Dynamic Channel Assignment and Reassignment for Exploiting Channel Reuse Opportunities in Ad Hoc Wireless Networks

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Abstract - In Ad Hoc networks, a channel that is occupied by a pair of hosts can be reused by another pair of hosts, only if their communication range is not overlapped. Exploiting the channel reuse opportunities may cause the co-channel interference problem. Two pairs of communicating hosts that use the same channel may be gradually close to each other. A channel reassignment operation should be applied to these hosts for maintaining their communication. This paper proposes a channel assignment protocol so that the channel resource could be highly utilized. A channel reassignment protocol is also proposed for preventing the communicating hosts from co-channel interference owing to mobility. The proposed reassignment protocol efficiently reassigns a new available channel for one pair of hosts that is suffering from co-channel interference. Experimental results show that the proposed protocols provide a larger amount of hosts with communication at the same time and prevent their communication from failure.

I. INTRODUCTION

MANET(Mobile Ad-Hoc wireless Network) consists of mobile hosts with presence of high mobility, low cost, and providing mobile users to communicate with each other.

To avoid the co-channel interference, communication of a pair of hosts will occupy a channel resource, causing the channel unable to use by the neighboring host. A channel used by one pair of hosts, say $\{a, b\}$, could be reused by another pair of hosts, say $\{c, d\}$, only if their communication range is not overlapped. Due to that the channels are limited resources, exploiting channel reuse opportunities and enhancing the channel utilization is the key technique for increasing the system capacity. However, exploiting the channel reuse opportunities may cause the co-channel interference problem. Consider that host a gradually moves to host c. As hosts a falls into the communication range of host c, their communication signal will interfere with each other. At this moment, if the host pair $\{a, b\}$ could rapidly changes their communication channel to a new one, the communication of these two pairs could be maintained without breakage.

In [3][4], a code assignment algorithm was proposed to schedule a set of code for a number of stations in a packet radio network. The assignment of the code guarantees that hidden terminal problem[1][2] could be avoided while the number of code consumed for assignment is minimal. In Ad Hoc networks, a set of single-channel MAC protocols[6][7]are proposed for creating a contention-free communication link. Though RTS/CTS reservation mechanism[10] and IEEE 802.11 protocols[5][11] provide the collision avoidance feature, most functions are defined on single code environment. Under the single code consideration, the system performance decreases with the number of communicating hosts. A number of multiple channel access protocols[7] are proposed to extend the flexibility of single code assignment and reduce the occurrence of collision and contention. However, a further investigation on channel assignment and reassignment problems are needed since most of the previous multi-channel research[7][9][10] did not take the mobility into consideration.

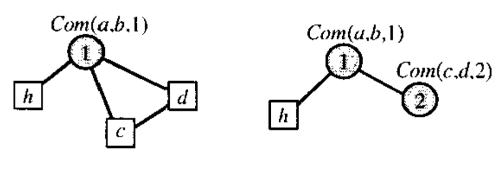
This paper investigates the channel assignment and reassignment problems in Ad Hoc networks. A channel assignment protocol is proposed to effectively exploit the channel reuse opportunities. The number of communicative pair of mobile devices is guaranteed to be maximized. A channel reassignment protocol is also proposed for eliminating the co-channel interference phenomenon, arising from that two pairs of communicating hosts gradually move close to each other. The proposed channel reassignment protocol dynamically reassigns a new channel to one pair of hosts that are suffering from the co-channel interference problem. The reassignment of new channel is not only effective and low maintaining overhead but also reduce propagating range of co-channel interference phenomenon. Experimental study reveals that the proposed channel assignment and reassignment protocol improve the capacity of Ad Hoc network and effectively reduce the breakage rate of communication.

II. DEFINITION AND BASIC CONCEPTS

In Mobile Ad Hoc NETwork (MANET), a pair of hosts can directly communicate to each other if their distance is smaller than the communication range. To avoid co-channel interference, communication of a pair of hosts will occupy a channel resource, causing the channel unable to use by the neighboring hosts. A channel used by one pair of hosts could be reused by another pair of hosts only if their communication range is not overlapped.

To simplify the presentation of the communication state of a MANET, communication of a pair of hosts $\{a, b\}$ on channel j will be represented by a circle numbered by j and a $Com(a, b, j)$ by the side of the circle in graph, as show in Fig. 1.

In the following, examples and cache structure of each host are introduced to illustrate the basic concepts of the proposed protocol. Each mobile host maintains a *Neighboring Communication Table(NCT)* in its cache which records the neighbors' channel usage information.



(a) Hosts a and b communicate on channel 1.

(b) Hosts c and d ask for communication on channel 2.

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Neighbor	Nchannel	Nnchannel	Cost
...	...	...	...

(c): *Neighboring Communication Table(NCT).*

Neighbor	Nchannel	Nnchannel	Cost
{a, b}	1	Null	1

(d) *NCT* of host *h*.

Neighbor	Nchannel	Nnchannel	Cost
{a, b}	1	2	2

(e) The *NCT* of host *h* in Fig. 1(b)

Figure 1: An example of Ad Hoc networks.

The information kept in *NCT* contains the *ID* of the neighboring hosts, the channel occupied by the one-hop and two-hop neighbors, and the cost of those channels. Fig. 1(c) demonstrates the *NCT* of each mobile host. Each row of Fig. 1(c) records a neighbor's communication information. The *Neighbor* field records the *ID* of each neighbor. This field records all neighbors including idle and communicating neighbors. The *Nchannel* field records the channel that is occupied by the neighbor whereas *Nnchannel* records the channel that is occupied by the neighbor of the neighbor (i.e. two-hop neighbor). If the neighbor is in the communication state, the *Nchannel* field record the occupied channel, otherwise, *Nchannel* has a *null* value.

The *Cost* field records the cost of reassigning a new channel to the neighbor. Let two communications *Com1*(*x*, *y*, *j*) and *Com2*(*x*', *y*', *j*) interfere with each other due to that the communication range of host *x* overlaps one of host *x*'. Hosts *x* and *x*' will check the cost of assigning a new channel to itself, exchanges the cost evaluation information and then determine one of *x* and *x*' assigning a new channel to obtain minimal cost. In case that there is no available channel for interference hosts, the new channel should be selected from those channels that are currently used by neighbors. However, this change possibly causes another co-channel interference problem of the neighbor, say *z*, since the neighbor host *z* has to reassign a new channel which may be currently used by *z*'s neighbor. An improper change of the new channel will cause that the co-channel interference propagates over the MANET. The *Cost* field records the number of neighbors that should change its channel. This field is helpful for the interference hosts to evaluate the cost of updating a new channel that is currently used by their neighbors.

Consider the communication graph shown in Fig. 1(a). The set of neighbors of host *h* is {*a*, *b*} which uses channel 1 for communication. The *NCT* of host *h* is shown in Fig. 1(d). Due to that the neighbors of hosts *a* and *b* are in idle state, the *Nnchannel* field has a null value. The *Cost* field has value 1 because that there is 'one' pair of hosts {*a*, *b*} requires to reassign a new channel, providing that host *h* asks to use the same channel with hosts {*a*, *b*}. At this moment, assume that hosts *c* and *d* hop to communicate with each other. They choose channel 2 for communication and transmit this information to neighbors. The communication graph will be changed as shown in Fig. 1(b). On receiving this information, host *h* updates its cache table as shown in Fig. 1(e). The contents stored in cache represent that two neighbors, *a* and *b*, use channel *Nchannel*=1 for communication. If host *h* asks to use channel 1 for communication, in worst case, 'two' pairs of hosts will update their channel. The situation is stated as follows. Therefore, the *Cost* field has a value 2.

Consider host *h* hopes to communicate to other host. It checks the cache table and selects a proper channel. In case that host *h* determines to use channel 1 for communication, hosts {*a*, *b*} will change their communication channel to avoid the occurrence of co-channel interference with host *h*. In the worst case, hosts {*a*, *b*} select channel 2 as their new channel. To avoid the co-channel interference with hosts {*a*, *b*}, hosts {*c*, *d*} again update their communication channel. Therefore, in the worst case, the use of channel 1 by host *h* causes two pairs of hosts updating their channel. This implies that the Cost value, for host *h* using channel 1 as its communication channel, will be 2, as shown in Fig. 1(b). Notable that only those hosts that are willing to create a new communication need to transmit the channel information. This will guarantee that the amount of control packet can be restricted.

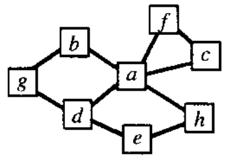
III. CHANNEL ASSIGNMENT PROTOCOL

This section presents examples to illustrate the basic operation of the proposed channel assignment protocol. The channel assignment protocol for enhancing the channel utilization is then proposed.

Fig. 2 gives an example to illustrate the communication process and the contents of cache table of those hosts that create new communication. In Fig. 2(a), hosts *a*, *b*, *c*, *d*, *e*, *f*, *g* and *h* are in idle state. Due to that host *d* has neighbors *a*, *e*, and *g*, the *NCT* of host *d* is shown in Fig. 2(b). Owing to that hosts *a*, *e*, and *g* are in idle state, the *Nchannel* and *Nnchannel* fields have a *null* value in Fig. 2(b).

The following example shows how hosts *a* and *d* execute the channel assignment protocol for assigning a common channel to communicate with each other.

- Step 1: Host *d* sends a *communication request message*(*CRM*) to host *a*. On receiving the message, host *a* replies a *communication approved message*(*CAM*) to host *d*.
- Step 2: As host *d* receives the *CAM* message, it exchanges with host *a* the information stored in *NCT*, including *neighbor ID*, *Nchannel*, and *Cost* fields.
- Step 3: Hosts *a* and *d* simultaneously compare the received message with information stored in their *NCT* tables, and append those two-hop information in their tables. Hosts *a* and *d* thus have identical tables.
- Step 4: Host *a* and *d* select channel 1 that has minimal *Cost* value for communication and then send a *communication notification message*(*CNM*) and *communication state Information*(*CSI*) to their neighbors *b*, *c*, *e*, *f*, *g*, and *h*. The format of *CNM* and *CSI* messages are shown in Figs. 2(c) and 2(d), respectively.
- Step 5: Hosts *b*, *c*, *e*, *f*, *g*, and *h* integrates the received *CNM* and *CSI* messages into their *NCT* tables. The operation of integration will be discussed later.
- Step 6: Any neighbor of hosts *a* or *d* that is in the communication state also transmits the integrated *CSI* information to neighbors. In this case, owing to that all neighbors of hosts *a* and *d* are in idle state, this step is omitted.



(a) The original communication state diagram.

Neighbor	Nchannel	Nnchannel	Cost
a	null	null	0
e	null	null	0
g	null	null	0

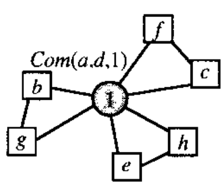
(b)*NCT* stored in host *d*.

Id	Channel

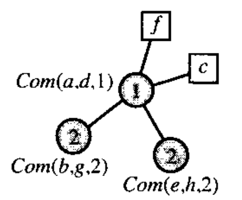
(c) Format of *Communication Notification Message(CNM)*

Neighbor ID	Channel	Total Cost

(d) Format of *Communication State Information(CSI)*



(e) Hosts *a* and *d* create a communication link *Com*(*a*,*d*,1).



(f) Communication state diagram. Host pairs {*b*, *g*} and {*e*, *h*} create the communication links.

Neighbor	Nchannel	Nnchannel	Weight
{a, d}	1	null	1
g	null	null	0

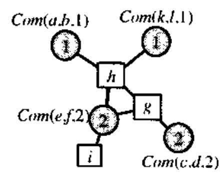
(g)*NCT* stored in host *b*.

Figure 2: An example for illustrating the channel assignment process.

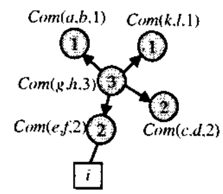
Fig. 2(e) displays the communication state graph. Fig. 2(g) denotes the contents of host *b*, as it integrates *CNM* and *CSI* information in its table.

Let *X* denote the pair of hosts that want to create a communication link. Both hosts in *X* execute the described steps for creating a communication link so that all hosts that neighbor *X*, say *N*(*X*), have *X*'s communicative information, including *CNM* and *CSI*. A subset of *N*(*X*), say *Y*, that consists of those hosts in communication state will combine the received *CNM* and *CSI* into their *NCT*, recalculate the *CNM* and *CSI* and then send the recalculated communicative information to *N*(*Y*). Hereafter, once two communicative pairs detect an interference, they use the collected communicative information to efficiently execute the channel reassignment protocol and one pair of hosts will reassign a new channel with the lowest cost for their communication before the communication breakage. Due to that the lowest cost of channel for each communicative host is varying as a new communication link creates, each host collects the two-hop neighbors' communicative information in its *NCT* table so that the lowest cost of each channel could be efficiently derived. Executing the describe steps, host pairs {*b*, *g*} and {*e*, *h*} will create communication links as shown in Fig. 2(f).

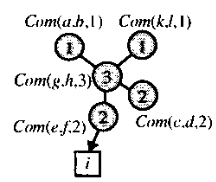
The *Cost* value of the channel that is currently used by neighbors is recorded in each host's *NCT* table. The *Cost* value is the estimation of cost for assigning or reassigning a new channel. An improper estimation of *Cost* value will increase the number of hosts that participate the channel reassignment operations, causing neighbors recursively execute the channel reassignment operations. In the following, an example is shown for illustrating the evaluation of *Cost* value.



(a) Communication state diagram before hosts {*g*, *h*} constructing a communication link.



(b) Hosts {*g*, *h*} select channel 3 for communication and send *CNM* to neighbors.



(c) Hosts {*e*, *f*} transmit *CSI* information to neighbors.

Figure 3: An example for illustrating the evaluation of *Cost* value.

Consider Fig. 3(a). Hosts *h* and *g* hope to create a communication link. Figs. 4(a) and 4(b) respectively give *NCT* tables stored in hosts *h* and *g*. By executing steps 2 and 3 described before, hosts *h* and *g* exchange their information and combine the information into their *NCT* table. The resultant table of host *h* is shown in Fig. 4(c). As shown in Fig. 3(b), hosts *h* and *g* then select channel 3 for creating a communication link since channel 3 has smallest *Cost* value in *NCT*. At executing step 4, hosts *h* and *g* transmit the communicative policy *CNM*=*Com*(*g*, *h*, 3) and the important information *CSI* of its table to their neighbors *a*, *b*, *c*, *d*, *e*, *f*, *k*, and *l*. The transmitted *CSI* information of hosts *h* and *g* is shown in Fig. 4(d).

Neighbor	Nchannel	Nnchannel	Cost
g	null	null	0
{a,b}	1	null	1
{e,f}	2	null	1
{k,l}	1	null	1

(a) *NCT* of host *h*.

Neighbor	*Nchannel*	*Nnchannel*	*Cost*
h	null	null	0
{*c*,*d*}	2	null	1
{*e*,*f*}	2	null	1

(b) *NCT* of host *g*.

Neighbor	*Nchannel*	*Nnchannel*	*Cost*
g	null	null	0
{*a*,*b*}	1	null	1
{*c*,*d*}	2	null	1
{*e*,*f*}	2	null	1
{*k*,*l*}	1	null	1

(c) *NCT* of host *h* after information exchange of hosts *g* and *h*.

Neighbor	*channel*	*Cost*
{*a*,*b*}	1	1
{*c*,*d*}	2	1
{*e*,*f*}	2	1
{*k*,*l*}	1	1

(d) *CSI* information transmitted by hosts *g* and *h*.

Neighbor	*Nchannel*	*Nnchannel*	*Cost*
i	null	null	0
{*g*,*h*}	3		

(e) *NCT* stored in hosts {*e*,*f*}

Neighbor	*Nchannel*	*Nnchannel*	*Cost*
i	Null	null	0
{*g*,*h*}	3	1	3
		2	2

(f) *NCT* of hosts {*e*, *f*} after computing the *Cost* value.

Figure 4: An example for illustrating the *Cost* evaluation.

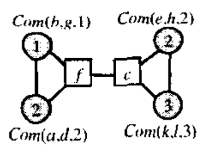
On receiving the *CNM* and *CSI* information, neighbors of hosts {*g*, *h*} combine the received information into their tables, as described before in step 5. In the following, an example is given to illustrate the information combination operation performed by hosts *e* and *f* which are in communication state. As shown in Fig. 3(b), hosts {*e*, *f*} will receive the *CNM* and *CSI* from hosts {*g*, *h*}. Hosts {*e*, *f*} append the information "hosts {*g*, *h*} communicate on channel 3" to its table, as shown in Fig. 4(e). The Cost value of row one in Fig. 4(e) will be calculated according from the information of *CSI*. In the transmitted *CSI* information, two channels 1 and 2 are used by neighbors of {*g*, *h*}, as shown in Fig. 3(b). Let *s* denote the cost summation value for all *Cost* value that the corresponding channel value in *CSI* is 1. Hosts {*e*, *f*} put the (*Nnchannel*=1, *Cost*=*s*+1) value to row 1 of their tables. In worst case, if hosts {*e*, *f*} use channel 3 as its new channel when there is an interference, there are *s*+1 pairs of hosts should change their communication channel. This is because that hosts {*g*, *h*} that use channel 3 for communication should change their channel to channel 1 to prevent co-channel interference with hosts {*e*, *f*}. However, there are *s* neighboring pairs use channel 1 for communication. To prevent co-channel interference with hosts {*g*, *h*}, the *s* pairs of hosts also need to change their communication channel. Therefore, the use of channel 3 for channel reassignment in {*e*, *f*} will cause *s*+1 pairs, updating their channel. The *s*+1 pairs are {*g*, *h*} and their neighboring pairs that use channel 1 for communication. Thus, the first row of table of {*e*, *f*} has filled with value <*Neighbor*={*g*, *h*}, *Nchannel*=3, *Nnchannel*=1, *Cost*=*s*+1=3>, as shown in Fig. 4(f). By similar calculation, the second row of table of {*e*, *f*} has filled with value <*Neighbor*={*g*, *h*}, *Nchannel*=3, *Nnchannel*=2, *Cost*=2>, as shown in Fig. 4(f). After recalculating their tables, hosts {*e*, *f*} create a new *CSI*, according to the contents of their tables, and transmit to their neighbors, as described before in step 6. The *CSI* message has value <*Neighbor ID*={*g*, *h*}, *Channel*=3, *Cost*=3>, where the *Cost* value is obtaining from the maximal *Cost* value of Costs in row <*Neighbor*={*g*, *h*}>. As soon as host *l* receives the *CSI* information from hosts {*e*, *f*}, it updates table by similar calculation described before.

IV. THE CHANNEL REASSIGNMENT PROTOCOL

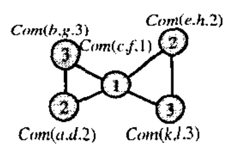
In this section, a channel reassignment protocol is introduced for increasing the capacity of Ad Hoc networks. Two types of opportunities that apply the channel reassignment scheme will increase the network capacity.

Type 1: Creating a new communication link

Assume that Ad Hoc network system has three channels resource in total that are numbered by 1, 2, and 3. As shown in Fig. 5(a), channel 1 is available for host *c*. At this moment, hosts {*c*, *f*} hope to create a communication link but have no common channel for communication. The selection of either channel 1 or 3 for communication of {*c*, *f*} will create co-channel interference with at least one neighbor who is using the same channel for communication, causing communicating neighbor execute the channel reassignment process. Thus, to reduce the number of hosts that execute the channel reassignment, selecting a channel that causes minimal number of hosts to change their communication channel is the basic requirement.



(a) Communication state diagram before the communication of hosts {*c*, *f*}.

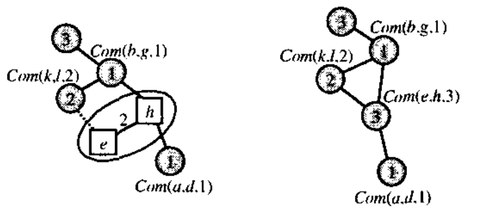


(b) Communication state diagram while hosts {*c*, *f*} create a new communication

Figure 5: An example of creating a new communication by hosts {*c*, *f*}.

Type 2: Mobility

Another opportunity for executing the channel reassignment protocol is that two pairs of hosts using same channel for communication are gradually close to each other so that the co-channel interference occurs with time.



(a) Host e interferes with $Com(k,l,2)$ due to mobility.

(b) The communication state diagram after executing the channel reassignment protocol.

Figure 6: An example for executing channel reassignment owing to mobility.

Both two types mentioned above utilize *NCT* table for executing channel reassignment protocol. This section provides a channel reassignment protocol to resolve the following two problems:

(1) Which hosts pair should reassign a new channel?

(2) Which channel is the candidate of the new channel?

In Fig. 6(a), hosts e and h are communicating on channel 2. Hosts k and l are using the same common channel for communication. As hosts e and l closed to each other, there is a dashed line connecting hosts $\{e,h\}$ and $\{k,l\}$ to denote that the interference of these two pairs is arisen gradually. Due to that each host maintains a information table, two pairs $\{e,h\}$ and $\{k,l\}$ check their tables and determine a candidate channel for channel reassignment. Each pair creates and transmits a Communication Interference Message(*CIM*) packet, as shown in Fig. 7, to another pair. On receiving another pair's *CIM* packet, host pair $\{e, l\}$ compares the *Cost* of the received channel and its candidate channel and determines that pair $\{e, h\}$ executes the channel reassignment operation. Finally, as shown in Fig. 6(b), hosts $\{e, h\}$ use channel 3 for communication. After executing the channel reassignment operation, hosts $\{e, h\}$ create a *CNM* packet to notify their neighbors about their change of communication channel. On receiving the *CNM* packet, neighbors of hosts $\{e, h\}$ update their information table and the channel reassignment protocol is entirely completed.

My ID	*Candidate channel*	*Cost*

Figure 7: Format of *CIM*.

The proposed channel reassignment protocol determines a minimal *Cost* channel for those communicative pairs that have co-channel interference. Communication thus can be maintained.

V. CONCLUSIONS

This paper proposes a channel assignment protocol for exploring the channel reuse opportunities, increasing the system capacity, and maintaining the lowest cost of channel information. The proposed channel assignment protocol evaluates the cost of each channel and maintains the communication state of communicating neighbors in each host's *NCT* table. A high reuse of channel resource improves the system capacity but introduces the co-channel interference while two pairs of hosts that use the same channel and gradually close to each other. Based on the *NCT*, a channel reassignment protocol is proposed to prevent the communication from breakage. By applying the proposed channel reassignment protocol, one of the two pairs will reassign a lowest-cost channel in time to eliminate the co-channel interference. Performance investigation shows that the proposed protocols improve the system capacity, reduce the rate of communication breakage, and thus improve the performance of Ad Hoc networks.

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