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Characterizing Interference Model for Wireless Mesh Networks

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Abstract

Wireless mesh networks (WMNs) have been proposed for realizing their goals, such as throughput and full connectivity, in wireless networks. The interference between nodes in WMNs is a critical limiting factor. Understanding of interference needs to develop novel approaches, such as channel re-assignment, route selection, and fair scheduling. Actually, throughput of WMNs has degraded when reassigning channels due to the intra and inters interference. In this paper, we study the extent problem of interference, which spreads the trials of channel re-assignment toward neighbor mesh routers. In particular, the extent of interference causes additional throughput degradation when compared to a pair-wise interference to a small fraction of the links. This implies that the pair-wise interference measurements may be optimistic when used to drive protocols in wireless mesh networks. We newly define an analytical model, which is referred to as a ripple effect problem. The defined model is a formal model of interference to estimate the maximum rate at which flows can safely send traffic without overloading network. The proposed model can exemplify how protocols should take the extent of interference into account. The simulation results show that the proposed model can exactly evaluate the attempts of channel re-assignment occurred from mesh networks.

Keywords: *Wireless Mesh Network (WMN), Interference Spreading, Channel overlapping, Mesh router (MR), Channel Re-assignment, Throughput*

1. Introduction

Wireless mesh networks (WMNs) are an attractive communication protocol due to their low cost and relative ease of deployment. A WMN typically consist of some mesh routers (MRs), some of which directly connected to the Internet [1, 6]. A MR forms a multi-hop wireless network to route traffics between the Internet and users. A mobile node in this network connects to the one of MRs. A WMN is reliable, and offers redundancy because when one node no longer operates, the rest of others nodes can still communicate with each other [2, 7]. Thus, the achievable throughput in a WMN is only limited by interference [3, 8]. The previous works have proposed

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the variety of interference models, which mainly describe a relation of the interferences between two physical links and a radio propagation characteristic depending on transmitter and receiver characteristics. Developing an analytical model for measuring performance is very easy in a binary analysis model that the interference happens between two nodes. However, interference is not binary [4]. In practice, interference is generally caused between more than two nodes. Hence, these proposed models have still unclear understanding of the behavior of various protocols in WMNs.

There are two domains, such as fixed channel assignment and dynamic channel assignment, for radio resource assignments. The first one manually assigns channels and the second dynamically. In this paper, we mainly consider a dynamic channel assignment method. A technique of multiple non-overlapping channels assignment, called dynamic channel assignment (DCA), has arisen as one of promising strategies to be applied in wireless systems. The power range overlapping of mesh router (MR) with neighbors in WMNs, referred to as cell, leads to inter or intra-channel interference due to sharing the same channel or path at neighbor MRs, respectively. Adjacent channel interference between neighboring cells that share the bandwidth may reduce a certain quality of service. In order to consider interference in WMN, methods for assigning channels and minimizing interference have been studied in [1, 2], respectively, where the authors focused on network capacity in routing and MAC fashions. They modeled traffic and interference, which is caused by acknowledgement packet. Solutions for joint channel assignment and routing are found in the literatures [3, 4], which does consider traffic loads, but not think over both of intra-flow interference and inter-flow. The performance in WMNs is specifically related to the intra/inter-flow interferences which are caused in the process of channel assignment, and which are mutual problems between MRs. For this reason, interference is extended to the other neighbors from a node since the interferences induced by the repetitive trials of channel re-assignment (referred to as a ripple effect problem hereafter).

This work is motivated by the view of characterizing interference in WMNs and it would be quite useful in developing protocol. The performance of WMNs is determined by channel assignment and the impact of interference. In this paper, this work focuses on what is the impact of interference from traffic on neighboring links. In order to measure the performance from the caused ripple effect problem by influencing collision ratio in the presence of the underlying link interference, which measures the performance of WMNs in terms of DCA using Markov chain?

The remainder of this paper is organized as follows: Section 2 describes the existing mesh network protocols in terms of interference; Section 3 models interference spreading problem which named the ripple effect problem. In order to analysis the performance of the ripple effect problem, the Markov model propose. A performance evaluation in Section 4 is conducted and a final summary is given in Section 5.

2. Related Works

Interference management is an important task in WMNs. A WMN is always appeared in the presence of interference. There are several solutions in previous research. The capacity of a link based on 802.11 mesh network is mainly determined by two main factors, such as which links are good link and what the impact of interference is. Two recent protocols [3] and [4] addressed the problem of interference aware routing in multi-radio infrastructure mesh networks and a critical limiting factor in realizing their throughput potential is the interference between nodes in the WMN, respectively. However, the quality of the link is given by the delivery ratio and loss rate in the appearance of any interference. The link capacity would be the product of the maximum sending rate of the sender and the delivery ratio of the link. Thus, most of them aim to reduce interference between nodes and improve the delivery ratio of the link.

The analytical model based on interference measurement has two weaknesses. First, interference received from a receiver-side is a very unstable metric because the measured signal power of received packets is always different depending on time. Second, the previous model is difficult to extend when there are multiple interferences. The heuristic interference model in [4] indicates interferences between two links interference and then quantifies the level of interferences with each other. However, this model is incorrect due to the initial model is in fact overly restricted.

The technique [5] that is used to estimate the performance of WMNs includes analytical techniques that it takes into account factors of WMNs, such as mobility, interference, etc. However, they do not provide an exact mechanism (or model) for measuring the interference and the problem of spreading interference is not addressed.

Therefore, in this paper, we propose a formal model for spreading interference toward the other neighbor nodes. The proposed model utilizes the Markov model to estimate the collision probability caused by the ripple effects.

3. Modeling of Interference Spreading Problem

This paper considers communication between two MRs based on the IEEE 802.11 (*e.g.*, 2.4 Ghz and 5.0 Ghz), and assumes that channel is assigned when data in radio interface is completely received [10-12]. And each channel is assigned by gateway MR, which is connected to the Internet. To cope with this, one channel at a time is assigned to each node but not simultaneously, which is returned when all data received is completely transmitted. In this analysis, the Markov chain model in [4] is utilized for calculating the conflict probabilities between a cell and its neighboring cells.

Figure 1 shows an example of communication of WMNs. In the case that MR A and B are communicating, this work considers a channel failure. MRs A and B try to find idle channels, and then they find an idle channel 2. They lastly reassign the channel 2. In the next step, when MR B tries to transmit data; the channel 2 in MR C and the channel 2 in MR B are conflicted. MR C starts to find idle channels. Actually, interference is extended to the other neighbors MRs from a MR since the interferences induced by the repetitive trials of channel re-assignments. Multiple radios in WMNs allow simultaneous communications with the others MRs, which are leaded to an increase of the channel interference. The results are expected to be higher in the multi radio networks.

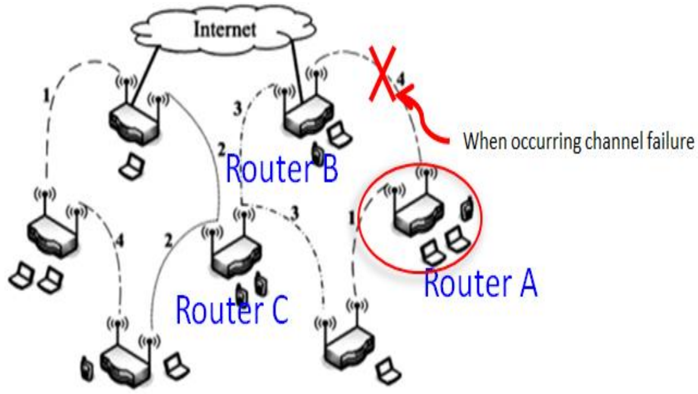

Figure 1. Interference Model of WMNs

To rethink interference, we consider two cells model (i.e. referred to as cells *i* and *j*), as shown in Figure 2.

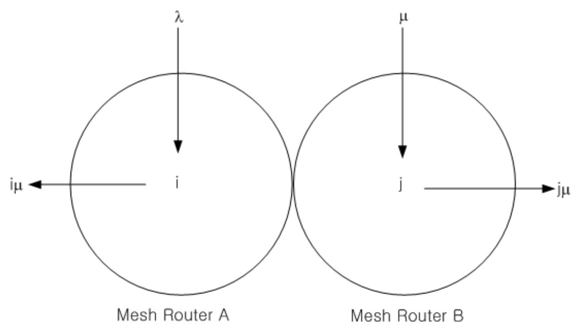

Figure 2. Markov Chain Model

Generally, interference always occurs between more than two channels (or near channels) over the same radio; we also assume interference as the conflict of the same channels in the specific time period of wireless networks due to the same results [5-6, 9].

Assuming that call arrivals, blocks, and departures originated in each state can be assumed as the requests, failures, and returns of assigned channels, respectively, in which the events follow the Poisson distribution with mean arrival rate λ and returns of channel due to finishing the service, link failure, and interferences have exponentially distributions, *i.e.*, the holding time of a channel assigned have exponential distributions with common means, $1/\mu$. Note that calls arrival, block, and departure originated in each state are as request, failure, and return of assigned channels, respectively. These events follow the Poisson distribution with mean arrival rate, l, and exponential distributions, *e.g.*, the holding time of a channel assigned, with common means $1/m$.

In order to estimate the collision probability caused by the ripple effect of Wi-Fi networks [13], the discrete-time Markov chain is defined using the bi-dimensional state $\{a_t, b_t\}$ in Figure 3.

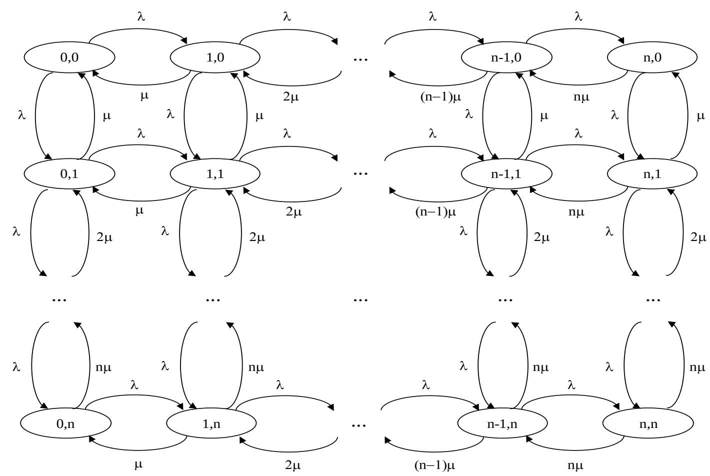

Figure 3. Markov Chain Model

Let $P(i, j) = \lim_{t\to\infty} P\{a_t = i, b_t = j\}$ be the steady state probability of Markov chain, where $i \in [0, n]$ and $j \in [0, n]$, (i.e., the number of occupied channels in two MRs A and B), respectively. Using the Markov chain, we can determine the global balance equations for the steady state occupancy probabilities $P(i)$ and $P(j)$ in states i and j for the Markov system, which can be expressed as:

$$P(i) = \frac{\frac{\rho^i}{i!}}{\sum_{i=0}^{n} \frac{\rho^i}{i!}}, \quad P(j) = \frac{\frac{\rho^j}{j!}}{\sum_{j=0}^{n} \frac{\rho^j}{j!}}, \quad \text{for } i \text{ and } j = 0, 1, 2, \ldots, n. \tag{1}$$

The number of channel occupied in MR A and the number of channel occupied in MR B at the same time instant are independent random variables. A two-cell network has a product-form solution, when the joint pmf of the vector of numbers of occupied channels in MRs. The $p(i, j)$ is equal to the product of the marginal pmf's of the number of occupied channels in the individual MR, which is given by

$$P(i,j) = P(i)P(j) = \frac{\frac{\rho^i}{i!}}{\sum_{i=0}^{n} \frac{\rho^i}{i!}} \frac{\frac{\rho^j}{j!}}{\sum_{j=0}^{n} \frac{\rho^j}{j!}}, \text{ for } i \text{ and } j = 0, 1, 2, \ldots, n. \tag{2}$$

Let $\alpha(i, j)$ be the collision probability between two cells in state $\alpha(i, j)$ of a Markov chain, which can be obtained as follows,

$$\alpha(i,j) = \begin{cases} 0, & \text{for } i = 0 \text{ or } j = 0 \\ 1, & \text{for } n - j < i, i >= j \\ 1, & \text{for } n - i < j, i < j \\ 1 - {}_{n-j}C_i / {}_nC_i, & \text{for } n - j >= i, i >= j \\ 1 - {}_{n-i}C_j / {}_nC_j, & \text{for } n - i >= j, i < j \end{cases} \tag{3}$$

Therefore, the collision probability P_c to new requests of channel assignment is given by

$$P_c = \sum_{i=0}^{n} \sum_{j=0}^{n} \alpha(i,j) P(i,j) \, . \tag{4}$$

The collision probability P_c is affected by the number of assigned channels when the assigned channels are increased by a steady rate. In order to measure the exact of analysis, we analyzed the P_c against the average loads depending on the number of assigned channels, as shown in Fig. 4. The simulation results based on IEEE 802.11g are seen more clearly in Figure 4, which plots P_c against the average loads.

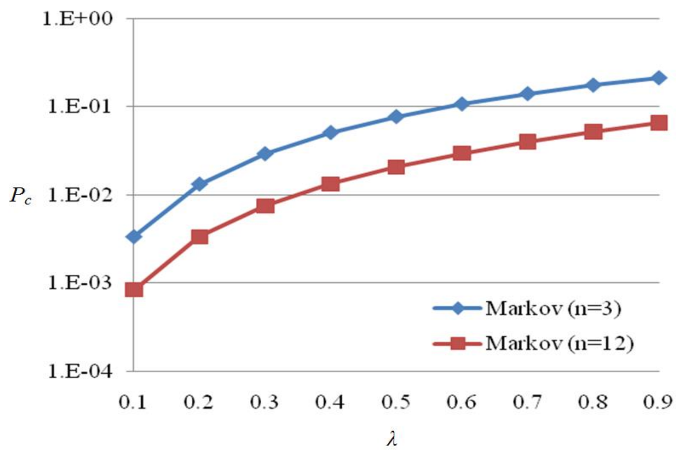

Figure 4. A Blocking Probability Depending on the Number of Assigned Channels

4. Performance Evaluation

We evaluated the conflict probability P_c and assumed that the channel condition is free of bust errors with a constant link rate, which yields a raw link rate about 5 Mbps. The model simulated on two MRs in which different number of channels is considered, i.e., 3 and 12 channels. Table 1 shows collision probability against network load depending on the number of channel assignments (n = 12) requested for service time, e.g., m = 1, respectively.

The saturations happened over a flow and inter-flow specifically are due to the failure of channel assignment, referred to as intra-channel interference and inter-channel, respectively. To obtain the offered load available at each node during the simulation, a fixed packet size, 1 Mbyte, and arrival rate, λ = 0.1 ~ 0.9, following a Poisson distribution are assumed. This means that channel assignment requests have been generated uniformly with value 1 for each router. The quantity estimations of the conflict probability between MRs A and B are shown in Table 1, which are indexed by $\alpha(i, j)$ where it expresses the channels to be assigned in each MR.

Note that the diagonal result values (not 1) in Table 1 do not occur the ripple effect problem in the process of channel reassignment; however, on the contrary, the ripple effect problem can be occurred when the number of assigned channels is equal to n (the total number of assigned channels in MRs involved in the network).

Table 1. A Blocking Probability Against Network Load Depending on the Number of Channel Assignments

A \ B	0	1	2	3	4	5	6	7	8	9	10	11	12
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	1/12	11/66	55/220	165/495	330/792	462/924	462/792	330/495	165/220	55/66	11/12	1
2	0	11/66	21/66	100/220	285/495	540/792	714/924	672/792	450/495	210/220	65/66	1	1
3	0	55/220	100/220	136/220	369/495	666/792	840/924	756/792	486/495	219/220	1	1	1
4	0	165/495	285/495	369/495	425/495	736/792	896/924	784/792	494/495	1	1	1	1
5	0	330/792	540/792	666/792	736/792	771/792	917/924	791/792	1	1	1	1	1
6	0	462/924	714/924	840/924	896/924	917/924	923/924	1	1	1	1	1	1
7	0	462/792	672/792	756/792	784/792	791/792	1	1	1	1	1	1	1
8	0	330/495	450/495	486/495	494/495	1	1	1	1	1	1	1	1
9	0	165/220	210/220	219/220	1	1	1	1	1	1	1	1	1
10	0	55/66	65/66	1	1	1	1	1	1	1	1	1	1
11	0	11/12	1	1	1	1	1	1	1	1	1	1	1
12	0	1	1	1	1	1	1	1	1	1	1	1	1

The experiment results are seen more clearly in Figure 5 (where *n* is between 3 and 12, which concerned the channels from the IEEE 802.11), which shows the proportional of the collision ratio against the average loads.

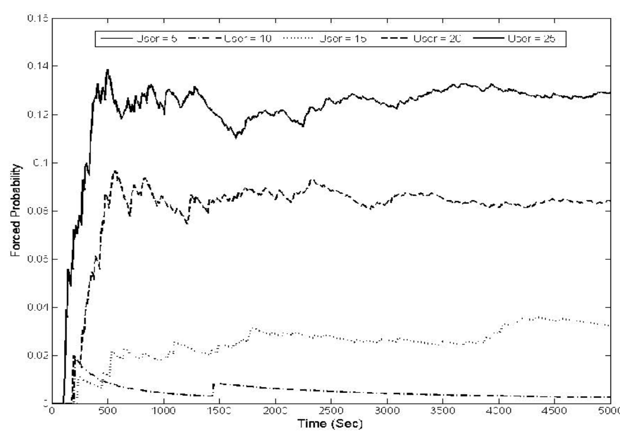

Figure 5. A Forced Probability among Interference

We addressed above that when the number of channel increases in steady rate, the collision ratio *C* is affected by the number of the channels assigned. Basically, for $n = 3$, C is higher than that for $n = 12$, which shown the decreased collision probability around 41 to 52 %. The proposed analytical model gives great promise in terms of the performance depending on the number of channels and reflects the precision we have not seen in the prior study from [1] because of concerning the variant features of distributed system.

The parameter which have an effect on network performance is a channel blocking. In this simulation, the transmission power of each node and the channel holding time are assumed to be fixed and 120 seconds, respectively. The number of channel is considered as

11 channels. Interference on each channel is calculated with respect to the random channel assignment. The effect of interference by increasing of node density was examined in Figure 5.

In order to know a change of a blocking probability depending on the increasement of the number of channels, this experiment is conducted, as shown in Figure 6. In this experiment, a channel holding time is 120 seconds and the number of channels is increased to 5, 11, 15, and 20 channels.

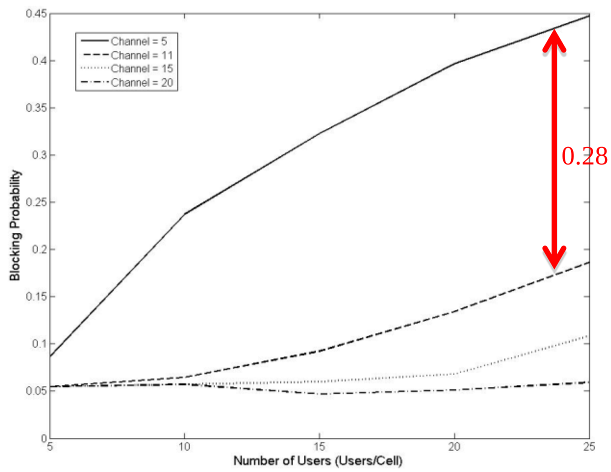

Figure 5. A Blocking Probability Depending on the Number of Channels

Blocking probability is higher when the channel gain is low. This is because network topology is denser. A blocking probability when increasing the numbers of channels is shown in Figure 6 and which is rapidly increased in the 5 channels. Blocking probability is related to the number of channels. Blocking probability decreases when channel bandwidth (or the number of channels) can accept the channel requirements of users and, on the contrary cases, increases and the demand of channel from users cannot accept. Blocking probabilities in 5 ~ 11 channels is more small in difference when compared with that of the blocking probability in 15 ~ 20 channels. Especially, the difference between 5 channels and 11 channels is 0.28. Therefore, both power ranges and the number of channels have an impact on reducing blocking probability. According to these results in Figures 5 and 6, the riffle effect problem became more critical than longer power ranges.

In order to analysis a change of the blocking probability against increasing and decreasing of the requirement of the channel, a blocking probability depending on network density is presented, as shown in Figure 7. The power ranges of the MRs in Figure 7 are compared. The parameter means the power strength in the edge part of cell, which is termed as cnedge, where cdedges are 15dB and 20dB.

The blocking probability is generally increased depending on the gain of channel. The efficient use of channels has a greater impact on the power range of channel.

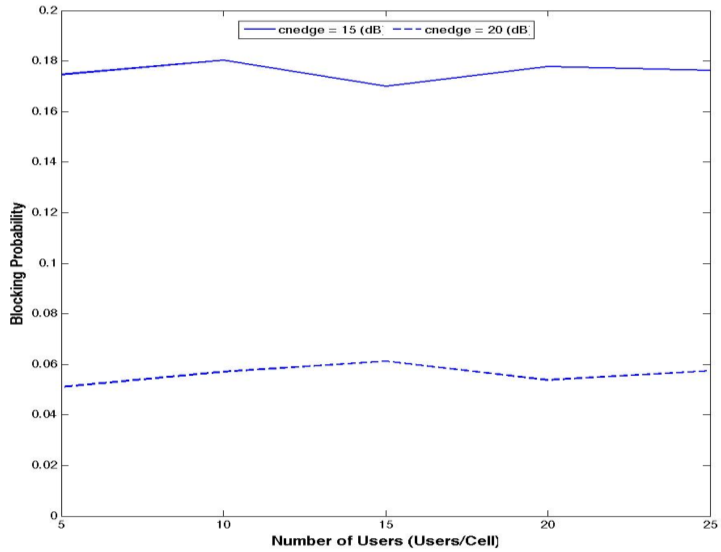

Figure 6. A Blocking Probability Depending on Network Density

5. Conclusions

In this work we investigate the effect of interference of multi-radio WMNs. The experiments results showed the impact of interference. The interference between nodes is critical limiting factors. Thus, performance, such as channel re-assignment and route selection, in a WMN is decreased due to interference.

In this paper, this work at first have identified interference caused by the ripple effect from WMNs, and proposed an analytical model to evaluate this problem using the two dimensional Markov model. The proposed analytical model, which takes into account the factual correlation about interference around channel, gives a clue to re-consider the policy of dynamic channel assignment as well as to guide the design of efficient distributed protocol on WMNs. The simulation results based on the IEEE 802.11 showed the proportional of the collision ratio against the average loads. Furthermore, a priori knowledge about these results from the experiments helps very much on choosing the best channel assignment methods.

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