A Dynamic Channel Selection Algorithm of Data Forwarding in Wireless Mesh Networks

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Abstract Wireless Mesh Networks (WMNs) is an emerging technology in networking, in which the devices (nodes) are configured with multi-radios, making the overall capacity improved significantly. Nodes avoid interference with each other by tuning to different channels of the spectrum space. When a node intends to communicate to other nodes, especially a node far away from it with multiple hops, it is critical to find the channel with largest bandwidth to forward the packet. A dynamic channel selection algorithm is presented in this article, by which each node is able to find its next hop based on the criteria of possible largest channel bandwidth to carry out the forwarding. The novel idea of our approach is that only three past numerical data are kept by each node, and then it is able to calculate the potential bandwidth capacity and continue the most efficient forwarding. Simulations experiments were conducted and the results demonstrated that our mechanism outperforms peer approaches in terms of bandwidth capabilities and delay in Wireless Mesh Networks.

1. Introduction

A WMN has many wireless devices (nodes) and gateways or mesh routers. Because of the features of WMNs, a WMN is able to consist of various wireless networks, such as 802.11, sensor networks, etc. The nodes are connected each other via gateways or mesh routers [1]. As such, WMNs provide connectivity and services to participating nodes by establishing a mesh topology through self-organization and self-configuration of gateways or routers and regular nodes. Wireless mesh networks are essential to provide ubiquitous network connectivity for subdivisions, communities, and many organizations. In a traditional wireless network, only one channel is used and each node only has one network interface, resulting in low bandwidth capacity. The limitation is significantly improved in WMNs because each node in an WMN is able to adopt multiple radios with multiple network interfaces, thus making much higher bandwidth capacities. For example, a node in a WMN can be equipped with one 802.11 a and one 802.11 b. Then it can connect to two other nodes at the same time.

A mesh node is able to connect to other node with different channels supported by different radios. Therefore, when a mesh node wants to communicate to other node, especially the node is far away from it with multiple hops, the choice of channels is critical for next hop. When a node is facing the selection of channels, the basic metric is to avoid interference because one channel cannot be used by multiple devices simultaneously in its transmission range [2-3]. Some scholars developed static channel allocation mechanisms, which pre-allocate fixed channel slices to each device. Although interference is
avoided, the channel utilization is low because many channels are idle while some other channels are very busy [4]. To overcome the limitation, many dynamic channel assignment approaches have been developed to assign channels for heterogeneous devices in terms of transmission types and bandwidth [3, 5-7].

We present a new dynamic channel selection algorithm in this paper. In our approach, three past numerical data regarding channel abilities are kept by a node, then it calculates and selects the next hop with the channel of possible highest bandwidth to continue the communication. We conducted simulations and the results indicate that our mechanism increases the bandwidth capabilities and decreases the delay significantly compared with peer approaches.

The paper is organized as follows. Section 2 discusses the peer work on this topic. Section 3 presents a novel method of dynamic channel selection. We carry out simulation experiments to evaluate the performance in Section 4. Section 5 concludes the paper.

2. Related Work

Scholars have developed many approaches for dynamic channel allocation. An existing typical scheme was to allocate and change the channels over the interfaces from time to time [8]. However, the frequent switch resulted in an unstable system.

To improve the capacities of WMNs, static channel allocations were explored [9-10]. This kind of approaches may change the channels with the variance of data transmission load or network topology. However, the change was manual rather than automatic. Therefore, it was inconvenient to handle the changes of network scenarios.

Zheng and Peng proposed an approach [11] to map the channel allocation problem to a graph. Based on the representation, they defined each vertex a number, which was the channel bandwidth over the possible number of users interfering with this channel. Furthermore, they came up with a greedy algorithm to always pick up the vertex with the highest label. Their objective was to maximize the utilization and minimize the interference. The objective was achieved in their work, but the fairness was ignored, meaning the approach did not assign channels to maximal number of users.

A centralized greedy heuristic algorithm called CLICA for channel allocation was proposed by Marina and Das [12]. Like the work in Ref. [11], they used graph as the data structure to represent the relationships between channels and users. Each vertex (node) in the graph stands for a channel. Once a channel was assigned, a node was colored. The approach pre-assigned a priority to each node and the coloring was based on the priorities. In particular, their approach colored the node with the lowest priority and then extended the coloring to its adjacent nodes until all the nodes are colored. The minimal interference was achieved and the network topology was maintained. However, it did not take the total bandwidth utilization into account.

3. Problem Formulation

3.1. The Basic Idea

Various devices can be connected in a WMN. Figure 1 shows the topology of a WMN, in which each device may have multiple interfaces and is able to use different radios. The different radios may not have the same bandwidth abilities because the radio types and channels are based on the physical characteristics of the network interfaces. A device sends data packets to other devices or to the gateway, and then to Internet. In our research, we call a device a node.

When a device, such as node a, wants to send a packet to a gateway, it has the option to choose different channels, such as ac, ad or ae. Because of the change of channel allocation and utilization, the bandwidth of ac, ad, and ae may vary from time to time. Node a always selects the channel with highest bandwidth. However, it is not easy to choose such a channel. For example, if ae is the channel with highest bandwidth, but the channel may be used by other communication at the moment. Hence, node a needs to use an algorithm to identify the channel that has potential highest bandwidth.
In a WMN, if the node $a$ needs to adopt channels to send a packet to a target node, it first sends the packet to one of its neighbours. Which neighbour is the next hop? It depends on the bandwidth ability of the channel. That is, node $a$ will select node $c$, by which the channel connecting $ac$ has the highest bandwidth.

![Figure 1. Topology of a wireless mesh network.](image)

3.2. Computation of Potential Bandwidth

In our model, suppose a node $p$ has its neighbors $e_1$, $e_2$, $e_3... e_n$. Then it has $n$ possible channels $Cpe_1$, $Cpe_2$, ..., $Cpe_n$. They have the bandwidth $B_1$, $B_2$, ..., $B_n$. For each channel, $p$ maintains the bandwidth of the channels in terms of the past three moments $t_0$, $t_1$, and $t_2$. For a communication, node $p$ must figure out the channel with the potential largest bandwidth. The trend of bandwidth’s changes is critical to calculate a channel’s potential bandwidth. Let the current time be $k$. Node $p$ saves the changes of the channel bandwidth $B_1$, $B_2$, ..., $B_n$ for the past three moments $t_0$, $t_1$, and $t_2$. By the representation in Numerical Analysis, we define a factor $Q_{ik}$ as follows:

$$Q_{ik}=\prod_{t=0}^{m} \frac{(t-t_i)}{(t_k-t_i)} B_{ik}$$

(1)

where $B_{ik}$ is the bandwidth of $B_i$ at time $m$, $m=0$, 1, and 2.

Then for the right next moment $\tau$, the bandwidth for $B_i$ is calculated as:

$$B_{i,\tau}=\sum_{k=0}^{t} Q_{i,k}$$

(2)

Node $p$ keeps each bandwidth $B_i$ of the past three moments. When the node $p$ wants to send packages to another node or the gateway, $p$ checks the possible $B_{i,\tau}$, and then it figures out the corresponding channel with highest possible bandwidth in future time $\tau$, and then selects the channel and related device as next hop. Apparently, $p$ will not consider any nodes opposite to the target node as forwarding candidates. For example, if $a$ sends a packet to the gateway, $a$ will not consider $b$ or $f$ as next hop but only consider $c$, $d$ or $e$. Geographical assistance routing is very common in current MWN. In such a routing approach, the initiator is aware of the target’s location and each node has its location by its equipped navigator [13, 14]. When $p$ wants to send packages to a target node $q$, $pq$ is virtually connected, then $p$ only searches the nodes in the region without dash lines to avoid the search in the opposite direction.

3.3. Algorithms

Algorithm 1: Calculation for the bandwidth of neighbour node $c_i$ for next time.

1. For neighbour $ci$, $p$ calculates $Q_{ik}$ with equation (1).
2. Node $p$ calculates $B_{i,\tau}$, the bandwidth of next time $\tau$ with the equation (2).

In algorithm 1, node $p$ uses equations (1) and (2) to calculate the bandwidth of next time of its neighbour $c_i$, based on the factor $Q_{ik}$ it maintains in the past three moments. It updates them with periods and saves their values.

Algorithm 2: Finding next hop.
(1) Node p figures out the region for next hop by the approach described in figure 2.
(2) For i=0 to n 
   Node p calls algorithm 1 to calculate $B_{i, \tau}$.
   Insert $B_{i, \tau}$ to a pre-defined priority queue
(3) Carry out pull() operation from the priority queue. Then find the next hop $p_1$ with highest
   bandwidth of next time $\tau$.
(4) Node p sends packet to the node $p_1$.

Figure 2. The sender figuring out the region of next hop.

4. Performance Evaluation
In order to access the algorithms proposed in this paper, we carry out the simulation experiments with
an assumed noiseless radio environment. We generated a number of nodes which are distributed in a
given region with heterogeneous radio ranges and bandwidths. In our simulation, we created nodes from
200 to 800 with increment of 50. For a certain number of nodes, 10 experiments were conducted in
terms of the aggregate throughput and delay. The average values were calculated and presented.

We abbreviate our dynamic channel selection algorithm as DCSA. Two peer approaches in Ref. [11]
were compared in our experiments. One is NMSB (Non-collaborative-Max-Sum-Bandwidth), the
second is CMSB (Collaborative-Max-Sum-Bandwidth). Ref. [11] used a graph as the data structure to
represent dynamic channel allocation. Based on the structure, both NMSB and CMSB are greedy
algorithms. The former selects the vertex with the largest bandwidth value, assigns the value to a user,
and cuts the corresponding edges until all channels are assigned by this approach. The latter selects the
vertex with the largest label, which was the channel bandwidth over the possible number of users
interfering with this channel until all channels are assigned.

Figure 3 shows the numerical data of aggregate throughput. Among the three approaches, our
approach DCSA has the highest throughput. This indicates that dynamic channel selection algorithm
improves aggregate throughput because the highest channel is selected. Figure 4 demonstrates that our
approach has lowest delay. The reason is that we always find the channel with highest bandwidth and
then the delay is the lowest.

Figure 3. The aggregate throughput of three approaches.  Figure 4. The delay of three approaches.
5. Conclusion
We proposed a new dynamic channel selection mechanism for Wireless Mesh Networks in this paper, in which each node keeps the data in the past three moments and then it calculates the possible largest bandwidth for its neighbours in the next moment. As such, it selects the next hop with the possible largest bandwidth to continue forwarding. Simulation experiments were carried out and the results demonstrated that our approach outperformed peer approaches in terms of throughput and delay.

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References
[1] Akyildiz I F, et al. 2005 A survey on wireless mesh networks IEEE Communications Magazine 43 (9) S23-S30.
[2] Raman B 2006 Channel allocation in 802.11-based mesh networks IEEE INFOCOM 2006 (Barcelona, Spain).
[3] Ramachandran K, et al. 2006 Interference-aware channel assignment in multi-radio wireless mesh net-works IEEE INFOCOM 2006 (Barcelona, Spain).
[4] Haykin S 2005 Cognitive radio: Brain-empowered wireless Communications IEEE Journal on Selected Areas in Communications 23 (02).
[5] Grandblaise D, et al. 2002 Dynamic spectrum allocation (DSA) and recongurability SDR Forum Technical.
[6] Ko B, et al. 2006 Distributed Channel Assignment in Multi-radio 802.11 Mesh Networks (Columbia University Technical Report).
[7] Kyasanur P and Vaidya N H 2004 Routing and Interface Assignment in Multi-Channel Multi-Interface Wireless Networks (UIUC Technical Report).
[8] Bahl P, Chandra R and Dunagan J 2004 SSCH: Slotted seeded channel hopping for capacity improvement in IEEE 802.11 ad-hoc wireless networks ACM Mo-biCom 2004 (Philadelphia, PA).
[9] Adya A, et al. 2004 A multi-radio unification protocol for IEEE 802.11 wireless networks Broadnets 2004 Symposium (San Jose, California, USA).
[10] Tang J, Xue G and Zhang W 2005 Interference-aware topology control and qos routing in multi-channel wireless mesh networks International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc).
[11] Zheng H and Peng C 2005 Collaboration and fairness in opportunistic spectrum access Proceedings of IEEE International Conference on Communications (ICC).
[12] Marina M and Das S 2005 A topology control approach for utilizing multiple channels in multi-radio wireless mesh networks Broadnets 2005 Symposium (Boston, MA).
[13] Yang J and Fei Z 2010 ITGR: Intermediate target based geographic routing 2010 Pro-ceedings of 19th International Conference on Computer Communications and Networks (ICCCN) pp 1-6.
[14] Yang J and Fei Z 2010 HDAR: Hole detection and adaptive geographic routing for ad hoc networks 2010 Proceedings of 19th International Conference on Computer Communications and Networks (ICCCN).