A Broadcast Channel Assignment Mechanism based on The Broadcast Tree for Multi-radio Multi-channel Wireless Mesh Networks

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Abstract. This paper proposed a broadcast Channel Assignment Mechanism on base of optimized Broadcast Tree for wireless Mesh network (WMN), which is created by Branch and Bound Method. The simulations show that our algorithm not only reduces the broadcast redundancy but also avoids the potential channel interferences produced by unnecessary relay nodes.

1. Introduction
Broadcast communication is widely used in many applications of wireless Mesh network (WMN), such as control instructions and data release. How to allocate the appropriate channel for the Mesh network nodes in the Broadcast communication is an important issue in the research of the WMN channel allocation technology.

Broadcast is a kind of communication mode which is widely used in network protocols. The original working characteristics of wireless broadcast communication can also provide support for many applications of WMN. If all nodes in WMN use the same channel, the data packets only need to be received by all the other neighbor nodes, so the broadcast protocol design for the single channel WMN only needs to take node as the center. However, the whole network uses a single channel radio is bound to produce channel interference. A certain number of nodes will be unable to properly receive the broadcast message due to channel interference. Re-broadcasting will increase the network communication overhead.

In multi-radio multi-channel WMN, wireless radio can use different channels while mesh nodes can transmit data with multiple wireless radios at the same time. Two nodes in the interference range can also use different channels to broadcast. If all the wireless radios of a mesh node use different channels and does not carry out the channel adjustment for broadcast communication, this mesh node...
have to broadcast data communication in multiple channels to transmit packets to all of its neighbors. This will undoubtedly weaken the effective use of the broadcast transmission characteristics and the wireless broadcast advantage (WBA) characteristics of the wireless transmission medium in a certain extent.

Due to the limitations on broadcast redundancy, channel interference and impossibility in reaching largest coverage in relay nodes selections in existing approaches based on leveled channel distribution algorithms, we did not follow the common method to level and then seek relay nodes, but provided a new algorithm for optimize Broadcast Tree based on Branch and Bound Method, and then fulfilled the optimization in selection of relay nodes via the optimization and pruning for Broadcast Tree, and thus completed the largest coverage. Then we designed a broadcast Channel Assignment Mechanism with low redundancy on base of optimized Broadcast Tree. It not only reduces the broadcast redundancy but also avoids the potential channel interferences produced by unnecessary relay nodes.

2. Related work
The research of multi-channel technology from the perspective of multicast and broadcast in WMN is still in the initial stage. There are some references to the broadcast problem in wireless Mesh networks, but most of them are only limited to the single channel, or based on the premise that the channel allocation is known.

Many researchers have studied the low redundancy broadcast mechanism for the single channel network environment. These methods mainly include the probability method [1], the method based on the cover [2], the cluster method [3] and the method based on connected dominating set [4,5,6].

The simplest way of broadcasting is flood. Flood is not required to maintain the topological structure of the network and the related routing calculation. Only the nodes that receive the information are requested to transmit the data to their neighbor nodes by broadcast. Paper [7] points out that the cost of flooding is high, and it will lead to the broadcast storm problem, that is, the serious redundancy, channel competition and conflict. The experimental results show that the channel allocation strategy has a great influence on network performance.

There are some studies on how to design a low redundancy and multi-channel broadcast in the given network channel allocation. P.Kyasanur proposed multi-channel flooding broadcast [8]: when the node first received a broadcast message, the data copies of the broadcast message will be rebroadcast in each channel queue. This kind of multi-channel flooding broadcast will undoubtedly lead to new forms of broadcast storm, the redundancy, conflict and competition of a large amount of broadcast data packets are inevitable.

Qin Shaohua proposed a distributed broadcast tree construction algorithm [9], which is simple and easy to implement. However, this paper mainly studies the construction of the broadcast tree. It does not combine multi-channel assignment with broadcasting. This paper also does not make full use of the advantages of a neighbor node that uses the same channel in wireless communication to receive broadcast messages at the same time.

Guokai Zeng proposed Level (Level-CA) based on the hierarchical channel assignment algorithm [10]. This algorithm is based on the breadth first search strategy, and the Level-CA hierarchy is the most classical method of building the broadcast tree. The drawback of Level-CA is that the channel interference of the same level nodes may be formed, and the available multi-channel resources cannot be fully utilized.

3. A New Broadcast Channel Assignment Mechanism

3.1. Problem Analysis
According to the network environment of multi-radio and multi-channel, the corresponding communication broadcast tree is created in this paper, and the appropriate relay nodes are optimized, and the redundancy broadcast communication is reduced. Based on the optimized communication
broadcast tree, the corresponding channel assignment scheme is designed for the multi-radio broadcast

tree node and relay node.

The broadcast source node S and the whole network nodes constitute an undirected connected

graph G= (V, E, Chs). V is a set of nodes, E is a collection of all links, and Chs is the available channel

numbers of the connected dominating set G.

G= (V, E) is given, if set S satisfies the following two conditions: S ⊆ V and S ≠ ∅ , if ∀x ∈ (V − S), the S is the dominating set of G, S=DS (G). If node x ⊆ S , or one neighbor node of x belongs to the dominant set S, it is known that the node x is dominated by the S cover. If the S=DS (G), the sub graph derived from S is a connected graph. There exists a path between each pair of nodes from S, such as node x and y, then the dominating set S is a connected dominating set (CDS). If the connected dominating set has the least number of nodes, it can be called the minimal connected dominating set MCDS. In this section, the WMN is abstracted into a connected undirected graph, and the optimization problem of multi hop broadcast tree in WMN is summarized as a classic MCDS (Minimum Connected Dominating Set) problem.

Taking into account the establishment of each edge in the graph G contains two nodes on a link should be adjusted to the same communication channel at the same time, the minimum connected dominating set problem is also equivalent to an edge coloring problem. In this paper, we study the combinatorial optimization problem of minimum connected dominating set and channel assignment problem. As we all know, the minimal connected dominating set problem and the edge coloring problem have been proved to be NP complete problem in graph theory.

3.2. Definitions

Through our in-depth analysis, the problem is summarized as follows: find a MCDS, based on this

MCDS, the broadcast source node can quickly reach all nodes in the network, and ensure that the entire network of radio and communication overhead is minimal. Therefore, from any one of the broadcast source node s, some neighbor nodes of s, should be chosen to act as the relay nodes. After assigned different channels, those relay nodes continue to broadcast until the original broadcast messages reach all nodes in the network G.

AA(Active Array): the current working state for the active node set, the array initialization phase is empty, that is {∅}.

UA(UnActive Array): the current working state for the non-active node set, the array initialization phase is empty, that is {∅}.

DSA(Dominating Set Array): DSA (Set Array Dominating), the active node set (dominating set) with the current working state is broadcast or re-broadcast(relay), in the initialization stage there is only broadcast source node S, {S}.

Related attributes Euv: if the two adjacent Mesh nodes v and u are both in DSA, then the link Luv between v and u should in DS, Euv=1, otherwise Euv=0.

Taking into account the broadcast characteristics of multi-channel allocation, one-hop neighbor

node coverage set of nodes V is divided into three kinds, N1(v), N2(v) and N3(v).

One-hop neighbor nodes of node v and node v consists of a collection of N[v], N[v] = N(v) ∪ {v}. One-hop neighbor nodes group of node v is N1(v), N1(v) = {u ∈ N(v) | N(u)∩N[v] ≠ ∅}. One-hop neighbor nodes table of node v is N2(v), N2(v) = {u ∈ N(v)\N1(v) | N(u)∩N1(v) ≠ ∅}.

One-hop leaf nodes table of node v is N3(v): N3(v) = [N(v) − (N1(v) ∪ N2(v))].

The following conclusions can be deduced from the definition given above, N(v) = N1(v) + N2(v) + N3(v).

The roles of these nodes in broadcast communication are different, and the status of the nodes are also different. In the forwarding process of the broadcast message, the nodes in N1(v) will act as relay nodes, so they should be attached to DSA. The nodes in N2(v) do not have to be involved in the relay
operation, which can be used as the receiving nodes of the broadcast message which have been
broadcasted by member nodes of \( N_1(v) \). Acting as the leaf nodes, the nodes in \( N_3(v) \) would be the
receiving nodes of the broadcast message and also do not have to be involved in the relay operation.

3.3. Method Description
The branch and bound method is proposed by Richard Kapp. It is a widely used algorithm, and its
basic idea is to search for all feasible solutions (limited) space of constrained optimization problem. In
general, the optimal solution can be obtained by using the branch and bound method.

Any one broadcast source node, first of all, should select the relay nodes from its neighbor nodes \( N(s) \). After allocating appropriate communication channels, those relay nodes continue to broadcast, until
the broadcast message reaches all nodes in the network \( G \). In this process, two key issues need to be
solved: the selection of relay node and channel assignment. We use the branch and bound method to
optimize the channel allocation. We design a broadcast tree creation algorithm based on branch and
bound method, and design the channel assignment mechanism in the construction process of broadcast
tree. Our new algorithm, called BTCAM, is the abbreviation for Branch and Bound Method Broadcast
Tree based Channel Assignment Mechanism.

The problem can be described as: \( \text{CA-broadcast} = \max \{cx: x \in S\} \). The problem is divided into a
plurality of branch, and the union of all branches is \( S \). For any \( i,j=1,\ldots,k \), when \( i \neq j \), \( S_i \cap S_j = \{0\} \).

In section 3.2, the neighbor nodes \( V \) is divided into three types of roles. According to the
different roles of the node, the corresponding branch is carried out. This can simplify the
number of branches, especially for dense network topology.

The current problem solution \( S_v \) can be divided for \( S_v = S_v^1 \cup S_v^2 \cup S_v^3 \), which \( S_v^1 \) is solution set for \( N_1(v) = \{u \in N(v) \mid N(u) \setminus N[v] \neq \emptyset\} \), \( S_v^2 \) is solution set for \( N_2(v) = \{u \in N(v) \setminus N_1(v) \setminus N[v] \} \), \( S_v^3 \) is solution set for \( N_3(v) = \{N(v) - (N_1(v) \cup N_2(v))\} \). The sub
problems are satisfied the following relations: \( S_v^1 \cap S_v^2 = \{0\}, S_v^1 \cap S_v^3 = \{0\}, S_v^2 \cap S_v^3 = \{0\} \).

According to the branch and bound method, the pruning strategy is described as follows.

Theorem Pruning Strategy. As a branch divided in the broadcasting process, If \( S_v^1 \) satisfies any
of the following three conditions, it will be pruning.

(1) Not feasible: \( S_v^1 \) solution is empty.
(2) Optimality: an optimal solution has been found for the current sub problem \( \text{CA-broadcast}(v) \);
(3) Optimal value comparison: a solution for the sub problem \( \text{CA-broadcast} (v) \) has been included
in some existing solution.

As the basic thought of the new Mechanism, the branch and bound method is used to realize the
broadcast tree pruning and optimization, in order to reduce the number of relay nodes and reduce the
broadcast redundancy and reduce channel interference in the neighbor broadcast communication links.

3.4. Construction of Broadcast tree and Assignment of channels
The broadcast source node \( S \) is the execution node of the corresponding algorithm of BTCAM. After
determining the DSA member, the broadcast tree can be created in the next stage. Based on the
broadcast tree, the channel assignment of the transmission link can be carried out in the third stage.

The input part of the BTCAM algorithm includes the following:

(1) \( G=\{V, E\} \), \( V \) is a set of nodes, \( E \) is a collection of all links.
(2) Each node maintains a neighbor information within two hops.
(3) The broadcast source node \( S \).

The output part of the BTCAM algorithm includes the active node set \( \{\text{DSA}\} \).
Due to the space, the algorithm details are omitted. The main steps of BTCAM are described as follows.

- Initialization of active node sets of work state, initial AA=\{S\}:
• Initialization of active node set (dominating set) with the current working state is broadcast or re-broadcast (relay), initial DSA = \{\emptyset\};
• Initialization of the non-active node set, initial UA = \{\emptyset\};
• Sets the relay identifier bit for all the nodes to 0, initial \text{Flag}=0;
• By the topology discovery and HELLO communication, the adjacent nodes can establish respectively \text{N[v]}, \text{N1(v)}, \text{N2(v)}, \text{N3(v)};
• Add a new DSA node \text{x}, add the node's neighbor table \text{N (x)} to join the AA set;
• According to the situation of neighbor table coverage and pruning strategy in section 3.3, increase the members of new DSA and UA members;
• Set the relay identifier bit of the relay node \text{Flag}=1;
• After executing the channel assignment function Assign-BC (Broadcasting node ID, receiving nodes list), the relay node will be assigned its broadcasting channel;
• The node of \text{N2(x)} executes the channel assignment function Assign-BC (Broadcasting node ID, receiving nodes list). Add \text{N2(x)} into UA set.
• The node of \text{N3(x)} executes the channel assignment function Assign-BC (Broadcasting node ID, receiving nodes list). Add \text{N3(x)} into UA set.
• All nodes in figure G, either in DSA, or in UA.

4. Simulations

Based on multi-radio multi-channel WMN simulation platform, we build the experimental environment. In the experiment, the NS2 platform is used to set up the wireless Mesh network (900×900 m²). The Mac layer protocol used in the simulation is 802.11a, the number of non superimposed channels is 12, and the channel bandwidth is 54Mbps. Network randomly generated multiple independent constant rate data stream (CBR).

Considering the structure of the algorithm, the Level-CA algorithm and BTCAM algorithm are compared from three major parameters. These parameters are network throughput performance under different available channel numbers, Broadcast delay under different node numbers and the proportion of the broadcast nodes to the whole network nodes under different node numbers.

As shown in figure 1 to 3, experimental results show that the BTCAM algorithm has better performance than the Level-CA algorithm.

![Fig. 1. Comparison of network throughput under different available channels](image-url)
Fig. 2. Comparison of delay under different Numbers of Mesh Nodes

Fig. 3. Transmission ratio contrast under different Numbers of Mesh Nodes

5. Conclusions
Due to the limitations on broadcast redundancy, channel interference and impossibility in reaching largest coverage in relay nodes selections in existing approaches, this paper proposed a new algorithm for optimize Broadcast Tree based on Branch and Bound Method, and then fulfilled the optimization in selection of relay nodes via the optimization and pruning for Broadcast Tree, and thus completed the largest coverage. Based on the optimized Broadcast Tree, a broadcast Channel Assignment Mechanism called BTCAM is designed, which is not only reduces the broadcast redundancy but also avoids the potential channel interferences produced by unnecessary relay nodes. The simulations show that BTCAM can acquire fine network capacity in WMN with different network environment and with different number of available channels.

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