Channel assignment exploiting partially overlapping channels for wireless mesh networks

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Abstract—**Unlike most IEEE 802.11-based ad hoc networks, in which only a single channel is used, wireless mesh networks allow the simultaneous use of multiple channels to increase the aggregated capacity. Many efforts have been taken to better exploit multiple non-overlapped channels. Although the IEEE 802.11 b/g standards, which govern the unlicensed 2.4 GHz industrial, scientific and medical (ISM) band, provide 11 channels, only three of them, namely 1, 6 and 11 are non-overlapped. In this paper, we propose a new channel assignment scheme named Channel Assignment Exploiting Partially Overlapping Channels (CAEPO). CAEPO can not only assign non-overlapped channels, but also exploit partially overlapping channels. In the proposed scheme, the traffic-aware interference between channels is considered to be the main factor, which is turned into a metric according to the overlapping degree between channels. In addition to that, packet loss ratio is another major consideration in the development of our proposed channel assignment scheme. From simulation results, we can see that using 11 channels, CAEPO effectively improves the network performance.**

Keywords-Channel assignment, partially overlapping channels, interference estimation, packet loss ratio, wireless mesh networks

I. INTRODUCTION

A wireless mesh network is a self-organizing, self-configuring multi-hop wireless network. It can be applied in many fields such as wireless broadband home networking, enterprise networking, broadband community networking, health and medical systems, security surveillance systems, emergency services, transportation services, and so on [1]. Due to its potentially ubiquitous applicability, it has attracted much research interest. A common wireless mesh network consists of three components, which are mesh clients, gateways connecting to existing wired networks, and mesh routers providing connectivity to mesh clients [2].

Wireless mesh networks are evolved from wireless ad hoc networks. In other words, the earliest stage of a wireless mesh network is the single radio ad hoc wireless mesh network. In the network, only one radio, and hence one channel, is used for both backhaul (link between mesh routers) and mesh client access. All nodes in the network share and contend for one radio, therefore, the aggregated capacity is greatly degraded. However, unlike wireless ad hoc networks and the earliest wireless mesh networks, current wireless mesh networks allow the use of multiple radios and multiple channels. As a result of the simultaneous use of multiple channels, wireless mesh networks do not have to suffer the network performance degradation brought by single radio and single channel. With the use of multiple radios and multiple channels, the network-aggregated throughput dramatically improves. Many researchers have investigated channel assignments to utilize multiple radios and multiple channels.

The IEEE 802.11b/g standards operate on the unlicensed 2.4 GHz industrial, scientific and medical (ISM) band. In North America, it provides 11 channels. Among the 11 channels, only three of them, namely 1, 6 and 11 are non-overlapped channels separated by 25 MHz at their center frequencies while the other 8 are partially overlapping. Currently, most of channel assignments focus on the better exploitation of multiple non-overlapped channels. In this paper, we propose a new channel assignment scheme named Channel Assignment Exploiting Partially Overlapping Channels (CAEPO). CAEPO is able to not only utilize non-overlapped channels, but also exploit partially overlapping channels.

The remainder of this paper is organized as follows. Section II describes the related work about channel assignments for wireless mesh networks. Section III presents the channel assignment metrics. Section IV depicts the proposed channel assignment scheme, namely Channel Assignment Exploiting Partially Overlapping Channels (CAEPO). Section V introduces the routing protocol we use. In Section VI, we evaluate the performance of the new channel assignment. And we conclude the paper in section VII.

II. RELATED WORK

Based on different criteria, there are multiple classifications for wireless mesh network channel assignments. Depending upon whether a central network controller is used, channel assignment can be classified into centralized channel assignment and distributed channel assignment. In [3] and [4], centralized channel allocations are described. In centralized schemes, a network controller is used to collect the topology information of the network and assign the channels for each node. In the schemes reported in [5][6] [7][8][9], no central controller is needed in distributed mechanisms, while mesh

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routers locally collect information and assign channels.

According to the duration of an interface tuned on a specified channel, channel assignment can be classified as static channel assignment, dynamic channel assignment and hybrid channel assignment.

In static channel assignments [10] [11], every network interface of each node is assigned to a specified channel by static assignment algorithms permanently or for a long duration of time. In [11], a static, centralized traffic and interference aware channel assignment is proposed by Skalli et al. A ranking technique is utilized to assigned channels. Aggregate traffic at a node, the distance from the gateway node and number of interfaces on a node are taken into account in the computation of rank function.

Unlike static channel assignments, a coordination mechanism is required in dynamic schemes to ensure that the sending and the receiving routers use the same frequency channel at the same time. In dynamic channel assignments [12][13][14][15], each interface could dynamically change its channel on demand among available channels in some short or long intervals. In [14], Kareem and Matthee propose a dynamic channel assignment scheme, the Adaptive Priority Based Distributed Dynamic Channel Assignment. In this scheme, an iterative adaptive priority algorithm recursively assigns channels by taking into account the spatial channel reuse and interference. Fast switching time and process coordination modules are the advantages of the mechanism. Makram and Günes [15] design a dynamic channel assignment using clustering. In their approach, a clustering is assumed and mesh routers are located around a cluster head, which has the most connections. Each cluster head gathers information from the nodes within its cluster and locally computes the channel assignment and allocate channels.

In hybrid channel assignments [16], the interfaces of each node are divided into two groups, "fixed interfaces" and "switchable interfaces". The fixed interfaces stay on a specified channel for long intervals while the switchable interfaces can frequently switch among the remaining non-fixed channels. Different nodes could select different channels for their fixed interfaces. When a sender has a packet to transmit, it switches its switchable interface to the fixed channel of the receiver to transmit the packet.

Besides the above classifications, some channel assignments combine routing problems. In [3], [5], [17], [18], [19] and [20] the joint channel assignment and routing problems are studied.

In [21], A. Mishra et al. proposed a partially overlapping channel model and employed the model in two scenarios, namely, WLANs and wireless mesh networks. In the scenario of wireless mesh networks, the authors utilized the channel assignment scheme from M. Alicherry's paper [3] and modified the link flow scheduling constraints accordingly. In M. Alicherry's paper, optimal traffic load balancing is assumed. However, in our paper, traffic load is used as a metric to implement channel assignment, and a balanced load is no longer an assumption to start with. In addition, in their scheme, a central controller is required to gather and calculate global topology information before each run, leading to a large latency while our scheme is a distributed one that could fast converge locally.

In our channel assignment scheme, each mesh router collects and computes information and implements channel assignment locally. The interfaces of each node are divided into fix group and switchable group. Therefore, Channel Assignment Exploiting Partially Overlapping Channels (CAEPO) is a hybrid distributed channel assignment.

III. METRICS

This section presents the estimation of channel assignment metrics. Interference between channels is considered to be the main factor in our proposed scheme where it is turned into a metric according to the overlapping degree between channels.

A. *Interference estimation*

The transmit spectrum mask for IEEE 802.11 standards using Direct Sequence Spread Spectrum (DSSS) modulation is depicted in Figure 1. And the distribution of the IEEE 802.11 b/g 11 channels over the 2.4GHz ISM band and the channel overlapping degree are shown in Figure 2 [22] and TABLE I [23], respectively.

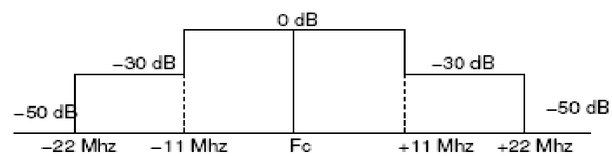

Fig. 1. Transmit spectrum mask for IEEE 802.11 standards using DSSS

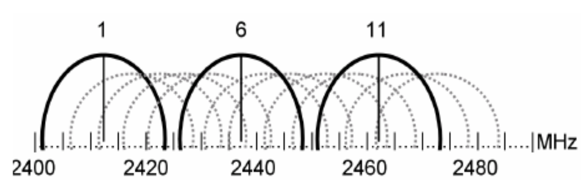

Fig. 2. Distribution of IEEE 802.11 b/g 11 channels over 2.4GHz ISM band (from [22])

TABLE I. CHANNEL OVERLAPPING DEGREE

Channel Separation	0	1	2	3	4	5	6	7	8~10
Overlapping Degree	1	0.7272	0.2714	0.375	0.0054	0.0008	0.0002	0	0

(Reproduced from [23])

In the estimation of interference metric, not only the channel overlapping degree is considered, but also traffic load is reflected by the proportion of the busy time of a node.

$$Interference[i] = \sum_{j \in N(i)} olf[i][j] * B(j), \quad (1)$$

where *Interference* [*i*] is the total interference node *i* suffering from the nodes in its transmission range. *olf*[*i*][*j*] is the channel overlap degree between the channel of node *i* and the

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channel of node j. $B(j)$ is the proportion of the busy time of the node j, that is, $B(j)$ = busytime(j) / (busytime(j) + idletime(j)). $N(i)$ is the set of the nodes in the transmission range of node i.

B. *Packet loss ratio*

In addition to interference, one quality-of-service metric, packet loss ratio is regarded as another major metric in our channel assignment algorithm.

$$\alpha \le \lambda \,. \tag{2}$$

When packet loss ratio α is more than λ, the channel assignment update is triggered where λ is the parameter that defines the largest value of packet loss ratio which can be endured for the data transmission in the network.

IV. PROPOSED CHANNEL ASSIGNMENT SCHEME

In the proposed scheme, we assume each node in the network has two interfaces. Each node divides its two interfaces into two groups. The interfaces in the first group are fixed interfaces tuned on specified channels for long intervals relative to packet. The fixed interface is responsible for receiving packets. The interfaces in the other group are switchable interfaces, which can frequently switch among the remaining non-fixed channels. When a node has no data to transmit, its switchable interface stays on a default channel. When the node has a packet to send, the switchable interface will switch to the receiver's fixed channel. Before we present the details of the proposed scheme, the following symbols are defined for the rest of the paper as given in TABLE II.

TABLE II. SUMMARY OF IMPORTANT SYMBOLS USED

Symbol	Definition
S	Set of the nodes in the network
i	Any node in S
$N(i)$	Set of the nodes in the transmission range of node i
J	Any node in $N(i)$
$B(j)$	Proportion of the busy time of node j
K	Number of available channels
C	Set of available channels in the network
c	Any channel in C

A. *Initialization Algorithm*

In Initialization Algorithm, the interference caused in the transmission range of each node is calculated after a randomly selected initial channel is assigned to the node. *Interference*[i] in Equation (1) is used as the metric to select the initial fixed channel for the fixed interface of each node. Once an initial fixed channel is selected by one node, the node notifies its neighbors of the selected fixed channel and the interference caused by the selected fixed channel and the interference information received from other neighbor nodes. Finally, the interference summation in Equation (3) is calculated by the last node selecting its fixed channel and the default channel is chosen. One the default channel is selected, the information is broadcast through the network. In this algorithm, we assume $B(j) = 1$.

$$Interferencesum = \sum_{i \in S} Interference[i] \,, \tag{3}$$

where S is the set of nodes in the network.

B. *Update Algorithm*

In the update algorithm, the optimal fixed channel is selected for the fixed interface of each node. *Interference* [i] in Equation (1) is used as the metric with a calculated value of $B(j)$.

C. *Channel Assignment*

The selection of fixed channels for nodes can be done in a distributed fashion. *Interference* [i] is considered as the main metric to select channels and packet delivery ratio is another metric. The procedure of the channel assignment is depicted as follows.

In the initial phase, Initialization Algorithm is employed to select the initial fixed channel for the fixed interface and the default channel for the switchable interface of each node. The selection of default channel has three advantages. The first one is that the default channel is able to ensure a basic connectivity between neighbor nodes. Secondly, if some link encounters failure, the node can choose an alternate path over the default channel. The final advantage is that the default channel carries control and data traffic so that the neighbor nodes can exchange updated information with each other over the default channel.

In the update phase, Update Algorithm is employed to select optimal fixed channels for those fixed interfaces. Each node periodically calculates *Interference* [i], and selects the channel, which causes the least interference in its transmission range as its fixed channel for its fixed interface. Moreover, when packet loss ratio does not meet the requirement, the interference recalculation is also implemented and the channel assignment will be updated.

Once one node changes its fixed channel, it advertises this information over the default channel. When a node has data to send, it switches its switchable interface to the fixed channel of the receiver. The receiver can receive the packet since its fixed interface is always listening to the channel. When the link fails, the default channel will be used to select an alternate path.

Initialization Algorithm

```
1:  For i ∈ S
     For c ∈ C
     Calculate Interference[i] in Equation (1), where B (j) = 1.

2:  For i ∈ S
     If when c = C (m) (1<= m<= K) is assigned to the fixed
     interface of node i, the metric Interference[i] in Equation(1)
     reaches the minimum
     Then select C (m) as the initial fixed channel of node i.

3:  For c ∈ C
     If when c = C (n) (1<= n<= K) is assigned, Interferencesum
     in Equation(3) reaches the minimum
     Then select C (n) as the default channel
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Update Algorithm

1: For $i \in S$
   For $c \in C$
   Calculate *Interference*[i] in Equation (1).

2: For $i \in S$
   If when $c = C(m)$ ($1 <= m <= K$) is assigned to the fixed interface of node i, the metric *Interference*[i] in Equation(1) reaches the minimum
   Then select $C(m)$ as the current fixed channel of node i.

V. ROUTING PROTOCOL

We use the modified AODV as our routing protocol, in which, the expected end-to-end transmission delay takes the place of hop count as the routing metric.

The expected end-to-end transmission delay is the summation of the expected transmission time of a single packet over a route,

$$ETD = \sum ETT \,. \tag{4}$$

We could obtain the expected transmission time from the expected transmission count, the packet size and the bandwidth of the link as in Equation (5),

$$ETT = ETX * \frac{S}{B} \,. \tag{5}$$

The Expected Transmission Count (ETX) is described in detail in [24]. Probe packets are broadcast to measure the packet loss probabilities P_f and P_r probabilities in the forward and reverse directions. With P_f and P_r, the probability of the unsuccessful packet transmission from one node to its one hop neighbor is calculated,

$$P = 1 - (1 - P_f) * (1 - P_r) \,. \tag{6}$$

And finally, the successful transmission probability *S(k)* and the expected transmission count ETX from a node to its one hop neighbor after k attempts are derived,

$$S(k) = P^{k-1} * (1 - P) \,, \tag{7}$$

$$ETX = \sum_{k=1}^{\infty} k * S(k) = \frac{1}{1 - P} \,. \tag{8}$$

VI. PERFORMANCE EVALUATION

We implement our channel assignment scheme using the Network Simulator 2 (NS2). Modification to the original module has been made to support multiple radios and multiple channels. In our simulations, the network is a 100-node square-grid network. 10 traffic profiles are generated and each contains 20 pairs of randomly chosen source and destination nodes. The ratio between interference and communication range is set to 2. For each profile, the traffic between each source-destination node pair is selected randomly between 0 and 3 Mbps. We use the modified AODV as the routing protocol, in which ETD replaces the hop count metric. The packet loss ratio parameter λ is set to 0.10.

From Fig. 4, we can see the network goodput of the channel assignment CAEPO using 11 channels is much better than the goodput of a single channel network. Besides, we compare our channel assignment CAEPO with the load-aware centralized channel assignment proposed in [4]. In the comparison, 3 non-overlapped channels are used in the load-aware channel assignment.

In the load-aware centralized channel assignment, because of the existence of a central network controller, the global topology information is collected and computed, a globally optimal channel assignment is implemented, whereas in the distributed CAEPO channel assignment, each router gathers and computes the local information, thus, the channel assignment is not globally but locally optimal. Despite that, as can be seen in Figure 4, the performance of CAEPO utilizing 11 channels is higher than that of the load-aware channel assignment using 3 non-overlapped channels. The reason is that in CAEPO, besides 3 non-overlapped channels, other partially overlapping channels are exploited as well. Thus, more available bandwidth can be used. Although some adjacent channel interference may be brought in, the using of the channel assignment CAEPO, which could mitigate interference by intelligent and effective algorithms improves the performance.

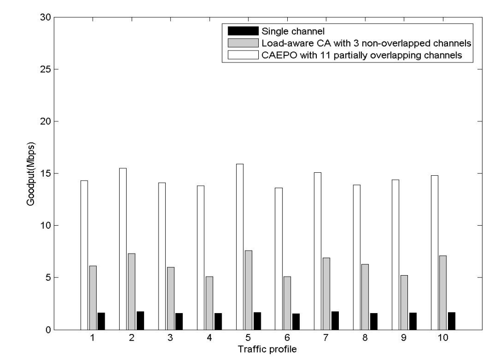

Fig. 4. Network goodput

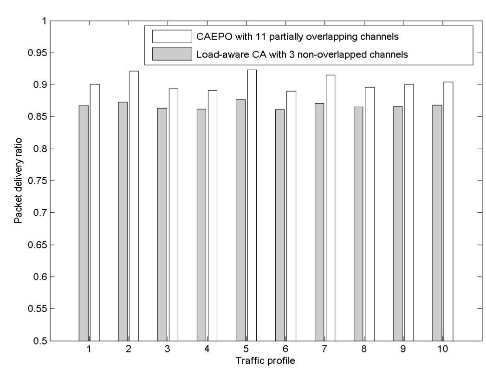

Fig. 5. Packet delivery ratio

As Fig. 5 shows, the packet delivery ratio of the channel assignment CAEPO using 11 channels is higher than that of the load-aware channel assignment with 3 non-overlapped channels. Hence, by exploiting partially overlapping channels, the channel assignment CAEPO not only exploits more available bandwidth but also improves the packet delivery ratio.

In Fig. 6, the number of source-destination node pairs is varied. We performed the simulations with 10, 20, 30, 40 and 50 source-destination pairs in the network. The channel assignment CAEPO with 11 channels shows more superiority than the load-aware channel assignment with 3 non-overlapped channels as more traffic load is introduced in the network.

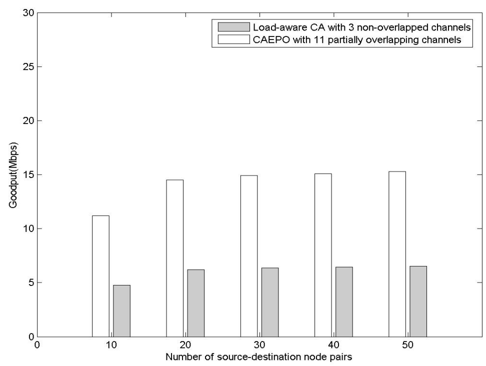

Fig. 6. Network goodput with varying traffic load

VII. CONCLUSIONS

In this paper, we proposed a new channel assignment scheme. It is a hybrid, distributed channel assignment. In the scheme, the fixed interface of each node is responsible for receiving data and the switchable interface switches to the receiver's fixed channel to send data when the node has data transmission requirement. Compared with most of other channel assignments focusing on utilizing multiple non-overlapped channels, our new scheme not only uses non-overlapped channels but also exploits partially overlapping channels in IEEE 802.11 b/g. The exploitation and utilization of more available channels can lead to more improvement of the aggregated network capacity. In our future work, we will investigate more comprehensive channel assignment schemes with QoS requirement incorporated and study the performance of the schemes under more practical channel conditions.

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