# A Novel Channel Assignment Algorithm for Multicast in Multi-radio Wireless Mesh Networks

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**Abstract:** With the development of Internet, many new applications with obvious multicast character come forth and become popular, which increase the importance of multicast in Internet especially in wireless access networks where the bandwidths of networks are very limited. In this paper, we consider the problem of channel assignment for multicast in multi-radio wireless mesh networks (WMNs), which have not been studied up to now. We propose a novel channel assignment strategy called UCAS based on unidirectional link model, and give an efficient greedy vertex coloring algorithm called BFVC. Finally, the results of simulations demonstrate the efficiency of the algorithms presented in this paper.

**Keywords:** channel assignment, multi-radio, wireless mesh networks, multicast

## I. INTRODUCTION

Wireless mesh networks (WMNs) are static multi-hop wireless networks consisting of some wireless routers [1-2]. They are usually used for broadband wireless access or constructing wireless local area networks (WLANs). As many other wireless networks, WMNs also have the capacity problem due to the very limited frequency bandwidth used for wireless communication. To relieve this problem, the technology of multi-radio is applied in WMNs by equipping every wireless router with multiple radio interfaces tuned to non-overlapping channels.

The problem of channel assignment is a key problem in WMNs where the co-channel interference is one of the most important reasons that affect the network performance. What we do here is to study how to assign the radio interfaces on wireless routers to the available channels to reduce the interference degree of WMNs. And the use of the technology of multi-radio increases the complexity of the problem of channel assignment. Now the problem of channel assignment in multi-radio WMNs has become to an active research area and some works on channel assignment in multi-radio WMNs have been published [3-9]. Reference [3] presented 3 main principles of distributed channel assignment. In [4-5], Raniwala, A. etc proposed the first multi-channel WMNs architecture called Hyacinth, which equipped each router with 2 802.11 network interface cards (NICs). Reference [6] presented two mixed integer line programming models fixed channel assignment to maximize the number of bidirectional links that could be activated simultaneously. In [7], the authors proposed a notion of a traffic-independent base channel assignment. In the beginning, they assigned every link with a channel as its default channel. Then whenever one node wanted to send packets to other node, they would select the default channel unless it was not available. Reference [8] proven that the problem of channel assignment with minimum overall network interference is NP-hard and gave two approximate algorithms, one was iteration algorithm and the other was greedy algorithm. Reference [9] proposed a centralized interference-aware channel assignment algorithm where the interference between WMNs and co-located wireless networks was taken into consideration.

However all these algorithm above have been presented to address the problem of channel assignment for unicast and taken that for multicast into no consideration. As we know, multicast is one of the most exciting technologies in Internet and is

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playing a more and more important role. With the development of Internet, some new network applications such as online video, p2p transmission and so on come forth and become very popular [10]. Comparing with those traditional applications, these new ones usually require more bandwidth and more hosts. And a host that runs a new kind application often needs to send the same packet to multiple receivers. If sending these data with unicast, this host should copy the packet for many times and then send these copies to each receiver one by one, while if do that with multicast, what the host should do is to send a single packet to all of these receivers. So we can see that multicast can save much bandwidth than unicast for these new applications. In this paper, we propose a channel assignment strategy for multicast and give a corresponding algorithm with minimum interference.

### A. Research Contributions

As mentioned above, in this paper we mainly research the problem of channel assignment for multicast in multi-radio WMNs. To the best of our knowledge, ours is the first time to study the channel assignment problem for multicast and the works before mainly focus on the same problem for unicast packets. And the contributions in this paper are shown as follows:

- In this paper, we propose a novel channel assignment strategy for multicast based on unidirectional links;
- We translate this problem into *k*-vertex-multi-coloring problem which prove to be NP-complete.
- We also present an efficient channel assignment algorithm for multicast.

### B. Paper Outline

The remainder of this paper is organized as follows: Section II discusses network topology and system model; Section III describes the channel assignment strategy based on unidirectional links called UCAS; In Section IV, we study the algorithm of channel assignment for multicast. In this section, we translate this problem into a *k*-vertex-multi- coloring problem and also give an efficient channel assignment algorithm; In Section VI, we demonstrate the efficiencies of this algorithm proposed in this paper through some simulations. Section VII concludes this paper.

## II. NETWORK TOPOLOGY AND SYSTM MODEL

Here we consider the typical WMNs in physical world. WMNs usually consist of two kinds of wireless nodes: wireless routers and wireless clients. All mesh routers compose the backbone network of WMNs, and the wireless clients compose the client networks with their access routers. The wireless routers are stationary and their positions are often designed carefully to obtain high performance, while the clients are usually dynamic to provide the convenient access service. Besides, there are often one or more mesh gateway(s) connecting to Internet or other networks when the WMNs are used as access networks. Here the mesh gateway is a special router running gateway function. Besides, every wireless router is usually equipped with multiple radio interfaces in order to improve throughput performance. Because the performance of the WMN is mainly decided by its backbone network, we ignore those client nodes in this paper.

To simplify the study of this problem, we make some assumptions as follows: All routers in WMNs are distributed on a plane arbitrarily. Each router is equipped with multiple radio interfaces, and the number of radio interfaces is not much than that of non-overlapping channels. All radio interfaces on wireless routers are half-duplex, use omni-directional antennas, and have identical transmission ranges and identical interference ranges denoted by $r$ and $R$ respectively.

Interference models: Due to the broadcast nature of wireless links, transmission along a wireless link is easy to be interfered by other nodes with the same channel nearby. In order to describe the interference situation, researchers have proposed some interference models, and the most popular two models of them are physical model and protocol model [11, 14-15]. And our discussion in this paper isn't limited to the special interference model.

In next section, we mainly introduce the channel assignment strategy called UCAS, and discuss how it can support both unicast and multicast.

## III. UNIDIRECTIONAL CHANNEL ASSIGNMENT STRATEGY (UCAS)

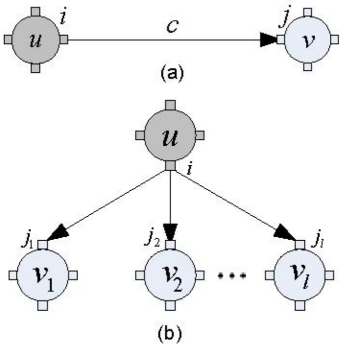


Fig. 1 the wireless links in WMNs
(a) one-to-one (b) one-to-multiple

In our strategy, channel assignment is based on unidirectional wireless link model. Within the range of 1-hop, the wireless links can be divided into two kinds: one-to-one and one-to-multiple which correspond to unicast and multicast. If node $u$ wants to send a unicast packet through its interface $i$ to the interface $j$ on node $v$, then these two interfaces should be tuned to a same channel $c$. Thus as shown in Fig.1 (a), there exists a one-to-one unidirectional link from interface $i$ on node $u$ to interface $j$ on node $v$, and the corresponding assigning of channel is represented as $u_i \xrightarrow{c} v_j$. The same is to transmission of multicast, if node $u$ wants to send a multicast packet through its interface $u_i$ to interfaces $v_{1,j_1}$ ,…, $v_{l,j_l}$ on node $v_1$ ,…, $v_l$, all of these interfaces should be tuned to a same channel $c$. Thus as shown in Fig. 1(b) there also exists a one-to-multiple unidirectional link from interface $u_i$ to interface $v_{1,j_1}$ ,…, $v_{l,j_l}$, and the corresponding assigning of channel is represented as $u_i \xrightarrow{c} \{ v_{1,j_1} ,\dots, v_{l,j_l} \}$.

In next section, we discuss how to get an efficient channel assignment scheme for multicast.

## IV. CHANNEL ASSIGNMENT ALGORITHM

At first, we formulate the problem of channel assignment for multicast. Here we use a directed graph $G(V,\vec{E})$ to represent the connectivity between nodes in this WMN, where $V$ represents the set of all nodes. For $\forall$ $u$ ,$v \in V$, $r(u_i,v_j)$ represents the communication range from radio interface $u_i$ on node $u$ to interface $v_j$ on node $v$, *iff* $0 < d(u,v) \le r(u_i,v_j)$ there exists an arc $\vec{e}(u_i,v_j) \in \vec{E}$ between node $u$ and $v$. So for an arc $\vec{e}(u_i,v_j)$, *iff* there exists a radio interface $w_k$ sending packets at the same channel with $u_i$, we say that there is an interference node $w$ that conflict with node $u$. Fig. 2 is a directed connectivity graph of a simple network with 4 nodes. Below we prove that the problem of channel assignment for multicast with minimum interference is NP-complete.

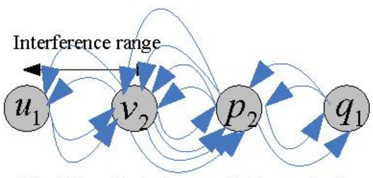


Fig. 2 the directed connectivity graph of a simple network with 4 nodes

***Theorem*** 1: the problem of channel assignment for multicast with minimum interference is NP-complete.

***Proof:*** here we give an undirected conflict graph $G'(V',E')$, for $\forall$ $\vec{e} \in \vec{E}$ in $G(V,\vec{E})$, there exists one vertex $v' \in V'$. For $\forall$ $u'$, $v' \in V'$, *iff* their corresponding arcs in $G(V,\vec{E})$ conflicts with each other, there exists an edge $e'$ between them. Thus the conflict graph of the network with 4 nodes can be shown in

Fig.3. Here the nodes with the same colors are arcs that from the same radio interface. For we know that the wireless link from the same radio interface should be assigned the same channel. So we combine all the nodes that with the same color in $G'(V',E')$ then get a weighed vertex conflict graph $G''(V'',E'')$ with a weight for each edge indicating the interference degree as shown in Fig. 4. And the problem has been translated into a problem of $k$-vertex-multi-coloring. The problem of vertex coloring with equal weight edges is known to be NP-complete. So the problem of channel assignment for multicast with minimum interference is also NP-complete. Below we give an approximate greedy algorithm called BFVC (Breadth First Vertex Coloring).

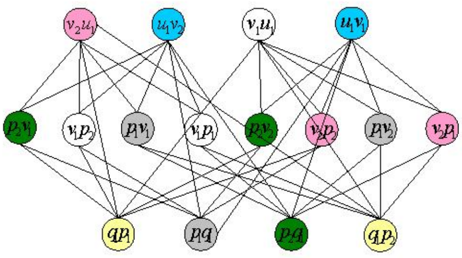
Fig. 3 the directed conflict graph for the network with 4 nodes

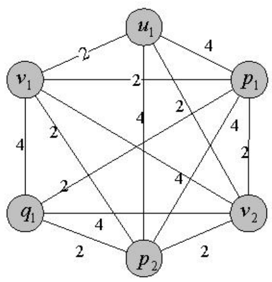

Fig. 4 the weighed vertex conflict graph

As shown in Fig.5, the algorithm of BFVC visits all the nodes from mesh gateway with the sequence of breadth-first. For each node to be visited, we compute its interference values at different channels, and then assign its radio interfaces to the channels with minimum interference values.

Below we introduce how to compute the interference values at different channels for a node to be colored.

```
Input: connectivity graph G and the
       channel set C
Output: channel assignment function f.

BEGIN:
  # start from gateway node g, Q is
  # the queue of nodes to be colored
  for each node u { stat(u)=UNCOL; }
  InitQueue(&Q);
  EnQueue(&Q, g), set stat(g)=TOCOL;
  while !QueueEmpty(Q)
  {
    DeQueue(&Q, &u), stat(u)= COLED;
    # neig(u,G) is the neighbor set of
    # u in graph G
    for each v in neig(u,G)
    {
      if (stat(u) = UNCOL)
        EnQueue(&Q, v);
    }
    for each c in C {state(c)=UNUSED;}
    for each interface i on node u
    {
      interf(u,i)= MAX;
      for each c in C
      {
        if (state(c)==USED)
          continue;
        inter = 0;
        for each node v,w
        {
          if (stat(v)!=COLED)
            continue;
          if ( 0 < d(u,w) <= r &&
               0 < d(w,v) <= R
               ||0 < d(u,w) <= R &&
               0 < d(w,v) <= r)
             inter=iner+weight(u,w,v)
        }
        if (inter < interf(u,i))
          then interf(u,i) = inter,
               f(u,i) = c;
      }
      state(f(u,i))=USED;
    }
  }
END
```

Fig. 5 the channel assignment algorithm–BFVC

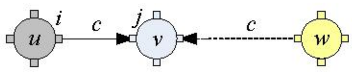

Fig 6 compute the interference values of the node at different channels

As shown in Fig. 6, node $u$ is the node to be colored, and the set $Ng(u)$ is the set of the neighbors of node $u$. For $\forall\ v \in Ng(u)$, let $IF(v,c)$ represent the set of nodes which has an interface assigned to the channel $c$ within the interference range of node $v$, and $p_t(w)$ represent the probability that the node $w$ send packets with the radio interface assigned channel $c$. And the interference value of node $u$ at channel $c$

$itf(u,c)$ can be represented as follows:

$$itf(u,c) = \sum_{v \in Ng(u)} \sum_{w \in IF(v,c)} p_t(w).$$

In next section, we will use the simulation tests to prove the effectiveness of the algorithm of BFVC.

## V. SIMULATIONS

In this section, we evaluate performance gains obtained by the algorithms presented above using extensive ns-2 simulator. Here we have modified ns-2 to support wireless node with multiple radio interfaces and unidirectional link, and we also modified the codes to ensure that it can support multicast routing protocol.

### A. Simulation Environment

The topology used in our simulation consists of 30 wireless routers distributed in a terrain of $1000 \times 1000m^2$, and there is a gateway located in the center. As shown in Fig. 7, there are no isolated wireless nodes and the distance between two every two nodes is larger than 100m. The transmission range of each node is 250m and the interference range of each node is 550m. Every wireless node is equipped with tree radio interfaces. In the simulations, there are 12 orthogonal channels, and the bandwidth of a channel is set to 11Mbps.

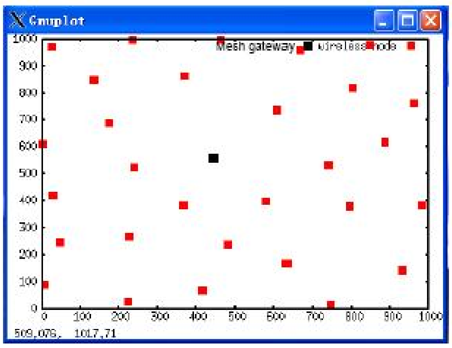


Fig. 7 the distribution of nodes in simulation tests

### B. Network Scenario

Here we consider two network scenarios in our evaluations: in scenario 1, we compare the performance of BFVC for unicast with the greedy algorithm proposed in [7]. Here we use AODV [12] as the routing protocol, and the packet size is fixed to 1000 bytes; in scenario 2, we compare the throughput performance of BFVC for unicast and that for multicast. Here ten nodes are randomly chosen to construct a group, and two nodes in this group are selected as data sources. Here we select ODMRP [13] as the multicast routing protocol in this wireless mesh network.

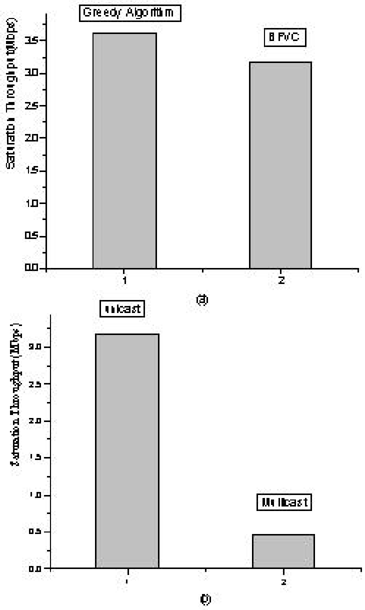


Fig. 8 the simulation results

### C. Simulation Results

Fig. 8(a) compares the throughput performance for unicast of BFVC with that of the Greedy algorithm. And we can see that the performance of BFVC for unicast is a little less than that of the Greedy algorithm. Fig. 8(b) shows the compare of throughput performance of BFVC for unicast with that for multicast. And we can see that the throughput performance of BFVC for multicast is much less than that for unicast, which is reasonable for we know, the interference of multicast is usually much more than that of unicast.

## VII. CONCLUSIONS

In this paper, we have proposed a novel channel assignment strategy based on unidirectional links that can support both unicast and multicast. Besides, we have also studied the channel assignment algorithm, and translated the problem of channel assignment with minimum total network interference into the problem of vertex multiple-coloring with the limited colors which has been proven to be NP-complete, and present a greedy algorithm. In the end, the simulation results have proven that the efficiencies of this algorithm presented above.

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