Cross-Layer Design of 802.11s-based Wireless Mesh Networks

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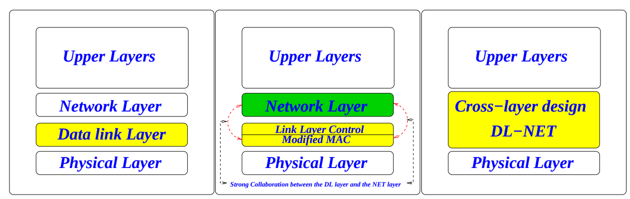
***Abstract*—Under the scope of improving the network performances in Wireless Mesh Network (WMN), a cross-layer design concerning channel allocation and routing algorithms is needed. IEEE 802.11 standard provides at least three non overlapping channels and thus, the possibility for the network in general and a node in particular, equipped with more than one network interface card (NIC), to operate on different channels simultaneously. This may increase the aggregate bandwidth available for end-users. Most of related works attempt to present a modified MAC layer that takes into account the routing and the channel allocation features. Only few of them present cross-layer solutions introducing a joint channel allocation and routing models that are claimed by their authors to provide performances nearly the theoretical optimum of use of the network capacity. However, most of the cross-layer MAC/Network proposals are done for a centralized manner. In this paper, we propose to review the different approaches to resolve the channel allocation problem for IEEE 802.11s backbone and we introduce two approaches for a distributed joint channel allocation and routing algorithms dedicated to a network where nodes are equipped with several network interface cards (NICs) working on multi-hop ad-hoc mode.**

I. Introduction

Nowadays, people have access to several technologies that provide to them different services. These technologies are in a continuous and considerable increase and so are the users needs. Wireless Mesh Networks (WMN) are providing high throughput and are connecting end users to several services. The IEEE community decided to extend the actual networks to WMN. These extension are considering several standards (IEEE 802.11, IEEE 802.15 and IEEE 802.16). The IEEE 802.11s is the extension of IEEE 802.11 for WMN.

In order to avoid transmission's collisions and improve network performances in wireless mesh networks (WMNs), a reliable and efficient medium access control (MAC) protocol and a good channel allocation are needed. Allowing multiple channels use in the same network is often presented as a possible way to improve the network capacity. As IEEE 802.11, IEEE 802.15 and IEEE 802.16 standards provide more than one channel, thus a trivial way to improve the network performances is to allow transmission on multiple channels in each network node. A lot of research work have been conducted in the area of multi-channel allocation in order to improve the aggregate bandwidth of the whole network. In this work, we focus our attention on how we can solve the channel allocation problem for Multi-Transceiver per node in the backbone level using the IEEE 802.11s technology.

II. State of the Art on Channel Allocation for WMNs



(a) (b) (c)

Fig. 1. Approaches of channel allocations according to their dependency to routing

In the backbone level of a WMN, a mesh router can have either single or multiple interfaces and can allocate a different channel to each interface. As the IEEE 802.11 standard provide at least three non overlapping channels (1, 6 and 11), thus, these channels can be scheduled independent of one another. The channel allocation's approaches aim to provide the best aggregate bandwidth of the whole network and we classify them into three categories. The first one (Figure 1.(a)) consists on channel allocation proposals done at the MAC level independently to the other layers. The second one (Figure 1.(b)) consists on a channel allocation approaches done by a modified MAC collaborating with upper layers. Finally, the third category (Figure 1.(c)) concerns channel allocation methods implemented in a new layer resulting from a cross-layer design between MAC and Network layer. Many excellent approaches for channel allocation have been reported in the literature. The ultimate objective of these techniques is to take the maximum of benefit from the available channels in wireless mesh network. These techniques have been proved by theirs authors to improve the network performances, however, the cross-layer design (Figure 1.(c)) is the approach that provide the best network performances. In fact, the proposed solutions to the issue of using all the network capacity is only achieved by a cross-layer design MAC Network where the performances that the authors claim are nearly the theoretical optimum of use of the network capacity. However, the best performances are provided by solutions done in a centralized manner. Based on the literature of channel allocation strategies for WMNs, it is clear that many research issues remain to be solved. Indeed, can we find a distributed dynamic strategy that affect channels dynamically according to the need? Can we create a distributed virtual structure over the mesh backbone that will work like a Centralized Channel Allocation Entity? How this could be feasible? Can we rely on smart antenna and beam-forming techniques to allow nodes to use the same channel without creating interference? ... For the rest of this paper, we try to reply to some of these questions.

III. Approaches for distributed joint channel allocation and routing

The most interesting past work done by the different research bodies presented approaches done for a cross-layer design between data-link layer and network layer that are mostly concerning a centralized manner. However, in a wireless environment, presenting a centralized approach is not too realistic because of who can supervise a such distributed network and how will, this supervisor do it? We strongly believe that these questions should be answered before presenting a centralized approach. By this section, we will propose two distribute solutions for this problem.

A. A distributed joint channel allocation and routing approach

In this approach, we propose to divide the whole network on clusters based on the neighborhood. Each cluster is manged by a cluster-head. The cluster-head is elected by its neighbors as being the node who has the highest number of neighbors. A cluster is formed by a cluster-head and all neighbors that are on a maximum of two hops of distance from it. Each cluster-head knows the composition and the network features of its cluster. All the clusters of the whole network are connected by relay nodes that are on the borders of each cluster and provide connectivity with a neighbor cluster. A relay node is member of only one cluster. All the cluster-heads of the whole network are connected and advertise periodically between them, their clusters topologies. If a node want to reach another node, it sends a message for communication request to its cluster-head over a fixed channel. If the destination is inside the same cluster, the cluster-head will choose the path and the channel of communication and will advertise its choice to both source and destination. Else, if the source and the destination are in different clusters, the cluster-head of the source will send a message to the cluster-head of the destination and to the other cluster-heads of the different clusters through which the communication in-between source and destination will occur. A communication path is then created between the relay nodes from the source to the destination and each cluster-head decide on the path and the channel of communication between the nodes members of the path source/destination and inside its cluster.

B. A WMN topology control over a distributed network

This section introduces an other approach to manage a distributed network and tries to create a distributed virtual structure over the mesh backbone that will work like a Centralized Channel Allocation Entity. A such structure will have three tasks that are network features and future traffic collection, network management and the advertisement of the decided network configuration. For creating this structure, we propose that, inside a neighborhood, nodes (wireless mesh routers) elect a master. As an election result, the node who has the highest connectivity inside its neighborhood becomes the master (dominant node) and advertises its decision to its neighborhood. A Connected Dominating Set (CDS) that connects the masters (dominant nodes) can be fulfilled by the masters from each neighborhood. A such CDS inside the mesh network would be used to manage the whole network and limits the retransmissions and the overhead number.

The following steps are done for the creation of the distributed topology control :

- Implementation of a neighbor discovery mechanism that will collect the neighborhood information
- Election of a local dominant that will represent its neighborhood
- Advertisement of the neighborhoods information between local dominant
- Each local dominant computes best Connected Dominating Set (CDS) that includes the least number of participant nodes
- Each local dominant advertises the CDS features to its neighborhood
- Network management inside the CDS

This approach will limit the number of the management message inside the network and will allow the use of centralized approaches to manage the network

IV. Conclusion

By this short paper, we, first, defined the problem statement for channel allocation in 802.11s-based wireless mesh networks. Then we described the related works and the limit that are facing. After that, we proposed some ideas to solve this problem.

Finally, we hope that the discussions given in this paper will stimulate the activity in the reseach community working on wireless mesh networks.