broadcast address so that all the neighboring nodes listen to it. The second field is the MAC address of source node which initiated the CH Req frame. The third field is the Request Type which shows the type of the frame used in the proposed channel assignment protocol. Six types of frames are used in theproposed model. CH, CH, CH, CH , CH and Hello, each having its own code in the Channel Type field, as shown in Figure 2. The fourth field of CH is 4 bits long showing the number of channels available to the system. Four bits are sufficient to cover all the non-overlapping channels in the IEEE 802.11 standardsHowever, the fourth field of the CH packet consist of 26 bits, where each two bit are used to show the usage of a channel by the replying node. Upon listening the CH broadcast, all the neighboring nodes reply with fields where this node has assigned its radios before, with the value of 1, if no prior channel is assigned by the replying node, this field is set to zero accordingly. CH frame has exactly the same fields as that of CH but with the last field having 26 bits as shown in the Figure. Each 2 consecutive bits in the last filed of CH represents the number of channels the replying node maintains in its Neighboring Channel Usage (NCU) table. Upon receiving to its radios according to the following rulesAssign among those channels which are not already been assigned to one of the initiating node own radios. This is necessary to avoid the co-channel interference on the initiating node.Assign a channel to each interface while applying rule 1 in neighbors prospective. This will ensure to avoid the co-channel interference on the neighboring nodes. For this, initiating node looks at the channels already been assigned by the sending nodes to their interfaces. Initiating node N assigns those channels to the interfaces which cause least interference to it by looking at the Neighbor's Channel Usage (NCU) list. If all channels under consideration cause same level of interference to initiating node N, send a unicast message to each neighboring node requesting for their NCU lists. Assign channels to each specific interface, causing least interference to the specific neighboring node. If neighboring nodes NCUs have a tie, assign channels to each interface arbitrarily keeping rules 1 and 2 in view.

An example channel assignment is shown in the Figure 1. Five non-overlapping channels are available to the system and node 'a' initiates the channel assignment process by broadcasting the CH $_{Req}$ frame to all of it.

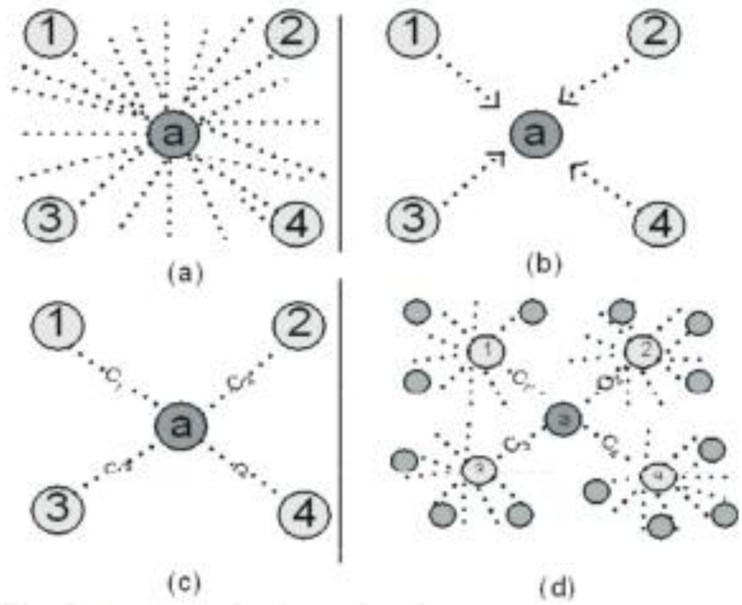


**Fig.1: An example channel assignment**

Neighbors nodes 1, 2, 3 and 4, as shown in the Figure, When these nodes receive the CH frame, each unicasts the CH frame to the initiating node, on Reply the channel on which it has received the CH broadcast. In the Figure, node 'a' assigns channels to its neighbors according to rules 1-5 mentioned earlier. Those nodes upon channel assignment to at least one of their interfaces, repeat the process for their neighbors, as shown in the Figure 3(d). Each node keeps the record of channel usage in two separate tables. The first one is of its own interfaces and the channels assigned teach. This table, called the Channel Usage Table, contains the information of each interface of the current node N, channels assigned to each interface and the MAC addresses of other neighboring.

## V. CHANNEL ASSESSMENT AND NEIGHBOURS MONITORING

When each node assigns channels to all of its radios/interfaces, they switch to the monitoring state. Monitoring state is the state in which each node frequently monitors the channel usage status of all its interfaces. Each node also monitors the status of all its neighbors, whether they are alive or not, through the exchange of Hello messages. The Hello messages, as shown in the Figure, are also used to update the link delay by the nodes they are connected through. This is necessary because the link delay on a bi-directional link is different from both nodes prospective. A greater delay in the Hello message replaces the smaller one on both nodes. Monitoring the link status is needed to calculate the metric for the QoS based routing later on, where the decision of selecting an end-to-end path is made based on the individual links quality in the path.

## VI. CONCLUSION

The channel assignment is an NP-hard problem, so most algorithms take the heuristic approach. Most static channel allocation algorithms are centralized, while most dynamic channel allocation algorithms are in distributed fashion. One challenge for future research is the design of channel allocation algorithms under more accurate interference models. Most previous work based their algorithms on the protocol model, which does not model the interference accurately. As a result, there will be some difference in the expected performance when the channel allocation algorithms are deployed in real environments. Therefore, it is necessary to design channel allocation algorithms based on more realistic interference models, such as the physical model.Despite many advances in wireless physical-layer technologies, limited bandwidth remains a pressing issue for wireless LANs. The bandwidth issue is most severe for multi-hop wireless mesh networks due to interference among successive hops of an individual path as well as among neighboring paths. As a result, conventional single-channel wireless mesh networks cannot adequately fulfill the role of an extended last-mile access network, let alone a wireless campus backbone that completely replaces wired Ethernet. In this paper, we propose a multi-channel wireless mesh network architecture based on 802.11 hardware that effectively addresses this bandwidth problem, and show how with proper channel assignment and routing algorithms such network architecture can become a serious contender for a campus-scale backbone network. Although the multi-NIC-per-node approach has been investigated in the past, it has not been fully explored. We show that channel assignment plays a crucial role in realizing the full potential of the proposed multi-channel wireless mesh network architecture, and discuss various issues involved in channel assignment.

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