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A survey of routing and channel assignment in multi-channel multi-radio WMNs

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ABSTRACT

Wireless mesh networks provide cost-effective coverage and high network performance by utilising advanced radio frequency technology such as multiple channel multiple radio (MCMR). In spite of the advantages in MCMR wireless mesh networks, some wireless mesh networks still suffer from performance issues such as throughput degradation and unacceptable latency when network size increases. Existing studies focused on solving the performance issues from a single aspect such as routing or channel assignment. A major limitation of these studies is its failure to consider the interaction between routing and channel assignment which is a key factor influencing network performance.

Different from the existing studies, we investigate routing and channel assignment in tandem. A new taxonomy is developed for evaluating the capabilities of current MCMR wireless mesh networks and used to organise past and ongoing research on routing and channel assignment algorithms. Our work provides a comprehensive analysis of existing studies from the interactive factors between routing and channel assignment. We aim to stimulate and guide the future research on joint design between routing and channel assignment in MCMR wireless mesh networks that can optimise network performance better than the individual solutions.

1. Introduction

Wireless mesh network (WMN) (Akyildiz and Wang, 2009) is a technology for next generation wireless networks that provides high performance, last-mile broadband Internet service (Pathak and Dutta, 2011). WMNs started with single-channel single-radio system due to the limitations of radio technology at the time. In single-channel single-radio WMNs, all nodes use one radio with a common broadcast channel. Therefore, channel contention and interference remained a major drawback in single-channel single-radio WMNs.

With the development of advanced radio technologies, MCMR functionalities at each node provide effective approaches to enhance network performance in WMNs (Draves et al., 2004a; Cheng et al., 2013; Malnar et al., 2015). In MCMR WMNs, each node has multiple radio interfaces. Radio interfaces on nodes may transmit simultaneously because each radio has its own physical (PHY) layer and medium access control (MAC) layers. Compared with single-channel and single-radio, MCMR technologies significantly increase network capacity, provide flexible connectivity, and reduce the interference among neighbouring links.

Even though MCMR technologies bring many benefits to WMNs, it also introduces some operational issues to achieve ubiquitous deployment of WMNs. Firstly, the design complexity is increased in some WMN protocols such as routing and channel assignment (Pióro et al., 2014). In single-channel single-radio WMNs, channel assignment is simple and routing does not need to consider the channel state because all nodes use the same channel. However in MCMR WMNs, the channel assignment algorithm needs to allocate different channels to the radios at a node and concurrently must select a channel for each link in the path through the routing process. Therefore, the protocols in MCMR WMNs need more sophistication to regulate the spatial resources and optimise network performance. Otherwise, WMNs may perform poorly due to inefficient utilisation of the multiple available channels and the multiple radios at its disposal (Gong et al., 2013; Ho et al., 2014).

Secondly, the interaction between routing and channel assignment is another critical factor influencing network performance because routing and channel assignment are dependent on each other. Some studies tackle routing and channel assignment separately or regard channel assignment as the lower layer protocol of routing (Si et al., 2010). These studies fail to consider the traffic information in the channel assignment stage and thus is not

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able to reap the benefits of joint optimisation between channel assignment and routing. In the same way, routing protocols have limited access to channel state. Hence, routing protocols cannot evaluate link quality and interference effectively and the improvement in network performance is limited (Si et al., 2010; Avallone et al., 2013).

In recent years, researchers have began to realise that joint design of routing and channel assignment provides a better solution in practice (Pathak and Dutta, 2011; Mogaibel et al., 2012; Ning et al., 2012; Zhou et al., 2012; Malik et al., 2015). In some harsh environments such as high density WMNs, routing protocol cannot meet quality of service (QoS) requirements due to the limited network capacity. In this case, channel assignment algorithm may complement the routing protocol by readjusting channel allocation towards the goal of improving QoS (Avallone et al., 2013; Hossain and Leung, 2007).

However, existing joint approaches between routing and channel assignment simplify their objective to solve a part of an interleaved problem (Li et al., 2009; Capone et al., 2010; Marina et al., 2010; Avallone et al., 2013; Doraghinejad et al., 2014) due to the complexity of combining routing and channel assignment. A global optimisation of network performance has not been studied well in MCMR WMNs and the lack of global optimisation leads to inefficient resource management in MCMR WMNs (Cheng et al., 2013). Therefore, a joint optimisation strategy involving routing and channel assignment with a global objective will be a novel approach for MCMR WMNs.

Many surveys about routing or channel assignment have been reported in the literature (Baumann et al., 2007; Si et al., 2010; Skalli et al., 2007; Sheshadri and Koutsonikolas, 2013; Kim et al., 2011; Draves et al., 2004b; Audhya et al., 2011; Borges et al., 2011; Waharte et al., 2008; El Haoudar and Maach, 2015). Besides these surveys, some studies have been done on comparing routing metrics and channel assignment through testbed experiments (Sheshadri and Koutsonikolas, 2014; Kala et al., 2015). These surveys and experimental studies provided valuable information for improving routing metric and channel assignment. However, these studies discuss routing and channel assignment separately, and separate discussions are unlikely to provide insights for global optimisation.

The purpose of this survey is to develop a taxonomy to organise past and on-going routing and channel assignment in MCMR WMNs. This taxonomy is built through identifying the critical factors involved in network performance, routing, and channel assignment. Such a taxonomy aims to comprehensively investigate the root cause of performance issue. To the best of our knowledge, our survey is the first paper to survey routing and channel assignment together, which allows researchers to rapidly gain high-level understanding on the state-of-art MCMR WMNs research.

The rest of this paper is organised as follows. Section 2 describes key design factors in MCMR WMNs and develops a taxonomy that will be used throughout this paper. Sections 3 and 4 categorise and discuss existing routing metrics and channel assignment algorithm based on the key factors. The conclusion is given in Section 5.

2. A new taxonomy for MCMR WMNs

The new taxonomy to be presented in this section is designed by judiciously combining several dimensions used in the existing classifications in WMNs. Four main factors chosen in the new taxonomy are topology, channel capacity, interference, and the number of available radios and channels at each node (MC-MR) (see Fig. 1). First, we give the definitions of these four factors. Then, we explain how routing and channel assignment are linked to these factors and the mutual influence between routing and channel assignment. The symbols for these factors together appear with a brief explanation in Table 1.

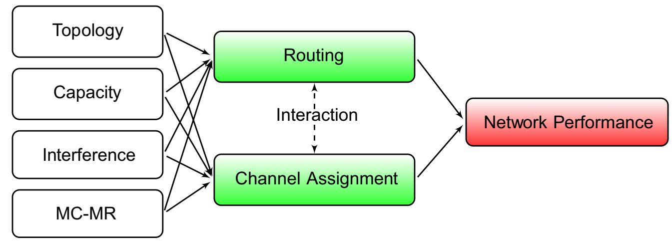

Fig. 1. Four critical factors relating routing and channel assignment to network performance.

Table 1
Notation: symbols and their meanings.

Symbol	Explanation
D_{tr}	The transmitter–receiver separation
R_i	The interferer proximity
P_r	The relative position of links in a path
P-C	PHY channel capacity
M-C	MAC channel capacity
P-I	PHY layer interference
Inter	Inter-flow PHY layer interference
Intra	Intra-flow PHY layer interference
M-I	MAC layer interference
MC-MR	The number of available channels and radios

- *Topology*: Network topology is the arrangement of the various elements such as nodes and links of a network, which forms the layout of WMNs. Two nodes within transmission range have a link if they share the same channel. Network topology in MCMR WMNs is more flexible because each node may communicate with its neighbours over multiple links by using different channels at different radio interfaces. WMNs provide multiple choices of links between a pair of nodes, which increases robustness and reliability in WMNs. Three factors, transmitter–receiver separation (D_{tr}), interferer proximity (R_i), and relative position of links in a path (P_r), are essential information in topology. Transmitter–receiver separation is defined as the distance between sender and receiver in a link while interferer proximity refers to the distance between a interferer node and a tagged node. Relative position of links in a path means the order of links in a path. The reason we chose these factors is that D_{tr} and R_i are a more realistic reflection of the information available to the network planner. While P_r is a critical factor for routing.
- *Capacity*: Channel capacity refers to the upper bound of the data rate at which packets can be reliably transmitted at each node. Channel capacity directly influences the achievable performance of a WMN. We categorise channel capacity into PHY layer capacity (P-C) and MAC layer capacity (M-C). P-C refers to the data rate of a channel over space while M-C is defined as the effective data rate by considering the overheads of MAC layer mechanisms on P-C. Generally, the effective rate seen by an application is a function of P-C and M-C. Therefore, these two capacity factors are essential inputs for routing and channel assignment.
- *Interference*: Interference is the main cause of performance degradation in WMNs. Interference in WMNs can be categorised into PHY layer interference (P-I) and MAC layer interference (M-I). P-I refers to the interruption of signals at the PHY layer. P-I is further divided into (i) intra-flow interference between the links along a path and (ii) inter-flow interference