An Active Helper Searching Mechanism for Directional Cooperative Media Access Control (MAC) Protocols

Yi-Yu Hsieh[†], Jiunn-Ru Lai[†*] and His-Lu Chao[††]
[†]Department of Electrical Engineering, National Kaohsiung University of Applied Sciences, Kaohsiung, Taiwan, R.O.C.
Email: jrlai@cc.kuas.edu.tw
[††]Department of Computer Science, National Chiao Tung University, Hsinchu, Taiwan, R.O.C.
Email: hlchao@cs.nctu.edu.tw

Abstract **— Cooperative communication [1] and directional antenna systems are considered two key technologies for future wireless networks. There are also issues about the combination of these two technologies.[12,13] Most research in this area needed a table recording the near-by transmission. However, due to the property of passive overhearing, the table may only be partially good for the operation, especially for directional antenna systems. In this paper, we proposed an active helper searching mechanism to improve the completeness of the table. The helper activated its own helpers searching rather than waiting for the overhearing communication from others'. We compared four schemes including the base 802.11g scheme, the D-NoopMAC scheme, the D-CoopMAC scheme with the CoopTable built by conventional methods and the D-CoopMAC scheme with D-CoTable built with our proposed active helper searching mechanism. The simulation results proved that coop-directional MAC schemes with the active helper scheme improved their performance. We also concluded that nodes with directional antenna should be regulated to help those omni-directional nodes to increase the total network throughput. We leaved node mobility issues as the future work.**

I. INTRODUCTION

Directional antenna [2-4] technology has recently attracted a lot of research attention since it suggests the potential for space reuse and longer transmission and reception range with the same power consumption. This technology leads to higher network capacity, less interference and less delay. However, issues like the deafness problem [8], destination position, effective channel reservation and the asymmetric hidden terminal problem still pose several challenges in developing the technology. Cooperative communications leverage the spatial diversity by choosing the enlisting relay stations and exchanging one-hop slow transmissions with two-hop fast transmissions [9], thus demonstrating that such cooperation among stations in a wireless LAN (WLAN) can achieve both high throughput and a lower interference. And while physical layer cooperation can also be exploited, it is more suitable for the making of designs built on the MAC layer. [10,11] addressed the issues cross layer design as it relates to cooperation. Although multi-hop relay standards, such as IEEE 802.16j, incorporate the concept of cooperative communication, IEEE 802.15.3 for personal area network (PAN) to IEEE 802.16 for metropolitan area network (MAN) have been considered for including the notation of beam-forming and directional transmission. It is time to face the challenges of integrating cooperation and directional capabilities at the MAC layer. Whereas many papers have been written about the directional antenna at the MAC layer [6-7], only few of them also discuss the problem of cross-layer integration. Thus, to fill this research gap, we choose to focus our attention on MAC integration.

[13] was the first paper to address and design the integration of cooperation and directionality. Based on the four-beam directional antenna, the proposed Co-opdirectional MAC made use of two main tables, the LocTable and CoopTable, to help find the helper for cooperative communication. All the control messages and data packets are sent with directional antenna. The source sent rotational RTS to ask for help and for transmission, and then a reply CTS from the destination is also sent to both the helper and source to ensure that he is willing to join the transmission. Finally, the helper decides whether or not to join the cooperative communication. On the other hand, the signaling process with CoopMAC [9] is a little different. [12] proposed another version, D-CoopMAC, in which the source chooses the candidate helper from its CoopTable and sends RTS by broadcast. After the helper hears the RTS and decides to help the source, it sends the HTS directionally to the destination. In the end, the last the destination sends a directional CTS to the source to ensure the cooperative communication. D-CoopMAC is more compatible with the CoopMAC and suitable for future heterogeneous mobile network design. In our examination of the protocol operation, we find that the CoopTable plays a key role in the operation. However, there are certain problems with the table establishment, such as the completeness and the convergence time. In this paper, we thus focus on the table setup problem. We refer to the scheme for the CoopTable establishment used in D-CoopMAC as the passive CoopTable setup mechanism, which is similar to that used in O-CoopMAC, which is designed for omni-directional antenna communications. The source ($\mathbf{S_s}$) fills its table entry as it overhears the RTS broadcast from the helper ($\mathbf{S_R}$) as the helper wants to communicate with the destination ($\mathbf{S_D}$). When the $\mathbf{S_s}$ wants to transmit data to the destination $\mathbf{S_D}$ with the help of $\mathbf{S_R}$, the signal process is an RTS broadcast to the helper and destination and then if the helper is willing to help, it will send a directional HTS to the destination. The signaling process

ends with the directional CTS from the destination to the source, and thereafter the data transmission process begins. The table setup mechanism at the source relies substantially on the signaling process of overhearing that is carried out by omni-directional broadcasting. However, there are two problems with the passive CoopTable setup mechanism. The first one is that since the table entry created by the source is from the overhearing of other communication pairs, the table setup may be incomplete due to the surrounding traffic. For example in the light traffic case, if there is not as much message as the source needs to setup the CoopTable, the helper may not be revealed to the source and direction communication is used by the source instead. This may result in low throughput and a higher delay. The second problem is that due to the spatial reuse characteristic of the directional antenna, a good helper candidate may be missed and then never known by the source due to the omni-directional signaling process. As Fig. 1 shows, given the passive and omni-directional signaling process, if H_2 is a better helper for the S_1-D_1 transmission pair, the S_1 will not discover H2 since it is out of the receiving scope of S_1.

II. RELATED WORK

To address the combination of cooperation and directionality at the MAC layer, [13] claimed its pioneering effort in designing a new protocol called Co-opdirectional MAC. With the help of two table data structures of LocTable and CoopTable, the paper provided simulation results to show the goodness of its use of cooperation for a mobile network with directional antenna nodes. For the control plane and data plane, directional transmission was used to fulfill the protocol. In addition to [13], which was inspired by [9] and [5], [12] is another key paper discussing the combination impact. In [12], a new protocol called D-CoopMAC was proposed and compared with three other protocol schemes, including the base 802.11g, O-CoopMAC and D-NoopMAC. D-CoopMAC is directional cooperation media access control protocol, and combines both cooperation and directionality. O-CoopMAC is the ad hoc version of [9]. D-CoopMAC is the general version of the non-cooperative MAC with directional antenna. [12] concluded that there are conflicts between the combination of cooperation and directionality, and that they are in fact foes rather than friends.

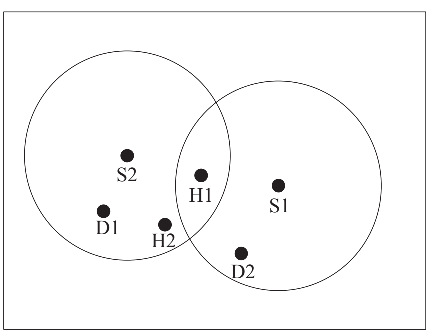

Fig. 1 Hidden helper in D-CoopMAC

This conclusion is also supported by the simulation results. However, we wonder if there is something that can be changed in order to improve D-CoopMAC's performance to be consistent with the conclusion proposed by [13]. Our suspicion takes into account [12], which is more compatible with the O-CoopMAC [9] and is more convenient for the design of protocols for heterogeneous mobile networks where directional nodes and omni-directional nodes are mixed. In this paper, we decided to use the D-CoopMAC as the base protocol. By inspecting both the D-CoopMAC and Co-opdirectional MAC, we found that the CoopTable where the cooperation information is recorded plays a key role in protocol operation. If the cooperative communication dominates the performance of the network, the completeness of the CoopTable will have a strong impact on performance.

III. ACTIVE HELPER SEARCHING MECHANISM FOR DIRECTIONAL COOPERATIVE MAC

In this part, we address how to establish the CoopTable used in D-CoopMAC with an active helper searching mechanism. The reference network model we used is shown in Fig. 1. In the passive table setup scheme, the time period the source may overhear the neighbor communication is a small part of the total transmission time. For this reason, the data transmission part is done by directional transmission which is not overheard by the source. Compared to that in an all omni-directional environment, the source can overhear the data transmission part of its neighbor's communication. However, whereas this spatial reuse property in directional antenna communication results in a much shorter overhearing time period, the incomplete table will hinder the source from taking advantage of cooperation.

From this perspective, we propose the active helper searching mechanism for the directional cooperation protocols, especially for the D-CoopMAC which is an extension of the CoopMAC. We also found that in the D-CoopMAC, the broadcast signaling process limits the source in discovering the candidate helpers which are available in the directional cooperation communication. We used the same table fields as those used in the D-CoopMAC while maintaining the same signaling process and data transmission process. We employed the active helper searching mechanism to find more candidate helpers for the source, which means that the source has a good helper list when it wants to transmit data with the assistance of helper's cooperation.

A. Active Helper Searching Mechanism

To address the full transmission process, we can divide it into three phases. The first phase involves our proposal—the active helper searching phase. The second one is the signaling phase, and the last one is the data transmission phase. In the active helper searching phase, we made use of a timer which is responsible for periodically refreshing the table entry. The default interval we used here was 5 seconds. We filled the entries of the table both from the active searching and passive overhearing. The process is outlined in Fig. 2.

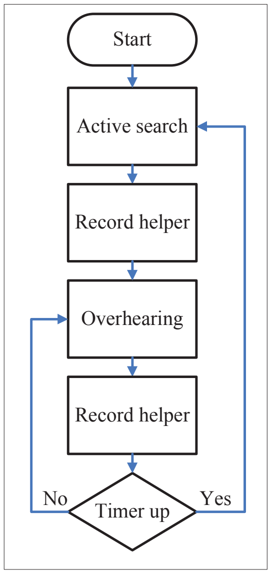

Fig. 2 Active helper searching scheme

In the active searching phase, the source sends a rotational directional RTS to ask for a reply from the candidate helpers. We needed to modify the way the helper replies to the RTS in the D-CoopMAC. In addition to the directional HTS to the destination, the helper has to send a directional HTS to the source which is like the broadcast HTS in the O-CoopMAC. The source may check each possible destination of its LocTable which is created for the recording of the relative location of its neighbor to find the possible candidate helpers for that destination. There is no data transmission, or very short data transmission, for this searching process. The main goal is to find the candidate helpers. After the active searching process, the routine overhearing process can enrich the entries of the CoopTable, And the active searching process may be re-activated if the timer is up. Once the source has data for a destination, it enters the second phase of signaling. Similar to the technique used in the O-CoopMAC, it will check if there are possible candidate helpers according the same rules used in the O-CoopMAC in order to check if the cooperation transmission outperforms the direct transmission. If this is the case, the source sends a directional RTS to the helper and the destination to notify of the cooperation transmission. If the helper is ready to help, it will send a directional HTS to the source and the destination. After the destination accepts the HTS, it sends the directional CTS to inform the source of the success of handshaking. If the source does not receive the CTS from the destination before pre-determined time, the cooperation trial fails. The source uses the direct transmission to the destination and updates the field for failure number in the table. In the last phase, if the cooperation is ready, the source sends the data directionally to the helper and the helper forwards the data directionally to the destination. The ACK message is sent directionally to the source by the destination.

We illustrate this process in Fig. 3. The fields we use in the CoopTable are the same as those in the D-CoopMAC. For a determined destination address, the mobile node has to keep a CoopTable for it. Each entry in the table contains 5 fields: 1) the ID field (48 bits) which records the MAC address of the helper; 2) the Time field (8 bits) which records the time last packet heard from the corresponding helper; 3) the R_{hd} (8 bits) field which records the transmission rate from the corresponding helper to the destination; 4) the R_{sh} (8 bits) field which records the transmission rate from the source to the corresponding helper; and 5) the NumOfFailures field which records the count of sequential transmission failures.In this paper, the main goal of our proposal is to make an active searching of its candidate helper for a specific destination. We modify some signaling processes and follow most of the operations proposed for D-CoopMAC.

B. *Illustrations*

We consider a scenario with the following description. The settings are referenced from [9], and are shown in Fig. 4. There are two possible cooperative transmission pairs.

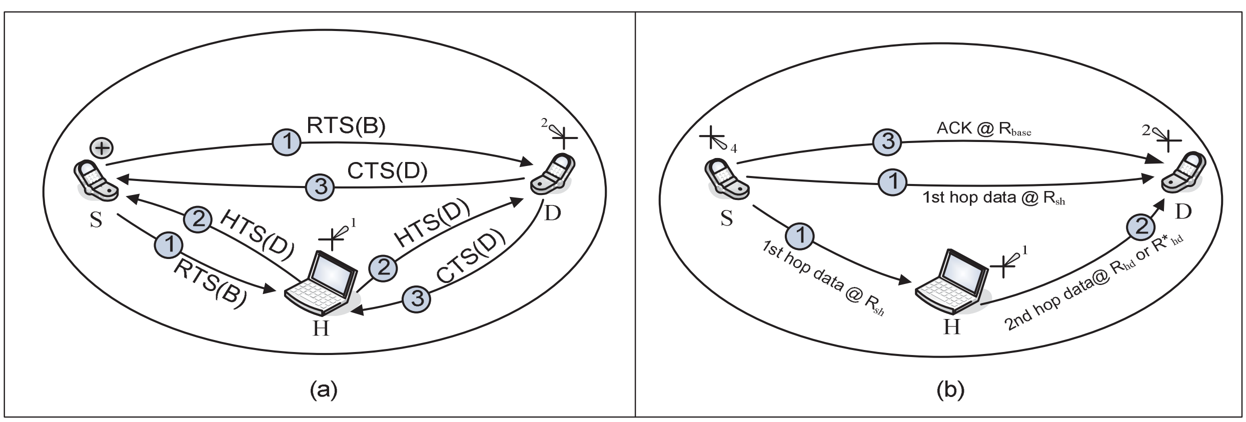

Fig. 3 D-CoopMAC with Active CoopTable

The first pair includes the source S1, the destination D1, one nearby helper H1, and one faraway helper H2. The other pair includes the source S2, the destination D2, and two helpers H1 and H2. The data rate settings are as follows: R_{S1D1}= 2M, R_{S2D2}= 2M, R_{S1H1}= 5.5M, R_{S2H1}= 5.5M, R_{S1H2}= 8M, R_{S2H2}= 8M, R_{H1D2}= 8M, R_{H2D1}= 11M, R_{H2D2}= 11M and R_{H1D1}= 11M.

With the active searching scheme, we can establish the CoopTables at the source nodes for its corresponding destination. As Table I shows, the CoopTable is more complete for the source S1 to choose the best helper H2 in order to assist the transmission, assuming that there is enough traffic among the nodes for the passive table setup scheme. The CoopTable is presented in Table II. However, if there is light traffic in the area, the entries in Table II will be smaller and it results in fewer cooperation chances. With the active searching scheme, a good helper will be much better known to other source nodes given that it is involved in more transmission pairs and will be overheard by more nodes. This is a positive indication for our scheme. On the other hand, the passive scheme is limited in its vision due to the omni-directional receiving scope and overlooks the possibility of directional help from other nodes.

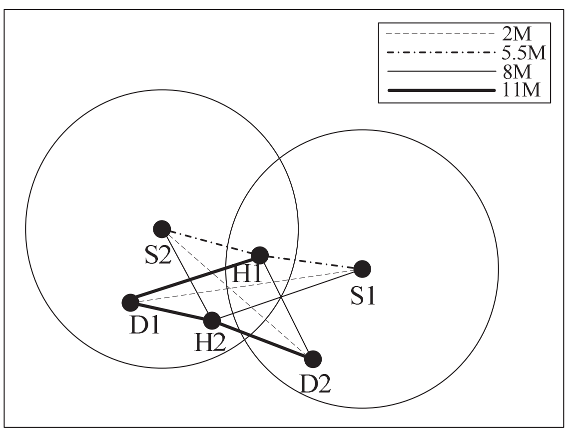

Fig. 4 Reference network model

Table I. D-CoTable (active)

(a)S1

ID(48bits)	Rhd(8bits)	Rsh(8bits)
H1	11M	5.5M
H2	11M	8M

(b)S2

ID(48bits)	Rhd(8bits)	Rsh(8bits)
H1	8M	5.5M
H2	11M	8M

Table II. CoopTable (passive)

(a)S1

ID(48bits)	Rhd(8bits)	Rsh(8bits)
H1	11M	5.5M

(b)S2

ID(48bits)	Rhd(8bits)	Rsh(8bits)
H1	8M	5.5M
H2	11M	8M

C. Analysis of Impact on Heterogeneous Mobile Networks

In this section, we discuss what the impact will be if a node with D-CoopMAC enters a network consisting of O-CoopMAC nodes. We start the analysis from mixing a node with a directional antenna with nodes with omni-directional antenna node. Adding more heterogeneous nodes in a network will be the focus of our future work.

The network model we use is depicted in Fig. 5. There is an on-going cooperative communication between the source node S and the destination node D with the help of H. The node E has a directional antenna, where the transmission range is 141m. As for S, D and H, they are all omni-directional nodes with transmission ranges equal to 100m. We consider three cases where E is close to the source, to the helper and to the destination. First, we looked at what happens if E is at the location X1. The source decides to choose the helper to start a cooperative data transfer to the destination. The source sends a broadcast RTS, which is received by E that sets its NAV interval. After this, the helper sends the HTS and the destination sends the CTS. The cooperative transmission starts without any interference. Moreover, no matter which the location E will take, i.e. either X1, X2 or X3, owing to the omni-directional receiving state E will have, E will enter the NAV state and not impact the cooperation. But if E takes advantage of using its directional antenna and lies outside the transmission scope of the omni-directional nodes, E will remain a hidden terminal to them. This is due to the omni-direction receiving range (say, 100 m) and directional transmitting range (say, 141m). Even if the source sends the RTS, the message may not be heard by the E. That is, E will initiate a transmission trial to the same destination node and results in collision.

In Fig.6, we analyze the positive and negative impact on the performance of the network if more transmission pairs are involved. In this scenario, we consider two cooperation transmission pairs where there are one source node (Si), one destination node (Di) and one helper node (Hi).

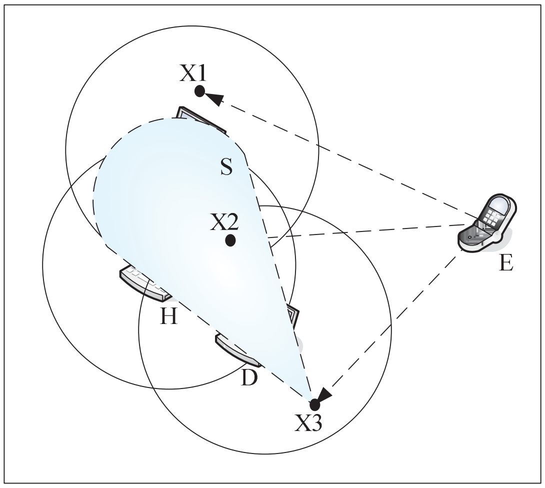

Fig. 5 One-directional antenna node in a network full of omni-directional nodes

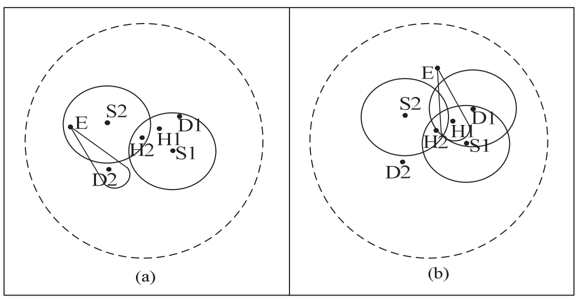

Fig. 6 Impact on cooperation by the directional node

Here, E is the node with directional antenna where the transmission range is 141m, and Si, Di and Hi are all omni-directional nodes with transmission ranges equal to 100m. In Fig. 6(a), we assume that there is a cooperation transmission from S1 to D1 with the help of H1, and S2 is out of the scope of H1 and D1. The HTS sent by H1 results in the NAV of D2 and H2. This hinders the cooperation transmission for pair 2. However, since the E node can reach the S2 and D2, it can be a good helper for pair 2. In this case, the performance can be improved with the introduction of the directional node. In Fig. 6(b), we consider the case of the helpers of pair 1 and pair 2 being close to each other. If pair 1 starts the transmission in advance, it will result in the direction transmission of pair 2, and E will be in the NAV state due to the HTS sent by H1. However, if pair 2 starts in advance, the HTS sent by H2 will result in H1's NAV state, assuming that E is out of the scope of S1 and D1. E will be the hidden terminal to the pair 2 and destroys the cooperation transmission.

We conclude that the directional transmission increases the spatial reuse, but also brings about the interference problem for the omni-directional nodes. From the literature, we know that both the cooperation and directional antenna can increase the network throughput and reduce the delivery delay. Based on our analysis, we speculate that for the heterogeneous network with two kinds of nodes, the directional one offers more of an advantage than the omni-directional one. For the case we investigated, we recommend that there be regulations for directional nodes given that they coexist with the omni-directional ones. This will be one of our future research issues.

IV. SIMULATION RESULTS AND DISCUSSION

We evaluated our proposal with the simulation tool network simulator (NS2.29) [14,15]. The network model we used is shown at Fig.6. There are two cooperation pairs and each involves the source node, the helpers (possibly two) and the destination node. The performance metrics we considered include the aggregate throughput and the packet delivery ratio.

The four protocol schemes we compared include the basic 802.11g [16] scheme, D-NoopMAC, D-CoopMAC with a CoopTable that was passively established (passive CoopTable) and D-CoopMAC with CoopTable which was built by our proposal (active CoopTable). The scenario was that S1 starts its transmission to D1 at T=5 sec with UDP traffic and after that at T=10 sec, S2 starts another UDP transmission to D2 till the end of the simulation. The total simulation was 120 sec. The parameters we used in the simulation are listed in Table III. We assume that the transmission range of the directional antenna was 141m, while the transmission and receiving range of the omni-directional antenna was 100m. The topology size was 1000m *1000m. We considered different kinds of transmission rates including 2M, 5.5M, 8M and 11M bps. The CBR packet interval varied from 2 ms to 10ms. The packet size was set as 128 Bytes.

Table III. Simulation parameters

Parameters	Value
Area	1000*1000
Transport layer protocol	UDP
Data Rate	2M, 5.5M, 8M, 11Mbps
CBR packet Arrival/Interval	2m-10m
Packet Size	128Byte
Simulation Time	120s

As indicated inFig.7, the X-axis is the CBR rate which means that the larger the network traffic load, , the busier the network. The Y-axis is the aggregate throughput. While in a light traffic condition, all the schemes grow linearly to the load except for the 802.11g scheme with its smaller slope. For this reason, the basic 802.11g scheme suffers from collision and has no chance to utilize the advantages of cooperation or directional antenna. As the traffic grows, the network becomes busier, and the D-CoopMAC with passive CoopTable performs more poorly than the D-NoopMAC. This is also pointed out in [12], which concluded that the cooperation and directionality are more like foes than friends. With our active helper searching proposal, the D-CoopMAC with active CoopTable outperforms the D-NoopMAC scheme, which was proposed in [13] with the claim that cooperation and directionality can be combined to increase the network performance.

We evaluated the packet delivery ratio, as seen in Fig. 8, and found that the packet delivery ratio is close to 1 when the load is not heavy for all the four schemes. However, as the traffic grows, collisions and traffic crowding result in the loss of packets and the delivery ratio is degraded. Notably, loss for the basic scheme 802.11g increases at a higher rate than the other schemes. We observed that for the passive overhearing table scheme, there is the possibility that the setup process of the table takes time to complete and the time depends on how active the nodes around the source node are.

V. CONCLUSION AND FUTURE WORK

Cooperative communication and directionality technology can be friends. The initial motivation of our research emerged from the conflicting conclusions arrived at by [12] and [13].

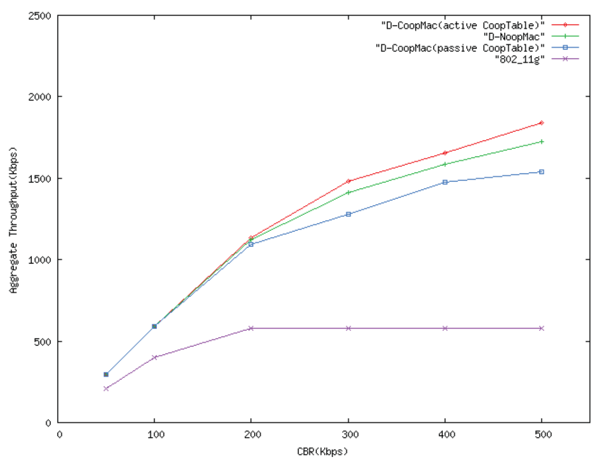

Fig. 7 Throughput v.s. traffic load

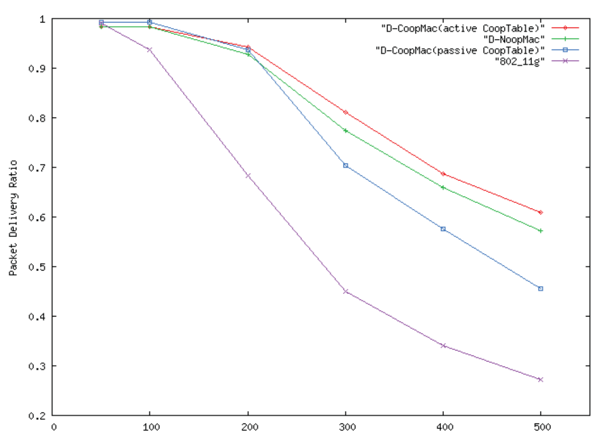

Fig. 8 Packet delivery ratio vs traffic load

From the point of view of resource discovery, there should be opportunities for cooperation among directional nodes. If we can make use of such an advantage, we can improve the network performance. However, due to the special characteristics of directional nodes, it is also possible that the chances for cooperation between pairs will be destroyed and interference to the surrounding nodes will be increased when one the directional node pair tries to utilize the cooperative communication. From our study, we conclude that if the directional nodes can fully exploit its CoopTable and be prevented from interfering with others as much as possible, they can be friends. We based our study on the D-CoopMAC and proposed an active helper searching scheme for the CoopTable to prove the above assumptions. We also analyzed the heterogeneous mobile network where directional nodes and omni-directional nodes are mixed. We found that in most of the cases, the directional node may be a hidden terminal to the omni-directional nodes, thereby degrading the performance. Regulations for the directional nodes are therefore needed. This is one of our future research issues. We will also consider cross-layer design for the combination of the two technologies. Node mobility is another useful direction for future research work.

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