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A Dynamic Channel Assignment Technique for Wireless Internet-access Mesh Networks

Walaa Hassan*† Nobuo Funabiki*‡ Toru Nakanishi‡*
* Department of Communication Network Engineering, Okayama University
3-1-1 Tsushimanaka, Okayama 700-8530, Japan
† {whassan}@sec.cne.okayama-u.ac.jp
‡ {funabiki, nakanisi}@cne.okayama-u.ac.jp

***Abstract*—The wireless Internet-access mesh network (WIMNET) has been studied to provide a flexible, inexpensive large-scale access network to the Internet. WIMNET is composed of multiple access points (APs) as wireless routers that are communicated with each others through multihop wireless links mainly by the wireless distribution system (WDS). In WIMNET, hosts may move in the field, which can raise issues such as the quality of service, the channel interference, and the network load management. As a result, the adaptive channel assignment to the wireless links between APs to host distributions, becomes essential to improve the performance of WIMNET. In this paper, we formulate this dynamic channel assignment (DCA) problem for WIMNET, and present a DCA technique through modifications of our existing study with the newly defined decision function for the channel reassignment. The effectiveness of our approach is verified through extensive simulations using the WIMNET simulator.**

***Index Terms*—Wireless mesh network, dynamic channel assignment, NIC assignment, optimization**

I. Introduction

Over the past few years, the Internet has become increasingly popular due to the rapid developments of inexpensive small communication devices and high speed communication technology. The Internet has provided a variety of information, data, and network services. As a result, demands for the high-speed, flexible, and inexpensive Internet access using wireless networks from every place and at any time have increased among the users.

The concept of the wireless mesh network has emerged as a scalable, flexible, and inexpensive wireless network [1]. The wireless mesh network is composed of multiple wireless routers that are distributed in the field, in order to expand the coverage area of a single router that is limited into a small space. In the wireless mesh network, communications between routers are offered by multi-hop wireless communications.

Among several variations of under-studying wireless mesh networks, our study has focused on the network that uses only access points (APs) as wireless routers, and realizes communications between APs on the MAC layer with the *wireless distribution system (WDS)*. From now, we abbreviate this wireless Internet-access mesh network as *WIMNET* for convenience. At least one AP in WIMNET acts as a gateway (GW) to the Internet. In WIMNET, a host can connect to the Internet through one of GWs after reaching it through multihop wireless communications between APs. Thus, wireless links around GWs are usually very crowded and may become the bottleneck in the whole communications of WIMNET.

In WIMNET, each AP takes two different roles in wireless communications, between APs and hosts, and between APs .To reduce the radio interference between them, we use different protocols with different channels (radio frequencies) for them. The IEEE 802.11b/g is assigned to the first role with the 2.4 GHz unlicensed frequency band. The IEEE 802.11a is assigned to the second role with the 5.4 GHz unlicensed frequency band. However, this protocol separation by the roles of APs is not sufficient to allow the scale-up of WIMNET while maintaining the performance, because more and more traffics concentrate into GWs as the increase of associated hosts.

For the optimal design of WIMNET, we have studied several optimization problems and their algorithms. In [2], we defined the AP allocation problem and presented its heuristic algorithm. In [3], we defined the channel configuration problem for AP communications with its algorithm. In [4], we defined the gateway AP selection problem with its algorithm.

The efficient use of limited channels to afford the increase of traffic capacity requires the proper channel assignment. This is one of the fundamental problems in WIMNET. There are two strategies for assigning channels to APs: Fixed Channel Assignment (FCA) and Dynamic Channel Assignment (DCA)[5]. The FCA strategy statically allocates channels to APs in advance, according to estimated traffic intensities in them, as in [3]. The DCA strategy may change channel assignments dynamically in real time, to meet changing traffic intensities. In DCA, however, channel reassignments should be avoided as best as possible to minimize the stopping time of network operations during channel reassignment procedures. In general, DCA exhibits better capacity, and better handoff performance in terms of lower forced termination. This is the motivation of our study of the DCA problem for WIMNET in this paper.

Our contribution in this paper is the proposal of a formulation for the DCA problem and a DCA technique through modifications of our existing study for the FCA problem [3]. We newly define a decision function for the channel reassignment. Our technique is divided into two stages: the initial stage and the dynamic stage. In the *initial stage*, a proper number of network interface cards (NICs) with proper channels are assigned to APs, using the information of the maximum number of hosts associated with each AP, such that the performance is maximized while the configuration cost is minimized according to [3]. In the *dynamic stage*, the decision function decides whether the channel reassignment should be done or not, according to the traffic balance between the links adjacent to GW, because the most traffic to/from the Internet passes through one of them. This decision function is designed to minimize the number of channel reassignments to reduce the stopping time of network operations during channel reassignment procedures. If the function returns yes, the channel is reassigned to the links using the FCA algorithm so that the performance of the network is maximized. The effectiveness of our approach is evaluated through simulations using the WIMNET simulator [4] that has been developed by our group.

II. Formulation of Dynamic Channel Assignment Problem

In this section, we formulate the DCA problem for WIMNET as a combinatorial optimization problem. This problem aims both to maximize the channel utilization and to minimize the number of channel reassignment to satisfy the demanded traffic.

A. Input

First, we describe the inputs to the DCA problem for WIMNET.

- The AP network topology graph, $G = (V, E)$:
  - A node v_i in V represents the i-th AP (AP_i), where the number of nodes is represented by N.
  - An edge $e_{ij} \in E$ represents the wireless link between AP_i and AP_j.
  - One node is designated as GW to the Internet, AP_g.
  - The communication route to GW is selected for AP_i, P_i.
- The AP routing subgraph, $R = (V, E_R)$:
  - An edge in $E_R(\subseteq E)$ is used in at least one communication route.
- The link interference matrix, D:
  - The radio interference between two neighbor links is represented by the link interference matrix D.
  - The element d_{ijpq} in D is 1 if the link from AP_i to AP_j is interfered with the link from AP_p to AP_q, and 0 otherwise.
- The channel interference matrix C:
  - The interference between two channels is described by the channel interference matrix C.
  - The element $c(x, y)$ in C is 1 if $x = y$, and 0 otherwise for the 802.11a protocol with orthogonal channels [6].
- The maximum number of hosts associated with APs, H:
  - The expected maximum number of hosts associated with each AP is given as the input, because it is usually necessary to design the Internet access network appropriately.
  - The element h_i in H represents the number for AP_i.
  - The expected traffic, t_{ij}, through the link from AP_i to AP_j for $i = 1, ..., N$ and $j = 1, ..., N$, is calculated from the number of hosts associated with each AP, assuming that every host has the same amount of traffic to/from the Internet.
- The design constraints of WIMNET:
  - The total number of NICs, B.
  - The maximum number of NICs at AP_i, b_i,
  - The number of channels, M.

B. Output

- The number of NICs assigned to AP_i, x_i.
- The channel assigned to the link between $AP_i$and AP_j, y_{ij}.

C. Constraint

This problem must satisfy the following constraints:

- The total number of NICs must be B or smaller: $\sum_{i=1}^{N} x_i \leq B$.
- The number of NICs at AP_i must be positive, and b_i or deg_i or smaller, where deg_i is the number of incident edges to AP_i in R: $1 \leq x_i \leq b_i$ and $1 \leq x_i \leq deg_i$.
- The channel must be feasible: $1 \leq y_{ij} \leq M$.
- The channel at the both directions of any link must be identical: $y_{ij} = y_{ji}$.
- The number of different channels assigned to the links incident to AP_i must be x_i or smaller.

D. Objective

This problem aims to minimize the following objective functions E_{NIC}, E_{link} and E_{stop}:

$$E_{NIC} = \max_i \left\{ \frac{\sum_{j \in N_i} (t_{ij} + t_{ji})}{x_i} \right\} \quad (1)$$

where N_i represents the set of APs adjacent to AP_i.

$$E_{link} = \sum_{i=1}^{N} \sum_{j=i+1}^{N} \sum_{p=1}^{N} \sum_{q=p+1}^{N} t_{ij} \cdot t_{pq} \cdot d_{ijpq} \cdot c(y_{ij}, y_{pq}) \quad (2)$$

$$E_{stop} = (\#\ of\ channel\ reassignments) \quad (3)$$

E_{NIC} seeks the minimization of the maximum load per one NIC, E_{link} seeks the minimization of interfered traffics among neighbor links, and E_{stop} seeks the minimization of channel reassignments.

III. FCA Algorithm

In this section, we review the two-stage algorithm in [3], composed of the *NIC assignment stage* and the *channel assignment stage*, for the channel configuration problem for AP communications in WIMNET.

A. NIC Assignment Stage

The NIC assignment stage repeats one NIC assignment to an AP where the traffic per NIC (NIC traffic, t^{NIC}) is maximum while the constrains are satisfied, so as to minimize E_{NIC}.

1) Initialization:

(1) Calculate the traffic per AP from link traffic t_{ij}:

$$t_i^{AP} = \sum_{j \in N_i} (t_{ij} + t_{ji}). \quad (4)$$

(2) Assign one default NIC to every AP: $x_i = 1$.

(3) Calculate the NIC traffic:

$$t_i^{NIC} = \frac{t_i^{AP}}{x_i}. \quad (5)$$

(4) Initialize the number of assigned NICs: X=N.

2) Sequential NIC Assignment:

(1) Assign one NIC to an AP (let AP_k) such that t_k^{NIC} is maximum with $x_k < b_k$. Then, $x_k{+}{+}$ and $X{+}{+}$.

(2) Terminate this stage if $X = B$ or every AP reaches the upper limit ($x_k = b_k$).

(3) Update the NIC traffic:

$$t_k^{NIC} = \frac{t_k^{AP}}{x_k}. \quad (6)$$

(4) Go to step (1).

B. Channel Assignment Stage

The channel assignment stage basically repeats one channel assignment to one link so as to minimize E_{link}.

1) Calculate the traffic collision:

$$col_{ij} = t_{ij} \cdot \sum_{p=1}^{N} \sum_{q=p+1}^{N} t_{pq} \cdot d_{ijpq}. \quad (7)$$

2) Sort all the links in descending order of traffic collision.

3) Assign channel 1 to the first link (the most congested link) and NICs at its both end APs.

4) Assign channels to links by the following steps:

a) *Channel assignment to links without choice*:

(i) When the same channel is assigned to NICs at both end APs of a link, this channel is assigned to the link. Here, if two or more such channels exist, the one to minimize E_{link} is selected among them, where unassigned links are not considered for its calculation.

(ii) When one channel is assigned to the sole NIC at one end AP and no channel is assigned to the NICs at another end AP of a link, this channel is assigned to the link and the NIC.

b) *Channel assignment to links with choice*:

(i) When all the NICs at either end AP of the link are assigned channels, the channel to minimize E_{link} among them is assigned to the link and the NIC. Note that unassigned links are not considered for the calculation of E_{link}.

(ii) When both end APs of the link have at least one unassigned NIC, the channel to minimize E_{link} among all of M channels is assigned to the link and the NICs.

c) *Assignment priority change for impossible links*: When different channels are assigned to the NICs at both end APs of an unassigned link, no channel can be assigned there. At this case, the assignment priority of such a link is increased by multiplying its traffic collision by a constant (> 1), and repeat this stage from 2).

d) *NIC assignment movement for unused NIC*: When some NICs are not assigned any channel after the completion of the channel assignment to every link, such NICs are moved to different APs satisfying the constraints, and repeat this stage from 2).

IV. DCA Technique

In this section, we propose a technique for the DCA problem, composed of the initial stage with the NIC assignment and the initial channel assignment, and the dynamic stage with the decision function for changing the channel assignment.

In the initial stage, we use the algorithm in the previous section to configure the number of NICs per AP. Here, the traffic is computed by using the expected maximum number of hosts associated to each AP that is given as inputs.

In the dynamic stage, we present the decision function for the channel reassignment. The idea of the decision function comes from the fact that the number of links incident to GW is usually limited even in a large-scale WIMNET, and the traffic of each such link should evenly distributed among them, so as to avoid that they become bottlenecks of the whole communications in WIMNET, where most traffics must pass through one of these limited links to access to the Internet. When the evenness of them is not satisfied by the current channel assignments, they should be changed. The decision function is actually defined as follows.

First, we calculate the total traffic of the links incident to GW using the same channel p, GT_p:

$$GT_p = \sum_{e_{gi} \in \ GL, y_{gi} = p} t_{gi} \quad (8)$$

where GL represents the set of the links incident to GW.

Then, we calculate the decision factor:

$$\max_{p,q} |\frac{GT_p}{GT_q} - 1| \geq \delta \quad (9)$$

where p and q represent any pair of the channels assigned to the links in GL. Each channel has a traffic capacity assigned to it. δ is the unbalance threshold of the bandwidth consumption for each channel. δ should be given empirically by considering the network topology, the traffic pattern, and the number of NICs assigned to GW. If the decision function returns Yes, the channel reassignment is applied by using the FCA algorithm in the previous section. If the decision function returns No, the last channel assignment is continued.

V. Performance evaluation by simulator

A. WIMNET Simulator

We discuss the performance evaluation of our approach using the WIMNET simulator. The WIMNET simulator simulates least functions for wireless communications of hosts and APs required to evaluate throughput and delays, because this simulator has been developed for evaluations of a large-scale WIMNET with reasonable CPU time on a conventional PC. Thus, a sequence of functions such as host movements, communication request arrivals, and wireless link activations, are synchronized by a single global clock called a time slot. Within an integral multiple of time slots, a host or an AP can complete the one packet transmission and the acknowledgement reception. In this paper, the duration time of one time slot is set 0.2ms. From our past experimental results, the maximum transmission speed between APs is set 30Mbps, and that between an AP and associated hosts is 20Mbps. Thus, the former link is completed with two slots, and the latter is with three slots, assuming every frame size is 1,500 bytes. When two or more links within their wireless ranges may be activated at the same time slot, randomly selected only one link among them is successfully activated, and the others are inserted into waiting queues to avoid collisions, supposing DCF and RTS/CTS functions. Before starting each simulation, every host has 1.000 packets transmitted to GW, and GW has 125 packets to every host. When every packet reaches the destination or is lost, the simulation is finished. The packets for each request are transmitted along routing path by our technique. Only the connection-less communication is implemented in the WIMNET simulator, where the retransmission between end hosts is not considered.

B. Simulation Instances

The simulations are executed with three different schemes. In *Static channel assignment scheme*, we obtain the static channel assignment by using the maximum number of hosts associated to each AP, and fix this channel assignment to any traffic change. In *Always changing channel assignment scheme*, whenever the traffic is changed, we change the channel assignment. In *Dynamic channel assignment scheme* , the decision function decides either to change the channel assignment or to keep the last channel assignment.

In our simulations, the expected maximum number of hosts associated to each AP is given as the input, and the host distribution among 24 discrete times for each AP is randomly selected from the seven patterns of the number of associated hosts with each AP shown in Figure 1. The maximum number of NICs at one AP b_i is set 2 or 3. Because the parameter δ depends on the network topology and the maximum number of NICs in/around GW, we simulate two different network topologies, and summarize the simulation results with various values for δ. The throughput and the number of channel assignment changes are observed under different traffic load patterns to the network.

C. Simulation Results in 3×3 *(N=9) Network Topology*

In our first simulations, 3×3 ($N = 9$) APs are regularly placed with the $100m$ interval on a $300m \times 300m$ field. The coverage distance from a host/AP is set $100m$. Thus, only the adjacent APs on the left, right, top and bottom can be communicated with each other. The center AP on the field is selected as GW to the Internet.

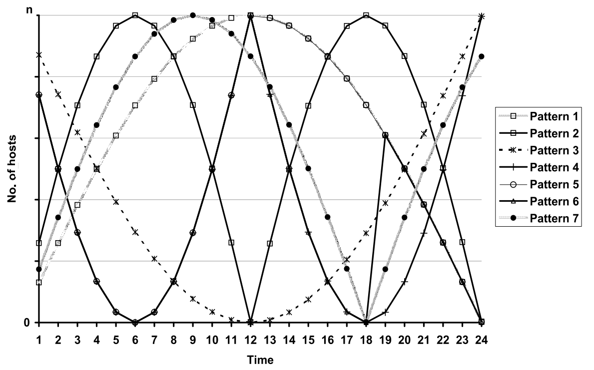

Fig. 1. Patterns of numbers of associate hosts, supposed that the maximum number of associated hosts is n

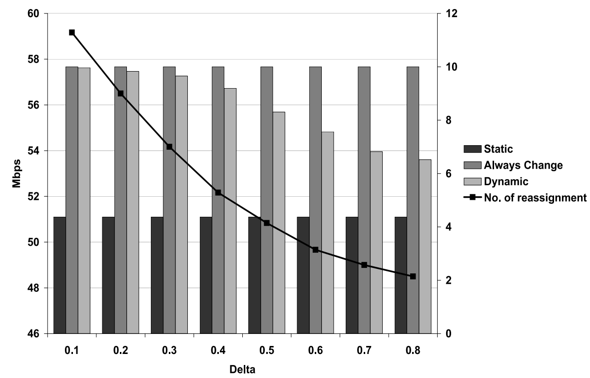

Fig. 2. Average throughputs and numbers of channel changes for 3 × 3 network with 2 max. NICs.

In Figure 2, where the maximum number of NICs per AP is 2, we can notice that there is a proportional relationship between the average throughput and the number of reassignment changes in our technique. For example, in the case with δ = 0.1, the number of changes over 24 times is 11.29, and the throughput is almost the same as that of *Always changing*. In the last case with $\delta = 0.8$, we found that the number of changes is 2.14 over 24 times, and the throughput of our scheme is still better than that of *Static*. δ for a specific network should be carefully selected in order to decrease the number of changes and to enhance the throughput at the same time. Figure 2 shows that, for the 3×3 network with 2 maximum NICs, the best case of δ that makes a balance between the number of changes and the throughput is 0.5.

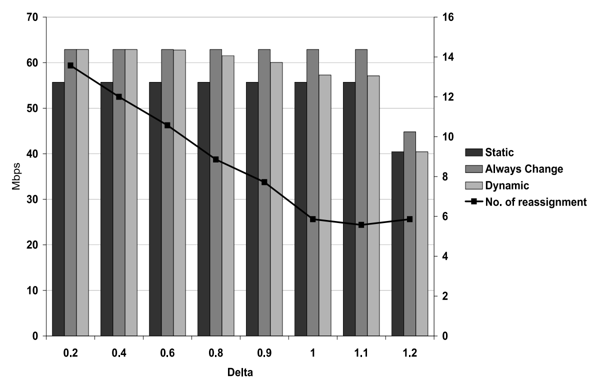

Fig. 3. Average throughputs and numbers of channel changes for 3 × 3 network with 3 max. NICs.

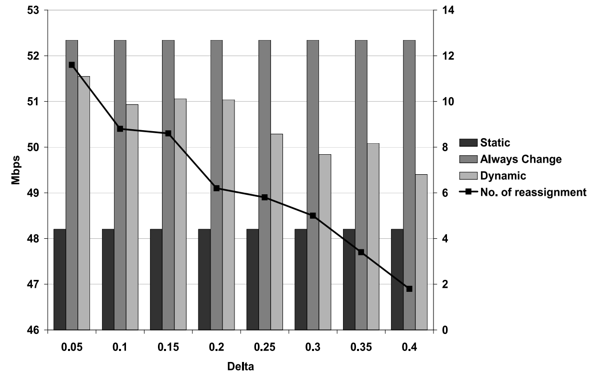

Fig. 4. Average throughputs and numbers of channel changes for 5 × 5 network with 2 max. NICs.

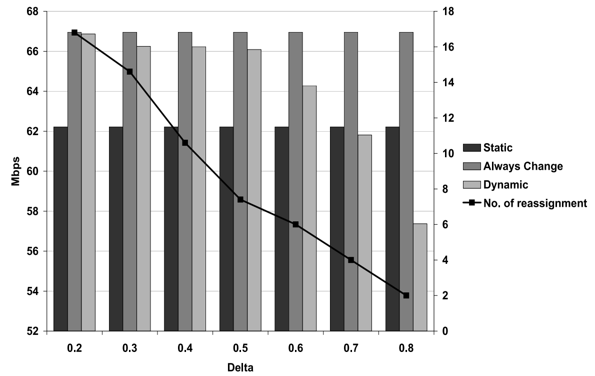

Fig. 5. Average throughputs and numbers of channel changes for 5 × 5 network with 3 max. NICs.

Figure 3 shows the results for the 3 × 3 network with 3 maximum NICs. Here, we notice that the best value for δ is 0.9 to decrease the number of changes and to enhance the performance of the network.

D. Simulation Results in 5×5 (N=25) Network Topology

In our second simulations, 5 × 5 ($N = 25$) APs are regularly placed with the $100m$ interval on a $500m \times 500m$ field. Figure 4 illustrates the simulation results with 2 maximum NICs. As noticed, the proper range of δ varies from the 3 × 3 network. The best choice of δ that improves the performance of the whole network and decreases the number of changes is 0.25, where 5.8 changes are taken place over 24 times, and the performance is much better than that of the static scheme.

Figure 5 shows the results for the 5 × 5 network with 3 maximum NICs. We can see that the best value of δ is 0.5. In this figure, when we notice the last case with δ, = 0.8, we need to say that some value of δ may lead to worse the performance of the network. Thus, the mathematical formula of calculating the proper value for δ is in our future studies.

VI. Conclusion

This paper has presented the formulation of the dynamic channel assignment (DCA) problem for the wireless Internet-access mesh networks (WIMNET), and a DCA technique composed of the initial stage and the dynamic stage through modifications from the existing study with a newly defined decision function. The effectiveness of our approach is verified through network simulations using the WIMNET simulator. The significant performance improvement is observed by choosing an appropriate δ with the decreasing number of changes. In future works, we will present a mathematical formula for δ, and implement APs with multiple NICs for AP communications so that we apply our DCA technique to justify our approach in the real world.

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