Automatic channel assignment and topology optimization in multi-radio wireless mesh networks

Krzysztof Grochla, Krzysztof Stasiak
Proximetry Poland, Katowice,
Al. Rozdzienskiego 91
{kgrochla|kstasiak}@proximetry.com

Vasilios A. Siris, Elias Tragos
FORTH, Vassilika Vouton, 711 10,
Heraklion, Crete, Greece, and
Athens University of Economics & Business
{vsiris|etragos}@ics.forth.gr,

1. Motivation and description of demonstrated features

Wireless mesh networks, comprised of nodes with multiple radio interfaces, are a promising technology for broadband residential Internet access or to provide connectivity for data transfer. In order to simplify network deployment, auto-configuration procedures that provide automatic network start-up, with minimum manual configuration of nodes, are increasingly important. In order to maximize the utilization of radio resources, efficient algorithms to select the optimal channel for the current radio propagation conditions are required. Typically, administrators manually determine the channels according to the measured signal propagation, and manually configure devices. This manual procedure is executed during initial network deployment, and whenever the network is upgraded or extended. The manual procedure requires many hours of human work, hence makes errors very costly. To address this, we have developed algorithms for fully automatic optimization of the channel assignment and topology optimization of the multi-radio wireless mesh networks. These algorithms work jointly with the auto-configuration, to provide fully automatic reconfiguration of the network and optimize the topology when nodes join or leave the network. They provide the network also with self-healing capabilities via automatic reconfiguration in response to errors.

We consider a centralized architecture, where all decisions are taken in a central node, the Network Manager. The proposed solution consists of a network management server and agent software running on mesh nodes. The agents on the mesh nodes provide results from neighborhood scanning to the server, and apply the configuration provided by the server.

The algorithms developed support two functions: automatic configuration and channel assignment. The auto-configuration allows the mesh nodes to join the network and receive the radio parameters from the Network Manager, and also supports re-configuration of the whole network when a node enters or exits the network, hence supporting self-healing capabilities in the case of node failures. The channel assignment algorithm is executed on the Network Manager. It selects the optimal channels for the interfaces of the mesh nodes. The communication between the mesh nodes and the server is realized using the CAPWAP and DHCP protocols. The channel assignment algorithm can work in two modes: incremental mode, integrated with auto-configuration, when the configuration is set for the nodes joining the network, and optimization mode where the manager initiates the optimization manually, after which the network executes scanning to find the current signal propagation conditions for all links, and reconfigures itself to improve the performance. In both modes, the procedure is fully automatic, starting from a node joining the network and finishing with a fully functional mesh network. The channel assignment algorithm may be executed with different optimization goals, such as throughput maximization, fairness, or connectivity reliability. The goal of the demo is to showcase the implementation of intelligent mechanisms for wireless mesh network control in a fully functional prototype, and how procedures based on optimization models can be adopted in practice to work with actual measurements in a mesh nodes neighborhood, thus illustrating the advantages from the collaboration of research and industry.

The proposed channel assignment and topology optimization algorithms have been implemented and tested on Linux OpenWRT platform installed on Mikrotik Routerboard devices. The Network Manager role is taken by a PC with Linux OS. To visualize the network topology and manage the configuration updates, Proximetry's AirSync network management system is used. The presented algorithms may work with any layer 3 routing protocol, and have been tested with OLSR. Moreover, the implementation is developed and tested on IEEE 802.11 devices, but can be easily adapted to any other networking technology.

2. Description of the novel algorithms presented

2.1 Auto-configuration

We developed novel auto-configuration procedures, based on extensions to the DHCP server and client implementations and BOOTP relays, to support both automatic and predefined configurations of multiple radio interfaces in the mesh nodes. To optimize the routing it can automatically partition the IP address space into subnets. The DHCP server works as a part of the Network Manager node and provides:

- simple and fast node attachment into the mesh network,
- optimization of the radio parameters assigned to the wireless interfaces,
- IP address assignment for node interfaces,
- automatic network boot-up,
- partitioning and merging of two disjoint networks.

The only inputs required to be configured on the nodes are the authorization credentials and a method of identification of mesh network that the node will connect to (e.g. by a mask on ESSID).

The IP address configuration of nodes having direct communication with DHCP server (within 1 hop distance) obtained by direct exchange of DHCP packets. For the auto-configuration of further nodes the BOOTP relays are used to forward DHCP requests to the server. The relays are working on all nodes that take part in packet forwarding - for example, in the case of OLSR protocol these would be all the multipoint relays. Each relay learns the DHCP server address automatically – it forwards packets to the DHCP server which provided IP addresses for the node it is working on.

The node starts by scanning for possible link candidates. After the scanning procedure the node should try to connect to any of the discovered networks or simply try to connect to any SSID that appears to be part of a mesh network. The node starts the joining procedure with only one radio interface turned on. It should start from the networks with strongest signal level. If required, the node must authorize to the current network, using the preconfigured credentials). The radio parameters for the first interface are provided by the Network Manager using vendor specific options added to the DHCP packet.

After the first interface is configured the node starts establishes a CAPWAP link with the Network Manager to get IP addresses for all the other interfaces. The node sends the scanning results to the server. The Network Manager runs the incremental channel assignment algorithm and provides the node with the parameters for remaining interfaces.

Every node that is forwarding packets should work as a BOOTP Relay and forward DHCP packets from, or for some other nodes. In order to support relaying the DHCP packet, all mesh nodes must accept the BOOTP packets with multicast addresses. The BOOTP relay works with the configured DHCP server address (implicitly, the Network Manager which provided the IP to the node) and forwards all packets to the Network Manager using unicast.

The autconfiguration provides self-healing capabilities by restart of the process when lack of connectivity is detected. We have implemented a process which monitors the availability of the backhaul and run the autoconfiguration procedure when it is not available. After the restart the node gets a new configuration from the Network Manager and restores to operational state.

A more detailed description of the auto-configuration procedures is given in [1].

2.2 Channel assignment and topology optimization

This section describes the utility-based framework for joint channel assignment and topology control in multi-rate multi-radio wireless mesh networks, which utilizes a greedy algorithm for solving the corresponding optimisation problem. Key features of the approach are support for different target objectives, which are expressed as utility functions of the MAC layer throughput, and the efficient utilization of wired network gateways, while guaranteeing that a path to a gateway exists for every mesh node.

We consider a wireless mesh network with a set of nodes *N*. Each mesh node has multiple radio interfaces. Some nodes, referred later on as gateway nodes, have wired network connections. The problem we address is to assign channels to mesh nodes and define node pairs that have a communication link, while ensuring that all nodes have a path to at least one gateway. Channel assignment alone does not fully define the node connectivity, since an interface's transmission rate depends on the destination interface it communicates with; the transmission rate in turn influences the throughput that is achieved by that link, as well as all other links in the same transmission range that operate on the same channel. Let *L* be the set of links between nodes, which contains elements of the form (*i*,*j*;*k*), denoting a link between nodes *i* and *j* operating on channel *k*. Note that can exist multiple links between two mesh nodes, operating on different channels. Also, different nodes can communicate with the same node on the same channel. L_{ij} denotes the set of links, and $X_{ij} = \{x_l, l \in L_{ij}\}$ the throughput of the links between nodes *i* and *j*. Finally, K_i and I_i is the number of assigned channels and the number of interfaces in node *i* respectively.

The channel assignment and topology control objective is to maximize the aggregate utility:

$$\max_{L} \sum_{i,j \in N} U(X_{ij})$$

s.t. $\exists$ path from i to a gateway, $\forall i \in N$ and $K_i \le I_i, \forall i \in N$

The utility $U(X_{ij})$ is a function of the throughput of links between nodes *i* and *j*. The above formulation considers the hop-by-hop throughput between nodes connected by one or more links. The utility *U* encodes different operator-dependent requirements and objectives, and may be optimized according to different optimization criteria: aggregate throughput objective, fairness or redundancy.

A more detailed description of the channel assignment algorithm is given in [2].

3. Description of demonstration

The demonstration will present to the audience the behaviour of joint auto-configuration and channel assignment procedures on 4 nodes network. The nodes will be placed within the demonstration area, and will be connected by RF cables with different attenuators to present how the optimization generates different topologies when the links between nodes are modified. A laptop PC will serve as the Network Manager and a graphical user interface for the topology optimization. Additionally, to present how the topology optimization behaves on large-scale network, we will connect to the laboratory network.

The audience will be presented with the visualization of the network topology before and after the optimization. Also, the operation of the incremental version of the channel assignment algorithm will be demonstrated. To realize this function, the nodes will be restarted, showing how the auto-configuration procedure joins a new node to the network. The traffic will be generated to present different throughput performance, depending of the network topology. The AirSync Graphical User Interface will be used to present the visualization of the network topology and traffic statistics. Figure 1 presents a sample screen illustrating the topology visualization.

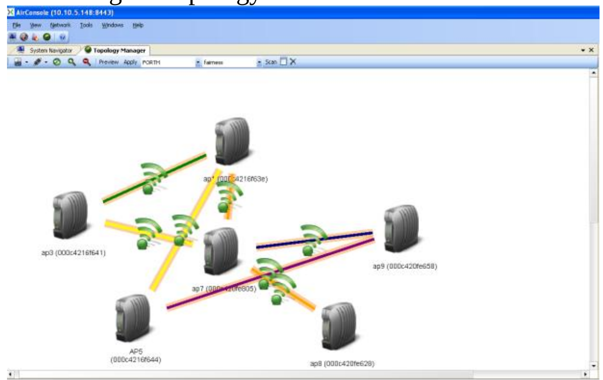

Fig. 1 Sample visualization of the network topology after optimization

The demonstration will be carried on using 4 Microtik RouterBoart RB532 devices, each of them equipped with 3 WIFI interfaces. The autoconfiguration and topology management server will be run on a laptop PC. The AirSync NMS with custom extensions developed by authors will be installed there. Another PC will be used for the presentation, to display the audience the current network topology and the graphical interface to the executed algorithms. The devices will be placed on a single table, the wireless internet access and a single power socket will be required.

Acknowledgement

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The references below contain more details of the algorithms implemented in the demo, and are available from the project website.

References

[1] Grochla K., Buga W., Pacyna P., Dzierżęga J., Seman A.:"Autoconfiguration procedures for multi-radio wireless mesh networks based on DHCP protocol", Proc. of HotMESH 09 Workshop, Kos, Greece 2009

[2] Dionysiou T., Siris V.A., Stamatakis G., "Utility-based Channel Assignment and Topology Control in Wireless Mesh Networks", IEEE Int'l Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM), Montreal, Canada, June 2010